ABHANDLUNGEN

BAND 76
2022

THE LITHOSTRATIGRAPHIC UNITS OF AUSTRIA: CENOZOIC ERA(THEM)

WERNER E. PILLER [ED.]

C E N O Z O I C
M E S O Z O I C
P A L E O Z O I C

QUATERNARY			HOLOCENE
QUATERNARY			PLEISTOCENE
NEOGENE	PLIOCENE	U.	PIACENZIAN
NEOGENE	PLIOCENE	L.	ZANCLEAN
NEOGENE	MIOCENE	UPPER	MESSINIAN
NEOGENE	MIOCENE	UPPER	TORTONIAN
NEOGENE	MIOCENE	MIDDLE	SERRAVALLIAN
NEOGENE	MIOCENE	MIDDLE	LANGHIAN
NEOGENE	MIOCENE	LOWER	BURDIGALIAN
NEOGENE	MIOCENE	LOWER	AQUITANIAN
PALEOGENE	OLIGOCENE	UPP.	CHATTIAN
PALEOGENE	OLIGOCENE	LOWER	RUPELIAN
PALEOGENE	EOCENE	UPP.	PRIABONIAN
PALEOGENE	EOCENE	MIDDLE	BARTONIAN
PALEOGENE	EOCENE	MIDDLE	LUTETIAN
PALEOGENE	EOCENE	LOWER	YPRESIAN
PALEOGENE	PALEOCENE	UPPER	THANETIAN
PALEOGENE	PALEOCENE	UPPER	SELANDIAN
PALEOGENE	PALEOCENE	LOWER	DANIAN

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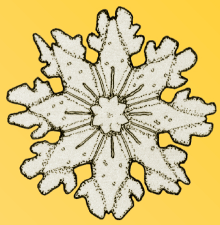

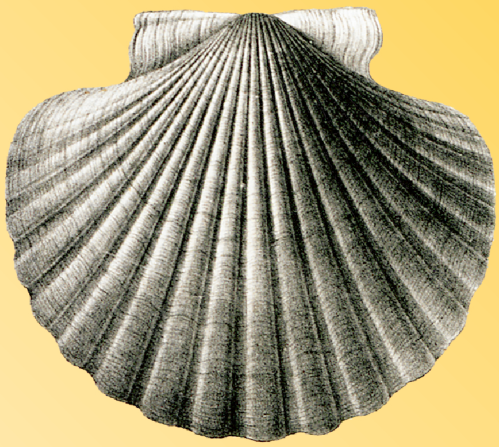

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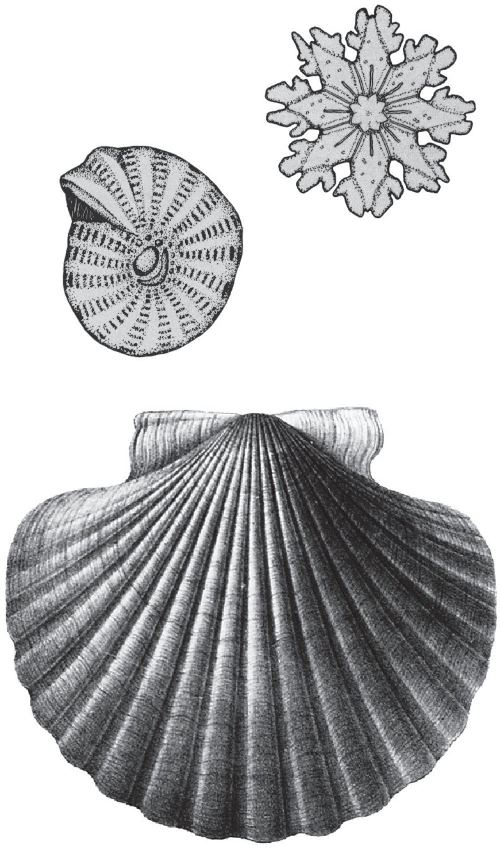

Geologische Bundesanstalt

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Recommended citation / Zitiervorschlag
Piller, W.E. [Ed.] (2022): The lithostratigraphic units of Austria: Cenozoic Era(them)
Abhandlungen der Geologischen Bundesanstalt, 76, 357 p., Wien.

ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT, BAND 76
ISSN 0378-0864
ISBN 978-3-903252-14-1

Medieninhaber, Herausgeber und Verleger: Geologische Bundesanstalt, Neulinggasse 38, 1030 Wien.
Technische Redaktion: Christoph Janda
Lektorat: Christian Cermak
Umschlaggestaltung und Bildbearbeitung: Monika Brüggemann-Ledolter
Satz, Gestaltung und Druckvorbereitung: Jarmila Böhm
Druck: Print Alliance HAV Produktions GmbH, Druckhausstraße 1, 2540 Bad Vöslau
Verlagsort: Wien

ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT
Abh. Geol. B.-A. | ISSN 0378-0864 | ISBN 978-3-903252-14-1 | Band 76 | 357 S. | Wien, Dezember 2022
The lithostratigraphic units of Austria: Cenozoic Era(them)

Contents

Introduction

WERNER E. PILLER

The Stratigraphic Chart of Austria 2004 (ASC 2004) has been published by PILLER et al. (2004). This chart was the outcome of a series of workshops including field trips organized by the Austrian Commission on Stratigraphy. The original goal which started in the late 1990s intended to describe all lithostratigraphic units of Austria, evaluate their status and formalize those which fulfil the requirements in accordance with the "Empfehlungen (Richtlinien) zur Handhabung der stratigraphischen Nomenklatur" (STEININGER & PILLER, 1999). It became, however, quickly clear that this work would require several decades to be carried out. Therefore, only the ASC 2004 has been prepared and published without explanations of the depicted lithostratigraphic units. The plan was to publish a description of all units depicted on the ASC 2004 during the following years. The first part of this project was published in 2013 and deals with lithostratigraphic units of the Paleozoic (PILLER, 2013a, b; HUBMANN et al., 2013). While assembling the Paleozoic units it became obvious that most of them do not meet the requirements for formalization. The result of this shortcoming was a restudy of the pre-variscan lithostratigraphic units of the Carnic Alps where many units have been revised, renamed and formalized (CORRADINI & SUTTNER, 2015).

Concerning the two other era(thems) – the Mesozoic and Cenozoic – it turned out that so many years after publication of the ASC 2004 the lithostratigraphic units have considerably changed in number, definition and status compared to the chart. This encouraged a work group of the Austrian Stratigraphic Commission to compile the lithostratigraphic units of the Cenozoic, which should represent the state of the art – and this is the content of the current volume.

A clear precondition of this compilation was not to revise or formalize units but just describe the status quo. Consequently, the current volume is not a description of the ASC 2004 or a re-evaluation of Cenozoic units but represents a catalogue of so far described Cenozoic lithostratigraphic units in Austria. Such a compilation of rock units has only been carried out so far in the Lexique Stratigraphique International in which Fascicule 8 of Volume 1 is dedicated to Austrian rocks (KUEHN, 1962). There, the entire stratigraphic column is treated and besides sedimentary also metamorphic units are included. The compilation and publication of the Lexique happened long before our current view on stratigraphic classification, which started essentially with HEDBERG (1976) and fundamentally changed the philosophy on stratigraphy. Consequently, most rock units described in the Lexique represent a mixture of various stratigraphic classification schemes such as lithostratigraphy, biostratigraphy and chronostratigraphy.

The descriptions of the lithostratigraphic units in this volume are in English and follow a fixed scheme. Only the name of the respective unit is documented first in German followed by the English expression. This was chosen because nearly all units treated here where originally named in German language and are also included in the geological maps in German language. The number and sequence of each description follows the recommendations of STEININGER & PILLER (1999) and the first application by RASSER & PILLER (1999a) and matches those of the published Paleozoic volume (HUBMANN et al., 2013). This list for each unit includes the following characteristics: Validity, Type area, Type section, Reference section(s), Derivation of name, Synonyms, Lithology, Fossils, Origin, Facies, Chronostratigraphic age, Biostratigraphy, Thickness, Lithostratigraphically higher rank unit, Lithostratigraphic subdivision, Underlying unit(s), Overlying unit(s), Lateral unit(s), Geographic distribution, Remarks, and Complementary references. Remarks may also follow directly the description of each category where necessary. For the locations of Type area, Type section and Reference section(s) international geographical coordinates (latitude, longitude) are provided. For map references both the UTM-system and the old Austrian BMN-system with numbers and names of map-sheets are indicated since the numbers and names do not coincide in both systems.

The lithostratigraphic units in this volume are arranged according to the major tectonic units including Cenozoic sediments and sedimentary rocks in a geographic arrangement from west to east and in stratigraphic order from older to younger. The tectonic units relevant for the Cenozoic are the Austroalpine Unit, Helvetic Unit, Ultrahelvetic Unit, Rhenodanubian Flysch Unit, North Alpine Foreland Basin, Waschberg Unit, Vienna (and Korneuburg) Basin, Eisenstadt-Sopron Basin, Oberpullendorf Basin, Styrian Basin, Fohnsdorf Basin and Lavanttal Basin. The definition of the tectonic units follows roughly the usual schemes, which are applied for the official geological maps of Austria published by the Geological Survey of Austria. These assignments are in most cases clear but some units are a matter of discussion both in definition and in content. Altogether 340 lithostratigraphic units have been described including 272 formations or formation level units, 2 beds, 51 members, 1 subgroup, 13 groups and 1 supergroup.

Herein, the Austroalpine Unit includes the informally called "Gosau Sediments" of Paleogene age. These sediments occur on top of the Northern Calcareous Alps (NCA), which are classified with the Gosau Group and represent the Gosau Beds s.str., which occur in several basins along the NCA. Equivalent sediments occur also on top of the Central Alps, which are in the Cenozoic restricted to the so called "Krappfeld Gosau" represented by the Guttaring Group.

A matter of debate are the Paleogene sediments of the Inn Valley (called frequently "Inntal Tertiär" or "Inneralpine Molasse"). They could have classified as "Gosau equivalents" since they also occur on top of the NCA. Their sedimentary succession shows, however, great similarities with the sediments of the North Alpine Foreland Basin (NAFB) and, in addition, a gap occurs between the NCA rocks and those of the "Inntal Tertiary"; the latter sediments are summarized in the Inntal Group, which we include here into the North Alpine Foreland Basin.

The North Alpine Foreland Basin was and still is frequently circumscribed as "Molasse Basin", "Molasse Zone", "Molasse Unit", or simply described as "Molasse Sediments". Since these historical names denominate only specific sediment types in an orogenic evolution, which is not restricted to the Alpine orogeny we prefer to use the term North Alpine Foreland Basin (NAFB). In Lower Austria, the part north of the Danube is frequently called North Alpine-Carpathian Foreland Basin (NACFB) to document that the NAFB grades laterally into the Carpathian Basin. The boundaries between NAFB and NACFB are to date not clearly defined.

Deviating from the geographical-stratigraphic scheme are Quaternary sediments, which are treated as a single unit because they are not related to the major tectonic units. The Quaternary lithologic units are so far possible stratigraphically arranged from older to younger. Most Quaternary units do not meet formal lithostratigraphic requirements but represent a mixture of glacial phenomena linked to their stratigraphic position. Only a few exceptions, e.g., Höttinger Breccia, Parndorf Formation, match formal lithostratigraphic rules. This conduct follows the discussion and recommendation of PILLER et al. (2003).

Acknowledgements

First of all, I (WEP) would like to express my appreciation to all authors involved in the compilation of the Austrian Stratigraphic Chart 2004. All of them did an excellent job and made publishing in a very short period possible. Furthermore, I would like to thank all authors of this volume for carrying out this tedious and sometimes boring job. They all worked through a tremendous amount of literature, sometimes highly inappropriate from a stratigraphic point of view, and accomplished the descriptions of the lithostratigraphic units! I also would thank many colleagues for specific information on the unit, in particular, Holger Gebhardt (Geological Survey of Austria).

Special thanks go to Thomas Hofmann and his staff at the library of the Geological Survey of Austria. Their support was extremely friendly, fast, efficient, and essential for assembling this volume. Thanks go also to Christian Cermak and Christoph Janda (both Geological Survey of Austria) for their constructive cooperation and patience during the final steps of layout and printing. Finally, we would like to express our gratitude to Monika Brüggemann-Ledolter (Geological Survey of Austria) for providing her expertise and courtesy in performing the stratigraphic chart.

Stratigraphic Chart of Austria – Cenozoic

The enclosed "Stratigraphic Chart of Austria – Cenozoic" follows widely the same principles as the Stratigraphic Chart of Austria 2004 ("Stratigraphische Tabelle von Österreich 2004", ASC 2004) in respect of chronostratigraphy/geochronology and arrangement of the tectonic units.

The chronostratigraphic framework is based on the International Chronostratigraphic Chart (ICC) of the International Commission on Stratigraphy, v. 2022/10 (Cohen et al., 2013, updated) and the Geologic Time Scale 2020 (GTS 2020; Gradstein et al., 2020).

In respect to geochronology, some differences exist between the ICC and GTS 2020 in the Cenozoic. For example, the base of the Lutetian is 47.8 Ma in the ICC and 48.07 Ma in the GTS 2020, the base Bartonian is at 41.2 Ma vs. 41.03 Ma, the Chattian base at 27.82 vs. 27.29 Ma. The differences are relatively small and we have chosen the data of ICC, which is the official chart of IUGS.

For the time interval from the Rupelian to the Early Pliocene the Regional Chronostratigraphic Stages of the Central Paratethys have been applied and correlated to the International Stages. The Regional Stages include the Kiscellian, Egerian, Eggenburgian, Ottnangian, Karpatian, Badenian, Sarmatian and Pannonian. Lake Pannon sedimentation ended in and with the Pannonian in the Pannonian Basin. The Pontian, Dacian and Romanian stages listed in the ASC 2004 were removed here because they are limited to the Eastern Paratethys. For post-Pannonian and pre-Quaternary lithostratigraphic units in Eastern Austria the international chronostratigraphic stages (Zanclean, Piacenzian) have been applied. According to Mandic et al. (2015), the Pannonian ended at 4.5 Ma in the Pannonian Basin and is followed by the Cernikian Stage. The later, however, is not represented in Austria but restricted so far to Lake Slavonia in Serbia and Croatia.

The basic lithostratigraphic unit, the Formation, represents also the frame of the chart. Where possible also Members are included and also higher rank units such as Group and Supergroup are indicated. Many of the included units do not meet the formal lithostratigraphical requirements and even denomination. In the latter case, an English translation close to the mostly descriptive terms has been applied.

Helvetic Unit

Werner E. Piller

The Helvetic Unit (Text-Fig. 1) covers a wide area at the surface in both Switzerland and Vorarlberg. Further to the east, from Bavaria to the eastern part of Upper Austria, this zone is reduced to a small stripe and to small tectonic slices with poor outcrops.

Paleogeographically, the Helvetic Zone represents the depositional area along the southern margin of the European continent during early Jurassic to Paleogene times in a passive marginal setting in respect to a plate tectonic context. The Helvetic Unit is dominated by shelf and upper slope deposits which grade in a southward direction into the continental slope deposits of the Ultrahelvetic Unit which were both part of the Penninic Ocean (= Alpine Tethys sensu Stampfli et al., 1998).

The Helvetic Unit is subdivided into a northern and a southern domain. In the North-Helvetic domain, Paleocene deposits are absent because the Adelholzen Beds of the basal Lutetian overly with an erosional unconformity rocks of the Maastrichtian Gerhartsreith Formation. The Adelholzen Beds are considered an equivalent of the Bürgen Formation in Switzerland (Hagn, 1954; Egger et al., 2013) where an equivalent hiatus between the Cretaceous and the Eocene occurs (Menkveld-Gfellner, 1997). Basinward, this main hiatus is less pronounced spanning only the uppermost Paleocene and the lowermost Eocene (Egger et al., 2009) at the southern part of the Helvetic shelf. A tectonically disturbed but continuous record exists across the K/Pg-boundary of the South-Helvetic domain (Kuhn & Weidich, 1987; Rasser & Piller, 1999a; Egger, 2011c).

A clear differentiation between Helvetic and Ultrahelvetic units in the field is only possible in Vorarlberg with the Säntis Nappe and Feuerstätter Nappe as part of the Helvetic Unit (Friebe, 2007a). However, the assignment of the Feuerstätter Nappe is highly controversially discussed if it belongs either to the Helvetic Unit or the Rhenodanubian Flysch Unit. Further to the east, an attribution to the Helvetic or Ultrahelvetic units – and even to the Rhenodanubian Flysch Unit – is more difficult due to tectonic complications and very limited outcrops.

Helvetic Unit: Vorarlberg – Säntis Nappe

Fraxner Grünsand / Fraxner Greensand

J. Georg Friebe & Werner E. Piller

Validity: Invalid; the term “Grünsand von Fraxern” was introduced by Merhart & Mylius (1914) for a blackish grey, partly glauconitic limestone with mass occurrences of nummulites. Merhart (1926) used the term “Fraxner Mergelschiefer” (occasionally also named “Fraxnerschiefer”), which he interpreted as equivalent of the Wang Formation. This “Mergelschiefer” (= “Schwarze Schiefer”, see below) is followed with a sharp boundary by greensand (Merhart, 1926). Besides the “Fraxner Grünsand” also the general name “Grünsandstein” is used in the literature. According to Oberhauser (1991: Abb. 3) it is restricted to the surroundings of Dafins, he discussed, however, in the same chapter all occurrences of “Grünsandstein” in Vorarlberg. Friebe (2007a) did also not differentiate between “Fraxner Grünsand” and “Grünsandstein” and, in fact, considered “Grünsandstein” as synonym of “Fraxner Grünsand”.

Type area: Around the municipality Fraxern, Vorarlberger Rheintal (Rhine Valley), Vorarlberg; ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Type section: Not defined.

Meesmann (1926) mentioned a small quarry near Fraxern (“ist aufgeschlossen in einem kleinen Steinbruch am Waldrande oberhalb von Fraxern”) (N 47°19′01″ / E 09°40′39″, 970 m a.s.l.). Merhart (1926) did not give an exact location, but noted that Fraxern lies in the area of the typical appearance of this unit.

Reference section(s): Not defined.

A possible reference section is exposed along a forest road in Fraxern, north of the type locality (approx. N 47°19′01″ / E 09°40′48″ to N 47°19′02″ / E 09°41′11″) (Oberhauser, 1991).

Derivation of name: After the municipality Fraxern, east of the Rhine Valley, Vorarlberg, Austria (N 47°18′52″ / E 09°40′26″); ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Remark: Taking the peculiarities of the local dialect into consideration, the correct spelling is “Fraxner Grünsand” (or “Fraxerner Grünsand”). The often-used spelling “Fraxener” is neither correct nor compliant with the local dialect.

Synonyms: Grünsand von Fraxern (Merhart & Mylius, 1914: p. 53), Fraxernergrünsand (Meesmann, 1926: p. 29), Fraxner Mergelschiefer, Fraxnerschiefer (Merhart, 1926: p. 21), Schwarze Schiefer p.p. (Oberhauser, 1958), kalkiger Grünsandstein: Eozän (Alexander et al., 1965), Grünsandstein, grünsandiger Mergel, Fraxerner Grünsand,

Text-Fig. 1.
Location of the Heltvetic und Ultrahelevetic units (grey shaded) in Austria.

schwarze sandige Schiefer p.p. (OBERHAUSER, 1991), Nummulitenschichten (grünsandig) (OBERHAUSER, 2007; see also FRIEBE, 2007a).

Lithology: Glauconitic sandstone and marl to shale. Occasional layers with small phosphorite nodules or cellophane grains also occur.

Remark: MEESMANN (1926) described this unit as glauconitic sandy limestone ("… ein stark glaukonitischer, etwas sandiger, den Wangschichten ähnlicher Kalk, …"), MERHART (1926) as blackish grey, rather hard marly shale ("… einen schwärzlichgrauen, ziemlich harten Mergelschiefer …").

Fossils: Debris of coralline algae, calcareous nannoplankton, larger benthic foraminifera (*Nummulites*, *Assilina*, *Discocyclina*) (e.g., OBERHAUSER, 1991), rare echinoids, brachiopods and shark teeth.

Origin, facies: Shelf deposits. This unit has never been studied in detail.

Chronostratigraphic age: late Paleocene, Selandian to early Eocene, Ypresian.

Biostratigraphy: Calcareous nannofossil Zones NP5–NP13: NP5 in basal sandy shales, NP9 and NP13 in marly intercalations within the glauconitic sandstone (STRADNER in OBERHAUSER, 1991) and NP12–NP13 in marly layers in the upper part (HANS EGGER, unpublished).

Thickness: Approximately 20 m, variable due to tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision. The informal basal black shales ("Schwarze Schiefer"; see below) are treated as separated unit, which may be defined as member.

Underlying unit(s): Wang Formation; the Black shales ("Schwarze Schiefer") were interpreted as uppermost part of the Wang Formation (OBERHAUSER, 1958). However, OBERHAUSER (1991) regarded these black shales as basal unit of the "Grünsandstein" (= "Fraxner Grünsand"). Following this concept, the underlying unit is the Wang Formation.

Overlying unit(s): Globigerinenmergel?

Lateral unit(s): Grades distally into Lithothamnion Limestone ("Lithothamnienkalk") (OBERHAUSER, 1991, 1995).

Geographic distribution: Vorarlberger Rheintal and Bregenzerwald (Andelsbuch); ÖK50-UTM, map sheets 1218 Bregenz, 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn, 112 Bezau).

Small occurrences of greensand (often associated with nummulitic limestone) recorded in the Emsrütti-Haslach Zone (Hohenems, Dornbirn), in the Rhomberg-Nackkopf Zone (Dornbirn) and in the Bregenzerwald might correspond to this unit.

OBERHAUSER (1991) mentioned a possible correlation with similar lithologies west of the hill Schörgisknorren near Oberriet/Kobelwies (St. Galler Rheintal, Switzerland) (EUGSTER et al., 1960: p. 21, "Glaukonitischer Kalksandstein z.T. mit Nummuliten"). HEIM (1923) interpreted these sediments as Eocene in age. However, the Schörgisknorren-Bank (which actually lacks nummulites) is nowadays considered to be a basal bed of the Wang Formation (SOOM et al., 2018). Consequently, there are no equivalents in the immediate vicinity at the Swiss side of the Rhine Valley (St. Galler Rheintal).

ALEXANDER et al. (1965) assumed that their "kalkiger Grünsandstein" might be considered as equivalent of the "Nebengestein von Kressenberg (Oberbayern)". Due to the limited occurrences of and information on the "Fraxner Grünsand" no further attempts have been made to correlate these rocks with established lithostratigraphic units in Bavaria (Kressenberg), Salzburg (Haunsberg) or Switzerland (Einsiedeln; Weisstannental). The Fraxner Greensand might correspond to the lower part of the Batöni Member (Euthal Formation) or to the basal strata of the Einsiedeln Member (Euthal Formation) sensu MENKVELD-GFELLER et al. (2016) in Switzerland.

Remarks: OBERHAUSER (1991) discussed all occurrences of "Grünsandstein" and mentioned already that the "Grünsandstein" in the Dafins area corresponds to the "Fraxner Grünsand" as well as to greensands in the Hohenems-Haslach area and in the tectonic melange north of Dornbirn ("Rhomberg-Nackkopf-Schuppen"). In the geological map of Vorarlberg, OBERHAUSER (2007) used the same signature [205 sandstone with glauconite, layers with white dots of collophane …] for all types of greensand including the occurrences near Fraxern, except the Kehlegg Formation of the Liebenstein Nappe. This and the view of FRIEBE (2007a) clearly indicate that the "Grünsandstein" has to be considered synonymous with the "Fraxner Grünsand".

The "Grünsande" mentioned by OBERHAUSER (1991) from the area of Dafins are not part of the section described by RASSER & PILLER (2001) for the Lithothamnion Limestone and Nummulite Limestone.

Fossils stored at the inatura Erlebnis Naturschau GmbH at Dornbirn, indicate also occurrences of glauconitic sandstone in Hohenems (Reute), Dornbirn (Haslach, Mühlebacher Tobel, Fallenberg-Grundegg) and Andelsbuch (Haslergraben) (see also OBERHAUSER, 1994).

Complementary references: OBERHAUSER (1965b, 1984), RICHTER (1969, 1978).

Schwarze Schiefer (Fraxner Grünsand) / Black Shales (Fraxner Greensand)

J. GEORG FRIEBE

Validity: Invalid; OBERHAUSER (1991) regarded this lithology as the basal section of his "Grünsandstein, grünsandiger Mergel = Nummulitenschichten (grünsandig)" (OBERHAUSER, 2007; FRIEBE, 2007a).

Type area: Isolated outcrops occur in the area of Fraxern and on the mountain Hohe Kugel, Vorarlberger Rheintal (Rhine Valley), Vorarlberg; ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Type section: Not defined.

A long time abandoned quarry northeast of the village Fraxern mentioned by MEESMANN (1926) can be regarded as type locality (N 47°19′11″ / E 09°40′39″, 970 m a.s.l.; see also OBERHAUSER, 1991); ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Reference section(s): -

Derivation of name: The name refers to the colour and lithology of this unit.

Synonyms: Fraxner Grünsand (Meesmann, 1926), Fraxner Mergelschiefer, Fraxnerschiefer (Merhart, 1926).

Lithology: Dark, glauconitic marls and black sandy shales (Oberhauser, 1991).

Fossils: Planktic foraminifera (autochthonous *Globorotalia compressa*, *Globigerina pseudobulloides*) as well as reworked fossils from Maastrichtian strata (Oberhauser, 1991).

Origin, facies: Shelf deposits. This unit has never been studied in detail.

Chronostratigraphic age: Late Paleocene (Oberhauser, 1958).

Biostratigraphy: Calcareous nannofossil Zone NP5 (Stradner in Oberhauser, 1991), detected approximately 1.5 m below the upper boundary (= first glauconitic layer of the "Fraxner Grünsand s.str.").

Thickness: A few meters (Oberhauser, 1991).

Lithostratigraphically higher rank unit: Fraxner Greensand.

Lithostratigraphic subdivision: -

Underlying unit(s): Wang Formation.

Overlying unit(s): Fraxner Grünsand (s.str.).

Lateral unit(s): -

Geographic distribution: Restricted to the area near Fraxern and the mountain Hohe Kugel, Vorarlberger Rheintal, Vorarlberg (Oberhauser, 1958).

Remarks: According to Oberhauser (1958), the sediments termed here "Schwarze Schiefer" gradually develop from the Wang Formation. Oberhauser (1958), however, placed them into the upper Cretaceous due to reworked foraminifera. The "Schwarze Schiefer" is not represented in the geological map of Vorarlberg (Oberhauser, 2007), but is included as basal unit in the legend as "205 Nummulitenschichten (grünsandig)" (see also Oberhauser, 1991).

Stacher (1980) prefers to regard this unit as an equivalent of the "Fliegenspitz-Schichten" (Fliegenspitz Beds) in Switzerland. However, the "Fliegenspitz-Schichten" sensu Stacher (1980) are not equivalent to the Fliegenspitz Member of the Euthal Formation sensu Menkveld-Gfeller (in Funk et al., 2013). They instead arguably belong to the Tierberg Member of the Wildstrubel Formation (Upper Eocene) (Menkveld-Gfeller et al., 2016). In fact, the "Schwarze Schiefer" in Vorarlberg might correspond to the Fliegenspitz Member of the Euthal Formation in Switzerland (Menkveld-Gfeller et al., 2016).

This unit probably corresponds to "dunkle, glaukonitische Sandmergel: Oberpaleozän–Untereozän" of Alexander et al. (1965).

Complementary references: Piller et al. (2004).

Lithothamnienkalk / Lithothamnion Limestone

J. Georg Friebe & Werner E. Piller

Validity: Invalid; patchy, tectonically isolated occurrences of Paleogene rocks of the Säntis Nappe have repeatedly been named "Lithothamnienkalk" (coralline algal limestone) according to their predominant lithology (e.g., Schaad, 1925). Due the limited and isolated occurrences, these rocks were mostly not treated as a separate unit (Prey, 1980b; Friebe, 2007a) and included in "Nummulitenkalk" or reported as "Nummuliten- und Lithothamnienkalk" (Schaad, 1925).

Type area: The here discussed "Lithothamnienkalk" is restricted to the area around the village of Dafins (municipality Zwischenwasser), Vorarlberger Rheintal, Vorarlberg; ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Type section: A 4 m-thick section along the creek Mühltobel (Mühletobel in Rasser & Piller, 2001), south of the village Dafins (Oberhauser, 1991; Rasser & Piller, 2001); approx. N 47°17′27″ / E 09°40′53″; ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Reference section(s): -

Derivation of name: The term "Lithothamnienkalk" refers to coralline algae as primary rock constituents. The name dates back when all coralline algae were included in the genus *Lithothamnium* (actual name: *Lithothamnion*).

Synonyms: Nummuliten- und Lithothamnienkalke (Schaad, 1925), Bürgenschichten (mit Lithothamnienkalk, z.t. vererzt) (Prey, 1980b: Abb. 41), Lithothamnienkalke (Bürgenschichten) (Tollmann, 1985), Lithothamnienkalk, Nummulitenkalk (Oberhauser, 1991).

Lithology: Coralline algal limestone with glaucony. Rhodolith floatstones and rudstones, partly terrigenous, with nummulitid-orthophragminid grainstone-packstone matrix or bioclastic packstone-grainstone matrix, with terrigenous components, detritic and authigenic glaucony (basal part of the Dafins section). For a more detailed microfacies analysis, see Rasser & Piller (2001).

Fossils: Coralline algae (rhodoliths and fragments), peyssonneliacean algae, larger (e.g., nummulitids, orthophragminids) and smaller foraminifera, corals, molluscs, bryozoans, serpulids (Böhm, 1936; Rasser & Piller, 2001).

Origin, facies: Shelf facies.

Chronostratigraphic age: Late Paleocene, Thanetian.

Biostratigraphy: Calcareous nannofossil Zone NP9 (near Dafins) (Stradner in Oberhauser, 1991).

Thickness: Approximately 4 m (of the overall 12 m long section in Dafins the upper 8 m do not belong to the Lithothamnion Limestone).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Wang Formation (Oberhauser, 1991, 1995).

Overlying unit(s): Globigerina Marl, Nummulitic Limestone; or tectonic upper boundary?

Lateral unit(s): The coralline algal limestone grades laterally into Fraxner Greensand (Oberhauser, 1991, 1995).

Geographic distribution: Only known from the Mühl(e) bach section in Dafins, Vorarlberger Rheintal (Rasser & Piller, 2001).

Remarks: No substantial attempts have been made to correlate these rocks with established lithostratigraphic units in Switzerland (Einsiedeln; Weisstannen Valley), Bavaria (Kressenberg) or Salzburg (Haunsberg). Biostratigraphic data for the Lithothamnion Limestone correspond with those of the Fackelgraben Member (Kressenberg Formation) in the Haunsberg area (Salzburg) (Rasser & Piller, 1999a) and also with the coralline algal limestones in Kressenberg (Bavaria) (Rasser & Piller, 1999a); to the west the Lithothamnion Limestone might correspond to the upper part of the Batöni Member (Euthal Formation) sensu Menkveld-Gfeller et al. (2016) in Switzerland.

Prey (1980b) and Tollmann (1985) correlated these rocks with the "Bürgenschichten" in Switzerland, which are, however, younger and do not contain coralline red algae (Menkveld-Gfeller et al., 2016).

Resch (1976a) mentioned "Lithothamnien-Schuttkalk" within the oldest portions of the Deutenhausener Schichten. Since these are younger and belong to the sediments of the NAFB, they should not be mixed up with the coralline algal limestone of the Helvetic realm.

Complementary references: Oberhauser (1986).

Nummulitenschichten / Nummulitic Limestone

J. Georg Friebe & Werner E. Piller

Validity: Invalid; patchy, tectonically isolated, small occurrences of Paleocene to Eocene rocks of the Säntis Nappe have repeatedly be named according to their predominant lithology, such as "Schwärzlich grauer, z.T. durch Glaukonit grün gefärbter Kalk mit massenhaften Nummuliten" (Merhart & Mylius, 1914) or "Nummulitenkalk" (e.g., Meesmann, 1926; Merhart, 1926); Friebe (2007a) introduced the name "Nummulitenschichten" differentiating between calcareous and green-sandy varieties. Hitherto, no attempt has been made to establish a formal lithostratigraphic unit or to correlate these rocks with existing lithostratigraphic units in Bavaria, Salzburg or Switzerland.

Type area: Vorarlberger Rheintal and Bregenzerwald, Vorarlberg; ÖK50-UTM, map sheets 1218 Bregenz, 1224 Hohenems (ÖK50-BMN, map sheets 111 Dornbirn, 112 Bezau).

Type section: Not defined.

Reference sections: Not defined.

Remark: The available outcrops in Vorarlberg are all isolated, (mostly) blocks which do not allow to establish reference sections (e.g., Dornbirn, Mühlebach (Küferbach) – N 47°23′34.5″ / E 09°45′09.5″; Dornbirn, Haslach – N 47°23′22″ / E 09°44′32.5″; Hohenems, Salzbach – N 47°21′41.5″ / E 09°41′48.5″; Oberhauser, 1986, 1991; Rasser & Piller, 2001; Egg, Schmiedebach [ÖK] = Schmittenbach [VoGIS]; approx. N 47°25′20″ / E 09°58′07″; Fessler et al., 1992: p. 832).

Derivation of name: According to the lithology of limestone with mass occurrences of larger foraminifera (*Nummulites*, *Assilina*, *Discocyclina*).

Synonyms: Nummulitenkalk (Meesmann, 1926), Nummuliten-Schichten (Richter, 1957), spätiger Großforaminiferenkalk, rotbrauner, sandiger Kalk mit Brauneisengeröllen? (Alexander et al., 1965: p. 114), Nummulitenschichten, Nummulitenschichten (kalkig) (Friebe, 2007a).

Lithology: Generally, a nummulitid and orthophragminid limestone with authigenic glaucony, variable amount of quartz and occasionally haematite impregnations. The variable amount of larger foraminifera allows a differentiation into nummulitid-orthophragminid grainstones-packstones, nummulitid-orthophragminid floatstones-rudstones with nummulitid-orthophragminid grainstone-packstone matrix or with bioclastic packstone-grainstone matrix. Besides, smaller foraminifera packstone and quartz sandstone with larger foraminifera also occur. For a detailed microfacies analysis see Rasser & Piller (2001).

Fossils: Foraminifera (larger benthics, such as *Nummulites*, *Assilina* and *Discocyclina*; smaller benthics and planktonics), molluscs, brachiopods.

Remark: Böhm (1936) gave a list of fossils originating both from greensand (Fraxner Greensand) as well as nummulitic limestone based on specimens stored at Siegfried Fussenegger's museum (today: inatura Erlebnis Naturschau GmbH, Dornbirn). Unfortunately, Fussenegger did not record the exact stratigraphic position. Besides the foraminifera (nummulitids, orthophragminids and others), gastropods and bivalves prevail. Other fossils (e.g., echinoids, crustaceans, fish teeth) are rare.

Origin, facies: A differentiation in larger foraminifera facies, smaller foraminifera facies and foraminifera sandstone facies hints at a laterally slightly changing environment. In general, it represents a shallow water, shelf depositional area with a proximal-distal distribution.

Chronostratigraphic age: Early Eocene, Ypresian to middle Eocene, Lutetian (Oberhauser, 1986, 1991; Rasser & Piller, 2001).

Biostratigraphy: The larger benthic foraminifera indicate Ypresian–Lutetian, and specifically *Nummulites gallensis* (Oberhauser, 1991) indicates SBZ13 (lower Lutetian) following Serra-Kiel et al. (1998) and Rodríguez-Pintó et al. (2012).

The smaller foraminifera facies in Vorarlberg is not dated, but it gradually develops from the Thanetian (NP9) rhodolith facies (Oberhauser, 1995; Rasser & Piller, 2001).

The limestones of Bad Haslach and Hohenems are associated with middle to lowermost upper Eocene marls („Staadschiefer") which were dated to calcareous nannofossil Zones NP15–16 (Stradner in Oberhauser, 1984: p. 228), but the contact could be of tectonic origin (Rasser & Piller, 2001).

Thickness: Oberhauser (1991) gave an overall thickness of approx. 10 m, however, it is highly variable due to tectonic truncation. In the Mühlebach-Haslach area (part of the town Dornbirn) the nummulitic limestone is represented by three, tectonically repeated morphological ridges.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Tectonic lower boundary or Fraxner Greensand.

MEESMANN (1926) assumed a transgressive contact over Amden Formation and Wang Formation, respectively.

Overlying unit(s): Globigerinenmergel or tectonic upper boundary.

According to MEESMANN (1926), the nummulitic limestone is associated with dark to light grey shales, which he termed "Globigerinenschiefer". He suggested that this unit might correspond to the "Stadschiefer" in Switzerland. This could be a possible equivalent to the "Globigerinenmergel", but it might also correspond to the "Globigerinenflysch" sensu OBERHAUSER (1991), or it has to be regarded as an independent lithostratigraphic unit. RICHTER (1957: p. 158) used the name "Stadschiefer" for fine-grained sediments above the Nummulitic Limestone, as well as OBERHAUSER (1984: misspelled as "Staadschiefer").

Lateral unit(s): -

Geographic distribution: Vorarlberger Rheintal and Bregenzerwald; Helvetic Säntis Nappe.

Remarks: The Nummulitenschichten/Nummulitic limestone of Vorarlberg most probably correspond to the Einsiedeln Member of the Euthal Formation in Eastern Switzerland (Alpstein, Fänerenspitz, Weisstannental) and Central Switzerland (Stoos-Fronalpstock region, Einsiedeln region, Sihlsee) (MENKVELD-GFELLER et al., 2016). This limestone also can be compared to similar lithologies of the Kressenberg Formation in Bavaria (Neukirchen/Siegsdorf) as well as Salzburg (Haunsberg) (RASSER & PILLER, 2001).

ALEXANDER et al. (1965) assumed that their "spätiger Großforaminiferenkalk" might be considered as an equivalent of the "Nebengestein von Kressenberg (Oberbayern)". Their "rotbrauner, sandiger Kalk mit Brauneisengeröllen" might correspond to the "Schwarzerz" at Kressenberg, Upper Bavaria.

Complementary references: HÜGEL (1956), FRIEBE (1995), LANZL (1966), RICHTER (1969, 1978), OBERHAUSER (1984), SULSER et al. (2010).

Globigerinenmergel / Globigerina Marl

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; MEESMANN (1926: p. 29) described from the area of Fraxern in Vorarlberg and from eastern Switzerland "Globigerinenschiefer", which he described to be similar to the "Stadschiefer" and mentioned that both occur on top of the nummulite limestone. RICHTER (1957) used the name "Stadschiefer" for fine-grained sediments above the nummulitic limestone ("Nummuliten-Schichten") as well as OBERHAUSER (1984; misspelled as "Staadschiefer"). Also SCHWERD (1984: p. 294) mentioned "pelagische Globigerinenmergel der Stadschiefer" above nummulitic limestone.

Type area: The area between the municipalities Fraxern and Satteins, district of Feldkirch, Vorarlberg, can be regarded as type area. ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheets 111 Dornbirn, 141 Feldkirch).

Type section: -

Reference section(s): -

Derivation of name: Named after lithology and the predominant planktonic foraminifera.

Synonyms: Globigerinenschiefer (Stadschiefer?) (MEESMANN, 1926), Globigerinen-Schiefer (HEISSEL et al., 1967), Globigerinenmergel (Leimernschichten) (HÖFLE, 1972), Globigerinen-Mergel (OBERHAUSER, 1973), Leimern-Schichten/Globigerinenmergel (FELBER & WYSSLING, 1979), Globigerinenschichten (PREY, 1980b) Staadschiefer (OBERHAUSER, 1984), Globigerinenmergel der Stadschiefer (SCHWERD, 1984).

Lithology: Grey, light yellowish weathering, mottled, slaty, slightly sandy marl or marlstone.

Remark: This Globigerina Marl can easily be confused with similar lithologies of the Amden Formation, which are in some localities close to each other. A reliable criterion to distinguish both units is their foraminifera fauna.

Fossils: Calcareous nannoplankton, planktonic foraminifera, echinoid ichnofossils.

Origin, facies: Marine, outer shelf environment.

Chronostratigraphic age: Paleocene (?), early Eocene, Ypresian–late Eocene, Bartonian (Priabonian?).

Remark: In the Southern Helvetic realm, the "Globigerinenmergel" are not older than early Eocene (OBERHAUSER, 1991).

Biostratigraphy: Calcareous nannofossil Zones NP11–NP16 (OBERHAUSER, 1984, 1991).

Thickness: Approximately 50 m, but 200–250 m in the area of Laterns-Nob/Männle (OBERHAUSER, 1991). Laterally highly variable due to tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Fraxner Greensand; transgressive with a hiatus of variable extent on Upper Cretaceous Wang Formation and even Lower Cretaceous Drusberg Formation (OBERHAUSER, 1991).

Overlying unit(s): Erosional or tectonic upper boundary.

Lateral unit(s): The Globigerina Marl is a southern equivalent of the Nummulite Limestone and Fraxner Greensand. In the southern part of the Helvetic Nappe, the "Globigerinenmergel" might interfinger with "Globigerinenflysch" (OBERHAUSER, 1991).

Geographic distribution: Vorarlberger Rheintal and Walgau, Bregenzerwald, Vorarlberg.

Remarks: OBERHAUSER (1991: p. 31) stated that all occurrences of "Globigerinenmergel" are tectonized slabs of the Helvetic Säntis Nappe and no "Globigerinenmergel" occur in the Liebenstein Nappe. OBERHAUSER, however, did not express this new concept in his stratigraphic chart (1991: Abb. 3). Following the concept of OBERHAUSER (1980, 1991), all occurrences of Paleogene "Amden Formation" (Säntis Nappe) in fact belong to the Globigerina Marl.

HEISSEL et al. (1967) separated the Paleogene "Globigerinenmergel" (as "Globigerinen-Schiefer") from the Cretaceous "Amdener Schichten". Before, it was assumed that the latter also include Paleogene deposits. Höfle (1972) considered the "Globigerienmergel" (p. 7) or "Globigerinenschiefer" as Paleocene part of the "Leimernschichten". Felber & Wyssling (1979: p. 705) denominated the Eocene "Leimern-Schichten" as "Globigerinenmergel".

Already Meesmann (1926), Richter (1957), Oberhauser (1984) and Schwerd (1984) mentioned the great similarities with the "Stadschiefer", Schwerd (1984) even considered the marl as part of the "Stadschiefer", which is widely distributed in Switzerland (and Bavaria). The former "Stadschiefer" was detailed described and formalized by Menkveld-Gfeller et al. (2016) as Stad Formation showing not only a very similar lithology but also stratigraphic range as the Globigerina Marl. This formation seems to be a possible equivalent of the Globigerina Marl or the marl could even be considered synonymous with the Stad Formation. Another problem is the separation of the Globigerina Marl from the "Globigerinenflysch" sensu Oberhauser (1991) since between both units a gradual transition occurs (see below) but the Globigerina Marl should be part of the Säntis Nappe and the "Globigerinenflysch" should be part of the Liebenstein Nappe.

Complementary references: Richter (1969, 1978), Oberhauser (1995, 2007), Prey (1980b), Friebe (2007a).

Helvetic Unit: Vorarlberg – Feuerstätter Nappe

Junghansen-Formation / Junghansen Formation

J. Georg Friebe & Werner E. Piller

Validity: Valid; Cornelius (1921) introduced the "Junghansenschichten" in which he included the "Rote Gschlief-Mergel" and later (Cornelius, 1925) also the "Bolgenkonglomerat". Richter (1957: p. 161) differentiated between Lower and Upper Junghansen Beds which he thought to be separated by the "Feuerstätter Sandstein" and "Hörnlein-Schichten". Schwerd & Risch (1983) discovered that the "Untere Junghansen-Schichten" are of Paleogene age, belong to the "Obere Junghansen-Schichten" and the putative Cretaceous age was based on reworked foraminifera. The subdivision of Richter (1957) is thus obsolete and not used furthermore (Richter, 1984; Weidich & Schwerd, 1987). Consequently, Fessler et al. (1992) redefined and formalized the Junghansen Formation including "Junghansen-Schichten (im engeren Sinn)" (representing a "Wildflysch facies"), "Bolgenkonglomerat", "Rote Gschliefschichten" and "Feuerstätter Sandstein".

Remark: The "Rote Gschliefschichten" are considered synonymous with the Rinderbach Formation, which is a formation on its own, and therefore not part of the Junghansen Formation (see below).

Type area: The Bavarian part of the Bolgenach valley, SE of Balderschwang, Landkreis Oberallgäu, Germany; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheet 113 Mittelberg).

Type section: -

A possible type section is along the river Bolgenach, SE of Balderschwang (Richter, 1957: Abb. 2; 1966: Abb. 14; 1984: p. 112, Abb. 30; Eggert, 1977) which is also an established Geotop in Bavaria (UmweltAtlas Bayern, 2021a: Geotop-Nummer: 780A005, N 47°26′37.8″ / E 10°08′05.1″). According to Schwerd & Risch (1983), this is the type locality of the former "Untere Junghansen-Schichten" (Richter, 1966: p. 70, who only wrote "ein Typusprofil"), which is now considered as part of the "Obere Junghansen-Schichten".

Remark: Eggert (1977) mentioned that unstable outcrops prone to erosion and mass movements make it difficult (and sometimes impossible) to rediscover sections described in older studies.

Reference section(s): -

Derivation of name: After the mountain hut Junghansen (N 47°26′50.6″ / E 10°07′52.9″) in the Balderschwang Valley at the eastern foot of the Schelpenkamm, municipality Balderschwang, Landkreis Oberallgäu, Bavaria, Germany; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheet 113 Mittelberg).

Synonyms: Ölquarzit (Cornelius, 1925), Wildflyschfazies (Alexander et al., 1965), Junghansen-Serie (Resch, 1976a), Junghansenschichten (Oberhauser, 1980), Hörnleinschichten (partim?) (Schwerd & Risch, 1983), Obere Junghansen-Schichten (Schwerd et al., 1983), Junghansenformation (Zacher, 1990), Wildflysch i. Allg. (inkl. Junghansenschichten und Feuerstätter Sandstein (Oberhauser, 2007; Friebe, 2007a), Hörnlein-Formation (partim?) (Oberhauser, 2007; Friebe, 2007a).

Lithology: A flyschoid succession of divers lithologies including dark to black shales and marls, black sandy shales often enriched in mica, black quartz sandstone, quartz breccias and mainly fine grained polygenic breccias, coarse conglomerates ("Bolgenkonglomerat"), rare intercalations of siliceous limestones and light limestones, fine grained and graded (carbonatic) quartz sandstones ("Ölquarzit") enriched in mica, grey and occasionally rusty weathered shales.

Fossils: Calcareous and agglutinated benthic and planktic foraminifera (frequently also reworked Upper Cretaceous fauna) (Fessler et al., 1992), radiolaria, molluscs, ostracods, echinoderms and bryozoa, ichnofossils (Schwerd et al., 1983).

Origin, facies: For (nearly) fossil-free black pelites, which are characteristic for the Junghansen Formation, Fessler et al. (1992) assumed deposition in a stagnant deep-marine basin mostly below the CCD with perhaps even euxinic conditions, which is only occasionally affected by turbidites or fluxoturbidites. The coarse conglomerates are interpreted as olithostromes (Schwerd & Risch, 1983).

Chronostratigraphic age: Late Cretaceous, Maastrichtian (?), early Paleocene–middle Eocene (Schwerd et al., 1983; Weidich & Schwerd, 1987).

Remark: The Junghansen Formation has undergone major shifts in age. When Cornelius (1921) coined the name, he assumed a stratigraphic contact to the underlying Mesozoic limestones ("Aptychenschichten") which he interpreted as Upper Jurassic (Malm). He thus postulated an Early Cretaceous age for the "Junghansenschichten".

Richter (1957) divided this lithostratigraphic unit into "Untere Junghansen-Schichten" of Early Cretaceous age and "Obere Junghansen-Schichten" of Late Cretaceous to Paleogene age. This subdivision is, however, obsolete after biostratigraphic data of Schwerd et al. (1983). Following Schwerd & Risch (1983), Fessler et al. (1992) pointed out, that nearly all deposits of the Feuerstätter Nappe contain reworked Upper Cretaceous microfossils. They dated pelites of the "Rote Gschlief-Schichten" as latest early to early middle Eocene.

Biostratigraphy: Schwerd & Risch (1983: p. 287) placed the type locality of the former "Untere Junghansen-Schichten" with planktic foraminifera in the middle Eocene. The outcrops at the Ränkertobel and Burgberger Starzlach yielded (poor) foraminifera faunas of lower Paleocene and lower to lower middle Eocene, respectively.

Thickness: Ranges from a few m to more than 100 m (? 200 m) (Cornelius, 1921; Alexander et al., 1965; Schwerd et al., 1983; Schwerd, 1996b); highly variable due to tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No valid, consistent and formalized subdivision exists.

Possible members within the Junghansen Formation are considered the Bolgen Conglomerate (Cornelius, 1925), the Rinderbach Beds ("Rote Gschliefschichten" sensu Cornelius, 1921) and the Feuerstätter Sandstone (Fessler et al., 1992) (for details see below).

Remark: Cornelius (1921) included the "Rote Gschliefschichten" in his Junghansenschichten. Fessler et al. (1992) also considered the "Rote Gschliefschichten" merely as a lithologic variation within their re-defined Junghansen Formation. Oberhauser (2007) and Friebe (2007a) treated the Rinderbach Formation (= "Rote Gschliefschichten") as a discrete lithostratigraphic unit independent of the Junghansen Formation. Also on the digital tectonic map 1:25,000 of Bavaria the "Rinderbach-Schichten", but also the "Feuerstätter-Sandstein", are separated from the "Junghansen-Schichten". The subdivision into "Untere und Obere Junghansenschichten" by Richter (1957) has been proved obsolete (Schwerd et al., 1983; Fessler et al., 1992) (see chronostratigraphy).

Underlying unit(s): Tectonic lower boundary.

Remark: Cornelius (1921) could not observe any sharp boundary between the Mesozoic limestone ("Aptychenkalk") and the "Junghansenschichten" and thus assumed a continuous transition. Eggert (1997) observed a clear tectonic contact between these two units in the Bolgenach valley. According to Fessler et al. (1992), it is still unclear if a tectonic or a sedimentary (transgressional) contact between "Aptychenschichten" (including coloured marls at their top) and the Junghansen Formation is present. Actually, the "Aptychenkalk" is interpreted as a tectonic slab within the Feuerstätter melange zone.

Overlying unit(s): Tectonic upper boundary.

Lateral unit(s): Schelpen-Serie (Fessler et al., 1992).

Geographic distribution: Vorarlberg: Isolated outcrops in the melange zone in the Bregenzerwald area between Dornbirn-Gütle, Schwarzenberg and Feuerstätter Kopf near Sibratsgfäll. A southern zone is squeezed in at the boundary between the Helvetic and Rhenodanubic Flysch nappes. Bavaria: Isolated outcrops in the melange zone between the border south of Balderschwang and Obermaiselstein in the east; also near Bad Hindelang and Wertach (Landkreis Oberallgäu).

Remarks: -

Complementary references: Lange (1956), Richter (1969, 1978), Prey (1980b), Tollmann (1985), Schwerd (1996b), Jaritz (2002), Jaritz et al. (2004).

Bolgen-Konglomerat (Junghansen-Formation) / Bolgen Conglomerate (Junghansen Formation)

J. Georg Friebe & Werner E. Piller

Validity: Invalid; Lupin (1809: p. 97ff.) first mentioned the exotic boulders at mount Bolgen. Sedgwick & Murchison (1832: p. 334) discussed "large, angular masses of granitoid gneiss and mica schist" at mount "Bolghen" and concluded, "that all the masses of primary rock were in situ". Gümbel (1861: p. 621) denominated it "Bolgen-Riesenkonglomerat" and described it to be predominantly composed of "Urgebirgsfelsarten". Cornelius (1925) coined the name "Bolgenkonglomerat" for a coarse-grained intercalation (including exotic blocks) within the "Junghansenschichten" and gave a detailed description of the components (Cornelius, 1925, 1926/1927). This opinion followed most subsequent authors (Fessler et al., 1992; Friebe, 2007a). The digital geological map of Bavaria 1:25,000 (umweltatlas.bayern.de) lists this unit as "Bolgen-Konglomerat" (UmweltAtlas Bayern, 2021b).

Type area: The area between Balderschwang and Obermaiselstein, Landkreis Oberallgäu, Bavaria; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheet 113 Mittelberg).

Type section: Cornelius (1925) referred to a "well known" location at the southern flank of mount Bolgen, E of the locality "Steinhaufen", c. 1,600 m a.s.l. Further detail information provided Eggert (1977: p. 120ff.). The type location is an established Geotop in Bavaria (UmweltAtlas Bayern, 2021c: Geotop-Nummer: 780A043, N 47°26′33.7″ / E 10°11′12.1″).

Reference section(s): Cornelius (1925) mentioned additional outcrops in the type area, along the way from Schönberg(er)-Alpe to Mittelalpe and in some creeks west of the hamlet Junghansen (Balderschwang Valley) but did include neither the exact location nor any description. A location in the "Löwenbach-Tal", SE of Sonthofen (N 47°30′07.5″ / E 10°18′26.4″) is mentioned in Schwerd & Risch (1983) and Schwerd et al. (1983).

Remark: The outcrops in the vicinity of Dornbirn mentioned by Hügel (1956) do not exist anymore.

Derivation of name: After mount Bolgen (1,687 m a.s.l; N 47°26′43″ / E 10°11′02″), W of the village Obermaiselstein, Oberallgäu, Bavaria; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheet 113 Mittelberg).

Synonyms: Urgebirgskonglomerat p.p. (Wepfer, 1909), Bolgenkonglomerat (Cornelius, 1925: p. 230), Saluier (Merhart, 1926), Feuerstätter Sandstein p.p. (Prey, 1968).

Remark: WEPFER (1909: p. 50f.) reported “Urgebirgsstücke (besonders Granit) und grüne Quarzite” which may be part of an “Urgebirgskonglomerat”.

A special case is the term “Saluier” which was particulary reported by MERHART (1926) along the road Dornbirn–Gütle–Salzmann. It seems that “Saluier” originally was a local name for a quartz sandstone used for the manufacturing of artificial whetstones (EBERLE, 2010). Following WEPFER (1909), MERHART (1926: p. 25) adopted this name both for the sandstone as well as for a breccia containing exotic boulders of varying size and lithology (= Bolgen Conglomerate). According to HÜGEL (1956: p. 86) the unit includes fine to medium grained glauconitic quartz sandstone and a polymictic breccia with conglomerates. PLÖCHINGER (1950: p. 97) restricted the name “Saluier (s.str.)” to granitic arkosic sandstone, and PREY (1968: p. 158) interpreted this sandstone as “Feuerstätter Sandstein”.

Lithology: Conglomerate beds up to several meters thickness with large (up to several tens of cubic meters), angular to well rounded, exotic crystalline boulders (granite, gneiss, mica schist, quartz-porphyry and occasionally also dolomite and limestone). The matrix is a greenish clay(stone), sandstone or calcitic cement (SCHWERD et al., 1983). CORNELIUS (1925) provided detailed descriptions of thin sections and EGGERT (1977) gave a more detailed description.

Remark: CORNELIUS (1925) mentioned that the Bolgen Conglomerate does not represent a well-defined stratigraphic level, but can be found at several levels within the Junghansen Beds. However, CORNELIUS (1926/1927: p. 8) stated that it occurs in one single horizon within the Junghansen Formation. OBERHAUSER (1980: p. 183) assumed that the conglomerate was deposited in several events between the Maastrichtian and Eocene.

Fossils: Rare agglutinated and calcareous foraminifera, rare bivalves, ostracodes, crinoids and fish teeth (EGGERT, 1977; SCHWERD & RISCH, 1983; SCHWERD et al., 1983). Foraminifera are also reworked from Cretaceous strata.

Origin, facies: EGGERT (1977) interpreted the conglomerate as proximal flysch deposits within a system of submarine canyons and submarine fans at the continental slope. OBERHAUSER (1980) considered it as a huge olisthostrome, which, however, represents several mass transport events.

Remark: The interpretation of CORNELIUS (1925) that it represents marine coarse-grained delta deposits at the mouth of torrents has to be rejected since it is embedded in the deep-sea deposits of the Junghansen Formation.

Chronostratigraphic age: Late Cretaceous, Maastrichtian (?), early Paleocene to early middle Eocene.

Remark: Being part of his Junghansenschichten, CORNELIUS (1925) assumed a possible Early Cretaceous age for the Bolgen Conglomerate. FESSLER et al. (1992) pointed out, that nearly all deposits of the Feuerstätter Nappe contain reworked Upper Cretaceous microfossils.

Biostratigraphy: Out of the conglomerate matrix Maastrichtian–Paleocene planktonic foraminifera were reported (RESCH, 1976b; EGGERT, 1977; SCHWERD & RISCH, 1983: p. 288), however the Cretaceous elements are considered to be reworked (WEIDICH & SCHWERD, 1987). EGGERT (1977) identified Paleogene conglomerate components.

Thickness: As maximum thickness > 30 m is reported by SCHWERD & RISCH (1983), but it is laterally highly variable.

Lithostratigraphically higher rank unit: Junghansen Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Occurs within the Junghansen Formation.

Overlying unit(s): Occurs within the Junghansen Formation.

Lateral unit(s): Occurs within the Junghansen Formation.

Geographic distribution: Vorarlberg: Within tectonically isolated slabs of Junghansen Formation in the eastern Bregenzerwald. Bavaria: Within tectonically isolated slabs of Junghansen Formation in the melange zone between the borders south of Balderschwang and Obermaiselstein in the east.

Remarks: Due the strong tectonic stress, which the Feuerstätter Nappe was exposed in general, and the overall bad outcrop situation, a consistent view of the distribution of the Bolgen Conglomerate is not possible. A formalization as member is therefore also not justified.

Complementary references: KRAUS (1926/1927), KRAUS & REIS (1929), RICHTER (1969, 1978), RESCH (1976a, b), PREY (1980b), TOLLMANN (1985), OBERHAUSER (1986, 2005), ZACHER (1990), SCHWERD (1996b), MOSER (2010).

Rinderbach-Formation / Rinderbach Formation

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; CORNELIUS (1921) introduced “Rote Gschlief-Mergel” for variegated shales which he considered part of the Junghansenschichten. For similar rocks the name “Rinderbachschichten” was introduced by HERB (1962: p. 76) representing a Flysch succession of variegated clays with oily quartzite layers of presumably (Pre-) Cenomanian age around Amden, canton Sankt Gallen, Switzerland. For Vorarlberg, OBERHAUSER (1965a, b) and PREY (1965b) first correlated similar lithologies within the Feuerstätter Nappe at the Pfudidetschbach in Satteins to the “Rinderbachschichten” which they placed near the Cretaceous/Paleogene boundary based on agglutinated foraminifera. BAYER (1982) studied various sections between the rivers Aare and Rhine, also the type section described by HERB (1962), and was able to place the “Rinderbach-Schichten” between the upper Campanian/lower Maastrichtian and lower Eocene. OBERHAUSER (2007) introduced the term “Rinderbach-Formation” on the geological map of Vorarlberg without further explanations, also FRIEBE (2007a: p. 68) did not provide a formalization.

Remark: In Switzerland, the “Rinderbach-Schichten” are regarded as informal. In the “Lithostratigraphisches Lexikon der Schweiz” (www.strati.ch) the age is still given as early Cenomanian, although HERB (1962: p. 77) took also a late Eocene into consideration.

Type area: Area around Amden, canton Sankt Gallen, Switzerland; Swiss National Map 1:50,000, map sheet 237 Walenstadt; 1:25,000, map sheet 1134 Walensee.

Type section: Mittlere Rinderbäche, c. 4 km ENE of the village Amden, canton Sankt Gallen, Switzerland (N 47°09′34″ / E 09°11′57″) (HERB, 1962).

Reference section(s): Satteins, Pfudidetschbach, Vorarlberg (N 47°14′33″ / E 09°41′00″); ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 141 Feldkirch) (PLÖCHINGER, 1950; OBERHAUSER, 1965b, 1991). Löwenbach-Tal, SE Sonthofen, Bavaria (N 47°30′06.9″ / E 10°18′27.2″) (SCHWERD & RISCH, 1983).

When CORNELIUS (1921: p. 142) described the "Rote Gschlief-Mergel" he did not define a type section but mentioned a location called "Rotes Gschlief" as locus typicus (N 47°26′24.7″ / E 10°06′33.4″), Bavaria; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, sheet 113 Mittelberg) (Bavaria: ATK25, map sheet S05 Hoher Ifen.

Derivation of name: Named after a group of ravines called Rinderbäche (HERB, 1962), ENE of the village Amden, canton Sankt Gallen, Switzerland.

Synonyms: Rote Gschlief-Mergel (CORNELIUS, 1921), Rotgschliefschichten (CORNELIUS, 1926/1927: p. 7), Rotgschliefschiefer (CORNELIUS, 1926/1927: p. 9), Rote(-) Gschliefschiefer (CORNELIUS, 1926/1927: p. 163), Wildflysch p.p. (OBERHAUSER, 1958), Rinderbachschichten (HERB, 1962), Rinderbach-Serie (OBERHAUSER, 1965a), Rinderbach-Schichten (BAYER, 1982), Rote Gschliefschichten (FESSLER et al., 1992), Rote Gschlief-Schichten (WEIDICH & SCHWERD, 1987; MOSER, 2010).

Lithology: Variegated, green, grey, and dark red ("blutwurstfarben" = colour of a black pudding) shales, with thin layers of fine-grained quartzitic breccias and quartz sandstones ("Ölquarzit"); all lithotypes are mostly carbonate-free (HERB, 1962; OBERHAUSER, 1991).

Fossils: Calcareous nannoplankton, radiolaria, agglutinated and calcareous foraminifera (HERB, 1962; SCHWERD & RISCH, 1983; SCHWERD et al., 1983; FESSLER et al., 1992), ichnofossils.

Origin, facies: Deep-sea sediments deposited well below the CCD; sedimented mostly on topographic highs without turbidites (FESSLER et al., 1992), only rarely turbitidic.

Chronostratigraphic age: Paleocene to middle Eocene.

Biostratigraphy: BAYER (1982) reported calcareous nannofossil Zones NP13–NP16 from the type locality.

OBERHAUSER (1984) referred to NP2–NP4 from a tectonic slab of black shales with occasional layers of quartz sandstone ("Ölquarzit") within the area of the town Dornbirn.

FESSLER et al. (1992) identified rare foraminifera from the "Rote Gschliefschichten" in the Bregenzerwald area which are considered to indicate upper lower Eocene–lower middle Eocene.

SCHWERD & RISCH (1983) found *Globigerina inaequispira* in "Rote Gschliefschichten" in the Löwenbach Tal, SE of Sonthofen, Bavaria, also pointing to lower–middle Eocene (Planktonic Foraminifera Zones E1–E8).

Thickness: At the type locality 20–30 m (HERB, 1962). In Vorarlberg reported OBERHAUSER (1991) approx. 70 m in Satteins (Pfudidetschbach). In Bavaria ("Rote Gschlief-Mergel") CORNELIUS (1921) mentioned more than 100 m; overall, highly variable due to tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Junghansen Formation.

Overlying unit(s): Tectonic contact.

Lateral unit(s): Not known.

Geographic distribution: Vorarlberg: Tectonically isolated slabs in the western Walgau, Rhine Valley and eastern Bregenzerwald. Bavaria: Tectonically isolated slabs in the melange zone between the border south of Balderschwang and Obermaiselstein in the east. For occurrences in Switzerland, see BAYER (1982).

Remarks: OBERHAUSER (1980, 1991) factually synonymised "Rote Gschliefschichten" and "Rinderbachschichten". Probably based on a misinterpretation of the description by OBERHAUSER (1980: p. 183), SCHWERD et al. (1983: p. 31) interpreted the "Roten Gschlief Schichten" as to represent only parts of the "Rinderbach-Schichten". FESSLER et al. (1992) considered the "Roten Gschliefschichten" as a lithologic variation within the Junghansen Formation sensu CORNELIUS (1921, 1926/1927). SCHWERD (1996b) preferred "Rote Gschliefschichten" but mentioned the "Rinderbachschichten" used by OBERHAUSER (1991). OBERHAUSER (2007) and FRIEBE (2007a) classified this unit as discrete Rinderbach Formation. Although the Rinderbach-Formation is an informal unit it is better defined than the "Roten Gschliefschichten" and we therefore use this term. The digital geological map of Bavaria 1:25,000 (umweltatlas.bayern.de) lists this unit as "Rinderbach-Schichten".

Complementary references: LANGE (1956), OBERHAUSER (1962, 1984), PREY (1980b).

Feuerstätter-Sandstein (Junghansen-Formation) / Feuerstätter Sandstone (Junghansen Formation)

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; already GÜMBEL (1861: p. 496) mentioned "Flyschsandstein" at the Feuerstädtberg and MYLIUS (1912: p. 79) from the Feuerstätterkopf. CORNELIUS (1925: p. 259) introduced the name "Feuerstättersandstein" for a green sandstone with intercalated conglomerates and breccias on top of the "Junghansenschichten". CORNELIUS (1926/1927: p. 9) formulated the term "Feuerstätter Sandstein" and provided a detailed description. Following CORNELIUS (1926/1927), FESSLER et al. (1992) included this unit into the Junghansen Formation. SCHWERD & RISCH (1983) and SCHWERD (1996b) considered the Feuerstätter Sandstein as a distinct lithostratigraphic unit. OBERHAUSER (2007) and FRIEBE (2007a) subsumed the "Feuerstätter Sandstein" with the "Junghansenschichten" under "Wildflysch im Allgemeinen".

Type area: The surroundings of the mountain Feuerstätterkopf between the Upper Bolgenach valley, village Balderschwang, Bavaria, and the village Sibratsgfäll, Vorarlberg; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK-BMN, map sheet 112 Bezau).

Type section: Not defined. A possible type section with a conglomerate bed and biostratigraphic data exists at the Upper Ränkertobel (Ränktobel), near Grasgehrenalpe

(N 47°26′28.3″ / E 10°10′32.2″), east of the mountain Bolgen, Bavaria (EGGERT, 1977: Abb. 27, Profil "i"; SCHWERD & RISCH, 1983).

Reference section(s): -

Derivation of name: After the mountain Feuerstätterkopf (also: Feuerstätter Kopf, Feuerstätterberg) (1,645 m a.s.l.; N 47°25′57.6″ / E 10°04′41.3″), c. 3 km ESE of the village Sibratsgfäll, Vorarlberg, close to the Austrian-German border; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK-BMN, map sheet 112 Bezau).

Remark: In the local dialect, the word "Kopf" within a mountain name is often omitted. In this case, the mountain is simply called "Feuerstätter" (on a historic Bavarian map even spelled "Feuerstädter"). The well-established name "Feuerstätter-Sandstein" should not be replaced by "Feuerstätterkopf-Sandstein".

Synonyms: Quarzit [am Feuerstätterkopf] (CORNELIUS, 1921: p. 145), Feuerstättersandstein (CORNELIUS, 1925), Feuerstätter Sandstein (CORNELIUS, 1926/1927), Saluier (HÜGEL, 1956; PREY, 1968), Feuerstätt sandstone (EGGERT, 1977), Wildflysch i. Allg. (inkl. Junghansenschichten und Feuerstätter Sandstein) (OBERHAUSER, 2007; FRIEBE, 2007a).

Remark: Partly also the "Saluier" (see Bolgen Conglomerate for details) is synonymous with the Feuerstätter Sandstone. According to HÜGEL (1956: p. 86) the unit includes glauconitic quartz sandstone followed by a polymictic breccia. PLÖCHINGER (1950) restricted the name "Saluier (s.str.)" to granitic arkose sandstone with conglomerates. PLÖCHINGER (1950: p. 97) restricted the name "Saluier (s.str.)" to granitic arkosic sandstone and PREY (1968: p. 158) interpreted this sandstone as "Feuerstätter Sandstein".

Lithology: A greenish, rarely also white and bluish green, fine to medium grained quartz sandstone with glauconite, mica and dolomite fragments often with a rusty brown to brownish red weathering surface. Layers of coarse sand and conglomerates also occur. The sandstone is predominantly thick-bedded but thin-bedded, platy and finely bedded parts are also reported (CORNELIUS, 1926/1927: p. 10; WEIDICH & SCHWERD, 1987).

Fossils: Generally, very poor in fossils. Rare agglutinated foraminifera and some calcareous forms; radiolaria, sponge spicules, bivalve fragments, bryozoa, crinoids, echinoid spines, non-specific bioturbations (EGGERT, 1977).

Origin, facies: Proximal flysch fan facies deposited in a channel/interchannel setting representing different gravitational transport mechanisms (EGGERT, 1977).

Chronostratigraphic age: Early Paleocene to Eocene (SCHWERD & RISCH, 1983; SCHWERD et al., 1983); middle Eocene (SCHWERD, 1996b; WEIDICH & SCHWERD, 1987).

Remark: Because biostratigraphic data were missing, CORNELIUS (1926/1927) dated the sandstone into the Gault (old term for late Early Cretaceous) and RICHTER (1957) to late Aptian to Albian.

Biostratigraphy: Planktonic foraminifera with *Subbotina triloculinoides* (SCHWERD & RISCH, 1983: p. 287) indicate Paleocene at the locality Ränkertobel.

Thickness: Generally, 8–50 m (EGGERT, 1977; SCHWERD et al., 1983; SCHWERD, 1996b), laterally highly variable due to tectonic truncation.

Lithostratigraphically higher rank unit: Junghansen Formation (CORNELIUS, 1925; FESSLER et al., 1992).

Lithostratigraphic subdivision: -

Underlying unit(s): Tectonic lower boundary (EGGERT, 1977). Only at the location Bolgenach a sedimentary transition from Eocene Junghansen Formation can be observed (EGGERT, 1977; SCHWERD & RISCH, 1983; WEIDICH & SCHWERD, 1987).

Overlying unit(s): Tectonic upper boundary (EGGERT, 1977).

Lateral unit(s): No lateral units are known.

Geographic distribution: Between Laterns, Vorarlberg, and Pfronten, Allgäu, Bavaria (EGGERT, 1977: p. 71).

Remarks: -

Complementary references: CORNELIUS (1925), LANGE (1956), RICHTER (1969, 1978), PREY (1980b), OBERHAUSER (1984, 1986, 1991, 1992), TOLLMANN (1985), ZACHER (1990), JARITZ (2002), JARITZ et al. (2004), MOSER (2010).

Schelpen-Serie / "Schelpen Series"

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; CORNELIUS (1926/1927: p. 60) introduced the name "Schelpenkalk" for dark, marly to occasionally sandy, flyschoid limestones alternating with dark shales. He interpreted this unit as facial variety of the "Piesenkopfkalk" of the Rhenodanubian Flysch. RICHTER (1957: p. 158) interpreted the "Schelpen-Serie" as the youngest stratum of the Liebenstein Nappe above the "Leimernschichten". HÖFLE (1972) pointed out that "Schelpenserie" and "Leimernschichten" had been deposited contemporaneously in adjacent areas. FESSLER et al. (1992) transferred the "Schelpen-Serie" into the Feuerstätter Nappe where it was considered to be deposited adjacent to the Junghansen Formation in a slightly shallower environment.

Type area: The mountain Hochschelpen, south of village Balderschwang, Bavaria, Germany; ATK25, map sheet S05 Hoher Ifen; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheet 113 Mittelberg).

Type section: -

Reference section(s): -

Derivation of name: After the mountain Hochschelpen (1,552 m a.s.l.; N 47°26′04.2″ / E 10°06′33.7″), south of the village Balderschwang, Bavaria, Germany; ATK25, map sheet S05 Hoher Ifen; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK-BMN, map sheet 113 Mittelberg).

Synonyms: Schelpenkalk (CORNELIUS, 1926/1927), Schelpenserie (LANGE, 1956), Schelpen-Serie (RICHTER, 1957), Globigerinen-Flysch (= Schelpen-Serie) (OBERHAUSER, 1973), Flysch unsicherer tektonischer Stellung (WEIDICH & SCHWERD, 1987), Globigerinenflysch (?= Schelpenserie) (OBERHAUSER, 1991: p. 34), Globigerinenflysch (inkl. "Schelpen-Serie") (OBERHAUSER, 2007), Globigerinenflysch (= "Schelpen-Serie"), Globigerinenflysch (inkl. "Schelpenserie") (FRIEBE, 2007a).

Remark: OBERHAUSER (1991) used the term "Globerinenflysch" both for deposits in the Liebenstein and Feuerstätter Nappe.

Lithology: Dark, predominantly marly, dense, less frequently also sandy, glauconitic flyschoid limestone ("Schelpenkalk") (5–15 cm, up to 40 cm) intercalated with dark (chocolate brown) clayey marls to shales and rare sandstone beds.

Remark: According to FESSLER et al. (1992: Tab. 1), the main features to distinguish the Schelpen Serie from the Junghansen Formation are the presence of carbonate lithologies, a richer microfauna and chocolate brown clay marls.

Fossils: Rich calcareous nannoplankton and agglutinated and planktonic foraminifera in the marls, very rare trace fossils.

Origin, facies: Deposited on the lower continental slope, but less deep than the Junghansen Formation (above the CCD) (FESSLER et al., 1992).

Chronostratigraphic age: Paleocene (?), early Eocene to late Eocene (FESSLER et al., 1992).

Remark: The possible Paleocene age may be merely based only reworked foraminifera.

Biostratigraphy: Planktonic foraminifera point to an Eocene age, but Paleocene cannot be excluded: PFZ P3b–E12 (*Morozovella velascoensis* (P3b–top E2; Selandian–Ypresian), *Morozovella subbotinae* (P5–E5, Thanetian–Ypresian), *Acarinina soldadoensis* (P4c–E7, Thanetian–Lutetian), *Acarinina bullbrooki* (E7a–E11, Ypresian–Bartonian), *Globigerinatheka kugleri* (E9–E13, Lutetian–Bartonian), *Morozovelloides lehneri* (E10–E12, Lutetian–Bartonian). Taxa described by HÖFLE (1972), WEIDICH & SCHWERD (1987) and FESSLER et al. (1992) were adjusted to current taxonomy. Calcareous nannofossil Zones NP11–NP14 (OBERHAUSER, 1991).

Thickness: > 100 m (RICHTER, 1957), obscured by tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Tectonic lower boundary.

Overlying unit(s): Tectonic upper boundary.

Lateral unit(s): Globigerinenflysch, Junghansen Formation.

Remark: With an increase in water depth at the lower continental slope, the Globigerinenflysch of the Liebenstein Nappe was replaced by the Schelpen Formation of the Feuerstätter Nappe. At the same time, the Junghansen Formation was deposited even farther south. Since these units were brought close to each other by tectonics, the exact relationship between these strata remains unclear (FESSLER et al., 1992).

Geographic distribution: The "Schelpen-Serie" is basically restricted to the area between the mountain Grünten in Bavaria and the river Subersach in the eastern Bregenzerwald and around Schwarzenberg, Vorarlberg, with additional occurrences in the Kleinwalsertal, Vorarlberg (RICHTER, 1957; FESSLER et al., 1992); TK50, map sheet L8526 Immenstadt i. Allgäu; ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheets 112 Bezau, 113 Mittelberg).

Remarks: -

Complementary references: RICHTER (1969, 1978), OBERHAUSER (1980, 1992), PREY (1980b), BAYER (1982), SCHWERD (1984, 1996a), TOLLMANN (1985), ZACHER (1990), JARITZ (2002), JARITZ et al. (2004), MOSER (2010).

Helvetic Unit: Salzburg – Upper Austria – Gresten Klippen Belt – Main Klippen Belt

Olching-Formation / Olching Formation

WERNER E. PILLER

Validity: Valid; GÖTZINGER (1929b) mentioned Olchinger Schichten, described the section along the Kroisbach and defined there the type locality of the "Oichinger Schichten" (GÖTZINGER, 1934: p. 38). RASSER & PILLER (1999a, b) formalized the unit as Olching Formation (preferring the name Olching instead of Oiching).

Type area: North of the hill Haunsberg, c. 16 km N of the city of Salzburg, Salzburg; ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Type section: Natural outcrop along the creek Kroisbach in the Kroisbachgraben, SE of the hamlet Klein-Olching, Salzburg; N 47°56′15″ / E 12°59′50″ (uppermost barrage in the creek – "Heinrich Herrle Sperre"); ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg) (RASSER & PILLER, 1999a, b: Abb. 1, 2).

Reference section(s): -

Derivation of name: Named after the village Olching, c. 2.2 km SSW of the village Nußdorf am Haunsberg, c. 16 km N-NNW of the city of Salzburg, Salzburg.

Synonyms: Schwarze Mergel (FUGGER, 1900), Olchinger Schichten (GÖTZINGER, 1929b), Oichinger Schichten (GÖTZINGER, 1934), Feinsandige, schwarze Mergel (HAGN & WELLNHOFER, 1973: Abb. 6), Olching Formation (RASSER & PILLER, 1999a).

Lithology: Dark grey to blackish claymarl with glaucony and highly variable sand content. Within the claymarl occasionally sand lenses occur. In the lower part of the section, the marls are well bedded. Sand layers (0.2–1 m) in the upper part are partly cross-bedded (mm-scale) (RASSER & PILLER, 1999a). Concretions of glauconitic sandstone and of clay ironstone (2–5 cm diameter) are abundant (TRAUB, 1990).

Fossils: Calcareous nannoplankton and planktic foraminifers are abundant and diverse (GOHRBANDT et al., 1963; KUHN, 1992). Gastropods and bivalves are abundant (e.g., TRAUB, 1938, 1979, 1980, 1981, 1984, 1989; TRAUB & WER-

NER, 1993; SCHULTZ, 1998), also scaphopods, coleoid cephalopods (*Beloptera broilii* TRAUB, 1938; *Belopterina neumaieri* TRAUB, 1982), decapod crustaceans, brachiopods, echinoids and corals (KÜHN & TRAUB, 1967) occur. SCHWARZHANS (2012) described fish otoliths of a very diverse fauna. In the upper most part of the type section abundant plant remains, wood fragments and coaly lenses occur.

REMARK: HAGN (1967: p. 270) stated that the macrofauna of the Olching Formation in the Kroisbachgraben represents the most fossil-rich Paleocene occurrence in entire Europe.

Origin, facies: Shallow marin environment of middle to outer shelf; foraminiferal associations indicate 50–150 m (KUHN, 1992).

Chronostratigraphic age: Paleocene, Danian to Thanetian (KUHN, 1992).

Remark: The age of this unit has been changed widely: FUGGER (1900) considered it Miocene, GÖTZINGER (1934: p. 38) suspected Oligocene and TRAUB (1936: p. 13; 1938) placed it in the Paleocene.

Biostratigraphy: Planktonic foraminifera Zones P1a/b–P5 (KUHN & WEIDICH, 1987; KUHN, 1992). Due to intense tectonics, the sections are imbricated and show no stratigraphically continuous succession. Calcareous nannofossil Zone NP2 is reported by EGGER (2009a).

Thickness: At the type locality 57 m (but lower boundary not exposed) (RASSER & PILLER, 1999a, b); TRAUB (1990) reports 150 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Gerhardsreuter Schichten (REIS, 1896 (used also the names Götzreuter Schichten and Götzreuther Mergel); TRAUB, 1938: p. 6; 1953: p. 5; ABERER & BRAUMÜLLER, 1947, 1958; TOLLMANN, 1985: p. 325f.; GÖTZINGER, 1937), Gerhardtsreiter Mergel by GOHRBANDT et al. (1963: p. 5), and Gerhartsreiter Schichten by HAGN (1981: p. 46) and KUHN (1992).

Overlying unit(s): Kroisbach Member (Kressenberg Formation).

Lateral unit(s): No units in direct contact reported.

Geographic distribution: Haunsberg, Matzing, Mattsee, all Salzburg, Austria; Kressenberg, southern Bavaria, Germany.

Remarks: As lateral equivalent the Bruderndorf Beds of the Waschberg Unit could be considered.

Complementary references: GÖTZINGER (1936a), ABERER & BRAUMÜLLER (1958), TOLLMANN (1985), RASSER & PILLER (2001), FUCHS & LUKENEDER (2014), STD 2016, KARL & TICHY (2019).

Kressenberg-Formation / Kressenberg Formation

WERNER E. PILLER

Validity: Valid; RASSER & PILLER (1999a) merged various well-known lithostratigraphic units of the Kressenberg area ("Sandstein mit *Pycnodonta* und *Crania*", "Unterer Lithothamnienkalk", "Roterschichten", "Zwischenschichten“, "Schwarzerzschichten", "Nebengestein des Schwarzerzflözes") (Upper Bavaria, Germany) and comparable units in the wider Haunsberg area ("Craniensandstein", "Gryphaeenbank", "Unterer Lithothamnienkalk", "Roterzschichten", "Mittelschichten", "Schwarzerzschichten", "Fossilschicht") (Salzburg, Austria) in the Kressenberg Formation.

Type area: Area SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein); for Austria: Haunsberg area, N of the city of Salzburg; ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Type section: Natural outcrop along the Kressengraben (N 47°49′23″ / E 12°43′36″), c. 1.5 km SW of the market village Neukirchen am Teisenberg, Upper Bavaria, Germany.

Reference section(s): Natural outcrop along the creek Kroisbach in the Kroisbachgraben, SE of the hamlet Klein-Olching, Salzburg; N 47°56′15″ / E 12°59′50″ (uppermost barrage in the creek – "Heinrich Herrle Sperre"); ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg) (RASSER & PILLER, 1999a, b: Abb. 1, 2). Well-developed lower boundary.

Derivation of name: Named after the hamlet Kressenberg (N 47°49′25″ / E 12°43′33″), c. 1.5 km SW of the village Neukirchen am Teisenberg, c. 6 km E of Siegsdorf, Upper Bavaria, Germany.

Synonyms: Eisenstein-Flötze am Kressenberg (BRONN, 1832: p. 176f.), Eisensteine vom Kressenberg (BRONN, 1832: p. 181), Kressenberger-Schichtenreihe (GÜMBEL, 1861: p. 612), Kressenberger-Schichten (GÜMBEL, 1861: p. 612), Untere Nummulitengruppe (GÜMBEL, 1861: p. 615).

For synonyms of subunits of the Kressenberg Formation, see description of members.

Lithology: A great lithologic spectrum occurs with sandstones, nummulite limestones and calcareous sandstones, iron oolites, red algal limestones (with marl intercalations) and coarse-grained sand. Mostly fossiliferous and calcareous, partly ferruginous, partly glauconitic. A micofacies study has been carried out by RASSER & PILLER (2001).

Fossils: Highly variable but in some units very diverse and abundant; already mentioned by FLURL (1792) and also published in popular science literature (e.g., MOOSLEITNER, 1988, 2004; SCHULTZ, 1998). For details, see descriptions of the members.

Origin, facies: See description of members.

Chronostratigraphic age: Paleocene, Thanetian to middle Eocene, Lutetian (HAGN, 1981; KUHN, 1992; EGGER, 2009a).

Biostratigraphy: Planktonic foraminifera Zones P5–P7 (KUHN, 1992). The upper boundary is not well constrained, but P7 was identified. Calcareous nannofossil Zones NP8–NP16 (EGGER, 2009a).

Thickness: Minimum thickness in the Kressengraben 30 m (lower and upper boundary not exposed), in the Kroissbachgraben a minimum of 70 m. The thickness generally decreases from W to E (VOGELTANZ, 1970: Abb. 3).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Kressenberg Formation is completely subdivided into members: Kroisbach Member, Fackelgraben Member, Frauengrube Member, Sankt Pankraz Kressenberg Member, Weitwies Member.

Underlying unit(s): Olching Formation. For the boundary, see Kroisbach Member.

Overlying unit(s): Stockletten (FLURL, 1792; GOHRBANDT et al., 1963; HAGN, 1981), but boundary not exposed.

Lateral unit(s): The lower part of the “Adelholzener Schichten” of the Northhelvetic Zone may correspond with the uppermost part of the Kressenberg Formation (HAGN, 1954, 1981: p. 48); in the Helvetic Zone of Neubeuern am Inn the units “Schwarzerz”, “Nebengestein”, “Mühlsandstein” and “Übergangsschichten” correspond with the Kressenberg Formation (HAGN & DARGA, 1989); a similar sequence to the Kressenberg Formation exists in the area of Grünten near Sonthofen (Swabia, Bavaria) but a direct correlation of the members is not possible (probably due to the strong tectonics at Grünten) (RASSER & PILLER, 1999a); the “Buntmergelserie” of the Ultrahelvetic Zone (TOLLMANN, 1985; WAGREICH & NEUHUBER, 2007).

Geographic distribution: Kressenberg, Upper Bavaria, Germany; Salzburg, Austria: Haunsberg, Matzing, Mattsee, Rohrmoos-Reitsham, and also at the southern margin of the Rhenodanubian Flysch Zone, in the so-called Heuberg-Fenster (tectonic window) at the Hochstein (N 47°49′58″ / E 13°06′53″) (EGGER, 2009a; EGGER & VAN HUSEN, 2009b; EGGER & MANDL, 2015).

Remarks: An angular unconformity exists between the Fackelgraben Member and the Frauengrube Member of the Kressenberg Formation (VOGELTANZ, 1977; RASSER & PILLER, 1999b) which may be related to tectonic activities of the so-called ‘Laramide 3′ Phase (TOLLMANN, 1964; RASSER & PILLER, 2001). This unconformity represents a sedimentary gap of c. 3 Ma (EGGER & VAN HUSEN, 2009b; EGGER et al., 2013). Because of this gap, it seems more adequate to split the Kressenberg Formation into two different formations. The lower including Kroisbach Member and Fackelgraben Member and an upper one including the Frauengrube Member, Sankt Pankraz Member, Kressenberg Member and Weitwies Member.

The Kressenberg Formation is well-known for iron ore mining (FLURL, 1792) since the Middle Ages; regular mining started in the Kressenberg area in the year 1537, the climax was between the middle of the 17th to the 18th century, mining was abandoned in 1925 (HAGN, 1961a: p. 157; DARGA, 2008: p. 130).

Complementary references: REIS (1896), HAGN & WELLNHOFER (1973), EGGER (2011a), STD 2016.

Kroisbach-Subformation (Kressenberg-Formation) / Kroisbach Member (Kressenberg Formation)

WERNER E. PILLER

Validity: Valid; the well-known “Craniensandstein” and the “Gryphaenbank” (GOHRBANDT et al., 1963) are separated at the type locality at Haunsberg, but cannot be clearly differentiated at Kressenberg and were therefore subsumed in the Kroisbach Member by RASSER & PILLER (1999a).

Type area: Haunsberg area, N of the city of Salzburg; ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg); Upper Bavaria, Germany: area SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Type section: Natural outcrop along the creek Kroisbach in the Kroisbachgraben, SE of the hamlet Klein-Olching, Salzburg; N 47°56′15″ / E 12°59′50″ (uppermost barrage in the creek – “Heinrich Herrle Sperre”); ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg) (RASSER & PILLER, 1999a, b: Abb. 1, 2).

Reference section(s): -

Derivation of name: Named after the creek Kroisbach in the Kroisbachgraben, SE of the hamlet Klein-Olching, Salzburg; ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg) (RASSER & PILLER, 1999a, b: Abb. 1, 2).

Synonyms: Craniensandstein p.p. (lower part of the member in the Haunsberg area) (GOHRBANDT et al., 1963: p. 20), Gryphaeenbank p.p. (upper part of the member in the Haunsberg area) (GOHRBANDT et al., 1963: p. 20), Glaukonitsandstein mit […] *Pycnodonta frauscheri* (TRAUB, 1938: p. 26), Glaukonitischer Grünsandstein […] mit *Cucullaea crassatina* LAMK., *Pycnodonta frauscheri* (TRAUB, 1938: p. 27), Sandsteine mit *Pycnodonte* und *Crania* in the Kressenberg area (HAGN, 1981: p. 99), “Gryphaeen-Sandstein” p.p. (HAGN, 1981: p. 104).

Lithology: At the type section, at the base 80 cm reddish brown, quartz sandstone with carbonate cement with pycnodont oysters, iron concretions and iron ooids (“Craniensandstein”). Overlain by 3 m slightly cemented, ochre coarse sands with abundant pycnodont oysters and iron-impregnated particles. Glaucony increases upsection.

Fossils: Foraminifera (GOHRBANDT et al., 1963; KUHN, 1992), brachiopods (*Crania austriaca* TRAUB), bivalves (*Pycnodonte pseudovesicularis* (GÜMBEL) und *P. haunsbergensis* TRAUB (formerly: *P. frauscheri*), cephalopods (*Aturia* (*Aturoidea*) *parkinsoni*), plant remains.

Origin, facies: Shallow marine, coastal-near environment (KUHN, 1992).

Chronostratigraphic age: Paleocene, Thanetian–early Eocene, Ypresian (KUHN, 1992). But see Fackelgraben Member.

Biostratigraphy: Planktonic foraminifera Zones P5–P6 (KUHN, 1992). But see Fackelgraben Member.

Thickness: 3.8 m at the type locality; GOHRBANDT et al. (1963) report 0.7–4 m for the “Craniensandstein” and 2.5–20 m for the “Gryphaeenbank”.

Lithostratigraphically higher rank unit: Kressenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Olching Formation.

Overlying unit(s): Fackelgraben Member.

Lateral unit(s): No lateral units exposed.

Geographic distribution: Haunsberg, Matzing, Salzburg, Austria; Kressenberg, Upper Bavaria, Germany.

Remarks: -

Complementary references: ABERER & BRAUMÜLLER (1958), VOGELTANZ (1972), TOLLMANN (1985).

Fackelgraben-Subformation (Kressenberg-Formation) / Fackelgraben Member (Kressenberg Formation)

WERNER E. PILLER

Validity: Valid; coralline algal limestones occur in two horizons in the Helvetic Zone in Bavaria and Salzburg: for the lower horizon the term "Unterer Lithothamnienkalk" (TRAUB, 1938: p. 17) has been widely used, for the "Oberer Lithothamnienkalk" (upper corallinacean limestone) which is interbedded with the "Stockletten" the term "Granitmarmor" (only in Upper Bavaria) (GÜMBEL, 1861: p. 618) has been introduced. The "Unterer Lithothamnienkalk" has been formalized by RASSER & PILLER (1999a) as Fackelgraben Member of the Kressenberg Formation.

Type area: Haunsberg area, N of the city of Salzburg, and area W of Lake Obertrum (Fackelgraben, Teufelsgraben); ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheets 63 Salzburg, 64 Straßwalchen); Upper Bavaria, Germany: Kressenberg area, SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Type section: Natural outcrop along a small creek in the Fackelgraben (N 47°57′17″ / E 13°03′57″) immediately adjacent in the NW of the hamlet Gimmelsberg, c. 700 m SW of the village Matzing, 2 km NNW of Obertrum am See, Salzburg, Austria; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg); lower and upper boundaries exposed.

Reference section(s): -

Derivation of name: Named after small creek bed Fackelgraben (alternate name: Mayrbachgraben), NW of the hamlet Gimelsberg, c. 700 m SW of the village Matzing, 2 km NNW of Obertrum am See, Salzburg, Austria.

Remark: The name Fackelgraben has been chosen because it was already mentioned by FRAUSCHER (1885: p. 175) and later on by VOGELTANZ (1970; as Vackelgraben) and it is also used by the local people.

Synonyms: Nulliporenkalk (FRAUSCHER, 1885: p. 176), tieferes Lithothamniumlager, Unterer Granitmarmor, Lithothamnium-Flötz (REIS, 1896), Lithothamnienkalksteine (GÖTZINGER, 1936b), Lithothamnienkalk (TRAUB, 1936), Unterer Lithothamnienkalk (TRAUB, 1938: p. 17).

Lithology: Greyish and pinkish, well bedded (dm-scale) corallinacean limestone (corallinacean debris and rhodoliths) with very thin marl intercalations. In the lower part are pycnodont oysters abundant as well as a higher content of glaucony. Corallinacean debris dominates in the lower part, in the upper part increases the amount of rhodoliths. The abundance and thickness of marl intercalations increase upsection. A microfacies study was carried out by RASSER & PILLER (2001).

Fossils: Calcareous nannoplankton, corallinacean algae, foraminifers: sessile *Acervulina*, larger benthic foraminifers (*Nummulites* cf. *fraasi, N. nitidus nitidus, N. praelucasi praelucasi;* discocyclinids), corals (*Porites*, *Isis*), bivalves (*Pycnodonte*), bryozoan, brachiopods, crinoids, echinids, decapod crustaceans.

Origin, facies: Shallow marine environment with a deepening upward trend (RASSER & PILLER, 2001).

Chronostratigraphic age: Late Paleocene, Thanetian.

The Fackelgraben Member was considered by HAGN (1981) to be of late Paleocene age. Based on planktonic foraminifers KUHN (1992) assigned an early Eocene (Ypresian) age but this was not very well constrained. Calcareous nannofossil Zone NP9 allowed a re-assignment to the Thantian, what fits also much better to a regional correlation.

Biostratigraphy: Calcareous nannofossil Zone NP9 (*Discoaster multiradiatus* Zone) (EGGER, 2009a).

Thickness: 16 m at the type section; for the occurrences in Salzburg a general thickness of 15 m is given by TRAUB (1953) and GOHRBANDT et al. (1963), VOGELTANZ (1977) reports 18–20 m from the Wartstein area. For the Kressengraben in Bavaria a minimum of 10 m and a maximum of 13 m is estimated.

Lithostratigraphically higher rank unit: Kressenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Kroisbach Member.

Overlying unit(s): Frauengrube Member (transgressive above unconformity) (e.g., EGGER & VAN HUSEN, 2009b; EGGER et al., 2013; RASSER & PILLER, 2001).

Lateral unit(s): -

Geographic distribution: Haunsberg, Matzing, Salzburg, Austria; Kressenberg, Upper Bavaria, Germany.

Remarks: In the Haunsberg- and Wartstein areas an angular unconformity is present between the Fackelgraben Member and the transgressive Frauengrube Member (see Kressenberg Formation). The age of the transgression has been dated to the Ypresian (NPZ NP12) by EGGER & VAN HUSEN (2009b).

Complementary references: ABERER & BRAUMÜLLER (1958), VOGELTANZ (1972), HAGN & WELLNHOFER (1973), TOLLMANN (1985).

Frauengrube-Subformation (Kressenberg-Formation) / Frauengrube Member (Kressenberg Formation)

WERNER E. PILLER

Validity: Valid; the best known sediments in the Helvetic Zone of the Kressenberg and Haunsberg areas are nummulite limestones with iron oolites which occur as so-called "Roterz" (red ore) and "Schwarzerz" (black ore) in two horizons. For the lower unit RASSER & PILLER (1999a, b) introduced and formalized the term Frauengrube Member.

Type area: Haunsberg area, N of the city of Salzburg; ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg); Upper Bavaria, Germany: area SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Type section: Section within the historical quarry "Frauengrube" (N 47°56′09″ / E 13°00′05″; RASSER & PILLER, 1999a, b: Abb. 1, 3), along a forest road from Schlößl Quarry near Sankt Pankraz am Haunsberg to the Frauengrube, close to the turnoff of the forest road to the hamlet Bauerstatt; c. 2.5 km S of the village Nußdorf am Haunsberg, Salzburg, Austria; ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg). Lower and upper boundary exposed.

Reference section(s): -

Derivation of name: Named after the locality "Frauengrube", a historical mining location for the so called "Roterz" (red iron ore).

Synonyms: Kressenberger-Rotherz (Gümbel, 1861: p. 617), Kressenberger Nummulitenschichten p.p. (Gümbel, 1868), Rotherzschichten (Reis, 1896), Rothflötz (Reis, 1898), Roterz (Schlosser, 1925a: p. 203), Nummuliten-Kalksandstein (Götzinger, 1936b), Nummulitenkalksandstein mit Roterz (Traub, 1938), Roterzschichten s.s., Roterzschichten s.l. (Traub, 1953), Rotkalk-Gruppe (Ziegler, 1960: p. 214), Rotkalk-Gruppe mit Roterzhorizont (Ziegler, 1975: p. 246).

Remark: In the Kressenberg area parts of the Frauengrube Member are represented by various ore seams, e.g., Ferdinandflötz, Josephflötz, Karlflötz (Flurl, 1792; Gümbel, 1861).

Lithology: Red to rusty brown, massive, iron-ooid bearing nummulite limestones to calcareously cemented, quartz-rich coarse sands to fine conglomerates. Quartz grains are frequently iron encrusted and bioclasts iron impregnated. Larger benthic foraminifers and iron ooids increase upsection, the iron content varies laterally. Iron-ooids are much more abundant in the Kressenberg area compared to Haunsberg. Microfacies studies have been carried out by Vogeltanz (1970) and Rasser & Piller (1999b, 2001).

Fossils: Larger benthic foraminifers: *Assilina*, *Nummulites* (*N. p. praelucasi*, *N. p. ganensis*), *Discocyclina*, *Aktinocyclina*, *Alveolina*), very rare corals, gastropods, bivalves, cephalopods, brachiopods, bryozoans, serpulids (*Ditrupa*, *Rotularia*), decapod crustaceans, echinoids vertebrates (sharks, crocodiles), plant remains.

Origin, facies: Shallow marine environment on highly structured sea bottom with shoals where the ooids have been formed and slightly deeper, protected areas where larger foraminifers thrived (Rasser & Piller, 2001).

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: The transgression of the Frauengrube Member started in calcareous nannofossil Zone NP12 (Egger & van Husen, 2009b), the larger benthic foraminifers indicate SBZ10 (Egger & van Husen, 2009b), planktonic foraminifers point at P6 or P7 (Kuhn, 1992).

Thickness: At the type section Frauengrube the thickness is c. 22.5 m, in the Kressengraben 7.1 m.

Lithostratigraphically higher rank unit: Kressenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Fackelgraben Member (Kressenberg Formation).

Overlying unit(s): Sankt Pankraz Member (Kressenberg Formation).

Lateral unit(s): In the south probably Buntmergelserie of the Ultrahelvetic Unit.

Geographic distribution: Haunsberg, Matzing, Mattsee, Ramoos-Reitsham (Salzburg, Austria); Kressenberg area (Upper Bavaria, Germany).

Remarks: The differentiation between Roterzschichten s.l. and s.s. as carried out by Traub (1938) is mostly a weathering feature (Vogeltanz, 1970).

The sediments of the Frauengrube Member have been mined for the iron in the Kressenberg area because of the higher iron content, in the Frauengrube the rock was mined only for millstone and grind stone production.

Complementary references: Götzinger (1936a), Traub (1936), Aberer & Braumüller (1958), Hagn (1961a), Vogeltanz (1968, 1972), Hagn & Wellnhofer (1973), Tollmann (1985), Kuhn (1992).

Sankt Pankraz-Subformation (Kressenberg-Formation) / Sankt Pankraz Member (Kressenberg Formation)

Werner E. Piller

Validity: Valid; for sandy sediments between the two ore horizons ("Roterz" and "Schwarzerz") the terms Zwischenschichten (Kressenberg area) and Mittelschichten (Haunsberg area) have been commonly used, for these sediments Rasser & Piller (1999a) introduced the unit Sankt Pankraz Member.

Type area: Haunsberg area, N of the city of Salzburg, ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg), Upper Bavaria, Germany: area SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Type section: East-oriented wall of the "Schlößlfelsen" near the church Sankt Pankraz am Haunsberg, at the parking lot for the church (Rasser & Piller, 1999a: Abb. 2, 3) (N 47°55′53″ / E 12°59′25″), immediately above the small village Schlößl, c. 3.5 km SSW of the village Nußdorf am Haunsberg, Salzburg, Austria, ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg).

Reference section(s): -

Derivation of name: Named after the church Sankt Pankraz am Haunsberg, located at the so-called Schlößlfelsen of the small village Schlössl, Salzburg, Austria, ÖK50-UTM, map sheets 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg)

Synonyms: Mittellagen (Reis, 1896: p. 36), Mittelschichten (Reis, 1896: p. 42), Zwischenschichten (Ziegler, 1960: p. 213), Zwischen-Schichten (Hagn, 1981: p. 100), Mittel-Schichten (Hagn, 1981: p. 105).

Lithology: In the Haunsberg area the sediments are weakly cemented, yellow weathered, fine grained, badly sorted quartz sands without fossils. In subsurface occurrences (Wartstein tunnel), however, they are firm, dark green quartz sandstones (Vogeltanz, 1977).

In the Kressenberg area the sediments of this member are represented by polymict, grey to brown coarse sandstones – fine conglomerates rich in larger benthic foraminifers.

Remark: In the Kressenberg area the sediments of the Sankt Pankraz Member are very similar to that of the Frauengrube Member but with a lower iron content.

Fossils: No fossils at the type locality, rare occurrences of nummulitids and alveolinids in other localities in Salzburg (Vogeltanz, 1970).

Remark: In the Kressenberg area some parts of the Sankt Pankraz Member belong to the fossil richest beds of the Kressenberg Formation including, besides larger benthic foraminifers (nummulitids and discocyclinas), a rich mollusc fauna, echinoids and shark remains (cf. Schlosser, 1925a).

Origin, facies: The sediments represent shallow subtidal sand bodies, which show a high fluvial influence and a high degree of reworking (Vogeltanz, 1970: p. 425).

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: The type section is barren of fossils.

Kressengraben: Calcareous nannofossil Zone NP13, larger benthic foraminifers with *Nummulites burdigalensis*, *N.* cf. *campesinus*, *Assilina laxispira*, and *A. maior* indicate a Cuisian age (Hagn, 1981: p. 105–107) and SBZ10–SBZ12.

Thickness: At the type section 31.5 m, in the Kressengraben only 2.5 m. Traub (1953: p. 27) reports from the Haunsberg area a thickness of 105 m and general increase in thickness from N to S.

Lithostratigraphically higher rank unit: Kressenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Frauengrube Member (Kressenberg Formation).

Overlying unit(s): Kressenberg Member (Kressenberg Formation).

Lateral unit(s): In the south probably Buntmergelserie of the Ultrahelvetic Unit.

Geographic distribution: Haunsberg, Matzing, Mattsee, Ramoos-Reitsham (Salzburg, Austria), Kressenberg area (Upper Bavaria, Germany).

Remarks: The quartz sands have been mined in the wider Haunsberg area (e.g., Egger & van Husen, 2009b).

Complementary references: Reis (1898), Traub (1953), Aberer & Braumüller (1958), Gohrbandt et al. (1963), Vogeltanz (1972), Hagn & Wellnhofer (1973), Tollmann (1985), Kuhn (1992), Egger & van Husen (2009a).

Kressenberg-Subformation (Kressenberg-Formation) / Kressenberg Member (Kressenberg Formation)

Werner E. Piller

Validity: Valid; the best known sediments in the Helvetic Zone of the Kressenberg and Haunsberg areas are nummulite limestones with iron oolites which occur as so-called "Roterz" (red ore) and "Schwarzerz" (black ore) in two horizons. For the upper ore unit Rasser & Piller (1999a, b) introduced and formalized the term Kressenberg Member.

Type area: Kressenberg area, SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Type section: Natural outcrop along the Kressengraben (N 47°49′23″ / E 12°43′36″), c. 1.5 km SW of the market village Neukirchen am Teisenberg, Upper Bavaria, Germany.

Remark: Currently no outcrops or continuous section exist in the Kressengraben. Unfortunately, the ore was completely exploited at the surface and only the under- and overlying units are preserved. The sediments of the member are preserved in the mining adits, these are, however, closed to the public. The SSW–NNE oriented morphological ridge between the Kressengraben and the village Weitwies (Ziegler, 1975: Abb. 70) is made up of the Kressenberg Formation and the occurrence of mining locations follow the Kressenberg Member and can therefore be laterally traced.

Reference section(s): On top of the type section of the Sankt Pankraz Member at the "Schlößlfelsen" near the church Sankt Pankraz am Haunsberg, at the parking lot for the church, the lower boundary of the Kressenberg Member is exposed (N 47°55′53″ / E 12°59′25″) (Piller & Rasser, 1999a: Abb. 2).

Derivation of name: Named after Kressenberg, SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Remark: The name has been selected because it is the classical and historical locality for mining of the "Schwarzerz", which is the richest iron ore in the Kressenberg area.

Synonyms: Kressenberger-Schwarzerz (Gümbel, 1861: p. 617), Schwarzerz (Gümbel, 1894), Schwarzerzschichten (Traub, 1953: p. 5), Schwarzerzhorizont (Ziegler, 1975: p. 243), Schwarzerz-Gruppe (Ziegler, 1975: p. 246).

Remark: In the Kressenberg area parts of the Kressenberg Member are represented by various ore seams, e.g., Emanuelflötz, Maxflötz, Albertflötz, Maurerflötz (Flurl, 1792; Gümbel, 1861).

Lithology: The sediments of the Kressenberg Member are coarse grained, brownish black, moderately to badly sorted calcareous sandstones rich in iron ooids and larger foraminifers (Vogeltanz, 1970: p. 40). Traub (1953: p. 17) reports typical "Schwarzerz" in the Haunsberg area only from Hochberg and S of Sankt Pankraz as brownish iron oolite of 0.6–2 m thickness. Comparable to the "Roterz" (now Frauengrube Member), also the Kressenberg Member starts with a quartz conglomerate which is finer than that of the Frauengrube Member and contains *Ostrea* (*Exogyra) eversa*.

Fossils: Smaller and larger benthic foraminifers (*Nummulites*, *Assilina*, *Discocyclina, Aktinocyclina*, alveolinids), rare corals, bivalves, serpulids (*Ditrupa*, *Rotularia*), brachiopods, decapod crustaceans, rare echinoids, and vertebrate remains (shark teeth, turtles, crocodiles, tapir remains) (Schlosser, 1925a; Traub, 1953; Vogeltanz, 1965, 1968, 1970, 1972; Hagn, 1981).

Origin, facies: Shallow marine environment on highly structured sea bottom with shoals where the iron ooids have been formed and slightly deeper, protected areas where larger foraminifers thrived (Rasser & Piller, 2001).

Chronostratigraphic age: Early Lutetian (ZIEGLER, 1960; HAGN, 1981: p. 100; TOLLMANN, 1985: p. 327).

Biostratigraphy: No modern biostratigraphic study available. Considering the larger benthic foraminifers described by SCHLOSSER (1925a) from the "Schwarzerz" *Nummulites laevigatus* and *Assilina spira* indicate SBZ13–14 (lower Lutetian).

Thickness: approx. 10 m (VOGELTANZ, 1977: p. 286), 6–12 m (TOLLMANN 1985: p. 326).

Lithostratigraphically higher rank unit: Kressenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Sankt Pankraz Member (Kressenberg Formation).

Overlying unit(s): Weitwies Member (Kressenberg Formation).

Lateral unit(s): In the north: lower Adelholzen Beds (HAGN, 1981: p. 48), in the west: Schwarzerz Beds of Neubeuern am Inn (HAGN & DARGA, 1989).

Geographic distribution: Kressenberg area (Upper Bavaria, Germany), Haunsberg, Matzing, Mattsee, Ramoos-Reitsham (Salzburg, Austria).

Remarks: -

Complementary references: TRAUB (1936), ABERER & BRAUMÜLLER (1958), VOGELTANZ (1972), HAGN & WELLNHOFER (1973).

Weitwies-Subformation (Kressenberg-Formation) / Weitwies Member (Kressenberg Formation)

WERNER E. PILLER

Validity: Valid; for the richest fossil beds in the Eocene of the Kressenberg and Haunsberg areas RASSER & PILLER (1999a) introduced and formalized the term Weitwies Member as uppermost unit of the Kressenberg Formation.

Type area: Kressenberg area, SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Type section: Kressengraben (N 47°49′23″ / E 12°43′36″), c. 1.5 km SW of the market village Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein). Lower and upper boundaries not exposed.

Reference section(s): -

Derivation of name: The name derives from the hamlet Weitwies, located E of the Kressengraben, c. 1 km SW of Neukirchen am Teisenberg, Upper Bavaria, Germany (ATK25, map sheet P16 Traunstein).

Synonyms: Dachgestein (GÜMBEL, 1861: p. 648), Glaukonitischer Sandstein (SCHLOSSER, 1925a: p. 173), Nebengestein der Schwarzerze (SCHLOSSER, 1925a: p. 173), Nebengestein des Emanuelflötzes (SCHLOSSER, 1925a: p. 183), Glaukonitischer Kalkmergel (TRAUB, 1936), Fossilschicht (TRAUB, 1953: p. 17), glaukonitische Fossilschicht (= "Nebengestein") (HAGN, 1960: p. 76), Flöz-Nebengestein (HAGN, 1967), Emanuelflöz-Nebengstein (HAGN, 1981), Mollusken-Fossilschicht (TOLLMANN, 1985: Tab. 14).

Lithology: In the Kressenberg area, greenish, glauconitic, fossil rich limestones grading upsection into glauconitic marls with nummulites and molluscs (HAGN, 1981: p. 107). In the Haunsberg area, green, glauconitic sandy marls with phosphorite nodules (TRAUB, 1953: p. 17).

Fossils: Extremely rich in macrofossils, besides calcareous nannoplankton and dinoflagellates, planktic and small benthic foraminifers and larger benthic foraminifers (*Nummulites*, *Assilina*, *Discocyclina*, *Aktinocyclina*), among invertebrates corals, gastropods, bivalves, cephalopods, brachiopods, decapod crustaceans, rare ostracods, crinoids and echinoids are described (SCHLOSSER, 1925a; VOGELTANZ, 1972; HAGN, 1981; COSTA & MARTINI, 1981). Vertebrates are represented by fish (chondrychthiids and teleosts) and turtles, plant fossils by fruits (TICHY, 1980).

Origin, facies: Shallow marine environment, somewhat deeper than that of the Kressenberg Member (TICHY, 1980), VOGELTANZ (1970: p. 396) considered a condensed sedimentation.

Chronostratigraphic age: Lutetian (HAGN, 1981).

Biostratigraphy: The marly upper part of the unit was correlated with calcareous nannofossil Zone NP16 (*Discoaster tani nodifer-Zone*) (HAGN, 1981: p. 109; COSTA & MARTINI, 1981).

Thickness: A minimum of 5.4 m at the type locality (upper boundary not preserved), 0.5–1 m in the Haunsberg area (TRAUB, 1953: p. 17).

Lithostratigraphically higher rank unit: Kressenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Kressenberg Member (Kressenberg Formation).

Overlying unit(s): Stockletten (FLURL, 1792; REIS, 1896; TRAUB, 1953; GOHRBANDT et al., 1963; HAGN, 1981) but boundary not exposed.

Lateral unit(s): Middle to Upper Adelholzen Beds (HAGN, 1960, 1981: p. 48).

Geographic distribution: Kressenberg area (Upper Bavaria, Germany), Haunsberg, Matzing, Mattsee, Ramoos-Reitsham (Salzburg, Austria).

Remarks: This member currently crops out only in the Kressenberg area. Since no outcrops exist in the Haunsberg area, no reference section has been defined by RASSER & PILLER (1999a).

Complementary references: TOLLMANN (1985).

Stockletten / Stockletten

WERNER E. PILLER

Validity: Invalid; the term "Stockletten" was introduced by FLURL (1792: p. 190) for fine grained marls from the ore mining area of Kressenberg (Upper Bavaria, Germany).

Remark: Originally, all soft beds between hard rock layers were termed "Stockletten". For example, GÜMBEL (1861: p. 619) stated "Stockletten ist ein kalkig-sandiger, geschieferter, dunkelfarbiger Mergel, welcher die Hauptmasse zwischen den einzelnen Eisenerz-, Kalk- und Sandsteinlagen der Nummulitengebilde auszufüllen pflegt und durch Aufnahme von Kalk und Sand in verschiedene, oft grobbankige und härtere Gesteinsarten verläuft." Reis (1896: p. 34) constricted this general usage and reserved the term "Stockletten" for upper Eocene marls in the Kressenberg area. "Stockletten" is the lowermost lithostratigraphic unit, which abrogates the facies difference between the Southern Helvetic Zone and the Northern Helvetic Zone by occurring in both zones.

Type area: In the area around Rohrdorf am Inn, c. 7 km SSE of the town Rosenheim, Upper Bavaria, Germany, ATK25, map sheet P14 Bad Endorf.

Type section: -

Remark: For the "Granitmarmor", Schafhäutl (1846: p. 650) and Gümbel (1861: p. 618) mentioned the hamlet Sinning, c. 1.5 km SE of Rohrdorf am Inn, c. 3.5 km ENE of Neubeuern am Inn, Upper Bavaria, Germany. This locality represents the currently active quarry in Rohrdorf (e.g., Hagn, 1981) where the "Stockletten" with the coralline algal limestones ("Granitmarmor") is well exposed. Due to the mining activities, the exposures change rapidly and the quarry is not open to the public. However, immediately E of the Rohrdorf quarry, c. 300 m south of the village Thalmann a small quarry with Stockletten and "Granitmarmor" exists (N 47°47′16.69″ / E 12°11′33.87″) which is defined as a Geotop (Nr. 187A030 (UmweltAtlas Bayern, 2021b)) and allows access to this unit.

Reference section(s): -

Derivation of name: The name Stockletten is a local expression of miners for the sticky character of marl, clay, mud and loam.

Synonyms: Granit-Marmor p.p. (Schafhäutel, 1846), "Granitmarmor" p.p. (Gümbel, 1861: p. 618), Neubeurer-Marmor p.p. (Gümbel, 1861: p. 618), Stockletten und Granitmarmor (Böhm, 1891), Stockletten und Lithothamnienkalke (Hagn, 1967), Obere Tonmergelschichten (Stockletten) mit eingelagertem Lithothamnienschuttkalk (Granitmarmor) (Ziegler, 1975: p. 246), graugrüne Globigerinenmergel mit "Granitmarmor"-Lagen (Lithothamnienkalksandstein) (Tollmann, 1985: p. 328), Globigerinenmergel (STD 2016), Stad-Formation (UmweltAtlas Bayern, 2021d).

Lithology: At the base occurs a horizon (4–5 m) of dark grey to blackish, pyrite rich clayey marls to clays sharply overlain by greenish grey, hard, partly sandy, glauconitic, mottled calcareous marls rich in planktonic foraminifers ("Globigerina marl") (Hagn, 1960: p. 49; 1967: p. 282). At the Wartstein (W Mattsee), the base of the Stockletten is a 0.5 m black sandstone or sandy marl (with abundant shark teeth) overlain by 40 m of typical Stockletten (Vogeltanz, 1972).

Intercalated in these marls (= Stockletten) are yellowish grey to grey coralline algal limestones as single beds or bundles of beds with abundant larger benthic foraminifers (Ziegler, 1960: p. 216) which are also known as "Granitmarmor" (Schafhäutel, 1846: p. 650). In the Kressenberg area, they start to occur 125 m above the boundary of the Kressenberg Member. The boundary between the marls and limestones is gradual with (abundant) coralline algal debris in the marls.

Fossils: A rich microfauna occurs with calcareous nannoplankton, planktic and smaller and larger benthic foraminifers, radiolarians and ostracods but the macrofauna is very poor (Gümbel, 1868; Ziegler, 1960; Hagn, 1961a, 1967). Microfossils are most abundant in the coralline algal debris marls. In the coralline limestones besides red algae (as rhodoliths and debris) and foraminifers, bryozoan are very abundant. The coralline algae have already been studied by Gümbel (1871) and Rothpletz (1891), a more updated list is given by Moussavian (1993b).

Origin, facies: The onset of the Stockletten above the Weitwies Member of the Kressenberg Formation reflects a deepening of the paleoenvironment with deposition of pelagic planktic foraminiferal marls in several hundreds to 1,000 meters of water depth (Darga, 1992: Abb. 5). The coralline algal limestones ("Granitmarmor") and also the larger benthic foraminifers are considered allochthonous, gravity mass transport accumulations (olisthostromes, slump facies) (Buchholz, 1989; Hagn & Darga, 1989; Moussavian, 1993a, b) which originated on top of the Intrahelvetic Swell, a topographic high (e.g., Hagn, 1954, 1960, 1967), and were transported into the basin.

Chronostratigraphic age: Middle Eocene (Lutetian?, Bartonian) to upper Eocene (Priabonian).

The age assignment has been intensively discussed. One problem is that Stockletten and "Buntmergelserie" are difficult to distinguish, particularly in tectonic complex positions (as in Salzburg and Upper Austria).

Biostratigraphy: Calcareous nannofossil Zones NP16–NP19 (Hagn, 1981). From the drill site Kressenberg 7, Costa & Martini (1981) reported for the Stockletten CNP Zones NP16–NP20 and for dinoflagellates the *Rhombodinium porosum*-Zone and *R. perforatum*-Zone.

Egger (2009a: p. 30) reported NP19 from the uppermost part of the Wartstein (near Mattsee). For the lower Stockletten Egger & Rögl (2009) identified NP15 but these sediments were later on (Rögl & Egger, 2010) considered to belong to the "Buntmergelserie". Planktic foraminifera with, e.g., *Globigerinatheka index* and *Turborotalia cerroazulensis*, also indicate Priabonian (PFZ E14–E16 sensu Wade et al., 2011).

Thickness: Up to 200 m (Egger, 2009a), the coralline algal limestones are reported from the Haunsberg area by Gohrbandt et al. (1963: p. 20) with a maximum of 15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Kressenberg Formation.

Overlying unit(s): None, the Stockletten represents the termination of sedimentation in the Helvetic Zone.

Lateral unit(s): In Switzerland, the Stad-Formation (old name: Globigerinenmergel, Stadschiefer, Ypresian–Priabonian, Menkveld-Gfeller et al., 2016; Hagn, 1981) is partly an equivalent of the Stockletten.

Geographic distribution: In Upper Bavaria, Stockletten occurs between the area of Neubeuern am Inn/Rohrdorf–Siegsdorf–Teisendorf but it is also reported from the area Grünten–Sonthofen (Swabia, Bavaria) (Reis, 1896, 1898, 1926; Heim, 1919).

In Austria, Stockletten is proven only in a few occurrences: south of the Wartstein, west of the market village Mattsee (Gohrbandt et al., 1963; Vogeltanz, 1972), in a quarry north of the hamlet Bauerstatt where the transition from the Weitwies Member (Kressenberg Formation) into basal Stockletten and typical Stockletten was exposed (Gohrbandt, 1963: p. 52), Gschliefgraben (Upper Austria) with Stockletten and coralline algal limestones, which Prey (1983: p. 108) considered equivalent to the "Granitmarmor". An occurrence of Stockletten is reported from Vorarlberg (Bödelestrasse near Dornbirn) by Resch (1976a).

Remarks: The Stockletten are the lithostratigraphic unit, which occurs both in the North Helevetic Zone, overlying the "Adelholzen Beds" (Gebhardt et al., 2013b), and the South Helvetic Zone, overlying the Kressenberg Formation ("Nebengestein", Hagn, 1981: p. 49).

Stockletten and sediments of the "Buntmergelserie" are difficult to distinguish and several reports of Stockletten occurrences in the Haunsberg area had to be placed into the "Buntmergelserie" (Gohrbandt et al., 1963). The only approved Stockletten currently outcropping occurs south of the Wartstein (W Mattsee, Salzburg).

Complementary references: Götzinger (1937), Traub (1936, 1938, 1953), Prey (1951), Hagn & Hölzl (1952), Aberer & Braumüller (1958), Hagn (1961a, 1978), Vogeltanz (1970), Hagn & Wellnhofer (1973), Ganss (1977), Egger (2011a).

Ultrahelvetic Unit

Werner E. Piller

Similar to the Helvetic Unit, this unit is well preserved only in Vorarlberg. Further to the east (Salzburg, Upper Austria) it occurs only in tectonic slices and in narrow tectonic windows within sediments of the Rhenodanubian Flysch Unit. In Upper Austria (approx. east of lake Traunsee) and western Lower Austria the sediments are considered part of the Gresten Klippen Belt and further to the east they belong to the Main Klippen Belt ("Hauptklippenzone") of the Vienna Woods.

Paleogeographically, the Ultrahelvetic Unit is the southward continuation of the Helvetic Unit representing continental slope deposits on the northern slope of the Penninic Ocean. The sediments of the Ultrahelvetic Unit grade further to the south into the Rhenodanubian Flysch Unit (Wagreich & Neuhuber, 2007: Abb. 3). The Ultrahelvetic Unit is split into a North-Ultrahelvetic Unit and a South-Ultrahelvetic Unit. The North-Ultrahelvetic Unit is dominated by hemipelagic to pelagic deep-water sediments and subordinate sandstones and limestones – summarized in the widely used unit "Buntmergelserie" for Paleogene and also older sediments. The South-Ultrahelvetic Unit consists mostly of flyschoid sediments also containing very coarse-grained breccias and conglomerates ("Wildflysch") (Hagn, 1960; Freimoser, 1972).

A clear differentiation between Helvetic and Ultrahelvetic units in the field is only possible in Vorarlberg with the Liebenstein Nappe as part of the Ultrahelvetic Unit (Friebe, 2007a). Further to the east, an attribution to either of these two units is difficult due to intense tectonic disturbance and very limited outcrops.

Ultrahelvetic Unit: Vorarlberg – Liebenstein Nappe

Kehlegg-Formation / Kehlegg Formation

J. Georg Friebe & Werner E. Piller

Validity: Invalid; Oberhauser (1984: p. 228) suggested the name "Kehleggschichten" for the first time for a succession in the Liebenstein Nappe and named it Kehlegg-Formation (Oberhauser, 2007) without further description and formalization.

Type area: Area between Kehlegg and Gütle, Dornbirn, Vorarlberger Rheintal, Vorarlberg, ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Type section: A natural outcrop in the woods between Eschenau and Salzmann, above a meadow east of Salzmann (N 47°23′42″ / E 09°46′41″), in the easternmost part of the town Dornbirn, Vorarlberg, ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Reference section(s): -

Derivation of name: Named after the hamlet Kehlegg, part of the municipality of the town Dornbirn, Vorarlberg.

Synonyms: Kehleggschichten (Oberhauser, 1984), Kehlegg-Formation (Oberhauser, 2007).

Lithology: Alternation of thickly bedded, glauconitic calcareous sandstones and brownish black marls (Oberhauser, 1984).

Fossils: Calcareous nannoplankton, Planktonic foraminifera.

Origin, facies: Marine, outer shelf environment.

Chronostratigraphic age: Early Paleocene, Danian to early Eocene, Ypresian (Oberhauser, 2007; Friebe, 2007a).

Biostratigraphy: Calcareous nannofossil Zones NP2–12 (Oberhauser, 1984, 1986).

Thickness: A maximum of 30–40 m (Oberhauser, 1984, 1986), laterally variable due to tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Leimern Marl (Upper Cretaceous) or tectonic lower boundary.

Overlying unit(s): Erosional or tectonic upper boundary or "Globigerinenflysch".

Lateral units: Not known.

Geographic distribution: Restricted to the area E of Dornbirn, Vorarlberger Rheintal, Vorarlberg.

Remarks: OBERHAUSER (2007) mentioned on the map of Vorarlberg the "Dreiangelserie" in Bavaria (as a possible synonym?). For a description and discussion of the Dreiangel-Serie, see SCHWERD et al. (1983).

Complementary references: HÜGEL (1956), OBERHAUSER (1991, 1995), SCHWERD (1996a).

Globigerinenflysch / Globigerina Flysch

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; OBERHAUSER (1958: p. 125) described "Globigerinensandkalke" from the Liebenstein Nappe and considered this unit time equivalent to the "Globigerinenschiefer" (now Globigerina marl). Later on, OBERHAUSER (1973) introduced "Globigerinen-Flysch (= Schelpen-Serie)" immediately above "Globigerinen-Mergel" and OBERHAUSER (1991) clearly distinguished between "Globigerinenmergel" and "Globigerinenflysch", the latter being restricted to the Liebenstein Nappe.

Type area: In the area around Fraxern where OBERHAUSER (1958) first described "Globigerinensandkalke", ÖK50-UTM, map sheet 1224 Hohenems (ÖK50-BMN, map sheet 111 Dornbirn).

Type section: -

Reference section(s): -

Derivation of name: Named after the lithology, related depositional and tectonic setting as well as the predominant fossils (planktonic foraminifera).

Synonyms: Globigerinensandkalke (OBERHAUSER, 1958: p. 125), Globigerinen-Flysch (= Schelpen-Serie) (OBERHAUSER, 1973: p. A78), Flysch mit Globigerinen und Globorotalien (OBERHAUSER, 1984: p. 227), Globigerinenflysch (inkl. "Schelpen-Serie") (OBERHAUSER, 2007).

Lithology: Alternations of brownish to dark grey marls and yellowish-reddish to orange weathered thin (5–15 cm, max. 40 cm) sandy limestone beds (OBERHAUSER, 1991: p. 34). Subordinate occur partly graded, mica-rich sandstones and fine-grained breccias.

Fossils: Calcareous nannofossils, planktic and rare agglutinated foraminifera, radiolaria.

Origin, facies: Outer shelf to upper bathyal paleoenvironment with flyschoid transport features. The "Globigerinenflysch" is considered a time-equivalent, distal continuation of the Globigerina Marl.

Chronostratigraphic age: Early Eocene, Ypresian to middle Eocene, Lutetian.

Biostratigraphy: Calcareous nannofossil Zones NP11–NP14 (OBERHAUSER, 1984, 1991).

Thickness: 10–30 m, max. 50 m (OBERHAUSER, 1991: p. 34), laterally variable due to tectonic truncation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Tectonic lower boundary or Kehlegg Formation.

Overlying unit(s): Erosional or tectonic upper boundary.

Lateral unit(s): In the southern part of the Helvetic Säntis Nappe the "Globigerinenflysch" might interfinger with Globigerina Marl (OBERHAUSER, 1991), in the Feuerstätter Nappe with the "Schelpen-Serie".

Geographic distribution: Vorarlberger Rheintal and Walgau, Bregenzerwald, Vorarlberg.

Remarks: Before OBERHAUSER (1967) separated the Paleogene "Globigerinenflysch" from the Cretaceous Leimern Formation, it was assumed that the latter also includes Paleogene deposits. This opinion was still pursued (as "Globigerinenschiefer" or "Globigerinenmergel") by HÖFLE (1972) and FELBER & WYSSLING (1979). However, following the concept of OBERHAUSER (1991), all occurrences of "Paleogene" Leimern Formation (Liebenstein Nappe) belong to the "Globigerinenflysch".

Although the occurrence of "Globigerinenflysch" was originally restricted to the Liebenstein Nappe, OBERHAUSER (1991) used the term "Globigerinenflysch" both for deposits in the Liebenstein Nappe and the Feuerstätter Nappe. Consequently, what was assigned to "Globigerinenflysch" in the Feuerstätter Nappe corresponds to the "Schelpen Serie" (sensu FESSLER et al., 1992). As further consequence according to the above-mentioned papers, there is no "Globigerinenmergel" in the Liebenstein Nappe but all occurrences of that lithostratigraphic unit are exclusively interpreted as slabs derived from the Helvetic Säntis Nappe.

Complementary references: OBERHAUSER (1965b, 1986, 1995), SCHWERD (1996b).

Ultrahelvetic Unit: Salzburg – Upper Austria – Lower Austria – Vienna

„Buntmergelserie" / "Succession of variegated marls"

MICHAEL WAGREICH & WERNER E. PILLER

Validity: Invalid; first described by PREY (1952: p. 42), named "Buntmergel-Fleckenmergelserie" and considered it part of the Rhenodanubian Flysch Zone. Later on widely used as "Buntmergelserie" on Austrian and Bavarian map sheets but it has never been revised and formalized, herein we focus on the Paleogene part.

Type area: An area called Rogatsboden, located between the town Scheibbs and the market town Purgstall an der Erlauf in the east and the market town Gresten in the west, ÖK50-UTM, map sheet 4328 Scheibbs (ÖK50-BMN, map sheets 53 Amstetten, 54 Melk).

Type section: -

Reference section(s): Not defined, possible reference sections were already indicated by PREY (1951) which are the Rehkogelgraben creek (N 47°56′08″ / E 13°55′30″, Wagreich & Neuhuber, 2007), ENE of the town Gmunden and the Gschliefgraben (N 47°53′05″ / E 13°49′25″, Wagreich & Neuhuber, 2007), SE of the town Gmunden. Lower boundary defined by the change from indurated grey mottled limestones to dark grey or red marls and marly limestones, tectonic upper boundary.

Derivation of name: Named after lithology and colour: variegated and spotty marls.

Synonyms: Buntmergel-Fleckenmergelserie (Prey, 1952: p. 43), Rehkogelgraben Schichten (Stratigraphische Kommission Deutschlands, 2000: p. 154, Tab. 22), p.p. "Buntmergel-Gruppe" (Wagreich & Neuhuber, 2007), Buntmergel-Serie, „Buntmergel-Serie" i. Allg. (z.T. Wildflysch) (Egger, 2011a).

Remark: "Rehkogelgraben Schichten" are mentioned by Stratigraphische Kommission Deutschlands (2000: p. 154) for the Albian–Cenomanian part or an equivalent of the Buntmergelserie without any further description, probably based on Prey (1952, 1983).

Braunstingl (1986) named mainly Maastrichtian marls "Brambergerbach Schichten" or "Brambergerbachschichten" (Braunstingl, 1988) (excluding explicitly Paleogene parts).

Wagreich & Neuhuber (2007) discussed the possibility to upgrade the Buntmergelserie to a lithostratigraphic group with several formations without establishing the later and formalizing the group because of the strongly tectonized appearance.

Lithology: The main lithology is represented by grey, red and grey green marls and clays, including some marly limestones and black claystones. Especially in the Paleogene part of the succession, thin sandstone turbidites and breccia layers are present, including also large olistholiths such as the Buch-Denkmal "granite" (granodiorite-gneiss) (Faupl, 1977, 1978; Widder, 1986, 1988; Faupl & Schnabel, 1987).

Faupl (1977, 1978) focussed on the clastic Paleogene part of the "Buntmergelserie" in the eastern occurrence area (between Waidhofen an der Ybbs, Lower Austria, and Vienna) and differentiated four lithologic facies types: "Bernreither Fazies" (calcareous breccias and conglomerates with high siliciclastic content), "Texinger Fazies" (biogenous calcirudites and -arenites), "Schaittener Fazies" (quartzarenite-conglomerate facies), "Turbidit-Fazies" (alternation of sandstone and marl, the sandstones belong to part b and c of a Bouma cycle).

Fossils: Planktic foraminifera make up more than 50 %, often more than 95 % of the foraminiferal assemblages of the Paleogene, in parts deposited below the CCD agglutinated foraminifera dominate. In the clastic Paleogene part allochthonous larger foraminifera ae documented. Rare to very rare macrofossils occur (inoceramid fragments, rare ammonites, echinoids). Bioturbation is common.

Origin, facies: The "Buntmergelserie" is a typical pelagic-hemipelagic facies of bathyal-abyssal water depths from 200 m to several thousand meters below the calcite compensation depth (Butt, 1981; Wagreich & Neuhuber, 2007).

Chronostratigraphic age: Early Cretaceous, middle Albian–middle Eocene, Lutetian.

Biostratigraphy: Planktonic foraminifera *Rotalipora subticinensis-Zone* to P10 plankton zone, calcareous nannofossil Zones CC9/UC0–NP15 (Widder, 1988, Egger, 2011a).

Thickness: Several tens of meters to more than 100 m, Freimoser (1972: p. 22) reported 200 m for SE Bavaria, highly variable due to strong tectonic deformation.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Blassenstein Formation, defined by the change from indurated grey mottled limestones to dark grey or red marls and marly limestones.

Overlying unit(s): Tectonic upper boundary, in Upper Bavaria Freimoser (1972) described turbiditic sediments as "Achthaler Sandstein", Egger & Mohamed (2010, 2011) formalized this unit as Achthal Formation and interpreted it as representing a slope-basin environment.

Lateral unit(s): Gerhardsreit Formation, Pattenau Formation (both for the Cretaceous part), Olching Formation.

Geographic distribution: From Bavaria to Vienna in Helvetic/Ultrahelvetic units and the Gresten Klippen Zone.

Remarks: Two facies types, a carbonate-rich (marl-limestone) and a carbonate-poor (shale-marl) development can be distinguished, thus, Prey (1983) separated a northern (calcareous) Ultrahelvetic from a southern (clayey) Ultrahelvetic facies.

Complementary references: Prey (1975), Kennedy & Summesberger (1984, 1999), Widder (1987), Egger & Rögl (1996), Egger et al. (2007d), Wagreich et al. (2009), STD 2016, Moser & Linner (2019), Moser (2019), Ruttner et al. (2019).

Rhenodanubian Flysch Unit

Werner E. Piller

The Rhenodanubian Flysch Unit (RDFU) represents a 500 km long, more than 2,000 m thick imbricated thrust pile which trends parallel to the northern margin of the Eastern Alps (Text-Fig. 2). The RDFU is present all along this stretch, only interrupted south of the lake Chiemsee in southern Bavaria (Egger & Schwerd, 2008).

The flysch sediments were deposited between the Barremian (Lower Cretaceous) and Ypresian (Eocene) in the Penninic Ocean (= Alpine Tethys sensu Stampfli et al., 1998), which separated the European continental plate to the north and the Adriatic Plate to the south. Rifting started in the Permian and Triassic and continued during the Jurassic by the formation of oceanic lithosphere. Due to the presence of lower Eocene sedimentary rocks in the Penninic units, the final closure of the Penninic Ocean did not occur before the Eocene (Neubauer et al., 2000). The flysch sediments were detached from their original basement in the Oligocene and thrusting and wrenching have destroyed the original basin configuration and the relationship to source areas. This makes their reconstruction difficult what resulted in highly different interpretations (Egger et al., 2002). However, various data (Butt, 1981) indicate that the Rhenodanubian Flysch was deposited adjacent to the passive continental margin of the European Plate at the continental rise off the southern shelf and slope of the European Plate (e.g., Schuster, 2015). This implies that its deposition took place on a transitional crust after continental rifting was completed and the Penninic Ocean basin had begun to form by seafloor spreading (Egger et al., 2002).

Due to the oblique collision of the European and Adriatic plates, the disappearance of the Penninic Ocean started in the West and prograded continuously to the East. Thrusting in the Eastern Alps started at latest in the middle Eocene, whereas in the Western Carpathians the onset of thrust formation was around the Eocene/Oligocene boundary (Decker & Peresson, 1996). In the Eastern Alps, continuing convergence during the Miocene caused lateral tectonic escape of crustal wedges along strike slip faults, which strongly affected the RDFU (Egger & Peresson, 1998).

In the westernmost part of the RDFU (Vorarlberg) only Cretaceous rocks are preserved belonging to three nappes (Obersdorf-, Üntschen- and Sigisdorf Nappe) which can, at least partly, be traced into Upper Bavaria (e.g., Friebe, 2007a). In the central part (Salzburg to western Lower Austria), the RDFU consists of the so-called "Hauptflyschdecke" (Main Flysch Nappe) (e.g., Schnabel, 1999) which is differentiated into several sub-nappes (Egger, 1989). In the eastern part (Vienna Woods), three nappes were differentiated based on Friedl (1920) and Götzinger (1944) from north to south: Greifenstein-, Kahlenberg-, and Laab Nappe. However, Egger (2013a) stated that no major

Text-Fig. 2.
Location of the Rhenodanubian Flysch Unit (grey shaded) in Austria.

lithostratigraphic and chronostratigraphic differences exist between Greifenstein- and Kahlenberg Nappe and considered the former Kahlenberg Nappe to represent only southern tectonic slices (Kahlenberg- und Satzberg Slice) of the Greifenstein Nappe being lithostratigraphically summarized in the Greifenstein Group. Originally, sediments of the later were deposited south of the Laab Nappe.

With regard to lithostratigraphy, the RDFU is represented by the Rhenodanubian Supergroup which consists primarily of siliciclastic and calcareous turbidites. Thin, hemipelagic claystone beds occur in all formations of the Rhenodanubian Supergroup and indicate a deposition below the local calcite compensation depth (> 3,000 m). Paleocurrents and sedimentation pattern suggest that the deposition occurred on a flat, elongate, weakly-inclined abyssal basin plain which was not disturbed by syndepositional tectonic deformation. The majority of the turbidites indicate a paleotransport parallel to the basin axis and individual sediment intervals can be traced over long distances. In general, all sections of the Rhenodanubian Flysch Unit show a similar lithostratigraphic succession.

Rhenodanubian Flysch Unit: Greifenstein Nappe

Rhenodanubische-Supergruppe / Rhenodanubian Supergroup

Werner E. Piller

Validity: Valid; Egger & Schwerd (2008) introduced the Rhenodanubian Group as a lithostratigraphic unit for the sedimentary sequence of the Greifenstein Nappe, however, the Rhenodanubian nappe system consists of several nappes. As a consequence, Egger (2013a, b) dismissed the Rhenodanubian Group and assigned the sequences of the Greifensten Nappe to the Greifenstein Group and that of the Laab Nappe to the Laab Group and introduced the Rhenodanubian Supergroup as overarching unit for the Rhenodanubian Flysch.

Type area: See formations.

Type section: See Greifenstein Group.

Reference section(s): -

Derivation of name: Named after the two streams Rhine (Latin: Rhenus) and Danube (Latin: Danuvius).

Synonyms: Rhenodanubische Supergruppe (Moser et al., 2019).

Lithology: Siliciclastic and calcareous turbidites alternating with hemipelagic non-calcareous mudstones.

Fossils: See formations.

Origin, facies: The paleoenvironment was an abyssal basin mostly below the calcite compensation depth.

Chronostratigraphic age: Early Cretaceous, Barremian–early Eocene, Ypresian.

Biostratigraphy: See formations.

Thickness: More than 2,000 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Greifenstein Group, Laab Group (Egger, 2013a, b).

Underlying unit(s): Tectonic contacts.

Overlying unit(s): Tectonic contacts.

Lateral unit(s): Tectonic contacts.

Geographic distribution: The Rhenodanubian Supergroup extends from Vorarlberg in the W, over southern Bavaria and Salzburg, Upper to Lower Austria (including Vienna) and continues in the subsurface of the Vienna Basin into the Western Carpathians (under different names).

Remarks: In the course of restructuring the lithostratigraphic units of the Rhenodanubian Flysch EGGER (2013a) considered the Kahlenberg Nappe as part of the Greifenstein Nappe based on similar or identical sequences and ages of the classical lithostratigraphic units. Two remnants of the former Kahlenberg Nappe remain as tectonic slices, the "Kahlenberg Schuppe" and the "Satzberg Schuppe". Consequently, the lithostratigraphic classification follows the tectonic concept, i.e., the units of the Kahlenberg unit are part of the Greifenstein Group and the Paleogene "Sieveringer Schichten" area synonymous to the Altlengbach Formation.

Complementary references: -

Greifenstein-Gruppe / Greifenstein Group

WERNER E. PILLER

Validity: Valid; EGGER (2013a) united all lithostratigraphic units of the Greifenstein Nappe and the former Kahlenberg Nappe in the Greifenstein Group.

Type area: See Greifenstein Formation.

Type section: See formation.

Reference section(s): -

Derivation of name: Named after the village Greifenstein, c. 6 km NW of the town Klosterneuburg, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 40 Stockerau).

Synonyms: -

Lithology: Variable turbiditic lithologies with sandstones, marls and clays and also hemipelagic pelites.

Fossils: See formations.

Origin, facies: The paleoenvironment was an abyssal basin mostly below the calcite compensation depth.

Chronostratigraphic age: Early Cretaceous, Barremian to early Eocene, Ypresian.

Biostratigraphy: See formation.

Thickness: c. 3,000 m (EGGER & WESSELY, 2014).

Lithostratigraphically higher rank unit: Rhenodanubian Supergroup.

Lithostratigraphic subdivision: For the Paleogene only: Altlengbach Formation, Anthering Formation, Greifenstein Formation, Gablitz Formation, and Irenental Formation.

Underlying unit(s): -

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: The Greifenstein Group extends over the full range of the Rhenodanubian Flysch occurring from Vorarlberg in the W, to Bavaria (EGGER & SCHWERD, 2008), Salzburg, Upper and Lower Austria (EGGER, 2011b, 2013a).

Remarks: -

Complementary references: PREY (1962).

Altlengbach-Formation (Greifenstein-Gruppe) / Altlengbach Formation (Greifenstein Group)

WERNER E. PILLER

Validity: Valid; MOJSISOVICS (1890) described from the village Muntigl, N of the city of Salzburg, sandstones, marls and marly limestones, which he called "Muntigler Flysch". Similar rocks in the area of Altlengbach (Lower Austria) have been denominated "Altlengbacher Schichten" by GÖTZINGER & BECKER (1932a); a suite of other names have been introduced for this widespread Flysch unit, e.g., "Fanóla-Serie" in Vorarlberg and the Allgäu- (ALLEMANN et al., 1951) and "Bleicherhorn-Serie" in Southern Bavaria (RICHTER, 1955; KRAUS, 1955). MOJSISOVICS (1890), however, used the term "Muntigler Flysch" as a general name for Flysch sediments in Salzburg; HOFER & TICHY defined 1983 a type section for the "Muntigler Serie", but this section is part of the so-called "Zementmergelserie". To avoid further problems, EGGER (1995) re-described and formalized this unit as "Altlengbach-Formation".

Type area: The type area of the formation is within the area Altlengbach–Neulengbach–Kasten, part of the Vienna Woods, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheets 56 St. Pölten, 57 Neulengbach).

Type section: SCHNABEL (1992b) stated that it is not possible to describe a continuous type section in the type area of Altlengbach (see above). As a consequence, EGGER (1995: p. 76) defined a lectostratotype in the Ahornleitengraben (base of the formation: N 47°56′33″ / E 14°33′16″), c. 7 km N of Großraming and c. 16 km SE of the town Steyr, Upper Austria; ÖK50-UTM, map sheet 4202 Ternberg (ÖK50-BMN, map sheet 69 Großraming). The Ahornleitengraben is the best-known section through the formation with all four members of the formation represented; however, for the uppermost unit, the Acharting Member, only the basal parts are preserved.

Reference section(s): -

Derivation of name: Named after the market town Altlengbach, c. 12 km WSW of the town Pressbaum, c. 34 km WSW of the city centre of Vienna, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Synonyms: Muntigler Flysch (MOJSISOVICS, 1890), Altlengbacher Schichten (GÖTZINGER & BECKER, 1932a), Sieveringer Sandstein (GÖTZINGER, 1944), Fanóla-Serie (ALLEMANN et al., 1951), Bleicherhorn-Serie (RICHTER, 1955; KRAUS, 1955), Mürbsandsteinführende Oberkreide bis Paleozän (PREY, 1969, 1980a, b), Muntigler Serie (HOFER & TICHY, 1983), Sieveringer Schichten (GÖTZINGER, 1954a: p. 53), Sievering Formation (KERN, 1978), Sievering-Formation (SCHNABEL, 2002a, b), Altlengbach-Formation (EGGER et al., 2007a, b).

Remark: Already TOLLMANN (1985: p. 391) considered the "Sieveringer Schichten" as facies of the Altlengbacher Schichten"; EGGER (2013b) and EGGER & WESSELY (2014) treat the "Sieveringer Schichten" as part of the Greifenstein Group and, as a consequence, they have to be considered synonymous with and included in the Altlengbach Formation.

Lithology: The Altlengbach Formation (Egger, 1995) is characterized by thick-bedded, coarse- to medium-grained turbiditic sandstones. These are rich in quartz and muscovite and grade frequently into grey, silty to sandy marlstone or clayey marlstone at their tops. In variable percentages, these characteristic beds of the Altlengbach Formation alternate with calcareous turbidites, which are very similar to those of the underlying Hällritz Formation (Röthenbach Subgroup).

Fossils: Calcareous nannoplankton, foraminifera, pollen and spores, very rare macrofossils (inoceramid bivalves and ammonites, e.g., in old Muntigl and Bergheim quarries, N of Salzburg), ichnofossils.

Origin, facies: Turbidites and non-turbiditic hemipelagic claystones.

Chronostratigraphic age: Late Cretaceous, late Campanian–late Paleocene, Thanetian (top).

Remark: Roßgraben Member: early Maastrichtian; Ahornleiten Member: early Maastrichtian; Kotgraben Member: late Maastrichtian; Acharting Member: late Maastrichtian–late Paleocene (Thanetian).

Biostratigraphy: Calcareous nannofossil Zones CC22b-c–NP9 (Egger et al., 1997; Egger & Schwerd, 2008).

Thickness: Maximum thickness in composite sections c. 1,500 m (Egger, 1995; Egger & Wessely, 2014) or even up to c. 2,000 m (Egger, 1989; Egger & van Husen, 2009b).

Lithostratigraphic higher rank unit: Greifenstein Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: Roßgraben Member, Ahornleiten Member, Kotgraben Member, Acharting Member.

Remark: In the type area and in some other regions a four-fold subdivision into members is possible (Egger, 1995). The Roßgraben Member at the base consists mainly of thick-bedded siliciclastic sandstone; the Ahornleiten Member is characterized by the common occurrence of light grey turbiditic marlstone; the Kotgraben Member consists mainly of thick-bedded siliciclastic sandstone; the Acharting Member is dominated by pelitic rocks, which very often consist of dark grey turbiditic marlstone.

Remark: Since only the Acharting Member includes part of the Paleocene only this is described herein.

Underlying unit(s): Röthenbach Subgroup (= Zementmergelserie in older literature; sensu Egger & Schwerd, 2008) with the Hällritz Formation, Perneck Formation (in the area between Salzburg and Lower Austria) (Egger, 1995). The base of the Altlengbach Formation is defined by the occurrence of the first thick-bedded siliciclastic sandstone.

Overlying unit(s): Anthering Formation, Greifenstein Formation, Gablitz Formation.

Lateral unit(s): -

Geographic distribution: The Altlengbach Formation is very widespread over the full range of the Rhenodanubian Flysch occurring from Vorarlberg in the W, to Bavaria (Egger & Schwerd, 2008), Salzburg, Upper and Lower Austria (Egger, 2011b, 2013a).

Remarks: -

Complementary references: Küpper (1968), Prey (1968, 1980b), Faupl et al. (1970), Plöchinger & Prey (1974, 1993), Thenius (1974), Faupl (1980, 1996), Tollmann (1985), Brix et al. (1987), Egger (1990, 1998, 2009c), Sauer et al. (1992a), Wessely (2006), Egger (2007a, b), Egger et al. (2007a, b), Egger & van Husen (2009a), Egger & Braunstingl (2014).

Acharting-Subformation (Altengbach-Formation, Greifenstein-Gruppe) / Acharting Member (Altlengbach Formation, Greifenstein Group)

Werner E. Piller

Validity: Valid; Egger (1995: p. 82ff.) described and formalized the Archating Member as highest unit of the Altlengbach Formation which is also the most widespread of the four members.

Type area: In the area of E of the village Acharting, c. 10 km N of the city of Salzburg, Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Type section: The type section is defined along the ditch "Strubach" (Egger, 1995: Abb. 4) (N 47°54′10.39″ / E 13°01′08.11″), a tributary of the creek "Archatinger Bach", NE of the village Acharting, c. 10 km N of the city of Salzburg, Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Reference section(s): -

Derivation of name: Named after the village Acharting, c. 10 km N of the city of Salzburg, Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Synonyms: -

Lithology: The Acharting Member is characterized by alternations of fine sandstone to siltstone with medium to dark grey claymarl. The coarser beds show a high carbonate content both in the matrix and in components. The latter are frequently bioclasts (foraminifera, coralline algae). These turbidites display base-truncated as well as complete Bouma sequences. Usually the upper part of the Bouma sequences consists of medium-grey clayey marl (c. 35 % of this member) with intercalated green coloured hemipelagic shale layers (< 15 %). A distinct feature of this turbidite facies is the intercalation of thick-bedded and coarse-grained sandstones with high amounts of mica and quartz. These are marker beds for mapping the Altlengbach Formation. Further up-section, hemipelagic shale ("Strubach Tonstein") becomes the dominant rock-type suggesting starvation of turbidite sedimentation.

Fossils: Calcareous nannoplankton, agglutinated foraminifera, ichnofossils.

Origin, facies: Deep sea sediments with various turbiditic features, partly below the calcite compensation depth.

The transport directions switched from an E–W direction in the lower part to an W–E transport in the upper part (upper Paleocene).

Chronostratigraphic age: Late Cretaceous, late Maastrichtian to late Paleocene, late Thanetian.

Biostratigraphy: Calcareous nannofossil Zones CC25–NP9.

Thickness: A maximum of 800 m is reported by EGGER (2011b).

Lithostratigraphically higher rank unit: Altlengbach Formation (Greifenstein Group, Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Kotgraben Member, Ahornleiten Member (Altlengbach Formation).

Overlying unit(s): Anthering Formation, Gablitz Formation, Greifenstein Formation.

Lateral unit(s): Kotgraben Member (Altlengbach Formation).

Geographic distribution: A wide distribution ranging from Salzburg via Upper Austria to the Vienna Woods of Lower Austria.

Remarks: -

Complementary references: EGGER & VAN HUSEN (2009b), EGGER (2007a, b), EGGER et al. (2007a, b).

Anthering-Formation (Greifenstein-Gruppe) / Anthering Formation (Greifenstein Group)

WERNER E. PILLER

Validity: Valid; EGGER (1995) introduced, described and formalized the "Anthering-Formation" for carbonate-rich mud turbidites which represent the uppermost part of the Rhenodanubian Flysch sequence in Salzburg and Upper Austria.

Type area: The area immediately to the north of the city of Salzburg, Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Type section: The type section (c. 250 m thick) is exposed along the ditch "Kohlbachgraben" (N 47°53′19″ / E 13°01′17″), a northern tributary to the creek "Antheringer Bach", c. 1 km NE of the village Anthering, c. 9 km N of the city of Salzburg, Salzburg (EGGER, 1995: Abb. 3; EGGER et al., 1997: Text-Fig. 1); ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Reference section(s): -

Derivation of name: Named after the village Anthering, c. 9 km N of the city of Salzburg, Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Synonyms: -

Lithology: The Anthering Formation predominantly consists of graded silty marlstones. Occasionally, these marls overlie silty to sandy beds deposited from the same turbidity current. These layers usually display base-truncated Bouma sequences. Single turbidite layers can reach thicknesses up to 2 m. The fine-grained sand-fraction represents, on average, 5 % of the rocks. The fine-grained (silty-clayey) sediment displays carbonate contents of 29 % to 53 %. The clay fraction is dominated by smectites.

The turbidite beds are often separated by hemipelagic claystone layers. They are carbonate-free and in sharp contacts to the turbiditic marls. Usually the claystones show a greenish to greyish colour with intensive bioturbation. Only occasionally dark-grey homogenous claystones with abundant pyrite framboids and relatively high contents of organic carbon (0.94 % on average) occur.

Bentonites are restricted to a 40 m thick part of the Anthering section which represents the lower part of calcareous nannofossil Zone NP10. Altogether 23 bentonite layers were counted with thicknesses up to 3 cm (EGGER, 2009b). They are interpreted as tuffs of air-fall derivation and analyses suggest an original basaltic composition of most of the ashes.

Fossils: Calcareous nannoplankton, benthic agglutinated (> 90 species) and planktic foraminifera, dinoflagellates, radiolarian, diatoms, pollen and spores, ichnofossils (EGGER et al., 2005, 2011).

Origin, facies: Typical for an abyssal plain facies with water depths of 3,000–5,000 m (EGGER et al., 2011).

Chronostratigraphic age: Early Eocene, Ypresian.

Remark: The base of the formation corresponds with the Paleocene/Eocene boundary proven by the negative carbon isotope excursion (CIE) in the upper part of calcareous nannofossil Zone NP9 (EGGER et al., 1997, 2009; EGGER, 2009b, c). The CIE interval, which is about 15 m thick at the type section, is also characterized by the acme of the dinocyst *Apectodinium augustum*.

Biostratigraphy: Calcareous nannoplankton indicates upper part of Zone NP9–NP11 and planktonic foraminifera indicate Zones P5 and P6.

Thickness: c. 150 m (EGGER, 1995).

Lithostratigraphically higher rank unit: Greifenstein Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Archating Member (Altlengbach Formation).

Overlying unit(s): The Anthering Formation is the youngest lithostratigraphic unit of the Rhenodanubian Supergroup in Salzburg and Upper Austria.

Lateral unit(s): Greifenstein Formation.

Geographic distribution: The formation is widely distributed reaching from Salzburg, Upper Austria to the western part of Lower Austria (EGGER, 1998) where it interfingers with the Greifenstein Formation.

Remarks: -

Complementary references: EGGER et al. (2000, 2005, 2007b), EGGER & BRÜCKL (2006), EGGER (2011b), EGGER & MANDL (2015).

Greifenstein-Formation (Greifenstein-Gruppe) / Greifenstein Formation (Greifenstein Group)

WERNER E. PILLER

Validity: Valid; as a general term for (Flysch-)sandstones in the area between Salzburg and Vienna the term "Wiener Sandstein" has been already introduced by VON LILIENBACH (1830). STUR (1891a, d) and PAUL & BITTNER (1894) introduced the term "Greifensteiner Sandstein" and "Greifensteiner Nummulitensandstein". A detailed study was carried out by HÖSCH (1985).

Type area: The between the villages Höflein an der Donau and Greifenstein and the market town St. Andrä-Wördern, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 40 Stockerau).

Type section: An approx. 125 m-thick section (FAUPL, 1996) in the abandoned quarry "Strombauamt" (Fa. Karner; formerly quarry "Hollitzer") (N 48°20′59″ / E 16°15′29″), at the western margin of the village Höflein an der Donau in the direction to the village Greifenstein, c. 6 km NW of the town Klosterneuburg, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 40 Stockerau).

Reference section(s): -

Derivation of name: Named after the village Greifenstein, approx. 6 km NW of the town Klosterneuburg, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 40 Stockerau).

Synonyms: Wiener Sandstein p.p. (VON LILIENBACH, 1830: p. 201), Sandsteine von Greifenstein (HAUER, 1857: p. 285), Greifensteiner Nummuliten-Sandstein (STUR, 1891a), Greifensteiner Sandstein, Greifensteiner Nummulitensandstein (PAUL & BITTNER, 1894), Glaukonitsandsteinserie (GRILL, 1953), Steinbergflysch (GRILL, 1953), Greifensteiner Schichtkomplex (HEKEL, 1968), Greifenstein Formation (KERN, 1978), Steinbergflyschserie (RAMMEL, 1989), Glauconite-Sandstone Formation (SAUER et al., 1992a).

Lithology: Following the detailed description of HÖSCH (1985), the most widespread and typical lithology are yellowish weathered, thick-bedded, massive, medium to coarse grained, glauconitic quartz sandstones, which are occasionally amalgamated and some show fine planar of cross bedding. The beds are sharp and evenly bedded and they show a lens-like appearance. This lithotype makes up c. 40 % of the total thickness of the Greifenstein Formation.

A second, abundant lithology are turbidites frequently with incomplete developed Bouma sequences starting with graded fine to medium grained sandstones overlain by a pelitic interval (Ta + Te). Another turbidite type is represented by Tb/Tc–Te sequences with Ta missing. On top of turbidites with Bouma sequences Tb/Tc–Te (distal turbidites) frequently alternations of siltstones and claystones occur up to dm-thickness. These turbidites make up c. 30 % of the total thickness of the Greifenstein Formation.

The third lithology type are conglomerates, which may be graded or non-graded, grading can be normal or inverse. The majority is composed of fine- to medium-grained gravels but clasts up dm-size also occur. Many of these conglomerates are matrix poor (clast supported) and the beds show erosive bases and pinch out laterally at short distances (few tens of meters); rip-up clasts up to 30 cm also occur. The thickness of the conglomerate beds increases from west (several tens of meters) to east (maximum of 6 m).

Fossils: Calcareous nannofossils, agglutinated (and subordinate planktic) foraminifera (GRÜN, 1969), larger benthic foraminifera (*Nummulites*, *Assilina*, *Operculina*, *Discocyclina*), dinocysts; ichnofossils are divers and include, e.g., *Zoophycos*, *Chondrites*, *Phycosiphon*, *Scolicia*, *Palaeodictyon*, *Spirorhaphe*, *Cosmorhaphe*) (HAUER, 1850; GÖTZINGER, 1951; PAPP, 1962b; KERN, 1978). A variety of allochthonous fossils was reported: orbitoidid larger foraminifers, gastropods, bivalves (inoceramids, ostreids, pectinids), serpulids, bryozoan, echinoid fragments, fish teeth (GÖTZINGER & BECKER, 1932b).

Remark: The occurrence of nummulites was of great importance for dating the Greifenstein Formation where autochthonous macrofossils are widely missing. First reports go back to HAUER (1850, 1857, 1858) followed by several authors (e.g., PAUL & BITTNER, 1894; SCHUBERT, 1913; JAEGER, 1914) but GÖTZINGER & BECKER (1932b) reported a high diverse larger foraminiferal fauna (and also other fossils) which has been dated to the Paleocene and Ypresian. The age was supported by new collections described by PAPP (1962a).

Origin, facies: Overall, the sedimentary environment of the Greifenstein Formation was a deep sea fan and the lithologies point at a position on the lower upper-to-upper middle fan. The input of gravitational sediment transport came from the north, the transport directions are NW–SE oriented and were not basin parallel. The conglomerates and thick bedded, massive sandstones are interpreted as channel fills, the turbidites as interchannel deposits. Grain size, geometries and paleocurrent directions indicate a proximal facies.

Chronostratigraphic age: Late Paleocene, Thanetian–early Eocene, Ypresian.

Biostratigraphy: The first occurrence of the dinocyst *Apectodinium augustum* in the lowermost part of the Greifenstein Formation (MOHAMED & WAGREICH, 2013) indicates that the Paleocene/Eocene boundary is at or near the base of the Greifenstein Formation.

Calcareous nannofossil Zones NP8 (*Heliolithus riedeli* Zone) to NP14 (*Discoaster sublodoensis*) (HEKEL, 1968; STRADNER, 1969; HÖSCH, 1985).

Thickness: 500–900 m (HÖSCH, 1985; SCHNABEL, 1988).

Lithostratigraphically higher rank unit: Greifenstein Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: Not formalized.

Remark: BRIX (1969: p. 460) differentiated between Lower (thick bedded, massive sandstones) and Upper Greifenstein Beds (thin bedded sandstones, clayey marls, marly shales). HEKEL (1968) separated several units, in particular, a diachronous alternation of "Coccolithenschiefer" and "Sandsteinhorizonte" which are three times repeated; the "Oberer Coccolithenschiefer" is synonymous with the Steinbergflysch. Both subdivisions, however, cannot be consistently applied (cf. HÖSCH, 1985).

Underlying unit(s): Altlengbach Formation.

Overlying unit(s): The Greifenstein Formation is predominantly the uppermost unit of the Greifenstein Group with an erosive top; in some areas the Gablitz Formation (Wessely, 2006) or/and the Irenental Formation (Faupl, 1996) may overly the Greifenstein Formation.

Lateral unit(s): It interfingers with or grades into the Gablitz Formation to the south, and the Anthering Formation to the west.

Geographic distribution: The Greifenstein Formation is nearly restricted to the Wienerwald (Vienna Woods), Lower Austria and Vienna; it dominates in the northern part of the Greifenstein Nappe and interfingers with the Gablitz Formation to the south and the Anthering Formation to the west; its westernmost occurrence is reported from the area around the river Pielach (Schnabel, 1992c); ÖK50 UTM, map sheets 4329 Wilhelmsburg, 4330 Neulengbach, 5319 Tulln an der Donau, 5320 Wien, 5325 Baden (ÖK50-BMN, map sheets 40 Stockerau, 41 Deutsch Wagram, 55 Ober-Grafendorf, 57 Neulengbach, 58 Baden).

Remark: The Greifenstein Formation is also recorded in isolated outcrops north of the Danube (Grill, 1953) and from drillings in the subsurface of the central and northern Vienna Basin (e.g., Kröll et al., 1993; Hekel, 1968; Rammel, 1989; Wessely, 2006; Mohamed & Wagreich, 2013). In these subsurface occurrences the terms “Glaukonitsandsteinserie” and “Steinbergflysch(serie)” are used for parts of the Greifenstein Formation (Grill, 1953; Hekel, 1968; Rammel, 1989; Wessely, 2006).

Remarks: As all tectonic units of the Rhenodanubian Flysch continue in the subsurface of the Vienna Basin into the Western Carpathians, also the Greifenstein Formation can be traced there under different lithostratigraphic names (Hekel, 1968; Rammel, 1989; Wessely, 2006).

Complementary references: Grill (1953, 1962a), Götzinger et al. (1954), Küpper (1968), Prey (1968, 1980b), Plöchinger & Prey (1974, 1993), Thenius (1974), Tollmann (1985), Brix et al. (1987), Sauer et al. (1992b), Schnabel (1997a), Ślączka (2012).

Gablitz-Formation (Greifenstein-Gruppe) / Gablitz Formation (Greifenstein Group)

Werner E. Piller

Validity: Invalid; Götzinger (1928) mentioned the name “Gablitzer Sandstein” and described it as intermediate between the “Greifensteiner Sandstein” und the “Laaber Sandstein”; in 1951, he introduced the term “Gablitzer Schichten” which he described more precisely in Götzinger (1954a) as siliceous sandstones and quartzites with intercalated friable sandstones similar to those of the Greifenstein Formation. Egger (1995: p. 74) described the “Gablitzer Schichten” as a facies variation of the Greifenstein Formation and suggested a lithostratigraphic status as member since the typical Greifenstein sandstone is still present although the dominant lithologies are described as green-grey clayey marls and marls.

Remark: The Gablitz Formation is considered invalid, because no type section is defined and also the relationship to the Greifenstein Formation is not clear. In addition, the position within the tectonic nappes is differently reconstructed, e.g., Götzinger & Becker (1932a) considered the “Gablitzer Zone” as northernmost part of the “Laaber Zone” (Laab Nappe), Götzinger (1954a) and Faupl (1996) placed this unit into the Kahlenberg Nappe and Schnabel (1997a) into the Greifenstein Nappe.

Type area: The type area is located between the market town Gablitz, the town Purkersdorf, the village Untermauerbach and the market town Mauerbach and neighbouring vales, immediately west of the border to Vienna, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 58 Baden).

Type section: -

Reference section(s): -

Derivation of name: Named after the market town Gablitz, c. 3 km NW of the town Purkersdorf, c. 17 km west of the city of Vienna, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 58 Baden).

Synonyms: Glaukoniteozän (Friedl, 1920), Gablitzer Sandstein (Götzinger, 1928: p. 52; 1929a: p. 46), Gablitzer Zone (Götzinger & Becker, 1932a: p. 354, 370), Gablitzer Schichten (Götzinger, 1951), Gablitzer Schiefer (Grill, 1962a: p. 256), Gablitz-Formation (Schnabel, 1997a).

Lithology: Marly mudturbidites with siliciclastic sandstones with glaucony. The lithologic description varies between authors: Götzinger (1954a) reported predominantly sandstone and quartzite, at the base variegated pelites; Faupl (1996) described a marl-rich sequence with thin siliceous sandstone beds.

Fossils: Calcareous nannoplankton, mostly agglutinated foraminifera but also nummulites (Jaeger, 1914), bivalves, echinoid spines, ichnofossils (Götzinger, 1951, 1954a).

Origin, facies: Deep-sea basin plain with predominant mud turbidites and subordinate sandstone intercalations; a more distal depositional environment compared with the Greifenstein Formation.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: Calcareous nannofossil Zones NP10–NP12 (Schnabel, 1992a; Egger, 1995); lower Eocene based on larger foraminifera (e.g., *Nummulites laevigatus*).

Thickness: About 100 m.

Lithostratigraphic higher rank unit: Greifenstein Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Greifenstein Formation. Schnabel (1997a), however, placed the Irenental Formation between the Greifenstein Formation and Gablitz Formation.

Overlying unit(s): The Gablitz Formation is considered the topmost formation in the Greifenstein Group but Faupl (1996) and Wessely (2006) placed the Irenentalschichten above the Gablitz Formation.

Lateral unit(s): Greifenstein Formation (Schnabel, 1992a, b), Anthering Formation (Egger, 2013a; Egger & Wessely, 2014).

Geographic distribution: Western and central part of the Vienna Woods, Lower Austria; ÖK50-UTM, map sheets 5319 Tulln an der Donau, 5330 Neulengbach (ÖK50-BMN, map sheets 57 Neulengbach, 58 Baden).

Remarks: GÖTZINGER & BECKER (1932a) introduced the "Gablitzer Zone" as unit north of the so-called "Hauptklippenzone" (Main Klippen Zone). GÖTZINGER (1954a: p. 61) considered the "Gablitzer Schichten" as transitional between the "Greifensteiner Sandstein" and "Laaber Schichten".

Complementary references: KÜPPER (1968), PREY (1968, 1980b), PLÖCHINGER & PREY (1974, 1993), THENIUS (1974), HÖSCH (1985), TOLLMANN (1985), BRIX et al. (1987), SCHNABEL (1988, 1992b, 1997a).

Irenental-Formation (Greifenstein-Gruppe) / Irenental Formation (Greifenstein Group)

WERNER E. PILLER

Validity: Invalid; SCHNABEL (1997a) introduced the name "Irenental-Formation" on the geological map, sheet 58 Baden, but did not provide a description, type section or boundaries of this unit.

Type area: A small stripe between the village Ameisberg and the hillside Buchberg (N 48°12′33.5″ / E 16°05′40″) in the NW part of the valley Irenental, c. 3 km NW of the village Unter-Tullnerbach, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 58 Baden) (SCHNABEL, 1997a).

Type section: -

Reference section(s): -

Derivation of name: Named after the Irenental, a small village and valley of the creek Tullnerbach, a northwestern tributary of the river Wien, which merge in the village Unter-Tullnerbach, c. 8 km W of the western border of Vienna, Lower Austria; ÖK50-UTM, map sheet 5319 Tulln an der Donau (ÖK50-BMN, map sheet 58 Baden).

Synonyms: Irenentalschichten (FAUPL, 1996), Irenental-Formation (Coccolithenschiefer) (WESSELY, 2006), ? Variegated shales complex (Irenental Formation) (ŚLĄCZKA, 2012).

Lithology: Predominantly yellowish-grey turbiditic marlstone, occasionally thin sandstone beds.

Fossils: Calcareous nannoplankton, foraminifera.

Origin, facies: Pelitic turbidites of a deep basin plain environment.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: Calcareous nannofossil Zones NP12–13 (WESSELY, 2006).

Thickness: About 50 m.

Lithostratigraphically higher rank unit: Greifenstein Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Greifenstein Formation or Gablitz Formation.

Overlying unit(s): This formation is the top of the Greifenstein Group.

Lateral unit(s): Gablitz Formation.

Geographic distribution: Reported only from the type area (see above).

Remarks: The Irenental Formation could be considered as the youngest part of the Gablitz Formation, which displays a similar lithology and is interfingering with the Greifenstein Formation.

Complementary references: -

Rhenodanubian Flysch Unit: Laab Nappe

Laab-Gruppe / Laab Group

WERNER E. PILLER

Validity: Valid; already STUR (1891a, d) and PAUL & BITTNER (1894) mentioned "Bunte Schiefer und Sandsteinschichten" from the early Tertiary of the Vienna Woods, FRIEDL (1920) used several names, e.g., "Glaukoniteozän" and GÖTZINGER (1928: p. 52) introduced the name "Laaber Schiefer und Sandsteine" for the "bunten Eozänschiefer und Sandsteine". The unit was then called "Laaber Schichten" (e.g., GÖTZINGER, 1931; GOTTSCHLING, 1966) but EGGER (2013b) introduced the "Laab-Gruppe" to include three formations in the group, which occur in the Laab Nappe of the Vienna Woods of Lower Austria.

Type area: The area around the village Laab im Walde (N 48°09′19″ / E 16°10′38″), Lower Austria, can be considered the type area; ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 58 Baden).

Type section: See formations.

Reference section(s): -

Derivation of name: Named after the village Laab im Walde, c. 6 km S of the town Purkersdorf, c. 11.5 km NW of the town Mödling, Lower Austria; ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 58 Baden).

Synonyms: Bunte Schiefer und Sandsteinschichten (STUR, 1891a, d; PAUL & BITTNER, 1894), Wiener Wald-Serie p.p., Laaber Eozän (FRIEDL, 1920: p. 36), Laaber Schiefer und Sandsteine (GÖTZINGER, 1928), Laaber Schichten (GÖTZINGER, 1931), Laaber Serie (GOTTSCHLING, 1966), Laab-Formation p.p. (SCHNABEL, 1996), Laab-Formation p.p., Kaumberg-Formation p.p. (SCHNABEL, 2002a, b).

Lithology: Thick-bedded coarse-grained siliciclastic sandstone beds in the lower part, in the upper part mainly claystones and silicified silt- and sandstone. In the uppermost part increasing proportion of clayey marlstone and marlstone.

Fossils: Calcareous nannoplankton, benthic and planktic foraminifera, rare bivalves, ichnofossils.

Origin, facies: Turbidites of the basin plain mostly below the calcite compensation depth.

Chronostratigraphic age: Late Cretaceous, Turonian to early Eocene, Ypresian.

Biostratigraphy: See formations.

Thickness: 2,150 m including all three formations from the Turonian to the Ypresian (Egger, 2013b).

Lithostratigraphically higher rank unit: Rhenodanubian Supergroup.

Lithostratigraphic subdivision: Kaumberg Formation (Turonian to late Campanian), Hois Formation, Agsbach Formation.

Underlying unit(s): Tectonic contact.

Overlying unit(s): Erosive.

Lateral unit(s): -

Geographic distribution: The Laab Group extends from approximately the market town Kilb in the SW to the western part of the city of Vienna in the NE (covering the distribution of the Laab Nappe), Lower Austria and Vienna; ÖK50-UTM, map sheets 4329 Wilhelmsburg, 4330 Neulengbach, 5325 Baden (ÖK50-BMN, map sheet 55 Ober-Grafendorf, 56 St. Pölten, 57 Neulengbach, 58 Baden).

Remarks: -

Complementary references: Prey (1962, 1979, 1980b), Küpper (1968), Thenius (1974), Kern (1978), Tollmann (1985), Schnabel (1997a), Stráník (1996b, 1998, 2000), Wessely (2006).

Hois-Formation / Hois Formation

Werner E. Piller

Validity: Valid; Prey (1965a) introduced the name "Hoisschichten" for the coarse clastic lower part of the "Laaber Schichten", Egger (2013b) raised this unit in the rank of a formation.

Type area: In the area of the upper "Kogelhofgraben" (Egger, 2013b: p. 189), between the villages St. Corona am Schöpfl and Glashütte, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: Prey (1965a) mentioned the quarry near the farmstead Hois (N 48°03′16″ / E 15°56′30″), c. 2 km SE of the village St. Corona am Schöpfl, Lower Austria, as type locality. Egger (2013b: p. 185) mentioned that this quarry is completely overgrown and defined a neostratotype in the part between 500 and 700 m a.s.l. of a ditch ("Kogelhofgraben"), E of the farmstead Kogelhof (N 48°05′17″ / E 15°52′21″), between the villages Glashütte and Wöllersdorf, community Brand-Laaben, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Reference section(s): -

Derivation of name: Named after the farmstead Hois, c. 2 km SE of the village St. Corona am Schöpfl, Lower Austria.

Synonyms: Hoisschichten (Prey, 1965a: p. 113), Hois Formation (Kern, 1978), Hois Member (Schnabel, 1999), Hois-Subformation (Schnabel, 2002b).

Lithology: Sandstone rich succession intercalated with marl.

Fossils: Calcareous nannoplankton, foraminifera, ichnofossils (*Nereites*, *Chondrites*).

Origin, facies: Turbidites of the basin plain mostly below the calcite compensation depth.

Chronostratigraphic age: Late Cretaceous, middle Campanian–late Paleocene, Thanetian.

Biostratigraphy: Calcareous nannofossil Zones CC20–NP9.

Thickness: 950 m (Egger, 2013b).

Lithostratigraphically higher rank unit: Laab Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: Kogelhofgraben Member, Schöpfl Member, Türkenstein Member.

Underlying unit(s): Kaumberg Formation.

Remark: Following Fuchs (1965b), Schnabel (1996, 1999) considered a possible hiatus due to a thrust plane at the base of the Laab Formation. Since such a structure is not indicated on map sheet 58 Baden (Schnabel, 1997a) it remains unclear if the Kaumberg Formation and the Hois Formation are in stratigraphic contact or belong to separate tectonic units.

Overlying unit(s): Agsbach Formation.

Lateral unit(s): -

Geographic distribution: The Hois Formation extends from Kilb in the SW to the western part of the city of Vienna in the NE (covering the distribution of the Laab Nappe), Lower Austria and Vienna; ÖK50-UTM, map sheets 4329 Wilhelmsburg, 4330 Neulengbach, 5325 Baden (ÖK50-BMN, map sheet 55 Ober-Grafendorf, 56 St. Pölten, 57 Neulengbach, 58 Baden).

Remarks: The "Hoisschichten" defined by Prey (1965a) included only the lower part of the Hois Formation which is now defined as Kogelgraben Member.

Complementary references: Prey (1968, 1980b), Plöchinger & Prey (1974, 1993), Thenius (1974), Tollmann (1985), Schnabel (1992a–c, 1997b), Sauer et al. (1992a), Faupl (1996), Stráník (1998, 2000), Wessely (2006).

Kogelhofgraben-Subformation (Hois-Formation, Laab-Gruppe) / Kogelhofgraben Member (Hois Formation, Laab Group)

Werner E. Piller

Validity: Valid; the "Kogelhofgraben-Subformation" has been introduced, described and formalized by Egger (2013b) for the lower part of the Hois Formation.

Type area: The area between the villages St. Corona am Schöpfl and Glashütte, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: The type section is exposed in a ditch ("Kogelhofgraben") between 460 and 570 m a.s.l., E of the farmstead Kogelhof (N 48°05′17″ / E 15°52′21″), between the villages Glashütte and Wöllersdorf, community Brand-Laaben, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Reference section(s): Egger (2013b) mentioned a good outcropping section along the creek Durlasbach, NNE of Rohrbach an der Gölsen, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Derivation of name: Named after the "Kogelhofgraben", E of the farmstead Kogelhof (N 48°05′17″ / E 15°52′21″), between the villages Glashütte and Wöllersdorf, community Brand-Laaben, Lower Austria.

Synonyms: Hoisschichten p.p. (Prey, 1965), Kogelhofgraben-Subformation (Egger, 2013b).

Lithology: Olive to brown siliciclastic turbidites of several meters; the turbidites show coarse sandstones or fine conglomerates at the base; predominantly in the lower part also subordinate calciturbidites occur. In the uppermost part hard, bright calcareous micrite beds (- 0.5 m) are reported. Intercalated between the hard beds occur grey claystones, representing either green pelagic or grey turbiditic beds. Overall, the psammite/pelite proportion is around 1:1.

Fossils: Calcareous nannoplankton, agglutinated foraminifera, ichnofossils (*Chondrites*, *Trichichnus*, *Zoophycos*; Uchmann, 1999).

Origin, facies: Turbidites of the basin plain mostly below the calcite compensation depth.

Chronostratigraphic age: Late Cretaceous, middle Campanian to late Maastrichtian, close to the Cretaceous/Paleogene boundary.

Biostratigraphy: The base of the Kogelhofgraben Member (and the Hois Formation) is dated to calcareous nannofossil Zone CC20 (*Ceratolithoides aculeatus* Zone). The uppermost documented zone is the *Micula prinsii* Zone of the upper Maastrichtian.

Thickness: 650 m (Egger, 2013b).

Lithostratigraphically higher rank unit: Hois Formation (Laab Group, Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Kaumberg Formation; the boundary is marked by a change from thin-bedded red hemipelagic claystones of the Kaumberg Formation to thick (calcareous) turbidites of the Kogelhofgraben Member.

Overlying unit(s): Schöpfl Member (Hois Formation); the boundary is marked by the disappearance of calciturbidites and thick-bedded siliciclastic sandstones of the Kogelhofgraben Member and dominating thin bedded sediments.

Lateral unit(s): -

Geographic distribution: The Kogelhofgraben Member is distributed in the southwestern area of the distribution of the Laab Group (Laab Nappe).

Remarks: Although the Kogelhofgraben Member is of late Cretaceous age it is included here because it may reach to the K/Pg-boundary and it is one of the three members of the Hois Formation.

Complementary references: -

Schöpfl-Subformation (Hois-Formation, Laab-Gruppe) / Schöpfl Member (Hois Formation, Laab Group)

Werner E. Piller

Validity: Valid; Egger (2013b) introduced the "Schöpfl-Subformation" to characterize the middle part of the Hois Formation.

Type area: The northern slope of the hillside Schöpfl; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: The type section is located along a forest road which crosses the ditch "Kogelhofgraben" at an altitude of 600 m a.s.l. (approx. N 48°04′49″ / E 15°52′51″), community Brand-Laaben, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Reference section(s): -

Derivation of name: Named after the hillside Schöpfl (893 m a.s.l.; the highest elevation in the Vienna Woods) (N 48°05′15.8″ / E 15°54′50.9″); ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Synonyms: Schöpfl-Subformation (Egger, 2013b).

Lithology: The sequence is composed predominantly of dm-bedded siltstone turbidites with subordinate thick bedded, siliceous turbiditic sandstone beds. Most turbidites lack the basal parts (T_a, T_b) of the Bouma cycle. Thin layers of yellow weathered claystones occur which are bioturbated by *Chondrites*.

Fossils: Rare calcareous nannoplankton, ichnofossils.

Origin, facies: Turbidites of the basin plain mostly below the calcite compensation depth.

Chronostratigraphic age: Early Paleocene, Danian to late Paleocene, Selandian, Thanetian (?).

Biostratigraphy: Nannoplankton is rare but *Coccolithus pelagicus* occurs clearly indicating a position above the K/Pg boundary. In the lower part of the sequence *Cruciplacolithus tenuis* was identified being indicative for Zone NP2 (Danian), *Fasciculithus tympaniformis* is indicative for the Selandian.

Thickness: 250 m (Egger, 2013b).

Lithostratigraphically higher rank unit: Hois Formation (Laab Group, Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Kogelhofgraben Member.

Overlying unit(s): Türkenstein Member; the politic sediments of the Schöpfl Member are distinctly overlain by quartz-arenitic sandstones of the Türkenstein Member.

Lateral unit(s): -

Geographic distribution: The distribution of the Schöpfl Member is restricted to that of the Hois Formation (see above).

Remarks: -

Complementary references: -

Türkenstein-Subformation (Hois-Formation, Laab-Gruppe) / Türkenstein Member (Hois Formation, Laab Group)

WERNER E. PILLER

Validity: Valid; EGGER (2013b) introduced the "Türkenstein-Subformation" for the upper unit of the Hois Formation.

Type area: Around the hillside "Türkenstein" in a small stripe striking between Hendlberg in the WSW and N of the Schöpfl summit in the ENE (EGGER, 2013b: Abb. 1), Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: At the "Türkenstein" at the eastern flank of the river Laabenbach (not further specified by EGGER, 2013b).

Reference section(s): -

Derivation of name: Named after the hillside "Türkenstein" (545 m a.s.l.) (N 48°04′30″ / E 15°51′53″) at the eastern flank of the river Laabenbach, c. 1 km S of the village Glashütte, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Synonyms: Türkenstein-Subformation (EGGER, 2013b).

Lithology: Nearly exclusively built of light brown weathered quartzarenites.

Fossils: No fossils detected.

Origin, facies: Compared to the Schöpfl Member, coarser turbidites of the basin plain mostly below the calcite compensation depth.

Chronostratigraphic age: Late Paleocene, Thanetian.

Biostratigraphy: In the Agsbach Formation immediately above the Türkenstein Member the dinocyst *Apectodinium augustum* was found which is indicative for the base of the Eocene.

Thickness: 50 m (EGGER, 2013b).

Lithostratigraphically higher rank unit: Hois Formation (Laab Group, Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Schöpfl Member (Hois Formation).

Overlying unit(s): Agsbach Formation (Laab Group); the Agsbach Formation is dominated by pelites in contrast to the psammites of the Türkenstein Member.

Lateral unit(s): -

Geographic distribution: The distribution of the Schöpfl Member is restricted to that of the Hois Formation (see above).

Remarks: This unit is probably represented by the "Glasige Quarzsandsteine" (glassy quartz sandstone) of GOTTSCHLING (1966).

Complementary references: -

Agsbach-Formation (Laab-Gruppe) / Agsbach Formation (Laab Group)

WERNER E. PILLER

Validity: Valid; PREY (1965a) split the "Laaber Schichten" into the lower Hoisschichten and the upper, finer grained Agsbachschichten. On the geological map 58 Baden (SCHNABEL, 1997a) introduced the "Agsbach-Formation" and changed it to a member (SCHNABEL, 1999) or to the "Agsbach-Subformation" on the geological map of Lower Austria (SCHNABEL, 2002a). A detailed description and formalization was only provided by EGGER (2013b).

Type area: In the area between the hillside Schöpfl, the village St. Corona am Schöpfl, the farmstead Wienhof and the Klammhöhe, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: PREY (1965a) designated a small quarry (N 48°07′37″ / E 16°01′50″) along the road S of the hamlet Agsbach as type section. This outcrop is, however, completely covered and EGGER (2013b) established a neostratotype along the river Triesting between the confluence of the Triesting with the Stützenreithbach (N 48°03′11″ / E 15°52′53″) and W of the bridge over the Triesting (N 48°03′03″ / E 15°53′06″) immediately NW of the farmstead "Wienhof", Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Reference section(s): -

Derivation of name: Named after the hamlet Agsbach (N 48°08′05.86″ / E 16°02′13.3″) (PREY, 1965a), c. 5 km NNE of the village Klausen-Leopoldsdorf, c. 6 km SW of the town Pressbaum, Lower Austria; ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 57 Neulengbach).

Synonyms: Agsbachschichten (PREY, 1965a: p. 113), Agsbach Formation (KERN, 1978), Agsbach Member (SCHNABEL, 1999), Agsbach-Subformation (SCHNABEL, 2002a, b).

Lithology: Dominated by pelitic turbidites with subordinate thin bedded sandstones. Characteristic are also light yellow to brownish weathered grey claystones. In the upper part of the formation, also calciturbidites occur as platy marl with *Chondrites* trace fossils. The pelite/psammite proportion is between 10:1 and 5:1.

Fossils: Calcareous nannoplankton, rare planktic foraminifera, rare ichnofossils.

Origin, facies: Mud turbidites of the basin plain mostly below the calcite compensation depth.

Chronostratigraphic age: Early Eocene, early Ypresian to latest Ypresian.

Biostratigraphy: The occurrence of the dinocyst species *Apectodinium augustum* in the lowest part of the formation clearly indicates lowest Eocene (NP9; *Discoaster multiradiatus* Zone). The uppermost biostratigraphic marker is the *Discoaster sublodoensis* Zone (NP14) (Egger, 2013b).

Thickness: 1,000 m (Egger, 2013b).

Lithostratigraphically higher rank unit: Laab Group (Rhenodanubian Supergroup).

Lithostratigraphic subdivision: -

Underlying unit(s): Türkenstein Member (Hois Group).

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: The distribution of the Schöpfl Member is restricted to that of the Hois Formation (see above).

Remarks: -

Complementary references: Prey (1968, 1980b), Plöchinger & Prey (1974, 1993), Thenius (1974), Tollmann (1985), Sauer et al. (1992a), Faupl (1996), Stráník (1998, 2000), Wessely (2006).

Austroalpine Units

Michael Wagreich

Upper Cretaceous/Paleogene sediments which rest unconformably upon deformed pre-Gosau sediments and also on metamorphic Austroalpine basement south of the NCA are informally called "Gosauschichten" (Text-Fig. 3).

Gosau Basins (Northern Calcareous Alps)

On top of the NCA, these Upper Cretaceous–Paleogene strata are summarized in the Gosau Group. The Gosau Group marks the deposition of a new sedimentary cycle from Turonian onwards up to the Eocene. Basin formation is still discussed and several basin types were interpreted, e.g., compressional piggy back and synthrust basin models, and extensional and pull-apart basin models (e.g., Wagreich & Decker, 2001). The Gosau Group of the NCA can be divided into two subgroups (Wagreich & Faupl, 1994). The Lower Gosau Subgroup (Upper Turonian–Paleogene) consists of diachronous terrestrial deposits at the base and passes gradationally into shallow-marine successions. Sandstones, rudist-bearing limestones, and marls are the main facies of the Lower Gosau Subgroup (Wagreich & Faupl, 1994). The Paleogene part of the Lower Gosau Subgroup comprises mainly shallow-water limestones and some mixed carbonate-siliciclastic rocks at the southeastern part of the NCA. The Upper Gosau Subgroup comprises deep-water deposits, such as hemipelagic and pelagic slope marls (Krenmayr, 1999) and a variety of deep-water clastics, deposited above and below the calcite compensation level. Facies distribution and paleocurrent data indicate a pronounced fault-controlled relief of a generally north-facing paleoslope (Wagreich, 2001).

The Upper Cretaceous strata on top of metamorphic Austroalpine units south of the NCA, i.e. the succession of the Krappfeld area (Carinthia), is transgressively overlain by Eocene terrestrial to shallow-marine strata of the Guttaring Group.

Gosau-Gruppe / Gosau Group

Michael Wagreich

Validity: Valid; the term "Gosauer Gesteine" was first used by Lilienbach (1830). Reuss (1854) was the first who defined a lower group ("Untere Gruppe", largely correlated to the actual Lower Gosau Subgroup) and an upper group ("Obere Gruppe" largely correlated to the actual Upper Gosau Subgroup). Lithostratigraphic units such as the Hochmoos Formation were named and described for the first time in the type area by Weigel (1937) and refined by Kollmann (1982). The term Gosau Group was first used by Kollmann (1982: "Gosau-Schichtgruppe") and Faupl et al. (1987).

Type area: Gosau Basin from the Gosau valley to the market town Abtenau, Upper Austria – Salzburg; ÖK50-UTM, map sheet 3217 Hallstatt (ÖK50-BMN, map sheet 95 St. Wolfgang im Salzkammergut).

Type section: The type section of the fossiliferous Hochmoos Formation can also considered as type section for the Gosau Group. According to Weigel (1937) and logged by Wagreich (1986, 1988), outcrops along the Tauerngraben up to the Hochmoos at Pass Gschütt, 1.5 km NW of Gosau-Vordertal, serve as a composite type section.

Reference section(s): -

Synonyms: Gosauschichten (Reuss, 1854), Gosauformation (Kühn, 1925b).

Lithology: Red and grey conglomerates, grey sandstones, siltstones and marls, limestones, coal seams, bauxite, red marls and marly limestones, mass-flow sands, conglomerates and breccias.

Text-Fig. 3.
Location of described Austroalpine units (Goau Group, Guttaring Group) (grey shaded).

Fossils: Calcareous nannofossils, planktic and benthic foraminifera, corals, molluscs (ammonites, inoceramids, rudists, …), brachiopods.

Origin, facies: Terrestrial to shallow-water and deep-water depositional environment, mainly clastic or mixed carbonate-clastic facies.

Chronostratigraphic age: Late Cretaceous, late Turonian–Paleogene, Eocene.

Biostratigraphy: Planctonic foraminifera *Dicarinella concavata* Zone to planktonic foraminifera Zone P10; calcareous nannofossil Zones CC13/UC9–NP12.

Thickness: Up to 2,500 m, strong variation in thickness.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Lower Gosau Subgroup, Upper Gosau Subgroup.

Underlying unit(s): Unconformably above Permian to Cretaceous rocks of NCA.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Northern Calcareous Alps, Central Alps.

Remarks: -

Complementary references: -

Obere Gosau-Subgruppe / Upper Gosau Subgroup

Michael Wagreich

Validity: Valid; a distinct upper part of the Gosau Group was already mentioned by Reuss (1854: "Obere Gruppe"); the Upper Gosau Subgroup was defined by Wagreich & Faupl (1994).

Type area: Gosau Basin, Upper Austria – Salzburg; ÖK50-UTM, map sheet 3217 Hallstatt (ÖK50-BMN, map sheet 95 St. Wolfgang im Salzkammergut).

Type section: The type section of the Nierental Formation (Krenmayr, 1999; Herm, 1962b) (N 47°40′31″ / E 12°52′34″) at Lattengebirge south of Bad Reichenhall, Bavaria, Germany; ÖK50-UTM, map sheet 3209 Bad Reichenhall (ÖK50-BMN, map sheet 93 Berchtesgaden).

Reference section(s): -

Synonyms: at least parts of "Obere Gosau" (Reuss, 1854), "Höhere Gosau", "Upper Gosau Complex" (Faupl et al., 1987).

Lithology: Red and grey marls and marly limestones, siltstones, sandstones, conglomerates and breccias, olisthostromes, rare limestones.

Fossils: Planktic foraminifera, calcareous nannoplankton.

Origin, facies: Deep-water facies including pelagic and hemipelagic deposits and mass-flow deposits including slope fans.

Chronostratigraphic age: Late Cretaceous, Santonian–Paleogene, Eocene (diachronous).

Biostratigraphy: Planctonic foraminifera *Dicarinella asymetrica* Zone to planktonic foraminifera Zone P10; calcareous nannofossil Zones CC16/UC12–NP12.

Thickness: Up to 1,500 m, strong lateral variations.

Lithostratigraphically higher rank unit: Gosau Group.

Lithostratigraphic subdivision: Several formations (see below).

Underlying unit(s): Lower Gosau Subgroup. Lower boundary defined by unconformity ("Intragosauische Diskordanz") and/or facies change from shallow-water to deep-water facies.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Northern Calcareous Alps, Central Alps.

Remarks: -

Complementary references: -

Nierental-Formation (Obere Gosau-Subgruppe, Gosau-Gruppe) / Nierental Formation (Upper Gosau Subgroup, Gosau Group)

Michael Wagreich

Validity: Valid; first description by Gümbel (1861) as "Kalkmergel vom Nierenthale"; later on several descriptions and different views on the status of this unit (e.g., Herm, 1962a, b); Kollmann (1982) mapped the unit in the Gosau valley type area as "Nierentaler Schichten"; the term "Nierental Formation" was used and defined by Faupl et al. (1987) and Wagreich & Faupl (1994), and formalized by Krenmayr (1999), including a detailed description of the type section as neotype and a discussion on the research history of the unit (Krenmayr, 1999: p. 411–412).

Type area: Nierental and Lattengebirge, south of the town Bad Reichenhall, Bavaria, Germany; ÖK50-UTM, map sheet 3209 Bad Reichenhall (ÖK50-BMN, map sheet 93 Berchtesgaden).

Type section: The type section (neostratotype defined by Krenmayr, 1999) is a composite section in the Lattengebirge (Herm, 1962b; Krenmayr, 1999) (N 47°40′31″ / E 12°52′34″), including the Dalsenalm/Röthelbach section and the Wasserfallgraben section, south of Bad Reichenhall, Bavaria, Germany.

Reference section(s): Reference sections of the Nierental Formation are in the area of Gosau, Rußbach and Abtenau (e.g., Rotwand N 47°32′26″ / E 13°29′34″, Elendgraben N 47°34′42″ / E 13°26′53″, Postalm road N 47°36′45″ / E 13°23′11″) and Gams bei Hieflau (Krenmayr, 1999; see also Wagreich & Faupl, 1994; Wagreich & Krenmayr, 2005). The lower boundary is defined by the change from grey silty marls with very fine sandstone layers to red and grey marly limestones without or only minor graded sandstone beds. The upper boundary is defined by the occurrence of turbidite conglomerates and an increase in graded sandstone layers above 50 %.

Derivation of name: After the creek Nierent(h)al, NW at the Nierentalkopf, SE Bad Reichenhall, Bavaria, Germany; ÖK50-UTM, map sheet 3209 Bad Reichenhall (ÖK50-BMN, map sheet 93 Berchtesgaden).

Synonyms: Kalkmergel vom Nierenthale (GÜMBEL, 1861), Nierentaler Schichten (PLÖCHINGER & OBERHAUSER, 1957), Schichten in Nierentaler Fazies (OBERHAUSER, 1963), Tasshofer Schichten (SUMMESBERGER, 1991; see WAGREICH et al., 2011).

Lithology: The main lithologies are thin- to medium-bedded, indurated, red and grey calcareous marls to marly limestones (50–90 % carbonate content). Sandstone layers of turbidite origin may be present but stay below 50 %. Marls and marly limestones consist mainly of planktic microfossils (calcareous nannoplankton, planktic foraminifera), terrigenous clay minerals and minor silt-sized quartz.

Fossils: Foraminifera; planktic foraminifera make up more than 50 %, often more than 95 % of the foraminiferal assemblages. Rare to very rare macrofossils (echinoids, ammonites, belemnites). Bioturbation and ichnofossils are common, e.g., *Chondrites* and *Zoophycus*.

Origin, facies: Pelagic-hemipelagic, pelitic facies with intercalated mass-flow deposits of bathyal water depths from 200 to 2,500 m (BUTT, 1981; KRENMAYR, 1996b, 1999).

Chronostratigraphic age: Late Cretaceous, Santonian–Paleogene, Paleocene, locally early to middle Eocene (diachronous).

Biostratigraphy: Planctonic foraminifera *Dicarinella asymetrica* Zone to planktonic foraminifera Zone P10; calcareous nannofossil Zones CC17/UC12–NP10 (HILLEBRAND, 1981; WAGREICH, 2001).

Thickness: Up to 350 m in the Gosau area.

Lithostratigraphically higher rank unit: Upper Gosau Subgroup, Gosau Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Grabenbach Formation (Lattengebirge; WAGREICH, 2003); Bibereck Formation, Ressen Formation (in the area of Gosau–Rußbach); also unconformably above various Permian–Mesozoic formations of the NCA.

Overlying unit(s): Zwieselalm Formation.

Lateral unit(s): Ressen Formation, Zwieselalm Formation, Krimpenbach Formation, Kambühel Formation, Gießhübl Formation.

Geographic distribution: Widespread within the NCA, occurring from Tyrol in the west to Vienna in the East (WAGREICH & FAUPL, 1994; KRENMAYR, 1996b, 1999; WAGREICH & KRENMAYR, 2005).

Remarks: The Nierental Formation continues into the Western Carpathians of the Slovak Republic known there as, e.g., Košariská Formation and Brezová Group (WAGREICH & MARSCHALKO, 1995).

Complementary references: KÜPPER (1956), KUEHN (1962), PLÖCHINGER (1980), HERM (1981), FAUPL (1983), TOLLMANN (1976, 1985), FAUPL et al. (1987), RISCH (1988), MANDL (2002).

Zwieselalm-Formation (Obere Gosau-Subgruppe, Gosau-Gruppe) / Zwieselalm Formation (Upper Gosau Subgroup, Gosau Group)

VERONIKA KOUKAL & MICHAEL WAGREICH

Validity: Invalid; SPENGLER (1914: p. 287) mentioned a unit "*aus krystallinen Geröllen zusammengesetztes Konglomerat*" from the area of Gosau, which was named "Zwieselalmschichten" by KÜHN (1930) and defined by KOLLMANN (1982) as "Zwieselalmschichten" in the rank of a formation; the term "Zwieselalm Formation" was used for the first time by FAUPL et al. (1987) and LAHODYNSKY (1988, 1989).

Type area: Area of the mountain pasture Zwieselalm (N 47°32′34″ / E 13°28′30″), Gosau Basin, Upper Austria – Salzburg; ÖK50-UTM, map sheets 3211 Bad Ischl, 3217 Hallstatt (ÖK50-BMN, map sheet 95 St. Wolfgang im Salzkammergut).

Type section: Not defined; for descriptions of possible type sections see, e.g., PERYT et al. (1993), KRENMAYR (1996b, 1999), EGGER et al. (2004).

Reference section(s): Krautgraben (N 47°39′46″ / E 14°53′09″), E of the village Gams bei Hieflau, Styria (EGGER et al., 2004); ÖK50-UTM, map sheet 4209 Hieflau (ÖK50-BMN, map sheet 101 Eisenerz). The lower boundary is defined by the change from marls and marly limestones to thick sandstone beds and conglomerates.

Derivation of name: After the Zwieselalm area around the mountain hut Liesenhütte (N 47°32′37.5″ / E 13°29′09.5″), c. 3 km southwest of the village Gosau-Hintertal, Upper Austria; ÖK50-UTM, map sheet 3217 Hallstatt (ÖK50-BMN, map sheet 95 St. Wolfgang im Salzkammergut).

Synonyms: Zwieselalmschichten (KÜHN, 1930), Liesenschichten (WEIGEL, 1937), Breccien-Sandsteinkomplex (KOLLMANN, 1964), (probably) Wörschachbergschichten (POBER, 1984).

Lithology: Sandstones, conglomerates, and grey and red marls and marly limestones; resedimented limestone clasts of the Kambühel Formation including olistholites (SCHLAGINTWEIT et al., 2003; KRISCHE et al., 2012).

Fossils: Calcareous nannoplankton, planktic foraminifera (EGGER et al., 2004); no autochthonous macrofossils, but transported shallow water fauna (e.g., corals, red algae) (KÜHN, 1930).

Origin, facies: Turbidite fan facies with minor hemipelagic intercalations.

Chronostratigraphic age: Late Cretaceous, late Maastrichtian to Eocene, Ypresian.

Biostratigraphy: Nannofossil Zones CC24–NP12 (EGGER & WAGREICH, 2001; EGGER et al., 2004).

Thickness: 200–300 m.

Lithostratigraphically higher rank unit: Upper Gosau Subgroup, Gosau Group.

Lithostratigraphic subdivision: -

Underlying units: Nierental Formation.

Overlying units: -

Lateral units: Nierental Formation (WAGREICH & KRENMAYR, 2005).

Geographic distribution: In the area of Gosau–Rußbach–Abtenau, Upper Austria – Salzburg (KOLLMANN, 1982) and in the area of Gams bei Hieflau, Styria (KOLLMANN, 1964; EGGER et al., 2004).

Remarks: K-Pg boundary sections are known from the Elendgraben near Rußbach (Gosau Basin), Salzburg (PREISINGER et al., 1986) and the Rotwandgraben, also in the Gosau Basin, Upper Austria (LAHODYNSKY, 1988, 1989, 2003; PERYT et al., 1993), at the transition from the Nierental Formation to the Zwieselalm Formation. Equivalent Paleogene strata in the area of Gams bei Hieflau, Styria, are also termed Zwieselalm Formation (EGGER et al., 2004) and include K-Pg and P-E boundary sections.

Complementary references: TOLLMANN (1976, 1985), MANDL (2002).

Brunnbach-Formation (Obere Gosau-Subgruppe, Gosau-Gruppe) / Brunnbach Formation (Upper Gosau Subgroup, Gosau Group)

MICHAEL WAGREICH

Validity: Valid; FAUPL (1983) suggested the name Brunnbachschichten and EGGER & FAUPL (1999) mapped the unit as "Brunnbach-Formation". The term "Brunnbach Formation" was used for the first time by FAUPL et al. (1987).

Type area: Area along the creeks Brunnbach–Pleißabach, c. 7.5 km south of the village Großraming, Upper Austria; ÖK50-UTM, map sheet 4202 Ternberg (ÖK50-BMN, map sheet 69 Großraming).

Type section: Brunnbach–Pleißabach (FAUPL, 1983: p. 225) (N 47°49′36″ / E 14°30′28″), c. 7.5 km south of the village Großraming, Upper Austria.

Reference section(s): FAUPL (1983: Fig. 14) presented several sections from Lumplgraben, Breitenberg, Spitzenbach that can be used as reference sections (see also PLÖCHINGER et al., 1987).

Derivation of name: After the hamlet Brunnbach, c. 7 km south of the village Großraming, Upper Austria; ÖK50-UTM, map sheet 4202 Ternberg (ÖK50-BMN, map sheet 69 Großraming).

Synonyms: Nierentaler Schichten (RUTTNER & WOLETZ, 1956).

Lithology: Carbonate breccias and polymict conglomerates, thick- and thin-bedded sandstones, grey and red silty marls, red and greenish claystones (hemipelagites).

Fossils: Calcareous nannoplankton, planktic and benthic foraminifera, trace fossils.

Origin, facies: Deep-water turbidite fans and carbonate-free hemipelagites.

Chronostratigraphic age: Late Cretaceous, late Campanian to Paleogene, early Paleocene, Danian (FAUPL, 1983; PLÖCHINGER, 1987).

Biostratigraphy: The Campanian–Maastrichtian is well established by calcareous nannoplankton and planktic foraminifera; Danian is proved by planktic foraminifera, e.g., *Globigerina triloculinoides, Morozovella pseudobulloides* and calcareous nannoplankton (FAUPL, 1983; PLÖCHINGER et al., 1987).

Thickness: Up to 1,000 m.

Lithostratigraphically higher rank unit: Upper Gosau Subgroup, Gosau Group.

Lithostratigraphic subdivision: No formal subdivision; based on turbidite facies models, FAUPL (1983) informally divided the formation into a "mergelreiche Turbiditfolge" (mainly the lower part in the northern outcrop areas) and a "sandstein- und breccienreiche Turbiditfolge" (mainly upper part in the north and entire Brunnbach Formation in the south).

Underlying unit(s): Nierental Formation, Spitzenbach Formation (unconformity at the base).

Overlying unit(s): Not known (overthrusted by higher nappe units of the Weyer Arc).

Lateral unit(s): -

Geographic distribution: Between the village Großraming and the market town St. Gallen (Enns Valley – Reichraminger Hintergebirge), Styria (Northern Calcareous Alps); ÖK50-UTM, map sheet 4202 Ternberg (ÖK50-BMN, map sheet 69 Großraming).

Remarks: -

Complementary references: OBERHAUSER (1963), FAUPL et al. (1987), WAGREICH & FAUPL (1994), MANDL (2002).

Gießhübl-Formation (Obere Gosau-Subgruppe, Gosau-Gruppe) / Gießhübl Formation (Upper Gosau Subgroup, Gosau Group)

MICHAEL WAGREICH

Validity: Invalid; named by PLÖCHINGER (1964) as "Gießhübler Schichten", described in detail by SAUER (1980). FAUPL et al. (1987) used the term "Gießhübl Formation" for the first time.

Type area: In the area of the village Gießhübl, SE of the city of Vienna, Lower Austria (Gießhübl Syncline); ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 58 Baden).

Type section: -

Reference section(s): Not defined, but several deep wells such as Aderklaa 5, Aderklaa 81, Schönkirchen Tief T21, T32, T90 would be good candidates (WESSELY, 1974, 1992, 2006).

Derivation of name: After the village Gießhübl, c. 16 km SE of the city centre of Vienna, Lower Austria; ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 58 Baden).

Synonyms: Gießhübler Schichten (PLÖCHINGER, 1964), Giesshübl Group (SAUER et al., 1992a, b; WESSELY, 1992), Höllgrabenschichten (WAGREICH, 2013).

Lithology: Carbonate breccias, conglomerates, sandstones, marls, claystones.

Fossils: Calcareous nannoplankton, planktic foraminifera; reworked corallinacean red algae, corals, orbitoids.

Origin, facies: Deep-water turbidite system with sandstone, marls, shales and breccias; including also coarse mass flows.

Chronostratigraphic age: Late Cretaceous, late Maastrichtian–Paleogene, Paleocene, Thanetian.

Biostratigraphy: Planktonic foraminifera (*Globigerina, Globorotalia*), calcareous nannoplankton, e.g., *Fasciculithus involutus* (Wessely, 1974).

Thickness: Several hundreds of meters.

Lithostratigraphically higher rank unit: Upper Gosau Subgroup, Gosau Group.

Lithostratigraphic subdivision: Three informal members (untere, mittlere, obere Gießhübler Schichten, Wessely, 1974; lower, middle, upper Giesshübl Formation, Wessely, 1992) were distinguished and used on maps, however, never defined as valid members. After Wessely (2006) these units can be separated: "Untere Gießhübl-Subformation" (red and grey shales and marls and quartz sandstones); "Mittlere Gießhübl-Subformation" (grey marls and carbonate breccias with corallinacean algae and corals); "Obere Gießhübl-Subformation" (carbonate-poor grey marls and quartz sandstones, minor conglomerates).

Underlying unit(s): Nierental Formation.

Overlying unit(s): Unknown (eroded or overthrust by tectonically higher units).

Lateral unit(s): -

Geographic distribution: Within the Gießhübl Syncline between Gießhübl–Furth an der Triesting–Lilienfeld, Lower Austria (NCA); ÖK50-UTM, map sheets 4329 Wilhelmsburg, 4330 Neulengbach, 5325 Baden (ÖK50-BMN, map sheets 56 St. Pölten, 57 Neulengbach, 58 Baden) (Wagreich, 2013); widespread also in the subsurface of the Vienna Basin (Wessely, 1974, 1992, 2006).

Remarks: The Gießhübl Formation continues into the Western Carpathians of the Slovak Republic, correlating to units within the Brezová Group and the Myjava Group (Wagreich & Marschalko, 1995).

Complementary references: Plöchinger (1980), Tollmann (1976, 1985), Mandl (2002).

Zweiersdorf-Formation (Obere Gosau-Subgruppe, Gosau-Gruppe) / Zweiersdorf Formation (Upper Gosau Subgroup, Gosau Group)

Michael Wagreich

Validity: Valid; Plöchinger (1956) introduced the name "Zweiersdorfer Schichten" and provided a detailed description in 1961. The term "Zweiersdorf Formation" was used for the first time by Sauer et al. (1992a).

Type area: In the area between Dreistetten and Grünbach (the so-called "Neue Welt – Grünbach Gosau"), bordered in the NW by the mountain range Hohe Wand, in the SE by the hill range Kienberg–Größenberg, Lower Austria; ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt).

Type section: Plöchinger (1961: p. 402, Abb. 7) described a c. 80 m-thick section in the village of Zweiersdorf, along a path east of the inn "Zum Hirschen" (N 47°48′24″ / E 16°02′19″) which can be considered the type section, however, the outcrop does not exist anymore.

Reference section(s): Not defined; however, Plöchinger (1961) described a 250 m-thick succession of dark grey, micaceous marl from the "Johannesstollen" (abandoned closed coal shaft) close to the village Oberhöflein which could be considered as a reference section.

Derivation of name: After the village Zweiersdorf (N 47°48′23.8″ / E 16°02′13.2″), c. 4 km ENE of the market town Grünbach am Schneeberg, c. 15 km W of the town Wiener Neustadt, Lower Austria.

Synonyms: Zweiersdorfer Schichten (Plöchinger, 1956, 1961).

Lithology: Sandstone-dominated turbidite succession with micaceous marl rich in coal particles. Sandstones contain clasts of corallinacean red algae and bryozoans.

Fossils: Calcareous nannofossils; benthic (e.g., *Bolivinoides draco*) and planktic foraminifera (e.g., *Morozovella pseudobulloides, M. trinidadensis, M. uncinata, M. angulata*); redeposited coralline red algae, larger benthic foraminifers, corals, and molluscs; trace fossils (Plöchinger, 1961).

Origin, facies: Bathyal turbidites.

Chronostratigraphic age: Late Cretaceous, Maastrichtian to Paleogene, Paleocene, Danian to Selandian ?

Biostratigraphy: Planctonic foraminifera *Gansserina gansseri* Zone to *Morozovella pseudobulloides*–*Morozovella angulata* Zone (P1–P3); Nannofossil standard Zones CC25–NP4 (Hradecká et al., 1999).

Thickness: 250 m (Plöchinger, 1961).

Lithostratigraphically higher rank unit: Upper Gosau Subgroup, Gosau Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Piesting Formation. Boundary defined by change from sandy-silty marls with few sandstone layers and inoceramid bivalves to sandstone-dominated succession rich in detrital mica and coal particles.

Overlying unit(s): -

Lateral unit(s): Kambühel Formation.

Geographic distribution: Neue Welt – Grünbach area, Lower Austria (see Type area); ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt).

Remarks: -

Complementary references: Plöchinger (1967, 1980), Tollmann (1976, 1985), Wessely (2006).

Kambühel-Formation (Obere Gosau-Subgruppe, Gosau-Gruppe) / Kambühel Formation (Upper Gosau Subgroup, Gosau Group)

Michael Wagreich

Validity: Valid; Plöchinger (1967) first described "Riffkalke des ? Dan-Paleozän" from the locations Prigglitz and Kambühel (Lower Austria); this unit has been denominated by Tollmann (1976: p. 449) as "Kambühelkalk". The term "Kambühel Formation" was used for the first time by Tragelehn (1996).

Type area: The hillside Kambühel, c. 3.7 km N of the town Ternitz, c. 5 km NW of the town Neunkirchen, Lower Austria; ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheet 105 Neunkirchen).

Type section: A 20 m outcrop-section southwest of the hill top Kambühel (Tragelehn, 1996) (N 47°44′45″ / E 16°01′48″); ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheet 105 Neunkirchen). According to Schlagintweit et al. (2016), the type section contains the K-Pg boundary.

Reference section(s): Not defined; several outcrops were studied by Tragelehn (1996) between Prigglitz (Lower Austria) and the Hochschwab mountains (Styria) and also from the area of Gams by Hieflau (Styria) which could be considered as reference sections.

Remark: Tragelehn (1996) is a Ph.D. thesis, which has not been published.

Derivation of name: After the hillside Kambühel (Kammbühel) (526 m a.s.l.), c. 3.5 km N of the town Ternitz, c. 5 km NW of the town Neunkirchen, Lower Austria; ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheet 105 Neunkirchen).

Synonyms: Riffkalke des ? Dan-Paleozän (Plöchinger, 1967), Kambühelkalk (Tollmann, 1976), Kambühel Limestone (Schlagintweit et al., 2003).

Lithology: Creamy white or reddish limestones and sandy limestones with corals and calcareous algae.

Fossils: Benthic foraminifera, calcareous algae (highly diverse green algal flora), corals, bryozoans, locally crustaceans, brachiopods (Tragelehn, 1996, 2000; Verhoff et al., 2009; Dulai et al., 2008; Krische et al., 2012; Schlagintweit et al., 2018).

Origin, facies: Shallow-water reef limestones including lagoonal and fore-reef facies.

Chronostratigraphic age: Late Cretaceous, upper Maastrichtian to Paleocene, upper Thanetian (Kegler et al., 2000; Schlagintweit et al., 2018).

Biostratigraphy: Planktonic foraminifera Zones *Pseudoguembelina hariaensis* (CF3 – upper Maastrichtian) – *Acarinina soldadoensis*/*Globanomalina pseudomenardii* Concurrent-range Subzone P4c (Schlagintweit et al., 2018; Schlagintweit & Rigaud, 2019); Larger benthic foraminifera SBZ1?–SBZ4 (Schlagintweit et al., 2016, 2018; Schlagintweit & Rigaud, 2019), Maastrichtian (*Siderolites*).

Thickness: Several tens of meters, but most known occurrences are olistholiths.

Lithostratigraphically higher rank unit: Upper Gosau Subgroup, Gosau Group.

Lithostratigraphic subdivision: No formal subdivision; Tragelehn (1996) subdivided the formation in two (informal) members: St. Lorenzen Member, Ragglitz Member (Tragelehn, 1996).

Underlying unit(s): Piesting Formation (sandstone with orbitoids) (Upper Cretaceous). Lower boundary defined by change from sandstone to creamy white or red limestones or sandy limestones.

Overlying unit(s): -

Lateral unit(s): Zweiersdorf Formation.

Geographic distribution: The Kambühel Formation is mainly restricted along the southeastern part of the NCA, but is also reported from the area of Golling, Salzburg (Krische et al., 2012).

Remarks: The type locality of the Kambühel Formation is the only known shallow-water locality preserving a K-Pg boundary (Schlagintweit et al., 2016). The boundary is marked by a hardground which represents a hiatus including the upper part of planktonic foraminifera Zones CF3 to the middle part of P1a(1) and is estimated at 1.5 Myrs (Keller et al., 2018).

Limestones, which can be correlated with the Kambühel Formation, continue into the Western Carpathians and were in detail described by, e.g., Samuel et al. (1972) and Bučék & Köhler (2017).

Complementary references: Plöchinger (1980), Lein (1982), Tollmann (1985), Faupl et al. (1987), Bryda et al. (2013).

Krappfeld, Carinthia

Guttaring-Gruppe / Guttaring Group

Werner E. Piller

Validity: Invalid; Keferstein (1829: 197–205) reported "*Mergelkalk, Nummulitenkalk und Kohle der Gegend von Althofen und Gutharing*" and correlated these sediments with the "Flyschformation" although Münster clearly indicated in his fossil identifications for Keferstein that they form the "untere Lage der tertiären Formationen" in other areas of Europe (p. 202). Hauer (1847) reported a coal seam and nummulite limestones from the area of Guttaring and dated them to the Eocene. A detailed description was given by Penecke (1885a, b) who subdivided the Eocene sediments of the Krappfeld into seven units: (1) "Rothe Liegendthone", (2) "Modiolamergel", (3) "Flötzmasse", (4) "Gasteropodenmergel", (5) "Nummulitenmergel", (6) "Nummulitenkalk", und (7) "Variolarius-Sandstein". van Hinte (1963) performed a detailed study and introduced the "Guttaring Gruppe" including five units. Wilkens (1989a, b) did not adopt the Guttaring Group of van Hinte (1963) but differentiated three units within the Paleogene sediments: Basis-Formation, Großforaminiferenmergel-Formation, Großforaminiferenkalk-Formation, which he later on (1991) renamed to "Holzer-Formation", "Sittenberg-Formation" and "Dobranberg-Formation". Hillebrandt (1993) applied the "Guttaring-Gruppe" but used proper lithostratigraphic names for the formations ("Sittenberg-Formation", "Dobranberg-Formation"). Hillebrandt (1993) did not know Wilkens (1991) paper because this is an unpublished Ph.D. thesis (and therefore the formation cannot be considered as valid).

Type area: Area within a polygon marked by the market towns Eberstein and Klein St. Paul, the village Wieting, the market town Guttaring, the town Althofen, and the village Passering, roughly between the rivers Gurk in the west and its tributary Görtschitz in the east, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remark: The Gurk river plain is also called "Krappfeld" and this name is generally applied for the occurrence of the Cretaceous and Paleogene sediments in the area (it includes, however, also the hillside east of the Gurk plain with Hollersberg, Dobranberg, and Sittenberg).

Type section: See formations.

Reference section(s): -

Derivation of name: Named after the market town Guttaring, c. 4 km NE of the town Althofen, c. 18 km NE of the town St. Veit an der Glan, northeastern Carinthia; N 46°53′26″ / E 14°30′42″; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: -

Lithology: The Guttaring Group contains a great variety of lithologies ranging from clay(stone)s, marls, coal seams, nummulite marls to nummulite limestones and sand(stone)s; the units are laterally highly variable (see description of formations).

Fossils: A rich fauna is already described by Penecke (1885a, b) with foraminifera, corals, echinoderms, polychaets, brachiopods, gastropods, bivalves, cephalopods and crustaceans, extended by Redlich (1905).

Origin, facies: From brackish near shore to shallow marine paleoenvironments (for details see descriptions of formations).

Chronostratigraphic age: Early Eocene, Ypresian to middle Eocene, Lutetian.

Remark: The lowermost sediments of the Guttaring Group were usually assigned to the Ilerdian stage. This later stage, however, has been redefined and is now considered only a regional stage correlated to the lower Ypresian with the base of the Ilerdian correlating with the base of the Ypresian (Pujalte et al., 2009; Gradstein et al., 2020).

Biostratigraphy: See formations.

Thickness: See formations.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Holzer Formation, Sittenberg Formation, Dobranberg Formation.

Underlying unit(s): Pemberger Formation (upper Campanian), discordant contact.

Overlying unit(s): Quaternary sediments.

Lateral unit(s): Not known.

Geographic distribution: See type area.

Remarks: -

Complementary references: Karsten (1821: p. 311), Rosthorn & Canaval (1853), Oppenheim (1901), Beck (1931), Papp (1955b), Beck-Mannagetta (1980a), Thiedig et al. (1984, 1999), Appold et al. (1986), Rasser (1994).

Holzer-Formation (Guttaring-Gruppe) / Holzer Formation (Guttaring Group)

Werner E. Piller

Validity: Invalid; Wilkens (1991) introduced the "Holzer-Ton-Sandstein-Formation" and the "Holzer-Formation", respectively. His paper is, however, an unpublished Ph.D. thesis and therefore the formation cannot be considered as valid.

Type area: In the area of the Sonnberg–Sittenberg, between Klein St. Paul and Guttaring, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: Pemberger Quarry (N 46°50′27″ / E 14°31′35″), c. 1.3 km NW of the market Klein St. Paul, Carinthia. The lower and upper boundary were outcropping (Wilkens, 1991: p. 7, 11, Abb. 14c); ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Reference section(s): -

Derivation of name: Named after the farmstead Holzer (N 46°53′44.3″ / E 14°30′09.3″), c. 1 km NW of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Rote, gelbe und weiße Liegendtone, Flözgebirge p.p. (Redlich, 1905), Speckbauer Roter Ton (van Hinte, 1963: p. 23), Flözführende Serie mit Basisschichten (Wilkens, 1984: p. 263), Basis-Formation (Wilkens, 1989a: p. 88), Holzer-Ton-Sandstein-Formation (Wilkens, 1991: p. 7), Holzer-Formation (Wilkens, 1991: p. 12).

Lithology: Red, green and grey sandy clay(stone) intercalated with coal seams; a black shale horizon occurs in the upper part of the sequence; all lithologies are carbonate-free.

Fossils: Rich in terrestrial playnomorphs, which can be subdivided into three palyno-facies: (1) at the base of the formation occur abundant and diverse fern spores and various Arecaceae, Myricaceae, and Juglandaceae; (2) in black trangressive shales marine dinoflagellates (*Apectodinium* dominated) and *Normapolles*, *Nypa*, palm pollen, and *Avicennia* co-occur; (3) grey and dark grey clays wind pollinated triporate taxa (e.g., *Normapolles*, Myricaceae, Juglandaceae), monosulcate palm taxa and numerous fern spores (Zetter & Hesse, 1995; Hofmann et al., 2012a; Hofmann & Egger, 2015).

Origin, facies: The different litho- and palynofacies allow a tripartite interpretation of the paleoenvironment: (1) Coal-bearing palm swamp; (2) coastal swamp with mangroves; and (3) shrubby back swamp; all reflecting a near shore environment with mostly terrestrial organic material; the black shale horizon represents the base of the Eocene marine transgression (Drobne et al., 2011; Hofmann et al., 2012a, b).

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: Lower part of calcareous nannofossil Zone NP12 (deduced from the overlying Sittenberg Formation for which NP12 is proved) (Hofmann et al., 2012a).

Thickness: WILKENS (1989a, 1991) reports 80 m at the Sonnberg and 1.5–20 m at the Sittenberg area; 8 m are reported from the Pemberger Quarry (HOFMANN et al., 2012a; HOFMANN & EGGER, 2015).

Lithostratigraphically higher rank unit: Guttaring Group (after VAN HINTE, 1963).

Remark: The Cretaceous and Paleogene sediments in the Krappfeld area are widely known as "Gosau" or "Gosau sediments" or "Krappfeld Gosau"; in the Northern Calcareous Alps sediments of this time interval are exclusively termed "Gosau" or "Gosau sediments" and the Cretaceous/Paleogene lithostratigraphic units are subsumed in the Gosau Group. The "Gosau sediments" in the Krappfeld area are also treated as part the Gosau Group and not as Guttaring Group.

Lithostratigraphic subdivision: Winkler Member and Offner Member in the Sittenberg area, Höhwirt Member and Sonnberg Member in the Sonnberg area.

Underlying unit(s): Pemberger Formation (Campanian age, late Cretaceous), unconformably overlain by the Holzer Formation.

Overlying unit(s): Sittenberg Formation.

Lateral unit(s): Not known.

Geographic distribution: The formation has the same distribution as the Guttaring Group (see above); ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: RASSER (1994), THIEDIG et al. (1999), EGGER et al. (2009), ZETTER & HOFMANN (1998, 2001), HOFMANN et al. (2011a, b, 2012b).

Sittenberg-Formation (Guttaring-Gruppe) / Sittenberg Formation (Guttaring Group)

WERNER E. PILLER

Validity: Invalid; VAN HINTE (1963) introduced the "Sittenberg Folge" which has been renamed by WILKENS (1991) to "Sittenberg-Großforaminiferenmergel-Formation" and "Sittenberg-Formation", respectively. His paper is, however, an unpublished Ph.D. thesis and therefore the formation cannot be considered as valid. HILLEBRANDT (1993) used the term "Sittenberg-Formation".

Type area: In the area of the Sittenberg, along the western flank of the Görtschitz Valley, W of Klein St. Paul and Guttaring, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: Not defined; in the Sittenberg area no continuous outcrops were available, at the Sonnberg a section along a forest road was relatively well exposed (WILKENS, 1991: p. 7).

Reference section(s): -

Derivation of name: Named after the hillside Sittenberg (or the farmstead Sittenberg), SW of the market town Klein St. Paul along the western flank of the Görtschitz valley, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Flözgebirge p.p. (REDLICH, 1905), Höhwirt Folge (VAN HINTE, 1963), Sittenberg Folge p.p. (VAN HINTE, 1963), Nummulitenmergel (WILKENS, 1984), Flözführende-Abfolge, Kalk-Mergel-Abfolge (WILKENS, 1989a), Sittenberg-Großforaminiferenmergel-Formation (WILKENS, 1991).

Lithology: Various lithologies represent this formation, dominated by nummulitic limestone and marlstone alternating with clay rich deposits with a more siliciclastic influenced lower part and a carbonate dominated upper part; in the lower part of the formation a coal seam occurs.

Fossils: Calcareous nannoplankton; larger foraminifera: *Assilina placentula*, *Nummulites burdigalensis kuepperi*, *Nummulites increscens*, and *Nummulites bearnensis* have been described from the base of this marine unit (SCHAUB, 1981; HILLEBRANDT, 1993; DROBNE et al., 2011).

Origin, facies: Shallow marine, inner neritic paleoenvironment, interrupted by a coal seam of non-marine origin in the lower part.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: The larger foraminiferal assemblage is indicative of the lower part of SBZ10, which has been correlated with calcareous nannofossil Zone NP12 (SERRA-KIEL et al., 1998) (DROBNE et al., 2011; ĆORIĆ et al., 2011); a poor planktonic foraminifera assemblage indicates also Ypresian but with a wider range between Zones P5–E5 (ĆORIĆ et al., 2011).

Thickness: WILKENS (1991) reports in the Sonnberg area (W of Guttaring) 110 m and in the Sittenberg area 60 m.

Lithostratigraphically higher rank unit: Guttaring Group.

Lithostratigraphic subdivision: At the Sittenberg, W of Klein St. Paul, the Sittenberg Formation was subdivided into the Winkler Member and the Offner Member, at the Sonnberg, W of Guttaring, it was subdivided into the lower Höhwirt Member and the upper Sonnberg Member (WILKENS, 1991).

Underlying unit(s): Holzer Formation; the boundary is defined with the first occurrence of larger foraminifera (WILKENS, 1991: p. 8).

Overlying unit(s): Dobranberg Formation; the boundary is defined with the onset of carbonate pure, fossil rich limestones above an alveolinid bearing calcareous sand to calcareous siltstone (WILKENS, 1991: p. 9).

Lateral unit(s): Not known.

Geographic distribution: The formation has the same distribution as the Guttaring Group (see above); ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: RASSER (1994), THIEDIG et al. (1999).

Winkler-Subformation (Sittenberg-Formation, Guttaring-Gruppe) / Winkler Member (Sittenberg Formation, Guttaring Group)

Werner E. Piller

Validity: Invalid; van Hinte (1963) introduced the “Sittenberg Folge” which has been renamed and reorganized into the “Winkler-Member” of the Sittenberg Formation by Wilkens (1991). His paper is, however, an unpublished Ph.D. thesis and therefore the member cannot be considered as valid.

Type area: In the area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: Not defined; Wilkens (1991: Abb. 4a) depicted a c. 2.5 m thick-section along a forest road from Of(f)ner to Wittwa, 280 m SW of the farmstead Of(f)ner (810 m a.s.l.), Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan)

Reference section(s): -

Derivation of name: Named after the farmstead Winkler (N 46°49′36″ / E 14°30′34″), in the Boden valley, c. 2.5 km SW of the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Sittenberg Folge (van Hinte, 1963).

Lithology: Sandy and marly, slightly micaceous larger foraminifera-mollusc limestones (“Ampullinen-Kalksandstein”) at the base (60 cm maximum) which grades upsection into an alternation of clays and sands rich in larger foraminifera. In the uppermost part of the section an 80 cm-thick coal seam occurs. Below the coal seam a clayey marl horizon with corals is reported (Wilkens, 1991). A great variety of microfacies types was described by Wilkens (1991).

Fossils: In the “Ampullinen-Kalksandstein” molluscs (mostly gastropods) occur frequently and larger foraminifera (nummulitids, alveolinids and orbitolites, but *Assilina* is missing). In the sediments above, the genus *Assilina* is very abundant including *Assilina placentula* but also *Nummulites burdigalensis kuepperi*, *Nummulites increscens*, and *Nummulites bearnensis* have been described (Schaub, 1981; Hillebrandt, 1993). Besides larger foraminifera molluscs are abundant and divers but also green algae occur (Wilkens, 1991: p. 225).

Origin, facies: Shallow marine, inner neritic paleoenvironment with full marine lagoons and shoals; the marine succession is interrupted by a coal seam of non-marine origin in the upper part.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: The larger foraminifera clearly indicate a Ypresian age.

Thickness: A maximum thickness of 30 m is reported by Wilkens (1991).

Lithostratigraphically higher rank unit: Sittenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Holzer Formation (Guttaring Group); the boundary is defined with the first occurrence of larger foraminifera in the Winkler Member (Wilkens, 1991: p. 8).

Overlying unit(s): Offner Member (Guttaring Group).

Lateral unit(s): Höhwirt Member.

Geographic distribution: Restricted to the area of the hillside Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: According to Wilkens (1991), the Winkler Member corresponds to the “Sittenberg-Folge” of van Hinte (1963).

Coal mining activities and quantities are reported by Weber & Weiss (1983). The coal seam of this member has been mined until 1960.

Complementary references: Rasser (1994).

Offner-Subformation (Sittenberg-Formation, Guttaring-Gruppe) / Offner Member (Sittenberg Formation, Guttaring Group)

Werner E. Piller

Validity: Invalid; Wilkens (1991) introduced the “Offner-Member” for the upper part of the Sittenberg Formation at the Sittenberg hillside. Wilkens′ paper is, however, an unpublished Ph.D. thesis and therefore the member cannot be considered as valid.

Type area: In the area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: Not defined; Wilkens (1991) reports a drilling from the coal mine, but does not provide any details. He depicts only a detailed section of approx. 5 m thickness from a forest road cut (Wilkens, 1991: Abb. 5).

Reference section(s): -

Derivation of name: Named after the farmstead Offner (N 46°49′18″ / E 14°32′02″) at the Sittenberg, c. 1.4 km SSW of the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remark: Wilkens (1991) applied the name Offner for this member after the farmstead, the actual name in the map ÖK50-UTM is Ofner.

Synonyms: Dobranberg Nummulitenschichten p.p. (van Hinte, 1963).

Remark: Wilkens (1991: p. 16) erroneously cited van Hinte (1963) in the synonymy with “Sittenberg-Nummulitenschichten” which, however, have not been introduced by the later author.

Lithology: Alternation of strongly cemented larger foraminiferal limestones with slightly cemented marls and calcareous sandstones partly rich in larger foraminifers; glauconite is occasionally abundant. Grey alveolinid- and nummulitid limestone beds can reach up to 7 m thickness. Wilkens (1991) differentiated various microfacies types.

Fossils: Larger foraminifera, such as *Alveolina*, *Orbitolites*, *Nummulites* and *Assilina*, are abundant and rock forming; molluscs are present but not as abundant as in the Winkler Member; green algae and also fish remains are recorded (WILKENS, 1991).

Origin, facies: Shallow marine carbonate paleoenvironment with fine siliciclastic influence.

Chronostratigraphic age: Early Eocene, late Ypresian.

Biostratigraphy: The larger foraminifera clearly indicate an Ypresian age.

Thickness: A maximum thickness of 30 m is reported by WILKENS (1991).

Lithostratigraphically higher rank unit: Sittenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Winkler-Member (Sittenberg Formation).

Overlying unit(s): Unterstein Member (Dobranberg Formation).

Lateral unit(s): Sonnberg Member (Sittenberg Formation) in the Sonnberg area.

Geographic distribution: Restricted to area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: RASSER (1994).

Höhwirt-Subformation (Sittenberg-Formation, Guttaring-Gruppe) / Höhwirt Member (Sittenberg Formation, Guttaring Group)

WERNER E. PILLER

Validity: Invalid; VAN HINTE (1963) described the "Höhwirt Folge" overlying the "Speckbauer Roter Ton". WILKENS (1991) redefined this unit as "Höhwirt-Member" and restricted it to the lower part of the Sittenberg Formation in the Sonnberg area. Wilkens' paper is, however, an unpublished Ph.D. thesis and therefore the member cannot be considered as valid.

Type area: In the area of the Sonnberg, W of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: -

Reference section(s): -

Derivation of name: Named after inn "Höhwirt" (N 46°53′08″ / E 14°29′49″), c. 1.3 km SW of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Modiolamergel p.p., Flötzmasse p.p., Gasteropodenmergel p.p. (PENECKE, 1885a, b), Kohlenschicht (PENECKE, 1885a), Höhwirt Folge (VAN HINTE, 1963).

Lithology: Dark sand and clay partly rich in molluscs and high organic content. The upper part is represented by coarser clastics.

At the base of the member the so-called "Modiolamergel" (PENECKE, 1885a, b) occurs, which is overlain by the so-called, c. 1 m thick upper coal seam ("Oberes Glanzkohlenflöz"). Above follow clays, sandy clays and calcareous sandstones, which grade into the "Gastropodenmergel" (PENECKE, 1885a, b; WILKENS, 1991: Abb. 10) with mollusc coquinas. The top of the unit is the so-called "Simmerle-Konglomerat" (WILKENS, 1991: p. 35, Abb. 11) a succession of alternating coarser and finer clastic sediments.

Fossils: Coralline red algae, green algae, larger foraminifera (*Alveolina*, *Orbitolites*, *Nummulites*), solitary corals, molluscs, bryozoan.

Origin, facies: Shallow marine paleoenvironment with variable amount of siliciclastic input and biogenous carbonate production.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: See Sittenberg Formation.

Thickness: WILKENS (1991) reported at least 25 m.

Lithostratigraphically higher rank unit: Sittenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Holzer Formation.

Overlying unit(s): Sonnberg Member (Sittenberg Formation).

Lateral unit(s): Winkler Member of the Sittenberg area.

Geographic distribution: Restricted to the area of the Sonnberg, W of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: Coal mining activities and quantities are reported by WEBER & WEISS (1983). The coal mine was closed 1939.

Complementary references: REDLICH (1905), RASSER (1994).

Sonnberg-Subformation (Sittenberg-Formation, Guttaring-Gruppe) / Sonnberg Member (Sittenberg Formation, Guttaring Group)

WERNER E. PILLER

Validity: Invalid; VAN HINTE (1963) described the "Sonnberg Nummulitenschichten" which have been renamed by WILKENS (1991) to "Sonnberg-Member". Wilkens' paper is, however, an unpublished Ph.D.-thesis and therefore the member cannot be considered as valid.

Type area: In the area of the Sonnberg, W of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: A section (c. 30 m) along a forest road at the western flank of the Sonnberg, c. 300 m E of the farmstead Simmerle (which is probably the farmstead Sonnberg in the actual ÖK50-UTM), according to WILKENS (1991: p. 37, Abb. 12).

Reference section(s): -

Derivation of name: Named after the hillside Sonnberg, c. 1.3 km W-WSW of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Nummulitenmergel p.p., Nummulitenkalk p.p., Variolarius-Sandstein p.p., Variolariussand p.p. (PENECKE, 1885a, b), Sonnberg Nummulitenschichten (VAN HINTE, 1963).

Lithology: Marl with rock forming nummulitids and intercalated fossil rich limestones. The lower part of the member is characterized by nummulite marls with 2 up to 5 m-thick beds with densely packed larger foraminifera. On top of the succession the so-called "Variolarius Sandstein" occurs. This is a c. 10 m-thick package composed of calcareous sandstone, larger foraminifers-mollusc-coquinas and subordinate siliciclastic larger foraminifera limestone.

Fossils: Larger foraminifera (*Alveolina*, *Orbitolites*, *Operculina*, *Nummulites*, *Assilina*, *Discocyclina*) are the dominating and sediment/rock forming constituents. Calcareous nannoplankton is abundant and diverse; coralline red algae (rhodoliths), green algae, benthic smaller foraminifera, rare corals, serpulids, and molluscs occur in variable amounts.

Origin, facies: Shallow, open marine paleoenvironment in a more distal and deeper position compared to the Höhwirt Member. The larger foraminifera accumulations represent event beds, the "Variolarius Sandstein" reflects a regressive phase on top of the Paleogene sequence in the Sonnberg area.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: Calcareous nannofossil Zone NP12; poorly constraint planktonic foraminifera Zones P5–E5 (ĆORIĆ et al., 2011); *Nummulites burdigalensis kuepperi*, *Nummulites increscens*, and *Nummulites bearnensis* also indicate a Ypresian age (SCHAUB, 1981; HILLEBRANDT, 1993).

The "Variolarius-Sandstein" described by PENECKE (1885a, b) was named after *Nummulites variolarius* Lamarck; PAPP (1958a) assigned this small nummulite, however, to *Nummulites pernotus* Schaub which also indicates Ypresian age.

Thickness: WILKENS (1991) reported at least 85 m.

Lithostratigraphically higher rank unit: Sittenberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Höhwirt Member (Sittenberg Formation); the boundary is marked by the grain size reduction and a change in the larger foraminiferal associations.

Overlying unit(s): -

Lateral unit(s): Offner Member of the Sittenberg area.

Geographic distribution: Restricted to the area of the Sonnberg, W of the market town Guttaring, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan)

Remarks: -

Complementary references: PAPP (1955b), RASSER (1994).

Dobranberg-Formation (Guttaring-Gruppe) / Dobranberg Formation (Guttaring Group)

WERNER E. PILLER

Validity: Invalid; VAN HINTE (1963) introduced the "Dobranberg Nummulitenschichten" which have been renamed as "Dobranberg-Formation" by WILKENS (1991). Wilkens' paper is, however, an unpublished Ph.D. thesis and therefore the member cannot be considered as valid.

Type area: Hillside Dobranberg as part of the Paleogene occurrences in the Sittenberg area, W of the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: See description of members.

Reference section(s): -

Derivation of name: Named after the hillside Dobranberg (Dobranberg is, however, also a hamlet on this hillside), W of the market town Klein St. Paul, Sittenberg area, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Echinidensand p.p., Nummulitenkalk p.p. (PENECKE, 1885a, b), Sonnberg Nummulitenschichten (VAN HINTE, 1963), Dobranberg Nummulitenschichten (VAN HINTE, 1963), Nummulitenkalk, Typen I bis III (WILKENS, 1984), Dobranberg-Großforaminiferenkalk-Formation, Dobranberg-Formation (WILKENS, 1991).

Lithology: Limestone and marl with larger foraminifers and coralline algae (see members for details).

Fossils: Larger foraminifera, corals, molluscs, bryozoan, brachiopoda, crustaceans, echinoids (VAN HINTE, 1963) (for details see members).

Origin, facies: Shallow water carbonate ramp with larger foraminifera shoals.

Chronostratigraphic age: Early Eocene, late Ypresian (Cuisian of older literature) to middle Eocene, Lutetian.

Biostratigraphy: SBZ10–SBZ15 (HILLEBRANDT, 1993; DROBNE et al., 2011) which can be correlated with calcareous nannofossil Zones upper NP15–lower NP16 (SERRA-KIEL et al., 1998). *Alveolina distefanoi* and *A. schwageri* indicate upper Ypresian (SBZ10), *Nummulites benehamensis*, *N. hilarionis*, and *N. krappfeldensis* middle Lutetian.

Thickness: A maximum thickness of 140 m is reported by WILKENS (1991).

Lithostratigraphically higher rank unit: Guttaring Group.

Lithostratigraphic subdivision: The Dobranberg Formation is subdivided into the Unterstein Member, the Kleinkogel Member and the Fuchsofen Member (WILKENS, 1991).

Underlying unit(s): Offner Member (Sittenberg Formation); the boundary is marked by a rapid change from calcareous sandstones to siltstones of the Sittenberg Formation.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Restricted to area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: OBERHAUSER (1963), BECK-MANNAGETTA (1980a), THIEDIG et al. (1999).

Unterstein-Subformation (Dobranberg-Formation, Guttaring-Gruppe) / Unterstein Member (Dobranberg Formation, Guttaring Group)

WERNER E. PILLER

Validity: Invalid; introduced by WILKENS (1991) as lowest member of the Dobranberg Formation with a detailed description and designation of a type section and reference sections. Wilkens' paper is, however, an unpublished Ph.D. thesis and therefore the member cannot be considered as valid.

Type area: Hillside Dobranberg as part of the Paleogene occurrences in the Sittenberg area, W of the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: A c. 65 m-thick section in the active Fuchsofen Quarry (Wietersdorfer Holding GmbH) (N 46°50′06″ / E 14°31′34″) at the Dobranberg, c. 1 km W of the market town Klein St. Paul (WILKENS, 1991: Abb. 7). Due to the mining activities, outrops and sections are changing considerably.

Remark: WILKENS (1991) called this quarry “Kalksteinbruch Sittenberg” (limestone quarry Sittenberg).

Reference section(s): A section 100 m E of the farmstead Unterstein and an outcrop at Kleinkogel at the northern flank of an incised valley (c. 50 m thick), c. 1 km E of the farmstead Unterstein (WILKENS, 1991).

Derivation of name: Named after the farmstead Unterstein (N 46°49′10″ / E 14°30′47″) in the Boden valley, c. 2.8 km SW od the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Synonyms: Unterstein-Member (THIEDIG et al., 1999).

Lithology: Massive-thick bedded, pure limestones composed predominantly of densely packed larger foraminifers. A suite of microfacies types has been described by WILKENS (1991).

Fossils: Larger foraminifers (*Alveolina*, *Orbitolites*, *Operculina*, *Nummulites*, *Assilina*, *Discocyclina*); in addition, corals, gastropods, bivalves (coquinas), cephalopods, bryozoans, brachiopods, and echinoids.

Origin, facies: Fully marine shallow subtidal carbonate ramp. The pure larger foraminiferal associations indicate a nummulite bank facies with nummulite shoals and in situ winnowing of the buildups.

Chronostratigraphic age: Early Eocene, Ypresian.

Biostratigraphy: Early Eocene, late Ypresian.

Thickness: A maximum of 65 m is reported by WILKENS (1991).

Lithostratigraphically higher rank unit: Dobranberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Offner Member (Sittenberg Formation).

Overlying unit(s): Kleinkogel Member (Dobranberg Formation); erosive boundary.

Lateral unit(s): -

Geographic distribution: Restricted to area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: -

Kleinkogel-Subformation (Dobranberg-Formation, Guttaring-Gruppe) / Kleinkogel Member (Dobranberg Formation, Guttaring Group)

WERNER E. PILLER

Validity: Invalid; introduced by WILKENS (1991) as middle member of the Dobranberg Formation with a detailed description and designation of a type section. Wilkens' paper is, however, an unpublished Ph.D.-thesis and therefore the member cannot be considered as valid.

Type area: In the Sittenberg area, SW of the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: A section 100 m E of the farmstead Unterstein (N 46°49′10″ / E 14°30′47″) which develops directly from the reference section of the Unterstein Member; it exposes the complete section of the Kleinkogel Member; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Reference section(s): -

Derivation of name: Named after the hill “Kleinkogel” (N 46°49′17″ / E 14°31′49″; 873 m a.s.l.), in the area of the Sittenberg, along the western flank of the Görtschitz valley, c. 1.5 km SW of the market town Klein St. Paul, Carinthia.

Synonyms: -

Lithology: Thick bedded, quartz bearing bioclastic limestones with rhodoliths and macroids of sessile foraminifera and coralline red algae (algal-foraminifera limestones). Intercalations of coarse siliciclastics of dm-thickness. The facies types are laterally highly variable. A suite of microfacies types has been described by WILKENS (1991) and RASSER (1994).

Fossils: Sessile benthic foraminifera (*Acervulina*) and red algae (*Sporolithon*, *Lithothamnion*, *Lithoporella*, *Pseudolithothamnium*; mostly as rhodoliths, but also as macroids together with sessile foraminifers) are rock forming constituents; in addition, larger foraminifera (*Alveolina*, *Orbitolites*, *Nummulites*, *Discocyclina*) (less abundant compared to the Unterstein Member), corals, gastropods, bivalves, serpulids, brachiopods, and echinoids occur.

Origin, facies: Shallow marine paleoenvironment with a slight deepening trend upsection and episodic siliciclastic input. Besides rhodoliths and macroids carpets seagrass or macroalgal meadows can be inferred (RASSER, 1994).

Chronostratigraphic age: Early Eocene, late Ypresian, up the boundary Ypresian/Lutetian (WILKENS, 1991: p. 25).

Biostratigraphy: Larger benthic foraminifera clearly indicate a late Ypresian age.

Thickness: WILKENS (1991) reported at least 45 m.

Lithostratigraphically higher rank unit: Dobranberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Unterstein Member (Dobranberg Formation); erosive contact.

Overlying unit(s): Fuchsofen Member (Dobranbrg Formation).

Lateral unit(s): -

Geographic distribution: Restricted to area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: THIEDIG et al. (1999).

Fuchsofen-Subformation (Dobranberg-Formation, Guttaring-Gruppe) / Fuchsofen Member (Dobranberg Formation, Guttaring Group)

WERNER E. PILLER

Validity: Invalid; introduced by WILKENS (1991) as upper member of the Dobranberg Formation without designation of a type section. Wilkens' paper is an unpublished Ph.D. thesis and therefore the member cannot be considered as valid.

Type area: Hillside Dobranberg (including the hill "Fuchsofen") as part of the Paleogene occurrences in the Sittenberg area, W of the market town Klein St. Paul, Carinthia; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Type section: Not defined; the basal part of the member and the contact to the underlying Kleinkogel Member is exposed in the uppermost part of the Fuchsofen Quarry (WILKENS, 1991: Abb. 8).

Reference section(s): Not defined; outcrops of the Fuchsofen Member, in addition to those of the Fuchsofen Quarry, are exposed 550 m NE of the farmstead Unterstein.

Derivation of name: Named after the hill "Fuchsofen" (872 m a.s.l.), in the area of the Sittenberg immediately above the Fuchsofen Quarry (Wietersdorfer Holding GmbH) (N 46°50′06″ / E 14°31′34″), along the western flank of the Görtschitz valley, c. 1.5 km NW of the market town Klein St. Paul, Carinthia.

Synonyms: -

Lithology: Massive, very pure limestones composed of rock forming larger foraminifera.

Fossils: Larger foraminifera (*Nummulites*, *Discocyclina*), *Discocyclina* dominates in the upper portion; encrusting benthic foraminifera and red algae form rhodoliths and macroids in the lower part of the member. Gastropods, bivalves and bryozoans occasionally occur.

Origin, facies: A shallow water proximal to distal carbonate ramp with a deepening upward trend. Nummulite shoals laterally change into *Discocyclina* dominated sediments.

Chronostratigraphic age: Middle Eocene, middle Lutetian.

Biostratigraphy: *Nummulites benehamensis*, *N. hilarionis*, and *N. krappfeldensis* indicate a middle Lutetian age (HILLEBRANDT, 1993).

Thickness: WILKENS (1991) reported a maximum of 20 m, however, the top of the unit is eroded.

Lithostratigraphically higher rank unit: Dobranberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Kleinkogel Member (Dobranberg Formation); boundary gradual but marked by strong increase in the amount of larger foraminifera and decrease in terrigenous material.

Overlying unit(s): "Waitschach-Schotter" (Waitschach Gravel) (Miocene) (WILKENS, 1991).

Lateral unit(s): -

Geographic distribution: Restricted to area of the Sittenberg, along the western flank of the Görtschitz valley, W of Klein St. Paul, Krappfeld area, Carinthia, Austria; ÖK50-UTM, map sheet 4102 Althofen (ÖK50-BMN, map sheet 186 St. Veit an der Glan).

Remarks: -

Complementary references: THIEDIG et al. (1999).

North Alpine Foreland Basin (Molasse Zone)

REINHARD ROETZEL

The North Alpine Foreland Basin (NAFB), in Austria also named Molasse Zone or Alpine-Carpathian Foredeep, is the elongated basin between the Alps in the south and the Bohemian Massif or in Bavaria the Franconian Platform in the north (Text-Fig. 4).

In Austria, it mainly extends in the federal states of Lower Austria, Upper Austria and Salzburg, from the Weinviertel in the northeast to the Alpine foothills in the west. There, it is about 300 km long and continues to the northeast into the Czech Republic and to the west into Germany. In addition, in the far west of Austria, the northeast of Vorarlberg is also made up by Molasse deposits. However, these differ significantly in facies, tectonic and also morphology from the Molasse in eastern Austria.

The NAFB reaches the greatest width with 130 km in the Bavarian foothills of the Alps and becomes significantly narrower to the east in the Austrian part. With a width of approx. 10 km, it has its narrowest location at the crystalline spur in the Amstetten region (western Lower Austria) and increases again to the east, north of the Danube, up to approx. 30 km.

It is a classical foreland basin with an asymmetrical cross-section formed by subduction of the European Plate under the African-Adriatic Plate. It is part of the former Central Paratethys, mainly filled with debris from the Alps but also from the northern foreland of the Bohemian Massif and in Bavaria from the Franconian Platform. It gets deeper towards the south and is filled with up to > 4,000 m-thick Cenozoic (late Paleogene and Neogene) sediments. While the sediments in the northern and central parts are largely undisturbed, they were folded and thrusted in the south by the advancing Alps. However, simultaneously with the thrusting sedimentation continued, leading to a complex tectonic and lithology. As demonstrated by numerous drillings, the sediments of the NAFB reach far below the Alpine body. The southernmost Molasse deposits were found about 36 km south from the northern thrust front of the Rhenodanubian Flysch Unit at a depth of 5,910 m (drilling Berndorf 1; WACHTEL & WESSELY, 1981).

The Molasse area of the undisturbed sediments is referred to as Autochthonous Molasse, while the Allochthonous Molasse (also Subalpine or disturbed Molasse) (BRIX & GÖTZINGER, 1964) is the tectonically deformed part of folded and/or imbricated Molasse sediments in front of and below the Alpine nappes. Parautochthonous Molasse is the term used to describe the sediments that extended from the NAFB onto the overthrusting nappes (piggy-back deposits) and were carried on top of the thrust sheets, similar to sediments at the base of the Vienna Basin or at the margin of the Korneuburg Basin (STEININGER et al., 1986). A special form of Parautochthonous Molasse are sediments that were included in the alpine nappe structure and are known as Inneralpine Molasse, like the sediments of the Inn Valley or in inneralpine tectonic windows (Rogatsboden, Urmannsau, etc.). In the tectonically highly disturbed Waschberg Unit north of the Danube of Lower Austria, these complex processes even led to the formation of nappes, where parts of the Mesozoic base were sheared off and incorporated into the nappe system.

The base of the NAFB in Lower Austria consists largely of crystalline rocks of the Bohemian Massif, whereas upper Paleozoic as well as Jurassic and upper Cretaceous epicontinental sediments form the base in the Weinviertel district east of the Mailberg fault. In Upper Austria and Salzburg Cretaceous and Jurassic sediments dominate at the

Text-Fig. 4.
Location of the North Alpine Foreland Basin (grey shaded).

base in the central and southern parts of the foredeep. The base of the NAFB shows an accentuated relief with horst- and graben-structures and fault-systems, like the Moosbierbaum horst or the Mailberg fault-system in Lower Austria. In Upper Austria, the base of the NAFB is divided by numerous swells into sub-basins. One of these tectonic horsts is the Landshut-Neuötting High, a crystalline swell in eastern Bavaria, which continues to Upper Austria as "Central Swell Zone" (cf. MALZER et al., 1993).

The age of the sediments of the NAFB ranges from the late Eocene to the late Miocene. In general, in the NAFB there is not only a shift in time of deposition from south to north, but also along the longitudinal axis from west to east. Additionally, the age of thrust of the sediments on the forehead of the Alps is also getting younger from west to northeast. The facies of the sediments is mainly marine and range from shallow marine deposits in the marginal areas to deep-water deposits in the central part of the Molasse trough. In some cases, they also were formed as brackish deposits or in freshwater (fluvial, lacustrine). Most of these sediments are only known from drillings. In the Autochthonous Molasse, close to the surface, mostly lower, middle and upper Miocene deposits are widespread, while Oligocene sediments are mainly restricted to the northern NAFB, close to the Bohemian Massif. In addition, Oligocene and lower Miocene sediments also occur in shallow bays and depressions on the Bohemian Massif. In the Allochthonous and Parautochthonous Molasse deposits from the late Eocene to the early Miocene are dominating, while younger sediments, due to the ongoing thrusting of the Alpine nappes, are missing there (cf. MALZER et al., 1993; WESSELY, 2006). In the Molasse deposits of Vorarlberg, however, the stratigraphic sequence extends from the lower Oligocene to the middle Miocene (FRIEBE, 2007a).

North Alpine Foreland Basin: Inn Valley ("Inneralpine Molasse")

HUGO ORTNER

The succession of Priabonian to Chattian rocks preserved along the Inn Valley and in the Kaiserwinkl was termed the "Inneralpine Molasse" (e.g., FUCHS, 1980b; TOLLMANN, 1985) for its similarities with the deposits of the peripheral North Alpine Foreland Basin. In the "Inneralpine Molasse", the first of two megasequences of the NAFB (e.g., KUHLEMANN & KEMPF, 2002) are preserved, equivalent to the Oligocene to early Miocene Lower Marine Molasse and Lower Freshwater Molasse. The Häring-, Paisslberg- und Unterangerberg Formations described here are part of the Lower Marine Molasse, while the Oberangerberg Formation is part of the Lower Freshwater Molasse. The existence of foreland deposits on top of the Alpine nappe stack documents a wedge-top depozone in the sense of DECELLES & GILES (1996), and the sediments were deposited during foreland-directed transport of the Alpine nappes. The subsidence history of the "Inneralpine Molasse" (ORTNER & SACHSENHOFER, 1996) and that of the NAFB (JACOB et al., 1982; ZWEIGEL et al., 1998) is comparable, but total subsidence is larger in the foreland because part of the subsidence was compensated by vertical uplift related to thrusting (ORTNER & STINGL, 2001).

The Priabonian Oberaudorf Beds of the "Inneralpine Molasse" overlap in time with deposition of Bartonian to Priabonian limestones in the Bad Reichenhall area (Germany) (RISCH, 1993), which were correlated with the "Inneralpine Molasse" already by FUCHS (1976b). EGGER et al. (2015, 2017) suggested to summarize the stratigraphic units of the "Inneralpine Molasse" (see below) and the Bartonian to Priabonian limestones of the Bad Reichenhall area in the Inntal Group. The Inntal Group would then include all syn-orogenic wedge-top deposits related to the Cenozoic Alpine orogeny in the Alps.

The Upper Cretaceous to Eocene Gosau Group is separated from the "Inneralpine Molasse" by a slightly diachronous (angular) unconformity, which is related to the collision of the European and Adriatic plates. In the Kaiserwinkl and the Bad Reichenhall area, the stratigraphic gap between the Gosau Group and the "Inneralpine Molasse" is remarkably small, and an almost complete stratigraphic succession from the Coniacian to the middle Eocene is preserved (e.g., ZERBES & OTT, 2000). ORTNER & STINGL (2001), ORTNER (2003) and ORTNER et al. (2006) speculated that a major normal fault parallel to the present day Inntal shear zone did downthrow the southern block at the end of the Rupelian. Subsequent deposition of the "Inneralpine Molasse" saved the Paleogene Gosau Group from erosion locally.

Inntal-Gruppe / Inntal Group

HUGO ORTNER

Validity: Valid; EGGER et al. (2015) informally proposed the Inntal Group for the collision-related deposits of the Northern Calcareous Alps; EGGER et al. (2017) formally amalgamated the formations of the "Inneralpine Molasse" into a group, representing the syn- to post-collisional wedge-top deposits of the Inn Valley and Reichenhall Basins.

Type area: Inn Valley between Kramsach and Kufstein, continuing to the East to Kössen (Tyrol) and Reit im Winkl (Bavaria).

Type section: The type section is a composite section of the type sections of the group formations.

Reference section(s): -

Derivation of name: The name derives from the Inn Valley, where many of the formations of the group are preserved.

Synonyms: Inneralpine Molasse (e.g., FUCHS, 1980b), Lower Inn Valley Tertiary (ORTNER & SACHSENHOFER, 1996).

Lithology: The Inntal Group is dominated by clastic deposits and is comparable to the foreland sedimentation of the peripheral North Alpine Foreland Basin. A basal part (Oberaudorf Beds, Priabonian) is extremely diverse, ranging from shallow marine carbonates and quartz-bearing sandstones to continental conglomerates, sandstones and claystones. The Oligocene representing the main part of the succession mimics, to a large extent, the sedimentary succession of the Alpine Foreland (ORTNER & STINGL, 2001): bituminous sandstones, marls und coals of the Häring Formation overlie older rocks locally, followed by shallow marine carbonates and sandstones and thick pelagic marls (Lower Oligocene Paisslberg Formation, pelagic marls comparable to the Lower Marine Molasse). An upward increasing amount of sandstones intercalated with marls is found in the Unterangerberg Formation. The succession ends with continental conglomerates of the Oberangerberg Formation (Upper Oligocene, equivalent to the Lower Freshwater Molasse).

Fossils: See the subsections regarding the individual formations.

Origin, facies: Foreland sediments of the depositional wedge-top (sensu DECELLES & GILES, 1996) of the North Alpine Foreland Basin. Facies change with the different stages of the foreland basin development.

Chronostratigraphic age: Late Eocene, Priabonian to late Oligocene, Chattian.

Biostratigraphy: See subsections regarding the individual formations.

Thickness: Cumulative thickness more than 2 km.

Lithostratigraphic higher rank unit: -

Lithostratigraphic subdivision: Oberaudorf Beds, Häring Formation, Paisslberg Formation, Unterangerberg Formation, Oberangerberg Formation.

Underlying unit(s): Transgressive contact to Triassic–Upper Cretaceous rocks.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: The Inntal Group is found in the Inn Valley, between Kufstein and Reit im Winkl, and in the Reichenhall Basin southeast of the city of Salzburg.

Remarks: -

Complementary references: -

Oberaudorf Schichten (Inntal-Gruppe) / Oberaudorf Beds (Inntal Group)

HUGO ORTNER

Validity: Invalid; a first description as "Nummulitenschichten" was already given by GÜMBEL (1861); HAGN (1960: p. 150) introduced the unit as "Oberaudorfer Schichten".

Type area: Mühlbacher Berg (892 m a.s.l.), SW of the village Oberaudorf, Inn Valley, Bavaria, Germany; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Type section: Not defined; the most complete section of the Oberaudorf Beds crops out along a road between Oberaudorf and the hamlet Mühlau (Mühlauer Straße; N 47°38′12″ / E 12°09′56″), Bavaria, Germany; ÖK50-UTM, map sheet 3207 Ebbs (ÖK50-BMN, map sheet 90 Kufstein). The contact to older rocks is hidden and the Oberaudorf Beds are the youngest rocks of the Mühlbacher Berg.

Reference section(s): Not defined; at the Kohlenbach Creek (N 47°38′23″ / E 12°23′05″) near the power station,

c. 1 km NNW the village Schwendt, c. 4 km S of Kössen (Tyrol), the Oberaudorf Beds overlie the Lower Cretaceous Schrambach Formation with an angular unconformity, however, laterally the angular unconformity is below the Lower Gosau Subgroup and older rocks. The upper contact of the Oberaudorf Beds to the lower Oligocene Paisslberg Formation is represented by a disconformity.

Derivation of name: The Oberaudorf Beds were named after the village Oberaudorf, Bavaria, Germany, c. 7 km north of the town Kufstein, Tyrol (Hagn, 1960).

Synonyms: (partim) Nummulitenschichten, Nummulitenkalk (Gümbel, 1861), Obereocaen von Oberaudorf (Schlosser, 1925b), Oberaudorfer Schichten (Hagn, 1960).

Remark: Gümbel (1861, 1894) included the Oberaudorf Beds into the obere Nummulitenschichten, together with the Oligocene sediments of the Inntal-, Kössen- and Reit im Winkl area, which also contain nummulite-bearing sandstones. Paleontological studies by Boussac (1912) and Schlosser (1910, 1923, 1925b) revealed the Eocene age of the Oberaudorf Beds.

Lithology: The sedimentary succession of the Oberaudorf Beds unconformably overlies Triassic to Upper Cretaceous rocks of the Northern Calcareous Alps between the Mühlbacher Berg west of Oberaudorf and the Miesberg mountain ridge north of the Durchholzen village (c. 10 km NE of the town Kufstein, Tyrol). In the type area, the succession starts with 50 m coarse-grained conglomerates alternating with calcareous sandstones containing plant debris (description following the compilation by Hagn, 1985). The conglomerates contain underlying Mesozoic rocks of the Northern Calcareous Alps, but also Paleocene to middle Eocene rocks of the Gosau Group. Some of the boulders show borings by marine organisms. A few meters of sandy marls containing opercula of land snails indicate short-lived limnofluvial conditions, before another 85 m of shallow marine sediments follow. Calcareous sandy marls and marly limestones ("Molluskenband") are rich in marine fossils. Fine, quartz-bearing carbonate sandstones containing abundant *Nummulites fabianii* (Prever) ("*Fabianii*-Sandstein") are probably the most widespread lithology of the Oberaudorf Beds and are also found in the outcrops between at the northern side of the mountain ridge Miesberg on top of basal conglomerates (Lindenberg, 1981). Conglomerates separate the *Fabianii*-sandstone from partly pebbly carbonate sandstones with poorly preserved echinoids ("Echinidensandstein"). 65 m of sandy conglomerates, sandstones, sandy marls, and marls organized in fining upward cycles follow, before the succession ends with 20 m of coarse conglomerates. Opercula of land snails in the marls point to the recurrence of limnofluvial conditions. The latter part of the succession is probably also equivalent to the widespread occurrences of Oberaudorf Beds at the NE edge of the Kaisergebirge (Allersmeier, 1981; see also compilation by Zerbes & Ott, 2000).

Fossils: The Oberaudorf Beds, especially the "Molluskenband", contain a rich fauna with nummulites, corals, bivalves, gastropods and echinoids which was studied by Gümbel (1861), Schlosser (1923, 1925b) and Völk (1960). Additional information on the fossil content of the "*Fabianii*-Sandstein" was provided by Hagn & Wellnhofer (1967). The nannoplankton of the marine part was studied by Stradner (in Schnabel & Draxler, 1976).

Origin, facies: The alternation of shallow marine and limnic conditions points to deposition in a marginal environment, in which small changes of relative sea level could have caused a switch in depositional conditions. The large, well-rounded and bored conglomerate clasts indicate a rocky shore environment, or redeposition of clasts from such an environment. The pronounced asymmetry of the syncline, in which the Oberaudorf Beds of the type area are found (cf. Fig. 27 of Hagn, 1985), with a much smaller thickness in the southern limb, point to the presence of angular unconformities within the succession in response to folding during deposition. This tectonic activity probably also caused short-lived changes in relative sea level.

Chronostratigraphic age: Late Eocene, Priabonian.

Biostratigraphy: *Nummulites fabianii* (Prever) points to SBZ19 and the limnic mollusc fauna (Schlosser, 1925b; Völk, 1960) indicates early Priabonian. The nannoflora indicates NP16 (late Lutetian) and younger (Stradner in Schnabel & Draxler, 1976).

Thickness: The preserved cumulative thickness in the type area at Mühlbacher Berg amounts to c. 230 m. In the Kohlenbach section, the Oberaudorf Beds are c. 70 m thick.

Lithostratigraphic higher rank unit: Inntal Group.

Lithostratigraphic subdivision: No formal subdivision.

Underlying unit(s): Transgressive contact to Triassic–Upper Cretaceous rocks.

Overlying unit(s): Paisslberg Formation; sharp, disconformable boundary due to onset of fine-grained marl deposition. Locally, this contact is an angular unconformity (e.g., Kohlenbach section).

Lateral unit(s): Hallthurm, Kirchholz and Marzoll formations in the Reichenhall Basin (Egger et al., 2017).

Geographic distribution: From the Mühlbacher Berg west of Oberaudorf (Bavaria) to north of the mountain side Miesberg and at the northeastern slope of the mountain range Kaisergebirge (Tyrol). Sediments of the same age were mentioned by Schlosser (1923, 1925a, b) at Hallthurm and Staufeneck near Bad Reichenhall, Bavaria, Germany.

Remarks: The Oberaudorf Beds are part of the Inntal Group denoting sediments transgressively overlying the Alpine nappes, which are comparable in facies to sediments of the North Alpine Foreland Basin (e.g., Fuchs, 1980b).

A large part of the redeposited pebbles in the Oberaudorf Beds are Upper Jurassic to Lower Cretaceous shallow water limestones referred to as limestones in Sulzfluh- und Urgonian facies by Allersmeier (1981). Local sediment transport directions indicate transport from south to west. Upper Jurassic to Lower Cretaceous shallow water limestones in the Lofer area (Lärchkogel Limestone, an equivalent of the Plassen Limestone), E–ESE of the outcrop area of the Oberaudorf Beds, are probably the source of these pebbles.

Complementary references: -

Häring-Formation (Inntal-Gruppe) / Häring Formation (Inntal Group)

HUGO ORTNER

Validity: Valid; formalized by ORTNER & STINGL (2001).

Type area: Area SE of the village Bad Häring, NE of the town Wörgl, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Type section: The Häring Formation is subdivided into the Lengerergraben Member und the Bergpeterl Member. For the type sections, see the Lengerergraben Member and the Bergpeterl Member below.

Reference section(s): -

Derivation of name: Named after the village Bad Häring, c. 5 km NE of the town Wörgl, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Synonyms: Steinkolen zu Häring (FLURL, 1814), especially regarding the subsurface coal mining district S of Bad Häring; Häringer Schichten sensu AMPFERER (1922), HAGN et al. (1962), HEISSEL (1951, 1956), STINGL & KROIS (1991). Häringer Schichten sensu LINDENBERG (1965, 1981), additionally including the Unterangerberg Formation.

Lithology: The Häring Formation includes locally sourced coarse-grained breccias and conglomerates interfingering with sandstones (Lengerergraben Member) in the proximal part of the deposition area, and coal, bituminous carbonate-sandstones and marls (Bergpeterl Member) in a more distal part.

Fossils: Coarse clastics lacking fossils. Sandstones and marls contain unidentifiable shell and plant fragments. The bituminous sandstones and marls contain a well-preserved plant fossil assemblage (see Bergpeterl Member).

Origin, facies: Succession and interfingering of facies types shows the development from a subaerial alluvial fan through a subaquatic fan delta deposit into a marine shallow-water, near-shore environment. The sandstones are interpreted as prodelta sediments and as a proximal equivalent of the Bergpeterl Member.

Chronostratigraphic age: Early Oligocene, early Rupelian; based on sequence stratigraphic correlations (KROIS et al., 1991; ORTNER & STINGL, 2001).

Biostratigraphy: No biostratigraphically useful fossils.

Thickness: Strong variations from 0 to some 10s of meters (depends on local relief).

Lithostratigraphic higher rank unit: Inntal Group.

Lithostratigraphic subdivision: Lengerergraben Member, Bergpeterl Member

Underlying unit(s): Transgressive and diachronous contact to Lower Triassic to Upper Eocene rocks of the Northern Calcareous Alps.

Overlying unit(s): Paisslberg Formation.

Lateral unit(s): -

Geographic distribution: Isolated occurrences between Reit im Winkl (Bavaria, Germany, ATK25, map sheet Q15 Reit im Winkl) in the NE and Oberangerberg, NE of the town Rattenberg, in the SW (Tyrol).

Remarks: -

Complementary references: -

Lengerergraben-Subformation (Häring-Formation, Inntal-Gruppe) / Lengerergraben Member (Häring Formation, Inntal Group)

VOLKMAR STINGL, HUGO ORTNER, JAMES H. NEBELSICK & PETER KROIS

Validity: Valid; formalized by ORTNER & STINGL (2001) as member of the Häring Formation with description of type section. First detailed sedimentological description by STINGL & KROIS (1991).

Type area: SE of the village of Bad Häring, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Type section: Schuhreißergraben creek at the western slope of the Pölven mountain (N 47°30′13″ / E 12°07′54.5″), which is a western tributary of the Lengerergraben Valley, c. 1.1 km SE of the centre of the village of Bad Häring (STINGL & KROIS, 1991).

Reference section(s): The nearby Lengerergraben (N 47°30′09.4″ / E 12°07′50.2″) and Burg (N 47°30′14.7″ / E 12°07′45″) sections illustrate rapid lateral facies changes (STINGL & KROIS, 1991). A slightly different development is exposed 400 m NW of the farm house "Schindler", Oberangerberg, c. 780 m altitude (N 47°29′01.8″ / E 11°56′01.8″) which represents a tectonic slice between Upper Triassic dolomites. It comprises dolomitic breccias with intercalated black carbonaceous marls and coquinas (AMPFERER, 1922; HAMDI, 1969; SCHNABEL & DRAXLER, 1976; STINGL, 1990a).

Derivation of name: Named after the type area around the Lengerergraben Valley, approx. 1.1 km SE of the centre of the village of Bad Häring, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Synonyms: Steinkolen zu Häring (FLURL, 1814), especially regarding the subsurface coal mining district S of Bad Häring; Grundbreccie der Häringer Schichten resp. Häringer Schichten sensu AMPFERER (1922), HAGN et al. (1962), HEISSEL (1951, 1956), STINGL & KROIS (1991), including basal conglomerates, coal bearing beds (= Bergpeterl Member of ORTNER & STINGL, 2001), and the Paisslberg Formation (former "Zementmergelserie") sensu ORTNER & STINGL (2001).

Lithology: The Lengerergraben Member consists of three interfingering facies types (STINGL & KROIS, 1991) arranged in an upward-fining succession:

Facies A: massive, coarse-grained breccias and conglomerates, only locally developed. Chaotic texture, structureless, locally derived pebbles (Triassic sandstones and carbonates).

Facies B: coarse- to fine-grained, stratified conglomerates, local material.

Facies C: laminated, carbonatic and slightly bituminous sandstones and marls, rare shell fragments and plant remains.

Fossils: Coarse clastics without fossils. Sandstones and marls contain unidentifiable shell and plant fragments. HEISSEL (1951) mentioned a single undetermined foraminifer.

Origin, facies: Succession and interfingering of facies types shows the development from a subaerial alluvial fan through a subaquatic fan delta deposit into a marine shallow-water, near-shore environment. The sandstones are interpreted as prodelta sediments and as proximal equivalent of the Bergpeterl Member.

Chronostratigraphic age: Early Oligocene, early Rupelian; based on sequence stratigraphic correlations (KROIS et al., 1991; ORTNER & STINGL, 2001).

Biostratigraphy: -

Thickness: Strong variations from 0 to some 10s of meters (depends on local relief).

Lithostratigraphic higher rank unit: Häring Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Triassic of the Northern Calcareous Alps, transgressive and diachronous contact.

Overlying unit(s): The Bergpeterl Member (Häring Formation) in the area around Bad Häring (gradational contact).

Lateral units: Bergpeterl Member (Häring Formation).

Geographic distribution: Isolated occurrences between Reit im Winkl (Bavaria, Germany, ATK25, map sheet Q15 Reit im Winkl) in the NE and Oberangerberg, NE of the town Rattenberg, in the SW (Tyrol).

Remarks: -

Complementary references: -

Bergpeterl-Subformation (Häring-Formation, Inntal-Gruppe) / Bergpeterl Member (Häring Formation, Inntal Group)

VOLKMAR STINGL, HUGO ORTNER, JAMES H. NEBELSICK & PETER KROIS

Validity: Valid; formalized by ORTNER & STINGL (2001) as member of the Häring Formation with description of type section. First detailed sedimentological description by STINGL & KROIS (1991).

Type area: Area S of the village of Bad Häring, c. 5 km NE of the town Wörgl, Tyrol; ÖK50-UTM, map sheets 2218 Kundl, 3213 Kufstein (ÖK50-BMN, map sheets 89 Angath, 90 Kufstein, 120 Wörgl, 121 Neukirchen am Großvenediger).

Type section: NE corner of the Bergpeterl Marl Quarry S of Bad Häring, in the "Juliusschacht" (Julius shaft) (N 47°29′58.30″ / E 12°07′32.50″) (ORTNER & STINGL, 2001: Fig. 5).

Remark: The former coalmine and parts of the type section inside the Julius shaft are now inaccessible.

Reference section(s): -

Derivation of name: Bergpeterl Member named after the type area in the Bergpeterl Marl Quarry S of Bad Häring, ca. 5 km NE of the town Wörgl, Tyrol.

Synonyms: Steinkolen zu Häring (FLURL, 1814), especially regarding the subsurface coal mining district S of Bad Häring; Häringer Kohle, Häringer Bitumenmergel of the Häringer Schichten sensu AMPFERER (1922), HEISSEL (1951, 1956), MOJSISOVICS (1869), and SANDER (1921). "Facies D" of the Häring Formation of STINGL & KROIS (1991).

Lithology: Laminated bituminous marls and carbonate sandstones with intercalated subbituminous coal seams. Typical structures: fine lamination, grading, slump folds, rare ripple marks, graded coquinas with bivalve and bryozoan detritus. Local oolites with bituminous matrix (locality Peppenau; GRUBER, 1995). Silicified beds ("Brandschiefer") near the coal beds. Coarse, blocky deposits with bituminous matrix (block breccias) in the western part of the Pölven Limestone Quarry. The very top of the Bergpeterl Member is marked by a coarse fossiliferous layer with reworked intraclasts, rare Triassic carbonates with borings, and small mud chips (HEISSEL, 1956; KROIS, 1992; STINGL & KROIS, 1991).

Fossils: The Bergpeterl Member is famous for its well-preserved plant fossil assemblage (BUTZMANN & GREGOR, 2002; BUTZMANN et al., 2009; ETTINGSHAUSEN, 1853a). Further fossils: hystrichosphaerideans, coccolithophorids, coralline red algae, charophyte oogonia, foraminifers, gastropods, bivalves, bryozoans (LÜHR, 1962; OEXLE, 1978; SCHLOSSER, 1925a; SCHNABEL & DRAXLER, 1976).

Origin, facies: Shallow-marine environment in a near-shore area of a restricted basin in front of a river system, derived from the S. Water depth increases to the N resp. NW. The marine environment is indicated by the fossil content, high ash and sulphur contents of coal and bituminous marls (HRADIL, 1953), high B content (JANDA & SCHROLL, 1959). Freshwater influence near the distributary mouth of a river is inferred from low contents of Cl, Br, J, and K (AUGUSTIN-GYURITS & SCHROLL, 1992). The near-shore position is also pointed out by widely distributed terrestrial plant remains, originating from a mesophytic forest, indicating a warm-temperate climate (BUTZMANN & GREGOR, 2002). Restricted oxygen-depleted conditions originate from high input and decay rate of plant remains and are favoured by a circulation barrier (structural high) N of the main distribution area. The block breccias in the Pölven Limestone Quarry are interpreted as scarp breccias, pointing to synsedimentary tectonics (ORTNER, 1996; ORTNER & STINGL, 2001).

Chronostratigraphic age: Early Oligocene, early Rupelian; based on sequence stratigraphic correlations (KROIS et al., 1991; ORTNER & STINGL, 2001), and indirectly inferred from the age of the overlying Paisslberg Formation (calcareous nannofossil Zone NP22, lower Rupelian) and a lower to middle Oligocene character of floral assemblage (BUTZMANN & GREGOR, 2002).

Biostratigraphy: -

Thickness: Coal measures from 1 to 10 m, bituminous marls and sandstones 15 to 20 m.

Lithostratigraphic higher rank unit: Häring Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Lengerergraben Member in the main distribution area S of Bad Häring. Triassic of the Northern Calcareous Alps, transgressive and diachronous contact.

Overlying unit(s): Paisslberg Formation (gradational, tectonically influenced?).

Lateral unit(s): Lengerergraben Member.

Geographic distribution: Main distribution S of Bad Häring, some small occurrences near Kufstein (Dux) and NE Bad Häring (hamlet Fleck), Tyrol.

Remarks: -

Complementary references: -

Paisslberg-Formation (Inntal-Gruppe) / Paisslberg Formation (Inntal Group)

Volkmar Stingl, Hugo Ortner, Peter Krois & James H. Nebelsick

Validity: Valid; formalized as Paisslberg Formation (including the Werlberg Member) by Ortner & Stingl (2001).

Type area: Area around Bad Häring, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheets 90 Kufstein, 121 Neukirchen am Großvenediger).

Type section: Bergpeterl Marl Quarry (N 47°29′54″ / E 12°07′24″) (Ortner & Stingl, 2001: Fig. 7) south of Bad Häring, on the northern slope of the Paisslberg, c. 5 km NE of the town Wörgl, Tyrol; lower boundary exposed; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Reference sections: Not defined, but the sections Buchaugraben near Kössen, Tyrol (N 47°38′32″ / E 12°22′05″), and Pötschbichlgraben near Reit im Winkl, Bavaria, Germany) (N 47°40′50″ / E 12°29′00″) could be considered as reference sections and document the diachronous nature of the Paisslberg Formation (see also Lindenberg, 1965).

Derivation of name: Named after the mountain Paisslberg (Juffinger Jöchl on ÖK50) south of Bad Häring (type locality is situated on the northern slope), Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 90 Kufstein).

Synonyms: Mergel von Häring (Flurl, 1814), Nummulitenbreccien und Zementmergel (Ampferer, 1922).

Lithology: Mainly grey to green (glauconite) marls and marly limestones. The lower part is more calcareous, the higher part more clayey, partly with nodular appearance (“Knollenmergel”). Intercalations of partly thick limestone breccias and conglomerates, rich in biogenic remains. Cm-thick bioarenite layers develop from lateral thinning of breccia layers. Both originate from neighbouring shallow water limestones (Nebelsick et al., 1996, 2001; Rasser & Nebelsick, 2003). An outstanding feature of the shallow water limestones are large bored Triassic pebbles and blocks. Limestones, breccias and bioarenites are summarized in the Werlberg Member.

Fossils: The marls of the Paisslberg Formation contain a rich macrofauna with anthozoans, gastropods, bivalves, scaphopods, cephalopods, crustaceans, brachiopods, echinoderms, and vertebrates (mainly fish), which were studied by Dreger (1892, 1902, 1904), Gümbel (1861), Löffler (1999), Löffler & Nebelsick (2001), Schachl (1939) and Schlosser (1923). The rich microfauna and microflora has been described by Dohmann (1991), Hochuli (1978), Lindenberg (1965), Löffler (1999), Schnabel & Draxler (1976) and Scherbacher et al. (2001).

The limestones of the Werlberg Member are dominated by corallinacean red algae, larger and smaller benthic foraminifers, corals, and bryozoans (Baron-Szabo & Sanders, 2020; Nebelsick et al., 2001; Rasser & Nebelsick, 2003).

Origin, facies: The fauna of the Paisslberg Formation points to open marine conditions. After Lindenberg (1981), water depth varies from 50–200 m in the lower part and from 200–600 m in the higher part. Based on mollusc faunas, Löffler (1999) also assumed a deepening from the lower neritic zone to the higher bathyal zone. More recent examinations of foraminifers (Scherbacher et al., 2001) result in 0–30 m at the base of the succession, a maximum depth of 200 m in the middle part, and 10–30 m in the highest part. The latter authors argue with telescoping of depth zonation of benthic foraminifers in marginal seas or large bights. The origins for telescoping effects are referred to differences in oxygen content and organic input, caused by complex coastal geometries and current systems. Water temperatures are estimated between 16 and 23 °C. The obvious transgressive-regressive trend is related to the Rupelian eustatic sea level rise with contemporary basin subsidence, which is overtaken by increasing sediment input in the higher part.

Chronostratigraphic age: Early Oligocene, Rupelian.

Biostratigraphy: Nannofossil Zone NP22 (Löffler, 1999; Löffler & Nebelsick, 2001). The higher part possibly reaches into NP23 (Cicha et al., 1971; Scherbacher et al., 2001).

Thickness: Data on the thickness of the Paisslberg Formation vary due to missing complete sections. Ampferer (1922) estimates a thickness of 1,000 m. The minimal evident thickness is about 200 m.

Lithostratigraphic higher rank unit: Inntal Group.

Lithostratigraphic subdivision: Werlberg Member within the Paisslberg Formation.

Remark: Various subdivisions according to mining activities (Ampferer, 1922) are invalid.

Underlying unit(s): Bergpeterl Member of the Häring Formation. Differences are grey to green colours and missing bitumen content in the Paisslberg Formation compared to the Bergpeterl Member.

Overlying unit(s): Unterangerberg Formation; gradational, the boundary is conventionally drawn with the first massive siliciclastic input (e.g., Glaurachgraben south of Inn river; Ampferer, 1922).

Lateral unit(s): In its higher parts, the Paisslberg Formation may interfinger with the Unterangerberg Formation.

Geographic distribution: Area south and southeast of the town Wörgl, along the northern slope of the Kaisergebirge mountains.

Remarks: -

Complementary references: -

Werlberg-Subformation (Paisslberg-Formation, Inntal-Gruppe) / Werlberg Member (Paisslberg Formation, Inntal Group)

VOLKMAR STINGL, HUGO ORTNER, PETER KROIS & JAMES H. NEBELSICK

Validity: Valid; formalized as Werlberg Member by ORTNER & STINGL (2001).

Type area: Area around Bad Häring, c. 5 km NE of the town Wörgl, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheets 90 Kufstein, 121 Neukirchen am Großvenediger).

Type section: Outcrop E of the village Brugger Mühle (N 47°29′39″ / E 12°05′54.20″), c. 2.4 km NE of the town Wörgl, at the beginning of the road to the hamlet Gasteig, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 121 Neukirchen am Großvenediger).

Reference section(s): -

Derivation of name: Named after the hamlet Werlberg at the western foothill of the Paisslberg, c. 2.4 km NE of the town Wörgl, Tyrol.

Synonyms: Nummulitenkalk or Nummulitenbreccie (AMPFERER, 1922), Lithothamnienkalkbreccie (LÜHR, 1962).

Lithology: A wide variety of rocks is summarized in the Werlberg Member, which include breccias, conglomerates, bioarenites and limestones. Near fault scarps, the breccias can be very coarse-grained (meter-sized clasts) and fossil free, however, the breccias quickly grade into sands and limestones laterally. An outstanding feature of the shallow water limestones are large bored Triassic pebbles and blocks. The Werlberg Member includes both autochthonous sediments in transgressive contact with older sediments at the basin margin and material transported into the basin by sediment gravity flows.

Fossils: The limestones of the Werlberg Member are dominated by corallinacean red algae, larger and smaller benthic foraminifers, corals, and bryozoans (BARON-SZABO & SANDERS, 2020; NEBELSICK et al., 2001; RASSER & NEBELSICK, 2003).

Origin, facies: The microfacies of the Werlberg Member points to a carbonate ramp, reaching from shallow, turbulent coastal waters (coralline algal facies, coral-coralline algal facies, foraminiferal facies) to deeper, more quiet water (over the coralline algal-bryozoans facies to the bryozoan facies). This zonation is reflected in coralline algal associations (RASSER & NEBELSICK, 2003). Initiated by earthquakes or storms, channelized debris flows reached deeper basin areas, preserving the original facies zonation.

Chronostratigraphic age: Early Oligocene, Rupelian.

Biostratigraphy: No biostratigraphically relevant fossils were found.

Thickness: The Werlberg Member shows a maximum of 100 m thickness with strong lateral variations.

Lithostratigraphic higher rank unit: Paisslberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformable contact to Triassic rocks of the Northern Calcareous Alps.

Overlying unit(s): Paisslberg Formation.

Lateral unit(s): Paisslberg Formation.

Geographic distribution: Area south and southeast of Wörgl, along the northern slope of the Kaisergebirge mountain range to the vicinity of the village Reit im Winkl (Bavaria, Germany, ATK25, map sheet Q15 Reit im Winkl) at the Austrian/German border; isolated occurrences near Osterndorf, c. 4.5 km S of the town Kufstein, and in the Kufsteiner Wald, c. 4 km SW of the town Kufstein, Tyrol.

Remarks: LINDENBERG (1965) postulated a basin-wide distribution of the "Lithothamnienkalk-Breccie" (= Werlberg Member) as an expression of a single tectonic event. As KROIS (1992) discussed, the occurrence of large slumpings and debris flow bodies in the Paisslberg Formation is not unique, therefore, basin-wide correlations are problematic.

Complementary references: -

Unterangerberg-Formation (Inntal-Gruppe) / Unterangerberg Formation (Inntal Group)

VOLKMAR STINGL, HUGO ORTNER & PETER KROIS

Validity: Valid; first named as "Unterangerberger Schichten" by HEISSEL (1951). Formalized as Unterangerberg Formation by ORTNER & STINGL (2001).

Type area: Type area along the northern banks of the River Inn and the adjacent area including the locality Unterangerberg, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheets 89 Angath, 120 Wörgl).

Type section: Section "Angath" (N 47°29′53.70″ / E 12°03′26.30″) (ORTNER & STINGL, 2001: Fig. 12) at the northern bank of the River Inn opposite to the town Wörgl, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheets 89 Angath). No complete section exists.

Reference section(s): Section "Kleinsöll" (N 47°28′54″ / E 11°59′15″) (ORTNER & STINGL, 2001: Fig. 11) at the northern bank of the River Inn opposite to the market town Kundl, containing the higher part of the Unterangerberg Formation and the base of the Oberangerberg Formation with the "Höllgraben Conglomerate" (boundary stratotype); ÖK50-UTM, map sheet 2218 Kundl (ÖK50-BMN, map sheet 120 Wörgl). The section "Innufer" (N 47°29′27.80″ / E 12°03′02.60″) (ORTNER & STINGL, 2001: Fig. 13) at the northern bank of the River Inn opposite the town Wörgl, represents a more distal facies of the Unterangerberg Formation; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 120 Wörgl).

Derivation of name: Named after the main distribution area around the village of Angerberg, a plateau north of the River Inn opposite the town of Wörgl, Tyrol; ÖK50-UTM, map sheet 3213 Kufstein (ÖK50-BMN, map sheet 89 Angath).

Synonyms: (partim) Angerberg Schichten (SCHLOSSER, 1895), Unterangerberger Schichten (HEISSEL, 1951).

Lithology: The Unterangerberg Formation consists of thin, graded turbiditic sandstone-marl-couplets and a few fine-grained conglomerate beds. These form small-scale, upward-fining sequences, which are organized in 1 to 20 m thick larger-scale cycles. Graded bedding, horizontal lamination and ripple bedding are common, sedimentary structures are dominated by various sole marks such as flute and groove casts.

Compositional spectra point to a diverse origin of the material. The sandstones and fine-grained conglomerates contain mainly carbonatic components, various types of metamorphic clasts from the large crystalline complexes, from the Northern Greywacke Zone, and from phyllite complexes south and west of the sedimentation area. The heavy mineral spectrum is dominated by garnet and staurolite (SCHNABEL & DRAXLER, 1976). Glauconite, plant remains, and bioclasts are present throughout the succession. An outstanding feature is the lack of ichnofauna typical for deep water, which may be due to high sedimentation rates.

East of Kufstein, the Unterangerberg Formation forms local sandstone channel fills within the higher part of the Paisslberg Formation.

Fossils: The Unterangerberg Formation contains an individual-rich but species-poor microfauna (HAGN, 1960; LINDENBERG, 1965). HEISSEL (1956) and HAMDI (1969) mention foraminifers (globigerinids dominate the middle part), bryozoans (deeper part), ostracods (higher part), coralline red algal fragments, corals, echinoderm remains, and sponge spicula. LINDENBERG (1981) noticed typical Rupelian faunal elements (faunal type e after LINDENBERG, 1981). The nannoflora is not indicative and contains a large part of reworked Eocene and to a lesser extent Paleocene and Upper Cretaceous taxa. Pollen and spores are rare and poorly preserved.

Origin, facies: Type of cyclicity, bedding types, sedimentary structures as well as grain-size distribution point to progression and/or lateral shift of a submarine fan in front of a river mouth (KROIS, 1992; ORTNER, 1996). Transport directions vary strongly, the main trend is from NW to SE, partly to NE. Some current marks point to N, but a major sediment input from S (SCHNABEL & DRAXLER, 1976) cannot be verified. In distal parts (towards E and NE) the Unterangerberg Formation interfingers with the higher parts of the Paisslberg Formation. The increasing content of benthic foraminifera in the uppermost part of the succession points to a regressive development due to shallowing of the sedimentation area (HAGN, 1960; HAMDI, 1969; LINDENBERG, 1965). Deposition of coarse material marks the base of the Oberangerberg Formation near the Rupelian/Chattian boundary due to a worldwide sea-level drop (ORTNER, 1996; ORTNER & STINGL, 2001).

Chronostratigraphic age: Early Oligocene, Rupelian. The sequence-stratigraphic interpretation by KROIS et al. (1991) suggests a late Rupelian age of the Unterangerberg Formation. The onset of the overlying Oberangerberg Formation coincides with the worldwide sea-level drop at the Rupelian/Chattian boundary.

Biostratigraphy: After KÖVECS (1964) and LINDENBERG (1965) the foraminifers of the Unterangerberg Formation point to a Rupelian age. HAMDI (1969) supports this opinion and also mentions the lack of any Chattian microfauna. An indirect argument is the age of the underlying Paisslberg Formation (NP22: LÖFFLER, 1999; LÖFFLER & NEBELSICK, 2001). SCHERBACHER et al. (2001) also mention a late Rupelian age (NP23?) for the Unterangerberg Formation.

Thickness: The mentioned sections represent a combined thickness of about 120 m without reaching the base. From outcrop and subsurface data an estimated thickness of about 300 m for the Unterangerberg Formation seems to be plausible (KROIS, 1992).

Lithostratigraphic higher rank unit: Inntal Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Paisslberg Formation. The Unterangerberg Formaton is distinguished by its high amount of siliciclastic material.

Overlying unit(s): Oberangerberg Formation.

Lateral unit(s): The Unterangerberg Formation interfingers with the higher parts of the Paisslberg Formation in the area east of Kufstein.

Geographic distribution: Mainly in the western and southern part of the Inn Valley between Breitenbach and the Kaisergebirge mountain range, Tyrol.

Remarks: -

Complementary references: -

Oberangerberg-Formation (Inntal-Gruppe) / Oberangerberg Formation (Inntal Group)

VOLKMAR STINGL, HUGO ORTNER & PETER KROIS

Validity: Valid; first named as "Oberangerberger Schichten" by HEISSEL (1951). Formalized as Oberangerberg Formation by ORTNER & STINGL (2001).

Type area: Type area is located north of the River Inn between the villages Kramsach in the W and Breitenbach am Inn in the E including the locality Oberangerberg, Tyrol; ÖK50-UTM, map sheet 2218 Kundl (ÖK50-BMN, map sheet 120 Wörgl).

Type section: Section "Voldöpp" in the southwestern part of the Oberangerberg (N 47°27′12″ / E 11°53′36″) (ORTNER & STINGL, 2001: Fig. 15), along a small road from the village Voldöpp to the lake "Reintaler See"; lower and upper boundary not exposed; ÖK50-UTM, map sheet 2218 Kundl (ÖK50-BMN, map sheet 120 Wörgl).

Reference sections: Section "Kleinsöll" N 47°28′54″ / E 11°59′15″) (ORTNER & STINGL, 2001: Fig. 11) at the northern bank of the River Inn opposite the market town Kundl, displays the lower boundary of the Oberangerberg Formation ("Höllgraben Conglomerate"); ÖK50-UTM, map sheet 2218 Kundl (ÖK50-BMN, map sheet 120 Wörgl). Section "Mühlbach gorge" (N 47°29′30″ / E 11°57′28″), c. 2 km NW of the village Breitenbach am Inn, shows a thick regressive, coarsening-upward sequence of the Oberangerberg Formation; ÖK50-UTM, map sheet 2218 Kundl (ÖK50-BMN, map sheet 120 Wörgl).

Derivation of name: Named after the main outcrop area Oberangerberg a hill side north of the River Inn between Kramsach and Breitenbach am Inn, Tyrol; ÖK50-UTM, map sheet 2218 Kundl (ÖK50-BMN, map sheet 120 Wörgl)

Synonyms: (partim) Angerberg Schichten (SCHLOSSER, 1895), Oberangerberger Schichten (HEISSEL, 1951).

Lithology: Various types of conglomerates constitute the Oberangerberg Formation (massive-unbedded, graded, trough or tabular cross-bedded, rarely inversely graded), graded conglomerates dominate by far. Single conglomerate beds reach thicknesses of up to some meters. The largest components occur within massive conglomerates. Horizontally bedded and trough cross-bedded sandstones, partly with pebble streaks, are minor constituents. Thin silty intercalations (with plant remains and coal fragments) are characterized mainly by horizontal lamination.

Examinations of the petrographic composition by HAMDI (1969), KROIS & STINGL (1991), MOUSSAVIAN (1983, 1984), SKERIES (1988), SKERIES & TROLL (1991) and KROIS (1992) show a dominance of Triassic carbonates, early Paleogene components and dark dolomites (probably from the Northern Greywacke Zone) over other pebble types. While the Höllgraben Conglomerate at the base of the Oberangerberg Formation is still dominated by pebbles of early Paleogene and Cretaceous age, their content diminishes towards higher parts. Vein quartz, various quartzites, phyllites, mica schists, gneisses, metamorphic conglomerates and others have their source in the Northern Greywacke Zone, the quartzphyllite areas and the Crystalline Complexes south and west of the Lower Inn Valley. Very rare andesitic to dacitic pebbles point to an source in the area of Reschenpass and Ortler mountains (BRÜGEL, 1998; BRÜGEL et al., 2000; KROIS, 1992; MAIR et al., 1992, 1996; STINGL et al., 1996).

Fossils: The fossil content is generally low. Besides very rare vertebrate remains (*Rhonzotherium cadibonense* ROGER: SCHLOSSER, 1910), mainly terrestrial gastropods (ZÖBELEIN, 1955b), unsculptured ostracods (HAMDI, 1969), badly preserved pollen and spores (SCHNABEL & DRAXLER, 1976), charophytes, and higher plant remains (HAMDI, 1969) occur. Remains of foraminifers and fish seem to be restricted to the basal part (HAMDI, 1969). LINDENBERG (1981) noticed brackish horizons with the bivalve *Polymesoda* in the deeper part of the Oberangerberg Formation near Reit im Winkl. A large part of the faunal and floral content comprises resedimented taxa from the Cretaceous and early Paleogene.

Origin, facies: The architecture of the conglomerates of the Oberangerberg Formation points to a slightly sinuous, braided river system with perennial high-energy runoff, as shown by KROIS & STINGL (1991). The Höllgraben Conglomerate and its equivalents can be interpreted as delta-front and delta-plain sediments due to their marine environment (sedimentary structures and fossil content). These delta sediments quickly grade into deposits of a prograding river system. Channel fills with longitudinal gravel and sand bars are the most widely distributed facies elements. The scarcity of fine-grained sediments of the overbank areas (levees, crevasse splays, marsh sediments, abandoned mud-filled channels) supports the model of a highly mobile channel system with various morphological levels (KROIS & STINGL, 1991; KROIS, 1992; ORTNER & STINGL, 2001). Transport direction was from NW–W to SE–E. SKERIES (1988) and MAIR et al. (1996) proof a mountain-parallel precursor fluvial system of the River Inn (“paleo-Inn river”) with its source in the area around Reschenpass and Ortler mountains (South Tyrol, Italy).

Chronostratigraphic age: Late Oligocene, Chattian. According to the sequence-stratigraphic interpretation by KROIS et al. (1991), the onset of the Oberangerberg Formation (progradation of a fluvial system) coincides with the global sea-level drop at the Rupelian/Chattian boundary (HAQ et al., 1988). Typical indicator pebbles from the Upper Engadine valley (Julier granite) are lacking in the Oberangerberg Formation and occur for the first time in the Aquitanian of the North Alpine Foreland Basin. Therefore, the highest parts of the Oberangerberg Formation seem still to be of Chattian age (KROIS, 1992; SKERIES, 1988; SKERIES & TROLL, 1991).

Biostratigraphy: The scarce fauna and flora of the Oberangerberg Formation point to a late Oligocene (Chattian) age (HAMDI, 1969; LINDENBERG, 1965; SCHLOSSER, 1910; ZÖBELEIN, 1955b).

Thickness: Due to the erosive top of the Oberangerberg Formation, the thickness can only be indirectly estimated. Few drillings and some reconstructed sections north of the Kaisergebirge mountain range indicate a remaining thickness of up to 1,000 m (ORTNER, 1996; ORTNER & STINGL, 2001). In the Oberangerberg area it is restricted to some 100 m. Thermal overprint (vitrinite reflection) in the area Häring–Oberangerberg points to a now missing, formerly overlying sediment thickness of 1,300 m (ORTNER & SACHSENHOFER, 1996).

Lithostratigraphic higher rank unit: Inntal Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Unterangerberg Formation. The conglomerates of the Oberangerberg Formation clearly differ from conglomerates of the Unterangerberg Formation and the Häring Formation by their pebble composition.

Overlying unit(s): Erosional top.

Lateral unit(s): -

Geographic distribution: In the entire distribution area of the Inntal Group north of the River Inn and north of the Kaisergebirge mountain range, from Kramsach in the W to Reit im Winkl (Bavaria, Germany, ATK25, map sheet Q15 Reit im Winkl) in the E.

Remarks: -

Complementary references: -

Augenstein-Formation / Augenstein Formation

WERNER E. PILLER

Validity: Valid; SIMONY (1851: p. 159) first mentioned “Urgebirgsgeschiebe” from the Dachstein mountain area; MOJSISOVICS (1899) introduced the term “Augensteine” and interpreted these clasts as denudation relicts of Tertiary gravel and conglomerate; FRISCH et al. (2001) first used the term Augenstein Formation which was then formalized by FRISCH et al. (2002).

Type area: Area of the Dachstein Plateau, S of Lake Hallstatt, Upper Austria; ÖK50-UTM, map sheets 3217 Hallstatt, 3218 Bad Mitterndorf (ÖK50-BMN, map sheets 95 St. Wolfgang im Salzkammergut, 96 Bad Ischl, 127 Schladming).

Type section: Natural outcrop in the “Augensteindlgrube” at the Dachsteinplateau (N 47°30′32″ / E 13°40′33″), 1.1 km SSE of Gjaidalm along the hiking trail 616 from Gjaidalm to the Guttenberg-Haus, Upper Austria (FRISCH et al., 2002). There, the sediments of the Augenstein Formation are cemented to the underlying limestone of the Dachstein Formation and this location is considered one of the rare autochthonous occurrences; ÖK50-UTM, map sheet 3218 Bad Mitterndorf (ÖK50-BMN, map sheet 96 Bad Ischl).

Reference section(s): -

Derivation of name: Named after the polished and shiny white quartz grains which have the appearance of eye balls (Götzinger, 1913b). An alternative explanation is that the quartz grains have been used for medical treatment of hordeolum styes (Frisch et al., 2002).

Synonyms: Urgebirgsgeschiebe (Simony, 1851), Augensteine (Mojsisovics, 1899), Augensteinschotter (Leuchs, 1924), Augenstein-Schotterdecke (Tollmann, 1985), Augenstein beds (Ortner & Stingl, 2001).

Remark: In relation with the occurrence of these sediments the terms Augensteinlandschaft, Augensteinlager (Lichtenecker, 1925) and Augensteinfelder (e.g., Mutschlechner, 1953) were also in use.

Lithology: Sandstone, gravel and conglomerate rich in polycrystalline quartz components. The conglomerate components show usually diameters of a few centimeters (rarely up to 20 cm), are subangular to well-rounded and moderately to poorly sorted. The quartz pebbles are derived from phyllites and include sometimes remnants of schist. Besides quartz also pebbles of quartzite, sandstone, lydite, rhyolite, greenstone, and (dark) carbonate rocks occur (Frisch et al., 2001, 2002).

Fossils: -

Origin, facies: The currently most commonly employed interpretation is that the sediments of the Augenstein Formation were deposited by a complex fluvial system with sediment delivery from the south including weakly metamorphic (rarely volcanic) Paleozoic rocks (derived from the Greywacke Zone) and Carboniferous to Lower Triassic siliciclastics from the base of the Northern Calcareous Alps. The rivers flowed on an intermediate relief from the mountainous source area into the North Alpine Foreland Basin. According to Frisch et al. (2001, 2002) the thickness of these fluvial sediments reached > 1.3 km.

An alternative interpretation has been suggested by Egger et al. (2017): these authors state that clasts of the Augenstein Formation display close similarity to pebbles in the marine Hallthurm Formation (Inntal Group), which was probably overlain by thick Oligocene marine deposits. Based on this, the Augenstein Formation is considered to represent erosional relics of this Priabonian formation. Additionally, heavy mineral assemblages rich in garnet and staurolite indicate uplift and erosional exhumation of metamorphic source areas already in the late Eocene. Furthermore, Frisch et al. (2001) report on euhedral zircon crystals of possible volcanic origin in the Augenstein Formation. These crystals gave Ypresian ages (53.6 ± 2.7 Ma), which correspond to the age of bentonite layers of the Nierental Formation. This is considered an indicator for the reworking of components of the Gosau Group within the Augenstein Formation.

Chronostratigraphic age: ?early Eocene, Ypresian; ?late Eocene, Priabonian to ?early Miocene, Burdigalian (Ottnangian) (Frisch et al., 2001, 2002; Egger et al., 2017).

Remark: Zircon and apatite fission-track data indicate ages between c. 35–30 Myrs for the basal sediments which seem to be diachronously deposited (Frisch et al., 2001, 2002). Egger et al. (2017), however, pointed out that some crystals gave an Ypresian age (53.6 ± 2.7 Ma). Frisch et al. (2001: p. 507) mentioned that these "older" crystals may be of volcanogenic origin or "derived from an Austro-Alpine orthogneiss or an intrusive body that underwent Tertiary cooling". This Ypresian age, however, has not been mentioned anymore in Frisch et al. (2002).

Biostratigraphy: -

Thickness: Patchy occurrence of thin lithified beds or loose gravel; where they occur autochthonously cemented to underlying rocks they reach a few dm in thickness; most occurrences are reworked and redeposited, frequently preserved in karstic depressions and fissures.

Remark: Thermochronological data suggest an original thickness of > 1.3 km or even > 2 km (Frisch et al., 2001), which has been nearly completely eroded.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Mostly Triassic carbonate rocks of the Northern Calcareous Alps.

Overlying unit(s): -

Lateral unit(s): Interfingers supposedly in the Lower Inn Valley with sediments of the Chattian (upper Oligocene) Oberangerberg Formation (Unterinntal Group) (Ortner & Stingl, 2001).

Geographic distribution: On top of the central and eastern areas of the Northern Calcareous Alps (e.g., Wilder and Zahmer Kaiser, Leoganger Steinberge, Steinernes Meer, Hochkönig, Hagengebirge, Untersberg, Tennengebirge, Dachstein, Totes Gebirge, Gesäuse, Hochschwab, Rax) (compare Frisch et al. (2001, 2002) and Ortner & Stingl (2001)). The Augenstein Formation does not occur west of the Inn Valley.

Remarks: The long lasting and still ongoing discussion on the origin of the sediments of the Augenstein Formation is shortly described above. Historically, in addition to the discussions on the origin of the sediments another discussion is a geomorphologic one about the horizon on which the Augenstein Formation has been deposited. The competing "classical" schools are represented by the geomorphologic terms "Raxlandschaft" (after the mountain Rax at the border between Lower Austria and Styria) (e.g., Lichtenecker, 1925; Solar, 1964) versus "Augensteinlandschaft" (discussion see in Riedl, 1966). The "Raxlandschaft" concept dealt with a single phase producing a leveling surface which has been later on tectonically disturbed. The "Augensteinlandschaft" concept reconstructed a "piedmonttreppe" with tectonic quiescence phases during which smaller scaled leveling surfaces originated. These concepts are, however, outdated (Frisch et al., 2002).

Complementary references: Götzinger (1913a, b, 1915), Slanar (1918), Lichtenecker (1926), Seefeldner (1926), Winkler (1928a, b), Brandl (1928, 1930), Schauberger (1935), Glaessner (1935), Goldberger (1955), Bauer (1954), Winkler-Hermaden (1933c, 1957), Pichler (1962), Tollmann (1985), Stingl (1990b), Krois & Stingl (1994), Sharman et al. (2018), Hülscher et al. (2021).

North Alpine Foreland Basin: Vorarlberg

Deutenhausen-Formation / Deutenhausen Formation

J. Georg Friebe & Werner E. Piller

Validity: Invalid; first denominated as “Deutenhausen Schichten” by Richter (1937: p. 166); a comprehensive description was given by Zeil (1953); Wagner (1996b) used the name Deutenhausen Formation in the NAFB of Upper Austria and Maurer et al. (2002) introduced the name Deutenhausen Formation in Upper Bavaria (“Ammerschlucht” along the river Ammer). Resch (1963a, b) introduced the name “Deutenhausener Schichten” in Vorarlberg. The following description provides some insight into Bavarian occurrences but focusses on localities in Vorarlberg.

Type area: The area S of Roßhaupten am Lech, c. 10 km north of the town Füssen (Swabia, Bavaria, Germany); ATK25, map sheet Q08 Halblech; GK25, map sheet 8330 Roßhaupten.

Type section: Not defined, but the section described in Deutenhausen does not exist anymore due to flooding after the pondage of the lake Forggensee (e.g., Dohmann, 1991).

Reference section(s): -

Derivation of name: Named after the small village Deutenhausen, near Roßhaupten am Lech, c. 10 km north of the town Füssen (Swabia, Bavaria, Germany). The village has been flooded after the pondage of the lake Forggensee.

Synonyms: Tonmergelstufe p.p. (Muheim, 1934: p. 184), Deutenhausener Schichten (Richter, 1937: p. 166; Resch, 1963a, b), Deutenhausenerschichten (Diem, 1986).

Remark: When Muheim (1934) introduced the unit “Tonmergelstufe” in Vorarlberg, this unit included basal deposits, which were later identified as part of the Deutenhausen Formation (Resch, 1963a, b, 1975).

Lithology: In the type area, generally sandstones, clay marls and conglomerates dominate which can be subdivided into three units following Zeil (1953): (a) Lower Deutenhausen Beds with thin-bedded, grey to brown, fine sandstones with grey, sandy marls intercalated. (b) Middle Deutenhausen Beds of thick-bedded, hard, grey to grey-blue sandstones. Less abundant are thin clay marl intercalations with coal remains. (c) Upper Deutenhausen Beds with dominating grey, thin-bedded clay marls with platy, fine-grained sandstone layers intercalated. In the uppermost parts occur conglomerates (up to 5 m thickness).

In Vorarlberg, Resch (1963a) differentiated the lower “Mühlbach-Schichten” of flyschoid sandstones and marls with abundant fish scales and the “Grundegg-Schichten” represented by clay marl with thin sandstone layers, thick, coarse-grained sandstone beds and in the uppermost parts conglomerates. These units have, however, not been used in later descriptions.

Remark: A prominent conglomerate bed near the village Schwarzenberg with only slightly rounded polymict components up to two meters in diameter was termed “Riesenkonglomerat” by Heim et al. (1928: p. 23) and named “Mühlbach-Konglomerat” by Resch (1963a) as part of his “Mühlbach-Schichten”.

Fossils: Calcareous nannoplankton (Dohmann, 1991: p. 122ff. for occurrences in Vorarlberg), planktic and benthic foraminifers, radiolarians, ostracods, molluscs, fish scales, shark teeth, plant remains, and trace fossils (Resch, 1976a: p. A124) were reported. Besides these mostly marine biota also freshwater gastropods and bivalves were recorded which raised doubts on the full marine conditions indicated by most other biota. Reworking is a serious problem because Cretaceous and early Paleogene microfossils were repeatedly identified (Resch, 1963a; Oberhauser et al., 1986b). In addition, the lower sediments of the Deutenhausen Formation were integrated in the “Tonmergelstufe” (e.g., Muheim, 1934: p. 189) and also the mentioned fossils are considered to be part of the Deutenhausen Formation (Resch, 1963a).

Origin, facies: Full marine, shallow- to middle bathyal (400–600 m water depth) paleoenvironment representing delta slopes in shallower parts and deep sea fans, channels and lobes in the deeper parts (Dohmann, 1991). Within the formation, a general coarsening upward and shallowing trend can be observed (Maurer et al., 2002). The coarse-grained sediments (conglomerates) in the Upper Deutenhausen Formation are interpreted as mass transport deposits, like debris flows and slumps, into a muddy prodelta environment (Maurer et al., 2002).

Remark: The interpretation of the environmental conditions of the Deutenhausen Formation was highly controversially discussed, reaching from shallow marine with brackish influence (Zöbelein, 1952b: p. 619), to fluvial-brackish (Zeil, 1954) to a deep sea environment of > 1,000 m (Fischer, 1960, 1979).

Chronostratigraphic age: Oligocene, Rupelian (early Kiscellian).

Biostratigraphy: Calcareous nannofossil Zones NP21/NP22 are identified by Dohmann (1991), the taxa identified by Stradner (in Oberhauser et al., 1986b) indicate NP22–NP23.

Thickness: In southern Germany up to 750 m are recorded (Zeil, 1953; Zöbelein, 1952b; Kuhnert & Ohm, 1974), in Vorarlberg near Dornbirn (Bödelestraße) approx. 60 m (Resch, 1976a); reduced by basal tectonic truncation.

Lithostratigraphically higher rank unit: Untere Meeresmolasse (Lower Marine Molasse) as informal unit in Bavaria (e.g., Maurer et al., 2002; Doppler et al., 2005).

Lithostratigraphic subdivision: None; Zeil (1954) subdivided the Deutenhausen Formation in southern Bavaria informally into three subunits which could be formalized at the member level; Resch (1963a) divided the “Deutenhausener Schichten” in Vorarlberg informally into the lower “Mühlbach-Schichten” and the upper “Grundegg-Schichten” but this differentiation has not been applied furtheron.

Underlying unit(s): Tectonic base.

Overlying unit(s): Grisigen Marl. The boundary between the Deutenhausen Formation and Grisigen Marl is defined with the disappearance of sandstones (Zeil, 1953: p. 106; Kuhnert & Ohm, 1974: p. 23).

Lateral unit(s): No lateral units known in Vorarlberg; in southern Bavaria a transition occurs basinward into so-called "Fischschiefer" and in the direction of the upper slope and outer shelf in the so-called "Tonmergel" (e.g., DOHMANN, 1991: Abb. 32; FREUDENBERGER & SCHWERD, 1996).

Geographic distribution: The Deutenhausen Formation occurs as narrow stripe in the southern limb of the Murnau Syncline/Steineberg Syncline of the Subalpine Molasse from Vorarlberg in the west to Murnau am Staffelsee (Upper Bavaria, Germany, ATK25, map sheet Q10 Murnau a.Staffelsee) in the east. Vorarlberg: Vorderer Bregenzerwald, Rheintal near Dornbirn and along the Bregenzer Ach; ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheets 111 Dornbirn, 112 Bezau). In addition, sediments of the Deutenhausen Formation are also reported from the Autochthonous Molasse of the NAFB in Upper Austria (WAGNER, 1996b, 1998).

Remarks: The Deutenhausen Formation represents the basal sediments in the NAFB without a sedimentary unit below.

Complementary references: WEPFER (1909), RICHTER (1940), HAGN & HÖLZL (1952), VOLLMAYR (1954), ZÖBELEIN et al. (1957), SCHMIDT-THOMÉ & GANSS (1955), HÜGEL (1956, 1962), SCHIEMENZ (1960), HAGN (1967), HÖFLE & KUHNERT (1969), BÜRGISSER et al. (1981), SCHWERD et al. (1983), SCHWERD (1984), DIEM (1986), OBERHAUSER et al. (1986a), STEININGER & WESSELY (2000), FRIEBE (2007b, 2008, 2012), STAUNER et al. (2015), STD 2016.

Grisigen Mergel / Grisigen Marl

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Valid (see remark); marls and sandstones in the area of Grisigen (Grisiger-Flühli, Grisiger-Risi) were first mentioned by KAUFMANN (1860: p. 16f.) as "graue Schiefermergel"; BAUMBERGER (1925b: p. 280) introduced the term "Grisigermergel" (= "rauchgraue Mergel"). RICHTER (1926: p. 319) introduced the name "Tonmergelstufe" for this unit in southern Germany and this term (with variations) was and is still in use (e.g., DOPPLER et al., 2005; STD 2016).

In Vorarlberg, the name "Grisiger Mergel" was first mentioned by HEIM et al. (1928: p. 14) for sediments below the "Bausteinschichten" ("Horwerschichten") in the Schwarzachtobel, but MUHEIM (1934: p. 184) and later authors still used the term "Tonmergelstufe"; a comprehensive description of the "Tonmergel-Schichten" was given by RESCH (1963a). The term Grisigen Formation has been introduced without formalization by FRIEBE (2007b). The following description provides some insight into Swiss and Bavarian occurrences but focusses on Vorarlberg.

Remark: The Swiss Stratigraphic Commission validated the term Grisigen-Mergel (Grisigen Marl) in the rank of a member, the lithostratigraphic higher rank unit is the "Formation de Vaulruz" (UMM-II) (https://www.strati.ch/en/stratigraphic/grisigen-mergel); the term Grisigen Formation (FRIEBE, 2007b) is not valid under rules of the Austrian Stratigraphic Commission and has to be rejected since Grisigen Marl is defined as a member in the type area.

Type area: Area around the village Horw, Kanton Luzern, Switzerland; map 1:25,000, map sheet 2510 Luzern – Pilatus – Rigi.

Type section: Abandoned marl pit Grisigen ("Mergelgrube Grisigen"; BUXTORF et al., 1941), c. 1 km W of Ennethorw, part of Horw, c. 4 km south of the town Luzern, Kanton Luzern, Switzerland; N 47°00′34″ / E 08°17′36″.

Remark: Planned recultivation of the marl pit Grisigen will make the type section of the "Grisiger-Mergel" (Grisigen Formation) inaccessible.

Reference section(s): Längacher Steinbruch, Biregg-Halbinsel near Horw, Kanton Luzern, Switzerland; N 47°00′16″ / E 08°19′23″ (https://www.strati.ch/en/stratigraphic/grisigen-mergel).

Derivation of name: Named after the hamlet Grisigen near Horw, Kanton Luzern, Switzerland.

Synonyms: graue Schiefermergel (KAUFMANN, 1860: p. 16; HEIM et al., 1928: p. 24, Fig. 10: No. 6), Tonpartie (GILLITZER, 1914: p. 156), Grisigermergel (BAUMBERGER, 1925a, b), Tonmergelstufe (RICHTER, 1926; MUHEIM, 1934: p. 184), Grisiger Mergel (HEIM et al., 1928: p. 16), Tonmergelserie (MUHEIM, 1934: p. 185), Ammer-Tonmergel p.p. (ZEIL, 1954), Tonmergel-Schichten, Tonmergelschichten (FISCHER, 1960), Grisigen shales (TRÜMPY et al., 1980: p. 25), Grisigen shale (MATTER et al., 1980: p. 281), Grisigen Marl (BACHMANN et al., 1987), "Tonmergel"-Formation (STEININGER & WESSELY, 2000), Tonmergel beds (KEMPF & PROSS, 2005), Grisigen-Formation (FRIEBE, 2007b).

Remark: When MUHEIM (1934) introduced the name "Tonmergelstufe" in Vorarlberg this unit included basal deposits, which were later classified with the Deutenhausen Formation (RESCH, 1963a, 1975).

Lithology: Grey to greenish grey, thinly bedded clayey marls with intercalations of calcareous sandstones of flyschoid character. Slumping structures are common. A detailed description can be found in MUHEIM (1934) and RESCH (1963a, b).

Fossils: Trace fossils are common, macrofossils are rare. Calcareous Nannoplankton (FREI, 1979), rare autochthonous ostracods; foraminifers are considered allochthonous (PLÖCHINGER et al., 1958; RESCH, 1976a).

Remark: The fossils mentioned by MUHEIM (1934: p. 189) (freshwater gastropods, shark teeth, fish scales, foraminifera) belong to the Deutenhausen Formation (RESCH, 1963a).

Origin, facies: Predominantly, flyschoid, marine deep water paleoenvironment (PLÖCHINGER et al., 1958).

Chronostratigraphic age: Oligocene, Rupelian (Kiscellian).

Biostratigraphy: Palynologically correlated to Paleogene Zone 20b (HOCHULI, 1978: p. 15); calcareous nannofossil Zone NP24 (FREI, 1979). The biostratigraphic significance of ostracods, in particular, *Cytheridea ventricosa*, described by GOERLICH (1953) and cited by PLÖCHINGER et al. (1958), cannot be considered a valid marker for the Rupelian anymore (DIEM, 1986: p. 504).

Thickness: In the type area 350 to 600 m (BUXTORF et al., 1941), in southern Bavaria 700 to > 800 m (FISCHER, 1960: p. 44) and even > 1,800 m (DOPPLER et al., 2005: p. 366).

Vorarlberg: 180 to 200 m near Dornbirn (Bödelestraße; RESCH, 1976b); estimated 350 m near Egg (PLÖCHINGER et al., 1958).

Lithostratigraphically higher rank unit: Untere Meeresmolasse (Lower Marine Molasse).

Lithostratigraphic subdivision: -

Underlying unit(s): Deutenhausen Formation in southern Bavaria and Vorarlberg; in Switzerland tectonic base (BUXTORF et al., 1941: p. 144).

Overlying unit(s): Horw Sandstone in Vorarlberg and Switzerland; "Bausteinschichten" in southern Bavaria.

Lateral unit(s): May laterally grade into Horw Sandstone ("Bausteinschichten").

Geographic distribution: The "Grisigen-Mergel" ("Tonmergel Schichten") is the most widespread lithostratigraphic unit in the Subalpine Molasse extending from the eastern part of Upper Bavaria to central Switzerland (e.g., DIEM, 1986). Vorarlberg: Vorderer Bregenzerwald, Rheintal near Dornbirn; ÖK50 UTM, map sheets 1218 Bregenz (ÖK-BMN, map sheets 111 Dornbirn, 112 Bezau).

Remarks: The Tonmergelstufe is also reported from the NAFB in Upper Austria (ABERER, 1958: p. 38; HOCHULI, 1978) being, however, now integrated in the Zupfing Formation.

Complementary references: STUCHLIK (1906), BAUMBERGER & KRÄUSEL (1934), HABICHT (1945), ZEIL (1953), HOLLIGER (1955), VOLLMAYR (1954, 1958), SCHMIDT-THOMÉ & GANSS (1955), HÜGEL (1962), RESCH (1963b), HAGN (1967), HÖFLE & KUHNERT (1969), KUHNERT & OHM (1974), GANSS (1977), SCHWERD (1978, 1984), FISCHER (1979), BÜRGISSER et al. (1981), SCHWERD et al. (1983), DIEM (1986), OBERHAUSER et al. (1986a), FREUDENBERGER & SCHWERD (1996), KELLER (2000), MAURER et al. (2002), FRIEBE (2008, 2012), STAUNER et al. (2015).

Horw Sandstein / Horw Sandstone

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Valid; KAUFMANN (1860: p. 16) described from "Grisiger-Flühli" near Horw fine grained, blueish sandstones above the Grisiger Marls (see also there) which he described in more detail later on (KAUFMANN, 1872, 1886), BAUMBERGER (1925a: p. 170) introduced the "Horwerschichten", however, he included also the "Grisigermergel" in this unit, RICHTER (1925: p. 310) separated the lower marls and the upper sandstone, the later called "Bausteinzone" which he considered equivalent to the "Horwer Schichten". RENZ (1937: p. 116) subdivided the Horwerschichten into Grisigermergel and Horwersandstein, BUXTORF et al. (1941) provided a detailed description and discussion. HEIM et al. (1928: p. 14) introduced the name "Horwerschichten" for a sandstone dominated sequence above the "Grisiger Mergel" in the Schwarzachtobel in Vorarlberg but separated the "Eggschichten".

In southern Bavaria, this unit was already described by GÜMBEL (1861: p. 719) as "Bausandsteinzone", there, it is widely distributed and also well documented, usually termed "Bausteinzone" or "Bausteinschichten" (cf. ZÖBELEIN, 1952b, 1961; ZÖBELEIN et al., 1957). The term "Bausteinzone" was introduced in Vorarlberg by MUHEIM (1934). The following description provides some insight into Swiss and Bavarian occurrences but focusses on Voralberg.

Remark: The "Horw-Sandstein" is validated by the Swiss Stratigraphic Commission in the rank of a member, the lithostratigraphic higher rank unit is the "Formation de Vaulruz" (UMM-III) (https://www.strati.ch/de/stratigraphic/horw-sandstein-umm). The „Bausteinschichten" are not validated and we prefer to use the term Horw Sandstone for the occurrences in Vorarlberg.

Type area: Area around the village Horw, Kanton Luzern, Switzerland, map 1:25,000, map sheet 2510 Luzern – Pilatus – Rigi.

Type section: Abandoned marl pit Grisigen ("Mergelgrube Grisigen", BUXTORF et al., 1941), c. 1 km W of Ennethorw, part of Horw, c. 4 km south of the town Luzern, Kanton Luzern, Switzerland, N 47°00′34″ / E 08°17′36″.

Reference section(s): Section at the Steiglebachtobel, along the road between Marbach–Nesslenbode, Kanton Luzern, Switzerland (https://www.strati.ch/de/stratigraphic/horw-sandstein-umm), N 46°50′42″ / E 07°54′48″.

Possible reference sections in Vorarlberg could be: Kirchfelsen Egg at the river Bregenzerach ("Eggschichten" sensu HEIM et al., 1928), N 47°25′52.5″ / E 09°53′38″, a well exposed section in an abandoned quarry at Schwarzachtobel ("Bausteinschichten", OBERHAUSER et al., 1979), N 47°26′36.5″ / E 09°47′10.5″, good outcrops are also exposed along the Bregenzerach near the powerplant Langenegg (N 47°28′12.5″ / E 09°51′48.5″).

Derivation of name: The name Horw-Sandstone derives from the village Horw, Kanton Luzern, Switzerland, map 1:25,000, map sheet 2510 Luzern – Pilatus – Rigi. The term "Bausteinschichten" indicates that the sandstones of this unit were frequently used as construction material ("building blocks").

Synonyms: Bausandsteinzone (GÜMBEL, 1861: p. 719), Horwerschichten (KAUFMANN, 1872: p. 203), Bausteinzone (STUCHLIK, 1906: p. 308), Sandsteinpartie, "Steinbruch- oder Baustein"-Schichten (GILLITZER, 1914: p. 157), Horwerschichten p.p., Horwerplatten p.p. (BAUMBERGER, 1925a: p. 170), Horwer Schichten (RICHTER, 1925), Eggschichten (HEIM et al., 1928: p. 22), Horwer Sandstein (RENZ, 1937), Baustein-Schichten (ZÖBELEIN, 1952b: p. 618), Murnauer Tonmergel p.p. (ZEIL, 1954), Egg-Schichten (HÜGEL, 1956), Horw sandstone (MATTER et al., 1980: p. 281), "Baustein"-Formation (STEININGER & WESSELY, 2000).

Remark: PLÖCHINGER et al. (1958) considered the "Eggschichten" as a special facies of the "Bausteinschichten". However, in their concept of the "Bausteinschichten" they included the lowermost conglomerates at the locality Egg-Kirchfelsen in this lithostratigraphic unit. This idea was rejected by OBERHAUSER et al. (1986b) as these conglomerates already belong to the Weißach Formation.

Lithology: Well-bedded sandstones, commonly with ripple marks and cross-stratification, with intercalated clay marl layers and conglomerate beds ("Nagelfluh") in the upper part. At the transition to the overlying Weissachschichten a coal seam occurs known as Echelsbacher Flöz (ZÖBELEIN, 1961: Abb. 1; HÖFLE & KUHNERT, 1969: p. 42; STAUNER et al., 2015: p. 99).

Fossils: Plant fossils (leaves) are common (KRÄUSEL, 1930), molluscs, ostracods, shark teeth (BAUMBERGER in HEIM et al., 1928; HABICHT, 1945; SCHWERD, 1978). Mass occurrences of the bivalve *Polymesoda* are characteristic for the "Eggschichten" (BAUMBERGER, 1934, 1937).

Origin, facies: The lower part represents mostly shallow marine conditions, which become brackish upsection representing a general shallowing and regressive trend. Good indication for brackich waters is the (mass) occurrence of the bivalve *Polymesoda*.

Chronostratigraphic age: Oligocene, Rupelian to Chattian (Kiscellian to ?Egerian) (ZÖBELEIN, 1961; GÖHLICH & FAHLBUSCH, 2000).

Biostratigraphy: The bivalves indicate Rupelian to Chattian age.

Thickness: In the Murnau Syncline of southern Bavaria ("Bausteinschichten") 140–170 m, with a maximum of 200 m (ZÖBELEIN, 1961: p. 261) and approx. 290 m (GÖHLICH & FAHLBUSCH, 2000: p. 185), along the Bödelestraße 65 m (RESCH, 1976a).

Lithostratigraphically higher rank unit: Switzerland: Formation de Vaulruz, Untere Meeresmolasse (Lower Marine Molasse) as informal group, Bavaria: Untere Meeresmolasse (Lower Marine Molasse) as informal group.

Lithostratigraphic subdivision: No formal subdivision. An informal subdivision in "Tiefere Bausteinschichten" and "Höhere Bausteinschichten" has been proposed by ZÖBELEIN (1961: p. 262) in the Murnau Syncline: the lower unit is represented by clay marl and sandstone alternations, the upper is characterized by thick bedded sandstones and some conglomerates. SCHWERD (1978: p. 9) differentiated three subunits in the westernmost Murnau Syncline: "Untere, Mittlere, Obere Bausteinschichten". The lower part is dominated by sandstones, the middle part by clay marls and the upper part show an increase in grain size from marl over sandstone to a conglomerate ("Dachbank") on top. These subdivisions are, however, laterally not consistent (SCHWERD, 1978: p. 21).

Underlying unit(s): Grisigen Marl ("Tonmergel"). In Bavaria: lower boundary gradational but defined with the decrease of clay marl content and the occurrence of the first sandstone beds (ZÖBELEIN, 1961: p. 261; SCHWERD, 1978: p. 9).

Overlying unit(s): Weißach Formation. Gradational, in western Bavaria with the change from marine to limnic-fluvial facies and in the east by the onset of brackish facies (ZÖBELEIN, 1961: p. 261).

Lateral unit(s): It may laterally grade into Grisigen Marl ("Tonmergel").

Geographic distribution: It is a widespread unit in the Subalpine Molasse of the NAFB stretching from western Switzerland to the eastern part of Upper Bavaria. Vorarlberg: Vorderer Bregenzerwald, Rheintal near Dornbirn-Wolfurt, ÖK50-UTM, map sheets 1218 Bregenz (ÖK-BMN, map sheets 111 Dornbirn, 112 Bezau).

Remarks: -

Complementary references: VOLLMAYR (1954, 1958), SCHMIDT-THOMÉ & GANSS (1955), SCHIEMENZ (1960), HÜGEL (1962), KUHNERT & OHM (1974), RESCH (1976a, 1977b), BÜRGISSER et al. (1981), SCHWERD et al. (1983), SCHWERD (1984), DIEM (1986), FREUDENBERGER & SCHWERD (1996), FRIEBE (2008, 2012), STD 2016.

Weißach-Formation / Weißach Formation

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; already GÜMBEL (1861: p. 131, 689) mentioned "Untere (bunte) Süsswassermolasse" above "Untere Cyrenenschichten (Untere Pechkohlenschichten)" from southern Bavaria, Vorarlberg and Switzerland, HEIM et al. (1928) described "bunte Molasse" from several locations in Vorarlberg, first, MUHEIM (1934: p. 206) introduced the name "Weissachschichten" to integrate highly variable sediments known under different names (e.g., "Teufelslochschichten", "Nesselburgschichten") of the Lower Freshwater Molasse in the Subalpine Molasse of Vorarlberg and southern Bavaria, the term was subsequently widely used in Vorarlberg and Bavaria (e.g., FREUDENBERGER & SCHWERD, 1996; DOPPLER et al., 2005); STEININGER & WESSELY (2000: p. 108) and FRIEBE (2007b: p. 37) introduced the name "Weißach-Formation" without formalization. The following description provides some insight into Swiss and Bavarian occurrences but focusses on Vorarlberg.

Type area: Area between the villages Oberstaufen (Upper Bavaria) and Doren (Vorarlberg) including the rivers Weißach and Bolgenach, ATK25, map sheet R05 Oberstaufen, ÖK50-UTM, map-sheet 2213 Sonthofen (ÖK50-BMN, map-sheet 83 Sulzberg).

Type section: Section in the Weißachschlucht (Weißach Gorge) along the river Weißach, c. 1 km NNE of Steibis, c. 2.3 km SSE of Oberstaufen, Upper Bavaria, N 47°32′12.41″ / E 10°01′44.69″, ATK25, map sheet R05 Oberstaufen (UmweltAtlas Bayern, Geotop-Nummer: 780A018, https://www.umweltatlas.bayern.de/mapapps/resources/reports/geotope/generateBericht.pdf?additionallayerfieldvalue=780A018).

Remark: A type section was not defined by MUHEIM (1934) but he mentioned the locality in the Weißach river, in particular. VOLLMAYR (1958: p. 35) also mentioned the complete section through the Weißachschichten and the lower Steigbachschichten in the Weißach gorge and VOLLMAYR & ZIEGLER (1976: p. 12) defined the Weißach gorge as type locality ("Weißachdurchbruch durch die Hornschuppe").

Reference section(s): A possible reference section in Vorarlberg is the railway viaduct (former power plant near Egg), N 47°26′08.5″ / E 09°53′19.5″ (PLÖCHINGER et al., 1958: p. 296).

Remark: A road cut along the Bödelestraße c. 300 m N of the Bödele pass, c. 5 km ENE of the town Dornbirn, gives a good impression of the marly to sandy lithologies with only occasionally intercalated conglomerates (N 47°25′34″ / E 09°48′33″, FRIEBE, 2008).

Derivation of name: Named after the river Weißach (a tributary of the Bregenzer Ach) which runs through southern Bavaria and Vorarlberg.

Synonyms: Bunte Molasse (STUCHLIK, 1906), Teufelslochschichten, Hochgratschichten, Nesselburgschichten, Nesselburgnagelfluh, Nesselburgserie, Zaumbergserie, Zaumbergschichten (KRAUS, 1926/1927), Bunte Molasse (HEIM et al., 1928: p. 16), Zone (Mergel) von Inngrüne p.p. (HEIM et al., 1928), Teufelsloch-Schichten (KRAUS & REIS, 1929), Hochgratschichten (RICHTER, 1932: p. 429), untere bunte Molasse (RICHTER, 1940: p. 10), Untere Rötliche Molasse (ZÖBELEIN, 1952b), Tiefere Cyrenenschichten (FISCHER, 1960), Weißach-Schichten (SCHWERD, 1984), Weissach Formation, Weissach-Beds (STEININGER & WESSELY, 2000), Weißachschichten (FRIEBE, 2008).

Lithology: A broad range of lithologies is characteristic for this unit: alternations of mostly red, also grey, greenish or brown marls and grey sandstones (beds up to 5 m thickness) which show occasionally intercalated conglomerates (up to 25 m in thickness). Conglomerates ("Nagelfluh") may dominate in some sections, while they are completely absent in other locations (MUHEIM, 1934; PLÖCHINGER et al., 1958; VOLLMAYR, 1958).

Fossils: Plant debris, pollen, characean gyrogonites, ostracods (GÖHLICH & FAHLBUSCH, 2000), terrestrial and freshwater gastropods (ZÖBELEIN, 1952a, 1955a), vertebrates include aquatic reptiles and land mammals (STEHLIN in HEIM et al., 1928; HÜNERMANN & SULSER, 1981; GÖHLICH & FAHLBUSCH, 2000), microfossils (foraminifera) are reworked from older deposits (RENZ, 1937; HAGN, 1950; PLÖCHINGER et al., 1958; HERRMANN et al., 1985).

Origin, facies: Limnic-fluvial-terrestrial environment (based on limnic and terrestrial gastropods) with alluvial floodplains (WEITHOFER, 1903; HAGN, 1950; ZÖBELEIN, 1952a, 1955a: p. 394; ZÖBELEIN et al., 1957: p. 60).

Chronostratigraphic age: Oligocene, Chattian (early Egerian).

Biostratigraphy: The Chattian age is based on terrestrial gastropos (ZÖBELEIN, 1952a) and land mammals. The land mammals have been correlated with Paleogene Mammal Zone MP25 by GÖHLICH & FAHLBUSCH (2000). From the Murnau Syncline, UHLIG (1999, 2002) reports MP24 and MP24/25 based on small mammals from the oldest formation ("Untere Cyrenen-Schichten") of the UBM (Lower Brackish Water Molasse) but also from the laterally equivalent "Untere Bunte Molasse" = Weissach-Schichten) of the USM (Lower Freshwater Molasse) (cf. UHLIG, 1999: Abb. 2, 3).

Thickness: 1,200–1,500 m in western Allgäu (Swabia, Bavaria) (MUHEIM, 1934; RICHTER 1940: p. 12), in the Weißachtal (Vorarlberg) 1,000 m but tectonically truncated at the base (HERRMANN et al., 1985).

Lithostratigraphically higher rank unit: Untere Süßwassermolasse (Lower Freshwater Molasse) as informal unit in Bavaria (e.g., DOPPLER et al., 2005).

Lithostratigraphic subdivision: No formal subdivision, RICHTER (1940: p. 12) differentiated "untere Weißachschichten" ("Nesselburgschichten") which are rich in conglomerates and "obere Weißachschichten" ("Zaumbergmergel") which a devoid of conglomerates

Underlying unit(s): Horw Sandstone ("Bausteinschichten"). Gradational, in western Bavaria with the change from marine to limnic-fluvial facies and in the east by the onset of brackish facies (ZÖBELEIN, 1961: p. 261).

Overlying unit(s): Steigbach Formation. The boundary is gradational based on grain size and colour (ZÖBELEIN et al., 1957; VOLLMAYR & ZIEGLER, 1976), in some locations the boundary is drawn above the uppermost red conglomerate bed (STAUNER et al., 2015).

Lateral unit(s): Cyrenenschichten (e.g., ZÖBELEIN, 1953).

Geographic distribution: It is a widespread unit in the Subalpine Molasse of the NAFB stretching from western Switzerland to the eastern part of Upper Bavaria. Vorarlberg: Vorderer Bregenzerwald, Rheintal near Dornbirn-Wolfurt, ÖK50-UTM, map-sheets 1218 Bregenz, 2213 Sonthofen (ÖK50-BMN, map sheets 83 Sulzberg, 111 Dornbirn, 112 Bezau).

Remarks: -

Complementary references: THOMAS (1926), RICHTER (1932), KORDIUK (1938), VOLLMAYR (1954), SCHMIDT-THOMÉ & GANSS (1955), SCHIEMENZ (1960), HÜGEL (1962), HÖFLE & KUHNERT (1969), RESCH (1976a), CZURDA et al. (1979), BÜRGISSER et al. (1981), STEININGER et al. (1982), SCHWERD et al. (1983), DIEM (1986), FRIEBE (2008, 2012), STD 2016.

Steigbach-Formation / Steigbach Formation

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; KRAUS (1926/1927: p. 16, 22, 28) introduced for a "*graue, rhythmisch scharf entwickelte Nagelfluh-Mergelfolge*" the term Steigbachschichten in the region Allgäu (Bavaria), MUHEIM (1934: p. 236) introduced the term in Vorarlberg for conglomerates ("Nagelfluh"), marls and sandstones above the "Weissachschichten", STEININGER & WESSELY (2000: p. 108) and FRIEBE (2007b: p. 37) introduced the name "Steigbach-Formation" without formalization.

Type area: Area SW of Immenstadt im Allgäu (Swabia, Bavaria), ATK25, map sheet R05 Oberstaufen, ÖK50-UTM, map sheet 2213 Sonthofen (ÖK50-BMN, map sheet 113 Mittelberg).

Type section: KRAUS & REIS (1929: p. 29) described in detail the Steigbach-Schichten along the lower Steigbach valley (Steigbachtobel), SW Immenstadt im Allgäu, N 47°33′10.87″ / E 10°12′48.06″, ATK25, map sheet R05 Oberstaufen, ÖK50-UTM, map sheet 2213 Sonthofen. (UmweltAtlas Bayern, Geotop-Nummer: 780A019, https://www.umweltatlas.bayern.de/mapapps/resources/reports/geotope/generateBericht.pdf?download=false&ids=1810&dsurl=https%3A%2F%2Fwww.umweltatlas.bayern.de%2Farcgis%2Frest%2Fservices%2Fgeologie%2Fageo_ftz%2FMapServer%2F14&layerfieldname=geotop_num&additionallayerfieldname=geotop_num&additionallayerfieldvalue=780R040).

Reference section(s): -

Derivation of name: After the creek Steigbach, left tributary to the river Konstanzer Ach, within and SW of the town Immenstadt im Allgäu (Bavaria, Germany), ÖK50-UTM, map sheet 2213 Sonthofen.

Synonyms: Steigbachschichten, Steigbachserie, Steigbachmolasse, Steigbach-Nagelfluh, Steigbachnagelfluh, Steigbach-Kalknagelfluh (KRAUS, 1926/1927), Steigbach-Schichten (KRAUS & REIS, 1929), Untere Grüngraue Molasse (Zöbelein, 1952b), Steigbach Formation, Steigbach-Beds (Steininger & Wessely, 2000), Steigbach-Formation (Friebe, 2007b).

Lithology: Rhythmic Alternations of grey, greenish or brown marls and sandstones with occasionally intercalated conglomerates. Generally, grain size decreases from S to N in the Steigbachschichten (e.g., Vollmayr, 1958: p. 19).

Fossils: Terrestrial gastropods (Muheim, 1934; Zöbelein, 1952b), land mammals (Stehlin in Heim et al., 1928; Hünermann & Sulser, 1981), wood remains and plant debris (Selmeier, 1972).

Origin, facies: Limnic-fluvial-terrestrial environment (based on limnic and terrestrial gastropods, e.g., Zöbelein, 1952a: p. 13) with alluvial floodplains. Decreasing grain size from S to N and nearly missing conglomerates in the N indicate major sediment input from the S and pinching out of the coarser material northward (e.g., Vollmayr, 1958: p. 19; Stauner et al., 2015).

Chronostratigraphic age: Oligocene, late Chattian (early Egerian).

Biostratigraphy: Chattian age is based on terrestrial gastropods (Zöbelein, 1952b).

Thickness: Up to 1,700 m in the "Hornschuppe" (Vollmayr, 1958: p. 23; Vollmayr & Ziegler, 1976: p. 12), up to 1,350 m in the "Salmaserschuppe" (Vollmayr, 1958: p. 23). Frequently truncated by tectonics.

Lithostratigraphically higher rank unit: Untere Süßwassermolasse (Lower Freshwater Molasse).

Lithostratigraphic subdivision: -

Underlying unit(s): Weißach Formation. As the colour is the only feature to distinguish the Steigbach Formation from the Weißach Formation, a diachronous boundary must be assumed.

Overlying unit(s): Granitische Molasse.

Lateral unit(s): Granitische Molasse, Cyrenenschichten (Richter, 1932; Zöbelein, 1952b).

Geographic distribution: It is a widespread unit in the Subalpine Molasse of the NAFB stretching from the eastern part of Upper Bavaria to eastern Switzerland. Vorarlberg: Vorderer Bregenzerwald, Rheintal near Dornbirn-Kennelbach, ÖK50-UTM, map-sheets 1218 Bregenz, 2213 Sonthofen (ÖK50-BMN, map sheets 83 Sulzberg, 111 Dornbirn, 112 Bezau).

Remarks: -

Complementary references: Richter (1932, 1940), Vollmayr (1954), Schmidt-Thomé & Ganss (1955), Zöbelein et al. (1957), Schiemenz (1960), Höfle & Kuhnert (1969), Schwerd (1984), Herrmann et al. (1985), Freudenberger & Schwerd (1996), Schwerd et al. (1983), Friebe (2008), STD 2016.

Granitische Molasse / Granitic Molasse

J. Georg Friebe & Werner E. Piller

Validity: Invalid; the term "Granitische Molasse" was introduced by Studer (1853: p. 348) in Switzerland for sandstone with coarse grains of quartz and variegated feldspar mimicking a fine-grained granite in the Subalpine Molasse, Gümbel (1861: p. 131) introduced the term "Blättermolasse" and metioned this unit also for Vorarlberg (p. 737–738), Heim et al. (1928) the term "Granitische Molasse" in Vorarlberg. The following description provides some insight into Swiss and Bavarian occurrences but focusses on Vorarlberg.

Type area: Following Kaufmann (1860) and Baumberger (1925a, b) the area around the Horw, S of the town Luzern, is the typical occurrence of "Grantische Molasse". In contrast, the "granititischer Sandstein" is much wider distributed (Baumberger, 1925a: p. 166), map 1:25,000, map sheet 2510 Luzern – Pilatus – Rigi.

Type section: Deep drilling Hünenberg-1, 6.5 km W of the town Zug, 16.5 km NE of the town Luzern, Kanton Luzern, Switzerland, N 47°10′28.86″ / E 08°25′37.42″ (https://www.strati.ch/de/stratigraphic/granitische-molasse-formation).

Reference section(s): Section along the creek Fischebach, a tributary of the river Rümlig (LU), E of the village Entlebuch and SW of the village Schwarzenberg, Kanton Luzern, Switzerland, N 46°59′15″ / E 08°08′28″ (https://www.strati.ch/de/stratigraphic/granitische-molasse-formation).

Derivation of name: The sandstone commonly contains red quartz and, in particular, red feldspar grains which gives this rock a granite-like appearance (Studer, 1853). The term Blättermolasse indicates the high content of leaves.

Synonyms: granitischer Sandstein, Zugersandstein, Bollingersandstein (Kaufmann, 1860: p. 8, 117), Blättermolasse (Gümbel, 1861), Horwersandstein (non Horwerplatten) p.p. (Baumberger, 1925a: p. 166), Granitische Molasse, granitischer Sandstein p.p., St. Margarethenstein (Heim et al., 1928), Sandsteinpaket (Müller, 1930), Granitische Sandsteine, St. Margarethen Sandstein, Zuger Sandstein (op. cit. Muheim, 1934: p. 258), Formation der Granitischen Molasse (https://www.strati.ch/de/stratigraphic/granitische-molasse-formation).

Lithology: Fine to coarse grained sandstone beds (8–10 m thickness) with red quartz and feldspar grains and muscovite alternating with yellowish, brown or grey marls, which dominate over the sandstone. In Switzerland and in Bavaria additional variegated conglomerates ("bunte Nagelfluh") occur (Kaufmann, 1860; Baumberger, 1925a, b; Müller, 1930).

Fossils: Characean gyrogonites (Baumberger in Heim et al., 1928), freshwater and terrestrial gastropods (Baumberger in Heim et al., 1928; Muheim, 1934; Wenz, 1935; Zöbelein, 1963), freshwater bivalves (Baumberger in Heim et al., 1928; Modell, 1934), reptiles and land mammals (Stehlin in Heim et al., 1928; Zöbelein, 1963), plant debris and leaves (collection Kräusel at the museum inatura Dornbirn).

Origin, facies: Limnic-fluvial paleoenvironment.

Chronostratigraphic age: Early Miocene, Aquitanian (late Egerian).

Remark: In Switzerland, the Granitische Molasse starts already in the Chattian (Zöbelein et al., 1957; Müller, 1971).

Biostratigraphy: Based on gastropods Aquitanian age.

Thickness: A maximum thickness of 1,800 m (as "Blättermolasse") is reported by KRAUS (1951: p. 125) and ZÖBELEIN et al. (1957: p. 64), 1,500–1,700 m between the rivers Rhein and Bregenzer Ach by HEIM et al. (1928: p. 12).

Lithostratigraphically higher rank unit: Untere Süßwassermolasse (Lower Freshwater Molasse).

Lithostratigraphic subdivision: -

Underlying unit(s): Steigbach Formation.

Overlying unit(s): Tectonic boundary in Vorarlberg, Switzerland: Luzern Formation.

Lateral unit(s): Kojen Formation (MUHEIM, 1934), Steigbach Formation, Cyrenen-Schichten (SCHWERD, 1984: p. 299), Switzerland: Uerscheli Formation, which is, however, of Chattian age (https://www.strati.ch/de/stratigraphic/uerscheli-formation).

Geographic distribution: This unit occurs from central Switzerland in the west to eastern Upper Bavaria. Vorarlberg: Vorderer Bregenzerwald, Rheintal near Dornbirn-Kennelbach, ÖK50-UTM, map sheets 1218 Bregenz (ÖK-BMN, map sheets 83 Sulzberg, 111 Dornbirn, 112 Bezau).

Remarks: -

Complementary references: RICHTER (1932, 1940), VOLLMAYR (1954), SCHMIDT-THOMÉ & GANSS (1955), VOLLMAYR & ZIEGLER (1976), HERRMANN (1978), SCHWERD et al. (1983), SCHWERD (1984), HERRMANN et al. (1985).

Kojen-Formation / Kojen Formation

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; MUHEIM (1934: p. 249) introduced and described the "Kojenschichten" as a coarse grained equivalent of the "Granitische Molasse" what has been supported by RICHTER (1932) and RICHTER (1940: p. 28) provided a detailed description, STEININGER & WESSELY (2000) and FRIEBE (2007b) used the term "Kojen-Formation" without formalization.

Type area: Along the mountain range "Nagelfluhkette" between the river Bolgenach (Vorarlberg) and the town Immenstadt im Allgäu (Bavaria), ÖK50-UTM, map sheet 1218 Bregenz, 2213 Sonthofen (ÖK50-BMN, map sheet 112 Bezau), ATK25, map sheet R05 Oberstaufen.

Type section: -

Reference section(s): -

Derivation of name: Named after the mountain range Kojen, south of the village Riefensberg (Vorarlberg) with the mountain Kojenstein (1.5 km SSE of Riefensberg) as highest elevation (1,300 m), ÖK50-UTM, map sheet 1218 Bregenz (ÖK50-BMN, map sheet 112 Bezau).

Synonyms: Hochgratschichten (KRAUS & REIS, 1929), Kojen-Schichten (HAGN & HÖLZL, 1952), Kojen Formation, Kojen-Beds (STEININGER & WESSELY, 2000).

Lithology: Badly sorted and rounded, mostly red conglomerates (up to 50 m in thickness) with occasionally very coarse gravel dominate over red, grey, greenish or brown marls and massive to platy sandstones (3–4 m in thickness) (MUHEIM, 1934; RICHTER, 1940).

Remark: Similar to the Weißach Formation but separated from this unit by the grey coloured Steigbach Schichten. The conglomerates are coarser in the Kojen Schichten than in the Steigbach Schichten.

Fossils: Terrestrial gastropods (MUHEIM, 1934: p. 257), marine biota (foraminifera, bivalves) mentioned by MUHEIM (1934: p. 258) are considered to be reworked.

Origin, facies: Fluvial-terrestrial with limnic intercalations.

Chronostratigraphic age: Early Miocene, Aquitanian (late Egerian).

Biostratigraphy: Based on terrestrial gastropods an Aquitanian age was proposed by MUHEIM (1934: p. 252) being in line with MÜLLER (1930).

Thickness: MUHEIM (1934: p. 257) reports an average thickness of 450–500 m in Vorarlberg, up to 1,000 m in the Hornschuppe near Immenstadt (Bavaria) (VOLLMAYR, 1958), DOPPLER et al. (2005: p. 367) report 1,200 m and SCHWERD et al. (1983) 1,200–1,300 m.

Lithostratigraphically higher rank unit: Untere Süßwassermolasse (Lower Freshwater Molasse).

Lithostratigraphic subdivision: -

Underlying unit(s): Steigbach Formation.

Overlying unit(s): Tectonically truncated.

Lateral unit(s): Granitische Molasse.

Geographic distribution: In southern Bavaria (Allgäu) and Vorarlberg (Bregenzerwald), ÖK50-UTM, map sheet 1218 Bregenz (ÖK50-BMN, map sheet 112 Bezau).

Remarks: -

Complementary references: RENZ (1937), KORDIUK (1938), VOLLMAYR (1954), SCHMIDT-THOMÉ & GANSS (1955), SCHIEMENZ (1960), HERRMANN & SCHWERD (1983), SCHWERD (1984), HERRMANN et al. (1985), STD 2016.

Luzern-Formation / Luzern Formation

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Valid; KAUFMANN (1860: p. 121) mentioned "Sandsteine der Luzerner plattenförmigen Molasse" and introduced (1872: p. 213, 316) the name "Luzernerschichten" for these bivalve-rich sandstones. The unit has been facially described in great detail by KELLER (1989) and he introduced the name "Luzerner-Formation", JOST et al. (2016) introduced the name Lucerne Formation.

In Vorarlberg, HEIM et al. (1928: p. 9) described "Untere Miocänmolasse, Burdigalien" and subdivided this unit into upper "grauer mariner Sandstein" (grey marine sandstone) and lower "marine Nagelfluhserie" (marine sandstones and conglomerates) with a possible correlation to the "Luzernerschichten" in Switzerland (p. 49). BLUMRICH (1930) introduced the name "Luzernerschichten" for the Burdigalian in the Pfänder area. A more detailed description gave PLÖCHINGER et al. (1958), HERRMANN & SCHWERD (1983), HERRMANN et al. (1985), SCHAAD et al. (1992), and FRIEBE (2007b: p. 35), the later introduced the term "Luzern-Formation".

The following description provides some insight into Swiss and Bavarian occurrences but focusses on Vorarlberg.

Remark: Regardless that KELLER (1989) described the unit only in an unpublished Ph.D. thesis, the Swiss Stratigraphic Commission validated the Luzern Formation (https://www.strati.ch/de/show/mol/mol/luzern-formation).

The name Lucerne Formation is not in accordance with the International Stratigraphic Guide (SALVADOR, 1994) because "*The geographic component of a name should not be altered by translation into another language*" (p. 20).

Type area: Area within and aound the city of Luzern, Canton Luzern, Switzerland, map 1:25,000, map sheet 2510 Luzern – Pilatus – Rigi.

Type section: Quarry "Lädelisteinbruch" in the city of Luzern, Canton Luzern, Switzerland, N 47°03′12.59″ / E 08°17′20.59″ (BAUMBERGER in NIGGLI, 1915: p. 46).

Remark: The quarry "Lädelisteinbruch" was mentioned by BAUMBERGER (in NIGGLI, 1915) but not explicitly defined as type section. The Swiss Stratigraphic Commission, however, lists this location as type section. In addition, they also list a location along the river bed in the Rümligschlucht, W of Schwarzenberg, Canton Luzern, as type section (N 47°00′13.37″ / E 08°08′26.88″) described by KELLER (1989: Fig. 4-2).

Reference section(s): Quarry "Waldisberg", c. 0.5 km W of Freienbach, Canton Schwyz, Switzerland, N 47°12′17.80″ / E 08°44′52.26″ (MÜLLER, 1971).

Remark: The Swiss Stratigraphic Commission lists this locality as a reference section, however, the quarry Waldisberg is the type section of the "Bächer Sandstein" which is considered equivalent to the Luzern Formation by MÜLLER (1971: p. 23) (https://www.strati.ch/de/stratigraphic/luzern-formation).

For Vorarlberg, the section along the Wirtatobel (Pfänder area) (which is one of the most important Miocene Molasse sections – cf. PLÖCHINGER et al., 1958: p. 313) could be considered as reference section. PLÖCHINGER et al. (1958: p. 313, Abb. 4, Tafel XXIV) provided a section description and documentation, N 47°30′08.2″ / E 09°47′36.6″ (coal seam at the top), ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz).

Derivation of name: Named after the City Luzern, capital of the Canton Luzern, Switzerland.

Synonyms: Luzernerschichten, Luzernersandstein (KAUFMANN, 1872), Rorschacher Sandstein p.p. (MILLER, 1876: p. 209), Rorschacher Plattensandstein p.p., Rorschacher Stein p.p. (MILLER, 1876: p. 210), Luzerner Sandstein (NIGGLI, 1915), Luzerner-Formation (KELLER, 1989), Luzern-Formation (FRIEBE, 2007b), Lucerne Formation (JOST et al., 2016).

Lithology: Well-bedded, bluegrey to greenish, glauconitic sandstone with rare lenses and thin layers of conglomerate, and thin sandy-silty intercalations, thin coal seams (e.g., BAUMBERGER, 1925: p. 168).

In Vorarlberg (Wirtatobel, Pfänder area), the Luzern Formation shows the following sequence (HEIM et al., 1928: p. 9, PLÖCHINGER et al., 1958, SCHAAD et al., 1992, FRIEBE, 2007b, FRIELING et al., 2009): basal conglomerate with oysters and shark teeth ("Basisnagelfluh") (1–2 m), glauconitic sandstone ("Zone der Glaukonitischen Sandsteine"), marls with coaly intercalations ("erster terrestrischer Horizont", 15 m), alternation of sandstone, marl and conglomerate (28–37 m), conglomerate with pebbles of several decimeters (Kanzelfels-Nagelfluh or Hauptnagelfluhbank, approx. 50–60 m), sandstone with marl intercalations (50 m), Gebhardsberg-Nagelfluh (30–40 m), coaly horizon (c. 2 m) ("Kohleflöz vom Wirtatobel", "zweiter terrestrischer Horizont"). FRIELING et al. (2009) provide also a detailed facial description and sequence-stratigraphic interpretation for Vorarlberg and southwestern Bavaria. The facies variations within the Pfänder delta system are of local importance only (SCHAAD et al., 1992), the coal seam on top, however, is widely distributed in Bavaria and Switzerland (known under various names), however, it disappears to the east in southern Bavaria.

Remark: The coal seam in the Wirtatobel was first mentioned by SCHMIDT (1879: p. 376) as "Kohlenflötz im Wirtatobel". Other names are, e.g., "Kohlehorizont" (HEIM et al., 1928: p. 8), "Horizont der Wirtatobel-Kohle" (HERRMANN & SCHWERD, 1983), "Wirtatobel-Pechkohlenflöz" (CZURDA, 1993), "zweiter terrestrischer Horizont" (SCHAAD et al., 1992). The coal bearing package is c. 2 m thick representing an alternation of marls and coaly layers, the exploited seam is only a few decimeters thick (maximum 0.7 m) and is a soft coal also named "Pechkohle" (pitch coal) and "Glanzkohle" (bright coal).

Fossils: Calcareous nannoplankton, benthic foraminifers, dinoflagellates, oyster beds (in conglomerates), badly preserved bivalves and gastropods, barnacles, plant remains, trace fossils (BLUMRICH, 1930, 1936; STEININGER et al., 1982; HERRMANN & SCHWERD, 1983; OBERHAUSER et al., 1986b; WENGER, 1987b; FRIEBE, 2001, 2007b), a single rhinoceros tooth together with abundant shark and occasionally ray teeth (LADSTÄTTER, 1992), rare land mammals (*Mastodon*) (GÜMBEL, 1896: p. 118; VACEK, 1887: p. 122) and terrestrial gastropods near the coal seam (HEIM et al., 1928; WENZ, 1933, 1935). Besides a rich selachian fauna and the irregular echinoid *Scutella*, small land mammals are recorded in central Switzerland (JOST et al., 2016).

Origin, facies: Shallow marine to deltaic paleoenvironment. In the Pfänder area of Vorarlberg, SCHAAD et al. (1992) and FRIELING et al. (2009) interpreted the alternations of conglomerates and sandstones as components of a Gilbert delta as part of the Pfänder alluvial fan-delta. The sandstones have been deposited in a shallow marine setting under the influence of tides and waves, respectively. The conglomerates represent the foreset and topset of the delta. The sequence is mostly terminated by marine sediments, however, the Wirtatobel coal seam shows freshwater and terrestrial biota.

Chronostratigraphic age: Early Miocene, Burdigalian (Eggenburgian).

Biostratigraphy: In Switzerland, the Lucerne Formation can be correlated to the Mammal Neogene Zones (? MN2b) MN3a–MN3b (JOST et al., 2016) which were calibrated with magnetostratigraphy (SCHLUNEGGER et al., 1996).

At the Wirtatobel, RÖGL (in HERRMANN & SCHWERD, 1983) and WENGER (1987b) identified Eggenburgian foraminifers (*Elphidium ortenburgensis*, *Uvigerina* cf. *bononiensis*), MÜLLER (in

Resch, 1977a: A83) identified the calcareous nannofossil Zone NN3 (*Sphenolithus belemnos*) 20 meters above the "Kanzelfels-Nagelfluh". See also discussion in Steininger et al. (1982).

Thickness: Baumberger (1925: p. 168) reports a thickness of c. 800 m from the area around Luzern. Thickness decreases in an eastward direction within Switzerland (cf. Heim et al., 1928). In Vorarlberg, Schaad et al. (1992: p. 149) reported 273 m and Blumrich (1930, 1936) 180 m from the Pfänder area.

Lithostratigraphically higher rank unit: Obere Meeresmolasse (Upper Marine Molasse) as informal unit in Bavaria (e.g., Doppler et al., 2005).

Lithostratigraphic subdivision: -

Underlying unit(s): In Vorarlberg discordantly above "Granitische Molasse" (Friebe, 2007b).

Overlying unit(s): St. Gallen Formation.

Lateral unit(s): -

Geographic distribution: The Luzern Formation extends from central Switzerland in the west to southern Bavaria in the east. In Vorarlberg, it occurs in the area around the mountain Pfänder, ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz).

Remarks: In older literature the term Luzern Formation has frequently not been used but these sedimentary rocks were only named Burdigalian.

The lithostratigraphic units "Gerhardsberg-Nagelfluh", "Kanzelfels-Nagelfluh" and "Glaukonitsandstein" which are shown in the ASC 2004 (Piller et al., 2004) for the OMM (Upper Marine Molasse), are subunits within the Luzern Formation, are only local features and are no valid lithostratigraphic units (beds or members).

The coal seam in the Wirtatobel, c. 3.5 km ESE of the city of Bregenz, has been exploited since the 1820s until 1948 (Heinrich, 1980; Weber & Weiss, 1983; Weiss, 1984). Scientifically, the coal was already described by Schmidt (1879), Gümbel (1896) and Blumrich (1908).

Since the coal seam, which occurs in Vorarlberg and clearly separates the underlying Luzern Formation from the overlying St. Gallen Formation, thins out to the east the differentiation of both formations is difficult. Consequently, most authors use only Upper Marine Molasse without any differentiation, or apply different lithostratigraphic units (Doppler et al., 2005) or use the chronostratigraphic names Burdigalian and Helvetian (which are not appropriate for lithostratigraphy).

Complementary references: Richter (1926), Kraus (1926/1927), Renz (1937), Schiemenz (1960), Bürgisser et al. (1981), Freudenberger & Schwerd (1996), Keller (2000), STD 2016, Schlüchter et al. (2019).

St. Gallen-Formation / St. Gallen Formation

J. Georg Friebe & Werner E. Piller

Validity: Valid; Studer (1853: p. 449) described from the marine Molasse in the area of St. Gallen fossil rich-marls and sandstones and provides a rich faunal list (identified by K. Mayer), Kaufmann (1872: p. 230) described the "Sanktgallerschichten" as conglomerates ("Nagelfluhzone") with marls rich in marine fauna, Miller (1876: p. 193) described the lithology and fossils of the unit which occurs from the area of Luzern to southern Bavaria and used the term "St. Galler Schichten", Keller (1989) described these sediments in detail and introduced the name "St. Galler Formation", Jost et al. (2016) changed it to St. Gallen Formation and Friebe (2007a, b) and Schlüchter et al. (2019) to "St.-Gallen-Formation".

The following description provides some insight into Swiss and Bavarian occurrences but focusses on Vorarlberg.

Remark: Regardless that Keller (1989) described the unit only in an unpublished Ph.D. thesis the Swiss Stratigraphic Commission validated the St. Gallen Formation (https://www.strati.ch/de/stratigraphic/st-gallen-formation).

The valid name of the formation is "St.-Gallen-Formation" in Swiss German but "St. Gallen-Formation" in Austria and Germany.

Type area: The area between the towns St. Gallen and Rohrschach, canton St. Gallen, Switzerland, TK25, map sheet 1075 Rohrschach (Miller, 1876: p. 209).

Type section: Along the river bed of the Goldach in the Martinstobel, c. 4.5 km ENE of the town St. Gallen, canton St. Gallen, Switzerland, N 47°26′33.36″ / E 09°25′46.50″, the lower and upper boundary are exposed. This location was already mentioned by Studer (1853: p. 451) and described by, e.g., Büchi (1967) and Keller (1989: Abb. 3-30), TK25, map sheet 1075 Rohrschach.

Reference section(s): Section along the river Sitter, c. 4.5 km SW of St. Gallen, canton St. Gallen, Switzerland, N 47°24′06.56″ / E 09°19′24.85″, TK25, map sheet 1075 Rohrschach (https://www.strati.ch/de/stratigraphic/st-gallen-formation).

For Vorarlberg, the section along the Wirtatobel (Pfänder area) (which is one of the most important Miocene Molasse sections – cf. Plöchinger et al., 1958: p. 313) could be considered as reference section. Plöchinger et al. (1958: p. 313, Abb. 4, Tafel XXIV) provided a section description and documentation, N 47°30′08.2″ / E 09°47′36.6″ (at the base of the formation at the coal seam of the Luzern Formation), ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz).

Derivation of name: Named after the town St. Gallen, capital of the canton St. Gallen, Switzerland.

Synonyms: Sanktgallerschichten (Kaufmann, 1872: p. 230), St. Galler Schichten (Miller, 1876), St. Gallerschichten (Kaufmann, 1886: p. 560), St. Galler Formation (Keller, 1989), St. Gallen Formation (Jost et al., 2016), St.-Gallen-Formation (Schlüchter et al., 2019).

Lithology: Generally, fossil-rich blueish and grey marls, sandstones and conglomerates in variable proportions. In the Wirtatobel section, the sediments of the St. Gallen Formation belong to the "zone of marls and fine-grained sandstones" (Frieling et al., 2009). For a detailed facies analysis see Schaad et al. (1992), Frieling et al. (2009) provide also a detailed facial description and sequence-stratigraphic interpretation for Vorarlberg and southwestern Bavaria.

Fossils: Well-known and described is a rich but mostly badly preserved fauna with gastropods and bivalves (KAUFMANN, 1872; MILLER, 1876; BLUMRICH, 1930, 1936; STEININGER et al., 1982; PFISTER et al., 2011). In addition, foraminifera (HERRMANN & SCHWERD, 1983), bryozoans, barnacles, ostracodes, echinoids, fish teeth, trace fossils and characeans (RESCH, 1977a) are recorded. JOST et al. (2016) described small mammals and a tooth of a proboscidean from Switzerland.

Origin, facies: Shallow marine to deltaic paleoenvironment. According to SCHAAD et al. (1992) the paleoenvironmental conditions were similar to that of the Luzern Formation with only minor fluvial incursions and the sediments can be interpreted as different components of a Gilbert delta as part of the Pfänder alluvial fan-delta. The sandstones have been deposited in a shallow marine setting under the influence of tides and waves, respectively. The conglomerates represent the foreset and topset of the delta.

Chronostratigraphic age: Early Miocenen, Burdigalian (Eggenburgian–Ottnangian).

Based on $^{87}Sr/^{86}Sr$-isotope-stratigraphy KELLER (1989) deduced a depositional age for the St. Gallen Formation between 18.5 and 17 Ma.

Biostratigraphy: The small mammals from Switzerland indicate Mammal Neogene Zones MN3b–MN4b, which are correlated with the late Burdigalian (JOST et al., 2016).

Foraminifera from the Wirtatobel gave an Eggenburgian age (RÖGL in HERRMANN & SCHWERD, 1983), from the river Goldach in the Martinstobel (St. Gallen, Switzerland) WENGER (1987b) reported Eggenburgian–Ottnangian. The mollusk fauna from Vorarlberg also indicates Eggenburgian–Ottnangian (HERRMANN et al., 1975; STEININGER et al., 1982: p. 83–84).

Thickness: In the area of Luzern c. 200 m (KELLER, 2000), in the Wirtatobel section only c. 100 m after SCHAAD et al. (1992), for southern Bavaria 300 m are reported (FRIEBE, 2007b). Thickness is laterally highly variable.

Lithostratigraphically higher rank unit: Obere Meeresmolasse (Upper Marine Molasse).

Lithostratigraphic subdivision: -

Underlying unit(s): Luzern Formation.

Overlying unit(s): “Pfänder-Schichten” (as part of the Upper Freshwater Molasse).

Lateral unit(s): No information available.

Geographic distribution: The St. Gallen Formation extends from central Switzerland in the west to southern Bavaria in the east. In Vorarlberg, it occurs in the area around the mountain Pfänder, ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz).

Remarks: Since the coal seam, which occurs in Vorarlberg and clearly separates the underlying Luzern Formation from the overlying St. Gallen Formation, thins out to the east the differentiation of both formations is difficult. Therefore, most authors use only Upper Marine Molasse (as informal group) without any differentiation, or apply different lithostratigraphic units (DOPPLER et al., 2005) or use the chronostratigraphic names Burdigalian and Helvetian (which are not appropriate for lithostratigraphy).

Complementary references: BÜRGISSER et al. (1981), STD 2016.

Pfänder Schichten / Pfänder Beds

J. GEORG FRIEBE & WERNER E. PILLER

Validity: Invalid; GÜMBEL mentioned the term “Obere Süsswassermolasse” in 1861 (p. 114) and also listed authors who used this name already before (p. 676); sediments of the Upper Freshwater Molasse (OSM) are widely distributed in Southern Bavaria and Switzerland, and they also occur in Vorarlberg; KAUFMANN (1872: p. 235) mentioned in Switzerland the “Napf- und Albisschichten” as units of the OSM, in southern Germany the OSM is regionally differently treated: in Swabia (Bavaria), e.g., the basal unit “Limnische Untere Serie” is followed by the “Fluviatile Untere Serie”, the “Geröllsandserie” and at the top the “Obere Serie” (DOPPLER, 1989), in Baden-Württemberg, and partly also in Switzerland, units such as “Haidenhofmergel”, “Steinbalmensande”, “Öhninger Schichten” and “Erolzheimer Sande” are used (ERB & KIDERLEN, 1955). A formalization and validation of these units is still missing (both in Switzerland and southern Germany).

In Vorarlberg, contrary to the other (informal) groups of the Molasse sediments, the Upper Freshwater Molasse (OSM) has never been subdivided into formations. HEIM et al. (1928: p. 8) introduced the term and synonymised it with the “Silvanaschichten”, in more recent literature it is only listed as OSM. It was FRIEBE (2007b), who started to specify the OSM in Vorarlberg and introduced the name “Pfänderschichten”.

Type area: The mountain range Pfänder, E of the city Bregenz, Vorarlberg, ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz).

Type section: Not defined, at the mountain Pfänder, HEIM et al. (1928) roughly described a sequence, which could be defined as type section.

Reference section(s): -

Derivation of name: Named after the mountain Pfänder (1,062 m), E of the city Bregenz, Vorarlberg, Austria, ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz).

Synonyms: Silvanaschichten (named after the gastropod “*Helix*” = *Cepaea silvana*) (in Vorarlberg introduced by HEIM et al., 1928), Obere Süsswassermolasse p.p. (GÜMBEL, 1861).

Lithology: Various types of sandstones, marls and brownish-reddish conglomerates occur in the Pfänder area. The succession shows cycles of conglomerate (“Nagelfluh”) – sandstone – silt/clay (HERRMANN & SCHWERD, 1983). In some places occur also freshwater limestones (e.g., locality Sorgen, N of the Pfänder summit, HERRMANN & SCHWERD, 1983). The lithologic composition changes laterally rapidly and the unit is dominated by brown-yellowish to grey marls (VOLLMAYR, 1954), these marls are also known as “Flinz” (grey-green brownish marls and mica-rich sandy marls, ZÖBELEIN et al., 1957: p. 59).

Fossils: Terrestrial and freshwater gastropods (HEIM et al., 1928; WENZ, 1933, 1935; HERRMANN & SCHWERD, 1983), freshwater bivalves (MODELL, 1934, 1940), plant debris and leaves (Kräusel, unpublished, collection inatura Dornbirn), reptiles and mammals (HÜNERMANN in STEININGER et al., 1982), onkoids frequently with gastropods as nuclei ("Eichenberger Kugeln") (BLUMRICH, 1927; KÜHNELT, 1981).

Origin, facies: The Pfänder Beds are part of the Pfänder alluvial fan what explains the rapid lateral lithologic changes with a dominance of fluvial sediments but also lacrustine deposits, such as freshwater limestones.

Chronostratigraphic age: Early to Middle Miocene, Burdigalian–Langhian (Ottnangian–Badenian, Sarmatian?).

Remark: For the OSM the lower boundary is still under discussion but most authors agree that it is located close to the Ottnangian/Karpatian boundary. The upper boundary varies regionally from the Badenian to the Pannonian (e.g., DOPPLER, 1989).

Biostratigraphy: Small mammals allow a correlation with MN6 of the Mammal Neogene Zones, which is correlated with the middle Badenian (HÜNERMANN in STEININGER et al., 1982). In general, for the type area a middle Miocene age is highly probable.

Thickness: HEIM et al. (1928) report 700–800 m for the Pfänder area, HERRMANN & SCHWERD (1983: p. 8) estimate 2,000–2,500 m.

Lithostratigraphically higher rank unit: Obere Süßwassermolasse (Upper Freshwater Molasse) as informal unit in Bavaria (DOPPLER et al., 2005).

Lithostratigraphic subdivision: -

Underlying unit(s): St. Gallen Formation, the boundary is not marked by a significant change in lithology. Fossils are the only criterion to distinguish the Pfänder Beds from the St. Gallen Formation.

Overlying unit(s): Erosional upper boundary.

Lateral unit(s): The Pfänder Beds interfinger with the (unnamed) freshwater deposits of the Sommersberg and Hauchenberg/Adelegg Fan, respectively.

Geographic distribution: At the mountain Pfänder, E of the city Bregenz, Vorarlberg, ÖK50-UTM, map sheet 1218 Bregenz (ÖK-BMN, map sheet 82 Bregenz), the unit continues further to the east (Bavaria) and to the west (Switzerland) but is lithostratigraphically differently treated (e.g., eastern Allgäu; MÜLLER, 1930, 1952; VOLLMAYR, 1954; ZÖBELEIN et al., 1957).

Remarks: The Pfänder Beds represent sediments deposited in the Pfänder Fan. This fan is only one of a series of paleorivers and connected alluvial fans along the Molasse trough from Switzerland to southern Bavaria. In the well-described southern Bavarian examples, the individual fans are not reflected in specific lithostratigraphic units but are summarized in the Upper Freshwater Molasse. The applies in a similar way to older sediments in this part of the North Alpine Foreland Basin which also belong to a series of alluvial fans. The concept to assign each alluvial fan a specific lithostratigraphic unit has to be discussed.

Complementary references: BLUMRICH (1904, 1930, 1936), SCHMIDT-THOMÉ & GANSS (1955), PLÖCHINGER et al. (1958), CZURDA (1993), MAURER & BUCHNER (2007).

North Alpine Foreland Basin: Salzburg – Upper Austria

Voitsdorf-Formation / Voitsdorf Formation

LUDWIG R. WAGNER & FRED RÖGL

Validity: Invalid; JANOSCHEK (1959) mentioned the "limnic series" of variegated clays and sandstones with lignite layers and (1961) "limnische Tone mit Kohlenflözen" and "Limnische Serie". For this unit the name "Voitsdorf-Formation" was introduced by WAGNER (1996b, 1998) (only subsurface).

Type area: In the area of the village Voitsdorf, c. 7 km SW of market town Kremsmünster and 17 km south of the town Wels, Upper Austria; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 49 Wels).

Type section: Not defined; proposed is the deep well Voitsdorf 1 (N 48°01′10″ / E 14°05′20″), Rohöl-Aufsuchungs AG, cores 2, 3 and 4, from 2,069 to 2,088 m; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 49 Wels).

Reference section(s): Not defined; proposed is the deep well Puchkirchen 1 (N 48°01′38″ / E 13°34′37″), Rohöl-Aufsuchungs AG; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Derivation of name: Named after the village Voitsdorf, c. 7 km SW of the market town Kremsmünster, which is the largest oilfield in Upper Austria.

Synonyms: Limnische Serie, limnic beds (JANOSCHEK, 1959), Sandsteinstufe p.p.

Lithology: Variegated pelites with quartz sandstones interbedded, with root imprints and coal seams (up to 3 m).

Fossils: Plant fragments and palynomorphs.

Origin, facies: Fluvial and limnic floodplain deposits north of the Central Swell Zone. The top of the unit is built by a coal bed of a swamp environment.

Chronostratigraphic age: Late Eocene, Priabonian.

Biostratigraphy: In deep well Kohleck 5, core 7 (2,554–2,553.4 m), Rohöl-Aufsuchungs AG, Paleogene floral Zone Pg.Z 18 was determined (HOCHULI, 1978).

Thickness: In the proposed type section in the deep drill Voitsdorf 1 it is 19 m. Maximum thickness with a high sand content is up to 80 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline or Mesozoic Basement.

Overlying unit(s): Cerithium Beds, Ampfing Formation, Lithothamnium Limestone.

Lateral unit(s): -

Geographic distribution: In the southern part of the NAFB of Salzburg and Upper Austria, and also in Bavaria.

Remarks: The so-called basal sandstones which represent the transgressive horizon on Mesozoic and crystalline basement are not differentiated here. They are not continuously preserved, but ABERER (1958) reports a thickness of up to 4.2 m ("Basisschichten") and UNGER (1996: "Priabon-Sandsteine", "Basissandsteine") mentions a thickness up to 30 m for the Eastern Molasse (Bavarian – W Upper Austria).

Complementary references: RÖGL & RUPP (1996).

Cerithien Schichten / Cerithium Beds

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Invalid; the term "Cerithium beds" was introduced by JANOSCHEK (1959: p. 850) and is widely used in wells for hydrocarbon exploration (only subsurface).

Type area: ABERER (1958) mentioned the area Mühlleiten–Puchkirchen–Wegscheid, Upper Austria, as occurrence for this unit; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheets 47 Ried im Innkreis, 48 Vöcklabruck). The deep well Eberstallzell 5 is further to the east (see below).

Type section: Not defined; a possible type section could be the deep well Eberstallzell 5 core 2: 2,080.2–2,086.1 m (N 48°02′54″ / E 13°58′38″), Rohöl-Aufsuchungs AG, Upper Austria; ÖK50-UTM, map sheet 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 49 Wels).

Reference section(s): Not defined; proposed is the deep well Hocheck 3 (N 48°03′34″ / E 13°19′34″), Rohöl-Aufsuchungs AG, Upper Austria; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Derivation of name: Named after the gastropod genus *Cerithium* frequently occurring as coquinas in the fossiliferous shale.

Synonyms: Brackisch-marine Serie (ABERER, 1958), Cerithienschichten (JANOSCHEK, 1961; WAGNER, 1980), Cerithian beds.

Lithology: Dark brown-grey to greenish soft fossiliferous clayey marl to clayey marlstone with quartz sandstones interbedded and molluscan coquinas in the marls.

Fossils: Dominated by the gastropod *Tympanotonos* ("*Cerithium*" is used as a general name for this type of gastropods); in addition, the bivalves *Polymesoda*, *Ostrea, Pecten, Cardium*, the worm tube *Rotularia*, as well as a rich ostracod fauna and some foraminifera occur.

Origin, facies: Restricted to an inner lagoonal environment with tidal flats transected by tidal channels. Deposited north of the Central Swell Zone (Landshut-Neuötting High in Bavaria) of the NAFB in Upper Austria and Bavaria.

Chronostratigraphic age: Late Eocene, Priabonian.

Biostratigraphy: Based on the ostracod fauna uppermost Lutetian to lower Oligocene ("Ledian") (ABERER, 1958).

Thickness: In deep well Eberstallzell 5 it is 6 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Voitsdorf Formation.

Overlying unit(s): Ampfing Formation.

Lateral unit(s): -

Geographic distribution: Distributed in a narrow belt close to the southern margin of the NAFB between Steyr, Wels and Mattsee, Upper Austria, and continues into Bavaria. The belt moves in time from SW to NE (WAGNER, 1980).

Remarks: A first record of Cerithium beds in the Molasse Basin in Upper Austria was drilled in 1956 in the deep well Puchkirchen 1 of Rohöl-Aufsuchungs AG.

Complementary references: JANOSCHEK (1961).

Ampfing-Formation / Ampfing Formation

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Invalid; the term was introduced by WAGNER (1996b: p. 40) as "Ampfinger-Formation" and "Ampfing-Formation" for the well-known "Ampfinger Sandstein" or "Ampfinger Schichten" in Upper Bavaria and Upper Austria (only subsurface).

Type area: Area around Ampfing and Mühldorf am Inn, Upper Bavaria, Germany. Geological map of Bavaria 1:50,000, map sheet L7740 Mühldorf am Inn.

Type section: Not defined; a possible type section could be deep well Ampfing 1 (N 48°14′26″ / E 12°24′27″), Mobil Oil Company, Bavaria, Germany.

Reference section(s): The deep well Puchkirchen 1 (N 48°01′38″ / E 13°34′37″), Rohöl-Aufsuchungs AG, is proposed as reference section in Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis). Upper Eocene sediments, including the sandstone of the Ampfing Formation, were drilled here for the first time.

Derivation of name: Named after the village Ampfing (N 48°15′22″ / E 12°24′52″) (and the oilfield Ampfing), 9 km W of Mühldorf am Inn, Upper Bavaria, Germany (ATK25, map sheet N15 Mühldorf a.Inn).

Synonyms: Ampfinger Sandstein (e.g., HAGN, 1967), Ampfinger Schichten (PREY, 1957; MÜLLER, 1978), Ampfing Sandstone, Sandsteinstufe p.p., Nummulitensandstein p.p.

Lithology: Light grey to brownish medium to coarse quartz sandstones and arkoses, bioturbated, sometimes fine-conglomeratic and glauconitic, corallinacean red algae and fragments.

Fossils: Corallinacean red algae, nummulites, bivalves, gastropods, trace fossils.

Origin, facies: Marine sediments, deposited on the inner shelf at the shoreface, in lagoonal environments and on inundated areas. The sand was shed from the subaerially exposed Landshut-Neuötting High (Central Swell Zone in Upper Austria) and deposited along the high in a 20–27 km wide belt (MÜLLER, 1978; UNGER, 1996) or deposited along the shore of the Bohemian Massif.

Chronostratigraphic age: Late Eocene, Priabonian to early Oligocene early Rupelian) (e.g., RUPP, 2011a).

Biostratigraphy: No data available.

Thickness: Maximum thickness 80 m in wells on top of the crystalline basement.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Gradational transition from underlying Cerithium Beds or directly on top of crystalline or Mesozoic Basement.

Overlying unit(s): Lithothamnium Limestone or Schöneck Formation.

Lateral unit(s): Lithothamnium Limestone (interfingering).

Geographic distribution: NAFB in Bavaria, Salzburg, and Upper Austria.

Remarks: The Ampfing Sandstone was introduced for Eocene sandstones in the hydrocarbon exploration in Bavaria (cf. MÜLLER, 1978). The Ampfing Sandstone was the first larger oil reservoir rock in the Molasse Basin. It was explored first in the oil field Ampfing close to the town of Mühldorf am Inn.

Complementary references: HEERMANN (1954), RÖGL & RUPP (1996), WAGNER (1998), DOPPLER et al. (2005).

Perwang-Gruppe / Perwang Group

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Invalid; WAGNER (1998) proposed the term Perwang Group for upper Eocene to lower Oligocene shelf to basin plain deposits south of the Central Swell Zone.

Type area: In the area north of the city of Salzburg, Perwang am Grabensee and N of lake Mondsee, North Alpine Foreland Basin, Upper Austria, Salzburg and Lower Bavaria.

Type section: Deep drilling Perwang 1/1a of Rohöl-Aufsuchungs AG; core numbers 57 to 62 in the Autochthonous Molasse (3,215–3,301 m) and core numbers 8, 13 to 21 and 25 to 36 in the Allochthonous Molasse (1,696–1,699 m, 1,995–2,138 m, 2,287–2,410 m, 2,481–2,490 m, 2,559–2,586 m); ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen) (N 48°01′34″ / E 13°03′55″).

Reference section(s): Not defined, but deep well Oberhofen 1 in the Molasse Basin of Upper Austria could act as reference section; ÖK50-UTM, map sheet 3305 Mondsee (ÖK-BMN, map sheet 65 Mondsee) (N 47°56′00″ / E 13°20′16″).

Derivation of name: Named after the village Perwang am Grabensee (Upper Austria) (N 48°00′26″ / E 13°05′02″), c. 23 km NNE of the city of Salzburg; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK-BMN, map sheets 45 Ranshofen, 46 Mattighofen).

Synonyms: See formations.

Lithology: Lithologies vary from larger benthic foraminiferal limestones and marls, planktonic foraminiferal limestones and marls to pelites with turbidites, mass flows and contourites.

Fossils: Fossil contents are highly variable depending on the respective facies (see subunits).

Origin, facies: The sediments of the Perwang Group were deposited south of the so-called Central Swell Zone (Landshut-Neuötting High) in an open marine area including shallow water coralline algal environments, larger benthic foraminiferal sands, limestones and marls, slope deposits, such as planktonic foraminiferal sediments, and pelitic sediments with mass transport features.

Chronostratigraphic age: Late Eocene, Priabonian to early Oligocene, early Rupelian.

Biostratigraphy: Calcareous nannofossil Zones NP19/20–NP22.

Thickness: Thickness in the autochthonous section of Perwang 1a is 86 m (cf. RUPP, 2011b).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: WAGNER (1998) informally differentiated several formations being represented here in 5 formation rank units: Nummulitic Sandstone, Perwang Formation ("Discocyclinen Mergel"), Lithothamnium Limestone, Nussdorf Formation ("Globigerina Marl"), Rogatsboden Formation.

Underlying unit(s): Transgressive on crystalline or Mesozoic basement or in a tectonic position.

Overlying unit(s): Schöneck Formation and different formations in tectonic position.

Lateral unit(s): See subunits.

Geographic distribution: NAFB in the southwest of Upper Austria, Salzburg north of the city of Salzburg, and Lower Bavaria; to a minor extent it also occurs in the western part of Lower Austria (Rogatsboden Formation).

Remarks: Most of the subunits are not exposed at the surface (except small occurrences of the Rogatsboden Formation). From many drillholes the Perwang Group is well known both from the autochthonous and the allochthonous (overthrusted, imbricated) NAFB in the southwestern part of Upper Austria, Salzburg north of the city of Salzburg but also from SE Lower Bavaria. All these sediments are deposited south of the Central Swell Zone (Landshut-Neuötting High in Bavaria) which is a subsurface topographic high of crystalline rocks of the Bohemian Massif.

The Katzenloch Beds form a transition between the Helvetic Zone and the NAFB in a facies of distal turbidites in the region between the rivers Inn and Salzach in Upper Bavaria (HAGN, 1978).

Complementary references: PILLER et al. (2004).

Nummuliten Sandstein (Perwang-Gruppe) / Nummulitic Sandstone (Perwang Group)

WERNER E. PILLER

Validity: Invalid; sandstones at the base of the upper Eocene depositional sequence are widespread in the Upper Austrian NAFB and well known since they are oil bearing. WAGNER (1980) differentiated several types of sandstones, one of which are "nummulitic sandstones within sublittoral to neritic sediments" which occur in the south of the Central Swell Zone (only subsurface).

Type area: In the NAFB in the area of Lamprechtshausen (N of the city of Salzburg) – Perwang am Grabensee, Salzburg and Upper Austria; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen).

Type section: Not defined; a possible candidate could be the F (between 3,217 and 3,209 m depth) of the Rohöl-Aufsuchungs AG, 4.5 km NW of the village Lamprechtshausen, north of the city of Salzburg; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen).

Reference section(s): -

Derivation of name: Named after the frequent occurrence of larger benthic foraminifers of the genus *Nummulites* in sandstone.

Synonyms: Nummulitenführender Sandstein und Kalksandstein, Nummulitensandstein, Nummulite Sandstone, nummulitic sandstone, Sandsteinserie p.p., Basisserie p.p., Basisschichten p.p., basal terrigenous series.

Lithology: Dark to light grey, green and brown, poorly rounded and sorted quartz sandstones with abundant nummulitid foraminifers. Nummulitids are usually not orientated and rarely fragmented, but affected by pressure solution (RASSER et al., 1999).

Fossils: Larger benthic foraminifers (*Nummulites*, *Discocyclina*), red algal debris, bryozoans and molluscs.

Origin, facies: The nummulite sandstone gradually develops from quartz sandstone and is interpreted as having formed in a higher energetic, maybe near-shore, environment. Upsection, the number of *Discocyclina* increases indicating a deepening upward trend.

Chronostratigraphic age: Late Eocene, middle Priabonian (RASSER et al., 1999).

Biostratigraphy: Larger benthic foraminifers *Discocyclina augustae augustae* and *Nummulites chavannesi* indicate SBZ19.

Thickness: A few meters only, 8 m in deep well Helmberg 1.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Underlain by an unnamed quartz sandstone of a few meters thickness.

Overlying unit(s): Lithothamnium Limestone (Perwang Group).

Lateral unit(s): Quartz sandstone (see above), Lithothamnium Limestone (Perwang Group).

Geographic distribution: In the NAFB in the area of Lamprechtshausen–Perwang am Grabensee–N of lake Mondsee, Salzburg – Upper Austria, and Lower Bavaria.

Remarks: The so-called basal sandstones ("Basissandsteine") are not differentiated here although they can reach a thickness up to 30 m (UNGER, 1996).

Complementary references: ABERER (1958).

Perwang-Formation (Perwang-Gruppe) / Perwang Formation (Perwang Group)

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Invalid; the unit was introduced by JANOSCHEK (1959) as "Discocyclinae marls" and "marls with Discocyclines and marly limestone". WAGNER (1996b, 1998) proposed for the "Discocyclinen Mergel" the term "Perwang-Formation" (only subsurface). In PILLER et al. (2004) it is also depicted as "Discocyclinenmergel".

Type area: In the NAFB in the area N of the city of Salzburg to Perwang am Grabensee, Salzburg; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen).

Type section: Not defined; proposed is the deep well Perwang 1/1a, Rohöl-Aufsuchungs AG, cores 61 (3,285–3,254 m) within the autochthonous part and cores 19 to 20, and 29 to 31 and 36 in the allochthonous part of the imbricated southern part of the Molasse Basin; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen) (N 48°01′34″ / E 13°03′55″).

Reference section(s): Deep well Helmberg 1, core 6 and 7, Rohöl-Aufsuchungs AG where the thickness is much higher than in Perwang 1/1a; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen) (N 48°01′20″ / E 12°55′27″).

Derivation of name: Named after the village Perwang am Grabensee, Upper Austria (N 48°00′26″ / E 13°05′02″), c. 23 km NNE of the city of Salzburg; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK-BMN, map sheets 45 Ranshofen, 46 Mattighofen).

Synonyms: Discocyclinae marl, Discocyclinenmergel, Discocyclinen Mergel, *Discocyclina* Marl.

Lithology: Dark brown to greenish marl and marly limestone with coquinas of the larger benthic foraminifer *Discocyclina*. The flat foraminiferal tests are commonly bent or wavy and mostly horizontally oriented.

Fossils: Larger benthic foraminifera, with *Discocyclina*, *Nummulites*, *Assilina*, bryozoans and the serpulid *Rotularia*.

Origin, facies: Deposited on the outer shelf to upper slope.

Chronostratigraphic age: Late Eocene, Priabonian.

Biostratigraphy: Calcareous nannofossil Zones NP19–20 and SBZ19–20 point to a middle Priabonian age (RASSER et al., 1999).

Thickness: In deep well Perwang 1a the thickness is 12 m; in Helmberg 1 it is 37 m.

Lithostratigraphically higher rank unit: Perwang Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Gradational transition from Nummulitic sandstones.

Overlying unit(s): Lithothamnium Limestone, Schöneck Formation.

Lateral unit(s): Interfingering with Nummulitic sandstone, Ampfing Formation, Bryozoan marls (see remarks) and Lithothamnium Limestone.

Geographic distribution: In the NAFB in the southwest of Upper Austria, Salzburg north of the city of Salzburg, and Lower Bavaria.

Remarks: The Bryozoan marl above the Discocyclina marls in deep drilling Helmberg 1 is considered part of the Perwang Formation (RASSER et al., 1999) and reflects an upward deepening.

Complementary references: -

Lithothamnienkalk (Perwang-Gruppe) / Lithothamnium Limestone (Perwang Group)

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Invalid; a first record of "Lithothamnienkalk" (Lithothamnium Limestone) in the NAFB was drilled in Bavaria in the deep well Taufkirchen 1 in the year 1936 (ANDRÉE, 1937) and assigned to the "? Alttertiär" (older Tertiary). The age assignment was difficult. NATHAN (1949: p. 41) and HAGN (1950: p. 9) discussed already the possibility of an Oligocene (Rupelian) age (only subsurface).

Type area: Area around the village Taufkirchen an der Vils (N 48°20′38″ / E 12°07′49″), Upper Bavaria, Germany.

Type section: Not defined; proposed is the deep well Taufkirchen 1 (1,365.2–1,371.6 m) (N 48°21′13.52″ / E 12°08′48.18″), 22 km south of the town Landshut, Bavaria; map of Bavaria 1:50,000, map sheet UK50-42 7738 München Ost.

Reference section(s): Not defined; for the Austrian NAFB the deep well Puchkirchen 1, Rohöl-Aufsuchungs AG, is suggested where for the first time upper Eocene sediments, including Lithothamnium Limestone, were drilled in Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis) (N 48°01′38″ / E 13°34′37″).

Remark: The deep well Puchkirchen 1 is also the stratotype for the Paratethyan Egerian stage (KÜPPER & STEININGER, 1975).

Derivation of name: Named after rock forming corallinacean red algae; Lithothamnium (correct genus name: *Lithothamnion*) is only one genus out of several others present in the unit.

Synonyms: Nulliporenkalk, Nullipore limestones and calcareous sandstones with *Nulliporae*, Upper and Lower Nulliporae limestone (JANOSCHEK, 1959), Lithothamnien-Kalksandstein (ABERER, 1958), Lithothamnien-Quarzsandstein (ABERER, 1958), Lithothamnium Sand, Lithothamnien-Schuttkalk, Unterer/Oberer Lithothamnienkalk.

Lithology: According to RASSER et al. (1999), RASSER (2000) and RASSER & PILLER (2004), different facies types are developed: quartz sandstones at the base above or near to the crystalline basement, coralline bind- and rudstones, rhodolith rudstones, crustose coralline algal frameworks, Peyssonneliacean bind- and rudstones. A detailed description of the Lithothamnium Limestone in SE Bavaria is given by BUCHHOLZ (1989) showing similar lithologies.

Fossils: Main components are rhodoliths, branches, and fragments of corallinacean algae, but also peyssonnelian red algae are abundant; foraminifera, especially nummulites and in the lower part discocyclinids; bryozoans, molluscs, echinoderms.

Origin, facies: Deposited on topographic highs (predominantly the Central Swell Zone in Upper Austria and Landshut-Neuötting High in Bavaria) with intercalated sand bars and channels. Debris is shedded both in a N–NW direction ("lagoon") and to the S-SE on the inner shelf. Water energy is highly variable reaching from high in the rudstone types to low in the crustose frameworks. Water depth ranges from intertidal environments to several 10s of meters.

Chronostratigraphic age: Late Eocene, Priabonian to earliest Oligocene, Rupelian.

Remark: The age assignment was discussed from the very beginning. NATHAN (1949: p. 41) mentioned for the well Taufkirchen 1 a middle Eocene? to Rupelian? Age, which was supported by HAGN (1950: p. 9).

Biostratigraphy: According to RASSER et al. (1999), the lower part tentatively belongs to larger foraminifera Zone SBZ20. According to ABERER (1958: p. 37), the upper part of the corallinacean limestone, without Eocene nummulitids and discocyclinids, belongs to the lower Oligocene ("Latdorfian": regional stage for the lowest Rupelian), which also interfingers with the Oligocene "Fischschiefer". HAGN (1960: p. 69) confirmed also an early Rupelian (Latdorfian) age for those limestones without discocyclinids.

Thickness: In the drilling Taufkirchen 1, a thickness of only 6.4 m is recorded; in Austria, the maximum thickness is reported from deep well Munderfing 1, Rohöl-Aufsuchungs AG, with 72 m (RUPP, 2011b). From Bavaria a thickness < 100 m is reported (DOPPLER et al., 2005).

Lithostratigraphically higher rank unit: Perwang Group.

Lithostratigraphic subdivision: In Bavaria, an informal subdivision between Lower and Upper Lithothamnium Limestone is made. The reason is that in some areas the sandstones of the Ampfing Formation transgrade from the NE over the (Lower) Lithothamnium Limestone and becomes upsection overlain by the (Upper) Lithothamnium Limestone. This twofold occurrence of these limestones with sandstones in between is, however, not consistent and a formal establishment of members has not been done so far.

Underlying unit(s): Gradational transition from underlying basal sandstones, Nummulitic sandstone and littoral Ampfing Formation in the north; in the south Perwang Formation (*Discocyclina* marls); in some areas directly on top of Mesozoic or crystalline basement.

Overlying unit(s): Schöneck Formation; locally the surface shows submarine erosion.

Lateral unit(s): Nummulitic sandstone, Basal Sandstone, Ampfing Formation (UNGER, 1996: p. 170; WAGNER, 1980).

Geographic distribution: Widespread in the subsurface of the NAFB in Bavaria, Salzburg, and Upper Austria.

Remarks: In the Helvetic Zone also Lithothamnium limestones occur which are part of the Ypresian Fackelgraben Member (Kressenberg Formation) (see there). These two units are sometimes mixed what may have caused confusion.

Complementary references: HEERMANN (1954), PILLER et al. (2004).

Nußdorf-Formation (Perwang-Gruppe) / Nußdorf Formation (Perwang Group)

LUDWIG R. WAGNER & FRED RÖGL

Validity: Invalid; WAGNER (1996b, 1998) proposed for this unit the terms "Nußdorf-Formation" (1998: p. 349) and "Nussdorf Beds" (1998: p. 366) as term for the well-established unit "Globigerinen-Kalk und -Mergel" (Globigerina Limestone and Marl) for Eocene–lower Oligocene slope facies in the Upper Austrian NAFB (only subsurface). PILLER et al. (2004) used the traditional name "Globigerinenkalk".

Type area: Molasse imbricates in the subsurface of Salzburg and Upper Austria.

Type section: Not defined; proposed is the shallow drill site Nussdorf CF 6, 5–117 m, in the imbricated southern part of the NAFB at the north-eastern shore of Lake Obertrum, Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 64 Straßwalchen) (N 47°58'44″ / E 13°04'51″).

Reference section(s): Not defined; deep well Perwang 1/1a of Rohöl-Aufsuchungs AG, core numbers 59 and 60 in autochthonous and 13, 33 to 36 in allochthonous sections could be considered (N 48°01′34″ / E 13°03′55″); ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen).

Derivation of name: Named after the counterflush drill site Nussdorf CF 6, at the northern shore of Lake Obertrum, Salzburg. The drilling is named after the village Nußdorf am Haunsberg, 20 km north of the city of Salzburg; ÖK50-UTM, map sheet 3204 Salzburg (ÖK50-BMN, map sheet 63 Salzburg).

Synonyms: *Globigerina* Marl, Globigerinenmergel, Globigerinenkalk. In Austria and Bavaria, the term "Globigerinen-Mergel" was used both for pelagic sediments in the Helvetic Zone and in the NAFB.

Lithology: Fine-grained, grey to brown-grey, bioturbated marls, occasionally with thin beds of corallinacean detritus from mass flows. In the upper part (Oligocene) of the section dark grey layers of calcareous shales with pyritized foraminifera occur. In the Molasse imbrications fine-grained, dark grey to brown-grey, bioturbated, marly limestones.

Fossils: Calcareous nannoplankton, planktonic foraminifera (*Subbotina, Tenuitella*) and benthic foraminifera, particularly *Uvigerina*.

Origin, facies: Hemipelagic sediments from the upper slope (upper bathyal). The occurrence of dark shales in the upper part (Oligocene) connects to the dysaerobic facies of the Schöneck Formation.

Chronostratigraphic age: Late Eocene, Priabonian to early Oligocene, early Rupelian.

Biostratigraphy: The identification of *Globigerina postcretacea* in deep well Taufkirchen 1 indicates latest Eocene to early Oligocene (HAGN, 1960). In the proposed type section for the Nußdorf Formation, the shallow drill site Nussdorf CF6, calcareous nannoplankton has shown a continuous marly sedimentation from Zone NP19/20 to NP22. In respect to benthic foraminifera, *Bulimina sculptilis* and costate uvigerinids indicate lower Oligocene. The Eocene/Oligocene boundary cannot be defined as in the planktonic foraminiferal fauna the index fossil *Cribrohantkenina* is missing.

Thickness: In drill site Nussdorf CF-6 > 110 m of marls are drilled. For the Globigerina limestone at Perwang 1a are 18 m and at Oberhofen 1 45 m encountered.

Lithostratigraphically higher rank unit: Perwang Group.

Lithostratigraphic subdivision: -

Underlying unit(s): In the proposed type section, Upper Cretaceous marls of units of the Helvetic Zone occur in tectonic contact. In other wells, the Perwang Formation (*Discocyclina* Marls) occurs in autochthonous positions or in allochthonous sections in tectonic contact.

Overlying unit(s): Lithothamnium Limestone at Perwang 1a; Schöneck Formation at Oberhofen 1.

Lateral unit(s): Perwang Formation (= *Discocyclina* Marl) and Lithothamnium Limestone.

Geographic distribution: Autochthonous and imbricated Molasse in Salzburg, Upper Austria, and Bavaria (subsurface only).

A lateral equivalent of the Nußdorf Formation is the Ottenthal Member (Ottenthal Formation) in the lower Oligocene of the Waschberg-Ždánice Unit (RÖGL et al., 2001).

Remarks: In the deep drilling Taufkirchen 1 HAGN (1960: p. 73) mentioned the interfingering of Globigerina Marls with Lithothamnium Limestone at a depth of 1,366 m. Due to the lithologic description of the well and the log correlation this section belongs to the lower Oligocene Schöneck Formation ("Fischschiefer") with reworked coralline algae debris.

Complementary references: -

Rogatsboden-Formation (Perwang-Gruppe) / Rogatsboden Formation (Perwang Group)

LUDWIG R. WAGNER & FRED RÖGL

Validity: Invalid; WAGNER (1996b, 1998) proposed the term Rogatsboden Formation as subunit of the Perwang Group for marine upper Eocene to lower Oligocene basin plain to slope sediments which are similar to the sediments in the so-called tectonic "Window of Rogatsboden". The unit has to be properly described and formalized.

Type area: So-called "Molassefenster von Rogatsboden", a part of the imbricated Molasse between the Helvetic Zone and the Rhenodanubian Flysch Zone, NW of the town of Scheibbs, Lower Austria; ÖK50-UTM, map sheet 4328 Scheibbs (ÖK50-BMN, map sheet 54 Melk).

Type section: -

Reference section(s): Not defined; suggested are the deep wells Urmannsau 1 (2,363–2,600 m), OMV-AG, Lower Austria (KRÖLL & WESSELY, 1967) (N 47°55′35″ / E 15°08′14″) and Mühlreith 1, Rohöl-Aufsuchungs AG, Upper Austria (N 47°58′14″ / E 13°27′22″).

Derivation of name: Named after the small village Rogatsboden, 6 km NW of the town Scheibbs, Lower Austria; ÖK50-UTM, map sheet 4328 Scheibbs (ÖK50-BMN, map sheet 54 Melk).

Synonyms: oligozäner Schlier (VETTERS, 1929a), Inneralpine Molasse (RICHTER, 1950).

Lithology: Generally, monotonous clayey marls with sandstone beds. Subordinate are conglomerates and Lithothamnium marls intercalated (PREY, 1957).

PREY (1957) described a variety of lithologies and tried to reconstruct a sequence in this tectonically complex area containing four units: (1) The lower part consists of dark grey, layered shales, sometimes finely laminated, with mica on the bedding planes. The shales alternate with grey, yellowish weathered calcareous sandstone layers (1–20 cm thick). They show cross and convolute bedding, ripple marks, trace fossils and plant debris. Coarse sandstones and fine conglomerates occur in the lower part of this unit. This unit is poor in fossils, but reworked fossils from the Helvetic Zone occur. (2) Upsection follow "Lithothamnienmergel", grey and greybrown, partly sandy marls with biogenic detritus, corallinacean nodules and larger pebbles of corallinacean limestone. (3) This unit is overlain by a second sequence of shales but contains a microfauna. (4) In the top of the sequence, lenses of coarse sandstones and conglomerates with reworked fossils occur along the southern rim of the "window". Components of the conglomerates are white and grey dolomites, sandy limestone, marls, light grey marly limestones, shales, quartz, and feldspar.

Fossils: According to PREY (1957), fish remains and fish skeletons on the bedding planes of the shales of the lower unit are common, similar to the fish shales of the Schöneck Formation. Microfauna is very scarce with a few agglutinated foraminifera, and some reworked larger foraminifera from the Helvetic Zone. Abundant fossils occur in the intercalated "Lithothamnienmergel" with corallinacean red algae, molluscs, bryozoa, brachiopods, echinoids, rich ostracod and foraminiferal assemblages. The upper shaly sequence contains a well-developed foraminiferal fauna, comparable to that of the Zupfing Formation (middle Oligocene) or the Kiscell Clay in Hungary, e.g., *Cancris* cf. *turgidus* (= *C. bavaricus*), *Bolivina elongata, B. nobilis, Loxostomum chalkophilum, Rotalia lithothamnica*, and large globigerinids. The coarse clastics of the top unit contain only reworked fossils from the Eocene and Upper Cretaceous.

Origin, facies: Basinal, deep marine sediments of the southern part of the basin with hemipelagites, turbidites, mass flow deposits and contourites. Especially the lower part of alternating shales and sandstones reflects the intermediate position between the turbiditic Deutenhausen Formation and the basin facies of the Schöneck Formation. The Lithothamnium marls and limestones have to be considered allochthonous.

Chronostratigraphic age: Late Eocene, Priabonian to early Oligocene, Rupelian.

Biostratigraphy: In the clayey marls, fossils are very rare. The ostracod fauna points to lower Oligocene (PREY, 1957: p. 304).

Thickness: In the deep well Urmannsau 1 the section between 2,363–2,600 m (237 m) was attributed to the "Inneralpine Molasse" (KRÖLL & WESSELY, 1967). In well Mühlreith 1, the Rogatsboden Formation is a tectonic wedge within the Imbricated Molasse.

Lithostratigraphically higher rank unit: Perwang Group, however, no contact with other formations of the Perwang Group is known.

Lithostratigraphic subdivision: -

Underlying unit(s): Tectonic contact in the "Rogatsboden Window" with sediments of the Rhenodanubian Flysch and Helvetic zones. In the deep drilling Urmannsau 1 this unit is a tectonic wedge within the "Buntmergelserie" of the Ultrahelvetic Zone.

Overlying unit(s): In the imbricated Molasse of Upper Austria tectonic contacts with the Eggerding Formation, Schöneck Formation and Puchkirchen Formation.

Lateral unit(s): -

Geographic distribution: The Rogatsboden Formation crops out in an imbricated zone between Gresten and Texing, along the Alpine Front in Lower Austria (WESSELY, 2006: p. 44), and is reported from the Imbricated Molasse in wells in Salzburg and Upper Austria but also from outcrops in Upper Bavaria.

Remarks: In the area of Rogatsboden three wells have been drilled. Rogatsboden 1 (461 m) and 1a (315 m) were redescribed by PREY (1957) and show the high tectonic complexity of the area. Rogatsboden 2 has been abandoned at 95 m.

In PILLER et al. (2004), the Rogatsboden Formation is included in "Inneralpine Molasse (z.B. Rogatsboden)".

Complementary references: SCHNABEL (2002a, b).

Schöneck-Formation / Schöneck Formation

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Valid; BÖHM (1891: p. 17) reported this unit as "*schwarzgrauer, dünnblättriger Mergelschiefer, auf den Schichtflächen reichlich mit Schuppen von Meletta sardinites Heckel, im Schönecker Graben und Habach*" for the first time but considered it part of the Helvetic Zone. It was HAGN (1960: p. 106) who introduced the term "Schönecker Fischschiefer" and pointed out the intermediate position between the Helvetic Zone and the sediments of the NAFB; DOHMANN (1991: p. 6) designated the type section along the Schöneck creek; the term Schöneck Formation was introduced by WAGNER (1996b).

Type area: The area S and SE of the village Siegsdorf, with outcrops along the Schöneck Creek, the Galon Creek and the Katzenloch Creek, Upper Bavaria, Germany; ATK25, map sheet P16 Traunstein.

Type section: Outcrop in the western Schöneck creek (N 47°48′18″ / E 12°39′05″), 2 km south of the village Siegsdorf, Upper Bavaria, Germany; ATK25, map sheet P16 Traunstein (GANSS, 1977; DOHMANN, 1991). Along the creek are 5–7 m of platy, dark grey to brownish marls exposed; the lower boundary is a tectonic contact to the Eocene "Stockletten" of the Helvetic Zone (see there), the upper boundary is not exposed (DOHMANN, 1991: p. 6).

Reference section(s): Not defined; a possible reference section is in the Galon Creek, SE Siegsdorf; ATK25, map sheet P16 Traunstein (N 47°48′25″ / E 12°40′56″) which exhibits a continuous sedimentation between the upper Eocene "Stockletten" and the Schöneck Formation and shows the lower boundary in the type area (DOHMANN, 1991: p. 11–12). As a reference section for the Autochthonous Molasse the deep well Ampfing 1 in Bavaria (N 48°14′26″ / E 12°24′27″) is proposed, where a continuous transition exists between the Lithothamnium Limestone and the Schöneck Formation (REISER, 1987: 44).

Derivation of name: Named after the Schöneck creek, 2 km south of the village Siegsdorf, Upper Bavaria, Germany; ATK25, map sheet P16 Traunstein.

Synonyms: Fischschiefer, Lattorf/Latdorf Fischschiefer, Sannois-Fischschiefer (e.g., UNGER, 1978), Schönecker Fischschiefer, Schöneck-Fischschiefer, Schoneck Fishshale (WAGNER, 1996a), Lattorfian fish-bearing shale (WAGNER, 1996b), *Meletta* Schichten (HAGN, 1960).

The term "Fischschiefer" (fish shale) was (and still is) used for different stratigraphic units, causing problems when chronostratigraphy is not mentioned in the context.

Lithology: In general, finely laminated, dark brown to grey-black and also grey green clayey marls to marly shales with minor sand content and black shales in the upper part. Although there is a lateral variation in facies SCHULZ et al. (2002) established three lithologic units which have been detailed by SACHSENHOFER & SCHULZ (2006): Unit A in the lower part consists of dark marls with strongly varying carbonate content and authigenic phosphorite; the base is often bioturbated and contains abundant glauconite. Laterally, intercalations of dark pack-, wacke- and rudstones occur. Unit B, in the middle part, consists of well-bedded marls with abundant planktonic foraminifers but without phosphorite. Unit C in the upper part consists of fine bedded to laminated, carbonate-free black shales, with few intervals of light-coloured marls. Total organic carbon contents (TOC) range between 2–2.5 % and reach 5 % in the upper part (SACHSENHOFER & SCHULZ, 2006), with an average value of 3.44 % (GERHARD, 1988).

Fossils: Fish remains (scales, teeth) on the bedding planes are characteristic, together with pteropods (*Limacina*). In the marly layers, a rich foraminiferal fauna, globigerinids but also benthics, occurs accompanied by calcareous nannoplankton (comp. STEININGER et al., 1976; DOHMANN, 1991; SCHULZ et al., 2002) and palynomorphs (HOCHULI, 1978). A detailed study on foraminifers and calcareous nannoplankton for several wells in Bavaria and Upper Austria provides DOHMANN (1991).

Origin, facies: Deposition of the pelites occurred in bathyal depths on the northern paleo-slope or even the basin floor of the NAFB between 400 and 600 m with a deepening during deposition (DOHMANN, 1991). The fast subsidence forced the development of a stagnant basin with oxygen-depleted (dysoxic to anoxic) bottom water (SCHULZ et al., 2002). High productivity in surface waters is assumed for the lower parts (Units A and B) of the Schöneck Formation with marly sedimentation and cyclic blooms of globigerinids. Major environmental changes occur within Unit C: the lower part is characterized by low surface water productivity, high surface water salinity and CO_2 recycling within the water column, the upper part reflects a decrease in stratification, surface water salinity and bottom water anoxia as a result of major fresh-water influx (SACHSENHOFER & SCHULZ, 2006). The stratification was caused by warm Tethyan surface water and cold bottom water undercurrents from the Polish lowlands. The widespread development of dark sediments and fish shale facies in the Central and Western Paratethys is connected with a first separation of the Mediterranean Sea and the Paratethys (RÖGL, 1998; POPOV et al., 2004; SACHSENHOFER & SCHULZ, 2006).

The fish fauna from the Galon creek lived mainly in the epipelagic and mesopelagic zones of a tropical to subtropical sea (PFEIL, 1981). In respect to palynomorphs, thermophilic pollen are common (HOCHULI, 1978).

Chronostratigraphic age: Late Eocene, late Priabonian to early Oligocene, early Rupelian (early Kiscellian).

Remark: For a discussion on the regional stage Latdorfian see MARTINI et al. (1986).

Biostratigraphy: Calcareous nannofossil Zones upper NP19–NP22 (SCHULZ et al., 2002) and even lower NP23 (SACHSENHOFER & SCHULZ, 2006), planktonic foraminifera Zones P18–lower P19 (CICHA et al., 1971; STEININGER et al., 1976), and Paleogene floral Zones Pg.Z. 19–Pg.Z. 20a (HOCHULI, 1978; RÖGL et al., 1979).

Thickness: The typical thickness is c. 10–25 m (SACHSENHOFER & SCHULZ, 2006; GROSS et al., 2018), a maximum thickness of 40 m is reported.

Lithostratigraphically higher rank unit: "Menilite Formation". The Menilite Formation of the Western Carpathians (Czech Republic, Poland) is subdivided into a Subchert Member, a Chert Member, the Dynów Member and the Šitborice Member The Subchert and Chert members can be correlated with the Schöneck Formation The Dynow Member is laterally continuous from the NAFB to the Western Carpathians and the Šitborice Formation can be correlated with the Eggerding Formation in the NAFB. In the Eastern Carpathians the Menilite Formation has a much longer extent (in dependence from the tectonic units) ranging from the Kiscellian to the Eggenburgian (SACHSENHOFER et al., 2018).

"Untere Meeresmolasse" (Lower Marine Molasse) in Bavaria (also termed Fischschiefer) (NATHAN, 1949; DOPPLER & SCHWERD, 1996; DOPPLER et al., 2005).

Lithostratigraphic subdivision: Not defined; the three units differentiated by SCHULZ et al. (2002) could be defined as members and are even developed in Bavarian occurrences (SACHSENHOFER & SCHULZ, 2006: p. 375).

Underlying unit(s): "Stockletten", Lithothamnium Limestone.

In the type section (Schöneck creek) there is a tectonic contact, but in the Galon creek continuous sedimentation exists with a rather sharp change from light coloured Eocene "Stockletten" of the Helvetic Zone to the "Fischschiefer" facies (DOHMANN, 1991: p. 16). Overall, a sharp boundary exists between the Lithothamnium Limestone and the Schöneck Formation (Sachsenhofer & Schulz, 2006). In the eastern foreland basin in Bavaria, the underlying Eocene Lithothamnium Limestone regionally shows a gradational development from a detritic glauconitic limestone facies to laminated dark shales (Dohmann, 1991: p. 33). In Upper Austria, in some deep wells (e.g., Dietach 1) a gradational facies change with intercalations of dark shales in the uppermost Lithothamnium Limestone is observed.

Overlying unit(s): Dynów Marlstone.

In deep wells in the uppermost part of the dark shales, whitish layers of calcareous nannoplankton occur forming a transition from the Schöneck Formation to the calcareous nannoplankton chalk of the Dynów Marlstone.

Lateral unit(s): Deutenhausen Formation. Interfingering of the slope deposits of the Schöneck Formation with the basin plain deposits of the Deutenhausen Formation (turbiditic sandstones in the southern Molasse imbrications) (Dohmann, 1991: p. 91).

The Subchert and Chert members of the Menilite Formation of the Western Carpathians may grade into or interfinger with the Schöneck Formation.

Geographic distribution: In the transition between the Helvetic Zone and the NAFB it is widely distributed in Upper Austria, Salzburg and Upper Bavaria. In the Carpathian Foreland of southern Moravia, the Menilite Formation (Pouzdřany Formation, with Subchert and Chert members) and in the Waschberg-Ždánice Unit the Ottenthal Member, are considered equivalents of the Schöneck Formation Units A and B (Krhovsky et al., 2001; Sachsenhofer & Schulz, 2006).

Remarks: A history of the outcrop description and stratigraphic discussion are given by Hagn (1960: p. 106) and Dohmann (1991: p. 3). “The Lattorfian fish shale (Lower Oligocene) is the proven source rock for the oil in Upper Austria” (Wagner, 1996a: p. 233).

In Piller et al. (2004) a sedimentation gap between the Lithothamnium Limestone and the Schöneck Formation is shown. As described above, however, sedimentary sequences are mostly continuous, only in some areas a gap can exist due to submarine erosion.

Complementary references: Heermann (1954), Hagn (1967), Kraus (1968a, b), Müller (1978), Roetzel & Krenmayr (1996), Wagner (1998), Gier (2000), Piller et al. (2004), Schulz et al. (2004), Rupp (2008a, b, 2009a, b, 2014), Sachsenhofer et al. (2010a, 2018), Gusterhuber et al. (2012, 2013, 2014).

Dynów Mergel / Dynów Marlstone

Werner E. Piller, Fred Rögl & Ludwig R. Wagner

Validity: Invalid (see remarks); named and described by Kotlarczyk (1966, 1979) as whitish silicified marls and cherts in the Dukla Unit of the eastern Polish Carpathians. Wójcik et al. (1996), when formalizing many units in the Polish Carpathians, considered the Dynów Marls as a member (Dynów Member) of the Menilite Formation. A detailed study of the type section was carried out by Górniak (2012).

Type area: In the area of Błażowa–Dynów, between Rzeszow and Przemyśl, Skole Unit, Polish Carpathians (Kotlarczyk, 1985; Górniak, 2012).

Type section: Abandoned Quarry located on the western slope of the Łysa Góra in the Straszydle Village, c. 9 km WNW of Błażowa and 20 km NW of Dynów, Poland (N 49°54′06″ / E 22°00′17″). Exposed is a 22 m-thick section with 15 m of compact marl overlain by a slump (Górniak, 2012: 250ff., Fig. 18).

Reference section(s): For the Austrian NAFB as reference sections are proposed the deep wells Oberschauersberg 1 (core 2, box 5–10) (N 48°07′33″ / E 13°59′30″), Rohöl-Aufsuchungs AG; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 49 Wels) and Eggerding 2 (N 48°19′45″ / E 13°31′54″), Rohöl-Aufsuchungs AG; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 29 Schärding).

Derivation of name: Named after the town Dynów, c. 40 km west of the town Przemyśl, Subcarpathian Province, Poland.

Synonyms: Heller Mergelkalk (Nathan, 1949; Aberer, 1958), Dynow-Mergel (Piller et al., 2004), Dynow-Formation (Wagner, 1996b; Rupp, 2009a, b, 2011a, b; Sachsenhofer et al., 2010a), “Bright Marlstone”, “Light Marly Limestone” (Wagner, 1996a).

Lithology: In the type area, “Dynów Marls are light brown, occasionally steelgray-green thin- to medium-bedded, hard, homogeneous and wavy laminated. Weathered they are beige-coloured. They contain chert lenses and sandstone intercalations.” (Górniak (2012: p. 250).

In the NAFB of Upper Austria, the Dynow Marl(stone) is predominantly composed of laminated to wavy bedded white limy marlstone and limestone (nannoplankton ooze). Schulz et al. (2004, 2005) recorded three sedimentary cycles. Each cycle starts with massive to laminated, whitish mudstones (nannochalk) and grades continuously into dark grey mudstones that contain fine-silty quartz. Cycles 1 and 2 show wavy laminations, cycle 3 is mostly laminated. A fourth cycle belongs already to the overlying Eggerding Formation. Phosphatic particles, framboidal pyrite, and rarely glauconite are distributed in the sediment. TOC contents range from 0.5 % to 3.0 % and are diluted by calcareous nannoplankton carbonate (Sachsenhofer & Schulz, 2006).

Fossils: Composed of very few, low-salinity tolerant species of calcareous nannoplankton (*Reticulofenestra ornata* dominated) and also rare diatoms. Characteristic is the co-occurrence of the CNP *Transversopontis fibula* with a small sized, endemic bivalve fauna (*Janschinella* fauna) and rare smooth shelled ostracods (Cyprididae) (Popov et al., 1985; Nevesskaja et al., 1987). This horizon is recorded from the Waschberg Unit (Rögl et al., 2001) and the Carpathians (Krhovsky et al., 2001), but is missing in the well Oberschauersberg 1 in Upper Austria (Schulz et al., 2004).

Origin, facies: The deposition of the Dynów Marls occurred in the deep basin similar to that of the Schöneck Formation, but the sediments were formed by cyclic blooms of coccolithophorids. It was Müller & Blaschke (1971) who for the first time detected that calcareous nannoplankton is the main constituent of the “Heller Mergelkalk” in the NAFB. The high amount of rock forming calcareous nannoplankton is an indication of high productivity in the upper water column, the low diversity points to a decrease in salinity due to increasing fresh water ingressions (SCHULZ et al., 2004). Missing bottom life was caused by anoxic bottom water. In the lower cycle of the Dynów Marl, wavy bedding indicates bottom water currents. Within each cycle, the percentage of marine organic material increases. Limestones were deposited during algal blooms, organic-rich marls during periods with low production of CNP.

The unit represents a major break in the Paratethys evolution when the connections to the Mediterranean and Indian Ocean were lost and the Paratethys became isolated and salinity was reduced (Solenovian Event).

Chronostratigraphic age: Early Oligocene, Rupelian (middle Kiscellian).

The deposition of the Dynów Marls can be correlated with the regional stage Solenovian of the chronostratigraphy of the Eastern Paratethys. The occurrence of this very specific unit is also known as "Solenovian Event" which can be traced and correlated Paratethys-wide.

Biostratigraphy: Calcareous nannofossil Zone NP23 (KRHOVSKY, 1981).

Thickness: In the Austrian Molasse Basin 5–17 m, in the well Oberschauersberg 1 5.5 m (SCHULZ et al., 2004).

Lithostratigraphically higher rank unit: Menilite Formation. The Menilite Formation of the Western Carpathians (Czech Republic, Poland) is subdivided into a Subchert Member, a Chert Member, the Dynów Member and the Šitborice Member. The Dynów Member is laterally continuous from the NAFB to the Western Carpathians. The Subshert and Chert members can be correlated with the Schöneck Formation and the Šitborice Formation with the Eggerding Formation in the NAFB. In the Eastern Carpathians the Menilite Formation has a much longer extent (in dependence from the tectonic units) ranging from the Kiscellian to the Eggenburgian (SACHSENHOFER et al., 2018).

"Untere Meeresmolasse" (Lower Marine Molasse) in Bavaria (as "Heller Mergelkalk") (NATHAN, 1949; DOPPLER & SCHWERD, 1996; DOPPLER et al., 2005)

Lithostratigraphic subdivision: -

Underlying unit(s): Schöneck Formation; mostly sharp contact, only rarely gradational; occasionally direct on Lithothamnium Limestone due to submarine erosion.

Overlying unit(s): Eggerding Formation, in gradational contact.

Lateral units: -

Geographic distribution: In the NAFB the Dynów Marlstone is widely distributed from Bavaria to Salzburg, and Upper Austria to the Waschberg-Ždánice Unit in Lower Austria. In some areas (wells), the unit is missing due to submarine erosion (SCHULZ et al., 2004; SACHSENHOFER & SCHULZ, 2006).

Superregionally, the calcareous nannoplankton chalk facies of the Dynów Marl is distributed over the Central Paratethys from Bavaria to the Carpathian arch to the Transylvanian Basin (KRHOVSKY & DJURASINOVIČ, 1993; KRHOVSKY et al., 1993; POPOV et al., 1993, 2004; RÖGL et al., 1997; RUSU et al., 1996).

Remarks: The lithostratigraphic rank and position of the Dynów Marl is highly inconsistent in respect to its regional occurrence. In the type area it is defined as a member of the Menilite Formation, in the Waschberg-Ždánice Unit it is a member within the Ottenthal Formation (but named Dynów Marlstone). However, the Ottenthal Formation consists of three members – Ottenthal Member, Galgenberg Member, Dynów Marlstone (member) and the latter is on top of the Ottenthal Formation. In Upper Austria the Dynów Marl was raised in rank to a formation (Dynów Formation: WAGNER, 1996b; RUPP, 2008b, 2009a, b, 2011a, b; SACHSENHOFER et al., 2010a). In Bavaria, the term "Heller Mergelkalk" is still in use (e.g., DOPPLER et al., 2005). These different treatments need a re-evaluation of the unit, both from a formal perspective (member vs. formation) and also the retention of the same name in very distant geological regions. Due to these problems and until their clarification, the name Dynów Marl(stone) will still be used herein.

Complementary references: HEERMANN (1954), KRAUS (1968a, b), MÜLLER (1978), DOHMANN (1991), KOTLARCZYK & LEŚNIAK (1990), KOTLARCZYK et al. (1991), ROETZEL & KRENMAYR (1996), SCHULZ et al. (2005), SACHSENHOFER et al. (2010a, 2018), GUSTERHUBER et al. (2012, 2013, 2014), GROSS et al. (2018).

Eggerding-Formation / Eggerding Formation

WERNER E. PILLER, LUDWIG R. WAGNER & FRED RÖGL

Validity: Invalid; Oligocene laminated pelites (marls) only recorded in wells from Upper Austria and Upper Bavaria are well-known as "Bändermergel" (NATHAN, 1949; HEERMANN, 1954; ABERER, 1958); WAGNER (1998) introduced the name Eggerding Formation for this unit; SACHSENHOFER et al. (2010a) provide a detailed study in the Upper Austrian part of the NAFB.

Type area: Area around Zupfing–Eggerding, Upper Austria; ÖK50-UTM, map sheets 3323 Ried im Innkreis, 3324 Grieskirchen (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis).

Remark: The Eggerding Formation is only known from wells. The proposed type section is well Eggerding W 1 and therefore also the type area should be defined there. Unfortunately, this is close to the northern margin of the occurrence in Upper Austria and represents a near-shore environment being not fully representative for the formation.

Type section: Proposed is the shallow well Eggerding W 1 (N 48°20′45″ / E 13°28′01″), Rohöl-Aufsuchungs AG, drill depth 610.4–620.6 m, cores 1, 2, 3 and 4, representing the entire formation in a near-shore environment, Upper Austria; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 29 Schärding). The well location is approx. 2 km SW of the village Eggerding.

Reference section(s): Deep well Perneck 1 (N 48°07′09″ / E 13°12′31″) representing upper slope facies (cf. SACHSENHOFER & SCHULZ, 2006); ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen) and deep well Eggerding 2 (N 48°19′45″ / E 13°31′54″) representing marginal facies; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 29 Schärding). Both cored drilled by Rohöl-Aufsuchungs AG in Upper Austria are proposed as reference sections.

Derivation of name: Named after the village Eggerding, c. 14 km south of the town Schärding and 8 km SW of the market town Andorf, Innviertel district, Upper Austria; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 29 Schärding).

Synonyms: Bändermergel (NATHAN, 1949: p. 22; ABERER, 1958: p. 38), "Rupel-Bändermergel" (BRIX & SCHULTZ, 1993), "Banded Marl" (WAGNER, 1996a, 1998).

Lithology: Dark grey, finely laminated shaly marlstone with thin white layers of calcareous nannoplankton without bioturbation; fine-grained, turbiditic sandstones interfinger with the marls in proximal positions. Framboidal pyrite occurs and TOC contents are about 5 % in the lower and 1.6 % in the upper part (SCHULZ et al., 2004; SACHSENHOFER et al., 2010a).

Fossils: Most common is calcareous nannoplankton of low-diversity assemblages (*Reticulofenestra ornata* dominates the lower part of the formation), forming (paper)thin white layers. The foraminiferal fauna is scarce, partly pyritized. Palynomorphs and partly rich dinoflagellate assemblages were determined from deep well Puchkirchen 3 (HOCHULI, 1978). A detailed description of the dinocyst assemblages from deep wells Eggerding 2, Oberschauersberg 1 and Puchkirchen 3 was carried out by SOLIMAN (2012) and reports 53 genera and 138 species. In respect to macrofossils, on bedding planes plant debris, small molluscs, and fish remains are observed.

Origin, facies: Similar to the Schöneck Formation and the Dynów Marl (and the overlying Zupfing Formation), the deposition of the Eggerding Formation occurred in the deep NAFB. The Eggerding Formation has been deposited in an oxygen deficient environment on the northern slope of the basin with salinity variations in the lower part of the formation (SACHSENHOFER et al., 2010a). The basal part of the Eggerding Formation is a continuation of the cyclic blooms of coccolithophorids (4^{th} cycle) of the three cycles of the Dynów Marl. Upsection, a decline in carbonate production is observed in the course of the change from nannochalk to shale facies; dysoxic bottom water conditions continued but salinity increased during deposition of the formation (SCHULZ et al., 2004). Slope instabilities are indicated by slumps within the Eggerding Formation and extensive submarine slides (SACHSENHOFER et al., 2010a).

Chronostratigraphic age: Late Oligocene, late Rupelian (Kiscellian).

Biostratigraphy: Calcareous nannofossil Zone NP23 (SACHSENHOFER et al., 2010a); Paleogene palaeofloral Zone Pg.Z. 20a (HOCHULI, 1978; RÖGL et al., 1979).

Thickness: Typically, 35–50 m (SACHSENHOFER & SCHULZ, 2006), a maximum thickness of 65 m is reported (due to re-deposition). In some wells, the formation is missing due to submarine erosion (SACHSENHOFER & SCHULZ, 2006; SACHSENHOFER et al., 2018).

Lithostratigraphically higher rank unit: "Menilite Formation". The Menilite Formation of the Western Carpathians (Czech Republic, Poland) is subdivided into a Subchert Member, a Chert Member, the Dynów Member and the Šitbořice Member. The Šitbořice Formation can be correlated with the Eggerding Formation in the NAFB. The Dynów Member is laterally continuous from the NAFB to the Western Carpathians. The Subchert and Chert members can be correlated with the Schöneck Formation In the Eastern Carpathians, the Menilite Formation has a much longer extent (depending on the tectonic units) ranging from the Kiscellian to the Eggenburgian (SACHSENHOFER et al., 2018).

"Untere Meeresmolasse" (Lower Marine Molasse) in Bavaria (as "Bändermergel") (NATHAN, 1949; DOPPLER & SCHWERD, 1996; DOPPLER et al., 2005).

Lithostratigraphic subdivision: -

Underlying unit(s): Dynów Marl(stone), gradational into the Eggerding Formation but erosive in the well Eggerding; occasionally direct on Lithothamnium Limestone due to submarine erosion; locally, turbiditic sand from the north into the basin, e.g., in deep well Eggerding 2.

Overlying unit(s): Zupfing Formation (transitional).

Lateral unit(s): Equivalents in the eastern NAFB are the lower part of the Thomasl Formation in the Waschberg Unit and the lower part of the Šitbořice Member in the Ždánice Unit (FUCHS et al., 2001a). In the Western Carpathians, the Šitbořice Member of the Menilite Formation correlates with the Eggerding Formation (SACHSENHOFER & SCHULZ, 2006; SACHSENHOFER et al., 2018).

Geographic distribution: Widespread occurrence in the NAFB from Bavaria, Salzburg, Upper Austria to the westernmost part of Lower Austria (east of the town Steyr, immediately east of the river Enns (wells Behamberg 1 and Hainbuch 1, Rohöl-Aufsuchungs AG)).

Remarks: In Bavaria, the term "Bändermergel" is still in use (e.g., DOPPLER et al., 2005).

The basal Šitbořice event, a synsedimentary discontinuity, is not observed in the NAFB. In the Transylvanian Basin the laminated facies of bituminous claystones and siltstones is represented in the Ileanda Formation, a marker horizon of calcareous nannoplankton chalk is represented by the Tylawa Limestone (HACZEWSKI, 1989; RUSU et al., 1996; MELINTE-DOBRINESCU & BRUSTUR, 2008: Fig. 6).

The Dynów Marl and the Eggerding Formation are secondary source rocks for oil and gas in the NAFB.

Complementary references: HEERMANN (1954), HAGN (1967), KRAUS (1968a, b), MÜLLER (1978), DOHMANN (1991), ROETZEL & KRENMAYR (1996), PILLER et al. (2004), RUPP (2008b, 2009a, b, 2011a, b, 2014), GUSTERHUBER et al. (2012, 2013, 2014), GROSS et al. (2018).

Zupfing-Formation / Zupfing Formation

LUDWIG R. WAGNER, FRED RÖGL & WERNER E. PILLER

Validity: Invalid; shaly marls overlying the Eggerding Formation ("Bändermergel") are well-known in Upper Austria and Bavaria as "Rupel-Tonmergel" or "Tonmergelstufe"; WAGNER (1996a, 1998) introduced the name Zupfing Formation for this unit.

Type area: Area around Zupfing–Eggerding, Upper Austria; ÖK50-UTM, map sheets 3323 Ried im Innkreis, 3324 Grieskirchen (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis).

Type section: Not defined; a possible type section could be deep well Zupfing 1 (N 48°15′26″ / E 13°37′43″), Rohöl-Aufsuchungs AG., with the most complete section through the unit; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 30 Neumarkt im Hausruckkreis).

Reference section(s): -

Derivation of name: Named after the small village Zupfing, c. 7.5 km NNE of Haag am Hausruck, c. 11 km WNW of Grieskirchen, Hausruckviertel district, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 48 Vöcklabruck).

Synonyms: Älterer Schlier, Tonmergelstufe (e.g., ABERER, 1958), Tonmergel-Schichten, Rupel-Tonmergel, Rupelian Marl, Dunkelolivgrüner Mergelton (NATHAN, 1949), Puchkirchener Serie.

Lithology: Grey to brownish-grey, bioturbated calcareous silty pelites with layers of greenish and brownish limestone beds (lithified nannoplankton ooze) in the lower part, and fine-grained turbiditic sand beds. The lower part of the Zupfing Formation contains a relatively high TOC content (1.5 %) characterizing a "Transition Zone" at the boundary between the Eggerding and Zupfing formations (SACHSENHOFER et al., 2010a, 2018).

Fossils: Calcareous nannoplankton; diverse, partly pyritized planktonic and benthic foraminifera (agglutinated forms are common); some pyritized diatoms, molluscs, plant- and fish remains. Palynomorphs and dinoflagellates were described by HOCHULI (1978).

Origin, facies: Deposited on the northern passive slope of the basin in greater water depth with distal turbidites from the south and slumps, slides and turbidites from the northern slope (SACHSENHOFER & SCHULZ, 2006). The slumps and extensive submarine slides culminated at the transition from the Eggerding to the Zupfing formations (SACHSENHOFER et al., 2010a, 2018). The change in facies from banded shales of the Eggerding Formation to the bioturbated sediments of the Zupfing Formation is correlated with a re-opening of the Paratethys to open oceans terminating the stratification of the water column but oxygen is still depleted.

Chronostratigraphic age: Oligocene, late Rupelian to early Chattian (late Kiscellian to early Egerian).

Biostratigraphy: Calcareous nannofossil Zone NP24 to lower NP25 (SACHSENHOFER et al., 2010a); planktonic foraminifera Zone P21 (*Paragloborotalia opima opima* is considered a marker species; RÖGL & RUPP, 1996); benthic index foraminifera are *Cancris bavaricus* and *Uvigerina moravia* (CICHA et al., 1998); Paleogene palaeofloral Zone Pg.Z. 20b (HOCHULI, 1978; RÖGL et al., 1979).

Thickness: In well Zupfing 1, 140 m of sediment are recorded, maximum thickness is 450 m (SACHSENHOFER & SCHULZ, 2006; GROSS et al., 2018).

Lithostratigraphically higher rank unit: "Untere Meeresmolasse" (Lower Marine Molasse) in Bavaria (as "Dunkelolivgrüner Mergelton" (NATHAN, 1949) or "Rupel-Tonmergel" (DOPPLER & SCHWERD, 1996; DOPPLER et al., 2005)).

Lithostratigraphic subdivision: -

Underlying unit(s): Eggerding Formation with sharp boundary; occasionally direct on Lithothamnium Limestone due to submarine erosion.

Overlying unit(s): Eferding Formation or Ebelsberg Formation, gradational development, depending on the position in the basin or erosive top with overlying Puchkirchen Formation or Miocene Hall or Innviertel Group.

Lateral unit(s): Erosional contact to the Puchkirchen Formation in the south and Innviertel Group in the north, interfingering to the north with sands of the Linz-Melk Formation. Towards the west, in Upper Bavaria the marine shale facies interfingers with the sand facies of the "Bausteinschichten" (REISER, 1987; SCHWERD et al., 1996; DOPPLER & SCHWERD, 1996) (herein named Horw Sandstone in the NAFB of Vorarlberg). In the southern Molasse imbricates the formation interfingers with the Rogatsboden Formation.

A corresponding deep-water facies is developed in the Waschberg Unit in the Thomasl Formation (FUCHS et al., 2001a). This formation continues to the northeast into the Šitbořice Member of the Ždánice Unit and, to the west, its upper part correlates with the Zupfing Formation. A similar facies and microfauna is observed in Hungary in the Kiscell Clay (BÁLDI, 1986).

Geographic distribution: Widespread in the NAFB in Upper Austria and Bavaria.

Remarks: -

Complementary references: MÜLLER (1978), PILLER et al. (2004), RUPP (2009a, b, 2011a, b, 2014), RUPP & ĆORIĆ (2017).

Eferding-Formation / Eferding Formation

WERNER E. PILLER, LUDWIG R. WAGNER & FRED RÖGL

Validity: Valid; WAGNER (1996a, 1998) introduced the name Eferding Formation for pelitic and sandy shelf sediments, which were part of "Älterer Schlier" in the older literature; RUPP & ĆORIĆ (2015) provide a detailed description and formalization of the formation.

Type area: Area around the town Eferding, Eferding Basin, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 31 Eferding).

Type section: Abandoned sand- and clay pit Obermair (owner Quarzsande GmbH) (N 48°18′14″ / E 13°59′37″) in the village Unterrudling, community Hinzenbach, c. 2 km west of the town Eferding, Eferding Basin, Upper Austria (RUPP & ĆORIĆ, 2015: p. 34–37). The Eferding Formation is about 20 m thick in this outcrop and the lower boundary is exposed; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 31 Eferding).

Reference section(s): Clay pit near the hamlet Polsenz (N 48°17′52″ / E 13°59′29″) (owner Leitl Spannton GmbH), 1 km south of the brickyard Unterrudling, community Hinzenbach, Eferding Basin, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 31 Eferding) (RUPP & ĆORIĆ, 2015: p. 37). Compared to the type section the reference section represents a slightly higher part.

Derivation of name: Named after the town Eferding, c. 20 km W of the city of Linz, Eferding Basin, Hausruckviertel district, Upper Austria; ÖK50-UTM, map sheet 4319 Linz (ÖK50-BMN, map sheet 31 Eferding).

Synonyms: Älterer Schlier p.p., Rupel-Tonmergel p.p., oligozäner Schieferton p.p., Puchkirchener Serie p.p., Puchkirchener Schichtengruppe p.p.

Lithology: Dark grey to dark brown-grey, silty and sandy, micaceous, well-bedded pelites with large dolomitic concretions or Fe-dolomitic banks/beds; strongly bioturbated. Sandy intercalations occur, especially near to the Linz-Melk Formation.

Fossils: Calcareous nannoplankton and rich benthic and scarce planktonic foraminiferal assemblages (Rupp & Ćorić, 2015) occur and some ostracods. Fish bones and teeth (Feichtinger et al., 2020), small molluscs, and trace fossils are abundant in some parts. Plant remains, especially leaves in the concretions (Kovar-Eder & Berger, 1987) are abundant. Palynomorphs are dominated by arctotertiary elements, and dinoflagellates are very diverse (Hochuli, 1978).

Origin, facies: Shelf deposits. At the type locality the lower part is deposited in the lower neritic zone, the upper part in bathyal depth (based on benthic foraminifers). The environment was mostly well oxidized with high food availability. Raised food levels (upwelling?) are expressed by nannoplankton blooms. Abundant shallow water foraminifers (e.g., *Asterigerinata*) point to transportation (Rupp & Ćorić, 2015). Slides and slumps of sediments of the Eferding Formation into the basin interfinger with the Rogatsboden Formation (Wagner, 1998).

Chronostratigraphic age: Late Oligocene, Chattian (early Egerian).

Biostratigraphy: Calcareous nannofossil Zone upper NP25 (Rupp & Ćorić, 2015), planktonic foraminifera Zone P22, paleofloral Zone Ng.Z.I (Hochuli, 1978; Rögl et al., 1979).

Thickness: In the stratotype Unterrudling about 20 m, in the reference section Polsenz 14 m, in deep wells 100 m are reported (e.g., Zupfing 1).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Zupfing Formation (basinward), Linz-Melk Formation (shoreward).

Overlying unit(s): Ebelsberg Formation and Linz-Melk Formation.

Lateral unit(s): Linz-Melk Formation (interfingering shoreward), Puchkirchen Formation.

Geographic distribution: In Upper Austria, the Eferding Formation occurs in the Eferding Subbasin south of the Danube and in the Gallneukirchen Subbasin north of the Danube (Grill, 1937). On a wider scale, occurrences are reported from Upper and Lower Austria (not as Eferding Formation but as "Älterer Schlier") and also from Bavaria. Similar sediments in the disturbed Molasse of Upper Bavaria (e.g., Traun section in Hagn & Hölzl, 1952) are southward directed slumps.

Remarks: The sediments, which were summarized in the unit "Älterer Schlier", became subdivided more recently in three formations (Zupfing Formation, Eferding Formation, Ebelsberg Formation). These represent all pelitic sediments (clays, clayey marls, marls with subordinate fine sand and silt content) and are very difficult to differentiate in small and tectonically disturbed occurrences; as a consequence, the old comprehensive term "Älterer Schlier" is still in use (e.g., Krenmayr & Schnabel, 2006; Rupp et al., 2011). Reports in the literature have therefore to be treated with care since a further differentiation has not made.

Complementary references: Piller et al. (2004), Schulz et al. (2004), Rupp (2008b, 2009a, b, 2011a, 2013c, 2016, 2018), Sachsenhofer et al. (2010a), Rupp & Ćorić (2012).

Ebelsberg-Formation / Ebelsberg Formation

Werner E. Piller, Ludwig R. Wagner & Fred Rögl

Validity: Valid; part of the "Älterer Schlier" in the Egerian is the so-called "Fischschiefer" (fish shale); for this unit, Wagner (1996a, 1998) introduced the name Ebelsberg Formation and Rupp & Ćorić (2012) provide a detailed description and formalization.

Type area: In the area between Linz-Ebelsberg and the town Wels along the river Traun, Upper Austria; ÖK50-UTM, map sheets 4319 Linz, 4320 Perg, 4325 Wels (ÖK50-BMN, map sheets 32 Linz, 33 Steyregg, 50 Bad Hall).

Remark: Surface outcrops are very rare nowadays but are reported along the river Traun within Linz-Ebelsberg, at the base of the castle of Ebelsberg and along the creek Aumühlbach in the subdistrict Ufer of Ebelsberg (Rupp & Ćorić, 2012). The outcrop Pucking (Gregorova et al., 2009; Grunert et al., 2010c) existed only temporarily for the building of an electric power plant at the river Traun (N 48°12′22″ / E 14°13′27″).

Type section: Shallow well UE 50 (32 m total depth; Ebelsberg Formation from 11–32 m) (N 48°15′09″ / E 14°20′27″), c. 400 m W of the railway station Ebelsberg, Ebelsberg is a district of the city Linz, Upper Austria; ÖK50-UTM, map sheets 4319 Linz, 4320 Perg (ÖK50-BMN, map sheets 32 Linz, 33 Steyregg).

Reference section(s): Not defined; a possible reference section could be the clay pit at the hamlet Graben, near Finklham, c. 5 km NE of the market town Bad Schallerbach (Krenmayr & Rupp, 1996) (N 48°14′32″ / E 13°59′24″); ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 49 Wels). This locality could act as reference section for diatomite/menilite occurrences within the formation, which are missing in the type section.

Derivation of name: Named after Ebelsberg, a district in the southern part of the city Linz, Upper Austria; ÖK50-UTM, map sheets 4319 Linz, 4320 Perg (ÖK50-BMN, map sheets 50 Bad Hall, 51 Steyr).

Synonyms: Älterer Schlier, *Meletta* Schlier, Aquitan-Fischschiefer, Schieferton, Phosphoritton, Puchkirchener Serie p.p.

Lithology: Dark grey to grey-brown, weathered light brown, well bedded to finely laminated, fine silty shales with variable carbonate contents. Interbedded are Fe-dolomitic limestone layers, commonly phosphoritic nodules and platy aggregates along the bedding planes. In various sections, diatomaceous shales and diatomites/menilites are interbedded with the shales.

Fossils: Calcareous nannoplankton (Krenmayr & Rupp, 1996; Gregorova et al., 2009; Rupp & Ćorić, 2012), planktonic and benthic foraminifera (Rupp & Haunold-Jenke, 2003; Grunert et al., 2010c), diatoms, silicoflagellates (Bachmann, 1970), siliceous sponge spicules, and molluscs (including pteropod mass occurrences) are well known. Outstanding is the preservation of fish remains and complete fish skeletons (e.g., giant sunfish *Austromola*: Harzhauser et al., 2008b; Gregorova et al., 2009; Grunert et al., 2010c) but also a dolphin was discovered. Palynomorphs and dinoflagellates were studied by Hochuli (1978) and Grunert et al. (2010c), and brown algae and plant leaves by Kovar (1982).

Origin, facies: Located at the northern shelf to slope of the NAFB, the sediments reflect a deep neritic to bathyal environment with full marine conditions and cold bottom water, oxygen depleted, nutrient rich, sometimes showing eutrophication by upwelling (Rupp & Ćorić, 2012). In some parts (e.g., locality Pucking), fine lamination, missing bioturbation and the excellent preservation of macrofossils point to dysoxic-anoxic bottom water conditions (Grunert et al., 2010c). Some species of the fish fauna come from the deep sea, indicating a deep basin of 1,000–1,500 m in southern direction (Rögl et al., 1979). The development of diatomites indicates nutrient rich surface water, possibly connected to upwelling. Since the NAFB was already closed to the west in Bavaria, restricted circulation was the result.

Chronostratigraphic age: Late Oligocene, Chattian (early Egerian) to early Miocene, Aquitanian (late Egerian).

Biostratigraphy: Calcareous nannofossil Zones upper NP25 to NN2 (Gregorova et al., 2009; Grunert et al., 2010c); palaeofloral Zone Ng.Z.II (Hochuli, 1978).

Thickness: In surface outcrops only few meters are exposed, in the type section 21 m and in deep wells, e.g., Zupfing 1, approximately 150 m are reported.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Eferding Formation, Linz-Melk Formation in transgressive or gradational contacts.

Overlying unit(s): Hall Group and Robulus Schlier (erosive).

Lateral unit(s): Puchkirchen Formation. Sediments of the Ebelsberg Formation as slides in the uppermost parts of the Puchkirchen Formation and slumps in the lower Miocene Lindach Formation are common.

Geographic distribution: Widespread in the NAFB in Upper and Lower Austria and Bavaria. Besides the very restricted surface outcrops, the unit is well known from many drillings in Upper Austria.

In Lower Austria, the term "Älterer Schlier" was already used by Nowack (1921) for pelitic sediments in the area between Ybbs an der Donau, Melk and St. Pölten which interfinger with the sand of the Linz-Melk Formation. Roetzel et al. (1983) suggested the term "Älterer Schlier Formation" for this unit. Harzhauser & Mandic (2001) described a mollusc fauna from the location Krustetten/Tiefenfucha (N 48°22′01″ / E 15°39′38″), c. 6.5 km SE of the town Krems an der Donau, assigned these pelitic sediments to the Ebelsberg Formation and gave a late Oligocene (early Egerian) age (calcareous nannofossil Zone NP25, planktonic formanifera Zone P22; palaeofloral Zone Ng. Z. I after Hochuli in Roetzel et al., 1983).

Besides the above-mentioned outcrops in Upper Austria, pelites with phosphoritic and dolomitic concretions in the Gallneukirchen Subbasin north of the Danube, belong also to the Ebelsberg Formation (Grill, 1937).

In the disturbed Molasse of Upper Bavaria, slumps of the Ebelsberg Formation, including diatomites, are described from, e.g., the Thalberg Beds (Hagn & Hölzl, 1952).

In the Waschberg Unit of Lower Austria, the deep-water facies of the Michelstetten Formation and Boudky Formation represent in part lateral equivalents, which continue in the Pouzdřany and Ždánice Units in Moravia. Siliceous microfossils are common but no diatomites occur. Further to the northeast, in the Polish Carpathian Skole Unit, the Piatkowa Diatomite Horizon is developed in the lower part of the Krosno Formation (Kotlarczyk et al., 1985).

Remarks: The sediments, which were summarized in the unit "Älterer Schlier", became subdivided more recently in three formations (Zupfing Formation, Eferding Formation, Ebelsberg Formation). These represent all pelitic sediments (clays, clayey marls, marls with subordinate fine sand and silt content) and are very difficult to differentiate in small and tectonically disturbed occurrences; as a consequence, the old comprehensive term "Älterer Schlier" is still in use (e.g., Krenmayr & Schnabel, 2006; Rupp et al., 2011). Reports in the literature have therefore to be treated with care since a further differentiation has not made.

Complementary references: Fuchs (1980a), Piller et al. (2004), Rupp (2009a, b, 2011a, 2013b), Sachsenhofer et al. (2010a), Rupp & Ćorić (2015).

Puchkirchen-Gruppe / Puchkirchen Group

Werner E. Piller, Ludwig R. Wagner & Fred Rögl

Validity: Valid; Janoschek & Kollmann (in Papp et al., 1968a: p. 12) proposed for the sequence between the "Tonmergelstufe" and the "Haller Serie" the term "Puchkirchener Serie" in the sense of a lithostratigraphic unit, and designated the deep well Puchkirchen 1 as stratotype.

Papp & Steininger (1975: p. 71–74) introduced the "Puchkirchener Schichtengruppe" (= Puchkirchen Group) subdividing it into "untere und obere Puchkirchener Schichten", "Untere und Obere Puchkirchener Schichtengruppe" and "Untere und Obere Puchkirchener "Serie"", respectively. In the same volume, Küpper & Steininger (1975: p. 205) designated the deep well Puchkirchen 1 as type locality for a faciostratotype of the "Puchkirchener Schichtengruppe" within the Egerian stage O/OM$_{ab(c)}$. Wagner (1996b: p. 41) introduced the terms "Puchkirchener Gruppe" and "Untere und Obere Puchkirchen-Formation", but in 1998 he only used "Puchkirchen Formation (Lower Portion)" and "Puchkirchen Formation (Upper Portion)". In Piller et al. (2004), the unit was named "Puchkirchen-Gruppe". This usage and the subdivision into a Lower Puchkirchen Formation and an Upper Puchkirchen Formation has then been followed by most authors, e.g., GRUNERT et al. (2013, 2015), GROSS et al. (2015a, b, 2018), GRUNDTNER et al. (2016), and SACHSENHOFER et al. (2018) but is still used inconsistently (e.g., SACHSENHOFER et al., 2010a; HÜLSCHER et al., 2019) and considered even problematic (HÜLSCHER et al., 2019).

Type area: Oil field Puchkirchen, WNW of Vöcklabruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Deep well Puchkirchen 1 (N 48°01′38″ / E 13°34′37″), 1,090.80–2,437.00 m, approx. 6.4 km WNW of the town Vöcklabruck, Rohöl-Aufsuchungs AG; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis). For a lithologic section of the deep well see KÜPPER & STEININGER (1975: Abb. 43). The lower boundary to the Zupfing Formation is concordant and gradational, the upper boundary to the Miocene Hall Formation is erosive.

Reference section(s): -

Derivation of name: Named after the village Puchkirchen am Trattberg (N 48°02′41″ / E 13°34′24″), c. 8 km NW of the town Vöcklabruck, Hausruckviertel district, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: Älterer Schlier p.p., Oligozänschlier p.p., Puchkirchener Serie (PAPP et al., 1968a), Puchkirchener Gruppe (WAGNER, 1996b), Puchkirchen-Gruppe (PILLER et al., 2004; RUPP, 2011a), Untere und Obere Puchkirchen-Formation (WAGNER, 1996b), Lower and Upper Puchkirchen Formation (WAGNER, 1996a), Puchkirchen Formation (Lower Portion) – Puchkirchen Formation (Upper Portion) (WAGNER, 1998), Lower and Upper Puchkirchen Beds (ZWEIGEL, 1998), Laakirchener Schichten (BÜRGL, 1949).

Lithology: The Puchkirchen Group contains a wide range of clastic lithologies, including clast-supported sandy conglomerate, muddy matrix-supported conglomerate, pebbly sandstone, fine to coarse-grained sandstone, siltstone, and mudstone (DE RUIG & HUBBARD, 2006; HUBBARD et al., 2009). The sandy and muddy conglomerates contain components from Central Alpine units (quartz, various crystalline rocks, dolomite, limestone, flint) but no Flysch or North Alpine components (WAGNER, 1998).

Fossils: Calcareous nannoplankton; deep-water foraminifera with common agglutinated species and rare planktonic species (GRUNERT et al., 2015); rare specimens of *Miogypsinoides complanatus* reported by KÜPPER (1966) are transported from the shallow shelf; ostracods. Palynomorphs and dinoflagellates have been investigated by HOCHULI (1978).

Origin, facies: The sediments of the Puchkirchen Group were deposited in the deep marine Puchkirchen Trough. Sedimentation occurred primarily in a basin-axial low-sinuosity channel belt, involving mass-transport complexes, overbank deposits and tributary channel sediments (Puchkirchen Channel; e.g., DE RUIG & HUBBARD, 2006; HINSCH, 2008; HUBBARD et al., 2005, 2009; BERNHARDT et al., 2012; GRUNERT et al., 2015; HÜLSCHER et al., 2019). The Puchkirchen Channel System was 3–5 km wide and > 100 km long, and reached a depth between 500 and 1,500 m. High surface water productivity resulted in an extensive oxygen minimum zone along the northern slope (WAGNER, 1998; GRUNERT et al., 2013, 2015; RUPP & ĆORIĆ, 2012). The channel system was fed from the Bavarian shelf and the Alpine hinterland (WAGNER, 1998; HINSCH, 2008; HUBBARD et al., 2009).

Along the median of c. 13.5°, the base of the Puchkirchen Group is characterized by a major unconformity at the northern slope of the basin, the so-called "Northern Slope Unconformity (NSU)" which includes a hiatus from 26.9 Ma to 24.5 Ma (HÜLSCHER et al., 2019).

Chronostratigraphic age: Late Oligocene, late Chattian to early Miocene, Burdigalian (Egerian–Eggenburgian).

Sedimentation of the Puchkirchen Group started at 26.9 Ma in the axial part and at 24.5 Ma on the overbanks (GRUNERT et al., 2015; HÜLSCHER et al., 2019). The top is difficult to define because of the mostly erosional gap between the Puchkirchen Group and the Hall Formation ("Base Hall Unconformity (BHU)", but is reconstructed in deep well H, where no erosion occurs, at c. 19.6 Ma (HÜLSCHER et al., 2019).

Biostratigraphy: Calcareous nannofossil zones cover upper NP25/CNO6 (CNO5 after HÜLSCHER et al., 2019) to upper NN2/CNM4, and planktonic foraminiferal Zones P22–N5 (O7–M2 (O6–M2 after HÜLSCHER et al., 2019)), larger benthic foraminifers SBZ23 (GRUNERT et al., 2015); palynomorphs show assemblages of palaeofloral Zones Ng.Z.I–Ng.Z.II (HOCHULI, 1978; RÖGL et al., 1979).

Thickness: In the deep well Puchkirchen 1 the unit reaches 1,346 m, increasing in thickness towards the south and reaching a maximum thickness of 2,500 m near the Alpine thrust front (MALZER et al., 1993; WAGNER, 1998; GRUNERT et al., 2015; GROSS et al., 2018).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Lower Puchkirchen Formation, Upper Puchkirchen Formation. JANOSCHEK & KOLLMANN (in PAPP et al., 1968a: p. 12) subdivided the "Puchkirchener Serie" into "untere Puchkirchener Serie" of Chattian age and "obere Puchkirchener Serie" of Aquitanian age. This differentiation has been used further on (PAPP & STEININGER, 1975) and is based, besides lithologic characters, on different foraminiferal faunas (GRUNERT et al., 2015). Due to a diachronic deposition of sediments in the central basin and the northern overbanks, HÜLSCHER et al. (2019) consider it difficult to identify the Lower and Upper Puchkirchen formations depending on the facies.

Underlying unit(s): Zupfing Formation; in some wells in gradational contact, but in deep wells H, W and Z with a major unconformity and an onlap of sediments of the Puchkirchen Group on the Zupfing Formation (HÜLSCHER et al., 2019).

Overlying unit(s): Hall Formation, with a major submarine erosional hiatus ("Base Hall Unconformity", BHU) (e.g., GROSS et al., 2015a, 2018; HÜLSCHER et al., 2019).

Lateral unit(s): Linz-Melk Formation towards the north. Zupfing and Ebelsberg formations to the south, partly with erosional contact.

Geographic distribution: The Puchkirchen Trough extends from Bavaria over Salzburg and Upper Austria in the central part of the NAFB paralleling the Alpine thrust front.

Remarks: In the older literature of Bavaria the Lower Puchkirchen Formation is commonly referred to as "Unter-Eger" (lower Egerian) and the Upper Puchkirchen Formation as "Ober-Eger" (upper Egerian) (e.g., Hagn, 1981; Reiser, 1987; Wenger, 1987a). More recently, however, the terms Lower and Upper Puchkirchen Formations are also applied (Zweigel, 1998; Doppler et al., 2005). The "Laakirchener Schichten", introduced by Bürgl (1949) belong the Hall Group.

Complementary references: Aberer (1958, 1960), Braumüller (1959), Báldi & Seneš (1975), Robinson & Zimmer (1989), Doppler & Schwerd (1996), Unger (1996), Rupp (2009a, b), Hinsch (2013).

Untere Puchkirchen-Formation (Puchkirchen-Gruppe) / Lower Puchkirchen Formation (Puchkirchen Group)

Werner E. Piller

Validity: Valid; see Puchkirchen Group.

Type area: Oil field Puchkirchen, WNW of Vöcklabruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Deep well Puchkirchen 1, Rohöl-Aufsuchungs AG, 1,846.00–2,437.00 m (N 48°01′38″ / E 13°34′37″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis). The lower boundary to the Zupfing Formation is concordant, as is the upper boundary to the Upper Puchkirchen Formation.

Reference section(s): -

Derivation of name: See Puchkirchen Group.

Synonyms: Älterer Schlier p.p., Oligozänschlier p.p., untere Puchkirchener Schichten(gruppe) (Papp & Steininger, 1975), Untere Puchkirchener "Serie" (Küpper & Steininger, 1975), Puchkirchen Formation (Lower Portion) (Wagner, 1998).

Lithology: Overall, grey clay marls, sandstones and conglomerates.

Aberer (1958) described the following sequence: fine grained, micaceous, hard, unbedded sandstone at the base with subordinate medium grey clay marl layers. Followed by a thick package of alternating conglomeratic gravel with grey, sandy marly matrix, grey fine grained sandstone and grey hard clay marl.

Braumüller (1959) gave a subdivision into four units (base to top): Chatt 4: dark grey to dark brownish grey, monotonous clay marl with thin sandstone layers; Chatt 3: alternation of dark grey, sandy clay marl with fish remains and sand and sandstone layers, fine gravel and thin coals layers; Chatt 1+2: predominantly clay marl.

Küpper & Steininger (1975) subdivided the Lower Puchkirchen Formation into "Liegende Tonmergel" (Lower calcareous shales), a "Sand-Schotterserie" (sand-gravel sequence) and "Hangende Tonmergel" (Upper calcareous shales).

Fossils: Calcareous nannoplankton, foraminifers (mostly agglutinated, planktonics subordinate), fish remains, plant remains.

Origin, facies: See Puchkirchen Group.

Chronostratigraphic age: Late Oligocene, late Chattian to early Miocene, early Aquitanian (late Egerian).

Sedimentation of the Lower Puchkirchen Formation started at 26.9 Ma in the axial part of the channel and at 24.5 Ma on the overbanks (Grunert et al., 2015; Hülscher et al., 2019).

The boundary between the Lower and Upper Puchkirchen formations is reconstructed continuously for the type section Puchkirchen 1 and is dated in deep well Hochburg 1 at 22.0–22.2 Ma (Grunert et al., 2015); in deep wells H, W and Z occurs a hiatus between 23.5–22.5 Ma (Hülscher et al., 2019: Fig. 12; in the text, however, the later authors refer to a boundary age ranging from 23.5–20.4 Ma!).

Biostratigraphy: Agglutinated foraminiferal assemblage with the lowest occurrence of *Psammosiphonella cyclindrica* (= *Rhabdammina linearis* in older literature) and *Reticulophragmium* aff. *amplectens* are indicative for the Lower Puchkirchen Formation (Rögl & Rupp, 1996; Rögl et al., 1998). Palynomorphs contain assemblages of paleofloral Zone Ng.Z.I (Hochuli, 1978; Rögl et al., 1979).

Thickness: In the type section of the deep well Puchkirchen 1, the Lower Puchkirchen Formation reaches 591 m.

Lithostratigraphically higher rank unit: Puchkirchen Group.

Lithostratigraphic subdivision: The three units described by Küpper & Steininger (1975) could be formalized as members.

Underlying unit(s): Zupfing Formation; in some wells in gradational contact, but in deep wells H, W and Z with a major unconformity and an onlap of sediments of the Puchkirchen Group on the Zupfing Formation (Hülscher et al., 2019).

Overlying unit(s): Upper Puchkirchen Formation. Continuous between the Lower and Upper Puchkirchen formations in the type section Puchkirchen 1, but also a semiregional erosional unconformity is reported (Hülscher et al., 2019).

Lateral unit(s): See Puchkirchen Group.

Geographic distribution: See Puchkirchen Group.

Remarks: -

Complementary references: Robinson & Zimmer (1989), Hubbard et al. (2005, 2009), Rupp (2009a, b, 2011a, b).

Obere Puchkirchen-Formation (Puchkirchen-Gruppe) / Upper Puchkirchen Formation (Puchkirchen Group)

Werner E. Piller

Validity: Valid; see Puchkirchen Group.

Type area: Oil field Puchkirchen, WNW of Vöcklabruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Deep well Puchkirchen 1, Rohöl-Aufsuchungs AG, 1,090.80–1,846.00 m (N 48°01′38″ /

E 13°34′37″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis). The lower boundary to the Lower Puchkirchen Formation is continuous, also the upper boundary to the Miocene Hall Formation (KÜPPER & STEININGER, 1975: Abb. 43).

Reference section(s): -

Derivation of name: See Puchkirchen Group.

Synonyms: Älterer Schlier p.p., Oligozänschlier p.p., obere Puchkirchener Schichten(gruppe) (PAPP & STEININGER, 1975), Obere Puchkirchener "Serie" (KÜPPER & STEININGER, 1975), Puchkirchen Formation (Upper Portion) (WAGNER, 1998).

Lithology: The Upper Puchkirchen Formation is lithologically more diverse than the Lower Puchkirchen Formation. Basically, packages of coarse-grained siliciclastics (gravel, conglomerates) alternating clay marls with sandy intercalations. ABERER (1958) differentiated four units, A4–A1 (base to top; "A" stands for Aquitanian); A4: conglomeratic gravel with a grey, sandy-marly matrix intercalated with subordinate greybrown, fine sandy, hard clay marl and grey fine grained sandstone layers. A3: browngrey, fine sandy, micaceous, indistinctly bedded, hard clay marls with some gravel in the lower part. A2: conglomeratic gravel with grey sandy-marly matrix, greybrown, hard clay marl, and grey fine grained, hard sandstone and a thick "Mürbsandstein" horizon. A1: greybrown, slightly fine sandy, micaceous, well bedded to laminated clay marl with fine-grained very thin sand layers. Abundant fish remains on the bedding planes ("A1 Fishshale").

Fossils: Calcareous nannoplankton, foraminifers (mostly agglutinated, planktonics subordinate), fish remains, plant remains.

Origin, facies: See Puchkirchen Group.

Chronostratigraphic age: Early Miocene, late Aquitanian to early Burdigalian (late Egerian to early Eggenburgian). The Aquitanian/Burdigalian boundary is within the Upper Puchkirchen Formation.

The boundary between the Lower and Upper Puchkirchen formations is reconstructed continuously for the type section Puchkirchen 1 and is dated in deep well Hochburg 1 at 22.0–22.2 Ma (GRUNERT et al., 2015); in deep wells H, W and Z occurs a hiatus between 23.5–22.5 Ma (HÜLSCHER et al., 2019: Fig. 12; in the text, however, the later authors refer to a boundary age ranging from 23.5–20.4 Ma!).

Biostratigraphy: The lower boundary of the Upper Puchkirchen Formation is defined by the first occurrence of the agglutinated foraminifer *Gaudryinopsis austriacus* (RÖGL & RUPP, 1996; RÖGL et al., 1998). In the Upper Puchkirchen Formation palaeofloral Zones Ng.Z.I–Ng.Z.II are recorded (HOCHULI, 1978; RÖGL et al., 1979).

Thickness: In the type section of the deep well Puchkirchen 1, the Upper Puchkirchen Formation reaches 755 m.

Lithostratigraphically higher rank unit: Puchkirchen Group.

Lithostratigraphic subdivision: The four units (A4–A1) described by ABERER (1958) could be formalized as members.

Underlying unit(s): Lower Puchkirchen Formation. Continuous between the Lower and Upper Puchkirchen formations in the type section Puchkirchen 1, but also a semi-regional erosional unconformity is reported (HÜLSCHER et al., 2019).

Overlying unit(s): Hall Formation, with mostly a submarine erosional hiatus ("Base Hall Unconformity", BHU) (e.g., GROSS et al., 2015a, 2018; HÜLSCHER et al., 2019).

Lateral unit(s): See Puchkirchen Group.

Geographic distribution: See Puchkirchen Group.

Remarks: -

Complementary references: BRAUMÜLLER (1959), ROBINSON & ZIMMER (1989), HUBBARD et al. (2005, 2009), RUPP (2009a, b, 2011a, b), BERNHARDT et al. (2012), SHARMAN et al. (2018).

Hall-Gruppe / Hall Group

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; the term was introduced by WAGNER (1996b, 1998). He included, however, units of different basins and tectonic units in this group what is not appropriate.

Type area: Area of Bad Hall and Steyr, Upper Austria; ÖK50-UTM, map sheets 4325 Wels, 4326 Steyr (ÖK50-BMN, map sheet 50 Bad Hall, 51 Steyr).

Type section: Not designated (see Hall Formation).

Reference section(s): -

Derivation of name: Named after the town Bad Hall, Upper Austria; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 50 Bad Hall).

Synonyms: Haller Serie (see remarks), Laakirchener Schichten (BÜRGL, 1949).

Lithology: Dominated by the so-called "Schlier", which represents greenish-grey pelites, weakly sandy and micaceous, evenly thin bedded to bioturbated, locally occur beds of sand and sandstone. In some areas, mostly at the base of the group, coarser grained sediments, coarse sandstones and conglomerates (Lukasedt Formation, Lindach Formation) occur.

Fossils: See formations off the Hall Group.

Origin, facies: Deposited in a several hundred meters deep basin, with distal turbidites, contourites and hemipelagites. Coarser grained sediments were deposited by mass wasting in a deep-water channel system (DE RUIG & HUBBARD, 2006; HUBBARD et al., 2009; BERNHARDT et al., 2012).

Chronostratigraphic age: Early Miocene, early Burdigalian (Eggenburgian).

Biostratigraphy: Calcareous nannofossil Zones NN2 and NN3; European land mammal Zone MN3; regional mollusc stratigraphy (PILLER et al., 2007).

Thickness: Maximum thickness > 800 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Lindach Formation, Hall Formation, Lukasedt Formation.

Remark: WAGNER (1996b, 1998) informally subdivided the Hall Group into the Hall Formation, Lukasedt Formation, Lindach Formation (all Upper Austria) and included also the units "Sandstreifenschlier", Ernstbrunn Formation and the Buchberg Conglomerate, which are located in Lower Austria and belong to the Molasse Zone and the Waschberg Unit, respectively.

Underlying unit(s): "Älterer Schlier", Ebelsberg Formation, Puchkirchen Formation.

Overlying unit(s): Innviertel Group, Robulusschlier.

Lateral unit(s): See formations.

Geographic distribution: Between the rivers Salzach, Inn and Enns in Salzburg and Upper Austria.

Remarks: The Haller Serie *sensu* JANOSCHEK & KOLLMANN (in PAPP et al., 1968a) comprises only the Haller Schlier between Salzach-Inn and Enns (Hall Formation) and its equivalents (actual: Lukasedt Formation and Lindach Formation).

Contrary to PILLER et al. (2004), RUPP (2008a, b, 2009a, b, 2011a) did not apply the term Hall Group.

Complementary references: RÖGL & RUPP (1996).

Lindach-Formation (Hall-Gruppe) / Lindach Formation (Hall Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; denominated by WAGNER (1996b, 1998) but not sufficiently described and formalized.

Type area: Lindach, NE Gmunden, Upper Austria; ÖK50-UTM, map sheet 3206 Gmunden (ÖK50-BMN, map sheet 67 Grünau im Almtal).

Type section: -

Reference section(s): -

Derivation of name: Deep drilling Lindach 1 (Rohöl-AG); N 48°00′38″ / E 13°49′22″.

Synonyms: Haller Basisschichten, Grobklastische Haller Basisschichten (ROETZEL & KRENMAYR, 1996), Lindacher Schichten, Lindach Gruppe, "Basal Silts" ("Basis Silte") (GRUNERT et al., 2013).

Lithology: An alternation of light grey, micaceous pelites, silts, sands and sandy and muddy conglomerates.

Fossils: An almost completely reworked microfauna; rare autochthonous agglutinated foraminifers.

Origin, facies: Deep-water erosional channel with turbidites, massflows and slumps (Basal Hall Formation Channel: HINSCH, 2008).

Chronostratigraphic age: Early Miocene, early Burdigalian (early (?) Eggenburgian).

Biostratigraphy: No data.

Thickness: Maximum thickness around 150 m (BERNHARD, 1988).

Lithostratigraphically higher rank unit: Hall Group (invalid).

Lithostratigraphic subdivision: -

Underlying unit(s): "Älterer Schlier", Upper Puchkirchen Formation.

Overlying unit(s): Hall Formation.

Lateral unit(s): Hall Formation.

Geographic distribution: Subsurface widely distributed in Upper Austria.

Remarks: The Lindach Formation is positioned by RUPP (2008b: Abb. 15) close to the base or at the base (RUPP, 2011a: Abb. 9; GRUNERT et al., 2013: Basal Silts) of the Hall Formation and the Lukasedt Formation near the top. Contrary, WAGNER (1996b: p. 43, Abb. 24; 1998: p. 356, Fig. 9) placed the Lukasedt Formation at the base of the Hall Group and considers also the younger Lindach Formation as sediments of an erosional channel which migrated into a more northward position.

Complementary references: RUPP (2009a, b).

Hall-Formation (Hall-Gruppe) / Hall Formation (Hall Group)

WERNER E. PILLER & CHRISTIAN RUPP

Validity: Invalid; the wide distribution of this sediment in the NAFB is frequently reported in the literature, usually named "Haller Schlier". Already FUCHS (1874: p. 111–112) introduced the name "Schlier von Hall", PETTERS (1936) used the term "Haller Schlier" and JANOSCHEK & KOLLMANN in PAPP et al. (1968a, b) suggested the term "Haller Serie".

Type area: Area of Bad Hall and Steyr, Upper Austria; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 50 Bad Hall).

Type section: Not designated.

Reference section(s): -

Derivation of name: Named after the town Bad Hall, Upper Austria; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 50 Bad Hall).

Synonyms: Schlier von Hall (FUCHS, 1874), Haller Schlier (e.g., PETTERS, 1936), Haller Serie (ROETZEL & KRENMAYR, 1996), "Schlier of Hall" (GRUNERT et al., 2013).

Lithology: Greenish-grey pelites, weakly sandy and micaceous, evenly thin bedded to bioturbated, locally beds of sand and sandstone.

Fossils: Molluscs (pteropods occur frequently in coquinas) (ABERER & BRAUMÜLLER, 1947; SIEBER, 1956a), foraminifera (RUPP & HAUNOLD-JENKE, 2003; GRUNERT et al., 2013). PETTERS (1936) distinguished between "Unterer und Oberer Haller Fauna" with a rich fauna in the upper part and a poor one in the lower.

Origin, facies: Deposited in a several hundred meters deep basin; the lower part represents the final infill and termination of the Puchkirchen Channel, the upper part is made up of clinoforms prograding from the south which fill up the basin within 1 Myrs (HÜLSCHER et al., 2019).

Chronostratigraphic age: Early Miocene, early Burdigalian (Eggenburgian to early Ottnangian) (GRUNERT et al., 2013). Sedimentation of the Hall Formation covers the time span from 19.6 to 18.1 Ma (HÜLSCHER et al., 2019).

Biostratigraphy: Calcareous nannofossil Zones NN2 and NN3 (GRUNERT et al., 2013), local foraminiferal stratigraphy (CICHA et al., 1998; RUPP & HAUNOLD-JENKE, 2003; PILLER et al., 2007; PIPPÈRR & REICHENBACHER, 2009).

Thickness: Maximum thickness > 800 m (ABERER, 1958; WAGNER, 1998; GRUNERT et al., 2015).

Lithostratigraphically higher rank unit: Hall Group (invalid).

Lithostratigraphic subdivision: Not defined, but already PETTERS (1936) differentiated "Unterer und Oberer Haller Schlier" which then have been frequently used in the literature (e.g., BÜRGL, 1946, 1949; ABERER, 1958, 1960; BRAUMÜLLER, 1959; CICHA et al., 1998).

Underlying unit(s): Lindach Formation (see also remarks) (gradational); "Älterer Schlier" (diachronous); Upper Puchkirchen Formation (Puchkirchen Group), with mostly a submarine erosional hiatus ("Base Hall Unconformity", BHU) (e.g., GROSS et al., 2015a, 2018; HÜLSCHER et al., 2019).

Overlying unit(s): Lukasedt Formation (but see also remarks), Innviertel Group, Robulusschlier.

Lateral unit(s): Lukasedt Formation (Hall Group), "Sandstreifenschlier" (in Lower Austria), "Ortenburger Meeressande" in SE Bavaria (e.g., PIPPÈRR & REICHENBACHER, 2009).

Geographic distribution: Between the rivers Salzach, Inn and Enns in Salzburg and Upper Austria.

Remarks: Based on a sequence stratigraphic model, GRUNERT et al. (2013) subdivided the Hall Formation in a lower, middle and upper portion representing the global 3rd-order sequences Bur 1–3.

The Lindach Formation is positioned by RUPP (2008b: Abb. 15) close to the base or at the base (RUPP, 2011a: Abb. 9; GRUNERT et al., 2013: Basal Silts) of the Hall Formation and the Lukasedt Formation near to the top. Contrary, WAGNER (1996b: p. 43, Abb. 24; 1998: p. 356, Fig. 9) places the Lukasedt Formation at the base of the Hall Group (see also Lukasedt Formation).

Complementary references: HOERNES (1875a, b), BRAUMÜLLER (1959), ROETZEL & KRENMAYR (1996).

Lukasedt-Formation (Hall-Gruppe) / Lukasedt Formation (Hall Group)

CHRISTIAN RUPP

Validity: Valid; denominated by WAGNER (1996b: p. 43) and formalized by RUPP (2009a).

Type area: Lukasedt, SE Oberndorf bei Salzburg, Salzburg; ÖK50-UTM, map sheet 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg).

Type section: Outcrop along the path to the sawmill ("upper mill") in the village Dreimühlen near Lukasedt, 1.3 km E Oberndorf in Salzburg (N 47°56′23″ / E 12°57′43″), Salzburg (ROETZEL et al., 1991a); ÖK50-UTM, map sheet 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg). Lower and upper boundaries not outcropping.

Reference section(s): -

Derivation of name: Named after the village Lukasedt (old name: Lukasöd, e.g., ABERER, 1958) near Oberndorf bei Salzburg, Salzburg; ÖK50-UTM, map sheet 3203 Freilassing (ÖK50-BMN, map sheet 63 Salzburg).

Synonyms: Geröllmergel, Geröllmergelgruppe des Schliers, Sandstein-Sandschlier, Sandschlier (TRAUB, 1948), Sand-Schottergruppe (ABERER & BRAUMÜLLER, 1947; ROETZEL et al., 1991a).

Lithology: Lower part: grey, gravelly sandy pelites and pelitic sands to muddy or sandy conglomerates, almost massive and rich in fossils, rarely beds of sandstone intercalated. The gravels are mainly quartz, quartzite and dark dolomite. Upper part: brownish, micaceous, partly pelitic, massive fine sands alternating with grey, sandy pelites, massive or laminated, often rich in plant debris. Several beds of sandstone are intercalated.

Fossils: The lower part contains many molluscs; the upper part is rich in plant debris (ROETZEL et al., 1991a). Foraminifers generally are rare (RUPP, 2009a).

Origin, facies: The lower part represents mudflow-sediments and the upper part are quickly deposited massive sands representing the distal and marine part of the "Paleo-Salzach" fan delta.

Chronostratigraphic age: Early Miocene, early Burdigalian (Eggenburgian).

Biostratigraphy: Molluscs (especially pteropods) and foraminifers indicate an Eggenburgian age.

Thickness: 350 m.

Lithostratigraphically higher rank unit: Hall Group (invalid).

Lithostratigraphic subdivision: -

Underlying unit(s): Hall Formation (Hall Group).

Overlying unit(s): Wachtberg Formation and Innviertel Group.

Lateral unit(s): Hall Formation (Hall Group).

Geographic distribution: Area north of the city of Salzburg (BRAUNSTINGL, 2005; RUPP, 2011a).

Remarks: Following the description of ABERER (1958: p. 47), RUPP (2008b: Abb. 15) positioned the Lukasedt Formation near the top of the Hall Formation Consequently, the Lindach Formation is close to the base or at its base (RUPP, 2011a: Abb. 9; GRUNERT et al., 2013: Basal Silts). Contrary to this opinion, WAGNER (1996b: p. 43; 1998: p. 356, Fig. 9) placed the Lukasedt Formation at the base of the Hall Group.

Complementary references: RUPP (2009a, b).

Wachtberg-Formation / Wachtberg Formation

WERNER E. PILLER

Validity: Invalid; this unit has been introduced as "Sand-Schottergruppe" by ABERER & BRAUMÜLLER (1947: p. 133ff.) and widely used, but renamed to "Wachtberg-Formation" by WAGNER (1996b: p. 44) without further indications.

Type area: Between the hill Wachtberg (E Oberndorf bei Salzburg) and Steinbach, c. 20 km north of the city of Salzburg in the surroundings of Nußdorf am Haunsberg, Salzburg; ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg (ÖK50-BMN, map sheets 63 Salzburg, 64 Straßwalchen).

Type section: -

Reference section(s): -

Derivation of name: The hill Wachtberg (500 m a.s.l.) (N 47°57′15″ / E 12°58′44″), c. 3 km NE of the town Oberndorf bei Salzburg, Salzburg; ÖK50-UTM, map sheet 3203 Freilassing (ÖK50-BMN, map sheets 63 Salzburg).

Synonyms: Sand-Schotter-Gruppe (ABERER & BRAUMÜLLER, 1947; ABERER, 1958), Sand-Schottergruppe (FAUPL & ROETZEL, 1987), Sandschottergruppe (FAUPL et al., 1988), sand gravel group, Wachtberg Gravel (WAGNER, 1998).

Lithology: Grey green, marly fine sands alternating with subordinate claymarl layers. Intercalated are gravel beds of quartz and crystalline rocks, partly conglomeratic. The gravels/conglomerates occur in three distinct belts between Wachtberg-Steinbach, Grub-Lauterbach, and Stießberg-Lielon-Thal.

Fossils: Molluscs, foraminifers (rare).

Origin, facies: Marine fan-delta sediments of the "Paleo-Salzach" river with laterial facies changes over short distances and rapid pinch out.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian–middle Ottnangian) (RUPP, 2009a).

Biostratigraphy: Stratigraphic markers nearly absent, but the occurrence of *Lenticulina buergli* (WENGER) and the pteropod *Clio triplicata* AUDENINO in the lowermost parts indicate an Eggenburgian age (RUPP, 2009a).

Thickness: Maximum of 100 m (ABERER, 1958: p. 48).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Lukasedt Formation (Hall Group) (RUPP, 2011a) (gradational).

Overlying unit(s): Mehrnbach Formation, Oncophora Formation.

Lateral unit(s): Robulus Schlier s.str., Ried Formation, Kletzenmarkt Formation to the north, Atzbach Formation and Vöckla Formation to the east and Braunau Formation to the west (ABERER, 1958; KRENMAYR & ROETZEL, 1996a; RUPP, 2011a).

Geographic distribution: Between Oberndorf bei Salzburg (Salzburg) and Feldbach near Lochen (Upper Austria); ÖK50-UTM, map sheets 3203 Freilassing, 3204 Salzburg, 3328 Mattighofen (ÖK50-BMN, map sheets 46 Mattighofen, 63 Salzburg, 64 Straßwalchen).

Remarks: WAGNER (1996b) did not provide any further explanations for renaming the "Sand-Schottergruppe" to Wachtberg Formation. Additionally, WAGNER (1998: p. 365) listed the "Wachtberg Formation (sand gravel group)" within the Innviertel Group.

Complementary references: KRENMAYR & ROETZEL (1996a), RUPP & VAN HUSEN (2007), RUPP (2009a, b, 2008b), EGGER & VAN HUSEN (2009b).

Vorchdorf-Formation / Vorchdorf Formation

WERNER E. PILLER

Validity: Valid; described and formalized by EGGER et al. (2007a: p. 29–30).

Type area: Restricted to the area around and along the river Alm south of the market town Vorchdorf, Traunviertel district, Upper Austria; ÖK50-UTM, map sheets 3206 Gmunden, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 67 Grünau im Almtal, 49 Wels).

Type section: Outcrop along the eastern undercut bank of the river Alm, E of the settlement Pappelleiten, c. 1.5 km SE of the market town Vorchdorf and c. 13 km NE of the town Gmunden, Upper Austria (N 47°59′28.81″ / E 13°56′08.17″); ÖK50-UTM, map sheet 3206 Gmunden (ÖK50-BMN, map sheet 67 Grünau im Almtal). Lower and upper boundaries not exposed.

Reference section(s): -

Derivation of name: Named after the market town Vorchdorf, Traunviertel district, Upper Austria; ÖK50-UTM, map sheet 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 49 Wels).

Synonyms: Robulusschlier s.str. (RUPP & KRENMAYR, 1996), Sandrinnen(fazies) im Robulusschlier (RUPP & KRENMAYR, 1996), "Robulusschlier mit Sandrinnen" (RUPP & HAUNOLD-JENKE, 2003).

Lithology: Blue-grey to olive-grey clayey silts with variable amount of sand and sandsilt, micaceous, poorly bedded, frequently bioturbated. Intercalated are several meters thick yellowish-grey to grey medium sandy fine sands, with low silt and clay content, micaceous, sometimes pelite clasts at the base. These sands are frequently concretionary. The sands pinch out laterally and reflect channels. In these sands, relicts of cross-bedding, flaser and lenticular bedding are sometimes preserved (RUPP & KRENMAYR, 1996; EGGER et al., 2007a).

Fossils: A rich microfauna with benthic (*Ammonia* and *Cibicidoides/Lobatula* dominated) and planktic (around 50 %) forms is reported from the pelitic parts. The shallow water indicators are considered to be reworked (RUPP & HAUNOLD-JENKE, 2003; EGGER et al., 2007a).

Origin, facies: The pelites correspond to the Robulusschlier and are marine, representing a deep-neritic to upper bathyal (?) basinal facies of quiet water conditions. This environment is interrupted by sand filled channels with allochthonous microfauna (EGGER et al., 2007a).

Chronostratigraphic age: Early Miocene, Burdigalian (early Ottnangian) (EGGER et al., 2007a). The base of the Vorchdorf Formation represents the Eggenburgian/Ottnangian boundary (RUPP & VAN HUSEN, 2008).

Biostratigraphy: The lower boundary of the Vorchdorf Formation is well defined by the last occurrence of *Lenticulina buergli* (top Hall Formation = top Eggenburgian) and the first occurrence of *Amphicoryna ottnangensis* (Rögl & Rupp, 1996).

Thickness: Several meters (but no clear indication in the literature).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Hall Formation (Hall Group).

Overlying unit(s): Robulusschlier s.str. (boundary drawn by the disappearance of the sand channels).

Lateral unit(s): Vöckla Formation (Egger et al., 2007a).

Geographic distribution: Restricted to a narrow area around Vorchdorf, Upper Austria.

Remarks: This formation seems to be a transitional unit between the Vöckl-Formation and the Robulus Schlier.

Complementary references: Egger (2007a), Egger & van Husen (2007), Rupp (2008b, 2009a, b, 2011a).

Robulus-Schlier / Robulus Schlier

Werner E. Piller

Validity: Invalid; mentioned for the first time as Robulus inornatus-Schlier by Petters (1936) but without providing details applicable to formalization. Aberer (1958) differentiated a Robulus Schlier s.l. and s.str. (see below). Herein we include only the Robulus Schlier s.str. For specific occurrences and details in Lower Austria compare with the description there.

Type area: Area between the market towns Bad Schallerbach and Lambach, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 49 Wels).

Type section: -

Reference section(s): -

Derivation of name: Named after the foraminiferal genus *Robulus* (= *Lenticulina*).

Synonyms: *Robulus inornatus*-Schlier (Petters, 1936), Robulus Schlier (Grill, 1941), Robulusschlier s.str. (Aberer, 1958; Rupp, 2008b), Ottnanger Schlier (Bürgl, 1946), miozäner Schlier p.p., Jüngerer Schlier (Rupp, 2011a).

Lithology: Olive grey to blue grey clayey sandy silts with a carbonate content > 25 %; finely, even to slightly wavy laminated with silty-sandy lenses, indistinctly bedded; in part strongly bioturbated.

Fossils: Foraminifers (the abundant occurrence of *Lenticulina* (= *Robulus*) is reflected in its name) dominated by small planktonic taxa (Fuchs, 1968a: p. 52; Krenmayr & Rupp, 1996a), ostracods (Zorn, 1997), macrofossils are rare (molluscs, irregular echinoids), trace fossils.

Origin, facies: Marine, deep-neritic to upper bathyal (?) basinal facies of quiet water conditions.

Chronostratigraphic age: Early Miocene, Burdigalian (early Ottnangian).

Biostratigraphy: The abundant occurrence of *Lenticulina ornata* (d'Orbigny) indicates lower Ottnangian (Rupp, 1997).

Thickness: Maximum of 250 m (Aberer, 1958), > 300 m (Rupp, 1997: Tab. 2).

Lithostratigraphically higher rank unit: Innviertel Group (Krenmayr & Rupp, 1996a; Wagner, 1996b, 1998; Krenmayr, 1997: p. 53, Tab. 2). Rupp (2008b: p. 9–10) explicitly excluded the Robulusschlier sensu stricto from the Innviertel Group.

Lithostratigraphic subdivision: No formal subdivision, but Aberer (1958) summarized "Vöcklaschichten", "Atzbacher Sande" und "Ottnanger Schlier" within the Robulus Schlier s.l.

Underlying unit(s): Hall Formation.

Overlying unit(s): Atzbach Formation, Kletzenmarkt Formation, Plesching Formation.

Lateral unit(s): Upper Austria: Vöckla Formation, Vorchdorf Formation; Lower Bavaria: Neuhofener Mergel, Neuhofener Schichten (Hagn, 1961b; Unger, 1984, 1996; Wenger, 1987a), Neuhofen Formation (Pippèrr et al., 2018); Lower Austria: "Sandstreifenschlier", Prinzersdorf Formation (Krenmayr, 2003a, c), Mauer Formation (Krenmayr, 2003a, b).

Geographic distribution: The Robulus Schlier occurs in the NAFB of Upper and Lower Austria. In Upper Austrian it dominates in the eastern part of the NAFB, however, it also occurs along the northern part of the NAFB from the Inn river in the west to the Enns valley in the east.

Remarks: Robulus Schlier is used as an informal overarching term for lower Miocene pelitic sediments including several units of the Innviertel Group. Aberer (1958) differentiated between Robulusschlier s.l. (including the Vöckla Formation, the Atzbach Formation and the Ottnang Formation) and Robulusschlier s.str., which is a unit in formation-rank on its own. This twofold use of Robulus Schlier caused and still causes confusion. The Robulus-Schlier depicted in Piller et al. (2004) describes only the Robulus-Schlier s.str. However, in the chart it is only indicated for Lower Austria, south of the Danube river.

In Upper Austria the Robulus Schlier is lithologically easy to distinguish from the adjacent Vöckla Formation and the Vorchdorf Formation and from the underlying Hall Formation by its fossil content. On the contrary, the silty to sandy Robulus Schlier in Lower Austria shows distinct sand intercalations and the boundary to the underlying Hall Formation often is not clear due to similar lithologies and the lack of index fossils. This is the reason why in Lower Austria Eggenburgian and Ottnangian pelites were often subsumed under the term "Sandstreifenschlier" (see there).

Complementary references: Janoschek (1959), Faupl & Roetzel (1987), Wagner (1996b), Kohl & Krenmayr (1997), Rupp (2009a, b).

Innviertel-Gruppe / Innviertel Group

Christian Rupp & Werner E. Piller

Validity: Valid; first mentioned as "Innviertler Serie" by Janoschek & Kollmann (in Papp et al., 1968a, b). Formalized by Rupp & van Husen (2008) comprising the Vöckla Formation, Atzbach Formation, Ottnang Formation, Reith Formation, Ried Formation, Mehrnbach Formation, Braunau Formation, Treubach Formation (all RUPP & VAN HUSEN, 2008) and the Kletzenmarkt Formation (KRENMAYR, 1994), the Plesching Formation (ROETZEL, 2002) and the “Enzenkirchner Sande” (ABERER, 1958).

Type area: Innviertel district in western Upper Austria.

Type section: Ottnang-Schanze, type section of the Ottnang Formation, Upper Austria (PAPP et al., 1968a) (see Ottnang Formation).

Reference section(s): -

Derivation of name: Named after “Innviertel”, a district in NW Upper Austria southeast of the river Inn; ÖK50-UTM, map sheets 3317 Passau, 3323 Ried im Innkreis, 3322 Braunau am Inn, 3327 Burghausen, 3330 Attnang Puchheim (ÖK50-BMN, map sheets 27 Braunau am Inn, 28 Altheim, 29 Schärding, 45 Ranshofen, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Synonyms: Innviertler Serie, p.p. Robulus Schlier s.l., p.p. Glaukonitische Serie.

Lithology: Sandy and pelitic sediments; see formations.

Fossils: See formations of the Innviertel Group.

Origin, facies: See formations of the Innviertel Group.

Chronostratigraphic age: Early Miocene, late Burdigalian (early to middle Ottnangian).

Biostratigraphy: See formations.

Thickness: Maximum thickness nearly 700 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Vöckla Formation, Atzbach Formation, Ottnang Formation, Reith Formation, Ried Formation, Mehrnbach Formation, Braunau Formation, Treubach Formation, Kletzenmarkt Formation, Plesching Formation and the “Enzenkirchner Sande”.

Underlying unit(s): Crystalline basement of the Bohemian Massif (diachronous), Hall Group (gradational).

Overlying unit(s): Oncophora Beds.

Lateral unit(s): Robulusschlier, Vorchdorf Formation, Wachtberg Formation (interfingering).

Geographic distribution: Predominantly in Upper Austria between the rivers Inn, Mattig, Vöckla, Aga and Traun and the Bohemian Massif in the north.

Remarks: ABERER (1958) subsumed Vöcklaschichten, Atzbacher Sande and Ottnanger Schlier under Robulusschlier *sensu lato*, the Rieder Schichten represent the Rotalienschlier and Mehrnbacher Sande, Braunauer Schlier and Treubacher Sande were united under the “Glaukonitische Serie”. JANOSCHEK & KOLLMANN (in PAPP et al., 1968a, b) subsumed in the “Innviertler Serie” Vöckla Formation, Atzbach Formation, Ottnang Formation, Ried Formation, Mehrnbach Formation, Braunau Formation, Treubach Formation and the Oncophora Beds. RUPP (2008b) emended the Innviertel Group but excluded the Oncophora Beds. The sediments of the Innviertel Group represent the last marine sequences in the NAFB of Salzburg and Upper Austria, in contrast, the Oncophora Formation consists of non-marine deposits.

Complementary references: GRILL (1954a), WAGNER (1996b, 1998), PILLER et al. (2004), RUPP (2009b).

Vöckla-Formation (Innviertel-Gruppe) / Vöckla Formation (Innviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; formalization by RUPP (2008b).

Type area: Between the market towns Vöcklamarkt and Lambach, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck).

Type section: “Vöcklabrucker Schlierwand”, outcrop at the northern flank of the river Vöckla, 1.7 km WNW of Vöcklamarkt (N 48°00′47″ / E 13°38′00″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck) (RUPP et al., 2007: p. 235); lower and upper boundaries not exposed.

Reference section(s): -

Derivation of name: Named after the river Vöckla, Upper Austria.

Synonyms: Vöckla-Schlier (BÜRGL, 1946), Vöcklaschichten (ABERER, 1958), Robulusschlier s.l. p.p. (ABERER, 1958), Vöckla-Schichten (ROETZEL & KRENMAYR, 1996; KOHL & KRENMAYR, 1997).

Lithology: Greenish-grey to grey, fine to medium quartz sands and sandy pelites, micaceous, partly glauconitic and badly sorted. Intensive alternation of wavy bedded, lenticular to flaser bedded sands and pelites. Bioturbation is common, sometimes obliterating primary sedimentary structures completely. Cross-bedded sands are less common.

Fossils: Macrofossils are rare (ABERER, 1958), pelitic intervals yield calcareous nannoplankton and a well preserved foraminiferal fauna (BÜRGL, 1946; RUPP, 2008b). Trace fossil associations are abundant and diverse (KRENMAYR, 1991; UCHMAN & KRENMAYR, 1995, 2004).

Origin, facies: Focussing on a sedimentological point of view (KRENMAYR, 1991), the Vöckla Formation seems to have been deposited in a shallow subtidal to intertidal marine environment heavily influenced by tidal currents with sand waves and ripple fields. The foraminifera association and the ichnofossils, however, point to a deeper sublittoral paleoenvironment and outer neritic zone (RUPP & VAN HUSEN, 2007).

Chronostratigraphic age: Early Miocene, late Burdigalian (early Ottnangian).

Biostratigraphy: *Amphicoryna ottnangensis* (TOULA) (Foraminifera) is indicative for the regional stage Ottnangian (RÖGL & RUPP, 1996).

Thickness: Maximum thickness more than 400 m (various drill sites of Rohöl Aufsuchungs AG).

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Hall Group (gradational), Wachtberg Formation.

Overlying unit(s): Atzbach Formation (gradational), Kobernaußerwald Formation (erosive).

Lateral unit(s): Wachtberg-Formation in the west, Robulusschlier s.str. in the east, Vorchdorf Formation (all interfingering).

Geographic distribution: Mostly between Vöcklamarkt and Lambach, Upper Austria; ÖK50-UTM, map sheets 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels).

Remarks: -

Complementary references: Wagner (1996b), Rupp (2009a, b).

Atzbach-Formation (Innviertel-Gruppe) / Atzbach Formation (Innviertel Group)

Christian Rupp & Werner E. Piller

Validity: Valid; formalized by Rupp (2008b: p. 12–16).

Type area: Between Ried im Innkreis und Vöcklabruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Abandoned sand-pit, WSW of the church of Puchkirchen am Trattberg and south of the village Berg (N 48°02′34″ / E 13°34′04″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis); lower and upper boundaries not exposed (Rupp et al., 2007).

Reference section(s): -

Derivation of name: Named after the village Atzbach, c. 10 km NNE of Vöcklabruck and NW of Schwanenstadt, Upper Austria; ÖK50-UTM, map sheet 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 48 Vöcklabruck).

Synonyms: Atzbacher Sande (Friedl in Petters, 1936), Oncophora-Sand (Bürgl, 1946).

Lithology: Grey to yellow, rather well sorted fine to coarse sands (rarely gravels) with minor greenish grey pelitic layers, bottom sets and mud drapes intercalated. The quartz-rich, micaceous, partly glauconitic sands are cross-bedded, subordinate massive and yield plant debris and pelitic clasts. Occasionally the sediments show bioturbation.

Fossils: With the exception of shark teeth, macrofossils are rare. Well-preserved microfaunas can be found within the pelitic layers (Krenmayr & Roetzel, 1996a; Rupp & Haunold-Jenke, 2003). This fauna was named “Cibicides-Fauna” by Friedl in Petters (1936). Trace fossils are diverse and abundant (Uchman & Krenmayr, 1995, 2004).

Origin, facies: The cross-bedded sands represent a subtidal marine environment of small-scale sand waves and ripples. The massive sands were deposited in subtidal channels. Polymodal distribution patterns of paleocurrent data give evidence of a distinct asymmetry of the intensity of tidal currents. Paleogeographical considerations lead to the interpretation, that the predominant current (ENE, with current speeds of approximately 0.5 m/s) represents the flood current and the subordinate WNW current the ebb current. Faupl & Roetzel (1987) provide a detailed facies analysis.

Chronostratigraphic age: Early Miocene, late Burdigalian (early Ottnangian).

Biostratigraphy: Rare occurrences of *Amphicoryna ottnangensis* (Toula) (Foraminifera) are indicative for the regional stage Ottnangian (Rögl & Rupp, 1996).

Thickness: Maximum thickness > 180 m (Rupp & van Husen, 2007), 250 m are reported by Bürgl (1946).

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Vöckla Formation (gradational), Robulusschlier s.str. (gradational).

Overlying unit(s): Ottnang Formation (gradational).

Lateral unit(s): Wachtberg Formation, Kletzenmarkt Formation, Robulusschlier s.str., Ottnang Formation (all interfingering).

Geographic distribution: In the Hausruckviertel und Innviertel districts of Upper Austria; ÖK50-UTM, map sheets 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels).

Remarks: -

Complementary references: Groiss (1989), Wagner (1996b, 1998), Rupp (2009a, b, 2011a).

Kletzenmarkt-Formation (Innviertel-Gruppe) / Kletzenmarkt Formation (Innviertel Group)

Christian Rupp & Werner E. Piller

Validity: Valid; Krenmayr (1994) established the “Kletzenmarkt-Glaukonitsand-Formation” providing all available information for a formalization of a lithostratigraphic unit. To follow the rules of the International Stratigraphic Guide (Salvador, 1994) the name Kletzenmarkt-Glaukonitsand-Formation has been transferred without any commentary into Kletzenmarkt Formation by Rupp (2008b: p. 9; cf. also Rupp, 2011a).

Type area: Surroundings of the village Kletzenmarkt, c. 2 km NW of Bad Schallerbach, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 49 Wels).

Type section: Small isolated outcrops in a W–E oriented ditch ESE Kletzenmarkt and NE of Schönau, Upper Austria (N 48°14′48″ / E 13°55′15″) (Krenmayr, 1994; Krenmayr & Rupp, 1996b); ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 49 Wels); lower and upper boundaries are not exposed.

Reference section(s): Ditch W Schönau (N 48°14′28″ / E 13°54′03″); S Unternberg near Grießkirchen (N 48°13′18″ / E 13°50′58″); SSE Stadl im Sulzbachtal (N 48°11′41″ / E 13°51′33″); W Holzwiesen (N 48°15′05″ / E 13°55′02″); SE Kaltenberg (N 48°15′08″ / E 13°56′01″); each locality exhibits its specific lithologic features (Krenmayr, 1994).

Derivation of name: Named after the village Kletzenmarkt, c. 6 km ENE Grießkirchen and c. 2 km NW of Bad Schallerbach, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 49 Wels).

Synonyms: Glaukonitsandserie (Grill, 1955), Kletzenmarkt-Glaukonitsand-Formation (Krenmayr, 1994, 2007; Roetzel & Krenmayr, 1996; Rupp & van Husen, 2007), Kletzenmarkt glauconitic sand (Wagner, 1998).

Lithology: Alternation of greenish grey pelites and greenish grey fine to coarse sands, sometimes gravelly. The sands are rich in quartz, sometimes cross-bedded, often wavy or flaser bedded and remarkably glauconitic, fossiliferous. The pelitic layers are laminated and often as thick as the sand layers (Kohl & Krenmayr, 1997).

Fossils: Badly preserved molluscs, which occur in coquinas at the base (Krenmayr & Rupp, 1996b). Foraminifers are well preserved and diverse (Rupp & Haunold-Jenke, 2003).

Origin, facies: The Kletzenmarkt Formation was deposited within a deep neritic environment influenced by tidal currents (Krenmayr, 1994; Rupp & Haunold-Jenke, 2003). Polymodal paleocurrent patterns from cross-bedded intervals give evidence for tidal activities. The Kletzenmarkt Formation is more pelitic than the adjacent Atzbach Formation and Plesching Formation.

Chronostratigraphic age: Early Miocene, late Burdigalian (early Ottnangian).

Biostratigraphy: Benthic foraminiferal faunas dominated by *Lenticulina* in combination with *Amphicoryna ottnangensis* (Toula) indicate an early Ottnangian age (Rupp & Haunold-Jenke, 2003).

Thickness: Maximum thickness approximately 70 m.

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Robulusschlier s.str. (gradational).

Overlying unit(s): Ottnang Formation (gradational).

Lateral unit(s): Atzbach Formation, Plesching Formation (both interfingering).

Geographic distribution: Distributed in the Upper Austrian Hausruckviertel district in the area between the market towns Kematen am Innbach – Bad Schallerbach – St. Marienkirchen an der Polsenz; ÖK50-UTM, map sheets 3324 Grieskirchen, 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 31 Eferding, 49 Wels).

Remarks: Because of poor outcrops of the formation, Krenmayr (1994) established a series of reference sections (called hypostratotypes by Krenmayr).

Complementary references: -

Plesching-Formation (Innviertel-Gruppe) / Plesching Formation (Innviertel Group)

Christian Rupp & Werner E. Piller

Validity: Invalid; detailed description and revision but no sufficient data for formalization by Faupl & Roetzel (1990); cited as Plesching Formation first by Roetzel (2002: p. 26) and in Rupp (2009a, 2011a).

Type area: Area around the village Rainbach im Innkreis, c. 6 km E of the town Schärding, Upper Austria; ÖK50-UTM, map sheet 3317 Passau (ÖK50-BMN, map sheet 29 Schärding) (Rögl et al., 1973). Since the sediments of the Plesching-Formation belong historically to two different units, the defined type area represents the so-called “Fossilreiche Grobsande” (Fuchs, 1968a). For the “Phosporitsande” (Schadler, 1934) the type area is located around Plesching near Linz (see below).

Type section: The original type locality was an abandoned sand-pit W Rainbach im Innkreis, c. 8 km E Schärding, Upper Austria (N 48°27′16″ / E 13°30′58″); lower and upper boundaries not exposed. It was designated as Faciostratotype for the Ottnangian stage by Rögl et al. (1973: p. 148ff.).

Remark: This sand-pit and all the other locations mentioned by Rögl et al. (1973) do not exist anymore. A possible type section for the Plesching Formation could be in the sandpit at Weinzierlbruck (N 48°19′20″ / E 13°54′04″), c. 0.6 km NW of the market town Prambachkirchen, c. 9 km W–WNW of the town Eferding, Upper Austria; ÖK50-UTM, map sheet 3324 Grieskirchen (ÖK50-BMN, map sheet 31 Eferding). Underlain by sands of the Linz-Melk Formation the Plesching Formation (“Phosphoritsande”) crop out for 12 m of sediments and are rich in mikro- and macrofossils. The upper boundary is not preserved (Faupl & Roetzel, 1990; Roetzel et al., 1991b; Rupp, 2015).

Reference section(s): Faupl & Roetzel (1990) described several sections which could be considered as reference sections: Oberreichenbach (N 48°19′35″ / E 14°23′44″), Außertreffling (N 48°19′41″ / E 14°20′48″), Holzheim (N 48°17′41″ / E 14°15′08″), Gschnarret (N 48°18′56″ / E 13°56′17″), Lindbruck (N 48°21′56″ / E 13°51′34″), Mitterndorf (N 48°25′38″ / E 13°37′26″).

Derivation of name: Named after the village Plesching, c. 4.5 km ENE of the city centre of Linz, north of the Danube close, Upper Austria; ÖK50-UTM, map sheet 4320 Perg (ÖK50-BMN, map sheet 33 Steyregg).

Synonyms: Phosphoritsande (Schadler, 1934), grobkörnige Sande der Taufkirchner Bucht (Aberer, 1958), Fossilreiche Grobsande (Fuchs, 1968a).

Lithology: Grey or greenish grey, medium to coarse sands, partly fine gravel; quartz sands with considerable amounts of feldspar, crystalline fragments and glauconite, in the eastern part of its distribution area with considerable amounts of phosphorite nodules (“Phosphoritsande”). Cross-bedded sand waves alternate with a pelitic interwave subfacies. A channel-facies with massive coarse sands and gravels is often incised into the sand wave facies.

Fossils: Molluscs (Grill, 1937; Fuchs, 1968a; Čtyroký et al., 1973a, b), corals (Kühn, 1965), and fish teeth (Schultz, 1969, 1972; Pfeil, 1983) are sporadically abundant but often allochthonous as many other fossils (Bürgl 1951; Gohrbandt in Braumüller, 1961). Foraminifers are frequent within the pelites (Rögl, 1969; Cicha et al., 1973).

Origin, facies: Deposited on the southern margin of the Bohemian Massif, the sands of the Plesching Formation show features typical for strong tidal activities. The cross-bedded sands can be interpreted as subtidal sand waves alternating with a pelitic subfacies of muddy inter-sand wave areas. The subordinate massive coarse sands and gravels were deposited in shallow channels. Polymodal paleocurrent patterns give evidence for highly asymmetrical tides. The NE directed flood current predominated with estimated current speeds of about 0.7 m/sec (Faupl & Roetzel, 1990).

Chronostratigraphic age: Early Miocene, late Burdigalian (early Ottnangian).

Biostratigraphy: *Amphicoryna ottnangensis* (TOULA) (Foraminifera) and *Pecten hermansenni* (DUNKER) (Bivalvia) are indicative for the regional stage Ottnangian.

Thickness: Maximum approximately 50 m, laterally highly variable.

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement of the Bohemian Massif, Linz-Melk Formation (diachronous), "Älterer Schlier" (diachronous), Robulusschlier, Hall Group (diachronous).

Overlying unit(s): Ottnang Formation, Enzenkirchen Sands.

Lateral unit(s): Robulusschlier? (interfingering).

Geographic distribution: Along the southern margin of the Bohemian Massif in the northern parts of the Upper Austrian Innviertel, Hausruckviertel and Traunviertel districts with limited occurrences also north of the Danube.

Remarks: Due to common reworked fossils (Bivalvia, Vertebrata) the Plesching Formation was earlier thought to be of Eggenburgian age (ABERER, 1958; see FAUPL & ROETZEL, 1990 for details).

Complementary references: KOHL & KRENMAYR (1997), WAGNER (1996b, 1998), PILLER et al. (2004), RUPP (2011a).

Ottnang-Formation (Innviertel-Gruppe) / Ottnang Formation (Innviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; formalized by RUPP (2008b: p. 16–20).

Type area: Between the market towns Ottnang am Hausruck and Wolfsegg am Hausruck, Upper Austria; ÖK50-UTM, map sheet 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 48 Vöcklabruck).

Type section: Abandoned clay pit called Ottnang-Schanze (10.2 m thickness), 500 m N of the market town Ottnang; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis) (N 48°06′07″ / E 13°40′03″); lower and upper boundaries are not exposed. The type section is also the holostratotype for the regional Ottnangian stage/age (RÖGL et al., 1973: p. 140ff.) and has been restudied by GRUNERT et al. (2010a, 2012).

Reference section(s): -

Derivation of name: Named after the market town Ottnang am Hausruck, c. 10 km N of Vöcklabruck, Upper Austria; ÖK50-UTM, map sheet 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 48 Vöcklabruck).

Synonyms: Schlier von Ottnang (REUSS, 1864), Ottnanger Schlier (HOERNES, 1875; BÜRGL, 1946; ABERER, 1958).

Lithology: Greenish-grey to grey, micaceous, badly sorted sandy pelite, subordinate silty sand. Badly stratified, often totally bioturbated, rich in plant debris.

Fossils: The Ottnang Formation is well known for its rich fossil occurrences since the 19th century. Already EHRLICH (1852) reported a list of foraminifera (identified by Reuss) and HÖRNES (1853) and HOERNES (1875) described molluscs and echinoids. Since then a number of taxonomic studies have been carried out including foraminifera, calcareous nannoplankton, dinoflagellate cysts, bivalves, gastropods, cephalopods, ostracods and fish otoliths (e.g., SIEBER, 1956a; ČTYROKÝ et al., 1973a, b; RUPP & VAN HUSEN, 2007; RUPP, 2008b; GRUNERT et al., 2010a).

Origin, facies: Deep neritic marine, low energy facies.

Chronostratigraphic age: Early Miocene, middle Burdigalian (early Ottnangian).

The stratotype Ottnang-Schanze has been correlated with polarity chron C5Dr.2r and an absolute age between 17.95 and 18.056 Ma was inferred (GRUNERT et al., 2010a).

Biostratigraphy: *Amphicoryna ottnangensis* (TOULA), *Sigmoilopsis ottnangensis* CICHA, CTYROKA & ZAPLETALOVA and *Bolivina scitula* HOFMANN (Foraminifera) are indicative for the regional stage Ottnangian. Calcareous nannoplankton taxa assigning the type locality to NN3 (GRUNERT et al., 2010a).

Thickness: Maximum thickness 100 m (KALTBEITZER, 1988).

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement of the Bohemian Massif (diachronous), Atzbach Formation, Kletzenmarkt Formation and Plesching-Formation (all gradational).

Overlying unit(s): Ried Formation and Reith Formation (both gradational).

Lateral unit(s): Robulusschlier (?), Enzenkirchener Sande (both interfingering).

Geographic distribution: Widespread in the Upper Austrian districts Innviertel (Schärding–Zell an der Pram) and Hausruckviertel (Grieskirchen–Frankenburg) (KALTBEITZER, 1988; RUPP, 2008a, b); ÖK50-UTM, map sheets 3317 Passau, 3323 Ried im Innkreis, 3324 Grieskirchen, 3329 Vöcklbruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis, 31 Eferding, 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels).

Remarks: -

Complementary references: GROISS (1989), PAPP et al. (1973), WAGNER (1996b, 1998), RUPP et al. (2007), RUPP (2009a, b), RUPP & VAN HUSEN (2007).

Enzenkirchener Sande (Innviertel-Gruppe) / Enzenkirchen Sands (Innviertel Group)

CHRISTIAN RUPP

Validity: Invalid; introduced by ABERER (1958: p. 58, "Enzenkirchner Sande") but not formalized.

Type area: Area between Enzenkirchen, Siegharting, Andorf and Raab, Upper Austria; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis).

Type section: No type section defined.

A potential type section: sand pit in Seifriedsedt, east of the creek, NNE Andorf, Upper Austria (N 48°23′21″ / E 13°35′20″); ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 30 Neumarkt im Hausruckkreis) (Krenmayr & Roetzel, 1996b: p. 27–28).

Reference section(s): No reference section defined.

A potential reference section: deeply incised hollow way in the village Raab (N 48°21′25″ / E 13°38′37″); ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 30 Neumarkt im Hausruckkreis) (Krenmayr, 1996a).

Derivation of name: Named after the village Enzenkirchen, c. 5 km ENE Andorf and c. 17.5 km SE Schärding, Upper Austria; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheets 30 Neumarkt im Hausruckkreis).

Synonyms: Sandiger Schlier (Bürgl, 1951), Enzenkirchner Sande (Aberer, 1958).

Lithology: Grey to greenish grey, partly silty fine sands, subordinate medium sands, micaceous, cross-bedded, wavy bedded or massive; greenish grey pelitic intervals with flaser bedding and lenticular bedding intercalated. Channels filled with pelitic clast breccias are frequent (Aberer, 1958; Fuchs, 1968a; Krenmayr & Roetzel, 1996a; Krenmayr, 1996a).

Fossils: Foraminifers (Rupp, 2011a), molluscs (Aberer, 1958).

Origin, facies: Subtidal marine environment influenced by tidal currents, with intense changes of deposition and erosion (Faupl & Roetzel, 1987).

Chronostratigraphic age: Early Miocene, late Burdigalian (early to middle Ottnangian) (Krenmayr & Schnabel, 2006).

Biostratigraphy: No data available.

Thickness: Maximum thickness approximately 20 m.

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Ottnang Formation (gradational).

Overlying unit(s): Ried Formation? (gradational).

Lateral unit(s): Ottnang Formation (interfingering).

Geographic distribution: In the northwestern part of the Upper Austrian Innviertel district; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis).

Remarks: -

Complementary references: Aberer (1960), Faupl & Roetzel (1990), Wagner (1998).

Reith-Formation (Innviertel-Gruppe) / Reith Formation (Innviertel Group)

Christian Rupp & Werner E. Piller

Validity: Valid; formalized by Rupp (2008b: p. 21–22).

Type area: Between Reith and Wolfharting, S Eberschwang, c 10 km SSE Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Cut river bank of a tributary to the Antiesen river, N Reith, 2.5 km S Eberschwang, Upper Austria (N 48°08′00″ / E 13°34′06″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis) (Rupp, 2011a); lower and upper boundaries are not outcropping.

Reference section(s): -

Derivation of name: Named after the hamlet Reith, S of the market town Eberschwang, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: Fofelsande (Rupp, 1985), Sande von Reith (Krenmayr & Schnabel, 2006; Rupp, 2011a).

Lithology: Greenish-grey to yellow fine to medium sands, rich in quartz, micaceous, occasionally with pelitic clasts. The sands are massive or cross-bedded, sometimes flaser-bedded with greenish grey pelitic, wavy to lenticular bedded layers intercalated.

Fossils: Foraminifers (*Ammonia* dominated) (Rupp, 1992, 2011a).

Origin, facies: The cross-bedded sands and the shallow water foraminiferal faunas indicate a shallow subtidal marine environment influenced by tidal activities.

Chronostratigraphic age: Early Miocene, late Burdigalian (middle Ottnangian).

Biostratigraphy: Very rare occurrences of *Amphicoryna ottnangensis* (Toula) together with autochthonous shallow water foraminiferal faunas infer a middle Ottnangian age.

Thickness: Maximum thickness 50 m (Rupp, 2008b).

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Ottnang Formation (gradational).

Overlying unit(s): Ried Formation (gradational).

Lateral unit(s): Ried Formation (interfingering).

Geographic distribution: North of the hillrange Hausruck between Eberschwang and St. Kollmann, Upper Austria (Rupp & van Husen, 2007); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Remarks: Differentiated from the Ottnang Formation by its foraminiferal fauna.

Complementary references: -

Ried-Formation (Innviertel-Gruppe) / Ried Formation (Innviertel Group)

Christian Rupp & Werner E. Piller

Validity: Valid; formalized by Rupp (2008b: p. 22–25).

Type area: Wider surroundings of Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Clay pit Eberschwang-Straß, 2.5 km SW Eberschwang and c. 700 m SSW Straß (N 48°08′11″ / E 13°32′16″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis); lower boundary not exposed, upper boundary a discordant, erosional contact with the Ampflwang Formation (Hausruckviertel Group; Pannonian) (ROETZEL & KRENMAYR, 1996; RUPP et al., 2007; RUPP & VAN HUSEN, 2007).

Reference section(s): -

Derivation of name: Named after the town Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: Schichten von Ried (BÜRGL, 1946), Rieder Schichten (ABERER, 1958; PAPP et al., 1968a; ROETZEL & KRENMAYR, 1996), Rotalienschlier (ABERER, 1958; FAUPL & ROETZEL, 1987; ROETZEL & KRENMAYR, 1996), Rotalien-Schlier (PAPP et al., 1968a).

Lithology: Greenish grey pelites, occasionally with thin sand to silt intercalations, micaceous, thinly laminated, even parallel to lenticular bedding with flat sand lenses.

Fossils: Molluscs (rare; RUPP et al., 1991), foraminifers, ostracods, siliceous sponge spicules, diatoms, trace fossils.

Origin, facies: Low water energy facies of a shallow subtidal marine environment, not heavily affected by tidal currents.

Chronostratigraphic age: Early Miocene, late Burdigalian (middle Ottnangian).

Biostratigraphy: Calcareous nannofossil Zones NN2–NN4 (ĆORIĆ, 2003; RUPP, 2008b). Very rare occurrences of *Amphicoryna ottnangensis* (TOULA) and *Bolivina scitula* HOFMANN together with autochthonous shallow water foraminiferal faunas infer a middle Ottnangian age.

Thickness: Maximum thickness 100 m (ARETIN, 1988), mostly 60–80 m.

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Ottnang Formation, Reith Formation (gradational).

Overlying unit(s): Mehrnbach Formation (gradational), Ampflwang Formation (erosional).

Lateral unit(s): Reith Formation, Mehrnbach Formation, Wachtberg Formation (all interfingering).

Geographic distribution: Widespread in the Upper Austrian Innviertel and Hausruck districts.

Remarks: The widely used name “Rotalienschlier” originates from the very abundant foraminiferal genus *Ammonia* (= “*Rotalia*”) (“Zone mit Rotalia”: PETTERS, 1936: p. 11).

Complementary references: ABERER (1960), RÖGL & RUPP (1996), WAGNER (1996b, 1998), RUPP (2009a, 2011a), RUPP & VAN HUSEN (2007).

Mehrnbach-Formation (Innviertel-Gruppe) / Mehrnbach Formation (Innviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; formalized by RUPP (2008b: p. 25–27).

Type area: W and SW of Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Abandoned sand-pit at Magetsham (c. 8 m thick), 7 km SW of Ried im Innkreis (N 48°10′11″ / E 13°25′07″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis); lower and upper boundaries are not exposed (RUPP & VAN HUSEN, 2007).

Reference section(s): -

Derivation of name: Named after the market town Mehrnbach, c. 3.5 km W of the town Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: Mehrnbacher Sande (ABERER, 1958), Oncophora-Sande (PETTERS, 1936; BÜRGL, 1946), p.p. Glaukonitische Serie (ABERER, 1958).

Lithology: Grey to yellow, fine to medium sands, rich in quartz, micaceous, variable glauconitic, occasionally with layers of pelitic clasts. The sands are cross-bedded or massive, sometimes flaser-bedded with greenish grey pelitic layers, wavy to lenticular bedded, intercalated. Bioturbation is sometimes substantial (FAUPL & ROETZEL, 1987).

Fossils: Foraminifers, molluscs, shark teeth, trace fossils.

Origin, facies: The cross-bedded sands and the shallow water foraminiferal fauna indicate a shallow subtidal marine environment influenced by tidal activities (SALVERMOSER, 1999).

Chronostratigraphic age: Early Miocene, late Burdigalian (middle Ottnangian).

Biostratigraphy: Very rare occurrences of *Bolivina scitula* HOFMANN together with autochthonous shallow water foraminiferal faunas infer a middle Ottnangian age.

Thickness: Maximum thickness 80 m (ABERER, 1958).

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Ried Formation (gradational).

Overlying unit(s): Braunau Formation (gradational).

Lateral unit(s): Glaukonitsande (Bavaria), Ried Formation (both interfingering).

Geographic distribution: North of the hillranges Hausruck and Kobernaußerwald, Innviertel district, Upper Austria (FAUPL & ROETZEL, 1987; RUPP & VAN HUSEN, 2007); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Remarks: Already in the 19th century HAUER (1868) described shark and ray teeth, as well as dolphin, sea cow and turtle remains from this formation. ABERER (1958) subsumed the “Mehrnbacher Sande” together with the “Braunauer Schlier” and the “Treubacher Sande” in the “Glaukonitische Serie”.

Complementary references: ABERER (1960), WAGNER (1996b, 1998), RUPP (2011a).

Braunau-Formation (Innviertel-Gruppe) / Braunau Formation (Innviertel Group)

CHRISTIAN RUPP

Validity: Valid; formalized by RUPP (2008b: p. 27–28).

Type area: In the surroundings of Gurten and Aspach in the east to the Inn river in the west around Braunau, Upper Austria (KRENMAYR & SCHNABEL, 2006); ÖK50-UTM, map sheet 3322 Braunau am Inn (ÖK50-BMN, map sheet 27 Braunau am Inn).

Type section: Right bank of the Inn river in the town Braunau (N 48°15′45″ / E 13°02′38″); ÖK50-UTM, map sheet 3322 Braunau am Inn (ÖK50-BMN, map sheet 27 Braunau am Inn) (ABERER, 1958); lower and upper boundaries are not exposed.

Reference section(s): -

Derivation of name: Named after the town Braunau am Inn, Upper Austria; ÖK50-UTM, map sheet 3322 Braunau am Inn (ÖK50-BMN, map sheet 27 Braunau am Inn).

Synonyms: Braunauer Schlier (ABERER, 1958), p.p. Glaukonitische Serie (ABERER, 1958).

Lithology: Greenish grey pelites, often with thin sand intercalations, micaceous, laminated, wavy (rarely even) to lenticular bedding with (glauconitic) sand lenses.

Fossils: Foraminifera, molluscs (ABERER, 1958; RÖGL in PAPP et al., 1970).

Origin, facies: A low water energy facies of a shallow subtidal marine environment not heavily affected by tidal currents

Chronostratigraphic age: Early Miocene, late Burdigalian (middle Ottnangian).

Biostratigraphy: Very rare occurrences of *Bolivina scitula* HOFMANN together with autochthonous shallow water foraminiferal faunas infer a middle Ottnangian age.

Thickness: Maximum thickness 100 m in deep drillings (RUPP & VAN HUSEN, 2007), 40–50 m in surface outcrops along the river Inn (ABERER, 1958).

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Mehrnbach Formation (gradational).

Overlying unit(s): Treubach Formation (gradational).

Lateral unit(s): Mehrnbach Formation (interfingering).

Geographic distribution: In the Upper Austrian Innviertel district, W of Ried im Innkreis; ÖK50-UTM, map sheet 3323 Ried im Innkreis (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Remarks: ABERER (1958) subsumed the “Braunauer Schlier” together with the “Mehrnbacher Sande” and the “Treubacher Sande” in the “Glaukonitische Serie”.

Complementary references: ABERER (1960), FAUPL & ROETZEL (1987), ROETZEL & KRENMAYR (1996), WAGNER (1996a, 1998).

Treubach-Formation (Innviertel-Gruppe) / Treubach Formation (Innviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; described by ABERER (1958) as “Treubacher Sande” formalized by RUPP (2008b: p. 29–30).

Type area: In the surroundings of Treubach and Aspach, Upper Austria (KRENMAYR & SCHNABEL, 2006); ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Type section: Abandoned sand-pit in the village Fraham, c. 2 km NW of the market town Aspach, Upper Austria (N 48°11′39″ / E 13°16′48″); ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen); lower and upper boundaries are not exposed.

Reference section(s): -

Derivation of name: Named after the village Treubach (Untertreubach), c. 14 km ESE Braunau, Upper Austria; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Synonyms: Treubacher Sande (ABERER, 1958), p.p. Glaukonitische Serie (ABERER, 1958).

Lithology: Grey to yellow fine sands, rich in quartz, micaceous, variably glauconitic. The sands are massive, subordinate cross-bedded with intercalated greenish grey pelitic layers, lenticular bedded. Small channels occur filled with pelitic clasts.

Fossils: Foraminifers, molluscs (rare) (ABERER, 1958), trace fossils.

Origin, facies: The (subordinate) cross-bedded sands and the shallow water foraminiferal fauna indicate a shallow subtidal marine environment somehow influenced by tidal activities.

Chronostratigraphic age: Early Miocene, late Burdigalian (middle Ottnangian).

Biostratigraphy: The shallow water foraminiferal fauna is comparable to those of the other middle Ottnangian formations (Mehrnbach Formation, Braunau Formation, etc.). No stratigraphically indicative species are reported.

Thickness: Maximum thickness 50 m.

Lithostratigraphically higher rank unit: Innviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Braunau Formation (gradational).

Overlying unit(s): Oncophora-Schichten (? erosive).

Lateral unit(s): No lateral units known.

Geographic distribution: In the Upper Austrian Innviertel district between Aspach and Treubach; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Remarks: ABERER (1958) subsumed the “Treubacher Sande” together with the “Mehrnbacher Sande” and the “Braunauer Schlier” in the “Glaukonitische Serie”.

Complementary references: ABERER (1960), PAPP et al. (1968a, b), WAGNER (1996b, 1998), SALVERMOSER (1999), RUPP (2011a).

Oncophora-Formation / Oncophora Formation

Werner E. Piller & Christian Rupp

Validity: Valid; the terms "Oncophorensande" (Rzehak, 1882b: p. 114) and "Oncophora-Schichten" (Rzehak, 1893) were first used for beds with the characteristic bivalve *Oncophora* (introduced by Rzehak, 1882a; actual name *Rzehakia*; cf. Čtyroký, 1972) in Moravia (Czech Republic). In Moravia, this unit was formalized as "Věstonické pískovce" (Vestonice Sandstone) by Adámek (2003) and Vestonice Formation by Picha et al. (2006). However, the Upper Austrian-Lower Bavarian occurrences do not coincide with this formation (see also remarks). The unit has been re-evaluated and formalized in Bavaria by Pipèrr et al. (2018).

Type area: Six facies-stratotype sections are reported from Loderham, Hinterholzer Bach, Brombach, Türkenbach, Kühstetten and Walksham between the rivers Inn and Rott, N–WNW of Simbach am Inn (Bavaria, Germany, ATK25, map sheet N17 Simbach a.Inn) (Čtyroký et al., 1973a; Pipèrr et al., 2018).

Type section: Section in a hollow way near the small hamlet of Prienbach-Dötling (Schneider et al., 2011: p. 46–48, Fig. 20) located on the left river bank of the Inn, c. 4 km NE of the town of Simbach am Inn, Bavaria, Germany, ATK25, map sheet N17 Simbach a.Inn) (N 48°16′59″ / E 13°04′38″) (Pipèrr et al., 2018: Fig. 6). The section comprises the Lower Oncophora Beds ("Mehlsande", "Schillhorizont", "Glimmersande") (see below).

Reference section(s): The sections listed under "Type area" may be considered as reference sections.

Derivation of name: Named after the bivalve *Oncophora* Rzehak 1882 (= *Rzehakia* Korobkov 1954). The genus *Oncophora* has been described first by Rzehak (1882a, 1893).

Synonyms: Oncophorasande (Rzehak, 1882b), Oncophora-Schichten (Rzehak (1893), Oncophora-Sande (e.g., Bürgl, 1946), Rzehakia-Schichten (Čtyroký, 1972), *Rzehakia (Oncophora)* Formation (Čtyroký et al., 1973a), Oncophora-Schichten (Roetzel & Krenmayr, 1996; Rupp & van Husen, 2007), Oncophora-Formation (Wagner, 1996b; Pippèrr et al., 2018). Lower Bavaria: Oncophora-Schichten (Wittmann, 1957), Oncophoraschichten (Lemcke et al., 1953), Upper Brackish (Water) Molasse (OBM: Obere Brackwassermolasse), *Rzehakia* (*Oncophora*) Formation.

Lithology: In Lower Bavaria, Wittmann (1957) subdivided the Oncophora-Schichten in "Mehlsande", "Schillhorizont", "Glimmersande", "Aussüßungshorizont", "Schillsande", "Süßwassersande und –Mergel" ("Unio-Sand"; Zöbelein, 1940). Schlickum (1964a, b, 1971) and Schlickum & Strauch (1968) subdivided the Oncophoraschichten in „Lower Oncophora Beds" containing "Mehlsande", "Schillhorizont" and "Glimmersande" and the "Upper Oncophora Beds" with "Aussüßungshorizont", "Schillsande", "Uniosande" and "Lakustrische Schichten". The "Mehlsande" are pale, well-sorted, silty fine sands, the "Schillhorizont" is a shell bed mainly made up by *Rzehakia* and the "Glimmersande" are fine to medium, heavily micaceous sands. The "Aussüßungshorizont" (desalination horizon) is made up of colourful pelites with oligohaline molluscs, the "Schillsande" are grey, sandy pelites with abundant shell remains, the "Uniosande" are yellow fine sands with the bivalve genera *Unio* and *Congeria*, the "Lakustrische Schichten" are brown to grey, non-stratified sands and pelites with minor coal seams.

Fossils: Molluscs (Aberer, 1958; Schlickum, 1963, 1964a, b, 1971; Čtyroký et al., 1973a, b), plant fossils (Upper Austria, Lower Bavaria) (Gregor, 1982), fish otoliths (Reichenbacher, 1993) and foraminifers (Cicha et al., 1973) in the lowest parts.

Origin, facies: Brackish to almost limnic sediments, only in the basal parts marine (30 psu) (Reichenbacher, 1993).

Chronostratigraphic age: Early Miocene, late Burdigalian (late Ottnangian–Karpatian).

The lower part of the Oncophora Formation is magnetostratigraphically correlated with polarity chron C5Dn (17.53–17.24 Ma) by Pipèrr et al. (2018), the uppermost part may be Karpatian in age (Pipèrr & Reichenbacher, 2017). Re-studying the Oncophora Formation magnetostratigraphically (including the type locality) by Hofmayer et al. (2019) suggested a correlation with Chron C5Cn and a (late) Karpatian age.

Biostratigraphy: *Rzehakia guembeli* (Gümbel, 1868) (= *Rzehakia partschi* (Mayer, 1876) sensu Schultz (2005) and Mandic & Ćorić (2007)) is regarded as characteristic for the upper Ottnangian in the North Alpine and Western Carpathian Foreland Basins (Central Paratethys) (Čtyroký et al., 1973b; Ćorić & Rögl, 2004; Mandic & Ćorić, 2007; Pipèrr & Reichenbacher, 2017).

Thickness: In surface outcrops up to 20 m; maximum thickness in drillings 70 m (Rupp, 2008b).

Lithostratigraphically higher rank unit: On a wider geographic scale the Upper Brackish (Water) Molasse (OBM: "Obere Brackwasser Molasse") may be considered a higher rank unit (as a Group: Doppler et al., 2005), in SE Bavaria and Upper Austria the OBM consists only of the Oncophara Formation (Schneider et al., 2011; Pipèrr & Reichenbacher, 2017; Pipèrr et al., 2018).

Lithostratigraphic subdivision: Two informal unit ranks were defined by Schlickum & Strauch (1968): Lower Oncophora Beds (with "Mehlsande", "Schillhorizont" and "Glimmersande"), Upper Oncophora Beds (with "Aussüßungshorizont", "Schillsande", "Uniosande" and "Lakustrische Schichten") (see above).

Remark: All these units are well described and a type locality has been defined for each (Strauch, 1973) but a formalization and validation is missing.

Underlying unit(s): Austria: Treubach Formation, Braunau Formation (diachronous?); Bavaria: "Glaukonitsande & Blättermergel" (Unger, 1984; Pipèrr & Reichenbacher, 2017; Pipèrr et al., 2018).

Overlying unit(s): Austria: Hausruckviertel Group (diachronous); Bavaria: Upper Freshwater Molasse ("Obere Süßwassermolasse", gradational), Ortenburg gravel (Ortenburger Schotter) (Haas, 1987).

Lateral unit(s): Bavaria: Ortenburg gravel (Ortenburger Schotter) (e.g., Unger, 1983, 1996; Haas, 1987; Abdul Aziz et al., 2010).

Geographic distribution: The Oncophora Beds are widespread in Lower Bavaria. In the Innviertel district of Upper Austria the outcrops are poor (e.g., around Treubach and Roßbach; Krenmayr & Schnabel, 2006), but they are widely recorded from drillings.

Remarks: Pippèrr et al. (2018) retained the name *Oncophora* (although this is not in line with the International Stratigraphic Guide) because they wanted to conserve this traditional and well-known name. This continuation of the name for this highly problematic lithostratigraphic unit may cause confusion in future literature.

The Oncophora Beds of Lower Bavaria and Upper Austria are well documented and discussed in the literature. Besides the herein considered beds of the Oncophora Formation, the name Oncophora Beds has been used for sediments from many other places in the Central Paratethys, however, all these occurrences seem to originate from isolated lakes (with endemic mollusc species each) (Harzhauser & Mandic, 2008) and cannot be summarized in a single lithostratigraphic unit.

For example, the “Oncophora Beds” from Lower Austria (e.g., Schnabel, 2002a: p. 7, code 120 on the map of Lower Austria 1:200,000; Roetzel, 2002: p. 25; Wessely, 2006) are lithologically and in their fossil content different from those of Lower Bavaria and Upper Austria (Harzhauser & Mandic, 2008). Consequently, they have been revised, formalized and summarized in the Traisen Formation (Pixendorf Group) by Gebhardt et al. (2013a).

The occurrences in Moravia, which were originally described as “Oncophorasande” by Rzehak (1882b) and “Oncophora-Schichten” (Rzehak, 1893), were more recently named and formalized as Vestonice Sandstone (Adámek, 2003) and Vestonice Formation (Picha et al., 2006).

The Oncophara-Sande described by Bürgl (1946) belong to the Atzbach Formation and the Mehrnbach Formation (Rupp & van Husen, 2007).

Complementary references: Rzehak (1883), Bittner (1893), Papp (1955a), Aberer (1958, 1960), Unger (1984, 1996), Faupl & Roetzel (1987), Wagner (1996b, 1998), Salvermoser (1999), Piller et al. (2004), Mandic & Ćorić (2007), Rupp (2008a, 2009a, b, 2011a).

Obere Süßwassermolasse / Upper Freshwater Molasse

Christian Rupp & Werner E. Piller

Validity: Invalid; introduced by Gümbel (1861) and often used as informal umbrella term summarizing all Paratethyan freshwater sediments younger than the “Obere Brackwassermolasse” (OBM) (Upper Brackish Water Molasse) or “Süßbrackwassermolasse” (SBM) (Lemcke et al., 1953; Unger, 1996) of the early Miocene (late Burdigalian; late Ottnangian to Karpatian) to late Miocene (Tortonian, Pannonian) in Switzerland, Southern Germany and Upper Austria. In the following, we focus on the occurrences in Upper Austria.

Type area: Not designated.

Type section: Not designated.

Reference section(s): -

Derivation of name: Named after the uppermost sedimentary part of the Second Miocene Cycle (Upper Marine Molasse – Eggenburgium–Ottnangium), Upper Brackish Water Molasse (upper Ottnangian–lower Karpatian) ending with freshwater sediments (Upper Freshwater Molasse – Karpatian–Pannonian) (e.g., Papp et al., 1968a, b; Doppler et al., 2005).

Synonyms: Upper Austria: Süßwassermolasse (because no Lower Freshwater Molasse is developed). Bavaria: Süßwasserschichten i.w.S. (Unger, 1984, 1996).

Lithology: Grey and blue clays dominate, clayey sands and gravels also occur, coal seams, rarely chalk.

Fossils: Plant fossils, molluscs, vertebrates.

Origin, facies: Limnic to fluvial sediments. Formed after the retreat of the Paratethyan Sea in the late Ottnangian and desalination of brackish lakes at the Ottnangian/Karpatian boundary and continues into the Pannonian.

Chronostratigraphic age: Early Miocene, late Burdigalian (latest Ottnangian) to late Miocene, Tortonian (Pannonian).

Biostratigraphy: Upper Austria: European land mammal Zones MN4b to MN9 (Doppler et al., 2005).

Thickness: Maximum thickness in Upper Austria: 250 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Rittsteig Beds**,** Kohleführende Süßwasserschichten (Coal-bearing Freshwater Beds), Hausruckviertel-Gruppe (see remarks).

Underlying unit(s): Upper Austria: Wachtberg Formation (diachronous), Innviertel Group (diachronous), Oncophora Formation (diachronous).

Overlying unit(s): Quaternary cover.

Lateral unit(s): Upper Austria: No lateral units known.

Geographic distribution: Innviertel and Hauruckviertel districts of Upper Austria.

Remarks: The name Upper Freshwater Molasse (Obere Süßwassermolasse – OSM) is an overarching term and is in Germany also considered to represent the rank of a lithostratigraphic group (e.g., Doppler et al., 2005). This explains the above units listed under “Lithostratigraphic subdivision”. Since no formal definition exists, also formations of the Hausruckviertel Group are included in the Upper Freshwater Molasse and muddle the entire system.

Graul (1937) included the Hauptschotter, summarizing the “Kohleführende Süßwasserschichten” and the “Hausruck-Kobernaußerwald-Schotter” under this term, in the Upper Freshwater Molasse (*sensu lato*). Götzinger (1925: p. 198) reduced the broad meaning of Gümbel's definition and Graul's usage including only predominantly pelitic sediments between the underlying Oncophora Formation and the overlying “Quarzschotter des Hausruck und Kobernauser Waldes” (= “Hausruck-Kobernaußerwald-Schotter”) excluding the later (Upper Freshwater Molasse *sensu stricto*).

Complementary references: Aberer (1958), Piller et al. (2004), Rupp (2011a).

Rittsteiger-Schichten / Rittsteig Beds

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; introduced by SEITNER (1977) but not formalized.

Type area: Between Rittsteig, part of district Heining, a western district of the town Passau, and Neuburger Wald, Lower Bavaria, Germany; ATK25, map sheet L19 Passau (UNGER, 1984).

Type section: Not unequivocally designated; UNGER (1984: Abb. 20) depicts two sections as "type localities" (Rittsteig, drilling for highway construction, N 48°34′55″ / E 13°21′43″; clay pit in Rittsteig, N 48°34′45″ / E 13°22′19″) (Lower Bavaria, Germany; ATK25, map sheet L19 Passau) (UNGER, 1984), but the sections are highly different.

Reference section(s): -

Derivation of name: Named after Rittsteig, a part of the district Heining, a western district of the town Passau, Lower Bavaria, Germany.

Synonyms: -

Lithology: Red or green gravelly clays, yellow clays, white to dark brown clays adjoining coal seams, fine to medium white sands, rarely gravel.

Fossils: Plant fossils.

Origin, facies: Lake (pond) to coal swamp sediments with minor fluvial ingressions.

Chronostratigraphic age: Early Miocene, late Burdigalian (late Ottnangian to early Karpatian) (UNGER, 1984).

Biostratigraphy: Phytozone OSM-2, European land mammal Zones MN4–6 (GREGOR, 1984).

Thickness: Maximum thickness 40 m (UNGER, 1984) or 50 m (SALVERMOSER & WALSER (1991).

Lithostratigraphically higher rank unit: Obere Süßwassermolasse (Upper Freshwater Molasse) (informal) (e.g., DOPPLER et al., 2005).

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement of the Bohemian Massif (diachronous).

Overlying unit(s): Liegendsande (SALVERMOSER & WALSER (1991), Pitzenberg gravel.

Lateral unit(s): No lateral units known.

Geographic distribution: Few occurrences in Upper Austria E of Passau and N of Münzkirchen (RUPP, 2011a); ÖK50-UTM, map sheet 3317 Passau (ÖK50-BMN, map sheets 12 Passau, 29 Schärding).

Remarks: -

Complementary references: PILLER et al. (2004).

Pitzenberg-Schotter / Pitzenberg Gravel

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; first mentioned by KÖNIG (1910), described by KOHL & SCHILLER (1963), FUCHS (1968a) and SALVERMOSER & WALSER (1991) but not formalized.

Type area: Hill Pitzenberg, c. 2 km W of the market town Münzkirchen, Upper Austria; ÖK50-UTM, map sheet 3317 Passau (ÖK50-BMN, map sheet 29 Schärding).

Type section: Not designated.

South of Englhaming, a village c. 2 km NW of Münzkirchen, an active gravel pit (Fa. Grünberger GmbH.) exists providing good outcrops which could serve as type locality.

Reference section(s): -

Derivation of name: Hill Pitzenberg (559 m a.s.l.), c. 2 km W of the market town Münzkirchen, Upper Austria; ÖK50-UTM, map sheet 3317 Passau (ÖK50-BMN, map sheet 29 Schärding).

Synonyms: "Tertiärschotter und Conglomerat in der Gegend von Münzkirchen" (COMMENDA, 1900: p. 174), Schotter des Pitzenberges (KOHL & SCHILLER, 1963), Quarzitkonglomerate des Pitzenberges (KINZL, 1927), Pitzenberg-Schotter (FUCHS, 1968a), Steinbergschotter (?) (FUCHS, 1980a), Lithozone L2 p.p. (UNGER, 1989), Steinberg-Schotter (SALVERMOSER & WALSER, 1991).

Lithology: Greyish white to reddish fine to coarse residual quartz gravel with silty sand-matrix, rich in kaolin. Gravel indistinctly bedded, sand-layers and sand-lenses rare. The uppermost meters heavily silicified and conglomerated ("Quarzkonglomerat", not to be mixed up with the Pramquellen Bed, see there).

Fossils: One elephant tooth (*Gomphotherium angustidens)* mentioned by TOLLMANN (1985).

Origin, facies: Fluvial sediments heavily kaolinized and partly silicified due to post- sedimentary semi-arid weathering (FUCHS, 1968a).

Chronostratigraphic age: Since fossils are nearly missing the age is highly unclear: early Miocene, late Burdigalian (late Ottnangian to early Karpatian) according to ROETZEL (1994a); middle Miocene, Langhian to Serravallian (early to late Badenian) according to UNGER (1989); middle Miocene, Serravallian (late Badenian to early Sarmatian) according to FUCHS (1968a).

Biostratigraphy: Highly uncertain. According to TOLLMANN (1985) based on *Gomphotherium angustidens*: European land mammal Zones MN4–MN8.

Thickness: Thickness extremely variable depending on the morphology of the crystalline basement; maximum thickness around 60 m (FUCHS, 1968a).

Lithostratigraphically higher rank unit: Obere Süßwassermolasse (Upper Freshwater Molasse) (informal).

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement of the Bohemian Massif (diachronous), Innviertel Group? (diachronous), Liegendsande (SALVERMOSER & WALSER, 1991; RUPP, 2011a) (gradational?).

Overlying unit(s): Quaternary cover.

Lateral unit(s): "Quarzrestschotter" (?) in Lower Bavaria (FUCHS, 1968a; SALVERMOSER & WALSER, 1991).

Geographic distribution: This unit does not form a continuous sediment cover but occurs mostly in isolated patches. It occurs in the "Taufkirchener Bucht" (Embayment of Taufkirchen) in Upper Austria east of Passau and Schärding; ÖK50-UTM, map sheet 3317 Passau (ÖK50-BMN, map sheets 12 Passau, 29 Schärding).

Remarks: The "Liegendsande" are named by SALVERMOSER & WALSER (1991) as unit underlying the Pitzenberg Schotter. They are mentioned also in RUPP (2011a) but not integrated in the map.

The "Steinberg-Schotter" (Steinberg gravel) occurs in a small area south and northwest of the settlement Steinberg, E of the town Schärding (Upper Austria). The lithology is very similar to the Pitzenberg gravel (SALVERMOSER & WALSER, 1991) and this unit is considered to be synonymous (see also RUPP, 2011a).

Complementary references: UNGER (1996), ROETZEL & KRENMAYR (1996), PILLER et al. (2004).

Kohleführende Süßwasserschichten / Coal-bearing Freshwater Beds

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; introduced by ABERER (1958: p. 70ff.) for coal bearing sediments between the Bavarian/Austrian border in the West and Wolfsegg am Hausruck in the East. It is an overarching term covering various units of different ages, including the Trimmelkam Beds (Badenian–Sarmatian), the Munderfing Gravel (Sarmatian–Pannonian) and the Hausruckviertel Group (Pannonian).

Type area: Hausruck and Kobernaußer Wald, Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329 Vöcklabruck (ÖK50-BMN, map sheets 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Type section: -

Reference section(s): -

Synonyms: Hauptschotter p.p. (GRAUL, 1937), Obere Süßwassermolasse (MACKENBACH, 1984).

Lithology: Pelites, sands and gravels of different colours with intercalated coal seams (see also: Trimmelkam Beds, Munderfing Gravel, Kobernaußerwald Formation, Ampflwang Formation, Hausruck Formation).

Fossils: Plant fossils, molluscs (rare), vertebrates.

Origin, facies: Limnic to fluvial sediments, see also Trimmelkam Beds, Munderfing Gravel, Kobernaußerwald Formation, Ampflwang Formation, Hausruck Formation.

Chronostratigraphic age: Early Miocene, late Burdigalian (latest Ottnangian) to late Miocene, Tortonian (Pannonian).

Biostratigraphy: See Trimmelkam Beds, Munderfing Gravel, Kobernaußerwald Formation, Ampflwang Formation, Hausruck Formation.

Thickness: Maximum thickness 250 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: It is an informal unit summarizing the Trimmelkam Beds, the Munderfing Gravel and the formations of the Hausruckviertel Group (Kobernauerwald Formation, Ampflwang Formation, Hausruck Formation).

Underlying unit(s): Wachtberg Formation (diachronous), Innviertel Group (diachronous), Oncophora Formation (diachronous).

Overlying unit(s): Quaternary cover.

Lateral unit(s): No lateral units known.

Geographic distribution: Between the Bavarian/Austrian border in the West and the Hausruck in the East (c. 70 km W–E), Upper Austria.

Remarks: The coal bearing sediments on the southern margin of the Bohemian Massif (e.g., Rittsteig Beds) were not included in the definition of ABERER (1958).

In the column "Alpine Vortiefe/O.Österreich, Salzburg" in PILLER et al. (2004) the term "Kohleführende Süßwasserschichten" was erroneously listed instead of the Ampflwang Formation (which was formerly called "Kohletonserie").

Complementary references: CZURDA (1978), ARETIN (1988), GROISS (1989), RUPP & VAN HUSEN (2007: p. 95–96), RUPP et al. (2011).

Trimmelkamer Schichten / Trimmelkam Beds

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; described by ABERER (1958), often mentioned (CZURDA, 1978; MACKENBACH, 1984; UNGER, 1989) but never sufficiently documented and formalized. It is also well known because of the occurrence of coal, which is part of the "Salzach-Kohlenrevier" (WEBER & WEISS, 1983).

Type area: The area of Trimmelkam and the Weilhartforst, Upper Austria; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheets 44 Ostermiething, 45 Ranshofen).

Type section: -

Reference section(s): -

Derivation of name: Named after the village of Trimmelkam, c. 2.7 km NE of St. Pantaleon (Upper Austria) and c. 25 km NNW of the city of Salzburg, close to the Austrian/Bavarian border; ÖK50-UTM, map sheet 3327 Burghausen (ÖK50-BMN, map sheet 45 Ranshofen).

Synonyms: Trimmelkamer Flözgruppe (CZURDA, 1978: p. 125), Lithozone L1 p.p. (UNGER, 1989).

Lithology: Following ABERER (1958), the Trimmelkam Beds include five units in the Trimmelkam coal area (from bottom to top). 1: the "Basisserie = Bunte Serie" (colourful sequence): colourful (grey, brown, red) pelites and sands, gravels subordinate, 2: the "Graue Serie mit Trimmelkamer Flözgruppe" (grey sequence with Trimmelkam coal seams): grey pelites to sands with (up to three) coal seams intercalated, 3: the "Grüne Serie" (green sequence): greenish, sandy pelites with chalky concretions, micaceous sands subordinate, 4: the "Radegunder Flöz" (Radegund coal seam), and 5: "Grüne Serie mit Quarz-Kristallinschotterlagen" (green sequence with gravel): greenish, sandy, poorly bedded pelites with horizons of quartz and crystalline gravel intercalated. This sequence becomes predominantly gravelly east and north of the type area. See also WEBER & WEISS (1983).

Fossils: Plant fossils, molluscs (rare terrestrial gastropods).

Origin, facies: Lake and coal swamp sediments, in the upper part interfingering with high-energy river channel sediments.

Chronostratigraphic age: Unit 1 to 3: Lower Miocene, Burdigalian (Karpatian) to Middle Miocene, Langhian (Badenian); unit 4 to 5: middle Miocene, Serravallian (Sarmatian) (ABERER, 1958; CZURDA, 1978; RUPP, 2011a).

Biostratigraphy: The Badenian section of the Trimmelkam Beds were dated by terrestrial gastropods (PAPP, 1950, cited in ABERER, 1958); the Sarmatian section was dated palynologically (MEYER, 1956).

Thickness: Maximum thickness 200 m (RUPP & VAN HUSEN, 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal subdivision into "Basisserie = Bunte Serie", "Graue Serie mit Trimmelkamer Flözgruppe", "Grüne Serie", "Radegunder Flöz", "Grüne Serie mit Quarz-Kristallinschotterlagen" (ABERER, 1958).

Underlying unit(s): Oncophora Beds (diachronous).

Overlying unit(s): Munderfing Gravel (gradational).

Lateral unit(s): ? Munderfing Gravel, probably interfingering with the "Grüne Serie mit Quarz-Kristallinschotterlagen".

Geographic distribution: Trimmelkam, Kobernaußerwald and Hausruck areas, Upper Austria.

Remarks: The coal of the Trimmelkam Beds was already mined in historical times, but the major exploitation has been carried out in the second half of the 20th century by the "Salzach Kohlenbergbau Gesellschaft" (SAKOG) which closed, however, the mining activities in 1993 (WEBER & WEISS, 1983; FRIEDL, 2010). Detailed annual reports were provided by GÖTZINGER (1955, 1957, 1958, 1959, 1960, 1961, 1962).

Complementary references: PILLER et al. (2004).

Munderfinger Schotter / Munderfing Gravel

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Invalid; the most detailed study was provided by MACKENBACH (1984). The Munderfing Gravel is often lumped with other sediments under the term "Kohleführende Süßwasserschichten" (ABERER, 1958). It is an informal unit, which is not included in official Austrian map sheets because of its vague distinction from the Kobernaußerwald Formation.

Type area: The western extensions of the Kobernaußerwald near Munderfing, Upper Austria; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Type section: Not designated.

Reference section(s): -

Derivation of name: Named after the village Munderfing, c. 5 km S of the town Mattighofen, Upper Austria; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Synonyms: Lithozone L4 p.p. (UNGER, 1989), Munderfinger-Kobernaußerwald-Hausruckerschotter (BRÜGEL, 1998), Munderfinger-Kobernaußerwaldschotter (RUPP & VAN HUSEN, 2007).

Lithology: Grey fine to coarse gravel, rarely conglomerates with sandy matrix. Gravel rather badly bedded, sometimes with thin sand-layers intercalated. Clast- to matrix-supported fabric. Clasts well rounded, predominately quartz, subordinate crystalline, carbonate very rare. Sandy and silty layers with coal seams intercalated (e.g., GÖTZINGER, 1925; CZURDA, 1978).

Fossils: Plant remains, vertebrates (very rare).

Origin, facies: High-energy river channel sediment with low energy coal swamp sediments intercalated.

Chronostratigraphic age: Middle Miocene, Serravallian (Sarmatian) to late Miocene, Tortonian (Pannonian).

Biostratigraphy: Rather unspecified assignment to the uppermost Sarmatian based on palynology (MEYER, 1956) or Sarmatian to Pannonian based on vertebrates (THENIUS, 1952a).

Thickness: Maximum thickness 140 m (MACKENBACH, 1984).

Lithostratigraphically higher rank unit: An assignment to the Hausruckviertel Group is uncertain and under discussion.

Lithostratigraphic subdivision: -

Underlying unit(s): Innviertel Group, Oncophora Formation (?) (diachronous).

Overlying unit(s): Kobernaußerwald Formation (gradational).

Lateral units: Kobernaußerwald Formation (?) (interfingering).

Geographic distribution: Kobernaußerwald, Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329 Vöcklabruck (ÖK50-BMN, map sheet 46 Mattighofen).

Remarks: MACKENBACH (1984) differentiated the Munderfing Gravel from the Kobernaußerwald Formation due to a lower content of limestone gravel in the later. An inclusion of the Munderfing Gravel into the Hausruckviertel Group or a synonymisation with the Kobernaußerwald Formation is in discussion (RUPP, 2008b).

Complementary references: UNGER (1983), BRÜGEL (1998), PILLER et al. (2004), RUPP (2009a, 2011).

Hausruckviertel-Gruppe / Hausruckviertel Group

CHRISTIAN RUPP

Validity: Valid; described and defined by RUPP (2008b: p. 33).

Type area: Hausruck and Kobernaußer Wald, Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329

Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Type section: See Hausruck Formation.

Reference section(s): -

Derivation of name: Named after the district Hausruckviertel, one of the four historic quarters of Upper Austria.

Synonyms: Coal-bearing Freshwater Beds p.p.

Lithology: Great variety of lithologies, ranging from coarse gravels, sands, clays and coals (see formations).

Fossils: See formations.

Origin, facies: Limnic, fluvial and terrestrial environments of high to low energy facies.

Chronostratigraphic age: Late Miocene, Tortonian (Pannonian).

Biostratigraphy: See formations.

Thickness: Maximum thickness approximately 250 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Kobernaußerwald Formation, Ampflwang Formation (with Grimberg Member and Pramquellen Bed), Hausruck Formation. The assignment of the Munderfing Gravel is uncertain (see above).

Underlying unit(s): Innviertel Group, Oncophora Formation (diachronous).

Overlying unit(s): No overlying units known.

Lateral unit(s): Unclear, since the assignment and boundaries of the Munderfing Gravel is uncertain.

Geographic distribution: Innviertel and Hausruckviertel districts of Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Remarks: -

Complementary references: RUPP (2009a, b, 2011a).

Kobernaußerwald-Formation (Hausruckviertel-Gruppe) / Kobernaußerwald Formation (Hausruckviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; described and formalized by RUPP (2008b: p. 33–35).

Type area: Kobernaußer Wald, Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329 Vöcklabruck (ÖK50-BMN, map sheets 46 Mattighofen, 47 Ried im Innkreis).

Type section: Gravel pit Schwarzmoos (RSK Gebrüder Ragginger Sand- und Kiesgewinnungs GesmbH.), between Schneegattern in the SW and Kobernaußen in the NNE (N 48°04′20″ / E 13°20′43″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis); lower and upper boundaries are not defined.

Reference section(s): -

Derivation of name: Named after Kobernaußerwald (also: Kobernaußer Wald, Kobernauserwald), a hilly wood area E–SE of Matttighofen in the Innviertel district, Upper Austria.

Synonyms: Hauptschotter p.p. (GRAUL, 1937); Hausruck-Deckschotter (BECKER, 1948); Kobernaußerwaldschotter, Kobernaußerwald-Schotter, Hausruck-Kobernaußerwald Schotter (ABERER, 1958; KRENMAYR, 1995), Limnisch-fluviatile Serie p.p. (MACKENBACH, 1984), Kobernaußer-Schotter (MACKENBACH, 1984).

Lithology: Grey fine to coarse gravel, rarely conglomerates with sandy, rarely silty matrix. Gravel even, wavy or cross-bedded, often with thin sand-layers intercalated. Clast- to matrix-supported fabric. Clasts well rounded, predominately quartz, subordinate crystalline rock fragments, carbonate rocks are very rare.

Fossils: Petrified wood and other plant remains, vertebrates (very rare) (THENIUS, 1952a; STEININGER, 1965).

Origin, facies: High-energy river channel sediment, interfingering with low energy swamp sediments of the Ampflwang Formation (RUPP & VAN HUSEN, 2007).

Chronostratigraphic age: Late Miocene, Tortonian (Pannonian).

Biostratigraphy: European land mammal Zones MN9–10 (RABEDER, 1985).

Thickness: Maximum thickness 200 m (RUPP & VAN HUSEN, 2007).

Lithostratigraphically higher rank unit: Hausruckviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Munderfing Gravel (gradational), Oncophora Formation (diachronous), Innviertel Group (diachronous).

Overlying unit(s): Hausruck Formation.

Lateral unit(s): Ampflwang Formation (interfingering).

Geographic distribution: Kobernaußerwald, Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329 Vöcklabruck (ÖK50-BMN, map sheets 46 Mattighofen, 47 Ried im Innkreis).

Remarks: The separation from the Munderfing Gravel and the Hausruck Formation is based on different gravel spectra (RUPP, 2008b). In PILLER et al. (2004), this unit is displayed as Kobernaußerwald Schotter.

Complementary references: SKERIES (1996), RUPP (2009a, 2011a).

Ampflwang-Formation (Hausruckviertel-Gruppe) / Ampflwang Formation (Hausruckviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; known already by BOUÉ (1830a, 1831), described and figured by WAGNER (1878), PETRASCHECK (1922/1924, 1926/1929) and POHL (1968) and finally renamed and formalized by RUPP (2008b: p. 37–41).

Type area: Around the hillside Hausruck, Upper Austria; ÖK50-UTM, map sheets 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 47 Ried im Innkreis, 48 Vöcklabruck).

Type section: Location "Kohleflöz Kalletsberg" (WEBER & WEIDINGER, 2006), c. 1.5 km SE of Zell am Pettenfirst and c. 4.5 km SE of Ampflwang im Hausruckwald (N 48°04′08″ / E 13°36′44″), Upper Austria. ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck); lower and upper boundaries not defined.

Reference section(s): -

Derivation of name: Named after the market town Ampflwang im Hausruckwald, c. 12 km NW Vöcklabruck; Upper Austria.

Synonyms: Kohlentonserie *sensu lato*, Hausruck-Kohlentonserie p.p. (e.g., TOLLMANN, 1985), Limnisch-fluviatile Serie p.p. (MACKENBACH, 1984), Kohlen-Ton-Folge (MACKENBACH, 1984), Produktive Kohlentonserie, Kohleführende Süßwasserschichten (GROISS, 1989), Lithozone L4 p.p. (UNGER, 1989), Hausruck-Kohleton-Serie (RUPP, 2011a).

Lithology: The most characterizing feature of this unit is the occurrence of up to three coal seams. An informal subdivision of the Ampflwang Formation has been provided by POHL (1968) and is used (modified) in the literature: Liegendschichten, Kohletonserie s.str., Hangendtone (WEBER & WEISS, 1983). These informal units are nowadays badly exposed and were therefore not formalized but are still in use (RUPP, 2008b: p. 38).

Liegendschichten: White to ochre, badly sorted sands and clays, rich in quartz, micaceous.

Kohletonserie *sensu stricto*: three coal seams (2–4 m thick each) are separated by sandy clays to silts and partly massive to fine bedded, micaceous sands.

Hangendtone: grey to grey blue clays (called "Tegel").

Gravelly intercalations at the base of the formation are separated as member (Grimberg Member) or bed (Pramquellen Bed).

Fossils: Rich in plant fossils (e.g., HOFMANN, 1927 – see also complementary references), vertebrates are rare (THENIUS, 1952a) but already reported (*Hipparion*, *Chalicotherium*) by TAUSCH (1883).

Origin, facies: Low energy coal swamp sediments and oxbow lake sediments, intensively interfingering with the high-energy river channel sediments of the Kobernaußerwald Formation.

Chronostratigraphic age: Late Miocene, Tortonian (Pannonian).

Biostratigraphy: Pollen give a middle to late Miocene age (late Sarmatian to early/middle Pannonian) (MASSELTER & HOFMANN, 2005), the vertebrate fossils give a Pannonian age: European land mammal Zones MN9–10 (RABEDER, 1985).

Thickness: Maximum thickness 60 m (POHL, 1968; WEBER & WEIDINGER, 2006).

Lithostratigraphically higher rank unit: Hausruckviertel Group.

Lithostratigraphic subdivision: Grimberg Member, Pramquellen Bed.

Underlying unit(s): Munderfing Gravel (gradational), Oncophora Formation (diachronous), Innviertel Group (diachronous).

Overlying unit(s): Hausruck Formation.

Lateral unit(s): Kobernaußerwald Formation (interfingering).

Geographic distribution: Hausruck, Upper Austria; ÖK50-UTM, map sheets 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 47 Ried im Innkreis, 48 Vöcklabruck).

Remarks: The overall finer sediments differentiate the Ampflwang Formation from the Kobernaußerwald Formation (RUPP, 2008b).

The term Kohletonserie *sensu lato* is synonymous to the Ampflwang Formation, the term Kohletonserie *sensu stricto* refers only to the middle part of the sequence including the three coal seams (see above). The coal of the Ampflwang Formation was industrially mined by the Wolfsegg-Traunthaler Kohlenwerks AG (WTK) but the mine was closed 1995 (WEBER & WEISS, 1983; FRIEDL, 2010).

Complementary references: BECKER (1948, 1949, 1950), ARETIN (1988), KOVAR-EDER & WÓJCICKI (2001), BECHTEL et al. (2002), MELLER (2007), RUPP (2009b, 2013a).

Grimberg-Subformation (Ampflwang-Formation, Hausruckviertel-Gruppe) / Grimberg Member (Ampflwang Formation, Hausruckviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; described by ROETZEL (1988b) and formalized by RUPP (2008b: p. 36–37).

Type area: Grimberg, N of the market town Frankenburg am Hausruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Type section: Gravel pit, SE Hintersteining, c. 3 km N of Frankenburg am Hausruck (N 48°05′42″ / E 13°29′27″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis); lower and upper boundaries not defined.

Reference section(s): -

Derivation of name: Named after the Grimberg, conventional name of the woody ridge between the villages Vordersteining and Hintersteining, N Frankenburg am Hausruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: Grimberger Kies (GRAUL, 1937); Grimberger Schotter (GRAUL, 1937); Grimbergkies (e.g., ROETZEL, 1988b).

Lithology: Light grey to ochre to brown fine to medium quartz gravel embedded in a polymict sandy matrix. Intercalated are decimeter-thick layers of massive to cross-bedded fine to coarse quartz sands.

Fossils: -

Origin, facies: High-energy fluvial sediments embedded within the low-energy Ampflwang Formation. Altered by descending acidic waters derived from coal swamps formerly generated above the member.

Chronostratigraphic age: Late Miocene, Tortonian (Pannonian).

Biostratigraphy: See Ampflwang Formation.

Thickness: Maximum thickness 15 m.

Lithostratigraphically higher rank unit: Ampflwang Formation. The Grimberg Member is a coarse clastic unit within the basal part of the Ampflwang Formation

Lithostratigraphic subdivision: Pramquellen Bed (RUPP, 2008b).

Underlying unit(s): Ampflwang Formation (gradational).

Overlying unit(s): Ampflwang Formation (gradational).

Lateral unit(s): Ampflwang Formation (interfingering).

Geographic distribution: S of the Hausruck ridge between Frankenburg am Hausruck and Hintersteining, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Remarks: GRAUL (1937) placed the "Grimbergkies" below the Ampflwang Formation.

Complementary references: RUPP & VAN HUSEN (2007), RUPP (2009a, 2011a).

Pramquellen-Bank (Grimberg-Subformation, Ampflwang-Formation, Hausruckviertel-Gruppe) / Pramquellen Bed (Grimberg Member, Ampflwang Formation, Hausruckviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; first mentioned by HAUER (1857: p. 272–273), described in detail by KÖNIG (1910), KINZL (1927) and MACKENBACH (1984), formalized by RUPP (2008b: p. 35–36) as "Pramquellen Bank". It represents the lowermost part of the Grimberg Member.

Type area: Between Haag am Hausruck in the east and Schernham in the west, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck).

Type section: Surroundings of the springs of the Pram creek, c. 2 km W of Haag am Hausruck, Upper Austria (N 48°10′53″ / E 13°37′07″); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck); lower and upper boundaries not defined.

Reference section(s): -

Derivation of name: Named after the springs of the Pram creek, W of the market town Haag am Hausruck, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck).

Synonyms: Quarzkonglomerat, Quarzitkonglomerat (HAUER, 1857; KÖNIG, 1910: p. 136; ROETZEL, 1988b).

Lithology: Grey to brownish, not always fully lithified conglomerate bed of quartz gravel with siliceous matrix.

Fossils: -

Origin, facies: High-energy fluvial gravel at the base of the Grimberg Member (Ampflwang Formation) altered by descending acidic waters derived from coal swamps formerly generated above the bed.

Chronostratigraphic age: Late Miocene, Tortonian (Pannonian).

Biostratigraphy: See Ampflwang Formation.

Thickness: Maximum thickness 2 m.

Lithostratigraphically higher rank unit: Grimberg Member (Ampflwang Formation).

Lithostratigraphic subdivision: -

Underlying unit(s): Part of the Grimberg Member (Ampflwang Formation) (gradational), Innviertel Group (diachronous).

Overlying unit(s): Part of the Grimberg Member (Ampflwang Formation) (gradational).

Lateral unit(s): Part of the Grimberg Member (Ampflwang Formation) (interfingering).

Geographic distribution: Occurs in the Hausruckviertel and Innviertel districts of Upper Austria and in SE Bavaria (KINZL, 1927).

Remarks: The conglomerate of this bed occurs mostly in lose blocks (KINZL, 1927; GRAUL, 1937; ROETZEL, 1988b). POHL (1968) places the "Quarzitkonglomerat" below the Kohlentonserie (= Ampflwang Formation).

Complementary references: ABERER (1958), GROISS (1989), RUPP & VAN HUSEN (2007), RUPP (2009a, 2011a).

Hausruck-Formation (Hausruckviertel-Gruppe) / Hausruck Formation (Hausruckviertel Group)

CHRISTIAN RUPP & WERNER E. PILLER

Validity: Valid; detailed description and formalization by RUPP (2008b: p. 41–43).

Type area: Hillside Hausruck, Upper Austria; ÖK50-UTM, map sheets 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 47 Ried im Innkreis, 48 Vöcklabruck).

Type section: Gravel pit Schernham, N of the hill Schloßberg, c. 2.5 km W of the market town Haag am Hausruck (N 48°10′27″ / E 13°36′37″) (RUPP et al., 2007; RUPP, 2008b: Abb. 12); ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 48 Vöcklabruck); lower and upper boundaries not defined.

Reference section(s): -

Derivation of name: Named after the hillside Hausruck, a gentle woody elevation in the Hausruckviertel and Innviertel districts of Upper Austria.

Synonyms: Hausruck-Deckschotter (BECKER, 1948), Hausruck-Kobenaußerwald-Schotter (ABERER, 1958), Hausruckschotter (POHL, 1968), Lithozone L5 (UNGER, 1989).

Lithology: Grey fine to coarse gravels to conglomerates with sandy matrix. Gravel normally badly bedded, occasionally cross-bedded. Clast- to matrix-supported fabric. Clasts well rounded, predominately quartz, subordinate crystalline rocks, limestones rare.

Fossils: Petrified wood, vertebrates (THENIUS, 1952a; DAXNER-HÖCK, 2004a).

Origin, facies: High-energy river channel sediment, no low-energy facies documented.

Chronostratigraphic age: Late Miocene, Tortonian (Pannonian).

Biostratigraphy: Mammals (rodents) allow an assignment to the upper part of European land mammal Zone MN10 (DAXNER-HÖCK, 2004a).

Thickness: Maximum thickness 150 m (MACKENBACH, 1984).

Lithostratigraphically higher rank unit: Hausruckviertel Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Kobernaußerwald Formation, Ampflwang Formation (diachronous).

Overlying unit(s): Quaternary cover.

Lateral unit(s): No lateral units known.

Geographic distribution: Hillside Hausruck, Upper Austria; ÖK50-UTM, map sheets 3328 Mattighofen, 3329 Vöcklabruck, 3330 Attnang-Puchheim (ÖK50-BMN, map sheets 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Remarks: -

Complementary references: WAGNER (1878), KÖNIG (1910), GRAUL (1937), GRAUL & WIESENEDER (1939), ABERER (1958), ARETIN (1988), GROISS (1989), SKERIES (1996), PILLER et al. (2004), RUPP & VAN HUSEN (2007), RUPP (2009a, b, 2011a).

North Alpine Foreland Basin: Lower Austria, South of the Danube

Rogatsboden-Formation (Perwang-Gruppe) / Rogatsboden Formation (Perwang Group)

(see North Alpine Foreland Basin: Salzburg – Upper Austria)

Pielach-Formation / Pielach Formation

HANS-GEORG KRENMAYR & REINHARD ROETZEL

Validity: Valid; POŠEPNÝ (1865) first described sediments with coal seams and fossils from the village Pielach (Lower Austria) and FUCHS (1868) reported additional fossils; NOWACK (1921) introduced the term “Pielacher Tegel” for these fine grained sediments below the “Melker Sande” and WAGNER (1998: p. 361) established the term Pielach Formation, however, without further description and formalization. HARZHAUSER & MANDIC (2001: p. 681) provided a paleontologic description of the Pielach Formation. Moreover, the term “Pielach-Formation” was already used in the ÖK50-BMN, map sheet 55 Ober-Grafendorf (SCHNABEL et al., 2012).

Type area: The type area is located in the surroundings of Melk close to the village of Pielach, where sediments of the Pielach Formation were already described in the 19th century (see Validity).

Type section: -

Reference section(s): -

Derivation of name: Named after the village of Pielach, c. 3 km E of the town of Melk, Lower Austria; ÖK50-UTM, map sheet 4323 Sankt Pölten (ÖK-BMN, map sheet 55 Ober-Grafendorf).

Synonyms: Tegel, sandige Tegel (POŠEPNÝ, 1865: p. 165), Sotzka-, Kohlen- u. Hangendschichten (STUR, 1891c); Sotzka-Kohlen- und Hangendschichtén (PAUL & BITTNER, 1894), Pielacher Tegel (NOWACK, 1921: p. 38), Starzinger Schichten (VETTERS, 1922), Tegel von Starzing (VETTERS, 1922: p. 117), kohleführende Schichten von Starzing (GÖTZINGER & VETTERS, 1923), Pielacher Schichten (VETTERS, 1922: p. 130), Tegel um Doppel (GRILL, 1937: p. 42).

Lithology: Sediments of the Pielach Formation are lithologically divers and comprise sandy silts and clays, clayey marls, clayey sands, sandstones, soft coal seams or lenses and blocky crystalline material in clayey matrix. Clayey sediments range from grey, dark grey or black, but also red, green, bluish and ochre to yellow occur, typically in a mottled manner, which helps for identification in the field.

Fossils: Most outcrops are poor in macrofossils; exceptional localities, mostly from short-lived excavations, are rich in molluscs (e.g., ROETZEL et al., 1983; HARZHAUSER, 2000; HARZHAUSER & MANDIC, 2001). The latter describe (p. 681) gastropods (*Tympanotonos, Granulolabium, Neritina*, etc.) and bivalves (*Mytilus, Isognomon, Anomia, Thracia*, etc.). A palynoflora from core material from the drillings Statzendorf and Thallern (Lower Austria) was described by HOCHULI (1978: p. 27, 38). KNOBLOCH (1977: p. 418) described rare fossil leaves from the locality Zelking.

Origin, facies: The Kiscellian to Egerian transgression of the Paratethys onto the Bohemian Massif flooded a relief of deeply weathered crystalline rocks. The Pielach Formation formed in the many small depressions and bays of this relief and also in protected lagoonal, fluvial-estuarine and mud flat environments, next to the sandy coastal and shelf sediments of the Linz-Melk Formation. Rootlet beds at the base indicate a limnic environment. The coal seams are of paralic origin; mollusc faunas generally imply brackish conditions. In the area of Melk, local oscillations of sea level and freshwater influx are documented, reflecting a complex transgression-regression history (HARZHAUSER, 2000).

Chronostratigraphic age: Oligocene, Rupelian to early Chattian (early Kiscellian to early Egerian).

Biostratigraphy: Pollen Zones PGZ 19–20b (= Kiscellian) and NGZ I (= early Egerian) were identified by Hochuli (in Roetzel et al., 1983).

The PGZ 19–20b (= Kiscellian) occur in those sediments of the Pielach Formation which follow directly above the crystalline basement. An early Egerian regression within the formation has been identified with NGZ I (Roetzel et al., 1983). Eschig (1992: p. 99) reported the dinoflagellate cyst *Wetzeliella gochtii* from coals of the drillhole Theiss, SE of Krems, which indicates Rupelian–lower Chattian and is correlated to calcareous nannofossil Zones NP22–NP25 (Pross et al., 2010; Soliman, 2012) and to CNO2–CNO5 (Raffi et al., 2016; Gradstein et al., 2020: Fig. 28.11), respectively.

Thickness: A maximum thickness of c. 125 m is recorded from drillholes. Sediment thickness is strongly dependent on the underlying relief of the crystalline basement and varies laterally within short distances.

In the type area, a maximum thickness of 10 m is reported by Roetzel et al. (1983: p. 165) from the locality Zelking, c. 8 km SW of Melk. Vetters (1923: p. 43) estimates about 20 m thickness for the coalfield Starzing-Hagenau (Allochthonous Molasse). From a borehole at Theiss (6 km SE of Krems), Eschig (1992: Tab. 2) reported 124.7 m of Pielach Formation and from the drillhole Herzogenburg (Lower Austria) Petrascheck (1926/1929: p. 292) described 123.5 m of coal-bearing strata, which can be ascribed to the Pielach Formation. In the drillhole Murstetten 1 (NE of St. Pölten), the Pielach Formation is more than 40 m thick (Brix & Götzinger, 1964: p. 5). The maximum thickness of the coal seams at the mining area of Starzing-Hagenau is 1.8 m (Vetters, 1923: p. 42). From the coalfield west of Statzendorf up to 2 m coal are reported and in the mining district south of Krems two 1.6 m and 2 m thick coal beds were mined (Weber & Weiss, 1983).

Lithostratigraphically higher rank unit: -

Remark: Abel (1904b) combined the “Melker Sande” and “Pielacher Tegel” as “Melker Schichten”; Kapounek et al. (1960: p. 111) suggested to unite the “Melker Sande” and “Pielacher Tegel” as “Melker Serie” and Kapounek et al. (1965: p. 111) denominated the same two units as “Untere Melker Serie” (with the “Älterer Schlier”) (compare this volume) and “Obere Melker Serie”. Roetzel et al. (1983: p. 132) proposed to combine “Pielacher Tegel” and “Melker Sande” as “Melker Formation”.

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline rocks of the Bohemian Massif. In interfingering areas with the Linz-Melk Formation also sandy sediments may form the underlying strata.

Overlying unit(s): Linz-Melk Formation.

Near the southern margin of the Bohemian Massif where younger sediments have been eroded, only the Mauer Formation is preserved on top of the Pielach Formation.

Lateral unit(s): The Pielach Formation interfingers with the Linz-Melk Formation.

In the tectonically strongly disturbed area in the surroundings of Neulengbach (Lower Austria) the Pielach Formation occurs in tectonic contact to a number of other lithostratigraphic units, e.g., the Ollersbach Conglomerate, “Older Schlier”, Buchberg Conglomerate, Hall Formation, and Rhenodanubian Flysch units.

Geographic distribution: The Pielach Formation mainly extends in Upper Austria in the surroundings of Eferding and Linz. In Lower Austria it crops out along the southern margin of the Bohemian Massif, especially between Melk and Krems as well as in the Allochthonous Molasse north of Neulengbach. ÖK50 UTM, map sheets 3324 Grieskirchen, 4319 Linz, 4320 Perg, 4321 Grein, 4322 Pöchlarn, 4323 Sankt Pölten, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg (ÖK50-BMN, map sheets 31 Eferding, 32 Linz, 33 Steyregg, 34 Perg, 37 Mautern an der Donau, 38 Krems an der Donau, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf, 57 Neulengbach).

Apart from outcrops along the southern margin of the Bohemian Massif and in the Allochthonous Molasse near Neulengbach, the Pielach Formation is widespread in the subsurface of the NAFB.

Remarks: An early reference to the coal deposits at Starzing-Hagenau (near Neulengbach, Lower Austria) gave Cžjžek (1849a: p. 96, “Sterzing, südwestlich von Sieghartskirchen” [sic!]), who supposed that the coal and the accompanying sediments belong to the “Wiener Sandstein” (i.e., Cretaceous flysch deposits); in 1852 (Cžjžek, 1852c) he described the sediments and coals of various mining tunnels in Starzing-Hagenau. Coal seams, well known from the area of Neulengbach and south of Krems, were intensively mined since the 18th century (Cžjžek, 1853a, b; Petrascheck, 1926/1929; Weber & Weiss, 1983). Cžjžek (1853a: p. 276) described sediments which are now considered to belong to the Pielach Formation as well as to the deeply kaolinitic weathered basement rocks from the village Oberfucha S of Krems (Lower Austria) as “Töpferthon” (= clay for pottery).

Complementary references: Götzinger & Vetters (1927), Grill & Waldmann (1951), Fuchs (1964a, b, 1969, 1980a), Tollmann (1985), Piller et al. (2004), Gebhardt (2007).

Linz-Melk-Formation / Linz-Melk Formation

Reinhard Roetzel

Validity: Invalid; the term Linz-Melk Formation was established by Krenmayr & Roetzel (2000a) and is informal and invalid.

Type area: As in literature the Oligocene sands in the vicinity of Linz (Upper Austria) were described first (Fitzinger, 1842; Ehrlich, 1848), the area in the surroundings of Linz and Steyregg can be regarded as type area.

Type section: -

Reference section(s): Not defined; in Lower Austria as reference sections can be regarded: Sandpits in the area south of Krems (Statzendorf embayment), e.g., sandpit Hermannschacht (abandoned) (N 48°18′55″ / E 15°36′33″), sandpit Winzing (abandoned) (N 48°17′05″ / E 15°35′06″), sandpit Großrust (abandoned) (N 48°16′40″ / E 15°36′24″) (cf. Roetzel et al., 1983). In these outcrops the upper boundary of the Linz-Melk Formation was exposed. Sandpits in the surroundings of Melk, e.g., Melk (N 48°13′17″ / E 15°21′17″) (Roetzel et al., 2013).

In Upper Austria as reference sections can be considered: Sandpits in the area of Prambachkirchen (e.g., Weinzierlbruck (abandoned): N 48°19′35″ / E 13°53′57″), west of Eferding (e.g., Unterrudling: N 48°18′17″ / E 13°59′38″; upper boundary exposed), east of Linz (e.g., Steyregg (abandoned): N 48°17′25″ / E 14°22′08″; St. Georgen/Gusen: N 48°17′07″ / E 14°26′22″), and north of Klam (Münzbach: N 48°14′52″ / E 14°46′29″) (Roetzel & Rupp, 1991).

Derivation of name: Named after the city of Linz, the capital of Upper Austria, and Melk, a town in the Wachau, 22 km W of St. Pölten, Lower Austria.

Synonyms: Linzer Sand(e), Melker Sand(e), (Kristall)sandstein von Perg, (Kristall)sandstein von Wallsee, Obritzberger Sand, Älterer resp. Jüngerer Linzer Sand, Älterer resp. Jüngerer Melker Sand, (Untere resp. Obere) Melker Serie, Melker Formation, Linz Formation, Melk Formation.

The Oligocene sands in the vicinity of Linz and Melk were described from the mid of the 19th century mainly due to their common fossil record, especially of vertebrates. In Lower Austria, they were called "Melker Sande" (Abel, 1904b), whereas in Upper Austria they were named "Linzer Sande" (Commenda, 1900). The partition of the sands in a fine-grained and a coarse-grained lithological type (Nowack, 1921; Grill, 1956) was interpreted by Fuchs (1968b; cf. 1972, 1974) chronostratigraphically, leading to the terms "Älterer Melker Sand", "Jüngerer Melker Sand" and "Älterer Linzer Sand", "Jüngerer Linzer Sand", respectively. A detailed study of the Melk Sands was presented by Roetzel et al. (1983). The distribution of the Melk Beds in drillings of the NAFB in Lower Austria was described by Fuchs et al. (1980). A comprehensive facies study was started by Krenmayr & Roetzel (2000a, b).

Lithology: The sediments of the Linz-Melk Formation are yellowish to whitish coarse- to fine-grained sands, rich in quartz and occasionally with granitic boulders and gravelly or clayey intercalations. These sands mainly show typical sedimentary structures of nearshore sediments with planar bedding, sometimes also cross bedding. East of Linz intercalations of variously consolidated fossiliferous coralline algae limestones occur.

Fossils: The sands of the Linz-Melk Formation are normally very poor in fossils. However, east of Linz sandpits in Plesching and Steyregg exhibit coralline algae, corals, balanids, brachiopods, bryozoans, ostracods, echinoderms, and molluscs (Steininger, 1966, 1969b, 1975; Roetzel et al., 1991c; Kaiser et al., 2001). From these outcrops also benthic foraminifers were described (Rögl & Steininger, 1970; Kaiser et al., 2001). Especially the sands in the Linz area are famous for their vertebrates. From the Linz-Melk Formation remnants of sharks, sea cows (*Halitherium christoli*), whales, crocodiles, turtles, rhinos, and Anthracotheriidae (*Microbunodon minus*, *Elomeryx borbonicus*) are reported (Fitzinger, 1842; Ehrlich, 1848, 1855; Toula, 1899; Abel, 1904a, 1914; König, 1911; Sickenberg, 1934; Thenius, 1960; Spillmann, 1959, 1969; Steininger, 1975). Frequently, trace fossils can be found (Hohenegger & Pervesler, 1985) and rarely also remnants of plants occur (Hofmann, 1932).

Origin, facies: The sandy sediments of the Linz-Melk Formation originate in many parts from a shallow marine wave dominated littoral to shallow sublittoral environment (Roetzel et al., 1983). However, in some areas besides those nearshore sediments also sands from highly bioturbated lagoonal facies as well as cross-stratified sandwave facies and channel-fill facies are detectable. Megasets give evidence of tide-influenced sandwave fields in an open shelf setting (Krenmayr & Roetzel, 2000b).

Chronostratigraphic age: Oligocene, Rupelian to early Miocene, Aquitanian (Egerian).

Biostratigraphy: By vertebrates such as the Anthracotheriidae *Microbunodon minus* and *Elomeryx borbonicus* as well as the sirenia *Halitherium christoli* the sands of the Linz-Melk Formation are dated to the late Oligocene (Sickenberg, 1934; Thenius, 1960). Due to the occurrence of the benthic foraminifer *Miogypsina formosensis* in Plesching and Steyregg, the sediments in these outcrops are dated to the late early Egerian (Rögl & Steininger, 1970; Kaiser et al., 2001).

Thickness: In most of the outcrops of the Linz-Melk Formation several tens of meters of sands are exposed, however, based on drillings a maximum thickness up to 100 m has to be assumed.

Lithostratigraphically higher rank unit: Abel (1904b) combined the "Melker Sande" and "Pielacher Tegel" as "Melker Schichten" and Kapounek et al. (1965) subsumed these two formations to the "Untere Melker Serie", in opposition to the "Obere Melker Serie" with the "Älterer Schlier". Roetzel et al. (1983: p. 132) replaced these terms by the "Melker Formation". All these higher rank units are invalid.

Lithostratigraphic subdivision: For the first time Nowack (1921) recognized a dichotomy of the Melk Sands and divided them into the "Untere Melker Sande" and "Obere Melker Sande". This partition of the sands in a fine-grained and a coarse-grained lithological type was also noticed by Grill (1956). Later on Fuchs (1968b; cf. 1972, 1974) interpreted this disparity chronostratigraphically and created the terms "Älterer Melker Sand" and "Jüngerer Melker Sand" and in the Linz area "Älterer Linzer Sand" and "Jüngerer Linzer Sand". Due to Roetzel et al. (1983), these lithological characteristics are mainly facies types which cannot be used as subdivision of the Linz-Melk Formation.

Underlying units: The Linz-Melk Formation follows widespread above the Pielach Formation at the southeastern and southern margin of the Bohemian Massif in Lower Austria and in some parts in Upper Austria, too. However, the sands can also transgress directly upon the crystalline basement of the Bohemian Massif or due to a prominent regression in the early Egerian interfinger with the Pielach Formation in the basal part (Roetzel et al., 1983).

Overlying units: The Linz-Melk Formation is in many areas overlain by pelites of the "Älterer Schlier", which is subdivided west of the river Enns into the Ebelsberg Formation, Eferding Formation, and Zupfing Formation. Furthermore, also Miocene sediments like the Plesching Formation, the Robulus Schlier, the Mauer Formation or the Hollenburg-Karlstetten Formation can discordantly follow above. In many parts also Pleistocene sediments cover the Oligocene sands.

Lateral units: At the southeastern and southern margin of the Bohemian Massif the Linz-Melk Formation interfingers with the Pielach Formation. In the Allochthonous Molasse in the surroundings of Neulengbach (Lower Austria) these sediments are in tectonic contact with a number of other lithostratigraphic units like the Ollersbach-Konglomerat, the “Älterer Schlier”, the Buchberg-Konglomerat, the Robulus Schlier, and the Rhenodanubian Flysch.

Geographic distribution: The sandy deposits of the Linz-Melk Formation are widespread at the southern and southeastern margin of the Bohemian Massif in Lower Austria and Upper Austria. The main distribution areas in Lower Austria are south of Krems and in the surroundings of Melk. In Upper Austria they are extending in the Basin of Gallneukirchen and in the areas around Linz, Eferding, Prambachkirchen, and Peuerbach. Lower Austria: ÖK50-UTM, map sheets 4322 Pöchlarn, 4323 Sankt Pölten, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg (ÖK50-BMN, map sheets 36 Ottenschlag, 37 Mautern an der Donau, 38 Krems an der Donau, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf); Upper Austria: ÖK50-UTM, map sheets 3324 Grieskirchen, 4319 Linz, 4320 Perg, 4321 Grein (ÖK50-BMN, map sheets 30 Neumarkt im Hausruckkreis, 31 Eferding, 32 Linz, 33 Steyregg, 34 Perg).

Apart from the outcrops along the southern margin of the Bohemian Massif, sediments of the Linz-Melk Formation can also be found in the Allochthonous Molasse near Neulengbach and in drillings west of the Waschberg Unit between Stockerau and Hollabrunn (Fuchs et al., 1980).

Remarks: -

Complementary references: -

Älterer Schlier / Older Schlier

Reinhard Roetzel

Validity: Invalid; the term “Älterer Schlier”, which was used first by Nowack (1921), is informal and invalid. As long as no detailed investigations exist to differentiate the Oligocene pelitic facies like in Upper Austria, the general term “Älterer Schlier” has to be used in Lower Austria.

Type area: The area between Oberwölbling and Karlstetten (Lower Austria) along the spur of the Bohemian Massif, south of the town Krems an der Donau and north of St. Pölten can be regarded as type area.

Type section: -

Reference section(s): Not defined; as possible reference sections can be regarded sandpits in the area south of Krems (Statzendorf embayment), e.g., sandpit Hermannschacht (abandoned) (N 48°18′55″ / E 15 36′33″), sandpit Winzing (abandoned) (N 48°17′05″ / E 15°35′06″), sandpit Großrust (abandoned) (N 48°16′40″ / E 15°36′24″) (Roetzel et al., 1983). In Großrust, the lower boundary of the “Älterer Schlier” is evident, in Hermannschacht and Winzing the lower and upper boundaries were exposed.

Derivation of name: From the older (Oligocene) deposits (“Älterer Schlier”) in contrast to the younger Miocene sediments (“Jüngerer Schlier”).

Synonyms: Oligozänschlier, Oligocänschlier, Schieferton, Oligozän Schieferton, *Meletta* Schlier, Älterer Schlier Formation, Obere Melker Serie, (Obere) Puchkirch(e)ner Serie, Ebelsberg Formation, Eferding Formation, Zupfing Formation.

These pelitic sediments (“Schlier”) were described already in the early 20th century, e.g., by Abel (1905). The name “Älterer Schlier” was first used by Nowack (1921: Fig. 1, p. 41) in the area between Krems and Melk to discern lithologically different pelitic deposits in lower positions (“Älterer Schlier”) from younger pelitic sediments in higher positions (“Jüngerer Schlier”). Later on, Petters (1936) could distinguish these Oligocene pelites from the Miocene pelites by foraminifer investigations and Grill (1933, 1937) discovered the interfingering of the “Oligocänschlier” with the coeval Linz Sands in the Basin of Gallneukirchen. Younger investigations were carried out by Fuchs (1972) and Roetzel et al. (1983).

Lithology: The pelitic sediments of the “Älterer Schlier” are dark grey to chocolate-brown thin-bedded micaceous clayey silts to clays with thin fine-sandy intercalations. Phosphoritic concretions like in Upper Austria cannot be found in Lower Austria, whereas nodular calcareous concretions with diameters up to half a meter are frequent.

Fossils: In the pelitic deposits remnants of fish (fish-scales: “*Meletta* Schlier”) and plants are very frequent. Additionally, silicoflagellates, diatoms, foraminifers and, in rare cases, molluscs occur.

Origin, facies: Sediments of the “Älterer Schlier” were deposited on the inner shelf, interfingering towards the north with the nearshore sediments of the Linz-Melk Formation.

Chronostratigraphic age: Late Oligocene, Chattian to early Miocene, Aquitanian (Egerian).

Biostratigraphy: In Lower Austria sediments of the “Älterer Schlier” were dated to the Neogen pollen Zone Ng.Z.I (Hochuli, 1978; Roetzel et al., 1983) and by calcareous nannoplankton to the Zones NP25–NN1 (Rögl et al., 1979; Krhovsky in Hofmann, 1997).

Thickness: In surface outcrops 10–20 m. In drillings (Brix & Götzinger, 1964; Brix et al., 1977), thickness varies between several meters and more than 170 m depending on the tectonic position.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: In Upper Austria the pelitic sediments of the “Älterer Schlier” are subdivided into the Ebelsberg Formation, Eferding Formation, and Zupfing Formation.

Underlying units: Normally, the pelitic sediments of the “Älterer Schlier” gradually pass from the sands of the Linz-Melk Formation below. In topographically higher parts, the pelites can directly follow discordantly upon the crystalline basement of the Bohemian Massif.

Overlying units: In Lower Austria south of Krems the “Älterer Schlier” is overlain by sediments of the Hollenburg-Karlstetten Formation (lower Badenian). Towards the west “Robulus Schlier” (Ottnangian) and “Sandstreifenschlier” (Eggenburgian–Ottnangian) follow discordantly above, but in many parts Pleistocene sediments cover the pelites.

Lateral units: Towards the margin of the Bohemian Massif the “Älterer Schlier” is interfingering with the nearshore sediments of the Linz-Melk Formation. In Lower Austria the bulk of the so-called “Älterer Schlier” mainly correlates with the Eferding Formation in Upper Austria.

Geographic distribution: The main distribution areas of the deposits of the "Älterer Schlier" are south of the Danube between Krems and St. Pölten and at the southern margin of the Bohemian Massif between Melk and the river Enns, Lower Austria; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4326 Steyr, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhemsburg (ÖK50-BMN, map sheets 38 Krems an der Donau, 51 Steyr, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf).

Remarks: West of the river Enns the "Älterer Schlier" is subdivided into the Ebelsberg Formation, Eferding Formation, and Zupfing Formation. The bulk of the so-called "Älterer Schlier" in Lower Austria seems to correlate with the Eferding Formation; a minor part towards the river Enns is comparable with the Ebelsberg Formation, too.

Complementary references: -

Ollersbach-Konglomerat / Ollersbach Conglomerate

HANS-GEORG KRENMAYR

Validity: Invalid; in early literature no differentiation was made between the various conglomerates within the Allochthonous Molasse at the eastern end of the Alps (e.g., CŽJŽEK, 1849a: p. 22; 1852a: p. 41; HAUER, 1858: p. 132); GÖTZINGER & VETTERS (1923: p. 7) introduced the term "Ollersbacher Konglomerat" to denote a basal variety of the Buchberg conglomerate (see below), and GÖTZINGER et al. (1954) realized that this conglomerate is a facies variation of the "Melker Sande" (Linz-Melk Formation); SCHNABEL (2002a) and ROETZEL (2002) introduced the term "Ollersbach-Konglomerat".

Type area: In the area of Ollersbach and Neulengbach, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: -

Remark: A possible type section could be the outcrop "Sportplatz Starzing" (Lower Austria), an abandoned gravel pit, described by GEBHARDT et al. (2008: p. 138), where a section of 28 m crops out; N 48°12′58.99 / E 15°57′59.22″. Note: PLÖCHINGER & PREY (1974) regarded this outcrop still as part of the Buchberg Conglomerate.

Reference section(s): -

Derivation of name: Named after the village Ollersbach, c. 5 km W–WSW of the town Neulengbach, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Synonyms: Ollersbacher Konglomerat (GÖTZINGER & VETTERS, 1923), Ollersbacher Quarz- und Granitkonglomerat (GÖTZINGER et al., 1952), Blockmergel von Königstetten (GÖTZINGER et al., 1952).

Remark: In the geological map of GÖTZINGER et al. (1952) the Buchberg Conglomerat still includes parts of the Ollersbach Conglomerate (GEBHARDT et al., 2008). GÖTZINGER et al. (1954) considered the "Blockmergel von Königstetten" as lateral facies variation of the Ollersbach Conglomerate.

Lithology: Most significant are medium to coarse grained, boulder bearing, poorly rounded, grain supported conglomerates with a sandy to fine gravelly matrix and carbonaceous cement. Cross-bedded sandstones to fine conglomerates also occur (GEBHARDT et al., 2008). The component spectrum of larger clasts is clearly dominated by sandstone of the Rhenodanubian Flysch, besides material from the Northern Calcareous Alps, rip-up-clasts of "Älterer Schlier", quartz-pebbles and a broad variety of crystalline rocks including so called "exotic boulders" (e.g., HAUER, 1858: p. 133; GÖTZINGER & EXNER, 1953; HUMER & FINGER, 2004, 2006). Granitic components may reach several meters in diameter. Fine grained conglomerates, dominated by quartz do also occur in close relationship to sandy sediments (GEBHARDT, 2007: p. 629).

Fossils: -

Origin, facies: A modern interpretation of the Ollersbach Conglomerate as deep water/slope-type fan delta is given in GEBHARDT et al. (2008). The conglomerates are in primary sedimentary contact with sandy sediments, which are referred to as Linz-Melk Formation. However, as described by GEBHARDT et al. (2008: p. 142), these sands are probably resedimented at the northern shelf as well as from upthrusted slices within the active southern slope. Sandy sediments of both sources seem to have mixed in the sedimentation area of the Ollersbach Conglomerate (compare with the model of WAGNER, 1996b: p. 229, Fig. 11).

Chronostratigraphic age: Oligocene, Chattian to early Miocene, Aquitanian (? Kiscellian–Egerian).

Remark: Since no fossils are known from the Ollersbach Conglomerate the age can only inferred from under- and overlying sediments.

Biostratigraphy: Within the Ollersbach Conglomerate, no fossils are known. In many places these sediments are, however, closely associated with those of the Pielach Formation, Linz-Melk Formation, and "Älterer Schlier" (GEBHARDT et al., 2008: p. 141). For the first unit calcareous nannofossil Zones NP22–NP25 are reported and for the "Älterer Schlier" close to the Ollersbach Conglomerate calcareous nannofossil Zones upper NP25–lower NN2 (ĆORIĆ in GEBHARDT, 2007: p. 629).

Thickness: In the outcrop near Starzing described by GEBHARDT et al. (2008), an unfaulted 28 m-thick section can be considered as minimum thickness. Since the Ollersbach Conglomerate occurs only in the tectonically strongly disturbed southernmost nappe of the Allochthonous Molasse a maximum thickness cannot be given but some dozens of meters can be expected.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Most probably resedimented sands of the Linz-Melk Formation (comp. "Origin, facies") or tectonic contact with various lithostratigraphic units (cf. Lateral Unit(s)).

Overlying unit(s): see below under Lateral units.

Lateral unit(s): The conglomerates interfinger with sediments of the Linz-Melk Formation but they occur also in manifold tectonic contacts to the following strata: Pielach Formation, Linz-Melk Formation, "Älterer Schlier", Hall Formation, Buchberg Conglomerate, and sediments of the "Nordrandzone" (Rhenodanubian Flysch), like the Wolfpassing Formation and the "Neokom-Flysch".

Geographic distribution: The Ollersbach Conglomerate occurs in a narrow, tectonically formed strip of about 1 km width in the area between the villages Ollersbach in the W and Ried am Riederberg in the E, Lower Austria; ÖK50-UTM, map sheets 4324 Herzogenburg, 4329 Wilhelmsburg, 4330 Neulengbach, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 39 Tulln, 56 St. Pölten, 57 Neulengbach).

Remarks: The occurrence of quartz and crystalline pebbles, boulders and blocks is the distinctive criterion for the differentiation of the Ollersbach and Buchberg conglomerates, as the latter almost lack completely quartz or crystalline material (GEBHARDT et al., 2008).

Complementary references: FUCHS (1980a), TOLLMANN (1985), PILLER et al. (2004), GEBHARDT (2011a).

Buchberg-Konglomerat / Buchberg Conglomerate

HANS-GEORG KRENMAYR

Validity: Invalid; HAUER (1858) already mentioned "Conglomerate des Buchbergs", the term "Buchbergconglomerat" was introduced by ABEL (1904b: p. 102); a detailed description of the "Buchberg-Konglomerat" gave GEBHARDT et al. (2008).

Remark: In the older literature no differentiation was made between various conglomerates within the Allochthonous Molasse at the eastern end of the Alps (e.g., CŽJŽEK, 1849a: p. 22; CŽJŽEK, 1852c: p. 41; HAUER, 1858: p. 132). After ABEL (1904b: p. 102) had suggested the term "Buchbergconglomerat", GÖTZINGER & VETTERS (1923: p. 7) introduced the term "Ollersbacher Konglomerat" to separate a basal variety of the Buchberg Conglomerate but GÖTZINGER et al. (1954) realized that this latter conglomerate is a facies variation of the "Melker Sande" (Linz-Melk Formation) (see also Ollersbach Conglomerate).

Type area: The area between Neulengbach and Starzing including the mountain Buchberg (Lower Austria) which is mostly formed by this conglomerate; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Type section: The abandoned quarry at the western margin of the village Burgstall (N 48°12′34″ / E 15°56′32″), c. 2.5 km NE of the small town Neulengbach, was defined by PLÖCHINGER & PREY (1974: p. 43) as type locality of the Buchberg Conglomerate. This outcrop is described in detail by GEBHARDT et al. (2008: p. 144) but no section could be measured due to intensive tectonic disturbance and also no lower and upper boundary could be defined.

Reference section(s): -

Derivation of name: Named after the mountain Buchberg (469 m a.s.l.), c. 3 km NE of the small town Neulengbach, Lower Austria; ÖK50-UTM, map sheet 4330 Neulengbach (ÖK50-BMN, map sheet 57 Neulengbach).

Synonyms: Conglomerate des Buchbergs (HAUER, 1858: p. 133), Buchbergconglomerat (ABEL, 1904b: p. 102), Buchbergkonglomerat (GÖTZINGER et al., 1952), Blocksande von Königstetten (GÖTZINGER et al., 1952), (partim) Ollersbach Conglomerate (GÖTZINGER et al., 1954).

Lithology: Grain supported, fine to coarse conglomerates with boulders up to > 1 m in diameter, with a fine to coarse sandy matrix; components are subrounded to rounded lacking preferred orientation; calcite cementation. Bedding is often indistinct, thick and massive beds are common. Flysch-derived components make up to 95 % of the spectrum alongside with material from the Northern Calcareous Alps. Quartz, quartzite and crystalline components are extremely rare or missing. Rip-up-clasts of the "Älterer Schlier" (dark claystone) are frequent. Matrix supported texture may occur in areas of interfingering with pelites of the Hall Formation.

Fossils: Calcareous nannofossils, foraminifers, diatoms, radiolarians, sponge spicules, ostracods, and sea urchin spines (GEBHARDT, 2007: p. 629). No macrofossils are known.

Origin, facies: The Buchberg Conglomerate is interpreted as proximal part of a deepwater fan delta at the base of the slope, built by the actively northward moving Alpine nappes, with a point source of the sedimentary material and with debris flows as dominant transport mechanism (GEBHARDT et al., 2008: p. 145).

Chronostratigraphic age: Early Miocene, Burdigalian (Eggenburgian to ?Ottnangian).

Biostratigraphy: Calcareous nannofossils from the matrix can be correlated to the upper NN2 (ĆORIĆ in GEBHARDT et al., 2008: p. 144), indicating an Eggenburgian age. Samples from the interfingering Hall Formation belong to NN2–NN3 (latest Eggenburgian–early Ottnangian). Foraminiferal associations indicate Eggenburgian age (GEBHARDT et al., 2008).

Thickness: A maximum thickness of about 700 m can be deduced from the profiles published by GÖTZINGER & VETTERS (1923: Plate I).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): The Buchberg Conglomerate is underlain and interfingering with the marly, fine-grained sediments of the Hall Formation.

Overlying unit(s): The Buchberg Conglomerate is the uppermost element of the sedimentary succession in its area of occurrence and only tectonically overlain by other units.

Lateral unit(s): The Buchberg Conglomerate is primary intercalated in and interfingering with the marly, fine-grained sediments of the Hall Formation. Tectonic contacts are indicated by geological maps (e.g., GÖTZINGER et al., 1952) with the Linz-Melk Formation, Pielach Formation, Ollersbach Conglomerate and maybe tectonic slices of the Rhenodanubian Flysch.

Geographic distribution: The distribution area extends between the market village of Kirchstetten, E of Böheimkirchen, and the village Elsbach near Sieghartskirchen (Lower Austria) in a tectonically formed narrow strip, less than 2 km wide; ÖK50-UTM, map sheets 4324 Herzogenburg, 4330 Neulengbach, 5319 Tulln an der Donau, 5325 Baden (ÖK50-BMN, map sheets 56 St. Pölten, 57 Neulengbach.

Remarks: The almost complete lack of quartz or crystalline material characterizes the Buchberg Conglomerate and discriminates it from the Ollersbach Conglomerate (Gebhardt et al., 2008).

Götzinger et al. (1952) combined the Eggenburgian Buchberg Conglomerate and the "Blocksande von Königstetten", the latter being a specific facies of the Buchberg Conglomerate (Götzinger et al., 1954: p. 104). Fuchs (1980a), Fuchs & Grill (1984a) and Schnabel (2002a) subsumed, however, the "Blocksande von Königstetten", the "Blockschichten vom Heuberg" and the "Blockmergel von Königstetten" within the lower Ottnangian. The results by Gebhardt et al. (2008) support, however, the view of Götzinger et al. (1952).

Complementary references: Vetters (1924), Grill & Waldmann (1951), Grill (1954b), Fuchs (1980a), Tollmann (1985), Piller et al. (2004).

Sandstreifenschlier / Sand-banded Schlier facies

Hans-Georg Krenmayr & Werner E. Piller

Validity: Invalid; Brix & Götzinger (1964: p. 58) introduced to science the term "Sandstreifenschlier" for sandy pelitic sediments in the Lower Austrian part of the NAFB south of the Danube; Kapounek et al. (1965: p. 111) gave a more precise description for this pelitic sediments ("Schlier") with variable sand or sandstone intercalations of Burdigalian (Eggenburgian and Ottnangian) age in the area between Wieselburg and St. Leonhard am Forst and in the southern Tulln Basin. The name was used further on (e.g., Papp et al., 1968a: p. 13; Fuchs, 1980a: p. 167; Roetzel, 2002: p. 26; Wessely, 2006: p. 54), when a differentiation between Hall Formation (Eggenburgian) and Robulus Schlier (lower Ottnangian) (or equivalents) was not possible.

Type area: Lower Austrian NAFB between Wieselburg and St. Leonhard am Forst; ÖK50-UTM, map sheet 4328 Scheibbs (ÖK50-BMN, map sheet 54 Melk).

Type section: -

Reference section(s): -

Derivation of name: The name is derived from sand layers intercalated in pelitic sediments ("Schlier"). The literal translation of "Sandstreifenschlier" is "sand striped Schlier", but Papp et al. (1968b: p. 23) translated the term as "sand-streaked Schlier"; we use herein the German term "Sandstreifenschlier" in quotation marks.

Synonyms: Burdigalschlier (Janoschek, 1963: p. 336), sand-streaked Schlier (Papp et al., 1968b: p. 23), "Sandstreifen Schlier" (Steininger & Wessely, 2000).

Lithology: The "Sandstreifenschlier" consists of laminated marly pelites with fine-sandy laminae and lenses, which alternate with sometimes completely bioturbated beds of the same grain-size composition. Sandstone beds, generally not thicker than 10–15 cm, are intercalated with variable frequency and show ripples, horizontal lamination, and hummocky cross-stratification. In addition, small-scale channel-fill sediments with chaotic internal structure occur (Krenmayr, 2000b). Kuffner (1994a, b) distinguished eight facies types which alternate rhythmically; roughly pelites, fine grained calcareous sandstones, fully bioturbated sediments, and layers with the trace fossil *Diplocraterion* supported by petrographic details including sandstone and clay mineral composition, cementation, and heavy-mineral content.

At the very base of the "Sandstreifenschlier" a few meters thick sandstone can occur in some places (Krenmayr, 2000b), e.g., in a road cut SW of the village of Sankt Leonhard am Forst (N 48°07′24″ / E 15°14′10″).

Fossils: Gastropods, including pteropods, bivalves, ostracods, sea urchin spines, fish and plant remains are reported by Brix & Götzinger (1964: p. 58), Kuffner (1994a, b) and Wessely (2006: p. 54). Benthic foraminifera are diverse; the plankton/benthos relationship is high Kuffner (1994a: p. 19). The rich ichnofauna includes *Diplocraterion*, *Teichichnus*, *Phycodes*, *Lockeia*, *Imbrichnus*, *Uchirites*, and *Planolites* (Sperling, 1993).

Origin, facies: Kuffner (1994b) states a periodically storm-influenced shallow sea environment, between the fair-weather and storm-wave base with a dominant oscillatory current component. This diagnosis is supported by sedimentary structures, microfauna assemblages, and ichnofacies. The sandstone intercalations become more frequent and thicker toward the south and also the heavy mineral composition suggests a sediment input from the Alps.

Chronostratigraphic age: Early Miocene, Burdigalian (Eggenburgian–early Ottnangian).

Remark: This age assignment results from the fact, that the "Sandstreifenschlier" includes the Eggenburgian Hall Formation and the early Ottnangian "Robulus-Schlier" in regions where their differentiation could not yet be achieved.

Biostratigraphy: Foraminifera indicate Eggenburgian to Ottnangian age (Kuffner, 1994a, b).

Thickness: Brix & Götzinger (1964: p. 5) report 700 m in the drilling Mank 1.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): "Sandstreifenschlier" discordantly overlies the "Älterer Schlier".

Overlying unit(s): All younger Neogene sediments above the "Sandstreifenschlier" were eroded, only Quaternary sediments can be found as overlying units.

Lateral unit(s): Hall Formation and Robulus-Schlier.

Geographic distribution: Lower Austrian Alpine Foreland between the river Enns and the river Mank and further to east in the area of St. Pölten and the Tulln Basin; ÖK50-UTM, map sheets 4326 Steyr, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg, 4330 Neulengbach, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 51 Steyr, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf, 56 St. Pölten, 57 Neulengbach, 39 Tulln, 40 Stockerau). "Sandstreifenschlier" is also reported from the Allochthonous Molasse below the alpine nappes, e.g., drilling Texing 1 (Brix & Götzinger, 1964: p. 59).

Remarks: Good surface outcrops of "Sandstreifenschlier" can be studied along the river banks of the Enns (W of the village Loderleiten: N 48°06′45″ / E 14°29′48″), the Ybbs (NE of Schönegg: N 48°07′27″ / E 15°02′12″) and the Erlauf (Türkensturz: N 48°05′48″ / E 15°08′35″).

Complementary references: GÖTZINGER (1954b), GRILL (1945, 1954b), THENIUS (1974), BRIX et al. (1977), FUCHS (1980c), BRIX & SCHULTZ (1993), HOFMANN (1997), PILLER et al. (2004), RASSER & HARZHAUSER (2008).

Hall-Formation (Hall-Gruppe) / Hall Formation (Hall Group)

WERNER E. PILLER

The Hall Formation, which has been historically called "Haller Schlier", is widespread in the NAFB of Upper Austria (see there). It also occurs E of the river Enns in Lower Austria but cannot be consistently separated from the "Robulus-Schlier". Because of these difficulties the term "Sandstreifenschlier" was introduced (see above) and is still used where a distinction between the Hall Formation and the "Robulus-Schlier" is not possible. For a detailed description of the Hall Formation see the NAFB of Upper Austria. Here, we refer only to specific features in Lower Austria.

Synonyms: Haller Schlier (GRILL, 1945), (partim) Jüngerer Schlier (FUCHS, 1964b), Haller Schlier und Äquivalente (Mergel, Sand und Sandstein) (SCHNABEL, 2002a; ROETZEL, 2002).

Chronostratigraphic age: Early Miocene, early Burdigalian (Eggenburgian).

Remark: Compared to the Hall Formation of Upper Austria the occurrences in Lower Austria are not well-dated.

Geographic distribution: The Hall Formation extends from the NAFB of Upper Austria eastwards over the river Enns and is recorded to the area of the river Ybbs (GRILL, 1945) but SCHNABEL (2002a) depicts its occurrence (as "Haller Schlier und Äquivalente (Mergel, Sand und Sandstein)") even to Neulengbach; ÖK50-UTM, map sheets 4326 Steyr, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg, 4330 Neulengbach (ÖK50-BMN, map sheets 51 Steyr, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf, 56 St. Pölten, 57 Neulengbach).

Remarks: -

Complementary references: GRILL (1957b), FUCHS (1964a, b, 1972, 1980a), KRENMAYR & ROETZEL (2000b), WESSELY (2006).

Robulus-Schlier / Robulus Schlier

CHRISTIAN RUPP, HANS-GEORG KRENMAYR & WERNER E. PILLER

See detailed description in the NAFB of Upper Austria. We refer here only to specific features in Lower Austria, which were mostly described by FUCHS (1972).

Synonyms: Mergel und Sandsteine des Tullner Beckens (ABEL, 1904b: p. 94), Schlier (vorwiegend Burdigal–Helvet) (GÖTZINGER, 1954b: p. 105), Upper Hall Schlier (JANOSCHEK, 1959), (partim) Jüngerer Schlier (FUCHS, 1972: p. 215), Robulus Schlier s.l. (FUCHS & GRILL, 1984b), Robulusschlier ("Ottnangienschlier") (TOLLMANN, 1985), Robulusschlier (HOFMANN, 1997), Kematen-Formation (KRENMAYR & ROETZEL, 2002).

Remark: ABEL (1904b) and GÖTZINGER (1954b) included also Eggenburgian sediments in this unit.

Chronostratigraphic age: Early Miocene, Burdigalian (early Ottnangian).

Underlying units: Hall Formation (gradational), Älterer Schlier, Linz-Melk Formation.

Overlying units: Atzbach Formation, Kletzenmarkt Formation (all gradational), Pixendorf Group (diachronous).

Lateral units: Vöckla Formation, Vorchdorf Formation (all interfingering), "Sandstreifenschlier", Prinzersdorf Formation, Mauer Formation.

Geographic distribution: In the NAFB of Upper Austria (see there) and Lower Austria. In Lower Austria it is known from the area of the river Mank in the west to the east into area St. Pölten and the Tulln Basin (e.g., FUCHS, 1976a). Since it is difficult to differentiate between the "Schlier" of the Hall Formation and the Robulus Schlier both units were and are summarized in the "Sandstreifenschlier". Therefore, also their distribution area is widely similar.

Remarks: In Upper Austria the Robulus Schlier is lithologically easy to distinguish from the adjacent Vöckla Formation and the Vorchdorf Formation and from the underlying Hall Formation by its fossil content. On the contrary, the silty to sandy Robulus Schlier in Lower Austria shows distinct sand intercalations and the boundary to the underlying Hall Formation often is not clear due to similar lithologies and the lack of index fossils. This is the reason why in Lower Austria Eggenburgian and Ottnangian pelites were often subsumed under the term "Sandstreifenschlier" (see above).

Complementary references: GRILL (1957a), BRIX et al. (1977), BRIX & SCHULTZ (1993), HOFMANN (1997), STEININGER & WESSELY (2000), WESSELY (2006), RASSER & HARZHAUSER (2008).

Prinzersdorf-Formation / Prinzersdorf Formation

HANS-GEORG KRENMAYR

Validity: Valid; ABEL (1904b: p. 96) denominated sandy sediments within the "schieferige Mergel" of the "Oberoligocän und Untermiocän" of the area NW of Neulengbach as "Sandsteine des Haspelwaldes"; GRILL (1954b: p. 118) considered the sandy sediments in the Haspelwald and adjacent areas as transitional beds between "Schlier-Oncophorasande"; FUCHS (1969: p. A29) introduced the term "Prinzersdorfer Sande" for these sediments and KRENMAYR (2003b: p. 462) gave a detailed description and formalized the unit as "Prinzersdorf-Formation".

Type area: It is located in the surroundings of the villages of Prinzersdorf–Pfaffing–Zendorf–Grillenhöfe, a few kilometers W of the city of St. Pölten, Lower Austria; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4329 Wilhelmsburg (ÖK50-BMN, map sheet 55 Ober-Grafendorf).

Type section: A 7 m-thick section at the undercut slope of the river Pielach, 700 m west of the chapel of the village

Pfaffing, c. 9 km W–WNW of the city centre of St. Pölten, Lower Austria (N 48°12′48″ / E 15°29′52″); ÖK50-UTM, map sheets 4323 Sankt Pölten, 4329 Wilhelmsburg (ÖK50-BMN, map sheet 55 Ober-Grafendorf).

Remark: The abandoned large loam- and sandpit at the southern margin of the village Prinzersdorf that could have served as type section is not exposed anymore.

Reference section(s): -

Derivation of name: The name derives from the market town Prinzersdorf, c. 8 km W of the city centre of St. Pölten, Lower Austria.

Synonyms: Sandsteine des Haspelwaldes (ABEL, 1904b: p. 96), Prinzersdorfer Sande (FUCHS, 1969: p. A29).

Lithology: The Prinzersdorf Formation is characterized by a repeated alternation of decimeter-to-meter thick sandy and pelitic intervals. The strongly sand dominated intervals, which are rarely more than 10 m thick (maximum: 17 m) (HOFMANN, 1997: p. 31), contribute with about one third to the whole sediment body. Sandy intervals are generally fine-to-medium grained, rarely coarse grained or even fine gravely, and display diverse sedimentary structures like slightly undulating lamination, cross bedding, flaser bedding and wavy bedding. Pelitic intervals are generally marly, well laminated, with thin sand laminae and lenses, and rare bioturbation. Slumping structures have repeatedly been observed. Rip-up-clasts of the pelitic material are frequently present within sandy sediment portions, even as large (dm- to m-scale), plastically deformed blocks within a matrix of massive sand (KRENMAYR, 2003b: p. 462).

Fossils: Calcareous nannoplankton, foraminifera (low diversity assemblages in bad preservation), radiolaria, diatoms, sponge spicula, very rare bivalves, ostracods and rare bioturbation (KRENMAYR, 2003b: p. 462).

Origin, facies: The Prinzersdorf Formation represents a shallow marine, tide influenced channel facies accompanied by submarine dune fields and mud grounds (KRENMAYR, 2003b: p. 462).

Chronostratigraphic age: Early Miocene, Burdigalian (early Ottnangian).

Remark: The early Ottnangian age is inferred by lateral interfingering with the Robulus Schlier (marly basin facies), which includes better preserved and more indicative microfossil assemblages (KRENMAYR, 2003b: p. 462).

Biostratigraphy: Calcareous nannofossil Zones NN2–NN4 (KRHOVSKY in HOFMANN, 1997: p. 31), which ranges, however, from the upper Egerian to the lower Badenian.

Thickness: In boreholes east of Prinzersdorf at least 50 m are reported, however, the lower boundary of the formation was not reached and the upper boundary is defined by the ground surface (KRENMAYR, 2003b: p. 462).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Possibly Robulus Schlier; the nature of the boundary is not visible in outcrops and not known from boreholes.

Overlying unit(s): Traisen Formation (Pixendorf Group) in the area West of St. Pölten; the contact is not exposed.

Lateral unit(s): Mauer Formation, Robulus Schlier.

Geographic distribution: An WSW–ENE trending strip, up to two kilometers wide, extends from the hamlet Rohr (ESE of the market town Loosdorf) in the West to the city of St. Pölten (district Waitzendorf) in the East; to the South the distribution area is bounded by the St. Pölten fault; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4329 Wilhelmsburg (ÖK50-BMN, map sheets 55 Ober-Grafendorf, 56 St. Pölten).

Remarks: FUCHS & GRILL (1984b) classified the sandy sediments alongside the northern edge of the Allochthonous Molasse in the Tulln Basin near the village of Königstetten as "Prinzersdorfer Sande". SCHNABEL (2002a) also followed this concept. KRENMAYR (2003c: p. 463), however, suggested to exclude these sediments from the Prinzersdorf Formation, as they belong to another tectonic unit, i.e. the Allochthonous Molasse.

Complementary references: FUCHS (1972), TOLLMANN (1980), PILLER et al. (2004).

Mauer-Formation / Mauer Formation

HANS-GEORG KRENMAYR

Validity: Valid; HÖDL (1901) was the first to mention sediments containing "Urgebirgsblöcke" without realizing the nature of these sediments; ABEL (1904b) first introduced the term "Blockschichten", however, included sediments in the area between Königstetten SE of Tulln in the east and to Loosdorf SE of Melk an der Donau in the west; GRILL (1957a) used the name "blockführende Schichten" and inferred a Miocene age based on foraminifera; this was supported by FUCHS (1964b) who also stated that these breccias are mass flows incorporated in Miocene "Schlier"; the term Mauer Formation was introduced and formally defined by KRENMAYR (2003a) who provided additional details later on (KRENMAYR, 2003b; LINNER & KRENMAYR, 2013; ĆORIĆ et al., 2013).

Type area: Typical sediments of the Mauer Formation occur in the triangle formed by the villages of Mauer bei Melk and Pielachhäuser and the market town of Loosdorf, area E and SE of the town Melk an der Donau, Lower Austria; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4329 Wilhelmsburg (ÖK50-BMN, map sheet 55 Ober-Grafendorf).

Type section: Road cut of a forest road, immediately east of the church of the village Mauer (N 48°13′48″ / E 15°25′30″) (KRENMAYR, 2003a). The type section shows a chaotic megabreccia with components of up to 5 m. The lower and upper boundaries of the Mauer Formation are not exposed.

Reference section(s): -

Remark: KRENMAYR (2003a) refers to outcrops which document a variety of facies types within the Mauer Formation, e.g., crystalline blocks floating in a matrix of slumped pelitic sediments (small road cut west of the village Pfaffing: N 48°13′56″ / E 15°25′34″), megabreccias with huge blocks of the Pielach Formation and "Älterer Schlier" (undercut slope of the runnel south of the church of the village Mauer: N 48°13′42″ / E 15°25′25″), sandy, gravelly and block-bearing channel fill bodies (old sand pit in the village of Pielachhäuser: N 48°12′16″ / E 15°27′18″). Outcrops in a gully north of the village of Rohr (between Loosdorf and Großsierning) are mentioned, still accessible and could also act a reference section (GRILL, 1957a; KRENMAYR, 2003a).

Derivation of name: Named after the village Mauer bei Melk, c. 6 km E of the town Melk an der Donau, c. 3 km NNE of the market village Loosdorf, Lower Austria; ÖK50-UTM, map sheet 4323 Sankt Pölten (ÖK50-BMN, map sheet 55 Ober-Grafendorf).

Synonyms: (partim) Blockschichten (ABEL, 1904b), blockführende Schichten (GRILL, 1957a: p. 29), Blockschichten von Rohr (FUCHS, 1972: p. 207), Blockmuren von Mauer (FUCHS, 1972: Tab. 1), Blockschichten von Rohr und Mauer (FUCHS, 1972: p. 214), Blockschichten von Mauer (FUCHS, 1972: Tafel 1 = Beilage 6).

Remark: ABEL (1904b) considered the “Blockschichten” as a facies type of the Aquitanian (considered to be Oligocene at that time) “Melker Schichten” but included sediments of the area between Königstetten and Loosdorf. Also ELLISON (1936, 1942) agreed with this opinion. Moreover, he interpreted the “Blockschichten” as coastal sediments and tried to reconstruct the former shoreline according to the topographically highest occurrences of these sediments. GRILL (1957a: p. 29), referring simply to “blockführende Schichten”, realized their Miocene age by microfossil studies. FUCHS (1964b) mapped the whole area of the occurrence of the “Blockschichten” (with different names, see above) (FUCHS, 1972) and described their nature as submarine debris flow deposits (FUCHS, 1972: p. 216), however, noting that this was already recognized by GRILL (1957a).

Lithology: The lithology is very diverse. The characteristic features are chaotic (mega)breccias with predominant crystalline components (up to 6 m in diameter) of the basement rocks from the close surroundings. Also blocks of sedimentary material from the Pielach Formation, of the “Älterer Schlier”, concretions from eroded sediments of the Linz-Melk Formation, and macrofossil-bearing calcareous sandstone blocks of Eggenburgian age contribute to the component spectrum. The sediments show no bedding and grading and sorting is very bad. Composition of the matrix is diverse and may comprise finer grained crystalline material, sand, gravel and squeezed intraclasts of muddy material. Additional lithologies comprise massive or laminated, sometimes cross-stratified, partly block-bearing sand and gravel, organized in channel shaped bodies, undisturbed as well as slumped marly mudstones, and well-rounded, quartz- and quartzite-dominated, fine to medium gravel and gravelly sand. The latter lithology is only present in the area north of Mauer bei Melk.

Fossils: Foraminifera (both planktics and benthics, badly preserved), rare radiolarians and sponge spicules occur in autothonous pelites (RUPP in KRENMAYR & ROETZEL, 2002). All macrofossils (mostly molluscs) are allochthonous, being reworked from the Pielach Formation (e.g., ABEL, 1904b) and, in particular, from the Fels Formation (STEININGER in FUCHS, 1964b).

Origin, facies: The Mauer Formation represents olisthostromatic debris flows and channel facies at the northern, passive margin of the NAFB. The presence of undisturbed or slumped marly mudstones, which are frequently interrelated with the coarse-grained Mauer Formation, indicates the interrelationship of the Mauer Formation with the basinal facies of the Robulus Schlier. Grain size trends and paleocurrent indicators suggest a dominant transport direction of the sediments towards ESE. The fine to medium gravel and gravelly sand facies north of Mauer bei Melk might indicate a small scale alluvial fan or delta environment. Foraminiferal assemblages from pelitic intervals suggest a shallow sublittoral environment (RUPP in KRENMAYR & ROETZEL, 2002: p. 10).

Chronostratigraphic age: Early Miocene, Burdigalian (early Ottnangian).

Remark: ABEL (1904b) and ELLISON (1936, 1942) correlated the Mauer Formation with the Linz-Melk Formation but already GRILL (1957a: p. 30) dated the unit into the Miocene. Since high-resolution biostratigraphic markers are not available, the most reliable age estimate is based on the interbedding of the Mauer Formation in the Robulus Schlier, which is dated into early Ottnangian.

Biostratigraphy: The only autochthonous fauna are foraminifera, which indicate lower Miocene (RUPP in KRENMAYR & ROETZEL, 2002: p. 10). As a more precise marker, e.g., *Bolivina scitula* may be considered to indicate Ottnangian age.

Thickness: Thickness can only be estimated but will hardly exceed 20 m. As uppermost Neogene formation on top of a pre-Ottnangian complex topographic relief sediments of the Mauer Formation occur only as erosive relicts.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement rocks of the Bohemian Massif, Pielach Formation, Linz-Melk Formation. All these units are discordantly overlain by the Mauer Formation.

Overlying unit(s): Quaternary deposits.

Lateral unit(s): Robulus Schlier and Prinzersdorf Formation interfinger with the Mauer Formation.

Geographic distribution: Sediments of the Mauer Formation extend from Loosdorf in the SW to Flinsbach, c. 6 km NE of St. Pölten, in the NE and never extend south of the railway track of the Westbahn, Lower Austria; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4329 Wilhelmsburg (ÖK50-BMN, map sheets 55 Ober-Grafendorf, 56 St. Pölten).

Remarks: ABEL (1904b) considered the “Blockschichten” as a facies type of the Aquitanian (considered Oligocene at that time) “Melker Schichten” but he also included lithological similar occurrences near Königstetten as part of this unit which should be treated as a separate formation.

Complementary references: FUCHS (1972), PILLER et al. (2004), WESSELY (2006), GEBHARDT (2021).

Pixendorf-Gruppe / Pixendorf Group

WERNER E. PILLER

Validity: Valid; RZEHAK (1882b) introduced the term “Oncophorasande” and “Oncophora-Schichten” (1893) in Moravia (Czech Republic) which were renamed as

"Věstonické pískovce" (Vestonice Sandstone) by ADÁMEK (2003) and Vestonice Formation by PICHA et al. (2006). The name "Oncophora-Schichten" was also used in the NAFB from Lower Austria, via Upper Austria to Lower Bavaria, however, these sediments were deposited in different lakes (HARZHAUSER & MANDIC, 2008) necessitating a differentiation between Moravia but also between Bavaria-Upper Austria and Lower Austria. For Bavaria-Upper Austria the term *Oncophora* (an old name for a bivalve with the actual name *Rzehakia*; cf. ČTYROKÝ, 1972) was retained by PIPPÈRR et al. (2018) in the Oncophora Formation (see details in the NAFB of Upper Austria). For Lower Austria, GEBHARDT et al. (2013a) subsumed the "Oncophora-Schichten" and the closely related "Eichberg-Konglomerat" as Traisen Formation and Dietersdorf Formation in the Pixendorf Group.

Type area: In the area between the villages Witzendorf (W of the city of St. Pölten) and Pixendorf (SW of Tulln an der Donau) in Lower Austria; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4324 Herzogenburg, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 38 Krems an der Donau, 39 Tulln, 56 St. Pölten).

Type section: See Traisen Formation.

Reference section(s): -

Derivation of name: Named after the village Pixendorf, c. 7 km SW of the town Tulln an der Donau, Lower Austria; ÖK50-UTM, map sheet 4324 Herzogenburg (ÖK50-BMN, map sheet 39 Tulln).

Synonyms: -

Lithology: Sand and sandstones but also conglomerates (see description of formations).

Fossils: See description of formations of the Pixendorf Group.

Origin, facies: See Traisen Formation and Dietersdorf Formation.

Chronostratigraphic age: Early Miocene, late Burdigalian (late Ottnangian).

Biostratigraphy: See Traisen Formation.

Thickness: The maximum thickness with 770 m is recorded in the deep drilling Moosbierbaum K2 and K5 (BRIX et al., 1977); thicknesses are laterally highly variable.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Traisen Formation, Dietersdorf Formation.

Underlying unit(s): Robulus Schlier.

Overlying unit(s): South of the Danube the Pixendorf Group is the youngest Neogene lithostratigraphic unit, which is only covered by Pleistocene deposits.

Lateral unit(s): It is assumed that the Traisen Formation of the Pixendorf Group is a time-equivalent of the Wildendürnbach Formation (GEBHARDT et al., 2013a; PALZER-KHOMENKO et al., 2018a, b).

Geographic distribution: The Pixendorf Group occurs in the area west of St. Pölten to southwest of Tulln an der Donau; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4324 Herzogenburg, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 38 Krems an der Donau, 39 Tulln, 56 St. Pölten).

Remarks: The sediments of the Pixendorf Group were deposited on a pronounced paleorelief, which explains its strong lateral thickness variations.

Complementary references: -

Traisen-Formation (Pixendorf-Gruppe) / Traisen Formation (Pixendorf Group)

WERNER E. PILLER

Validity: Valid; the first mention of this unit was by STUR (1891a, c, d) on the map of Vienna as "Sand und Sandstein des Donaubeckens" and in the map explanation by PAUL & BITTNER (1894: p. 18); BITTNER (1896) was the first to introduce the name "Oncophora-Schichten" in Lower Austria; ABEL (1904b) gave a more detailed description and distribution; GEBHARDT et al. (2013a) introduced, described and formalized the unit as Traisen Formation to clearly document that these sediments are neither equal to that of Moravia nor to those of Upper Austria-Bavaria (see also description of the Pixendorf Group).

Type area: The area in the northern part of the city of St. Pölten, Lower Austria; ÖK50-UTM, map sheet 4323 Sankt Pölten (ÖK50-BMN, map sheet 56 St. Pölten).

Type section: A c. 20 m-thick section in an abandoned sand pit in the Prater area, a district in the NW part of the community of St. Pölten; N 48°13′16.1″ / E 15°37′30.8″; ÖK50-UTM, map sheet 4323 Sankt Pölten (ÖK50-BMN, map sheet 56 St. Pölten). The lower boundary is not exposed and the Traisen Formation is overlain by Pleistocene loess deposits (GEBHARDT et al., 2013a: p. 20, Abb. 2, 3).

Reference section(s): A c. 6 m-thick section at the southern end of the village Rassing, east of the road to Rapoltendorf, c. 11 km NE of the city of St. Pölten, exposes a silty-clayey facies of the Traisen Formation (GEBHARDT et al., 2013a: p. 23, Abb. 7); N 48°14′44.1″ / E 15°45′55″; the lower and upper boundaries are not exposed.

A section of a few meters thickness in a temporary outcrop near Witzendorf, W of St. Pölten, was defined as reference section for the boundary of the Traisen Formation with the underlying Robulus Schlier, developed as an angular unconformity (the section was exposed during railway construction in 1998) (GEBHARDT et al., 2013a: p. 21, Abb. 5); N 48°12′47.5″ / E 15°34′58.8″; the section is not exposed anymore.

Derivation of name: Named after the river Traisen, which flows through the city of St. Pölten (where the type section is located) and the river bed cuts widely through the Traisen Formation in the northwestern part of the town; Lower Austria; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4324 Herzogenburg (ÖK50-BMN, map sheets 38 Krems an der Donau, 56 St. Pölten).

Synonyms: Sand und Sandstein des Donaubeckens p.p. (STUR, 1891a, d), Oncophora-Schichten (BITTNER, 1896), *Oncophora*-Schichten, *Oncophora*-Sande, *Oncophora*-Sand und -Sandstein (ABEL, 1904b), Oncophoraschichten (VETTERS, 1922: p. 116), Oncophorasande (GÖTZINGER & VETTERS, 1923: p. 21), Oncophora beds, Oncophora sands (PAPP et al., 1968b), Rzehakia-Schichten (ČTYROKÝ, 1972); Brachyhaline Schichten mit Rzehakia = "Oncophora-Schichten" (PAPP et al., 1973), Oncophoraserie (BRIX et al., 1977).

Lithology: Yellow-grey, micaceous, mostly massive but also laminated, medium to fine quartz sand to sandstone with silty-clayey intercalations, occasionally with layers of pebbles or conglomerates and lignite. In places, lens shaped or spherical concretions up to several meters in diameter occur. GEBHARDT et al. (2013a: p. 18) differentiate two lithofacies, a sand- to sandstone dominated facies and a clay-siltstone dominated one.

Fossils: The Traisen Formation is poor in calcareous fossils, both in micro- and megafossils. Some localities, however, show very specific molluscs which were already described by CŽJŽEK (1853a) and BITTNER (1896) from the area of St. Pölten. These fossils are similar to that of the "Oncophora-Schichten" (= Rzehakia-Schichten of Moravia) (ČTYROKÝ, 1972) and this was the reason to correlate these sediments with those in the NAFB of Upper Austria and Lower Bavaria. MANDIC & ĆORIĆ (2007) documented in detail a first mollusc fauna (lymnocardiid-rzehakiid assemblage) from Lower Austria (locality Rassing) and HARZHAUSER & MANDIC (2008) reported a total of 39 highly endemic gastropod species from what they call "Rzehakia Lake System".

Origin, facies: The sediments of the Traisen Formation were deposited in a brackish to freshwater lake system ("Rzehakia Lake System" of HARZHAUSER & MANDIC, 2008) which was isolated from similar lake systems in Upper Austria-Bavaria and Moravia, respectively.

Chronostratigraphic age: Early Miocene, late Burdigalian (late Ottnangian).

Remark: The Oncophora Formation in Lower Bavaria has been correlated (including the type locality) by HOFMAYER et al. (2019) with Chron C5Cn indicating a (late) Karpatian age.

The "*Rzehakia* Beds" in the Novohrad-Nógrád Basin of the Pannonian Basin (southern Slovakia) were also dated with calcareous nannoplankton into the Karpatian (RUMAN et al., 2021).

Biostratigraphy: The molluscs reported by MANDIC & ĆORIĆ (2007) from the area of Rassing (close to the reference section) support the late Ottnangian age. These authors, however, point already out that not all such assemblages indicate late Ottnangian age.

Remark: In the southern Slovakian Novohrad-Nógrád Basin of the Pannonian Basin a classical *Rzehakia* fauna cooccurs with calcareous nannoplankton and foraminifers. The CNP clearly indicates Zone NN4 (*Helicosphaera ampliaperta* and *Sphenolithus heteromorphus*, absence of *S. belemnos* and *H. waltrans)* and the foraminifer *Uvigerina graciliformis* a Karpatian age.

Thickness: The maximum thickness with 770 m is recorded in the deep drillings Moosbierbaum K2 and K5 (BRIX et al., 1977); thicknesses are laterally highly variable.

Lithostratigraphically higher rank unit: Pixendorf Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Robulus Schlier.

Overlying unit(s): Pleistocene loess, discordant.

Lateral unit(s): Dietersdorf Formation; interfingering with the Traisen Formation.

Geographic distribution: The Traisen Formation occurs from the area west of St. Pölten to southwest of Tulln an der Donau; ÖK50-UTM, map sheets 4323 Sankt Pölten, 4324 Herzogenburg, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 38 Krems an der Donau, 39 Tulln, 56 St. Pölten).

Remarks: -

Complementary references: BITTNER (1893), VETTERS (1924), GÖTZINGER et al. (1954), PAPP (1955a, 1963), PAPP et al. (1968a), SCHNABEL (2002a), ROETZEL (2002), PILLER et al. (2004), WESSELY (2006), GEBHARDT (2011b).

Dietersdorf-Formation (Pixendorf-Gruppe) / Dietersdorf Formation (Pixendorf Group)

WERNER E. PILLER

Validity: Valid; HAUER (1858) reported heterogenous sediments (including conglomerates) from the Tulln Basin but dated them into the Eocene; STUR (1891a) and PAUL & BITTNER (1894) called these sediments "Sotzka-Conglomerat" and dated them to the Aquitanian; ABEL (1904b) and VETTERS (1924) named these sediments "Buchbergconglomerat" locating them on the Eichberg and Einsiedlberg; GRILL (1954a) introduced the name "Eichbergkonglomerat", which has been used until GEBHARDT et al. (2013a) renamed and formalized the conglomerate as Dietersdorf Formation.

Type area: Southeastern foothill of the Eichberg, south of the village Dietersdorf, c. 3.5 km WNW of the market town Sieghartskirchen, Lower Austria; ÖK50-UTM, map sheet 4324 Herzogenburg (ÖK50-BMN, map sheet 39 Tulln).

Type section: A c. 24 m-thick section in an abandoned quarry close to the southern end of the village Dietersdorf, Lower Austria; N 48°15′32.6″ / E 15°57′43.6″ (GEBHARDT et al., 2013a: p. 29, Abb. 9A, 10A); ÖK50-UTM, map sheet 4324 Herzogenburg (ÖK50-BMN, map sheet 39 Tulln). The lower and upper boundaries are not exposed; the lower boundary is represented by a fault, Quaternary sediments cover the top.

Reference section(s): A c. 16 m-thick section in an abandoned quarry close to the southern end of the village Dietersdorf, Lower Austria; N 48°15′31.1″ / E 15°57′41.8″; ÖK50-UTM, map sheet 4324 Herzogenburg (ÖK50-BMN, map sheet 39 Tulln).

Derivation of name: Named after the village Dietersdorf at the eastern foothill of the Eichberg (319 m), c. 3.5 km WNW of the market town Sieghartskirchen, Lower Austria; ÖK50-UTM, map sheet 4324 Herzogenburg (ÖK50-BMN, map sheet 39 Tulln).

Synonyms: (partim) Mergel-, Sand- und Conglomeratablagerungen im Tullner Becken (HAUER, 1858: p. 132), (partim) Sotzka-Conglomerat (STUR, 1891a, b), Buchbergconglomerat des Eichbergzuges (ABEL, 1904b), Buchbergkonglomerat … am Eichberge und Einsiedlberge (VETTERS, 1924: p. 15), Eichbergkonglomerat (GRILL, 1954b: p. 119), Eichberg-Konglomerat (ROETZEL, 2002).

Lithology: Dominated by grey conglomerates with boulders up to > 1 m in diameter and sandy to pebbly matrix, mostly with siliceous cement. The components are rounded to subangular, predominantly sandstones from the Rhenodanubian Flysch but also limestones and dolomites as well as pelitic intraclasts occur. In addition, fine conglomerates and medium grained sandstones with graded and cross bedding, cut-and-fill structures, and ripples occur which are laterally not continuous. Clay, silt and fine sand are rare and occur only in thin layers.

Fossils: The sediments are mostly carbonate free; therefore, no calcareous fossils occur. Plant remains and trace fossils are reported.

Origin, facies: The coarse conglomerates and boulders are interpreted as subaquatic debris flows, sandstones and fine conglomerates as bed load and pelites as suspension load. Overall, the sediments of the Dietersdorf Formation were deposited as part of a fan-delta into the local lake system of the Traisen Formation. The general coarsening upward trend may indicate a progradation of the fan delta. The fine-grained conglomerates represent channel fill sequences of laterally shifting channel systems (Gebhardt et al., 2013a).

Chronostratigraphic age: Early Miocene, late Burdigalian (late Ottnangian).

Remark: Since no biostratigraphic marker fossils occur, the age can only be deduced from the lateral interfingering with the Traisen Formation.

Biostratigraphy: No biostratigraphically important fossils known.

Thickness: At the Eichberg were 380 m calculated (Gebhardt et al., 2013a).

Lithostratigraphically higher rank unit: Pixendorf Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Robulus Schlier.

Overlying unit(s): Quaternary sediments.

Lateral unit(s): Traisen Formation; interfingering with the Dietersdorf Formation.

Geographic distribution: The area of distribution reaches from the village Würmla in the West to Judenau in the east forming an approx. 3 km wide stripe. ÖK50-UTM, map sheet 4324 Herzogenburg (ÖK50-BMN, map sheet 39 Tulln).

Remarks: -

Complementary references: Fuchs (1976a), Fuchs & Grill (1984a, b), Schnabel (2002a), Piller et al. (2004), Wessely (2006), Gebhardt et al. (2008), Gebhardt (2011a, b).

North Alpine Foreland Basin: Lower Austria, North of the Danube and at the Bohemian Massif

Schichten von Freistadt-Kefermarkt / Beds of Freistadt-Kefermarkt

Reinhard Roetzel

Validity: Invalid; the term “Schichten von Freistadt-Kefermarkt” is informal and invalid.

Type area: The area around Freistadt and Kefermarkt in Upper Austria (eastern part of the Mühlviertel district) can be regarded as type area.

Type section: -

Reference section(s): -

Derivation of name: From the town Freistadt, 27 km NE of Linz and the market town Kefermarkt, 8 km SSE of Freistadt in the distribution area of the deposits; ÖK50-UTM, map sheet 4314 Freistadt (ÖK50-BMN, map sheet 16 Freistadt).

Synonyms: “Freistädter Tertiär”, “Freistädter Schotter”, “Kefermarkter Tertiär”, “Sedimente von Freistadt-Kefermarkt”, “Schichten von Freistadt und Kefermarkt”.

Remark: Genesis and age of these sediments were already discussed by many authors, such as Kinzl (1930) and Kohl (1957). Kohl (1957) separated an Oligocene “Kefermarkter Tertiär” from a younger “Freistädter Tertiär”. Recently, the sediments were mapped and described by Rockenschaub (1994, 1997, 1998); Brüggemann & Finger (2002); Rockenschaub & Schubert (2009); Schubert et al. (2010). A broad synopsis about the Beds of Freistadt-Kefermarkt was given by Chábera & Huber (2000).

Lithology: The Beds of Freistadt-Kefermarkt are badly sorted, micaceous and arkosic, coarse to fine sands and gravel with a pelitic matrix and intercalations of kaolinitic silts and clays, sometimes with coaly seams. The deposits show typical sedimentary structures of a fluvial environment. In the Kefermarkt area, a dichotomy in an upper sandy to gravelly part and a lower clayey part is described by Kohl (1957) and Rockenschaub (1997).

Fossils: In the sandy and gravelly sediments of the Beds of Freistadt-Kefermarkt silicified wood is common. In coaly clays pollen and spores rarely occur.

Origin, facies: The Beds of Freistadt-Kefermarkt are fluvial to lacustrine deposits from a river system draining the České Budějovice Basin in South Bohemia towards the south.

Chronostratigraphic age: Oligocene, Rupelian–Chattian to early Miocene, Aquitanian (Kiscellian–Egerian); poorly constrained.

Biostratigraphy: The Beds of Freistadt-Kefermarkt have been dated with pollen to the Oligocene (Draxler in Peresson-Homayoun et al., 2005: p. 37f.).

Thickness: The thickness of these sediments varies between a few meters and several tens of meters. The maximum thickness of about 40 to 60 m was documented in the surroundings of Kefermarkt, Freistadt, and Summerau (Rockenschaub, 1994, 1997; Peresson-Homayoun et al., 2005).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: A subdivision has informally been made into a lower part ("Kefermarkter Tertiär") and an upper part ("Freistädter Tertiär") (KOHL, 1957).

Underlying units: Sediments of the Beds of Freistadt-Kefermarkt are always following discordantly upon the crystalline basement rocks of the Bohemian Massif.

Overlying units: In some areas, Pleistocene sediments overlie the Beds of Freistadt-Kefermarkt.

Lateral units: It has to be assumed that the sediments of the St. Marein-Freischling Formation in Lower Austria are facies- and time-equivalent deposits of the Beds of Freistadt-Kefermarkt.

Geographic distribution: These sediments can be found in Upper Austria north of the Danube northeast of Linz in a narrow NNW striking sedimentary belt between Summerau, Freistadt, Kefermarkt and Selker; ÖK50-UTM, map sheets 4308 Leopoldschlag, 4314 Freistadt, 4320 Perg (ÖK50-BMN, map sheets 16 Freistadt, 33 Steyregg). Towards the north this unit continues to the Dolní Dvořiště (German name: Unterhaid) area in the Czech Republic.

Remarks: -

Complementary references: -

Ravelsbach-Formation / Ravelsbach Formation

REINHARD ROETZEL

Validity: Valid; the name "Ravelsbach-Formation" was established by ROETZEL (2017).

Type area: The western, upper course of the Ravelsbach creek, c. 600 m SW of the village Grübern, immediately east of the road between Grübern and Eggendorf am Walde is defined as type area (ROETZEL, 2017).

Type section: Not defined; ROETZEL (2017: p. 319) described outcrops in the small valley of the Ravelsbach creek (N 48°32′48.4″ / E 15°47′45.7″), c. 600 m south of the village Grübern, and c. 3.4 km SW of the town of Maissau (Lower Austria), which can be regarded as type section of the Ravelsbach Formation; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Reference section(s): Not defined; as reference sections can be regarded the abandoned sandpit Obernholz; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn) (N 48°30′50″ / E 15°44′16″) (STEININGER, 1968b, 1977d, 1983; STEININGER et al., 1991d). In this outcrop, sediments of the Ravelsbach Formation were described as St. Marein-Freischling Formation (STEININGER et al., 1991d; NEHYBA & ROETZEL, 2010).

Derivation of name: From the Ravelsbach creek, south of the village Grübern; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Fossilleere Serie, Fossilarme Serie, Kontinentale Serie, St. Marein-Freischling-Formation.

The sediments in the Ravelsbach creek were already mentioned by SUESS (1866a: p. 111) as unfossiliferous sands and clays. He correlated them with the deepest part of the "Schichten von Molt" (Mold Formation). STEININGER (1977d, 1968b, 1983) named these sediments in the Obernholz sandpit "Kontinentale Serie" and "Fossilarme Serie", respectively. Later, STEININGER et al. (1991d) and NEHYBA & ROETZEL (2010) included the basal deposits in Obernholz in the St. Marein-Freischling Formation. Based on mapping results and the outstanding position of these sediments in lithology and petrography ROETZEL (2017) established the Ravelsbach Formation.

Lithology: Sediments of the Ravelsbach Formation are varicoloured, mainly badly sorted and arkosic silty-clayey coarse to fine sands with intercalations of gravelly and silty to clayey layers. Partly, better sorted cross bedded sands with intraclasts and sands in small erosive channels with muddrapes occur. Gravel are from well-rounded quartz as well as subangular crystalline rocks. The sediments contain high amounts of feldspar and lithic components.

Fossils: Generally, the sediments of the Ravelsbach Formation are very poor in fossils, only with rare silicified wood. In parts, they are highly bioturbated with few trace fossils of *Ophiomorpha* (ROETZEL, 2017). Additionally, from sandpits west of the village Diendorf oysterbeds are reported (STEININGER, 1968b; ROETZEL, 2017).

Origin, facies: The sediments of the Ravelsbach Formation are presumably fluvial-estuarine to lagoonal deposits from the mouth of a small river system draining the hinterland in an early stage of the early Miocene transgression (NEHYBA & ROETZEL, 2010).

Chronostratigraphic age: Late Oligocene?, Chattian? to early Miocene, Aquitanian to early Burdigalian? (Egerian to early Eggenburgian?) poorly constrained.

Biostratigraphy: -

Thickness: For the Ravelsbach Formation a thickness of 6–13.5 m is reported (STEININGER et al., 1991d; ROETZEL, 2017).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: Sediments of the Ravelsbach Formation are following discordantly upon the crystalline basement rocks of the Bohemian Massif (Text-Fig. 5).

Overlying units: In some parts the sediments are overlain by the Fels Formation and Burgschleinitz Formation, respectively; in the Obernholz area also erosively by the Hollenburg-Karlstetten Formation.

Lateral units: It has to be assumed that the sediments of the Ravelsbach Formation are time-equivalent deposits of the St. Marein-Freischling Formation.

Geographic distribution: The distribution area of the Ravelsbach Formation extends along the Diendorf fault-scarp between the villages of Grübern and Obernholz in Lower Austria; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Remarks: Presumably, sediments of the Žerotice Formation (NEHYBA et al., 2019) in the Czech Republic are comparable to the Ravelsbach Formation.

Complementary references: -

Sankt Marein-Freischling-Formation / Sankt Marein-Freischling Formation

Reinhard Roetzel

Validity: Valid; the name “St. Marein-Freischling-Formation” was first used by Steininger (1983: p. 24) and afterwards also in the geological map sheet 20 Gföhl (Fuchs et al., 1984). These sediments were defined by Steininger & Roetzel (1991) and later on specified in Roetzel et al. (1999a).

Type area: As indicated by the geographic terms in the formation name, the area between the villages St. Marein and Freischling in the Horn Basin can be regarded as type area; ÖK50-UTM, map sheets 4311 Horn, 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 20 Gföhl, 21 Horn).

Type section: -

Reference section(s): Not defined; as reference sections can be regarded: sandpit 1 km WSW of St. Marein (abandoned) (N 48°40′55″ / E 15°29′12″); sandpit 1.3 km SE of Breiteneich (abandoned) (N 48°39′56″ / E 15°42′10″) (Roetzel & Steininger, 1991); clay-pit Maiersch (Frings) (abandoned), c. 2 km ENE of the village Maiersch (N 48°34′52″ / E 15°42′36″) (Steininger, 1976, 1977e: p. 75ff., 1983; Steininger et al., 1991c). The upper boundary was exposed in the clay pit Maiersch; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: From St. Marein, a village 12 km WNW of the town Horn, and Freischling, a village 5 km SE of Gars am Kamp, Lower Austria; ÖK50-UTM, map sheets 4311 Horn, 4318 Langenlois (ÖK50-BMN, map sheets 20 Gföhl, 21 Horn).

Synonyms: Fossilleere Serie, Fossilarme Serie, Kontinentale Serie.

These sediments were already mentioned by Suess (1866a) as unfossiliferous sands and clays in the surroundings of Horn. Steininger (1968a, b, 1969a, 1976, 1977e, 1979) named these sediments “Fossilleere Serie”, “Fossilarme Serie” or “Kontinentale Serie”.

Lithology: Sediments of the St. Marein-Freischling Formation are badly sorted arkosic and pelitic, coarse to fine sands and gravel with intercalations of kaolinitic silts and clays, showing typical sedimentary structures of a fluvial environment. In the southern part of the Horn Basin pelitic sediments are increasing towards the south and topwards in a progressively estuarine environment.

Fossils: In the sandy and gravelly sediments of the St. Marein-Freischling Formation silicified wood is common (Hofmann, 1933; Ellenberger, 1948; Gros, 1981, 1983, 1984, 1988; Cichocki, 1988), whereas in the pelitic parts remnants of leave impressions (Knobloch, 1977, 1981b), pollen, and spores (Hochuli, 1983; Draxler, 1991) occur.

Origin, facies: The sediments of the St. Marein-Freischling Formation are fluvial to lacustrine deposits from a river system draining the Třeboň Basin in South Bohemia and the southeastern Bohemian Massif from northwest to southeast (Nehyba & Roetzel, 2010). Due to the ingression of the sea, an estuarine environment was established in the southern Horn Basin in the upper parts of the formation (Steininger et al., 1991c).

Chronostratigraphic age: Oligocene, Rupelian–Chattian to early Miocene, Aquitanian to early Burdigalian? (Kiscellian to early Eggenburgian?) poorly constrained.

Biostratigraphy: The pollen-flora of clayey sediments of the St. Marein-Freischling Formation was dated by Hochuli (1983) to the palaeofloral Zones Pg.Z. 19, Pg.Z. 20a, Ng.Z.I and Ng.Z.II. Due to these datings a correlation with the Oligocene and lowermost Miocene (Kiscellian–Egerian) is possible.

Thickness: In the Horn Basin, about 100 m to 150 m of sediments of the St. Marein-Freischling Formation are reported by drillings (Herndler, 1979). West of the Horn Basin, the thickness of these deposits is normally between 20 m and 65 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: Sediments of the St. Marein-Freischling Formation mostly are following discordantly upon the crystalline basement rocks of the Bohemian Massif. In the Gmünd area it can be supposed that the Cretaceous Klikov Formation is lying below.

Overlying units: In the southern Horn Basin, the St. Marein-Freischling Formation is gradationally passing into the Mold Formation and is overlain in many parts by Pleistocene sediments, too.

Lateral units: It has to be assumed that the Beds of Freistadt-Kefermarkt in Upper Austria are facies- and time-equivalent deposits of the St. Marein-Freischling Formation.

Geographic distribution: The main distribution area of the St. Marein-Freischling Formation is located in the Horn Basin. However, these sediments extend from the Horn Basin towards the west to Neupölla, Großglobnitz, Kirchberg am Wald up to the area of Gmünd, Lower Austria; ÖK50-UTM, map sheets 4310 Zwettl, 4311 Horn, 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 5 Gmünd, 6 Waidhofen an der Thaya, 19 Zwettl, 20 Gföhl, 21 Horn).

Remarks: -

Complementary references: -

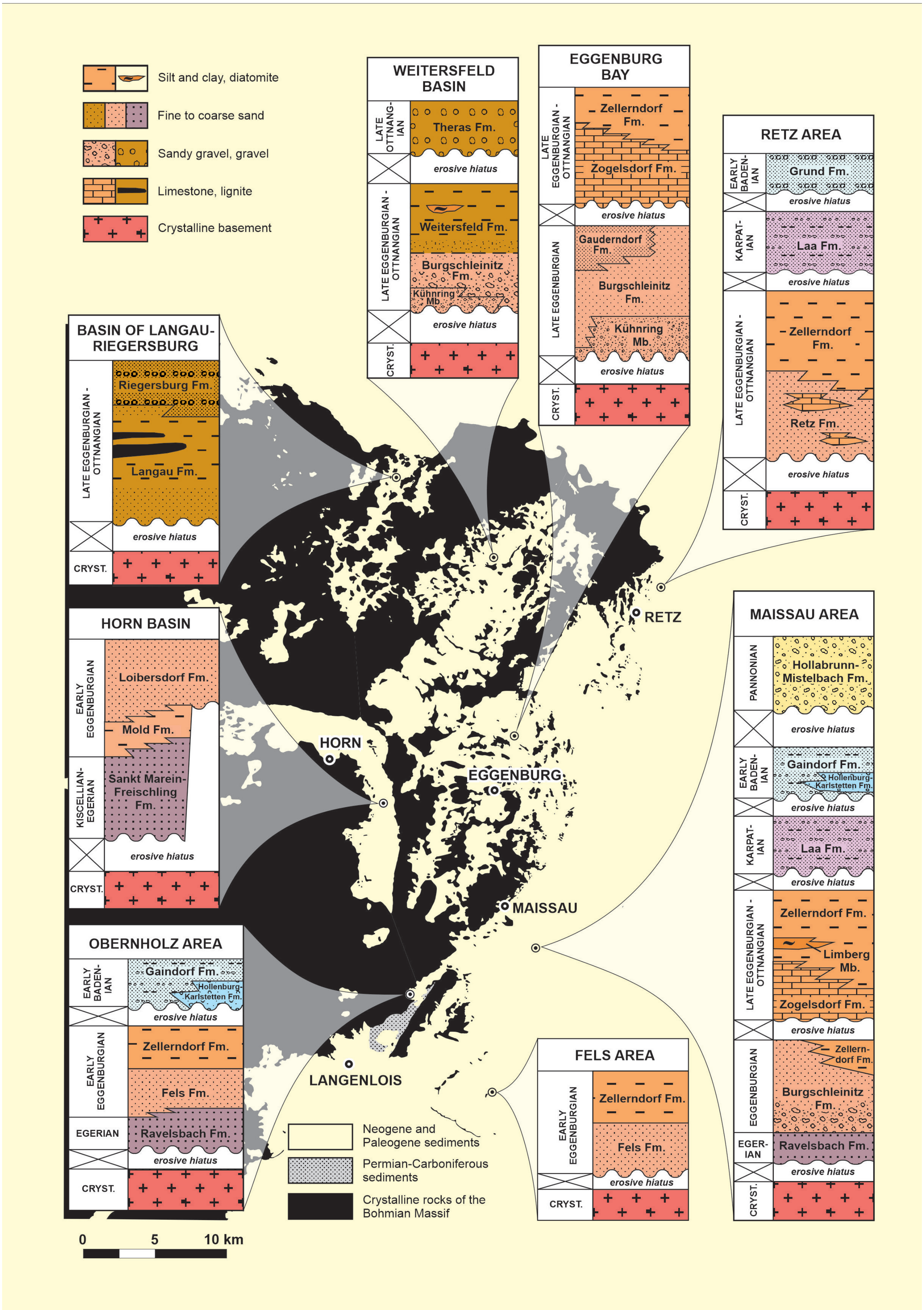
Eggenburg-Gruppe / Eggenburg Group

Reinhard Roetzel

Validity: Valid; Steininger & Roetzel (1991) subsumed all detritic fossiliferous formations of the Eggenburgian and early Ottnangian to the Eggenburg Group.

Type area: The type area corresponds with the geographic range of the formations of the Eggenburg-Group in the Eggenburg Bay, the southern Horn Basin, along the spur of the Bohemian Massif between Retz and Maissau, as well as in the surroundings of Obernholz and Fels am Wagram.

Text-Fig. 5. ▶
Overview of the lithostratigraphic units on the southeastern margin of the Bohemian Massif in Lower Austria (after Roetzel et al., 1999a, updated).



Silt and clay, diatomite
Fine to coarse sand
Sandy gravel, gravel
Limestone, lignite
Crystalline basement
WEITERSFELD BASIN
LATE OTTNANG-IAN
Theras Fm.
erosive hiatus
LATE EGGENBURGIAN - OTTNANGIAN
Weitersfeld Fm.
Burgschleinitz Fm.
Kühnring Mb.
erosive hiatus
CRYST.
EGGENBURG BAY
LATE EGGENBURGIAN - OTTNANGIAN
Zellerndorf Fm.
Zogelsdorf Fm.
erosive hiatus
LATE EGGENBURGIAN
Gauderndorf Fm.
Burgschleinitz Fm.
Kühnring Mb.
erosive hiatus
CRYST.
RETZ AREA
EARLY BADEN-IAN
Grund Fm.
erosive hiatus
KARPAT-IAN
Laa Fm.
erosive hiatus
LATE EGGENBURGIAN - OTTNANGIAN
Zellerndorf Fm.
Retz Fm.
erosive hiatus
CRYST.
BASIN OF LANGAU-RIEGERSBURG
LATE EGGENBURGIAN - OTTNANGIAN
Riegersburg Fm.
Langau Fm.
erosive hiatus
CRYST.
HORN BASIN
EARLY EGGENBURGIAN
Loibersdorf Fm.
Mold Fm.
KISCELLIAN-EGERIAN
Sankt Marein-Freischling Fm.
erosive hiatus
CRYST.
OBERNHOLZ AREA
EARLY BADEN-IAN
Gaindorf Fm.
Hollenburg-Karlstetten Fm.
erosive hiatus
EARLY EGGENBURGIAN
Zellerndorf Fm.
Fels Fm.
EGERIAN
Ravelsbach Fm.
erosive hiatus
CRYST.
MAISSAU AREA
PANNONIAN
Hollabrunn-Mistelbach Fm.
erosive hiatus
EARLY BADEN-IAN
Gaindorf Fm.
Hollenburg-Karlstetten Fm.
erosive hiatus
KARPAT-IAN
Laa Fm.
erosive hiatus
LATE EGGENBURGIAN - OTTNANGIAN
Zellerndorf Fm.
Limberg Mb.
Zogelsdorf Fm.
erosive hiatus
EGGENBURGIAN
Zellern-dorf Fm.
Burgschleinitz Fm.
EGER-IAN
Ravelsbach Fm.
erosive hiatus
CRYST.
FELS AREA
EARLY EGGENBURGIAN
Zellerndorf Fm.
Fels Fm.
erosive hiatus
CRYST.
RETZ
HORN
EGGENBURG
MAISSAU
LANGENLOIS
Neogene and Paleogene sediments
Permian-Carboniferous sediments
Crystalline rocks of the Bohmian Massif
0
5
10 km

Type section: Due to the different geographical distribution of the formations, the definition of a complete type section of the Eggenburg Group is impossible. There are only few outcrops in the surroundings of Eggenburg, where several formations (e.g., Burgschleinitz Formation (with Kühnring Member), Gauderndorf Formation, Zogelsdorf Formation) occur together (e.g., Maigen sandpit Stranzl (N 48°40′28″ / E 15°46′51″; STEININGER, 1977b, 1983; STEININGER et al., 1991a); Kühnring municipal sandpit (N 48°37′47″ / E 15°47′35″; STEININGER et al., 1991b); Limberg Hengl quarry (N 48°36′02″ / E 15°51′07″; ROETZEL et al., 1999f)); ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn).

Reference section(s): -

Derivation of name: Named after Eggenburg, a town c. 12 km ESE of the town Horn, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Horner Schichten, Erste Mediterran-Stufe, Burdigal (von Eggenburg), Eggenburger Serie, Eggenburger Schichten s.l., Eggenburg-Formation.

Originally, these sediments in the surroundings of Eggenburg and Horn were summarized by ROLLE (1859) to the “Horner Schichten” and subsequently FUCHS (1877) added the term “Erste Mediterran-Stufe”. Later on, also designations like “Burdigal (von Eggenburg)”, “Eggenburger Serie”, “Eggenburger Schichten s.l.” or “Eggenburg-Formation” were used (SCHAFFER & GRILL, 1951; STEININGER & SENEŠ, 1971; STEININGER, 1983).

Lithology: Due to their nearshore depositional environment, sediments of the Eggenburg Group are mainly detritic and fossiliferous, coarse to fine sandy deposits, locally with gravelly intercalations. In basal positions, silts and clays with badly sorted sandy intercalation may occur. In top positions, variously consolidated fossil-bearing siliciclastic limestones mark a new transgressive cycle above a distinct discordance.

Fossils: Most of the sediments of the Eggenburg Group are characterised by highly diverse and excellently preserved molluscan faunas. Additionally, the marine vertebrate fauna (fish-teeth, bones of dolphins, whales, crocodiles, turtles, sea cows) as well as micromammals and rare remnants of an anthracothere are noteworthy. Furthermore, in some parts echinoderms, foraminifers, ostracods, otoliths, and trace fossils are frequent. In the Zogelsdorf Formation and Retz Formation bryozoans, coralline red algae, barnacles, calcitic bivalves, echinoderms as well as serpulids dominate.

Origin, facies: The Eggenburg Group subsumes the sediments of the shallow marine marginal Eggenburgian to early Ottnangian Sea. They predominantly originate from littoral environments, partly with brackish-estuarine to terrestrial influence. Due to a complex paleotopography in the type region a multitude of different and locally controlled lithofacies and biofacies occur, laterally interfingering with each other. Additionally, the transgressive character of the Eggenburgian sediments caused a heterochronous onset on the crystalline base (Text-Fig. 5).

The gradual flooding of the crystalline margin during the Eggenburgian and early Ottnangian from southeast towards northwest is expressed by position and facies of the different formations combined with a decreasing age. Early in the transgression (early Eggenburgian), marine flooding started at the southern marginal zone with the Fels Formation, while in the Horn Basin an estuarine environment developed (Mold Formation). Afterwards, due to transgression, a fully marine environment was installed in the Horn Basin (Loibersdorf Formation). In a final step (late Eggenburgian), the sea reached the Eggenburg Bay, where deposits again differentiated into several facies-types, expressed in lithostratigraphic units (Kühnring Member, Burgschleinitz Formation, Gauderndorf Formation).

Interrupted by a distinct regression in the latest Eggenburgian a new transgression is marked by the discordantly following bryozoan-coralline algae limestones of the Zogelsdorf Formation. Basinward, these siliciclastic limestones are interfingering with the pelitic deeper-water facies of the upper Eggenburgian and Ottnangian Zellerndorf Formation. Towards the north and northwest in the Ottnangian, the transgression upon the Bohemian Massif continues with the lithofacies of the Burgschleinitz Formation and in the Retz area with the mixed siliciclastic-carbonatic lithofacies of the Retz Formation.

Chronostratigraphic age: Early Miocene, early to middle Burdigalian (Eggenburgian–early Ottnangian).

In terms of sequence stratigraphy and sea level changes, the general stratigraphic development of the Eggenburg Group coincides with three 3rd order sea level changes. According to PILLER et al. (2007) these can be correlated with the Aq 2 lowstand, marking the base of the Eggenburgian, Aq 3/Bur 1 and Bur 2, and end with the Bur 3 lowstand (top Eggenburgian/base Ottnangian) of HARDENBOL et al. (1998). However, it has to be discussed, if the base of the Eggenburgian correlates with the Aq 3/Bur 1 lowstand instead of the Aq 2 lowstand.

Biostratigraphy: In the Eggenburg Group calcareous nannoplankton clearly indicates nannofossil Zones NN2 and NN3 (STEININGER et al., 1976; ROETZEL et al., 1999a). The mammal fauna places it into the European land mammal Zone MN3 (basal Orleanian), which allows a direct correlation with the basal Burdigalian (MEIN, 1989; STEININGER et al., 1996; STEININGER, 1999). Moreover, the exceptionally preserved and highly diverse molluscan faunas allow a detailed correlation of the formations (STEININGER, 1963b; ROETZEL et al., 1999a; MANDIC & STEININGER, 2003; MANDIC et al., 2004). The dating corresponds with the pollen-flora of the Neogen pollen Zone Ng.Z.II (HOCHULI, 1978), and is also supported by the ostracod-faunas (ZORN, 1999a).

Thickness: Due to the marginal position of the different formations of the Eggenburg Group, the thickness of the shallow marine deposits is generally low. Normally it amounts several meters to some tens of meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Eggenburg Group includes the Fels Formation, Mold Formation, Loibersdorf Formation, Burgschleinitz Formation with Kühnring Member, Gauderndorf Formation, Zogelsdorf Formation, and Retz Formation.

Underlying units: In the Horn Basin, sediments of the Eggenburg Group (Mold Formation) are transgressively developing from Paleogene fluvial-lacustrine and estuarine sediments of the St. Marein-Freischling Formation. Between Grübern and Obernholz time-equivalent deposits of the Ravelsbach Formation lie below. In most of the other distribution areas they are following above crystalline basement rocks (see description of formations).

Overlying units: At the outer rim of the Eggenburg Bay as well as in small areas inside the bay the topmost part of the Eggenburg Group (Zogelsdorf Formation) is overlain by the Ottnangian Zellerndorf Formation (Text-Fig. 5). This superposition of the pelitic deep-water facies above the siliciclastic limestone facies is also proven by drillings east of the spur of the Bohemian Massif. Around Fels am Wagram and Obernholz a pelitic facies, comparable in lithology and facies to the Zellerndorf Formation, tops the Fels Formaton, but was probably deposited already in the early to late Eggenburgian. Additionally, south of Grübern these clayey silts occur below the Zogelsdorf Formation (Roetzel, 2017).

Lateral units: Besides lateral interfingering of different formations within the Eggenburg Group also an interfingering of the Zogelsdorf Formation (topmost Eggenburg Group) and the Zellerndorf Formation is recognized in some areas inside the Eggenburg Bay.

Geographic distribution: Sediments of the Eggenburg Group are widespread in Lower Austria, occurring north of the Danube along the southeastern margin of the Bohemian Massif. They widely occur in the surroundings of Eggenburg and Retz as well as around Fels am Wagram and in the southern Horn Basin; ÖK50-UTM, map sheets 4306 Langau, 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 8 Geras, 9 Retz, 21 Horn, 22 Hollabrunn, 38 Krems an der Donau).

Remarks: -

Complementary references: -

Fels-Formation (Eggenburg-Gruppe) / Fels Formation (Eggenburg Group)

Reinhard Roetzel

Validity: Valid; Steininger & Roetzel (1991) defined these sediments as "Fels-Formation" which later on was specified in Roetzel et al. (1999a).

Type area: The area north of Fels am Wagram, c. 17 km ENE of the city Krems an der Donau, can be regarded as type area.

Type section: Not defined; the "Dornergraben", a gully about 2 km north of Fels am Wagram (N 48°27′20.5″ / E 15°48′53″), could be regarded as type section of the Fels Formation (Steininger, 1963b, 1971: p. 157ff.). In this outcrop, the lower boundary is exposed; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 38 Krems an der Donau).

Reference section(s): As reference section the abandoned sandpit in Obernholz (N 48°30′50″ / E 15°44′16″) (Steininger, 1977d, 1968b, 1983; Steininger et al., 1991d) can be considered, where the lower boundary is exposed. The upper boundary of the Fels Formation is cropping out in a small sandpit south of Gösing am Wagram (N 48°27′40″ / E 15°48′43″) and in vineyards around Gösing am Wagram and Feuersbrunn (e.g., N 48°27′53″ / E 15°47′57.5″); ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 38 Krems an der Donau).

Derivation of name: Named after Fels am Wagram, a village about 12 km ESE of Langenlois, and 17 km ENE of the city of Krems an der Donau, Lower Austria; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 38 Krems an der Donau).

Synonyms: Felser Sande, Sande von Fels am Wagram, Felser/Loibersdorfer Schichten.

Sediments from the area of Fels am Wagram were already mapped by Cžjžek (1849b) and described by Schaffer (1914). Later on, these sands and their fauna were characterized in detail by Steininger (1963b, 1971: p. 157ff.) and named "Sande von Fels am Wagram". By Steininger (1983) the sediments were also called "Felser Sande" and "Felser/Loibersdorfer Schichten", respectively.

Lithology: The Fels Formation mainly consists of fossiliferous, well-sorted, coarse, medium and fine sands and sandstones with coarse gravelly layers, in some parts showing a distinct fining upward succession.

Fossils: The Fels Formation is dominated in the basal coarse parts by thick-shelled, shallow infaunal forms, such as *Glycymeris fichteli*, *Rudicardium grande, Discors spondyloides*, *Arctica girondica*, *Macrocallista lillacinoides*, and *Aporrhais speciosus*. This fauna is replaced in the fine sands above by thin-shelled deep infaunal species, like *Angulus* (*Peronidia*) *nysti*, *Lucinoma barrandei,* and *Panopea menardi* (Schaffer, 1910, 1912; Steininger, 1963b; Mandic & Steininger, 2003). Furthermore, ostracods, echinoderms, and trace fossils are very frequent in the sands (Kollmann in Steininger, 1963b; Steininger et al., 1991d).

Origin, facies: The Fels Formation is a fully marine littoral to shallow sublittoral succession, which is passing into pelitic open marine marls (Zellerndorf Formation) due to the transgression of the Eggenburgian Sea. The deepening upward is also documented by the mollusc assemblages in the sands.

Chronostratigraphic age: Early Miocene, late Aquitanian? to early Burdigalian (late Egerian? to early Eggenburgian).

Biostratigraphy: By Oligocene relict species such as *Aporrhais speciosus* in the gastropod-fauna and by the occurrence of the bivalves *Oopecten gigas plana* and *Rudicardium grande* the Fels Formation is restricted to the lowermost Eggenburgian (Roetzel et al., 1999a; Mandic & Steininger, 2003). The early Eggenburgian age is also proved by ostracods (Kollmann in Steininger, 1963b; Zorn, 1993).

Thickness: The thickness of the Fels Formation is about 5–10 m.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: -

Underlying units: The sediments of the Fels Formation mostly transgress upon the crystalline basement of the Bohemian Massif. In some parts, like in the Obernholz area, they are also concordantly following on top of the Ravelsbach Formation (formerly considered as St. Marein-Freischling Formation; Steininger et al., 1991d; Nehyba & Roetzel, 2010).

Overlying units: The Fels Formation is passing into pelitic sediments of the Eggenburgian part of the Zellerndorf Formation. In some parts, like in the Obernholz area, it is discordantly overlain by gravel and sands of the Hollenburg-Karlstetten Formation. However, in most areas Pleistocene sediments like loess cover the Fels Formation.

Lateral units: -

Geographic distribution: The sandy sediments of the Fels Formation are only distributed in Lower Austria in the area between Fels am Wagram and Obernholz, NE of Krems; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 38 Krems an der Donau). In the area east of Melk fossiliferous sandstone-boulders of the Fels Formation are reworked in debris of the Ottnangian Mauer Formation (AMRY, 1994; KRENMAYR, 2003a, b); ÖK50-UTM, map sheets 4323 Sankt Pölten, 4329 Wilhelmsburg (ÖK50-BMN, map sheet 55 Ober-Grafendorf).

Remarks: -

Complementary references: STEININGER (1977a).

Mold-Formation (Eggenburg-Gruppe) / Mold Formation (Eggenburg Group)

REINHARD ROETZEL

Validity: Valid; STEININGER & ROETZEL (1991) defined these sediments as "Mold-Formation" which was later on specified in ROETZEL et al. (1999a).

Type area: The area northeast of the village Mold and the settlement around the pilgrimage church Maria Dreieichen can be regarded as type area.

Type section: Not defined; due to the lack of any good outcrop in the Mold Formation, no type section was defined so far. However, as informal type section of this formation the so-called "Kirchensteig" can be considered, a field path from Mold to the pilgrimage church of Maria Dreieichen. Along this path the Mold Formation crops out in the fields west and southeast of the water reservoir (N 48°38′51″ / E 15°42′47.1″) (STEININGER, 1971: p. 112ff.; cf. SUESS, 1866a). Lower and upper boundaries do not outcrop but were accessible during an excavation in the late 1990s (MANDIC et al., 1999); ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Reference section(s): Not defined; as reference section can be regarded the clay pit Maiersch (Frings), c. 2 km ENE of Maiersch (N 48°34′52″ / E 15°42′36″). Although this clay pit is already abandoned, it is described in detail in STEININGER (1976, 1977e, 1983) and STEININGER et al. (1991c). In this clay pit, the lower boundary formerly was cropping out. The lower boundary on top of the St. Marein-Freischling Formation can also be studied in a small abandoned sandpit SE of Mold (N 48°38′22″ / E 15°43′08″); ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: From the small village Mold (old name: Molt), c. 4 km SE of the town Horn and c. 8 km WNW of the town Eggenburg, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Schichten von Molt, Molter Schichten, Molder Schichten.

The sediments were first named by SUESS (1866a) as "Schichten von Molt". Later on they were described in detail by SCHAFFER (1914) and STEININGER (1971: p. 112ff., 1983), who mainly used the name "Molter Schichten".

Lithology: The Mold Formation mainly consists of silts and clays with coaly seams and intercalations of fine to medium sands, which sometimes are badly sorted and clayey.

Fossils: In the Mold Formation mainly bivalves and gastropods which are tolerating different salinity ranges can be found, e.g., *Tympanotonos margaritaceum, Granulolabium plicatum, Turritella terebralis, Protoma cathedralis, Agapilia picta, Duplicata haueri, Ocinebrina schoenni, Anadara moltensis, Perna aquitanica,* and *Crassostrea gryphoides*. Molluscs such as *Melanopsis impressa, Polymesoda subarata sowerbii,* and *Mytilopsis basteroti* are evidence of a fluvial influence (SCHAFFER, 1910, 1912; STEININGER, 1971; MANDIC & STEININGER, 2003; MANDIC et al., 2004). The pollen-flora of the Mold Formation was described by HOCHULI (1978) and DRAXLER (1991).

Origin, facies: The sediments of the Mold Formation originate from a brackish estuarine environment with different salinity ranges from freshwater to marine. From the mollusk fauna, rich in individuals and poor in species, a eutrophic environment on intertidal mudflats and muddy coasts of an estuary or lagoon can be supposed. From the pollen-flora an annually very warm and humid climate can be assumed (MANDIC et al., 1999).

Chronostratigraphic age: Early Miocene, late Aquitanian? to early Burdigalian (late Egerian? to early Eggenburgian).

Biostratigraphy: HOCHULI (1978) dated the pollen-flora from the Mold Formation to the Neogen palaeofloral Zone Ng.Z.II, which can be correlated with the late Egerian to early Eggenburgian. This correlation is also supported by the mollusc fauna (STEININGER & ROETZEL, 1991; ROETZEL et al., 1999a).

Thickness: The thickness of the Mold Formation is about 5–20 m.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: -

Underlying units: The pelitic sediments of the Mold Formation are following upon the St. Marein-Freischling Formation, from which they gradationally pass.

Overlying units: The Mold Formation is gradationally passing into the Loibersdorf Formation above. In many locations also Pleistocene sediments cover the formation.

Lateral units: In some cases, an interfingering of the Mold Formation with the St. Marein-Freischling Formation as well as with the Loibersdorf Formation can be assumed.

Geographic distribution: The pelitic sediments of the Mold Formation can exclusively be found in the southern part of the Horn Basin (ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Remarks: -

Complementary references: STEININGER (1977a).

Loibersdorf-Formation (Eggenburg-Gruppe) / Loibersdorf Formation (Eggenburg Group)

REINHARD ROETZEL

Validity: Valid; STEININGER & ROETZEL (1991) defined these sediments as "Loibersdorf-Formation" which was later on specified in ROETZEL et al. (1999a).

Type area: The area east of the hamlet Loibersdorf can be regarded as type area.

Type section: Not defined; informally, an abandoned sandpit about 500 m ENE of Loibersdorf (N 48°36′36.3″ / E 15°43′26.6″) (STEININGER, 1971: p. 105ff.) can be regarded as type section of the Loibersdorf Formation. Lower and upper boundaries are not exposed there. This locality was also designated as the holostratotype of the Eggenburgian stage (STEININGER, 1971: p. 105ff.); ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Reference section(s): A small sandpit in the forest ("Oberer Molder Berg") c. 1.6 km NNW of Maria Dreieichen (N 48°39′53″ / E 15°42′39″) can be considered as reference section of the Loibersdorf Formation ("Scutellensande": KÜHN, 1936; STEININGER, 1971: p. 115ff.); ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: Named after the hamlet Loibersdorf, c. 8 km SSE of the town Horn and c. 5 km ENE of the market town Gars am Kamp, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Sand von Loibersdorf, Schichten von Loibersdorf resp. Loibersdorfer Schichten, Felser-Loibersdorfer Schichten, Scutellensande, and Lithothamnienkalk.

The sediments were first named by SUESS (1866a) as "Schichten von Loibersdorf". Later on ABEL (1898a, b) used the name "Loibersdorfer Schichten" also for the sands in the Eggenburg Bay, which were then separated by FUCHS (1900) as "Liegendsande" (synonym for Burgschleinitz Formation).

Lithology: The Loibersdorf Formation is made up of mostly planar-bedded, micaceous, fine to coarse sands with gravelly layers, showing an overall fining upward succession. In its upper part the fine sands alternate with coralline red algal limestone layers.

Fossils: From the Loibersdorf Formation a very diverse, large-sized and thick-shelled molluscan fauna is well known (SCHAFFER, 1910, 1912; STEININGER, 1971; MANDIC & STEININGER, 2003; MANDIC et al., 2004). Frequently, the bivalves, such as *Laevicardium kuebecki, Anadara fichteli, Glycymeris fichteli, Acanthocardia moeschana, Macrocallista lilacinoides, Panopea menardi,* or *Oopecten gigas gigas* are concentrated in coquinas. From the so called "Scutellensande" echinoderms and limestones with coralline red algae were reported (KÜHN, 1936; SCHAFFER, 1962; STEININGER, 1971: p. 115ff.; NEBELSICK, 1989a).

Origin, facies: The sands of the Loibersdorf Formation were settled in a fully marine littoral to shallow sublittoral warm environment, arising from an estuarine environment due to the transgression into the Horn Basin from the south. Numerous interstratified coquinas give evidence of reworking during heavy storms (MANDIC et al., 2004). In the upper parts of the formation, oysters and echinoderms, such as sand-dollars, provide hardgrounds for coralline red algae biostromes.

Chronostratigraphic age: Early Miocene, Burdigalian (early Eggenburgian).

Biostratigraphy: Based on the presence of giant-sized bivalve species and the index fossils *Oopecten gigas gigas* and *Laevicardium kuebecki* the Loibersdorf Formation can be correlated to the upper part of the lower Eggenburgian (ROETZEL et al., 1999a; MANDIC & STEININGER, 2003; MANDIC et al., 2004).

Thickness: The Loibersdorf Formation is in the Horn Basin between 20 and 30 m thick.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: -

Underlying units: The sands of the Loibersdorf Formation gradationally pass from the underlying Mold Formation. In some parts they also directly transgress on the crystalline basement of the Bohemian Massif, where gravelly sands prevail.

Overlying units: On top of the Loibersdorf Formation mainly Pleistocene sediments are preserved. In rare cases also limestones of the Zogelsdorf Formation follow above.

Lateral units: The Loibersdorf Formation, in parts, laterally interfinger with the Mold Formation.

Geographic distribution: The sandy sediments of the Loibersdorf Formation can be found exclusively in the southern part of the Horn Basin; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Remarks: -

Complementary references: STEININGER (1977a).

Burgschleinitz-Formation (Eggenburg-Gruppe) / Burgschleinitz Formation (Eggenburg Group)

REINHARD ROETZEL

Validity: Valid; STEININGER & ROETZEL (1991) designated these sediments as "Burgschleinitz-Formation" which was later on specified in ROETZEL et al. (1999a).

Type area: The main distribution area of the Burgschleinitz Formation is the Eggenburg Bay in the surroundings of the town Eggenburg and the market town Burgschleinitz which can be regarded as type area.

Type section: Not defined; informally, the abandoned sandpit "Kirchenbruch", 150 m SSE of the church of the market town Burgschleinitz (N 48°36′17″ / E 15°48′58″) can be regarded as type section for the Burgschleinitz Formation (ROETZEL et al., 1991e; cf. SCHAFFER, 1914: p. 90ff.; PERVESLER et al., 2011). In this outcrop the upper and lower boundaries are exposed; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn).

Reference section(s): As reference sections with different facies types of the Burgschleinitz Formation can be regarded: Maigen sandpit Stranzl (abandoned) (N 48°40′28″ / E 15°46′51″; STEININGER, 1977b: p. 59ff., 1983; STEININGER et al., 1991a); Kühnring municipal sandpit (N 48°37′47″ / E 15°47′35″; STEININGER et al., 1991b); Limberg Hengl quarry (N 48°36′02″ / E 15°51′07″; ROETZEL et al., 1999e). The upper and lower boundaries are exposed in Maigen sandpit Stranzl and Limberg Hengl quarry, in Kühnring municipal sandpit only the upper boundary crops out; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: From Burgschleinitz, a market town 4 km S of the town Eggenburg and 4 km N of the town Maissau, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Loibersdorfer Schichten (in the area of Eggenburg), Liegend-Sande, Liegendsande, Liegendschichten, Liegendsandstein, Patellensande von Roggendorf, Grobsandentwicklung von Burgschleinitz, Basale Grobsande.

In first descriptions these sediments were combined with the "Schichten von Loibersdorf" in the Horn Basin (SUESS, 1866a; ABEL, 1897, 1898b). By FUCHS (1900) the sands in the Eggenburg Bay were considered separately and nominated as "Liegend-Sande". Later on, the "Liegendsande" together with the "Liegendtegel" were also summarized as "Liegendschichten" (SCHAFFER, 1914). A special facies type was described as "Patellensande von Roggendorf" (SCHAFFER, 1913). STEININGER (1971) characterized the coarse sands from Burgschleinitz as "Grobsandentwicklung von Burgschleinitz" or generally as "Basale Grobsande" (STEININGER, 1983).

Lithology: The Burgschleinitz Formation is characterized by an alternation of moderately to poorly sorted, coarse to fine sands with gravelly intercalations. These sands can laterally pass into muddy sands and silts (Kühnring Member).

Fossils: In the Burgschleinitz Formation thick-shelled and large-sized molluscs from marine, littoral to shallow sublittoral environments are typical, such as *Glycymeris fichteli*, *Isognomon rollei*, *Gigantopecten holgeri*, *Pecten pseudobeudanti*, *Ostrea lamellosa*, *Pelecyora* (*Cordiopsis*) *incrassata*, *Pelecyora* (*Cordiopsis*) *schafferi*, *Paphia* (*Callistotapes*) *benoisti praecedens*, *Lutraria sanna*, and *Protoma cathedralis* (SCHAFFER, 1910, 1912; STEININGER, 1971; MANDIC & STEININGER, 2003). Additionally, remnants of vertebrates like fish-teeth (sharks, breams, rays) and bones of dolphins (*Schizodelphis sulcatus*), whales, crocodiles (*Gavialosuchus eggenburgensis*), turtles, sea cows (*Metaxytherium krahuletzi*), and the anthracothere *Brachyodus onoideus* occur (TOULA & KAIL, 1885; NEUMAYR, 1888; DEPÉRET, 1895; ABEL, 1904a; SCHAFFER, 1925; BRZOBOHATÝ & SCHULTZ, 1971; DAXNER-HÖCK, 1971; STEININGER, 1971: p. 134ff., 146ff., 154ff.; PERVESLER et al., 1995; DOMNING & PERVESLER, 2001). Furthermore, trace fossils are very frequent (EHRENBERG, 1938; HOHENEGGER & PERVESLER, 1985; PERVESLER et al., 2011).

Origin, facies: The marine sediments of the Burgschleinitz Formation are mainly deposited in wave- and storm-dominated littoral to shallow sublittoral environments. In open marine sites, basal conglomerates with granitic boulders and cobbles are frequent. Generally, lithofacies and biofacies of the Burgschleinitz Formation are very variable and inconstant, depending on multiple local factors, like paleorelief, water depth, paleocurrents, etc.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian to ?early Ottnangian).

Biostratigraphy: The sediments of the Burgschleinitz Formation (and the Kühnring Member) are dated by their mammal fauna to the European land mammal Zone MN3 (basal Orleanian), which allows a direct correlation with the basal Burdigalian (MEIN, 1989; STEININGER et al., 1996; STEININGER, 1999). Moreover, the Burgschleinitz Formation can be placed into the late Eggenburgian by the presence of Burdigalian, Mediterranean-type pectinid species such as *Gigantopecten holgeri* and *Flexopecten palmatus*. Additionally, it can be separated from the early Eggenburgian Loibersdorf Formation by the absence of the Paratethys endemic species and early Eggenburgian index fossil *Oopecten gigas* (MANDIC & STEININGER, 2003).

Thickness: In most occurrences the thickness of the Burgschleinitz Formation amounts to several meters but does not exceed 10 m.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: Badly sorted silts, sands and gravel of the Kühnring Member locally represent the basal part of the Burgschleinitz Formation.

Underlying units: In most cases the Burgschleinitz Formation transgresses directly upon the crystalline basement of the Bohemian Massif.

Overlying units: In the central Eggenburg Bay, the Burgschleinitz Formation is usually concordantly overlain by the Gauderndorf Formation. In those parts of the bay, where the Gauderndorf Formation is not developed, the Zogelsdorf Formation frequently follows discordantly above.

Additionally, in the areas around Theras and Weitersfeld, north and northwest of the Eggenburg Bay, a lithofacies similar to the Burgschleinitz Formation is distributed, following above the crystalline basement. In these areas the Ottnangian Zellerndorf Formation resp. Weitersfeld Formation superimposes concordantly the Burgschleinitz Formation.

Lateral units: In some areas the top parts of the Burgschleinitz Formation laterally interfinger with the Gauderndorf Formation.

Geographic distribution: The lithofacies of the Burgschleinitz Formation is widespread in the Eggenburg Bay in the wider surroundings of Eggenburg, but is also reaching as far as Weitersfeld and the Basin of Obermarkersdorf in the north and to Maissau and Grübern in the south; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 8 Geras, 9 Retz, 21 Horn, 22 Hollabrunn).

Remarks: In the areas around Theras and Weitersfeld sediments similar to the Burgschleinitz Formation occur, concordantly overlain by the Ottnangian Zellerndorf resp. Weitersfeld Formation. Due to the advancing gradual flooding towards the west and northwest, a continuous sedimentation of the Burgschleinitz Formation without discordance up to the Ottnangian seems possible.

Complementary references: -

Kühnring-Subformation (Burgschleinitz-Formation, Eggenburg-Gruppe) / Kühnring Member (Burgschleinitz Formation, Eggenburg Group)

Reinhard Roetzel

Validity: Valid; Steininger & Roetzel (1991) defined these sediments as "Kühnring-Subformation" (Kühnring Member) which was specified in Roetzel et al. (1999a).

Type area: The area northwest of Kühnring, along the road to Horn, can be regarded as type area.

Type section: Not defined; informally, for the Kühnring Member the locality "Judenfriedhof", a gully and the nearby ditch of the road to Horn, about 1 km WNW of Kühnring (N 48°38′11″ / E 15°46′11″), can be regarded as type section (Steininger, 1971: p. 130ff.; cf. Fuchs, 1868, 1900; Schaffer, 1914). In this outcrop only the upper boundary is exposed; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Reference section(s): As reference section a historical water tunnel ("Brunnstubenstollen", "Raimundstollen") in the southern part of the town Eggenburg (between N 48°38′19.6″ / E 15°49′03.5″ and N 48°38′08.6″ / E 15°49′03.7″) can be considered (Abel, 1898b; Fuchs, 1900; Schaffer, 1914). Here the upper and lower boundaries are exposed, too; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: From Kühnring, a market town 2.5 km SW of the town Eggenburg, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: (dunkel)blauer Tegel or Mergel, Liegendtegel, Molter Schichten (in der Eggenburger Bucht), Crassostreen-Schichten von Kühnring.

The pelitic sediments at the base of the Eggenburgian sequence in the surroundings of Eggenburg were first named "(dunkel)blaue Tegel" or "Liegendtegel" (Fuchs, 1900). Later on they were correlated with the "Molter Schichten" (Mold Formation) in the Horn Basin. By Steininger (1971) they were called "Crassostreen-Schichten von Kühnring", because of their mass-occurrences of oysters.

Lithology: The sediments of the Kühnring Member consist of badly sorted, fossiliferous silt and clay alternating with muddy sand and gravel.

Fossils: The low diversity and specimen-rich molluscan fauna of the Kühnring Member is characterized by large *Crassostrea gryphoides* reefs, together with *Perna aquitanica* beds and dense *Granulolabium* accumulations (Schaffer, 1910, 1912; Steininger, 1971; Mandic & Steininger, 2003). Comparably, the foraminifer assemblage also shows a low diversity (Tollmann, 1957). Furthermore, from the Kühnring Member some of the terrestrial vertebrates of the Eggenburg Group like the anthracothere *Brachyodus onoideus* (Daxner-Höck, 1971) as well as a remarkable micromammal fauna (Mein, 1989) originate from these sediments. Brzobohatý (1989) described a rich and diverse otolith fauna (Brzobohatý & Schultz, 1971).

Origin, facies: The sediments of the Kühnring Member were deposited in marine to brackish influenced, sheltered intertidal and lagoonal subtidal environments of small estuaries. The low diversity molluscan fauna indicates fluctuating water salinity.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian).

Biostratigraphy: The most important biostratigraphic data for the Eggenburgian sediments comes from the mammal fauna of the Kühnring Member, dating to the European land mammal Zone MN3 (basal Orleanian), which allows a direct correlation with the basal Burdigalian (Mein, 1989; Steininger et al., 1996; Steininger, 1999). This dating corresponds with the pollen-flora from the Neogen palaeofloral Zone Ng.Z.II (Hochuli, 1978) and the calcareous nannoplankton, dating to the Zones NN2–NN3 (Müller in Steininger, 1979).

Thickness: Mostly the thickness of the Kühnring Member does not exceed 5 m.

Lithostratigraphically higher rank unit: Burgschleinitz Formation (Eggenburg Group).

Lithostratigraphic subdivision: -

Underlying units: The sediments of the Kühnring Member are always deposited upon the crystalline basement of the Bohemian Massif.

Overlying units: In most cases the Kühnring Member is passing into the sandy part of the Burgschleinitz Formation.

Lateral units: Southeast to west of Klein-Meiseldorf the Kühnring Member is laterally interfingering with sandy and gravelly fluvial-estuarine sediments of a so far unnamed formation, which spreads towards Rodingersdorf in the northwest, connected with the incised valley of Geras-Langau.

Geographic distribution: Sediments of the Kühnring Member can mainly be found in the surroundings of Eggenburg, such as in Sigmundsherberg, Maigen, Klein-Meiseldorf, Engelsdorf, Kühnring, and Eggenburg; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Remarks: -

Complementary references: -

Gauderndorf-Formation (Eggenburg-Gruppe) / Gauderndorf Formation (Eggenburg Group)

Reinhard Roetzel

Validity: Valid; the term "Gauderndorf-Formation" was first established by Steininger & Roetzel (1991) and specified in Roetzel et al. (1999a).

Type area: The area between the villages Gauderndorf and Kattau, north of the town Eggenburg, can be regarded as type area.

Type section: Not defined; informally, the former sandpit "Zimmermann" in the village Gauderndorf can be regarded as type section for the Gauderndorf Formation (N 48°39′26.9″ / E 15°49′32.1″; Steininger, 1971: p. 139ff.). The sandpit at the southeastern outskirts of Gauderndorf, east of the road to Eggenburg, is now abandoned and inaccessible. However, a section at the former entrance is still accessible. In this outcrop are the lower and upper boundary of the Gauderndorf Formation exposed; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Reference section(s): As reference sections can be considered: Maigen sandpit Stranzl (abandoned) (N 48°40′28″ / E 15°46′51″; STEININGER, 1977b: p. 59ff., 1983; STEININGER et al., 1991a). Kühnring municipal sandpit (N 48°37′47″ / E 15°47′35″; STEININGER et al., 1991b), Burgschleinitz Kirchenbruch (N 48°36′17″ / E 15°48′58″; ROETZEL et al., 1991e). In Maigen sandpit Stranzl and Kühnring municipal sandpit the lower and upper boundaries are exposed, in Burgschleinitz Kirchenbruch only the lower boundary; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: From Gauderndorf, a village 2 km N of the town Eggenburg, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Niveau von Gauderndorf, Gauderndorfer Niveau, Mugelsand(e) (von Gauderndorf), Tellinensande (von Gauderndorf), Schichten von Gauderndorf, Gauderndorfer Schichten, Gauderndorfer Sande.

The sediments were first named by SUESS (1866b) as "Schichten von Gauderndorf". Also the terms "Niveau von Gauderndorf" or "Gauderndorfer Schichten" were used. Due to common concretions in the sediments they were also called "Mugelsande" and the most frequent bivalve led to the name "Tellinensande" (STEININGER, 1971: p. 139ff.).

Lithology: Sediments of the Gauderndorf Formation are fine sands and silts with rare thin gravelly layers, frequently with irregular concretions.

Fossils: The typical mollusc assemblage of the Gauderndorf Formation is dominated by thin-shelled, deep infaunal, sublittoral bivalves, such as *Angulus* (*Peronea*) *zonarius*, *Pharus saucatsensis*, and *Solen marginatus*. Sublittoral, shallow infaunal species such as *Mactra bucklandi* and *Pelecyora* (*Cordiopsis*) *incrassata* are commonly present as well (SCHAFFER, 1910, 1912; STEININGER, 1971: p. 139ff.; MANDIC & STEININGER, 2003). Compared to the other formations of the Eggenburg Group the foraminifer and ostracod assemblages of the Gauderndorf Formation are more divers (TOLLMANN, 1957).

Origin, facies: The fine sands and silts of the Gauderndorf Formation originate from a shallow marine, sublittoral environment, deposited at calm, protected, muddy grounds of the Eggenburg Bay. The sediments reflect the deepening, maximal flooding and gradual infill of the accommodation space during the Eggenburgian transgression in this bay.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian).

Biostratigraphy: In the Eggenburg Bay, the Gauderndorf Formation represents a unique litho- and biofacies without any biostratigraphic relevant fauna. However, due to the clear relation to the sediments of the Burgschleinitz Formation the same age can be assumed.

Thickness: The thickness of the Gauderndorf Formation averages usually several meters, however, in the town Eggenburg it is up to about 15 m.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: -

Underlying units: Usually, the Gauderndorf Formation is concordantly overlying the Burgschleinitz Formation. In few areas, they lie directly upon the crystalline basement.

Overlying units: The Gauderndorf Formation is very often discordantly overlain by the Zogelsdorf Formation, besides Pleistocene deposits.

Lateral units: There are evidences that the Gauderndorf Formation is laterally interfingering with the Burgschleinitz Formation.

Geographic distribution: The fine sandy sediments of the Gauderndorf Formation occur only in the surroundings of Eggenburg, in the area between Kattau, Maigen, Gauderndorf, Eggenburg, Kühnring, and Burgschleinitz; ÖK50-UTM, map sheet 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn).

Remarks: -

Complementary references: STEININGER (1977a).

Zogelsdorf-Formation (Eggenburg-Gruppe) / Zogelsdorf Formation (Eggenburg Group)

REINHARD ROETZEL

Validity: Valid; the "Zogelsdorf-Formation" was established by NEBELSICK (1989a, b).

Type area: The type area of the Zogelsdorf Formation is located west of the village Zogelsdorf, between the village and the old big quarries ("Waldbruch").

Type section: For the Zogelsdorf Formation the locality Zogelsdorf-Johannesbruch is defined as type section (N 48°37′12″ / E 15°48′38″) (NEBELSICK, 1989a, b; NEBELSICK et al., 1991a). The lower and upper boundary does not occur in this outcrop; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn) .

Reference section(s): For the Zogelsdorf Formation the following sections can be regarded as reference sections: Eggenburg-Brunnstube (N 48°38′09″ / E 15°49′04″; STEININGER, 1971: p. 119ff.; 1977c: p. 65 ff.; 1983; NEBELSICK et al., 1991b), Maigen sandpit Stranzl (abandoned) (N 48°40′28″ / E 15°46′51″; STEININGER, 1977b: p. 59ff., 1983; STEININGER et al., 1991a), Groß-Reipersdorf Hatei quarry (N 48°41′10.6″ / E 15°51′30.8″; NEBELSICK et al., 1991c). In Eggenburg-Brunnstube and Maigen sandpit Stranzl is the lower boundary and in Groß-Reipersdorf Hatei quarry the upper boundary of the Zogelsdorf Formation exposed; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn).

Derivation of name(s): From the village Zogelsdorf, 3 km S of the town Eggenburg and 5 km N of the town Maissau, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: Nulliporenkalk, Molassesandstein, Brunnstubensandstein, Schichten von Eggenburg, Eggenburger Schichten, Pectenschichten von Eggenburg, Zogelsdorfer Stein, Zogelsdorfer Sandstein.

The Zogelsdorf Formation is equivalent to the sediments which SUESS (1866a: p. 114) defined as "Schichten von Eggenburg", and which were later on also called "Eggenburger Schichten" (e.g., STEININGER, 1977a) and "Zogelsdorfer Sandstein". It also includes the fossiliferous "Brunnstubensandstein" (ABEL, 1898a, b), which was earlier designated by ROLLE (1859) and SUESS (1866a) as "Molassesandstein" (STEININGER, 1977c).

Lithology: The Zogelsdorf Formation includes basal conglomerates, coarse sands, sandstones as well as variously consolidated poorly sorted coarse detritic coralline algae and bryozoan limestones. At the base above a distinct discordance and relief extensive reworking of basal Burgschleinitz and Gauderndorf Formation is, in some parts, visible. Close to crystalline elevations, the bioclastic limestones frequently include terrigenous components. The Zogelsdorf Formation shows a fining and deepening upward succession, passing upsection into the marine clays and marls of the Zellerndorf Formation but interfinger also laterally with them.

Fossils: The bioclastic limestones of the Zogelsdorf Formation are dominated by bryozoans, coralline red algae, barnacles, calcitic bivalves (*Pecten hornensis*, *Anomia*, *Ostrea*), echinoderms as well as serpulids (SCHAFFER, 1910, 1912; KÜHN, 1925a; VÁVRA, 1978b, 1979, 1981; NEBELSICK, 1989a, b; NEBELSICK et al., 1991a). In the foraminifer assemblages benthic forms prevail, reflecting different facies by their compositions (JENKE, 1993; cf. TOLLMANN, 1957). Aragonitic shelled organisms (gastropods, most bivalves) are rare or occur as impressions and steinkerns.

Origin, facies: Sediments of the Zogelsdorf Formation are nearshore deposits of a shallow marine sublittoral environment. In the Zogelsdorf Formation several microfacies types can be distinguished, reflecting an exposed coastal environment versus a protected bay-like area behind elevated islands (NEBELSICK, 1989a, b).

In the Eggenburg Bay, the Zogelsdorf Formation can be assumed as sublittoral sandy environment with secondary hardgrounds. NEBELSICK (1989a, b) interpreted the bioclastic limestones as temperate water carbonate deposits.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian–early Ottnangian).

The Zogelsdorf Formation is marked by a distinct hiatus at the base and represents within the Eggenburg Group a new marine ingression into the Eggenburg Bay. Within the Zogelsdorf Formation the boundary between Eggenburgian and Ottnangian can be supposed.

Biostratigraphy: The Zogelsdorf Formation is characterized by the first occurrence of *Pecten hornensis*. Therefore, latest Eggenburgian to earliest Ottnangian age is assumed (MANDIC & STEININGER, 2003).

Thickness: The thickness of the Zogelsdorf Formation is estimated to be at most around 10 m.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: -

Underlying units: Sediments of the Zogelsdorf Formation not only transgress discordantly over the Burgschleinitz Formation and Gauderndorf Formation, but also directly over the crystalline basement of the Bohemian Massif.

Overlying units: The Zogelsdorf Formation gradationally continues upward into the pelitic sediments of the Zellerndorf Formation and is in some parts also overlain by Pleistocene deposits.

Lateral units: There are indications that the Zogelsdorf Formation interfingers with the Zellerndorf Formation in deeper parts of the Eggenburg Bay as well as basinward towards the open marine environment in the east. It may also grade laterally into the Ritzendorf Formation (see Vienna Basin).

Geographic distribution: The limestones of the Zogelsdorf Formation are exposed in a number of outcrops and old quarries around Eggenburg and between Pulkau, Limberg, Maissau, and Grübern; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn).

Remarks: The limestones of the Zogelsdorf Formation were widely mined in open-pit mines in Baroque époque (17th to 18th century) and were used as building and sculpture stones until the beginning of the 20th century (KIESLINGER, 1935; GASPAR, 1995).

Complementary references: -

Retz-Formation (Eggenburg-Gruppe) / Retz Formation (Eggenburg Group)

REINHARD ROETZEL

Validity: Valid; the "Retz-Formation" was first used in the geological map sheets 22 Hollabrunn and 9 Retz (ROETZEL, 1998; ROETZEL et al., 1999c) and defined in ROETZEL et al. (1999a); cf. ROETZEL (2005).

Type area: The municipal area of Retz and the surroundings of the town can be regarded as type area.

Type section: Not defined; informally, the abandoned sandpit in the "Hungerfeld", 1 km south of the village Unternalb (N 48°43′46″ / E 15°57′10″) can be considered as type section of the Retz Formation (BERNHAUSER, 1955; KROH & HARZHAUSER, 1999). The lower and upper boundary does not occur in this outcrop; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 22 Hollabrunn).

Reference section(s): -

Derivation of name(s): Named after the town Retz, 16 km NE of the town Eggenburg, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 9 Retz).

Synonyms: Retzer Sande.

Primarily, the sands in the vicinity of Retz were included in the "Schichten von Eggenburg" by SUESS (1866b). Later on, they were defined as "Retzer Sande" (VETTERS, 1918; BERNHAUSER, 1955).

Lithology: The siliciclastic sediments of the Retz Formation are mainly coarse to fine sands with high portions of quartz, in some parts comparable to the Burgschleinitz Formation. However, in some areas intercalations of fossiliferous limestones show the lithological and chronostratigraphical relation to the Zogelsdorf Formation.

Fossils: Generally, sediments of the Retz Formation are quite poor in fossils. In some parts of the Retz Formation a diverse bryozoan fauna occurs (KÜHN, 1955; VÁVRA, 1979,

1981) besides molluscs (Bernhauser, 1955; Lukeneder et al., 1999; Mandic & Harzhauser, 1999), echinoderms (Kroh & Harzhauser, 1999), ostracods (Zorn, 1999a), and vertebrates (Bernhauser, 1955).

Origin, facies: Sediments of the Retz Formation are nearshore deposits of a shallow marine sublittoral environment.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian to early Ottnangian).

Biostratigraphy: In the Retz Formation, the occurrence of *Pecten hornensis* and *Gigantopecten holgeri* enables the correlation with the Zogelsdorf Formation (Mandic & Harzhauser, 1999). The Eggenburgian age is also supported by ostracods (Zorn, 1999a).

Thickness: The Retz Formation is normally 20–30 m thick, increasing to more than 60 m east of the town Retz.

Lithostratigraphically higher rank unit: Eggenburg Group.

Lithostratigraphic subdivision: -

Underlying units: The Retz Formation follows above the Burgschleinitz Formation or crystalline, mainly granitic rocks.

Overlying units: The Retz Formation gradationally continues upward into the pelitic sediments of the Zellerndorf Formation, and is in some parts also overlain by Pleistocene deposits.

Lateral units: There are indications that the Retz Formation basinward interfingers with the Zellerndorf Formation.

Geographic distribution: The distribution area of the Retz Formation is mainly in the surroundings of Retz, continuing northwards into the Czech Republic; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheets 9 Retz, 22 Hollabrunn).

Remarks: -

Complementary references: -

Zellerndorf-Formation / Zellerndorf Formation

Reinhard Roetzel

Validity: Valid; the term "Zellerndorf-Formation" was established by Steininger & Roetzel (1991) and specified in Roetzel et al. (1999a).

Type area: The area between the market town Zellerndorf and the town Pulkau along the river Pulkau can be regarded as type area for the Zellerndorf Formation.

Type section: Not defined; informally, the abandoned brickyard in Zellerndorf (N 48°41′34″ / E 15°57′19″) can be regarded as type section of the Zellerndorf Formation (Roetzel et al., 1999d). The lower and upper boundary is not exposed in this outcrop; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 22 Hollabrunn).

Reference section(s): As reference section can be regarded the abandoned quarry Hatei, 1.5 km SE of Groß-Reipersdorf, south of the town Pulkau (N 48°41′10.6″ / E 15°51′30.8″) (Nebelsick et al., 1991c), where the lower boundary is exposed above the Zogelsdorf Formation; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 22 Hollabrunn).

Derivation of name(s): From the market town Zellerndorf, 6 km S of Retz, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 22 Hollabrunn).

Synonyms: Melettaschlier, Schlier des Unteren Helvet, Schlier von Platt (und Zellerndorf), Zellerndorfer Schlier, Zellerndorf-Schlier Formation, Äquivalente des Haller Schliers.

In the first descriptions, all pelitic sediments were simply termed as "Tegel" (Cžjžek, 1853b). By Suess (1866b; cf. Suess, 1891) they were subsumed to the so-called "Schlier" together with other Oligocene and Miocene pelitic deposits. Later, the lower Miocene pelites were separated and named "Schlier des Unteren Helvet" (Weinhandl, 1957) and afterwards "Schlier von Platt (und Zellerndorf)" and "Zellerndorfer Schlier" (Fuchs, 1980a). Pelites following the Fels Formation were named by Grill "Äquivalente des Haller Schliers" (cf. Fuchs & Grill, 1984a).

Lithology: In the Zellerndorf Formation two different lithologies occur. The main and widespread type, mainly from the Ottnangian, consists of evenly laminated clays, silty clays and silts, sometimes with thin fine-sandy layers. In the mostly decalcified pelites – sometimes with gypsum – plant debris and fish scales are characteristic. Smectite is the absolutely dominating clay mineral. This type is in superposition with the Zogelsdorf Formation or laterally interfingering.

The second, older type from the Eggenburgian is more silty or fine sandy and mostly calcareous with a common microfauna. These sediments occur on top of the Fels Formation or in the area south of Grübern directly below the Zogelsdorf Formation (Roetzel, 2017).

Fossils: Most of the Zellerndorf Formation is bare of fossils or just contains fish remains and plant debris. Only in the basal parts, at the transition to the Zogelsdorf Formation and Retz Formation, and in the top parts, above the intercalated Limberg Member, marine microfaunas occur. Contrary, in the pelites on top of the Fels Formation and below the Zogelsdorf Formation microfaunas are abundant. The foraminifer assemblages are characterized by small planktonic (*Globigerina ottnangiensis*, *G. praebulloides*) and benthic (*Stilostomella*, *Bulimina*, *Bolivina*) taxa (Roetzel et al., 2006; Grunert et al., 2010b; Roetzel, 2017).

Origin, facies: The fully marine Zellerndorf Formation represents the deep water facies of the Eggenburgian and Ottnangian Sea north of the Danube, close to the Bohemian Massif. The sediments were deposited in a deep marine environment. While the pelitic sedimentation in the Eggenburgian occurred in the open marine areas east to southeast of the Bohemian Massif, in the Ottnangian the pelitic facies shifted westward towards the Massif, due to the transgression of the sea, covering the older nearshore sediments of the Eggenburg Group.

Chronostratigraphic age: Early Miocene, Burdigalian (Eggenburgian–Ottnangian).

Biostratigraphy: Based on the typical composition of the planktonic foraminifer assemblages with frequently occurring *Globigerina ottnangiensis* together with *Globoturborotalita woodi* for the Zellerndorf Formation an early Miocene age can be deduced.

Thickness: Depending on the deposition-area, the thickness of the Zellerndorf Formation varies from several meters to about 100 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Limberg Member; in the eastern surroundings of Maissau, in the area between Limberg and Parisdorf, diatomites of the Limberg Member are intercalated in the pelites of the Zellerndorf Formation.

Underlying units: The Zellerndorf Formation is concordantly overlying sediments of the Zogelsdorf Formation and Retz Formation, interfingering with each other in the lower parts. However, the pelitic sediments can also directly cover the crystalline rocks of the Bohemian Massif. In the south, the pelitic sediments are passing from the sands of the Fels Formation.

Overlying units: In some areas the Zellerndorf Formation is discordantly overlain by the Laa Formation of the Karpatian, sometimes also by sediments of the Gaindorf Formation (lower Badenian) or Pleistocene deposits.

Lateral units: From mapping-results it can be expected that the fully marine pelites of the Zellerndorf Formation laterally pass westward into the brackish influenced pelitic sediments of the Weitersfeld Formation. Basinward, towards the east, at least in its top parts, an interfingering with the Wildendürnbach Formation is discussed (Palzer-Khomenko et al., 2018a, b).

Geographic distribution: The main distribution area of the Ottnangian Zellerndorf Formation lies on the eastern margin of the Bohemian Massif between Retz, Pulkau, Limberg and Platt, extending as far as south of Maissau. However, relicts of these pelites also occur in the Eggenburg Bay, in the surroundings of Brugg, Rafings, and Reinprechtspölla. Pelites from the Eggenburgian part of the Zellerndorf Formation occur in the area around Fels am Wagram, Obernholz, and Grübern; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois, 5307 Haugsdorf (ÖK50-BMN, map sheets 9 Retz, 21 Horn, 22 Hollabrunn, 38 Krems an der Donau).

Remarks: -

Complementary references: -

Robulus-Schlier / Robulus Schlier

(see North Alpine Foreland Basin: Salzburg – Upper Austria and North Alpine Foreland Basin: Lower Austria, South of the Danube)

Limberg-Subformation (Zellerndorf-Formation) / Limberg Member (Zellerndorf Formation)

Reinhard Roetzel

Validity: Valid; the term "Limberg-Subformation" was established by Steininger & Roetzel (1991) and specified in Roetzel et al. (1999a).

Type area: The area directly east of the village Limberg can be considered as type area of the Limberg Member.

Type section: Not defined; informally, the abandoned diatomite-pit in Limberg-Taubenberg (N 48°35′56″ / E 15°52′16″) can be considered as type section of the Limberg Member (Roetzel et al., 1991d). Only the upper boundary is exposed in this section; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Reference section(s): For the Limberg Member as reference section the abandoned diatomite-pit in Parisdorf (N 48°33′57″ / E 15°51′26″) (Roetzel et al., 1999e) can be considered, where the lower and upper boundaries were previously exposed; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Derivation of name(s): From the village Limberg, 3.5 km NE of Maissau, Lower Austria; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Synonyms: Menilitschiefer, Diatomit von Limberg (-Parisdorf).

Based on chert layers (menilite) these pelitic sediments were termed in the first descriptions as "Menilitschiefer" (Cžjžek, 1849a, 1853b). Afterwards, the diatomites were called "Diatomit von Limberg (-Parisdorf)".

Lithology: The diatomite of the Limberg Member is a firm and finely laminated silt-clay, mostly clearly striped due to rhythmic stratification of whitish (high content of diatoms) and greyish (high content of clay) layers.

Fossils: In the diatomite of the Limberg Member diatoms, silicoflagellates, and calcareous nannoplankton occur besides remains of birds, fishes, insects, crabs, palm leaves and bladder wrack (seaweed) (Stradner, 1959, 1971; Berger, 1955a; Bachmayer, 1975, 1980, 1983; Řeháková, 1992, 1993, 1996; Roetzel et al., 2006; Hyžný et al., 2015).

Origin, facies: The diatomite of the Limberg Member shows distinct features for coastal upwelling during the Ottnangian, related to the steep southeastern scarp of the Bohemian Massif (Roetzel et al., 2006; Grunert et al., 2010b; Tulan et al., 2020). A very high content of smectite in the clay minerals of the diatomites and the surrounding clays points to a prominent input of acidic volcanic ash at this time (Roetzel et al., 1994; Nehyba & Roetzel, 1999), also proven by time-equivalent nearby volcaniclastics (Roetzel et al., 2014).

Chronostratigraphic age: early Miocene, Burdigalian (Ottnangian).

Biostratigraphy: In the nannoplankton assemblages of the Limberg Member the co-occurrence of *Sphenolithus disbelemnos* with *Helicosphaera ampliaperta* and *H. mediterranea*, as well as the absence of *Sphenolithus heteromorphus*, indicate the uppermost part of the nannofossil Zone NN2 and Zone NN3. Among the silicoflagellates of the diatomitic sediments, the species *Distephanopsis crux* var. *parva* and *Distephanus speculum* var. *cannopiloides* are typical for the Ottnangian (Roetzel et al., 2006). The diatom flora of the Limberg Member points to the upper part of the early Miocene (Ottnangian–Karpatian). The flora is close to that of the Karpatian, although index fossils are missing (Řeháková, 1993, 1996).

Thickness: The intercalated diatomites of the Limberg Member are 5–7.5 m thick. By tectonical folding in the Parisdorf area it is up to 10 m thick.

Lithostratigraphically higher rank unit: Zellerndorf Formation.

Lithostratigraphic subdivision: -

Underlying units: The diatomites of the Limberg Member are passing from the pelites of the Zellerndorf Formation below.

Overlying units: Pelites of the Zellerndorf Formation follow upon the Limberg Member.

Lateral units: The Limberg Member thins out eastward and interfingers laterally with the pelites of the Zellerndorf Formation.

Geographic distribution: The diatomite of the Limberg Member appears between the villages Parisdorf, Oberdürnbach, Limberg, and Niederschleinz, east to northeast of the town Maissau; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn) (Roetzel, 1998; Roetzel et al., 1999c).

Remarks: -

Complementary references: -

Weitersfeld-Formation / Weitersfeld Formation

Reinhard Roetzel

Validity: Valid; the "Weitersfeld-Formation" was established by Roetzel (1993) in the course of the geological mapping of ÖK50-BMN, map sheet 8 Geras (Roetzel & Fuchs, 2001).

Type area: The area around Weitersfeld, a market town c. 16 km N of the town Eggenburg, can be regarded as type area.

Type section: Not defined; sediments of the Weitersfeld Formation are poorly outcropping in general. Informally, a small pit near the silo at the northwestern end of the village Weitersfeld (N 48°47′18″ / E 15°48′02″) can be considered as type section. The sediments of this outcrop were primarily described as Zellerndorf Formation (Roetzel, 1988a; Roetzel & Řeháková, 1991). Lower and upper boundaries are not exposed there; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 8 Geras).

Reference section(s): -

Derivation of name: From Weitersfeld, a village 11 km WNW of Retz and 15 km N of Eggenburg, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 8 Geras).

Synonyms: Zellerndorf Formation.

Before the Weitersfeld Formation was described as a distinct formation (Roetzel, 1993) the sediments were included in the Zellerndorf Formation (Roetzel, 1988a; Roetzel & Řeháková, 1991).

Lithology: The main part of the Weitersfeld Formation consists of very fine-grained, smectitic, non-calcareous clays to silty clays. East of Weitersfeld, within those pelites, an intercalation of diatomitic clays was reported (Roetzel, 1989; Řeháková, 1992). In the basal parts micaceous silty fine sands to fine-sandy silts prevail (Roetzel, 1993, 2005; Roetzel & Fuchs, 2008).

Fossils: The clayey sediments of the Weitersfeld Formation are very poor in fossils. In the sandy basal parts, spicules of sponges are common and in rare cases diatomitic intercalations with diatoms and archaeomonad cysts occur in the clays (Roetzel & Řeháková, 1991; Řeháková, 1992).

Origin, facies: Lithologically the pelitic sediments of the Weitersfeld Formation are very similar to the Zellerndorf Formation, deposited in offshore areas during the transgressional phase at the beginning of the Ottnangian. For the Weitersfeld Formation a shallower environment with reduced salinity must be assumed due to intercalations of diatomites with brackish diatoms. Like in the Zellerndorf Formation, it is assumed that the high content of smectite in the clay-fraction is derived from a rhyolitic volcanoclastic source (Roetzel et al., 1994; Nehyba & Roetzel, 1999).

Chronostratigraphic age: Early Miocene, Burdigalian (Ottnangian).

Biostratigraphy: The brackish diatoms in diatomitic clayey intercalations are restricted to the lower Miocene (Ottnangian–Karpatian). Due to the dating of the units below and above, the Weitersfeld Formation must be of Ottnangian age.

Thickness: The observed thickness of the sediments of the Weitersfeld Formation is usually between 2 and 9 m. However, in a drilling south of Weitersfeld more than 16 m of the pelitic sediments were verified.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: In the basal part of the Weitersfeld Formation, a transition from the underlying Burgschleinitz Formation is observable. In some cases, the Weitersfeld Formation is also following directly upon crystalline rocks of the Bohemian Massif.

Overlying units: Sediments of the Theras Formation are lying discordantly upon the Weitersfeld Formation and in some areas also Pleistocene deposits.

Lateral units: It can be expected that the brackish influenced pelitic sediments of the Weitersfeld Formation laterally pass into the fully marine pelites of the Zellerndorf Formation towards the east and southeast.

Geographic distribution: Sediments of the Weitersfeld Formation are mainly common in the basins of Weitersfeld and Niederfladnitz, northwest of Retz. The widest distribution is around Fronsburg and between Weitersfeld and Röhrawiesen, Lower Austria; ÖK50-UTM, map sheets 4306 Langau, 4312 Retz (ÖK50-BMN, map sheets 8 Geras, 9 Retz, 21 Horn).

Remarks: -

Complementary references: -

Langau-Formation / Langau Formation

Reinhard Roetzel

Validity: Valid; the "Langau-Formation" was established by Roetzel (1993) in the course of the geological mapping of ÖK50-BMN, map sheet 8 Geras (Roetzel & Fuchs, 2001).

Type area: The area of the abandoned coalmine north of Langau can be regarded as type area.

Type section: Not defined; informally, as type section for the Langau Formation the drilling LC1 (N 48°50′05.7″ / E 15°42′57.5″) can be considered. In this 40.5 m deep well, which was drilled by the OMV for coal-prospection (Brix, 1981), the Langau Formation is 16.5 m thick (drilling-section 21.5–38 m) (Roetzel & Fuchs, 2008: p. 109). Lower and upper boundaries are exposed in this drilling; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 8 Geras). The cores of the type section are stored in the core-storage of the Geological Survey of Austria.

Reference section(s): -

Derivation of name: From the market town Langau, 19 km NNE of the town Horn and 19 km NW of Retz, Lower Austria; ÖK50-UTM, map sheet 4306 Langau (ÖK50-BMN, map sheet 8 Geras).

Synonyms: "(kohleführende) Schichten von Langau", "Schichten von Langau-Riegersburg".

Lithology: Sediments of the Langau Formation mainly consist of sandy to gravelly, kaolinitic and micaceous silts and clays but also of silty to clayey gravel and fine to coarse sands. In some areas, like in the basins of Langau-Šafov and Riegersburg, coaly clays and several meter thick lignitic coal seams are interbedded in the pelitic deposits. In the basins of Langau-Šafov and Niederfladnitz tuffitic layers from a rhyolitic volcanism occur (Roetzel et al., 1994; Nehyba & Roetzel, 1999). In many parts of the coal basins, a fining upward succession with bad-sorted debris at the base is overlain by a sandy part, superimposed by a fine-grained pelitic column with lignite.

Fossils: Sandy clays below the coal seams contain brackish to shallow marine molluscan faunas with *Granulolabium plicatum moravicum*, *Melanopsis impressa*, *Polymesoda langauensis*, *Mytilopsis* cf. *basteroti*, *Crassostrea gryphoides*, *Perna haidingeri*, *Agapilia picta* ssp., *Cardium* sp., *Ostrea* sp., *Hydrobia* sp., and *Valvata* sp.

The foraminifer assemblages, dominated by *Aubignyna simplex* and with rare *Elphidiella* cf. *heteropora*, *Elphidium granosum*, *Elphidium* cf. *flexosum,* and ?*Triloculina* sp. also point to a littoral environment.

Furthermore, plant remains, like fruits, seeds and megaspores (Berger, 1957; Knobloch, 1978, 1981a; Gregor, 1980; Klaus, 1980; Meller & van Bergen, 2003) as well as pollen and spores (Klaus, 1952; Obritzhauser-Toifl, 1954; Gabrielová, 1973; Hochuli, 1978; Draxler, 1991) dominate in the coaly clays, allowing the reconstruction of a variegated vegetation.

Additionally, remains of vertebrates, like teeth from a small rhino and from *Gomphotherium angustidens* besides teeth and bones from crocodiles and sea cows were found during the coal mining (Zapfe, 1953).

Origin, facies: In the Langau area, for the lower part of the Langau Formation a deposition in an estuary can be assumed. Reflected by lithology and fossil content a basal brackish and strongly fluvially influenced environment is followed by shallow marine estuary deposits. After a supposable interruption by a regressive phase (maybe in the late Eggenburgian), coastal swamps with high organic production and formation of coaly seams are spreading at the beginning of the new Ottnangian transgression. Subsequently, the area was flooded again and nearshore sediments of the Riegersburg Formation were deposited above.

Chronostratigraphic age: Early Miocene, Burdigalian (late Eggenburgian? to Ottnangian).

Biostratigraphy: By the fragment of a tooth from *Gomphotherium angustidens* (Zapfe, 1953) the sediments below the main coal seam can be dated to the mammal Zone MN4 (Rögl, 1996), correlated with the Ottnangian (late Burdigalian) (Steininger et al., 1989). This dating corresponds with the pollen-flora from the Neogen palaeofloral Zone Ng.Z.III (Hochuli, 1978), and is also supported by the dating by mollusc-faunas, foraminifers, ostracods, and seeds. Basal parts of the Langau Formation may already be dated to the Eggenburgian.

Thickness: In the coal basins of Langau-Šafov and Riegersburg the thickness of the sediments of the Langau Formation is between 13 and 20 m. South of Geras and in the basin of Niederfladnitz, around 40 m of mostly bad-sorted sediments were verified in drillings.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: The sediments of the Langau Formation are directly following upon the crystalline rocks of the Bohemian Massif.

Overlying units: In the basins of Langau-Šafov, Riegersburg and Kottaun sediments of the Riegersburg Formation overlie the Langau Formation.

Lateral units: -

Geographic distribution: The distribution of the Langau Formation is mainly proved by drillings in the basins of Langau-Šafov, Riegersburg and Kottaun north to northeast of Geras. North of Langau the sediments continue into the Czech Republic. Also in depressions south of Geras and in the basin of Niederfladnitz northwest of Retz these sediments were verified by drillings and surface-outcrops; ÖK50-UTM, map-sheets 4305 Raabs an der Thaya, 4306 Langau, 4311 Horn, 4312 Retz (ÖK50-BMN, map sheets 8 Geras, 9 Retz) (Roetzel, 1993; Roetzel et al., 2005; Roetzel & Fuchs, 2008).

Remarks: Between 1947 and 1963, the lignitic coal of the Langau Formation was mined in open-pit mines in Langau and Riegersburg (Roetzel, 1994b, 2004).

On the ASC 2004 (Piller et al., 2004) the sign for coal is missing in the Langau Formation.

Complementary references: -

Riegersburg-Formation / Riegersburg Formation

Reinhard Roetzel

Validity: Valid; the "Riegersburg-Formation" was established by Roetzel (1993) in the course of the geological mapping of ÖK50-BMN, map sheet 8 Geras.

Type area: The area between Riegersburg and Langau, Lower Austria, can be regarded as type area.

Type section: Not defined; informally, the abandoned coal mine northeast of Langau (N 48°50′54″ / E 15°44′01″) can be considered as type section of the Riegersburg Formation. In the northeastern part of the flooded open-pit mine outcrops do still exist (ROETZEL, 1993). Lower and upper boundaries are not exposed there; ÖK50-UTM, map sheet 4306 Langau (ÖK50-BMN, map sheet 8 Geras).

Reference section(s): -

Derivation of name: From Riegersburg, a village 17 km NW of the town Retz and 22 km NNE of the town Horn, Lower Austria; ÖK50-UTM, map sheet 4306 Langau (ÖK50-BMN, map sheet 8 Geras).

Synonyms: No synonyms are known.

Lithology: The Riegersburg Formation is mainly made up of silty fine sands to fine-sandy silts with a high content of fine-grained muscovitic mica. In the mostly planar-bedded fine sands, intercalations of medium to coarse sands are rare. Towards elevations of crystalline rocks, mainly of mica schists, the sands are interfingering with well-rounded gravel of quartz and quartzite (ROETZEL, 1993; ROETZEL et al., 1999a; ROETZEL & FUCHS, 2008).

Fossils: Until now, only spicules of sponges and diatoms were found in the sediments of the Riegersburg Formation.

Origin, facies: From lithology and the rare fossils in the sediments a very shallow marine to brackish environment is presumable.

Chronostratigraphic age: Early Miocene, Burdigalian (Ottnangian).

Biostratigraphy: For the Riegersburg Formation so far no biostratigraphic data are available.

Thickness: The maximum thickness of the Riegersburg Formation of about 20 m was verified in the basin of Langau, whereas in the other basins 5–8 m were mostly referred.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: In the majority of drillings sediments of the Langau Formation underlie the Riegersburg Formation.

Overlying units: -

Lateral units: -

Geographic distribution: Sediments of the Riegersburg Formation are distributed in the basins of Langau-Šafov, Riegersburg, and Kottaun north to northeast of Geras. North of Langau they continue into the Czech Republic; ÖK50-UTM, map sheet 4306 Langau (ÖK50-BMN, map sheet 8 Geras).

Remarks: -

Complementary references: -

Wildendürnbach-Formation / Wildendürnbach Formation

REINHARD ROETZEL

Validity: Valid; the "Wildendürnbach-Formation" was established by PALZER-KHOMENKO et al. (2018b).

Type area: The area between the Mailberg fault and the front of the Waschberg Unit in the northwestern NAFB in Lower Austria, in the surroundings of Mailberg, Laa an der Thaya, and Wildendürnbach, can be regarded as type area.

Type section: The Wildendürnbach Formation is only known from drill cores. For the Wildendürnbach Formation the deep well Laa 1 (N 48°42′28″ / E 16°25′48″) in the depth between 1,550 m and 1,855 m is defined as type section (PALZER-KHOMENKO et al., 2018b).

The lower and upper boundary of the Wildendürnbach Formation cannot be defined exactly, as they are defined by an overall reduction and increase in the carbonate content (the carbonate minimum interval – CMI) which change gradually over tens of meters. Additionally, the upper boundary is defined by the appearance of calcareous nannofossils and Karpatian foraminiferal assemblages (RÖGL et al., 1997; ĆORIĆ & RÖGL, 2004); ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheet 10 Wildendürnbach).

Reference section(s): As reference sections the OMV wells Wildendürnbach K4 (N 48°44′39″ / E 16°30′23″; 1,300–1,535 m) and Altenmarkt im Thale 1 (N 48°35′01″ / E 16°13′52″; 880–1,125 m) can be regarded (PALZER-KHOMENKO et al., 2018b); ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5313 Hollabrunn (ÖK50-BMN, map sheets 10 Wildendürnbach, 23 Hadres).

Derivation of name: From the village Wildendürnbach (N 48°45′22.6″ / E 16°30′02.9″), close to the Austrian-Czech boarder, 9 km NE of the town Laa an der Thaya and 13 km NW of the town Poysdorf, Lower Austria; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheet 10 Wildendürnbach).

Synonyms: Oncophoraschichten (Oncophora-Schichten), Oncophorasande (Oncophora-Sande), Oncophoraserie (Oncophora-Serie), *Rzehakia*-Schichten, Fischfazies.

Primary, the terms "Oncophorasande" (RZEHAK, 1882a) and "Oncophora-Schichten" (RZEHAK, 1893) were used for beds with the characteristic bivalve *Oncophora* (actual name *Rzehakia*; cf. ČTYROKÝ, 1972) in Moravia (Czech Republic). Later, this term was extended and used for many micaceous and carbonate-free fine sands and silts of the same period in Bavaria, Upper Austria, and Lower Austria. In Lower Austria, the outcropping Oncophora Beds south of the Danube (cf. BITTNER, 1896; ABEL, 1904b) have been revised, formalized and summarized in the Traisen Formation (Pixendorf Group) by GEBHARDT et al. (2013a). North of the Danube, this term was used by oil-companies for a lithologically comparable succession in drillings west of the Waschberg Unit (cf. BRIX & GÖTZINGER, 1964). In unpublished OMV reports, the sediments were described as "Oncophorasande", "Oncophoraschichten" ("Oncophora Beds"), or "Fischfazies" (cf. PALZER-KHOMENKO et al., 2018b).

Lithology: The Wildendürnbach Formation consists of bluish-grey fine grained silts and silty clays with intercalated unstructured coarse grained silts, muds and fine grained micaceous sands as well as fining upward cycles of grey to yellowish sands and yellowish to brownish muds. Beds of medium sands occur. In sandy to silty fining upward cycles, sedimentary structures grade from massive to planar parallel stratification, ripple cross lamination, and mm-laminated silts. Slumping and dewatering structures as well as rip-up clasts can be found. The pelites are usually rich in mica and calcite-free. Intercalated sands consist of quartz, muscovite, chlorite, dolomite, and feldspar and show a variable calcite content (PALZER-KHOMENKO et al., 2018b).

Fossils: The Wildendürnbach Formation is normally barren of microfossils and nannofossils. Even resedimented Cretaceous and Paleogene nannofossils are missing. In rare cases, when calcareous nannofossils are present, few *Coccolithus pelagicus, Reticulofenestra minuta, R. pseudoumbilicus, R. haqii, Coronosphaera mediterranea*, and *Braarudosphaera bigelowii* were determined in the assambleges (PALZER-KHOMENKO et al., 2018b), comparable to the underlying Robulus Schlier and overlying Laa Formation. Fish scales frequently occur; shell fragments are rare. Plant remains usually occur in fining upwards cycles.

Origin, facies: For the Wildendürnbach Formation a fully marine depositional environment with turbiditic and mass-flow sedimentation was reconstructed (HAMILTON, 1997; HAMILTON & KUCHER, 1997). In unpublished OMV core-studies sedimentary structures typical for deep-water turbiditic trough sedimentation in front of the Waschberg Unit are reported (PALZER-KHOMENKO et al., 2018b).

Chronostratigraphic age: Early Miocene, Burdigalian (late Ottnangian).

Biostratigraphy: Rare calcareous nannofossils in the Wildendürnbach Formation are similar to underlying and overlying units and indicate nannofossil Zones NN3–NN4. A biostratigraphic distinction between Ottnangian and Karpatian is not possible.

Thickness: Up to 300 m (deep well Laa 1).

Lithostratigraphically higher rank unit: -

Remark: GEBHARDT et al. (2013a) included only the Traisen Formation and the Dietersdorf Formation in the Pixendorf Group. PALZER-KHOMENKO et al. (2018b) integrated also the Wildendürnbach Formation into the Pixendorf Group, however, the Wildendürnbach Formation represents a different facies and an interfingering between both formations (Traisen Formation and Wildendürnbach Formation; PALZER-KHOMENKO et al., 2018b: Fig. 7) can only be intuitively stated since no surface outcrops and no sufficient seismic data exist.

Lithostratigraphic subdivision: -

Underlying unit(s): Robulus Schlier s.l.

Remark: In most of the OMV drillings in the northeastern NAFB, generally sediments of the Eggenburgian–Ottnangian are reported underlying the Oncophora Beds (cf. ROETZEL, 2009). These sediments belong mainly to the "Robulus Schlier s.l." (ĆORIĆ & RÖGL, 2004). Recently, also the Zellerndorf Formation is discussed as underlying and lateral unit, respectively PALZER-KHOMENKO et al. (2018b), however, clear evidences are missing.

Overlying unit(s): Laa Formation.

Remark: In numerous OMV drillings in the NAFB north of the Danube the Laa Formation follows with a transition zone above the "Oncophora Beds" (ROETZEL, 2003c; ĆORIĆ & RÖGL, 2004) or Wildendürnbach Formation (PALZER-KHOMENKO et al., 2018a, b), respectively. PALZER-KHOMENKO et al. (2018b) included the carbonate bearing upper part of the former "Oncophora Beds" into the Laa Formation.

Lateral unit(s): It is assumed that the Traisen Formation is a time-equivalent lateral unit of the Wildendürnbach Formation (GEBHARDT et al., 2013a; PALZER-KHOMENKO et al., 2018a, b). Additionally, PALZER-KHOMENKO et al. (2018a, b) postulate that at least the upper part of the Zellerndorf Formation is a lateral unit of the Wildendürnbach Formation. GRILL (1962b) correlated the "Limonitic Clays and Sands" (Křepice-Formation, "Eisenschüssige Tone und Sande") in the Waschberg-Unit with the former "Oncophora Beds" (cf. GEBHARDT et al., 2013a; PALZER-KHOMENKO et al., 2018b).

Geographic distribution: Sediments of the Wildendürnbach Formation are mainly reported from the area east of the Mailberg fault up to the front of the Waschberg Unit in the northwestern NAFB in Lower Austria. The boundary to the Traisen Formation in the south is not defined. In addition, the continuation in the Czech territory is unknown up to now. ÖK50-UTM, map sheet 5307 Haugsdorf, 5308 Laa an der Thaya, 5313 Hollabrunn (ÖK50-BMN, map sheet 10 Wildendürnbach, 23 Hadres, 24 Mistelbach, 40 Stockerau).

Remarks: Sediments of the Křepice-Formation ("Eisenschüssige Tone und Sande") in the Roseldorf Subunit at the outer front of the Waschberg-Unit are thought to be equivalents of the upper part of the Wildendürnbach Formation ("Oncophora-Beds") (KRHOVSKY et al., 2001). In the Vienna Basin, sediments of the upper part of the Lužice Formation are correlated (HARZHAUSER et al., 2020).

The Wildendürnbach Formation is an important gas reservoir in the gas fields Altprerau, Merkersdorf, Neuruppersdorf, Pottenhofen, Roseldorf, and Wildendürnbach (LOGIGAN & DIEM, 1964; ANIWANDTER et al., 1990).

Complementary references: -

Laa-Formation / Laa Formation

REINHARD ROETZEL

Validity: Valid; on the occasion of the geological mapping of ÖK50-BMN, map sheet 22 Hollabrunn, the sediments called, e.g., "Laaer Serie" (see synonyms) were renamed to the "Laa-Formation" (ROETZEL, 1998; ROETZEL et al., 1999a).

Type area: The area around the town of Laa an der Thaya, Lower Austria, can be regarded as type area.

Type section: The type section of the Laa Formation is the former brickyard (clay pit) of the Wienerberger Ziegelindustrie GmbH in Laa an der Thaya (N 48°43′08″ / E 16°24′41″) (KAPOUNEK et al., 1960; RÖGL, 1969; PAPP et al., 1970; STEININGER in VASS & SENEŠ, 1975; RÖGL et al., 1997). The upper – erosive – boundary is defined in this outcrop; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheet 24 Mistelbach).

Reference section(s): As reference section can be regarded the brickyard (clay pit) of the Wienerberger Ziegelindustrie GmbH in Göllersdorf (N 48°30′07″ / E 16°07′27″), c. 8 km SSE of the town Hollabrunn, Lower Austria (ROETZEL et al., 1999b); ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheets 23 Hadres, 40 Stockerau).

Derivation of name: From Laa an der Thaya, a town 22 km NW of the town Mistelbach and 29 km NE of the town Hollabrunn, Lower Austria; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheet 24 Mistelbach).

Synonyms: Laaer Schichten (Laa Beds), Laaer Serie, Karpatische Serie, Schichten mit *Uvigerina bononiensis*, Untere Grunder Schichten.

The "Laaer Serie" (also named "Laaer Schichten", Laa Beds) was established by KAPOUNEK et al. (1960). Before, these sediments were integrated in the Grund Beds ("Grunder Schichten": ROLLE, 1859). By the investigations of VAŠÍČEK (1946), WEINHANDL (1957), and GRILL (1958) the Grund Beds were divided into a lower part ("Untere Grunder Schichten") of the Helvetian (today Laa Formation: Karpatian) and an upper part ("Obere Grunder Schichten") of the Tortonian (today Grund Formation: lower Badenian).

Lithology: Sediments of the Laa Formation show an alternation of calcareous silts, sandy silts and calcareous and micaceous fine- to medium-grained sands, which are in some places consolidated to sandstone. Towards the top, an increase of sandy intercalations is observable. Also fine gravel and gravelly sands sometimes occur. In some areas, in the proximity of the front of the Waschberg Unit, matrix-supported gravelly and blocky mass flow sediments (debris-flows) are intercalated into the deposits.

Fossils: The Laa Formation normally contains typical foraminifer assemblages of the Karpatian with *Uvigerina graciliformis* together with rich faunas of *Uvigerina acuminata, Pappina primiformis*, and *P. breviformis*. Planktonic foraminifers, mainly globigerinids, are fairly rich. In the middle part of the Karpatian, few horizons with large pyritized globigerinids with *Beella clavacella* and *Virgulinella pertusa* are present (RÖGL, 1969; CICHA, 1997; RÖGL et al., 1998; SPEZZAFERRI & ĆORIĆ, 2001). In the upper part of the Laa Formation, the onset of *Globigerinoides bisphericus* is recorded. The pteropods *Vaginella austriaca*, *Limacina valvatina*, and *Limacina miorostralis* are common (ZORN, 1999b; BOHN-HAVAS & ZORN, 2003). Open marine conditions are indicated by the frequent occurrence of the nautilid *Aturia aturi*.

In the pelitic Laa Formation normally molluscs are rare. Only in more sandy deposits in the top part of the type section in Laa an der Thaya molluscs and plant fragments are quite frequent (SUESS, 1866b; STEININGER in VASS & SENEŠ, 1975; BINDER, 2003; HARZHAUSER, 2003; MANDIC, 2003). However, these sediments are no longer part of the Laa Formation (cf. remarks).

Origin, facies: The sediments of the Laa Formation were deposited in a marine, outer neritic to upper bathyal setting, relatively close to the shore in an environment characterized by a generally high concentration of organic matter, suboxic to dysoxic conditions, high nutrient availability, variable salinity and generally cool water. As indicated by foraminifers a shallowing trend can be interpreted from base to top (SPEZZAFERRI & ĆORIĆ, 2001). Changing calcareous nannoplankton assemblages allow a high-resolution climate reconstruction related to solar cycles (AUER et al., 2015).

Chronostratigraphic age: Late early Miocene, Burdigalian (Karpatian).

The Ottnangian/Karpatian boundary, roughly coinciding with the base of the Laa Formation, is assumed to be close to 17.2 Ma. This is based on the $^{40}Ar/^{39}Ar$ age of 17.23 ± 0.18 Ma from an acidic tuff on top of the Ottnangian Zellerndorf Formation at the margin of the Bohemian Massif near Straning (ROETZEL et al., 2014). The tuff shows a reversed paleomagnetic polarity and can be correlated with chron C5Cr of the late Burdigalian (early Karpatian) and with the lowstand systems tract of the Bur 4 global 3rd order sea level cycle (cf. HARZHAUSER et al., 2019a).

Biostratigraphy: The base of the Karpatian in the NAFB is marked by the first appearance of the foraminifer *Uvigerina graciliformis*. The pyritized horizon with *Virgulinella* can be correlated with the middle part of the Karpatian (VAŠÍČEK, 1952). The planktonic foraminifers enable a correlation with the Zone M4 of BERGGREN et al. (1995). The entire Karpatian sediments are attributed to calcareous nannofossil Zone NN4 (MARTINI & MÜLLER, 1975; SPEZZAFERRI & ĆORIĆ, 2001).

Thickness: The thickness of the Laa Formation increases towards the east, coinciding with the drawdown of the crystalline basement. West of the Mailberg fault-zone a thickness up to about 300 m is reported while on the swell-zones around the Buchberg near Mailberg and the northeastern continuation of the Moosbierbaum horst only about 90 m are proven. East of the Mailberg fault-zone a stepwise increasing towards the east and southeast to more than 1,000 m is verified (CICHA, 1997; GOLDBRUNNER & KOLB, 1997; ROETZEL, 2003c, 2009).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Laa Formation is subdivided into the lower Lakšary Member and the upper Závod Member (HARZHAUSER et al., 2019a).

The "Nový Přerov-Formation" as depicted in the ASC 2004 (PILLER et al., 2004) has changed in rank to Nový Přerov Member ("Nový Přerov-Subformation") as unit within the Laa Formation together with the Mušov Member following ADÁMEK (2003). However, in the Slovakian part of the Vienna Basin, already in the 1960s ŠPIČKA & ZAPLETALOVÁ (1964) and ŠPIČKA (1966) split the Laa Formation into two members, the Lakšary Member and the Závod Member. Since these names have priority, HARZHAUSER et al. (2019a) subdivided the Laa Formation into a lower Lakšary Member and an upper Závod Member, synonymizing the Mušov Member with the Lakšary Member and the Nový Přerov Member with the Závod Member.

In the Czech Republic the Laa Formation is divided into the pelitic Mušov Member (mušovské vrstvy) at the base and the sandier Nový Přerov Member (novopřerovské vrstvy) above (ADÁMEK, 2003; ADÁMEK et al., 2003).

Underlying units: In all drillings east of the Mailberg fault, the Wildendürnbach Formation (former "Oncophora Beds") of the upper Ottnangian underlies the Laa Formation. In the southwest and west, also sediments of the Robulus Schlier and the Zellerndorf Formation (Ottnangian) lie below these deposits.

Overlying units: In Austria, the Laa Formation is in some parts overlain by the Grund Formation and Gaindorf Formation (lower Badenian). South of Hollabrunn, fluvial sediments of the Pannonian Hollabrunn-Mistelbach Formation follow upon the Laa Formation, in some parts also lower Sarmatian marine to brackish sediments of the Ziersdorf Formation. In some areas loess and Pleistocene gravel (terraces) cover these deposits.

In the Czech territory, sediments of the Iváň Formation of the lower Badenian follow above an angular unconformity above the Nový Přerov Member of the Laa Formation (Adámek, 2003; Adámek et al., 2003; Dellmour & Harzhauser, 2012; Harzhauser et al., 2019a, 2020) (cf. also Vienna Basin).

Lateral units: -

Geographic distribution: In Austria, sediments of the Laa Formation are widespread in the area of the NAFB north of the Danube. In the west, close to the Bohemian Massif, the Karpatian sediments are partly sheared off by the Diendorf fault-system or pinch out immediately west of the fault-zone. In the east, sediments of the Laa Formation expand to the front of the Waschberg Unit and are partly included into its nappe system. In the south, the Laa Formation sediments reach to the Danube and are limited by the crystalline horst of Fels am Wagram in the southwest, whereas in the north they continue to the Czech Republic; ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois, 5307 Haugsdorf, 5308 Laa an der Thaya, 5313 Hollabrunn (ÖK50-BMN, map sheets 9 Retz, 10 Wildendürnbach, 11 Drasenhofen, 22 Hollabrunn, 23 Hadres, 24 Mistelbach, 39 Tulln, 40 Stockerau).

Remarks: The sandy and fossiliferous top-part in the abandoned brickyard in Laa an der Thaya (N 48°43′08″ / E 16°24′41″) (Rögl et al., 1997; Dellmour & Harzhauser, 2012) which some authors formerly correlated with the Korneuburg Formation (Korneuburg Beds; Grill, 1968; Aniwandter et al., 1990) was depicted in the ASC 2004 (Piller et al., 2004) as "Nový Přerov-Formation" (correctly Nový Přerov Member, following Adámek, 2003). Recently, Harzhauser et al. (2019a, 2020) interpreted these deposits as channel fill sediments ("Laa Channel") of the terminal Karpatian, correlating with the Ginzersdorf Formation in the Vienna Basin (cf. description in section Vienna Basin).

Complementary references: Auer et al. (2014).

Lakšary-Subformation (Laa-Formation) / Lakšary Member (Laa Formation)

Mathias Harzhauser

Validity: Invalid; the formation was based on drillings in the area between Týnec and Lanžhot (Czech Republic) and Senica in Slovakia (Špička & Zapletalová, 1964; Špička, 1966).

Type area: Northern Vienna Basin.

Type section: -

Reference section(s): -

Derivation of name: After the village Lakšárska Nová Ves in the Slovak Republic (N 48°34′42.35″ / E 17°11′2.9″) (Špička & Zapletalová, 1964; Špička, 1966).

Synonyms: Lakšárska Nová Ves Formation.

Lithology: Laminated grey to brownish marly claystone, silt and siltstone with intercalations of sandstone.

Fossils: Foraminiferal assemblages with *Bulimina elongata, Caucasina schischkinskayae, Globigerina ottnangiensis, Globorotalia scitula* and *Trilobatus bisphericus* are typical (Kováč et al., 2004).

Origin, facies: Outer neritic to upper bathyal with widespread dysoxic bottom conditions in the NACFB and Slovak part of the VB (Spezzaferri & Ćorić, 2001; Spezzaferri et al., 2002). Inner to middle neritic in the Mistelbach Halfgraben.

Chronostratigraphic age: Early Miocene, late Burdigalian (Karpatian); c. 16.7–17.2 Ma.

Biostratigraphy: Foraminifera Zone M4a and calcareous nannofossil Zone NN4 (Kováč et al., 2004; Ćorić et al., 2004).

Thickness: A maximum of 390 m in the Austrian part of the Vienna Basin.

Lithostratigraphically higher rank unit: Laa Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Rhenodanubian Flysch, Lužice Formation.

Overlying unit(s): Závod Member (Laa Formation), Iváň Formation.

Lateral unit(s): Mušov Member in the NACFB (Adámek et al., 2003).

Geographic distribution: Slovak part of northern Vienna Basin, Mistelbach Halfgraben.

Remarks: -

Complementary references: Harzhauser et al. (2019a).

Závod-Subformation (Laa-Formation) / Závod Member (Laa Formation)

Mathias Harzhauser

Validity: Invalid.

Type area: Northern Vienna Basin.

Type section: Not defined; Špička & Zapletalová (1964) and Špička (1966) described this unit based on drillings in the area between Břeclav (Czech Republic) and Závod and Senica (Slovakia).

Reference section(s): -

Derivation of name: After the village Závod in the Slovak Republic (N 48°32′51.82″ / E 17°01′48.50″).

Synonyms: -

Lithology: Grey claystone with intercalations of sandstone.

Fossils: Shallow marine foraminifera.

Origin, facies: At the base open marine; upsection a distinct shallowing trend is indicated by the dominance of *Ammonia* assemblages.

Chronostratigraphic age: Early Miocene, late Burdigalian (late Karpatian); c. 16.1–16.7 Ma.

Biostratigraphy: Nannofossil Zone NN4 (Kováč et al., 2004); a late Karpatian age is based on co-occurrences of *Uvigerina graciliformis, U. semiornata, U. pygmoides* and *U. breviformis*. Especially, the occurrence of *Trilobatus bisphericus* and the absence of *T. sicanus* and *Praeorbulina* spp. is indicative for a late Karpatian age (Spezzaferri et al., 2002).

Thickness: Up to 500 m in the Mistelbach Halfgraben.

Lithostratigraphically higher rank unit: Laa Formation.

Lithostratigraphic subdivision: Not defined; several subdivisions are commonly used in the literature; these, however, lack formalization.

Šaštín Member: fine to medium sand of up to 400 m thickness; represents the basal part of the Závod Formation; interpreted as part of the Závod delta (Vass, 2002). Shallow marine foraminifera, such as *Elphidium* and *Ammonia viennensis*, are mentioned by Kováč et al. (2004).

Jablonica Member: polymict gravel of a delta fan situated at the northern tip of the Malé Karpaty Mountains (Kováč et al., 2004).

Underlying units: Rhenodanubian Flysch, Lakšary Member.

Overlying units: Iváň Formation, Baden Formation.

Lateral units: Upper parts of the Schönkirchen Member, Korneuburg Formation (considered as synonym of the Závod Member by Harzhauser et al., 2019a) in the Korneuburg Basin (Zuschin et al., 2014); Nový Přerov Member in the NACFB (Adámek et al., 2003).

Geographic distribution: Mistelbach Halfgraben, Slovak part of northern Vienna Basin.

Remarks: -

Complementary references: -

Theras-Formation / Theras Formation

Reinhard Roetzel

Validity: Valid; the Theras Formation was defined by Roetzel & Řeháková (1991) on the occasion of the geological mapping of ÖK50-BMN, map sheet 8 Geras and was described in detail by Roetzel & Fuchs (2008).

Type area: The main distribution area in the surroundings of the villages Theras and Kainreith, northeast of the town Horn, can be regarded as type area.

Type section: Not defined; the lack of good outcrops in the Theras Formation prevented the definition of a type section so far.

Reference section(s): -

Derivation of name: From the village Theras, 10 km NNW of the town Eggenburg and 12 km NE of the town Horn, Lower Austria; ÖK50-UTM, map sheet 4312 Retz (ÖK50-BMN, map sheet 21 Horn).

Synonyms: No synonyms known.

Lithology: Well-rounded fine to coarse gravel (quartz, quartzite) and coarse sand in a bad sorted silty to sandy reddish-brown to ochre brown matrix. Sometimes also silts as well as bad sorted medium to coarse-grained sands in a pelitic matrix occur (Roetzel & Řeháková, 1991; Roetzel & Fuchs, 2008).

Fossils: From the Theras Formation no fossils are reported so far.

Origin, facies: The distribution of the Theras Formation in Austria is linked with the occurrence of adjacent mica schists pointing to the source of the quartz gravels from segregation quartz lenses of these metasediments. A shallow marine deposition of the gravelly to sandy sediments connected with the Ottnangian transgression is presumed. The reddish-brown matrix probably originates from a subsequent deep terrestrial weathering.

Chronostratigraphic age: Due to the lack of fossils, dating of the Theras Formation is difficult. It is absolutely certain that the sediments are younger than the Ottnangian Weitersfeld Formation. Therefore, they are dated tentatively as early Miocene ([late] Ottnangian). However, also a Karpatian or even Badenian age is possible.

Biostratigraphy: Up to now no fossils for biostratigraphic dating could be found.

Thickness: In few outcrops 2–5 m, in drillings up to 12 m are proven.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: The Theras Formation follows discordantly upon pelitic sediments of the Weitersfeld Formation (Ottnangian), in some places also sandy sediments of the Burgschleinitz Formation (Eggenburgian–Ottnangian) are lying below.

Overlying units: In some areas Pleistocene sediments (loess, solifluidal sediments) cover the Theras Formation.

Lateral units: -

Geographic distribution: The Theras Formation extends in Lower Austria northeast of Horn, in the area between Kainreith, Theras, Starrein, Weitersfeld, and Merkersdorf; ÖK50-UTM, map sheets 4306 Langau, 4312 Retz (ÖK50-BMN, map sheets 8 Geras, 9 Retz, 21 Horn) and continues into the region around Znojmo in the Czech Republic.

Remarks: -

Complementary references: -

Grund-Formation / Grund Formation

Reinhard Roetzel

Validity: Valid; on the occasion of the geological mapping of the ÖK50-BMN map sheets 22 Hollabrunn and 23 Hadres, the Grund Beds were renamed as “Grund-Formation” (Roetzel, 1998, 2007b, 2009; Roetzel et al., 1999a) and detailed described by Roetzel & Pervesler (2004).

Type area: The type area of the Grund Formation is north of Hollabrunn around the villages of Grund, Guntersdorf, Kalladorf, Immendorf, and Wullersdorf, Lower Austria; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheets 22 Hollabrunn, 23 Hadres).

Type section: Not defined; sections logged in the course of excavations around the wine cellars north (N 48°38′15″ / E 16°03′47.7″) and northwest (N 48°38′19.1″ / E 16°03′28.5″) of the village Grund can be regarded as type section (ROETZEL & PERVESLER, 2004). Lower and upper boundaries did not outcrop there; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheet 22 Hollabrunn).

Reference section(s): The lower boundary of the Grund Formation is defined in the deep drilling Roggendorf 1 (N 48°36′46.7″ / E 16°08′04.3″), which is a reference section for the formation (ĆORIĆ & RÖGL, 2004; ROETZEL, 2009); ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheet 23 Hadres).

Derivation of name: From the village Grund, 8 km N of the town Hollabrunn and 18 km E of the town Eggenburg, Lower Austria; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheet 22 Hollabrunn).

Synonyms: Grunder Schichten (Grund Beds), Obere Grunder Schichten.

The "Grunder Schichten" (Grund Beds) were defined by ROLLE (1859), but for long time they have been considered as time equivalent with other sediments of the lower Miocene (e.g., Laa Formation, Korneuburg Formation). Later, they were placed at the base of the "2. Mediterranstufe" and the Helvetian Stage, respectively. By the investigations of VAŠÍČEK (1946), WEINHANDL (1957) and GRILL (1958) the Grund Beds were divided into a lower part ("Untere Grunder Schichten") of the Helvetian (today Laa Formation: Karpatian) and an upper part ("Obere Grunder Schichten") of the Tortonian (today Grund Formation: lower Badenian) (about the problem of the Grund Beds cf. ĆORIĆ et al., 2004).

Lithology: The Grund Formation mainly consists of clayey to sandy and marly silt beds alternating with fine- to medium-, rarely coarse-grained sand beds; in some parts clayey silts with thin sandy layers dominate. North of Guntersdorf, Kalladorf and Immendorf, and between Wullersdorf and Grund (including the suggested type section), at least two several tens of meters thick sandy intercalations occur in the Grund Formation. They contain the famous, well-preserved molluscan faunas.

Fossils: The very rich, diverse and well-preserved molluscan assemblages, dominated by large specimens, contain among others bivalves like *Cubitostrea digitalina*, *Loripes* (*Microloripes*) *dentatus*, *Timoclea* (*Parvivenus*) *marginata*, *Ervilia pusila*, *Clausinella vindobonensis*, *Corbula* (*Caryocorbula*) *carinata* and gastropods, such as *Granulolabium bicinctum*, *Turritella eryna*, *Sandbergeria perpusilla*, *Alvania perregularis*, *Natica tigrina*, and *Nassarius schoenni*. Since the 19th century the molluscan faunas have been described and discussed in many taxonomic studies (e.g., HÖRNES, 1851, 1870; HÖRNES & PARTSCH, 1856; HOERNES & AUINGER, 1879–1882, 1884–1891; KAUTSKY, 1928, 1936, 1940; SIEBER, 1937a, b, 1947a, b, 1949, 1956b, 1960; BEER-BISTRICKY, 1958; SCHULTZ, 2001a; ZUSCHIN et al., 2006). In addition, several studies on micro- and nannofossils (RÖGL et al., 2002; ĆORIĆ & ŠVÁBENICKÁ, 2004; SPEZZAFERRI, 2004; ZORN, 2004), molluscs (MANDIC, 2004b; PERVESLER & ZUSCHIN, 2004; ZUSCHIN et al., 2004), ichnofossils (PERVESLER & UCHMAN, 2004), and vertebrates (DAXNER-HÖCK, 2003b; GÖHLICH, 2003; MIKLAS-TEMPFER, 2003; NAGEL, 2003; SCHULTZ, 2003; ZIEGLER, 2003; DAXNER-HÖCK et al., 2004) have been carried out.

Origin, facies: In the Grund Formation pelitic, open marine deposits dominate. Sandy channel-like intercalations contain mixed, synchronous-allochthonous shell debris from shallow to moderately deep environments. Together with land snails and bones of terrestrial vertebrates they were reworked and transported by bottom currents from shallow marine to offshore areas during high energy storm events (ROETZEL & PERVESLER, 2004). In higher and younger parts of the Grund Formation coralline algae limestones with coquinas (Mailberg Formation) were deposited on submarine swells, which also were reworked during storms.

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian).

In the Grund Formation a normal magnetization is correlated with Chron C5Bn.2n (ĆORIĆ et al., 2004). A find of a moldavite in the Grund Formation in the surroundings of Immendorf (ROETZEL, 2009) is limiting these deposits to an age of about 14.8 Ma (cf. HARZHAUSER et al., 2020).

Biostratigraphy: In the lower parts of the Grund Formation the occurrence of the foraminifers *Praeorbulina glomerosa circularis* and *Uvigerina macrocarinata* points to the planktonic foraminifera Zone M5 (BERGGREN et al., 1995) indicating early Badenian (Langhian, middle Miocene). In the upper part of the Grund Formation the planktonic foraminifera Zone M6 is indicated by *Praeorbulina glomerosa circularis* accompanied with *Orbulina suturalis*. The calcareous nannoplankton indicates nannofossil Zone NN5 (RÖGL et al., 2002; ĆORIĆ & ŠVÁBENICKÁ, 2004). In the ostracod assemblages *Acanthocythereis hystrix* and *Heliocythere vejhonensis* are rare, but typical for the early Badenian (ZORN, 2004). In respect to the mammal zonation, the section in Grund is correlated with the late MN5 (DAXNER-HÖCK et al., 2004). Therefore, the sediments can be correlated with the Mailberg Formation, Gaindorf Formation, and thus, the Hollenburg-Karlstetten Formation (RÖGL et al., 2002; ĆORIĆ & RÖGL, 2004; ĆORIĆ et al., 2004).

Thickness: The estimated total thickness of the Grund Formation reaches a maximum of about 450 m, of which the main part is not exposed at the surface. The OMV deep drilling Roggendorf 1 revealed the Grund Formation in the depth interval from 2 to 255 m upon basal clastics of the lowermost Badenian between 255 and 360 m depth (ĆORIĆ & RÖGL, 2004).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: In the surroundings of Hollabrunn the sediments of the Grund Formation are lying discordantly on the Laa Formation (Karpatian). In the area NE of Retz and in the Czech Republic, the Grund Formation follows upon lower Miocene (Eggenburgian–Ottnangian) Retz Formation and Zellerndorf Formation.

Overlying units: East of Hollabrunn, sediments of the Ziersdorf Formation (Sarmatian) and the Hollabrunn-Mistelbach Formation (Pannonian) follow discordantly upon the Grund Formation. In some parts also loess and other Pleistocene sediments cover the Grund Formation.

Lateral units: The sediments of the Grund Formation are interfingering with sediments of the Mailberg Formation and in the southwest also with the Gaindorf Formation (lower Badenian).

Geographic distribution: The Grund Formation is mainly distributed in the northwestern to northeastern surroundings of Hollabrunn. A smaller distribution area occurs NE of Retz, on both sides of the Austrian-Czech border (ÖK50-UTM, map sheets 4312 Retz, 4318 Langenlois, 5307 Haugsdorf, 5313 Hollabrunn (ÖK50-BMN, map sheets 9 Retz, 22 Hollabrunn, 23 Hadres).

Remarks: -

Complementary references: -

Iváň-Formation / Iváň Formation

(see Vienna Basin, Korneuburg Basin)

Gaindorf-Formation / Gaindorf Formation

Reinhard Roetzel

Validity: Valid; the Gaindorf Formation was separated from the Grund Formation on the occasion of the geological mapping of ÖK50-BMN, map sheet 22 Hollabrunn (Roetzel, 1998; Roetzel et al., 1999a).

Type area: The area around the village Gaindorf, 4 km SE of the town Maissau and 15 km W of the town Hollabrunn, can be regarded as type area.

Type section: Not defined; a gully SE of Gaindorf (N 48°33′05″ / E 15°52′30″) can be regarded as type section (Roetzel, 1996: p. 292). Lower and upper boundaries do not outcrop there; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Reference section(s): As reference section can an excavation in Mühlbach am Manhartsberg (N 48°31′05.1″ / E 15°47′33.6″) be regarded, where fossiliferous sediments of the Gaindorf Formation have been exposed (Harzhauser et al., 2003b; Roetzel, 2003b); ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 21 Horn).

Derivation of name: From Gaindorf, a village 4 km SE of Maissau and 15 km W of the town Hollabrunn, Lower Austria; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Synonyms: Grunder Schichten (Grund Beds) (cf. Grund-Formation / Grund Formation).

Lithology: Silts and silty clays with intercalations of fine to medium sands, sometimes also fine to medium gravel.

Fossils: The Gaindorf Formation usually contains only typical foraminifer assemblages of the Lower Lagenidae Zone (Cicha, 1999), ostracods (Zorn, 1999a) and few remnants of molluscs and echinoderms (Schaffer, 1913: p. 55ff.; Roetzel, 1996). The Gaindorf Formation in the section Mühlbach am Manhartsberg exhibits exceptionally rich and diverse terrestrial and marine faunas with foraminifers, ostracods, balanids, molluscs, fishes, reptiles, and small mammals (published in a special issue in "Annalen des Naturhistorischen Museums", vol. 104 A, 2003). From these sediments, several studies on micro- and nannofossils (Ćorić, 2003; Rögl & Spezzaferri, 2003), ostracods (Zorn, 2003), molluscs (Mandic & Harzhauser, 2003), and vertebrates (Boon-Kristkoiz, 2003; Daxner-Höck, 2003b; Miklas-Tempfer, 2003; Schultz, 2003; Ziegler, 2003) have been carried out.

Origin, facies: Sediments of the Gaindorf Formation are interpreted as open marine deposits; however, in comparison with the Grund Formation these sediments were deposited closer to the shore and probably were also influenced by the deltaic deposition of the Hollenburg-Karlstetten Formation in the south (Harzhauser et al., 2003b; Roetzel, 2017).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian).

Remark: The placement into the early Badenian follows Ćorić et al. (2004). Based on the occurrence of *Orbulina*, however, a correlation with the middle Badenian seems to be more likely (see Harzhauser et al., 2020).

Biostratigraphy: In the section Mühlbach am Manhartsberg the foraminifer assemblages of the Gaindorf Formation with *Praeorbulina glomerosa circularis* transitional to *Orbulina suturalis* indicate the top of the planktonic foraminifera Zone M5b/Mt5b and the regional ecostratigraphic Lower Lagenidae Zone (Rögl & Spezzaferri, 2003). The co-occurrence of *Sphenolithus heteromorphus* and *Helicosphaera waltrans* indicates nannofossil Zone NN5 (Ćorić, 2003). In respect to the mammal zonation the section Mühlbach is correlated with the late MN5 (Daxner-Höck, 2003b; Harzhauser et al., 2003b; Daxner-Höck et al., 2004). Concerning the ostracod-fauna, the species *Mutilus polyptychus* and *Acanthocythereis hystrix* support the early Badenian age (Zorn, 1999a). Therefore, the sediments can be correlated with the Mailberg Formation, Grund Formation, and thus, with the Hollenburg-Karlstetten Formation (Rögl et al., 2002; Ćorić & Rögl, 2004; Ćorić et al., 2004).

Thickness: The OMV deep drilling Glaubendorf 1 revealed, at least, 110 m, possibly up to 165 m sediments of the Gaindorf Formation (Cicha, 1999).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: The Gaindorf Formation follows discordantly upon the Zellerndorf Formation (Ottnangian) and Laa Formation (Karpatian). In Frauendorf an der Schmida, in the valley of the river Schmida, pelitic sediments of the Gaindorf Formation are lying directly on crystalline rocks (mica schists) of the Bohemian Massif.

Overlying units: The Gaindorf Formation is overlain by sediments of the Ziersdorf Formation (Sarmatian) and the Hollabrunn-Mistelbach Formation (Pannonian), in some parts also by Pleistocene sediments (loess, solifluidal sediments).

Lateral units: The sediments of the Gaindorf Formation are interfingering with sediments of the Grund Formation (lower Badenian). In the south, a connection and interfingering with the Hollenburg-Karlstetten Formation is proven.

Geographic distribution: The Gaindorf Formation extends in Lower Austria west and southwest of Hollabrunn along the Schmida valley between Sitzendorf and Ziersdorf and in the surroundings of Gaindorf, Ravelsbach, Zemling, and Mühlbach. Southward, it extends to the Langenlois and Krems area; ÖK50-UTM, map sheets 4317 Krems an der Donau, 4318 Langenlois (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn, 38 Krems an der Donau).

Remarks: -

Complementary references: -

Mailberg-Formation / Mailberg Formation

REINHARD ROETZEL

Validity: Valid; ROETZEL et al. (1999a) renamed the coralline algal limestones as "Mailberg-Formation", a detailed description was carried out by MANDIC (2004a) and ROETZEL (2007a, 2009).

Type area: The summit area around the hill Buchberg (altitude 417 m), west of the village Mailberg, Lower Austria, can be regarded as type area.

Type section: The abandoned quarry south of the top of the Buchberg hill (N 48°40′16.6″ / E 16°09′23.6″), west of the village Mailberg, exposes a 6–10 m thick section described by MANDIC (2004a: p. 163, Fig. 2). The lower boundary was proven by a drilling in this outcrop (ROETZEL, 2009: p. 30). The upper boundary is not exposed there; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheet 23 Hadres).

Reference section(s): As reference sections can be regarded the abandoned quarries in the Locatelliwald (N 48°40′10″ / E 16°06′53″) and in the Altenbergen (N 48°39′01″ / E 16°09′37″) west and southwest of Mailberg; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheet 23 Hadres).

Derivation of name: From the village Mailberg (N 48°40′21″ / E 16°10′58″), 14 km NNE of Hollabrunn and 16 km WSW of Laa an der Thaya, Lower Austria; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheet 23 Hadres).

Synonyms: Grobkalk und tertiäres Conglomerat, Corallinaceenkalk, Leithakalk vom Buchberg (bei Mailberg), Lithothamnienkalk vom Buchberg.

In the first map of this area (PARTSCH, 1843, 1844) the limestones were mapped as "Grobkalk und tertiäres Conglomerat" and were later on described as "Leithakalk vom Buchberg (bei Mailberg)" or "Lithothamnienkalk vom Buchberg" (VETTERS, 1914; STINY, 1928; WEINHANDL, 1957). More recently, the Mailberg Formation was mapped in detail (ROETZEL, 2007b) and described by MANDIC (2004a) and ROETZEL (2007a, 2009).

Lithology: Coralline red algae limestone with marly intercalations. The limestones interfinger laterally mainly with clayey, sometimes also sandy sediments of the Grund Formation.

Fossils: Limestones with coralline red algae, bryozoans, barnacles, and coquinas of thick-shelled molluscs, where the aragonitic shells are often dissolved. In the molluscan fauna, mainly bivalves (*Glycymeris deshayesi*, *Gigantopecten nodosiformis, Spondylus crassicostatus*) predominate, while gastropods (*Crepidula, Vermetus, Calyptraea*, conids, strombids) are rare (SIEBER, 1952; ROETZEL, 2007a, 2009). In the marls, benthic foraminifers such as *Cibicidoides* and *Elphidium* prevail, whereas in the planktonic fauna *Globorotalia, Paragloborotalia, Turborotalita* as well as *Globigerina praebulloides* and *G. tarchanensis* dominate. Stratigraphically important are *Orbulina suturalis*, *Praeorbulina glomerosa curva*, and *Praeorbulina glomerosa circularis* (ACHUTHAN, 1967; CICHA & RUDOLSKÝ, 1995; ČTYROKÁ in ČTYROKÝ, 1996, 1997; MANDIC, 2004a). Additionally, ostracods (HUBER-MAHDI, 1984) and calcareous nannoplankton (ACHUTHAN, 1967) are described from the marls.

Origin, facies: The sediments were deposited in an open marine environment on submarine swells at about 30–50 m water depth (MANDIC, 2004a). The coquinas with thick-shelled molluscs point to a shallow water, high-energy deposition during storms.

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian).

Remark: The placement into the early Badenian follows ĆORIĆ et al. (2004) who correlated it with Chron C5Bn.r based on the assumption that the deposits are of early Badenian age. Based on the occurrence of *Orbulina*, however, a correlation with the middle Badenian seems to be more likely (see HARZHAUSER et al., 2020).

Biostratigraphy: The foraminifer assemblages of the Mailberg Formation contain *Orbulina suturalis* accompanied by *Praeorbulina glomerosa circularis*, indicating planktonic foraminifera Zone M6 (BERGGREN et al., 1995) of the middle Badenian (Langhian, middle Miocene) and the calcareous nannoplankton indicates Zone NN5. Therefore, the sediments can also be correlated with the Grund Formation, Gaindorf Formation, and in further consequence with the Hollenburg-Karlstetten Formation (RÖGL et al., 2002; ĆORIĆ & RÖGL, 2004; ĆORIĆ et al., 2004).

Thickness: The maximal thickness of the limestones, e.g., at the type locality on the Buchberg, is up to 25 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: The sediments of the Mailberg Formation overly concordantly deposits of the Grund Formation (lower Badenian) but also interfinger with them.

Overlying units: In some places the Mailberg Formation is covered by Pleistocene sediments (loess, solifluidal sediments).

Lateral units: The sediments of the Mailberg Formation interfinger with sediments of the Grund Formation (lower Badenian). In the lower and older parts of the Grund Formation small intercalations of coralline red algae limestone occur, which get thicker upsection.

Geographic distribution: The Mailberg Formation is distributed in the area west and southwest of Mailberg, mainly on the hill ridge of Buchberg, Blickenberg, Locatelliwald, and Galgenberg. Additionally, they occur E of Patzenthal and SSW and NE of Stronegg; ÖK50-UTM, map sheet 5307 Haugsdorf (ÖK50-BMN, map sheets 22 Hollabrunn, 23 Hadres).

Remarks: -

Complementary references: -

Hollenburg-Karlstetten-Formation / Hollenburg-Karlstetten Formation

Reinhard Roetzel

Validity: Invalid; Roetzel et al. (1999a: p. 44) introduced the "Hollenburg-Karlstetten-Formation", but the formation is not formalized so far.

Type area: The area between the villages Hollenburg, SE of Krems, and Karlstetten, NW of St. Pölten, can be regarded as type area.

Type section: -

Reference section(s): -

Derivation of name: Named after the villages Hollenburg (N 48°22′46″ / E 15°41′30″) and Karlstetten (N 48°15′32″ / E 15°34′00″), between Krems and St. Pölten, Lower Austria; ÖK50-UTM, map sheet 4323 Sankt Pölten, 4324 Herzogenburg (ÖK50-BMN, map sheets 37 Mautern an der Donau, 38 Krems an der Donau).

Synonyms: Hollenburger Konglomerat, Karlstetten-Hollenburger Konglomerat, Hollenburg-Karlstettener Konglomerat.

The conglomerates of this formation were first named by Lorenz (1831) as "Nagelfluhe der Hollenburger-Berge", but before also Partsch (1824, 1831) and afterwards Cžjžek (1852a, 1853a, b) described these sediments. First, the distribution of the conglomerates was shown in the geognostic map of Cžjžek (1849b). Hassinger (1905a) denominated it as "Hollenburger Konglomerat" and Vetters (1925, 1926, 1927, 1929b) mapped its distribution area. Vetters (1937) renamed the conglomerates as "Karlstetten-Hollenburger Konglomerat" and in Schaffer (1943) the sediments were named "Hollenburg-Karlstettener Konglomerat". A detailed description of the deposits was given by Grill (1957b) and Fuchs (1972), who also mapped this formation (Grill, 1956, 1962a; Fuchs & Grill, 1984b).

Lithology: The differently compacted conglomerates, mainly from components of limestones and sandstones, show intercalations of marls and sandstones. Pelitic intercalations are increasing northward.

Fossils: In the shallow marine deltaic marly sediments, in the surroundings of Hollenburg, foraminifer assemblages with large-sized lenticulinids (*Lenticulina calcar, L. cultrata, L. inornata*), dentalinids, marginulinids, and globigerinids occur. Sometimes reworked molluscs (*Ostrea* sp.) can be found.

Origin, facies: In the southern distribution area, northeast of Karlstetten, the conglomerates are interpreted as fluvial deposits of a river ("Proto-Traisen"), draining the Northern Calcareous Alps and the Rhenodanubian Flysch in the south. Northward, in the surroundings of Statzendorf and Hollenburg, marly intercalations with marine microfaunas point to shallow marine proximal deltaic sediments at the mouth of the river (Hassinger, 1905a; Grill, 1957b; Fuchs, 1972). North of the Danube, the gravel interfinger with the Gaindorf Formation, showing several hundred meters long straight intercalations of coarse gravel from limestones and sandstones which can be interpreted as distal deltaic strings, presumably from a birdfoot delta (Roetzel, 2017).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian).

Biostratigraphy: In intercalated pelitic sediments of the Hollenburg-Karlstetten Formation in the surroundings of Hollenburg the foraminifer assemblages contain *Orbulina suturalis* accompanied by *Praeorbulina glomerosa circularis* (Fuchs & Schmid, 1972), which point to planktonic foraminifera Zone M6 (Berggren et al., 1995) and early Badenian (Langhian, middle Miocene). Therefore, the sediments can also be correlated with the Grund Formation, Gaindorf Formation, and in further consequence with the Mailberg Formation (Rögl et al., 2002; Ćorić & Rögl, 2004; Ćorić et al., 2004).

Thickness: The maximum thickness of the deposits of the Hollenburg-Karlstetten Formation is supposed to be between 80 and 100 m (Vetters, 1925; Grill, 1957b), but usually it is about 40 to 50 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: South of the Danube the sediments of the Hollenburg-Karlstetten Formation are mainly following discordantly upon deposits of the Linz-Melk Formation or the Older Schlier (Älterer Schlier) (Egerian). In some places they also lie upon the Traisen Formation of the Pixendorf Group (Ottnangian) or directly upon crystalline rocks of the Bohemian Massif. In small parts north of the Danube they discordantly superimpose the Fels Formation (early Eggenburgian) and the Zellerndorf Formation (Ottnangian), respectively.

Overlying units: In some locations loess and Pleistocene gravel (terraces) cover the Hollenburg-Karlstetten Formation.

Lateral units: In the Krems Basin pelitic sediments of equivalents of the Gaindorf Formation (lower Badenian) interfinger with the Hollenburg-Karlstetten Formation.

Geographic distribution: The Hollenburg-Karlstetten Formation extends mainly north of St. Pölten (Ćorić et al., 2016; Egger & Ćorić, 2017), in the northeastern surroundings of Karlstetten and between Statzendorf and Hollenburg as well as south of Mautern (Matura, 1983, 1989; Fuchs & Grill, 1984a). Rare occurrences are also east of the river Traisen (Rabeder et al., 2013). North of the Danube it occurs north of Rohrendorf bei Krems and Gedersdorf as well as west of Stein an der Donau and in the surroundings of Obernholz. Intercalations in the Gaindorf Formation exist southwest of Ravelsbach between Ronthal and Baierdorf (Roetzel, 2017); ÖK50-UTM, map sheets 4317 Krems an der Donau, 4318 Langenlois, 4323 Sankt Pölten, 4324 Herzogenburg (ÖK50-BMN, map sheets 21 Horn, 37 Mautern an der Donau, 38 Krems an der Donau, 56 St. Pölten).

Remarks: -

Complementary references: Cžjžek (1852a).

Ziersdorf-Formation / Ziersdorf Formation

Reinhard Roetzel

Validity: Valid; Sarmatian sediments in the NAFB were subsumed as "Ziersdorf-Formation" by Roetzel et al. (1999a) and first denominated on the geological map ÖK50-BMN, map sheet 22 Hollabrunn (Roetzel, 1998). The Ziersdorf Formation was formalized in Roetzel et al. (1999a).

Type area: The area northeast of Ziersdorf, north of the "Parthkapelle" (Parth chapel), can be regarded as type area.

Type section: Not defined; however, the former brickyard near the "Parthkapelle", NE Ziersdorf (N 48°32′01.1″ / E 15°56′41″), where MILLES & PAPP (1957) described the Sarmatian sediments, can be regarded as type section. Lower and upper boundaries cannot be observed there; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Reference section(s): Not defined; the former sandpit Weik, NE of Hollabrunn (N 48°34′23.1″ / E 16°05′08.5″), on the road to Aspersdorf could have been considered as reference section (MANDIC et al., 2008) although this outcrop is already destroyed and recultivated; ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheet 23 Hadres).

Derivation of name: From Ziersdorf, a small market town 12 km SW of Hollabrunn and 9 km SE of Maissau, Lower Austria; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 22 Hollabrunn).

Synonyms: Sarmat von Hollabrunn, Sarmat von Ziersdorf, Sarmat von Langenlois.

Sarmatian sediments near Hollabrunn were first described by SUESS (1866b) and also VETTERS (1914) referred to these deposits. A first thorough paleontological approach was given by PAPP (1950), who also described the deposits near Ziersdorf (MILLES & PAPP, 1957) and Langenlois (PAPP, 1962c). Later on, Papp and Steininger (in PAPP et al., 1974) introduced the section Hollabrunn as a faciostratotype of the lower Sarmatian. During geological mapping ROETZEL (2003a, 2007a, 2009) showed, that these deposits are widespread east of Hollabrunn. MANDIC et al. (2008) gave a detailed study of the Hollabrunn outcrop.

Lithology: Mostly silt and clay in alternation with fine to coarse sands; in some areas, for example east of Hollabrunn, polymict, well-rounded, and badly sorted coarse gravel ("Reisbergschotter") are intercalated in the silty to sandy deposits (ROETZEL, 2003a, 2007a, 2009).

Fossils: Marine to brackish bivalves (e.g., *Solen subfragilis, Ervilia dissita, Sarmatimactra eichwaldi, Obsoletiforma vindobonensis*) and gastropods (e.g., *Granulolabium bicinctum, Mohrensternia angulata, Turritella eryna sarmatica, Ocenebra striata, Euspira helicina*) are common. Terrestrial gastropods are frequent as well (e.g., *Negulus grazilis, Gastrocopta nouletiana, Truncatellina lentilii, Vertigo angulifera, Testacella schuetti, Tropidomphalus gigas*) (PAPP, 1950, 1956, 1962c; MILLES & PAPP, 1957; SCHÜTT, 1967; PAPP & STEININGER in PAPP et al., 1974; ROETZEL, 2003a, 2007a; KOWALKE & HARZHAUSER, 2004; MANDIC et al., 2008; GEBHARDT et al., 2009; BINDER, 2017). Due to intensive reworking of older deposits, a high content of Karpatian and Badenian microfossils (foraminifers, ostracods) besides autochthonous faunas with Sarmatian elphidiids (e.g., *Elphidium grilli, E. glabrum, E. aculeatum, E. josephinum, E. reginum, E. microelegans, E.* cf. *incertum, E. tumidocamerale, E.* ex gr. *hauerinum*), nonionids (e.g., *Nonion* cf. *serenus, N. bogdanowiczi*), *Bolivina moravica* and *Porosononion granosum* occur (RUPP in ROETZEL, 2003a, 2007a, 2009). In the ostracod fauna autochthonous forms like *Aurila kollmanni, A. mehesi, Aurila merita, Callistocythere* aff. *egregia, C. maculata, C. postvallata, Cyamocytheridea leptostigma leptostigma, Cyamocytheridea leptostigma foveolata, Cytheridea hungarica, Hemicyprideis dacica, Hemicytheria loerentheyi sarmatica, H. omphalodes* prevail (ZORN, 1999a; ZORN in ROETZEL, 2003a, 2007a, 2009).

Origin, facies: Marine to brackish tidal-flat deposits in an incised valley in a long, narrow and shallow embayment of the Central Paratethys Sea during the early Sarmatian (HARZHAUSER & PILLER, 2004a; MANDIC et al., 2008, GEBHARDT & ROETZEL, 2013).

Chronostratigraphic age: Late middle Miocene, late Serravallian (early Sarmatian).

Biostratigraphy: Aside from the index genus *Mohrensternia*, the occurrence of *Abra reflexa*, *Plicatiforma pseudoplicata*, and *Turritella eryna sarmatica* allow a dating of the formation to the early Sarmatian *Mohrensternia* Zone (HARZHAUSER & PILLER, 2004b). Furthermore, the foraminifer assemblage with large-sized elphidiids allows a correlation with the *Elphidium reginum Z*one defining the upper part of the *Mohrensternia* Zone. The ostracod fauna with *Aurila kollmanni, A. mehesi*, and *Aurila merita* indicates Zone B of the early Sarmatian.

Thickness: The thickness of the Ziersdorf Formation in surface outcrops is not more than a few meters. The maximum thickness of 110 m was reported from the OMV deep drilling Hollabrunn 1 (BRIX et al., 1977).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision; the "Reisbergschotter" (Reisberg gravel) east of Hollabrunn could be considered as a subunit of the Ziersdorf Formation.

Underlying units: The sediments of the Ziersdorf Formation follow discordantly on sandy and clayey deposits of the Karpatian (Laa Formation) and Badenian (Grund Formation, Gaindorf Formation) sediments.

Overlying units: Around Ziersdorf and east of Hollabrunn sediments of the Hollabrunn-Mistelbach Formation (Pannonian) follow with an erosive contact upon the Ziersdorf Formation. In some areas, especially around Langenlois, thick Pleistocene loess covers the Sarmatian.

Lateral units: -

Geographic distribution: The deposits of the Ziersdorf Formation are known from the surroundings of Langenlois (FUCHS & GRILL, 1984b), Ziersdorf (ROETZEL, 1998) and the area on both sides of the Göllersbach east of Hollabrunn (ROETZEL, 2007b, 2009); ÖK50-UTM, map sheets 4317 Krems an der Donau, 4318 Langenlois, 5307 Haugsdorf, 5308 Laa an der Thaya, 5313 Hollabrunn (ÖK50-BMN, map sheets 22 Hollabrunn, 23 Hadres, 24 Mistelbach, 38 Krems an der Donau).

Presumably, these sediments are part of an approximately 50 km long continuous Sarmatian sedimentary belt, following a roughly WSW–ENE trending narrow zone from the Bohemian Massif near Krems in the west to the Vienna Basin in the east, now mostly covered by younger sediments.

Remarks: -

Complementary references: -

Hollabrunn-Mistelbach-Formation / Hollabrunn-Mistelbach Formation

REINHARD ROETZEL

Validity: Valid; the name "Hollabrunn-Mistelbach-Formation" was first used in STEININGER & ROETZEL (1996). Subsequently, ROETZEL et al. (1999a) specified this formation and NEHYBA & ROETZEL (2004) and ROETZEL (2009) described it in detail. The Hollabrunn-Mistelbach Formation was formalized in ROETZEL et al. (1999a).

Type area: The woodland (Hollabrunner Wald, Glasweiner Wald, Ernstbrunner Wald) between the town Hollabrunn and the village Klement and the surroundings of Mistelbach can be regarded as type area.

Type section: -

Reference section(s): -

Derivation of name: Named after the towns Hollabrunn and Mistelbach in the northeastern part of Lower Austria; ÖK50-UTM, map sheets 5313 Hollabrunn, 5314 Mistelbach (ÖK50-BMN, map sheets 22 Hollabrunn, 24 Mistelbach).

Synonyms: Hollabrunner Schotter(kegel), Mistelbacher Schotter(kegel), Hollabrunner und Mistelbacher Schotter(kegel), "Ostracodenmergel von Mariathal".

First descriptions of the sediments were done by HASSINGER (1905a, b), KEINDL (1929), and VETTERS (1914). GRILL (1953) distinguished between the "Hollabrunner Schotterkegel" and the "Mistelbacher Schotterkegel", but correlated both. Later, the terms "Hollabrunner Schotter" and "Mistelbacher Schotter" were also used (e.g., GYURITS & KURZWEIL, 1976).

Lithology: Overall, the sediments of the Hollabrunn-Mistelbach Formation are gravel-bed deposits. In the west, mostly sandy fine to coarse gravel prevail, sometimes solidified to conglomerates. They show intercalations of silt and clay and frequently cross-bedded medium to coarse sand. In the east, within the Vienna Basin, besides fine to medium gravel and pelitic intercalations, sands are more frequent. Within the polymict, good sorted and well-rounded gravels quartz and quartzitic pebbles are dominant besides limestones, dolomites, cherts, sandstones, and various crystalline rocks (NEHYBA & ROETZEL, 2004). In some basal parts reworking of older sediments (e.g., shown by reworked Badenian and Sarmatian molluscs or gravel components from the Hollenburg-Karlstetten Formation) is proven (GRILL, 1968; ROETZEL, 2017).

Fossils: From the Hollabrunn-Mistelbach Formation many mammal fossils with a typical "*Hipparion*-fauna" are reported (e.g., PIA & SICKENBERG, 1934; ZAPFE, 1949; GRILL, 1968; THENIUS, 1982a; RABEDER, 1985; DAXNER-HÖCK & GÖHLICH, 2009). Also micromammals (Insectivora, Rodentia) (DAXNER-HÖCK, 1975, 1996; HARZHAUSER et al., 2011) and a tooth of a hominoid primate (THENIUS, 1982a, b, 1983; DAXNER-HÖCK, 2000) were found. Molluscs are mainly described from the surroundings of Mistelbach (GRILL, 1968, HARZHAUSER et al., 2000, 2003a, 2011). Additionally, ostracods (WEINHANDL, 1957; GRILL, 1968; ZORN in ROETZEL, 2007a, 2009) and plant remnants (KOVAR, 1979; KOVAR-EDER, 1988; HARZHAUSER et al., 2003a; MELLER, 2014) were published. From diatomitic clays and sands around Droß and Priel, northwest of Krems, limnic diatoms and chrysomonad cysts are depicted (GRILL, 1962c; STRADNER, 1962c).

Origin, facies: The sediments of the Hollabrunn-Mistelbach Formation are mostly fluvial, partly also lacustrine deposits from a Proto-Danube river (gravel-bed river) draining the Alpine-Carpathian Foredeep from west to east during the late Miocene. East of the Waschberg Unit, already in the Vienna Basin, the sediments pass into a braid-delta environment towards the outflow into the Lake Pannon (GYURITS & KURZWEIL, 1976; HARZHAUSER et al., 2003a, 2004; NEHYBA & ROETZEL, 2004).

Chronostratigraphic age: Late Miocene, Tortonian to ?Messinian (early to late Pannonian).

Biostratigraphy: The onset of deposition of the Hollabrunn-Mistelbach Formation is dated to the Pannonian Zone A/B (ELMMZ Neogen MN7/8 – latest Astaracian) but only a minor part of the sediments can be attributed to Zone A/B or B. The bulk of the deposits are correlated with Zone C–E of the early Pannonian (MN9 – early Vallesian) (PAPP in GRILL, 1968; DAXNER-HÖCK, 1996, 2004b; ROETZEL et al., 1999a; STEININGER, 1999; HARZHAUSER et al., 2004). Late Pannonian Zone H (MN12 – middle Turolian) is only proven in deposits in the relatively highest altitudes in the west (ZAPFE, 1957). The whole time span of deposition is supposed to be about 3.6 Myrs (HARZHAUSER et al., 2004).

In the mammal-faunas, Proboscidea (*Deinotherium giganteum, Gomphotherium angustidens, G. longirostris, G. longirostris avernensis*: ZAPFE, 1957; BACHMAYER & ZAPFE, 1976) and Perissodactyla (*Diceros, Chalicotherium, Anchitherium, Hippotherium*: THENIUS, 1950, 1957; STEININGER, 1963a; ZAPFE, 1974; BERNOR et al., 1988, 1993) are stratigraphically important. Most of the molluscan faunas with *Mytilopsis* (*Congeria) ornithopsis*, *Melanopsis impressa,* and *Mytilopsis (Congeria) hoernesi,* respectively, are typical for the mollusc zones Pannonian B and C according to PAPP (in GRILL, 1968; e.g., HARZHAUSER et al., 2000, 2003a). In the Hollabrunn and Mistelbach area, the ostracod *Cyprideis tuberculata* indicates Pannonian Zone A/B and *Sinegubiella rakosiensis* Zones D and E (WEINHANDL, 1957; GRILL, 1968; ZORN in ROETZEL, 2007a, 2009).

Thickness: The maximum thickness of the deposits of the Hollabrunn-Mistelbach Formation is supposed to be more than 100 m in the west, only about half of the thickness is confirmed by drillings. Thickness decreases towards the east in the Mistelbach area.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision; GRILL (1968) called clayey intercalations west of Hollabrunn, rich in ostracodes, "Ostracodenmergel von Mariathal" (informal). Similar limnic sediments are diatomitic clays and sands in the surroundings of Droß and Priel (GRILL, 1962a, 1974a; STRADNER, 1962c) which in older literature were described as Pielach Formation (MATURA, 1983, 1989).

Underlying units: Sediments of the Hollabrunn-Mistelbach Formation lie discordantly on sandy and clayey deposits of the Karpatian (Laa Formation), Badenian (Grund Formation, Gaindorf Formation), and Sarmatian (Ziersdorf Formation). In the Zaya Gate, the passage of the Proto-Danube through the Waschberg Unit, they cover sediments of this unit, whereas in the Vienna Basin they mostly overlie Sarmatian sands and clays, in some cases also Badenian deposits.

Overlying units: In many areas Pleistocene loess follows above the Hollabrunn-Mistelbach Formation. In Neudegg, southeast of Hohenwarth, Pliocene loess and paleosols with micromammals cut the Hollabrunn-Mistelbach Formation in an erosive channel (FRANK & RABEDER, 1996, 1997d; ROETZEL, 2016).

Lateral units: It is assumed that the "Schichten von Laimbach-Trandorf" (Laimbach-Trandorf Beds) north to northwest of Melk are a lateral continuation of the Hollabrunn-Mistelbach Formation towards the west (NAGEL & VERGINIS, 1989; NEHYBA & ROETZEL, 2004). In Upper Austria, sediments of the Hausruck Formation are analogous equivalents (RUPP, 2008b).

Geographic distribution: The Hollabrunn-Mistelbach Formation extends in Lower Austria north of the river Danube in a WSW–ENE direction from Krems and Langenlois towards Hohenwarth, Ziersdorf, Hollabrunn, and Ernstbrunn to the surroundings of Mistelbach and further to Zistersdorf over a length of more than 86 km (ÖK50-UTM, map sheets 4317 Krems an der Donau, 4318 Langenlois, 5307 Haugsdorf, 5308 Laa an der Thaya, 5313 Hollabrunn, 5314 Mistelbach, 5315 Zistersdorf (ÖK50-BMN, map sheets 21 Horn, 22 Hollabrunn, 23 Hadres, 24 Mistelbach, 25 Poysdorf, 37 Mautern an der Donau, 38 Krems an der Donau, 39 Tulln, 41 Deutsch Wagram). The width of this sediment body is between 3 km and 14 km west of the Waschberg Unit, in the Vienna Basin around Mistelbach it increases to 20 km.

Remarks: -

Complementary references: -

Schichten von Laimbach-Trandorf / Laimbach-Trandorf Beds

REINHARD ROETZEL

Validity: Invalid; the unit "Schichten von Laimbach-Trandorf" is informal and badly defined.

Type area: The depression between Altenmarkt, Laimbach, Pöggstall, Raxendorf, Trandorf, Mühldorf, and Spitz an der Donau in the southern Waldviertel area can be regarded as type area.

Type section: -

Reference section(s): -

Derivation of name: Named after the village Laimbach am Ostrong (N 48°19′02″ / E 15°07′23″), 6 km W of Pöggstall and 11 km NNW of Marbach an der Donau, and the village Trandorf (N 48°21′40″ / E 15°18′38″), 3.5 km SW of Mühldorf and 8 km W of Spitz an der Donau, Lower Austria; ÖK50-UTM, map sheet 4322 Pöchlarn (ÖK50-BMN, map sheet 36 Ottenschlag).

Synonyms: Sedimente von Laimbach-Trandorf.

These sediments were first described by MICHL (1912), who discovered the fluvial character of the deposits. Later, the deposits were mapped by WALDMANN (1937, 1938, 1953, 1954, 1955). FUCHS (1977) supposed the sediments in the depression of Laimbach-Trandorf-Mühldorf being brackish to marine equivalents of the Oligocene Pielach Formation ("Pielacher Tegel") and Linz-Melk Formation ("Ältere Melker Sande") (MATURA, 1983, 1989; FUCHS & FUCHS, 1986). Additionally, FUCHS & FUCHS (1986) included "Streitwiesener Schotter" and "Heiligenbluter Blockschotter" in this sedimentary association. Later, ROETZEL (in FUCHS & ROETZEL, 1990) considered all these sediments as a fluvial complex of the Laimbach-Trandorf Beds.

Lithology: The Laimbach-Trandorf Beds consist of badly sorted sands, gravel and clay with coaly seams and intercalations of coarse debris. The sandy and gravelly sediments frequently show typical features of fluvial deposits. Intercalated sediments with cobbles and boulders from local crystalline rocks can be interpreted as debris flow deposits from adjacent hills.

Fossils: From the Laimbach-Trandorf Beds coalified wood (HOFMANN in RIEDEL, 1952) and pollen and spores (HOCHULI, 1983; DRAXLER in FUCHS & ROETZEL, 1990) are known. Fruits and seeds from Laimbach are described by KNOBLOCH (1981a).

Origin, facies: The Laimbach-Trandorf Beds are fluvial, partly also lacustrine deposits, presumably from a Proto-Danube river, flowing in this depression during the late Miocene (NAGL & VERGINIS, 1989). Eastward, the sediments of the Hollabrunn-Mistelbach Formation form the continuation of this fluvial system in the Alpine-Carpathian Foredeep (NEHYBA & ROETZEL, 2004).

Chronostratigraphic age: Late Miocene, Tortonian to ?Messinian (Pannonian).

Biostratigraphy: By pollen and spores the sediments are dated to the late Miocene (HOCHULI, 1983). However, for the coaly clays of the brickyard Haide, west of Laimbach, DRAXLER (in FUCHS & ROETZEL, 1990) postulated an age younger than Sarmatian, probably Pontian to Pliocene, which may represent the final stage of deposition in this depression.

Thickness: In most of the outcrops the thickness of the Laimbach-Trandorf Beds does not exceed 10 m. A thickness of at least 15 m was reported by WALDMANN (1937) in a drilling in Trandorf and MICHL (1912) assumed a former thickness of about 80 m of sediments.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying units: As known so far, sediments of the Laimbach-Trandorf Beds are generally following discordantly upon crystalline basement rocks of the Bohemian Massif.

Overlying units: The Laimbach-Trandorf Beds are in many parts overlain by Pleistocene sediments.

Lateral units: It can be assumed that the Laimbach-Trandorf Beds laterally continue towards the east into the Hollabrunn-Mistelbach Formation (NEHYBA & ROETZEL, 2004).

Geographic distribution: The sediments of the Laimbach-Trandorf Beds are distributed in Lower Austria north of the Danube in the depression between Altenmarkt, Laimbach, Pöggstall, Trandorf, Mühldorf, and Spitz an der Donau; ÖK50-UTM, map sheets 4322 Pöchlarn, 4323 Sankt Pölten (ÖK50-BMN, map sheets 35 Königswiesen, 36 Ottenschlag, 37 Mautern an der Donau).

Remarks: -

Complementary references: -

Waschberg Unit

WERNER E. PILLER

The Waschberg Unit extends north of the Danube from the surroundings of Korneuburg (Lower Austria) up to the Pavlovské vrchy (“Pollauer Berge”) in the Czech Republic (Text-Fig. 6). It is bordered by the sediments of the North Alpine-Carpathian Foreland Basin (NACFB) in the west and by the nappes of the Rhenodanubian Flysch Unit and sediments of the Vienna Basin and the Korneuburg Basin in the east. The unit includes sedimentary rocks from the Upper Jurassic to the Oligocene, which are embedded into a lower Miocene succession. The unit is tectonically highly complicated and consists of several tectonic nappes and slices. This tectonic melange originated from overthrusting of the sediments of the Waschberg Unit onto those of the NACFB during the early Miocene (e.g., WESSELY, 2006). This overthrusting was accompanied by submarine olisthostromes and giant olistholiths (GEBHARDT, 2021).

The Waschberg Unit is differentiated into a Waschberg Unit s.str. and the externally located subunit of the Roseldorf Zone with dominating Ottnangian and partly Karpatian sediments; the Roseldorf Zone is overthrusted onto the NACFB along the Senning thrustfault. The boundary between the Roseldorf Zone and the Waschberg Unit s.str. is the Leitzersdorf thrustfault. Also the Waschberg Unit s. str. is heavily imbricated and includes sediments from the Upper Jurassic to the lower Miocene. The Cenozoic succession ranges from the Paleocene Bruderndorf Beds to the lower Miocene (Karpatian) Laa Formation (cf. WESSELY, 2006; ROETZEL, 2002, 2009).

The Waschberg Unit is treated as a separate tectonic unit but it shows strong similarities to the sedimentary succession of the NACFB although it is very complex due to tectonic disturbances. The Cenozoic successions of the NACFB and that of the Waschberg Unit are generally coeval but due to synsedimentary thrusting the sediments of the NACFB are partly transported by piggy-back mechanisms in northwestern direction.

The Waschberg Unit continues to the NE into the Czech Republic. There it is also divided into two parts, the western external Pouzdřany Unit (“Pausramer Einheit”) and the Ždánice Unit (“Steinitzer Einheit”) in the east. The Waschberg Unit s.str. seems to merge into the Ždánice Unit what is reflected in the frequently used name Waschberg-Ždánice Unit (e.g., GEBHARDT, 2021). If the Roseldorf Zone can be correlated with the Pouzdřany Unit remains unclear. The lithostratigraphic units are widely different, in particular in the lower part of the succession besides the Rupelian (early Kiscellian) Dynów Marlstone, which is widely distributed. In the upper part of the succession, the former “Auspitzer Mergel” (Auspitz Marl) is now included in the Ždánice-Hustopeče Formation which is part of the Ždánice Unit. The former “Pausramer Mergel” (Pausram Marl) is now included in the Boudky Formation and the “Eisenschüssige Tone und Sande” in the Křepice Formation; both formations, however, belong to the Pouzdřany Unit (KRHOVSKY et al., 2001) what makes the correlation of the tectonic units difficult.

Text-Fig. 6.
Location of the Waschberg Unit (grey shaded).

Bruderndorfer Schichten / Bruderndorf Beds

FRED RÖGL & WERNER E. PILLER

Validity: Invalid; the “Bruderndorfer Schichten”, fossiliferous Danian calcareous sandstones and corallinacean limestones, were first reported by KÜHN (1926) only from boulders at a hillside in the strongly imbricated area of the southern Waschberg Unit. KROH (2001) introduced the unit as Bruderndorf Formation.

Remark: The corallinacean limestones which are reported from the Bruderndorf Beds are considered to represent the upper Paleocene Zaya Formation (see below).

Type area: As reported by KÜHN (1926), the area between Niederfellabrunn and Bruderndorf in the surroundings of Ernstbrunn, Lower Austria, southern Waschberg Unit; ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheet 40 Stockerau).

Type section: On the hill side S of the hamlet Haidhof, 1 km W of Ernstbrunn, Lower Austria (this was a temporary outcrop due to an excavation in 1959 by the Palaeontological Institute, University Vienna) (N 48°31′30″ / E 16°20′39″); ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach) (KÜHN, 1960: p. 3–4).

SCHMID (1962) described the location in more detail with 1.20–1.40 m of sandstone (“Bruderndorfer Sandstein”) underlain by marly fine-sand (“Bruderndorfer Feinsand”) (the originally published coordinates N 48°31′35″ / E 16°20′48″ have been corrected, see above).

Remark: In the Lexique Stratigraphique International, Fasc. 8, Autriche, KUEHN (1962) erroneously mentioned the “steep hillside at the Reingruberhöhle [sic]” as type locality, although he transferred the type locality to the above mentioned Haidhof (KÜHN, 1960) (compare also SEIFERT & STRADNER, 1978).

Reference section(s): -

Derivation of name: Named after the small village Bruderndorf (N 48°28′20″ / E 16°17′36″), c. 8 km SW of Ernstbrunn, Lower Austria.

Synonyms: Bruderndorfer Kreide (KÜHN, 1926), Bruderndorfer Feinsand (KÜHN, 1930), Bruderndorfer Sandstein (KÜHN, 1930), Bruderndorfer Lithothamnienkalk (KÜHN, 1930), Bruderndorfer Schichten (GLAESSNER, 1937), Nulliporenkalk (e.g., GRILL, 1962b), Bruderndorf Formation (KROH, 2001).

Lithology: KÜHN (1930) clearly differentiated between "Bruderndorfer Sandstein" and "Lithothamnienkalk". According to SCHMID (1962) based on results of excavations (see above), the probably lower part of the sequence is composed of light grey, marly fine sand, with a scarce macrofauna and a rich foraminiferal fauna. The sand seems to be overlain by the main facies, a whitish to light grey, glauconitic, marly, fine- to medium-grained, fossiliferous sandstone with plant debris. The light grey to light yellowish, locally glauconitic corallinacean limestone ("Lithothamnienkalk") is now considered to represent the Zaya Formation (SEIFERT & STRADNER, 1978).

Fossils: KÜHN (1926, 1930) reported from the sandstone facies molluscs (including the nautilid index fossil for the Danian *Hercoglossa danica*), echinoids, and fish remains. A description and revision of the echinoid fauna was given by KROH (2001, 2003, 2004) reporting 19 taxa. From the sandy facies, SCHMID (1962) described 70 foraminifera species (planktonics dominate, 37.5 % benthics), 16 species of ostracoda (det. KOLLMANN in SCHMID, 1962), some bryozoa (det. KÜHN in SCHMID, 1962), and a small coral (det. KÜHN in SCHMID, 1962). Calcareous nannoplankton was described by STRADNER (1961, 1962b, and in SCHMID, 1962).

Origin, facies: The sediments of the isolated outcrops provide only limited environmental information. Based on foraminifers, the marly fine sands are considered to be deposited on the outer shelf in a neritic environment of 100–200 m water depth, in cool water under full-marine conditions (SCHMID, 1962); such environment is also reconstructed for the sandstone with burrowing echinoids (KROH, 2001).

Chronostratigraphic age: Early Paleocene, Danian to Selandian.

In the ASC 2004 (PILLER et al., 2004) the Bruderndorf Beds cover also part of the Thanetian because the Zaya Formation has been included.

Biostratigraphy: The occurrence of *Prinsius martinii* and *Neochiastozygus saepes* points to an assignment to calcareous nannofossil Zone NP3–4 (PERCH-NIELSEN et al., 1985). GEBHARDT (2018a) reports NP6–NP8, but relate the studied marls to the "Zaya-Einheit" (see below). The planktonic foraminifera *Globanomalina praemenardii, Parasubbotina pseudobulloides, Globanomalina compressa*, and *Praemurica inconstans* allow an assignment to Zones P1a–P3a, Danian to lower Selandian (BERGGREN & PEARSON, 2005; WADE et al., 2011).

Thickness: Only a few meters were exposed for scientific excavations.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision.

Underlying unit(s): Maastrichtian marls (discontinuous).

Overlying unit(s): Zaya Formation, but with a hiatus (SEIFERT et al., 1978). Usually, the beds are in tectonic contact with Miocene "Schieferige Tonmergel" and rarely with middle Eocene Haidhof Beds.

Lateral unit(s): -

Geographic distribution: Recorded only in the Waschberg Unit between the villages Niederfallabrunn and Klement, with a detailed description of localities by GLAESSNER (1930), BACHMAYER (1960), GRILL (1962b) and KROH (2001). ÖK50-UTM, map sheets 5313 Hollabrunn, 5314 Mistelbach (ÖK50-BMN, map sheets 40 Stockerau, 24 Mistelbach).

Remarks: -

Complementary references: RZEHAK (1891), GRILL (1953, 1968), KUEHN (1962), THENIUS (1962, 1974), ROETZEL (2002), WESSELY (2006), RÖGL et al. (2009), GEBHARDT (2018b).

Zaya-Formation / Zaya Formation

FRED RÖGL & WERNER E. PILLER

Validity: Valid; described and formalized by SEIFERT & STRADNER (1978) as "Zaya-Einheit" representing the upper part of the Bruderndorf Beds. KRHOVSKY et al. (2001: p. 231) introduced the term Zaya Formation.

Type area: North of the hillside of the Leiser Berge, between the villages Michelstetten and Zwentendorf, c. 11 km WNW of the town Mistelbach, Weinviertel district, Lower Austria. ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

Type section: The location is in a farming field with a marker layer of a corallinacean-bryozoan limestone (N 48°35′27″ / E 16°24′52″), c. 1 km NW of the village Michelstetten, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

The type locality was excavated and the section was at the base composed of green, marly glauconitic sands and grey marls overlain by a 70 cm thick bryozoan limestone bed followed above by ochre to yellowgreen marls (SEIFERT & STRADNER, 1978).

Reference section(s): In the bounds of "Kurze Zeißelbergen", NE of Michelstetten (N 48°35′30″ / E 16°25′58″). Sandy, glauconitic marls and clayey marls below the bryozoan limestone show a longer stratigraphic range as in the type section; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

Remark: Badly exposed, for studies an excavation is necessary.

Derivation of name: Named after the river Zaya, a tributary to the river March, Weinviertel district, Lower Austria.

Synonyms: Bruderndorf Beds p.p., Bruderndorfer Lithothamnienkalk (KÜHN, 1930), Nulliporenkalk (e.g., GRILL, 1962b), Höhere Einheit der „Bruderndorfer Schichten s.l." (SEIFERT & STRADNER, 1978), "Zayaeinheit der Bruderndorfer Schichten s.l." (SEIFERT, 1982), "Zayaschichten" (SEIFERT, 1982), Zaya Formation (KRHOVSKY et al., 2001), Zaya-Formation (ROETZEL, 2002).

Lithology: Glauconitic clayey marl and marl, partly marly sand; fossil-rich corallinacean-bryozoan limestone.

In the lower part of the excavation at the type section, bright green, marly glauconitic sands and grey marls were exposed, followed up-section by a 70 cm thick glauconitic corallinacean-bryozoan limestone bed, and at the top by ochre to yellowish-green marls. The microfacies of the limestone was described by LOBITZER (1978).

Fossils: Calcareous nannoplankton (STRADNER, 1978), bryozoa, echinoid debris, brachiopods, the larger foraminifer *Discocyclina seunesi*, and smaller foraminifera (SCHMID, 1978) are reported from the marls. In the limestone coralline algae, bryozoan, molluscs, brachiopods, serpulids, coral and echinoids occur as well as foraminifers with *Discocyclina* (LOBITZER, 1978). VAVRA (1978a) described 16 bryozoan species, *Membranipora selandica, Lunulites slathomensis* and *Anornithophora polygona* are restricted to the Paleocene.

Origin, facies: According to LOBITZER (1978), the corallinacean-bryozoan limestone was deposited on the outer shelf-to-shelf margin.

Chronostratigraphic age: Late Paleocene, Thanetian.

Biostratigraphy: Calcareous nannofossil Zones NP7–NP9, planktonic foraminifera Zone P4, larger benthic foraminiferal Zone SBZ3.

The lowermost marls contain a calcareous nannoplankton flora with *Discoaster gemmeus* and *Heliolithus kleinpelli* (Zone NP7), followed by sands and marls with *Heliolithus riedeli* (NP8), and the marls on top contain *Discoaster multiradiatus* (NP9) (STRADNER, 1978). Stratigraphically important planktonic foraminifera are *Globanomalina pseudomenardii*, *Morozovella acuta, M. occlusa,* and *Acarinina mckannai*, which indicate planktonic foraminifera Zone P4 (SEIFERT & STRADNER, 1978). The occurrence of *Discocyclina seunesi* indicates larger benthic foraminiferal Zone SBZ3 and an early Thanetian age (SERRA-KIEL et al., 1998).

Thickness: Only a few meters of sediment have been documented.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Upper Jurassic Klentnitz Beds and Maastrichtian Poysdorf Formation (tectonic contacts), Bruderndorf Beds (disconformity).

Overlying unit(s): Michelstetten Formation (tectonic contact).

Lateral unit(s): -

Geographic distribution: Known only from the southern Waschberg Unit in Lower Austria between Haidhof, Michelstetten and Zwentendorf. ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

Remarks: The biostratigraphic data indicate a gap (nannofossil Zones NP5–NP6 are missing) between the Bruderndorf Beds (NP3–4) and the Zaya Formation (NP7–9).

Complementary references: GLAESSNER (1937), GRILL (1968), WESSELY (2006), GEBHARDT (2018a).

Waschberg Schichten / Waschberg Beds

WERNER E. PILLER & FRED RÖGL

Validity: Invalid; first mentioned as "calcaire à nummulite jaunâtre … forment les cimes de la butte de Holingstein, près de Nieder-Hollabrunn, …" by BOUÉ (1830b: p. 376), PARTSCH (in REUSS, 1848: p. 5) gave a first lithologic description and HAUER (1858) provided already lithological and paleontological details. The "Waschbergkalk" has been first dated to the lower Eocene by GLAESSNER (1937); a detailed microfacial description was given by SEIFERT (1982).

Type area: The hills of the Waschberg, Michelberg (in older literature: Michelsberg) and Praunsberg, 6–12 km NE of the town Stockerau, Weinviertel district, Lower Austria. ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheet 40 Stockerau) (compare TORRES-SILVA & GEBHARDT, 2015).

Type section: Not defined; at the Waschberg, S–SE of the village Wollmannsberg, c. 6 km NE of the town Stockerau (N 48°25′14″ / E 16°16′09″), where the limestone was quarried but outcrops are poor.

Reference section(s): -

Derivation of name: Named after the hill Waschberg (388 m alt.), c. 6 km NE of Stockerau, Weinviertel district, Lower Austria.

Synonyms: Calcaire à nummulite jaunâtre (BOUÉ, 1830b: p. 376), Calcaires à coraux (BOUÉ, 1831: p. 138), Nummulitenschichten der Umgebung von Stockerau (RZEHAK, 1888b), Kalkstein vom Waschberge, Korallenkalkstein, Tertiärkalke vom Waschberge (PARTSCH in REUSS, 1848), Waschberg-Nummulitenkalk (PAUL & BITTNER, 1894: p. 27–32), Waschbergserie (KOHN, 1911), Waschbergkalk (GRILL, 1962b), Waschberg-Kalk (THENIUS, 1962), Waschberg-Schichten (RÖGL et al., 2009), Waschberg-Formation (ROETZEL, 2002; RÖGL et al., 2009; GEBHARDT & ĆORIĆ, 2014), Waschberg Limestone (GEBHARDT, 2021).

Lithology: At the Waschberg, it is a reddish to yellowish-brown sandy limestone characterized by a high amount of angular crystalline components. The limestone is well bedded with sandy marl intercalations (HAUER, 1858). Further north at the Michelberg and Praunsberg (W of the village Karnabrunn), the Waschberg Beds are developed as reddish brown nummulitic sandstone (GRILL, 1962b). At the Praunsberg, crystalline breccias and conglomerates are interbedded in the nummulitic sandstone (KOHN, 1911). A detailed microfacies analysis was published by SEIFERT (1982).

Fossils: The Waschberg Limestone is very fossil rich including (hermatypic) corals, coralline algae, green algae, bryozoans, bivalves, gastropods, echinoids, shark teeth, and, in particular, larger foraminifera (e.g., REUSS, 1848; PAUL & BITTNER, 1894; BACHMAYER, 1961; GRILL et al., 1963; SEIFERT, 1982).

RZEHAK (1888b) described a rich fauna of benthic foraminifera (about 100 taxa) with *Nummulites partschi* and *N. oosteri*, and PAPP (1962a) re-evaluated the status of *N. partschi*. TORRES-SILVA & GEBHARDT (2015) re-studied the larger benthic foraminiferal association. STRADNER & PAPP (1961) and STRADNER (1962b) reported on calcareous nannoplankton.

Origin, facies: The Waschberg Beds were deposited on the shelf of the Bohemian Massif in the vicinity of crystalline islands which produce large crystalline blocks and conglomerate beds. In the limestone, SEIFERT (1982) defined five microfacies types ranging from a reef core facies to a transitional zone from reef detritus facies to the outer shelf zone. Water depth ranged from 0 to > 60 m and the biota indicates tropical to subtropical temperatures and full marine conditions. Contrary, based on sedimentary structures and planktic foraminifera, GEBHARDT (2021: p. 64) considers the "Waschberg Limestone" as "*an allochthonous, mixed sediment and its components were transported in from different sources*".

Chronostratigraphic age: Early Eocene, Ypresian (in older literature Cuisian) to middle Eocene, early Lutetian.

Biostratigraphy: Calcareous nannofossil Zones NP12?, NP13 to NP15 (SEIFERT, 1982: p. 139); planktonic foraminifera Zones E5–E9 (GEBHARDT & ĆORIĆ, 2014), larger benthic foraminifera indicate SBZ10–SBZ11 (TORRES-SILVA & GEBHARDT, 2015).

Remark: Calcareous nannoplankton species *Discoaster lodoensis* (STRADNER, 1962b) and planktonic foraminiferal species *Morozovella aragonensis* (GRILL et al., 1963) are stratigraphically indicative for the lower and middle Eocene. Based on benthic foraminifera, RZEHAK (1888b) considered the Waschberg Beds to be upper Eocene. Based on the two gastropod species, *Velates schmideliana* and *V.* cf. *circumvallata,* BITTNER (1892) assumed already an early Eocene age. The occurrence of *Nummulites partschi, N. distans* var. *minima*, and *N. bolcensis* var. *densispira*, studied by ROZLOZSNIK (GLAESSNER, 1937), clearly indicated an early Eocene age.

The ages based on larger benthic foraminifera (*Nummulites*) and planktic foraminifera and calcareous nannoplankton show a clear mismatch (53–49 Myrs for LBF) and 49–40 Myrs (for PF and CNP) which is the reason for GEBHARDT (2021) to consider the Waschberg Beds as allochthonous unit (see above).

Thickness: At the Waschberg hill a thickness of 50–60 m can be estimated.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): "Schieferige Tonmergel" in tectonic contact.

Overlying unit(s): Tectonic contact with Mesozoic units.

Lateral unit(s): No lateral units outcropping.

Geographic distribution: Restricted to the southern Waschberg Unit, between Waschberg and Praunsberg in a tectonic alignment, called "Waschberg-Eozänkalkzone" by GLAESSNER (1930).

Remarks: PARTSCH (1824) considered the Waschberg Schichten as Jurassic limestone what has also been resumed by BOUÉ (1829: p. 261, 296) but PARTSCH (1830: p. 102) then reported a Tertiary age.

Complementary references: GRILL (1943), WESSELY (2006).

Haidhof Schichten / Haidhof Beds

WERNER E. PILLER & FRED RÖGL

Validity: Invalid; GLAESSNER (1937: p. 4) reported for the first time the term "Haidhof-Schichten mit Nummulites distans" for middle Eocene limestones from the hamlet Haidhof, W of the village Ernstbrunn, Lower Austria.

Type area: The Haidhof Beds are best known from a small area W of the village Ernstbrunn, Weinviertel district, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

Type section: Not defined; there is only a small outcrop used as sand pit for road construction W of Haidhof at the road to the village Simonsfeld, 1 km W of Ernstbrunn, Lower Austria (N 48°31′44″ / E 16°20′10″).

Reference section(s): -

Derivation of name: Named after the hamlet Haidhof, 1 km W of the village Ernstbrunn, Weinviertel district, Lower Austria.

Synonyms: Haidhof-Schichten mit Nummulites distans (GLAESSNER, 1937), Haidhofschichten (THENIUS, 1962), Haidhof-Schichten, Haidhof Formation (ROETZEL, 2002; RÖGL et al., 2009), Haidhof-Schichten (WESSELY, 2006).

Lithology: Grey brown to yellowish brown limestone to calcareous and marly sandstone with a high amount of limonitic grains ("Bohnerz", iron ooids), rich in small nummulites. SEIFERT (1982) differentiated five microfacies types

Fossils: Coralline algae (crusts and rhodoliths), foraminifers, calcareous nannoplankton, rare corals, bryozoan, brachiopods, bivalves, gastropods, abundant serpulids (*Rotularia spirulea, Protula extensa*), crustaceans, and echinoids (BACHMAYER, 1958; SEIFERT, 1982).

GLAESSNER (1937) already reported *Nummulites distans* var. *depressa, N. irregularis* and a diverse macrofauna.

Origin, facies: Deposited on the inner to outer shelf of the Bohemian Massif. Water depth may have ranged between 20 and > 100 m, the biota indicates temperate waters and full marine salinity.

Chronostratigraphic age: Early Eocene, late Ypresian to middle Eocene, early Lutetian.

Biostratigraphy: Calcareous nannofossil Zones NP12–NP16.

Based on the occurrence of *Nummulites distans*, GLAESSNER (1937) already proposed a middle Eocene age. BACHMAYER (1958) mentioned *Nummulites* cf. *distans* and *Assilina spira* (determined by H. SCHAUB) and deduced an early middle Eocene age.

SEIFERT (1982: p. 139) reported Zones NP15–NP16, but more recent data by Hans Egger (pers. communication) rendered, e.g., *Pontosphaera plana, P. scissura, Helicosphaera riedelii, Reticulofenestra dictyoda, Transversopontis sigmoidales, Campylosphaera eodela, Zygrhablithus bijugatus, Chiasmolithus bidens, Sphenolithus radians,* and rare *Discoaster barbadiensis, D. gemmifer,* and *D. lodoensis*; this assemblage points to a stratigraphic range from Zones NP12 to lower NP14.

Thickness: Only a few meters are outcropping.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: See remarks.

Underlying unit(s): In tectonic contact "Schieferige Tonmergel", Michelstetten Formation, and Thomasl Formation.

Overlying unit(s): In tectonic contact "Schieferige Tonmergel", Michelstetten Formation, and Thomasl Formation.

Lateral unit(s): -

Geographic distribution: The occurrences of Haidhof Beds have been reported by BACHMAYER (1958): Haidhof, W of Ernstbrunn (several small outcrops) and a locality north of the river Zaya between the villages Zwentendorf and Altmanns; all in a small area in the Weinviertel district, Lower Austria.

Remarks: According to the calcareous nannoplankton stratigraphy, the Haidhof Beds may represent a sandier, time-equivalent facies of the Waschberg Beds.

Middle Eocene marls, partly corresponding to the "Globigerinenschichten" of GRILL (1953), are outcropping SE of Niederhollabrunn and yield well preserved calcareous nannoplankton and foraminiferal assemblages (EGGER et al., 2007c). The nannoplankton species *Chiasmolithus gigas, Nannotetrina pappii,* and *Discoaster sublodoensis* indicate Zone NP15. Planktonic foraminifera *Subbotina compacta, Turborotalia frontosa, T.* ? *griffinae,* and *Globigerinatheka rubriformis* are characteristic for Zone P11. RZEHAK (1888a) described a poor foraminiferal fauna from similar sediments in the area of Niederhollabrunn. These marls could be considered a subunit of the Haidhof Beds.

Complementary references: KUEHN (1962), THENIUS (1974), ROETZEL (2009), GEBHARDT (2018b).

Reingruberhöhe-Formation / Reingruberhöhe Formation

WERNER E. PILLER & FRED RÖGL

Validity: Valid; for the first time GLAESSNER (1937) introduced the terms "Serie der Reingruberhöhe" and "Reingruber Serie" for these upper Eocene sediments. The unit was formalized by KRHOVSKY et al. (2001) using, however, the incorrect term Reingrub Formation instead of Reingruberhöhe Formation (see below). The authors considered the Pfaffenholz Beds and the Hollingstein Limestone as part of the Reingruberhöhe Formation (see below).

Type area: At the hillside Raingrubenhöhe (formerly Reingruberhöhe), 2.5 km NNE of the village Bruderndorf, c. 5.5 km SW of the market town Ernstbrunn, Lower Austria. ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheet 40 Stockerau).

Type section: Abandoned quarry, 10–12 m high but widely overgrown, at the W slope of the hill Raingrubenhöhe (formerly Reingruberhöhe) (N 48°29′33″ / E 16°18′33″) (KÜHN, 1930: p. 527; GLAESSNER, 1937: p. 4; GEBHARDT, 2018b); ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheet 40 Stockerau).

Remark: STRADNER (1962a) described several new calcareous nannoplankton taxa from the type locality which have been used by MARTINI (1971) to define his nannofossil Zone NP19. Therefore, the type locality of the Reingruberhöhe Formation is the stratotype locality of nannofossil Zone NP19.

Reference section(s): -

Derivation of name: Named after the hill Raingrubenhöhe (formerly Reingruberhöhe) (322 m alt.), 4.8 km N of the village Niederhollabrunn and 2.5 km NNE of the village Bruderndorf, Weinviertel district, Lower Austria.

Remark: Since the official topographic term for the hill was Reingruberhöhe (changed now to Raingrubenhöhe), the name of the formation has to be Reingruberhöhe Formation (instead of Reingruber Formation as listed in the ASC 2004 – PILLER et al., 2004).

Synonyms: Bartonschichten von der Reingrubhöhe (PAUL & BITTNER, 1894: p. 26), Obereozänsandstein (GLAESSNER, 1930), Serie der Reingruberhöhe (GLAESSNER, 1937: p. 4), Reingruber Sandstein, Reingruber Serie (GLAESSNER, 1937: p. 7; GRILL, 1953: p. 89), Sande und Sandsteine der Reingruberhöhe (GRILL, 1962b: p. 21), Reingruberserie (BRIX & GÖTZINGER, 1964), Reingruber-Formation (STEININGER, 1991: p. 146), Nemtschitzer Schichtenfolge (STRÁNÍK, 1997: p. 291), Reingrub Formation (KRHOVSKY et al., 2001: p. 230), Reingruber Beds (ZÁGORŠEK, 2003), Reingruberhöhe-Formation (RÖGL et al., 2009: p. 37), Reingrub-Formation (WESSELY, 2006).

Lithology: Greenish-brown glauconite sands to sandstones, grey siltstones and marls, with layers rich in mollusks and (larger) foraminifers, coralline algal limestone with *Discocyclina* and bryozoan sandstone.

A first description was given by RZEHAK (1891) but he included also Paleocene and Oligocene/Miocene units. The "Tegeliger Sand" at the base is late Paleocene, the "Melettamergel", which corresponds to the "Auspitzer Mergel" or "Schieferiger Tonmergel", is Oligocene/Miocene in age. A detailed description was given by GOHRBANDT (1961) and SEIFERT (1980) with the succession composed of glauconitic sand, organogenic *Discocyclina* and bryozoan limestone and "Hauptsandstein" (main sandstone, which grades into a bryozoan sandstone). At the base of the Hauptsandstein he discovered a 1 m-thick yellowish biogenic limestone layer composed of corallinaceans with numerous *Discocyclina* and some nummulites. SEIFERT (1982) performed a microfacies study and differentiated five microfacies types

Remark: Two additional upper Eocene units have been described from the area E and SE of Niederhollabrunn, which have been included in the Reingruberhöhe Formation by KRHOVSKY et al. (2001): Hollingstein Limestone and Niederhollabrunn Limestone. ROETZEL (2002) differentiated "Hollingsteinkalk" and "Pfaffenholzschichten" which he summarized within the "Niederhollabrunner Kalk" but included these units in the "Reingrub-Formation" (= Reingruberhöhe Formation).

The Hollingstein Limestone was first mentioned by HAUER (1858: p. 130) from the quarry at the Hollingstein hill from erratic blocks and PAUL & BITTNER (1894: p. 32) introduced the term "Hollingsteiner Schichten mit *Lucina globulosa Desh.*" It is a light to dark brown-grey dolomitized limestone with fissures filled by white sparitic limestone (KOHN, 1911).

The Niederhollabrunn Limestone was introduced by PAUL & BITTNER (1894: p. 33) as "Pfaffenholzschichten mit *Mytilus levesquei Desh.*". It is a blue-grey, yellowish weathered, porous, bituminous limestone, with pebbles of quartz and crystalline rocks, partly rich in fossils. It frequently contains stromatolites, peloids and rare dasycladacean algae (SEIFERT, 1982: p. 160). For further discussion see also GEBHARDT (2021).

Fossils: The unit yielded rich biota including calcareous nannoplankton, foraminifers, corals, bryozoans, brachiopods, serpulids, molluscs, ostracods, decapod crustaceans, and echinoids (RZEHAK, 1891; GLAESSNER, 1937; GOHRBANDT, 1961; SIEBER, 1953; PAPP, 1958a; STRADNER, 1962a, b; ZAGORŠEK, 2003).

STRADNER (1962a) described several new species of calcareous nannoplankton (*Discolithus macroporus, Corannulus germanicus, C. arenarius, Zygolithus aureus, Trochoaster conglobatus, Guttilithion cassum, Lanternithus minutus*).

A rich foraminiferal fauna was already described by RZEHAK (1891), providing data for each of the lithologic subdivisions but he included also upper Paleocene ("Tegeliger Sand") and an Oligocene/Miocene ("Melettamergel") sediments. The smaller foraminifers were re-described and evaluated by GOHRBANDT (1961). In respect to larger benthis foraminifers, GLAESSNER (1937) mentioned *Nummulites, Asteroyclina, Discocyclina*, PAPP (1958a) reported *Nummulites incrassatus, N. ramondiformis, N. chavannesi,* and *N. bouillei*, and TORRES-SILVA & GEBHARDT (2015) *Asterocyclina priabonensis, Nummulites stellatus,* and *Discocyclina trabayensis vicenzensis.*

GLAESSNER (1937) mentioned from the glauconitic sand also a diverse mollusc fauna with *Spondylus buchi*; a more detailed description of the mollusc fauna provided SIEBER (1953) with 66 species. The bryozoan fauna was extensively described (153 taxa) by ZAGORŠEK (2003) from the localities Reingruberhöhe and Haselbach.

From the Hollingsteinkalk and Niederhollabrunnerkalk a rich bivalve fauna is known, with *Mytilus (Arcomytilus)* cf. *levesquei* and *Anodontia globulosa* in both facies types (BACHMAYER, 1961).

Origin, facies: The sandy sediment and the biota indicate a full marine, shallow water environment (maximum 50 m) (GOHRBANDT, 1961). The fine-grained sediments may point to an outer shelf position. The biota belongs to the foramol-association and indicates temperate water conditions (SEIFERT, 1982). The Niederhollabrunn Limestone with stromatolites, peloids and rare dasycladacean algae represents a lagoonal deposit ranging from intertidal to shallow subtidal water depths (SEIFERT, 1982: p. 160).

Chronostratigraphic age: Late Eocene, Priabonian.

Remark: GOHRBANDT (1961) assigned the formation to the late Ledian, which was considered (by some authors) part of the Priabonian, but it is not a formal chronostratigraphic unit anymore (DE GEYTER et al., 2006).

Biostratigraphy: Calcareous nannofossil Zones NP19–NP20 (SEIFERT, 1980). The type locality is the stratotype for the Calcareous nannofossil Zone NP19 of MARTINI (1971). Planktonic foraminifera point at Zone P15 (*Subbotina linaperta, Globigerinatheka index, Catapsydrax unicavus, Globorotaloides suteri, Turborotalia cerroazulensis*), larger benthic foraminifera indicate SBZ19–SBZ20 (e.g., *Nummulites incrassatus ramondiformis, N. stellatus*) (PAPP, 1958a; TORRES-SILVA & GEBHARDT, 2015).

The Hollingstein Limestone and the Niederhollabrunner Limestone are considered to be late Eocene according to the mollusc fauna (BACHMAYER, 1961; ČTYROKÝ, 1966).

Thickness: At the type locality 37 m (SEIFERT, 1980), currently < 10 m of the upper part crop out.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision exists; the Hollingstein Limestone and the Niederhollabrunn Limestone (both mentioned already by HAUER, 1858) have been included in the Reingruberhöhe Formation by KRHOVSKY et al. (2001) but could be defined as members of this formation.

For the Hollingstein Limestone the name "Hollingsteiner Schichten mit *Lucina globulosa Desh.*" was introduced by PAUL & BITTNER (1894), GLAESSNER (1937: p. 7) mentioned them as Maunitz-Hollingstein-Schichten, SEIFERT (1982) as "Hollingsteinkalk".

The name Niederhollabrunn Limestone was introduced by BACHMAYER (1961: p. A15) as "Niederhollabrunner-Kalk" (synonyms: "Limestone with *Mytilus levesquei*" (PAUL & BITTNER, 1894), "Pfaffenholzschichten" (Pfaffenholz Beds)). GEBHARDT (2018a) described "Blockschichten mit *Mytilus levesquei*" and considered the Niederhollabrunn Limestone blocks as reworked in lower Miocene sediments.

Underlying unit(s): "Tegeliger Sand" of RZEHAK (1891) of late Paleocene age (GOHRBANDT, 1961), in tectonic contact.

Overlying unit(s): Shales of the "Schieferige Tonmergel", in tectonic contact.

Lateral unit(s): Interfingering with the "Globigerinenschichten"?

Geographic distribution: The Reingruberhöhe Formation is only known from the type locality, from the Michelberg, near the hamlet Haselbach, E of the village Wollmannsberg, and from the area of Niederhollabrunn, Weinviertel district, Lower Austria.

Remarks: SEIFERT (1982: p. 140) considered both the Hollingstein Limestone and the Niederhollabrunn Limestone as carbonate facies of the Ottenthal Formation.

GLAESSNER (1937) and later on ČTYROKÝ (1966) considered the Hollingstein Limestone a lateral equivalent of the Mautniz Limestone (Moutnice Limestone). ČTYROKÝ (1966) placed it into the Ždánice Unit.

GRILL (1953: p. 79) described as informal unit "Globigerinenschichten" considering them, at least in part, a marly equivalent of the Reingruberhöhe Formation. However, in these beds also Oligocene sediments have been included and should be split or included into different units. SEIFERT (1982: p. 139) suggested to include into the "Globigerinenschichten" brown-grey and brown marls and clayey marls ranging from NP12–NP19. For the younger sediments of Grill's "Globigerinenmergel" SEIFERT (1982: p. 139) introduced the unit "Ottenthaler Schichten" (see below). In Moravia, the Globigerina marl facies corresponds in the Pouzdřany Unit to the Pouzdřany Marl, and in the Ždánice Unit to the (upper) Němčice Formation (CICHA et al., 1963).

Complementary references: THENIUS (1962, 1974), GRILL (1968), PERCH-NIELSEN et al. (1985), WESSELY (2006), ROETZEL (2009), GEBHARDT & ĆORIĆ (2014).

Ottenthal-Formation / Ottenthal Formation

FRED RÖGL & WERNER E. PILLER

Validity: Valid; JÜTTNER (1938a: p. 96) reported an alternation of greenish-grey clays, "Pausram Marl" and "Menilitschiefer" from the area of Ottenthal, and subsumed the variegated clays and the Pausram Marls in the "Pausramer Schiefer"; SEIFERT (1982: p. 139) introduced the term "Ottenthaler Schichten" for these heterogeneous sediments, SEIFERT et al. (1991) gave a detailed description of the Ottenthal section, RÖGL et al. (1997) introduced the term Ottenthal Formation and RÖGL et al. (2001: p. 325) revised this unit and formalized it as Ottenthal Formation.

Type area: Between the villages Ottenthal and Altruppersdorf, WNW–NNW of the town Poysdorf (Lower Austria) and SW of the town Mikulov (Czech Republic). ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 24 Mistelbach, 25 Poysdorf).

Type section: The outcrop extends along the small road between the villages Ottenthal and Kleinschweinbarth, at the east side of the village Ottenthal in the common "Untere Leithen", Lower Austria. The section is located between N 48°45′33.6″ / E 16°34′52.6″, 251 m a.s.l., and N 48°45′31.6″ / E 16°34′56.0″, 264 m a.s.l. The first documentation of this section was given by JÜTTNER (1938a), a detailed description is presented in SEIFERT et al. (1991) and RÖGL et al. (2001). The section is tectonically disturbed as documented in SEIFERT et al. (1991: Abb. 5–7) and RÖGL et al. (2001: Figs. 2, 3). The lower part of the section is now overbuilt and the upper part is overgrown; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen).

Reference section(s): "Waldweg section", at the east side of the village Ottenthal in the common "Untere Leithen" parallel to the type section; the section provides better information on facies and boundaries. Section location between N 48°45′34.9″ / E 16°34′53.3″, 261 m a.s.l., and N 48°45′33.2″ / E 16°34′55.6″, 266 m a.s.l. The section is tectonically disturbed as documented in RÖGL et al. (2001: Figs. 3, 4); ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 24 Mistelbach).

Locality "Staglgraben", at a creek near a water reservoir, E of the village Altruppersdorf, c. 8 km SSW of Ottenthal, Lower Austria; N 48°41′45″ / E 16°33′29″. This section exposes the lower part of the Ottenthal Formation with *Globigerina* marl facies and substitutes the lower part of the now overbuilt type section.

Derivation of name: Named after the village Ottenthal, c. 11 km NNW of the town Poysdorf, c. 5 km W of Drasenhofen, c. 5 km south of the border between Austria and the Czech Republic, Weinviertel district, Lower Austria.

Synonyms: Bunte Tone, Pausramer Schiefer, Menilitschiefer, Niemtschitzer Schichten (JÜTTNER, 1938a, b) Globigerinenschichten p.p. (GRILL, 1953), Mergel und bunte Tone des Obereozäns p.p. (GRILL, 1968), Ottenthaler Schichten (SEIFERT, 1982), Menilitschichtenfolge (STRÁNÍK, 1997), Graue Mergel (?) (GEBHARDT, 2018a).

Lithology: The lithology of the Ottenthal Formation is highly variable corresponding to the stratigraphic succession. The lowermost part is formed by light grey, light brown and greenish soft (*Globigerina*) marls, followed by laminated light and dark brown marls and shales with layers of black-brown bituminous clay, sometimes bituminous coal. Upsection follow grey, non-calcareous, diatomaceous shales, diatomites, and chert layers (menilites). The top part is formed by whitish to light grey massive marls and layers of silicified marlstone (nannoplankton ooze) (see members for detailed description).

Fossils: Rich nanno- and microfossil assemblages are reported, the macrofauna is very scarce (SEIFERT et al., 1991; RÖGL et al., 2001). For details, see description of the members.

Origin, facies: SEIFERT (1982) considered the deposition of the Ottenthal Formation in shallow, lagoonal waters with restricted connection to the open sea, and the coaly layers were interpreted as mangrove swamp deposits. Based on a re-interpretation of the foraminiferal fauna and nannoplankton, these sediments were, however, deposited in deep water on the outer shelf to slope. Due to the constriction of the Paratethys from the open ocean during the late Eocene a change from open marine to reduced marine conditions resulted.

Chronostratigraphic age: Late Eocene (?), late Priabonian (?) to early Oligocene, early Rupelian (early Kiscellian).

The basal part of the Ottenthal Formation is not exposed, therefore it is possible that the Eocene-Oligocene boundary occurs in its lower part.

Biostratigraphy: Calcareous nannofossil Zones NP21–NP23; planktonic foraminifera Zones P18 (or earlier) to P20.

Based on calcareous nannoplankton, the sediments of the Ottenthal Formation have been considered upper Eocene to lower Oligocene (GRILL, 1953, 1968; STRADNER, 1962b; SEIFERT, 1982). The studies by SEIFERT et al. (1991) at the type section indicate NP22–NP24, that of RÖGL et al. (2001) at the type section and at the section Staglgraben, near Altruppersdorf, NP21 to NP23, and planktonic foraminifera Zone P18 (or earlier) to P20 (estimated). The nannofossil Zone NP21 crosses the Eocene/Oligocene boundary, but Eocene marker species have not been recorded in the foraminiferal fauna.

Thickness: The outcropping thickness at the type locality was > 60 m according to SEIFERT (1980: p. 182) but actual thickness is 14–15 m (RÖGL et al., 2001).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Ottenthal Formation is subdivided into three members: Ottenthal Member, Galgenberg Member, and Dynów Marlstone (see below).

Underlying unit(s): Reingruberhöhe Formation and "Schieferige Tonmergel", in tectonic contact.

Overlying unit(s): In the type and reference sections overlain by Thomasl Formation either gradational, erosional or in tectonic contact; Pleistocene gravels, transgressive; otherwise only in tectonic contact.

Lateral unit(s): Not recorded due to tectonic disturbance.

Geographic distribution: In Lower Austria the Ottenthal Formation is restricted to the Waschberg Unit between Ernstbrunn and the boundary between Austria and Czech Republic.

The unit continues to the NE into Moravia (Czech Republic) as already mentioned by JÜTTNER (1938a, b); RÖGL et al. (1997, 2001) and KRHOVSKY et al. (2001) correlate the Pouzdřany Formation and parts of the Uherčice Formations of the Pouzdřany Unit and parts of the Němčice Formation and "Menilitic formation" of the Ždánice Unit with the Ottenthal Formation.

Remarks: The Dynów Marlstone, uppermost member of the Ottenthal Formation, has a very widespread distribution but an inconsistent lithostratigraphic positioning (see below).

Complementary references: Kuehn (1962), Cicha et al. (1963), Braunstein (1985), Perch-Nielsen et al. (1985), Wessely (1998, 2006), Krhovsky et al. (2001), Roetzel (2002, 2009), Rögl et al. (2009), Gebhardt (2018b), Pupp et al. (2018).

Ottenthal-Subformation (Ottenthal-Formation) / Ottenthal Member (Ottenthal Formation)

Fred Rögl

Validity: Valid; introduced and formalized by Rögl et al. (2001: p. 330) as Ottenthal Member, to formally separate the Globigerina marls of the Ottenthal Formation from similar lithologic units.

Type area: Between the villages Ottenthal and Altruppersdorf, WNW–NNW of the town Poysdorf (Lower Austria) and SW of the town Mikulov (Czech Republic). ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 24 Mistelbach, 25 Poysdorf).

Type section: The outcrop extends along the small road between the villages Ottenthal and Kleinschweinbarth, at the east side of the village Ottenthal in the common "Untere Leithen", Lower Austria. The section is located between N 48°45′33.6″ / E 16°34′52.6″, 251 m a.s.l., and N 48°45′31.6″ / E 16°34′56.0″, 264 m a.s.l. Since the succession is tectonically strongly disturbed and imbricated the lower part of the Ottenthal Member occurs in the section between 0.00–1.25 m and 43.60–47.00 m; the upper part between 1.25–3.10 m, 5.50–7.80 m, 14.00–17.40 m, and 35.50–41.70 m (Rögl et al., 2001: p. 330, Fig. 2). The base of the Ottenthal Member is not exposed; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen).

Reference section(s): "Waldweg section", at the east side of the village Ottenthal in the common "Untere Leithen" parallel to the type section; the section provides better information on facies and boundaries. Section location between N 48°45′34.9″ / E 16°34′53.3″, 261 m a.s.l., and N 48°45′33.2″ / E 16°34′55.6″, 266 m a.s.l. The succession is tectonically strongly disturbed and imbricated and the Ottenthal Member occurs in the section between 18.20–32.60 m (Rögl et al., 2001: p. 330, Fig. 4); ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 24 Mistelbach).

Locality "Staglgraben", at a creek near a water reservoir, E of the village Altruppersdorf, c. 8 km SSW of Ottenthal, Lower Austria; N 48°41′45″ / E 16°33′29″. This section exposes the lower part of the Ottenthal Formation in Globigerina marl facies and substitutes the lower part of the now overbuilt type section.

Derivation of name: Named after the village Ottenthal, c. 11 km NNW of the town Poysdorf, c. 5 km W of Drasenhofen, c. 5 km south of the border between Austria and the Czech Republic, Weinviertel district, Lower Austria.

Synonyms: Bunte Tone, Pausramer Schiefer, Menilitschiefer, Niemtschitzer Schichten (Jüttner, 1938a, b), Globigerinenschichten p.p. (Grill, 1953), Mergel und bunte Tone des Obereozäns p.p. (Grill, 1968), Ottenthaler Schichten p.p. (Seifert, 1982).

Lithology: The lower part of the member consists of light grey to light brown Globigerina marls, the upper part are cyclically alternating yellowish brown to dark brown, banded and laminated, more clayey marls with black-brown bituminous clay layers. Silt laminae and layers with pteropods occur, and in the uppermost part diatomaceous shales are interbedded.

Fossils: In the light coloured *Globigerina* marls and in the yellowish layers of the banded marls, calcareous nannoplankton and planktonic foraminifera are divers and occur in rock-forming quantities. A detailed description gives Rögl et al. (2001).

The benthic foraminiferal fauna in the lower part is diverse with agglutinated and calcareous species. In the laminated part benthic foraminifers are scarce and small. Only in pteropod-layers, richer assemblages occur, with normal sized *Bulimina sculptilis*, an index fossil for the lower Oligocene.

In a few horizons of the laminated part, the pteropod *Limacina* ("*Spiratella*") is common, but badly preserved. On the bedding planes fish teeth and bones are common.

Origin, facies: The lower Oligocene *Globigerina* marl facies (widespread along the Carpathian arch) represents open marine conditions with oxygenated bottom waters. During the deposition of the laminated marls and shales a stronger seasonality with wet periods forced changes in calcareous nannoplankton production with light and dark brown laminae. Circulation was reduced, intense stratification caused dysoxic bottom water conditions and high organic production, culminating in the deposition of black bituminous clay and sapropel layers (Krhovsky et al., 1993).

Chronostratigraphic age: Late Eocene (?), late Priabonian (?) to early Oligocene, early Rupelian (?early Kiscellian).

Remark: The basal part of the Ottenthal Member is not exposed, therefore it is possible that the Eocene-Oligocene boundary occurs in its lower part.

Biostratigraphy: Nannofossil Zones NP21–NP22; planktonic foraminifera Zones upper P18/O1 to lower P19/O2 (after Berggren & Pearson, 2005).

The base of the Ottenthal Member is not exposed. In the lowermost part, e.g., at Staglgraben, Altruppersdorf, nannofossil Zone NP21 is reported and this zone extends over the Eocene-Oligocene boundary. In terms of planktonic foraminifers, no marker for the boundary is present and the fauna corresponds to planktonic foraminifera Zone P18/O1 of Berggren & Pearson (2005). In the type section at Ottenthal the Globigerina marls show nannofossil Zone NP22 as well as all the banded marls of the upper part of the member. A detailed zonation by means of foraminifera is not possible.

Thickness: Estimated in the type section for about 8–10 m, but strongly reduced by tectonics.

Lithostratigraphically higher rank unit: Ottenthal Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Reingruberhöhe Formation and “Schieferige Tonmergel”, in tectonic contact.

Overlying unit(s): Galgenberg Member of the Ottenthal Formation.

Lateral unit(s): -

Geographic distribution: See Ottenthal Formation.

Remarks: The Ottenthal Member can be correlated with Units A and B of the Schöneck Formation (SCHULZ et al., 2002) in the NAFB of Upper Austria.

Complementary references: THENIUS (1962, 1974), KRHOVSKY et al. (2001), WESSELY (2006), RÖGL & HANSEN (2009).

Galgenberg-Subformation (Ottenthal-Formation) / Galgenberg Member (Ottenthal Formation)

FRED RÖGL

Validity: Valid; RÖGL et al. (2001) introduced the Galgenberg Member for diatomites and cherts (menilites) of the Ottenthal Formation. The first record of menilites (“Menilitschiefer”) in the Waschberg Unit was published by GLAESSNER (1931: p. 10) from the locality “Jungfrau-Föhren” (designated as type section by RÖGL et al., 2001).

Type area: Between the villages Ottenthal and Altruppersdorf, WNW–NNW of the town Poysdorf (Lower Austria) and SW of the town Mikulov (Czech Republic). ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 24 Mistelbach, 25 Poysdorf).

Type section: Section along an old sunken road in the direction from Falkenstein to the wooded area of “Jungfrauföhren”, c. 2 km SW of Falkenstein, W of the hill Galgenberg (425 m), Lower Austria. HERLICSKA (1989: p. 88) recorded it as section D and described and figured the outcrop, RÖGL et al. (2001: Fig. 6) gave a detailed description; N 48°42′29″ / E 16°34′02″. ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 24 Mistelbach).

Reference section(s): “Waldweg section”, at the east side of the village Ottenthal in the common “Untere Leithen”. Section location between N 48°45′34.9″ / E 16°34′53.3″, 261 m a.s.l., and N 48°45′33.2″ / E 16°34′55.6″, 266 m a.s.l. The succession is tectonically strongly disturbed and imbricated and the Galgenberg Member occurs in tectonic wedges IV and V p.p. (14.60–18.20 m), upper part of wedge IX (32.60–33.50 m), and wedge X (33.50–38.15 m) according to RÖGL et al. (2001: p. 332, Fig. 4). The lower boundary to the underlying Ottenthal Member is preserved in wedge IX; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen).

Derivation of name: Named after the nearest landmark to the type section, the hill Galgenberg (425 m), c. 1 km S of the village Falkenstein, c. 5.5 km NW of Poysdorf, Weinviertel district, Lower Austria.

Synonyms: (partim) Menilitschiefer (GLAESSNER, 1931), Menilitschiefer und Diatomite (GRILL, 1968: p. 43), Menilitschichtenfolge (STRÁNÍK, 1997).

Lithology: Grey to brown, non-calcareous, diatomaceous thin-bedded shales and claystones, light grey laminated diatomites, and red-brown laminated cherts.

Fossils: The diatomites and shales are mostly barren of calcareous fossils, but contain marine diatoms in the lower part of the member and blooms of *Aulacoseira prae-islandica* in the upper part; in the basal part also nasselariid radiolarians occur. Abundant archaeomonads co-occurring with silicoflagellates have been studied by BRAUNSTEIN (1985) differentiating four assemblages. Only in very few layers of shales calcareous nannoplankton was observed and foraminifera.

Origin, facies: The shales at the base of the Galgenberg Member show normal marine conditions by the presence of calcareous nannoplankton, foraminifera, and radiolaria in thin layers. The lower part of the diatomites is also fully marine, whereas in the upper part the conditions changed to reduced salinity. Blooms of the brackish diatom species *Aulacoseira* show lowered salinity (c. 15 psu), what is supported by corresponding archaeomonad assemblages.

In comparison with the Chert Member of the Menilitic Formation in the Ždánice Unit astronomically influenced depositional cycles formed the lower part of the diatomites during a dryer period, whereas in the upper part wetter conditions prevailed (KRHOVSKY, 1995).

Chronostratigraphic age: Early Oligocene, early Rupelian (early Kiscellian).

Biostratigraphy: Calcareous nannofossil Zones upper NP22 to lower NP23.

The range is defined by the underlying upper part of the Ottenthal Member and the overlying Dynów Marlstone.

Thickness: At the type locality a minimum of 12 m, but reduced by tectonics.

Lithostratigraphically higher rank unit: Ottenthal Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Ottenthal Member.

Overlying unit(s): Dynów Marlstone.

Lateral unit(s): -

Geographic distribution: See Ottenthal Formation.

Remarks: The Galgenberg Member can be correlated with Unit C of the Schöneck Formation (SCHULZ et al., 2002) in the NAFB of Upper Austria. Instead of diatomites, black shales with a high TOC content have been deposited in the NAFB.

Complementary references: JÜTTNER (1938a), STRADNER & SEIFERT (1980), SEIFERT (1982), KRHOVSKY et al. (2001), WESSELY (2006).

Dynów Mergel (Ottenthal-Formation) /
Dynów Marlstone (Ottenthal Formation)

WERNER E. PILLER & FRED RÖGL

Validity: Invalid (see remarks); named and described by KOTLARCZYK (1966: p. 30) as whitish silicified marls and cherts in the Dukla Unit of the eastern Polish Carpathians. WÓJCIK et al. (1996), when formalizing many units in the Polish Carpathians, considered the Dynów Marls as a member (Dynów Member) of the Menilite Formation. A detailed study of the type section was carried out by GÓRNIAK (2012). See also discussion and description for the NAFB in Upper Austria.

Type area: In the area of Błażowa–Dynów, between Rzeszów and Przemyśl, Skole Unit, Polish Carpathians (KOTLARCZYK, 1985; KOTLARCZYK et al., 1985; GÓRNIAK, 2012).

Type section: Abandoned Quarry located on the western slope of the Łysa Góra in the Straszydle Village, c. 9 km WNW of Błażowa and 20 km NW of Dynów, Poland (N 49°54′06″ / E 22°00′17″). Exposed is a 22 m thick section with 15 m of compact marl overlain by a slump (GÓRNIAK, 2012: p. 250ff., Fig. 18).

Reference section(s): For the Waschberg Unit the best outcrop occurs at the "Waldweg section", at the east side of the village Ottenthal in the common "Untere Leithen", Lower Austria. Section location between N 48°45′34.9″ / E 16°34′53.3″, 261 m a.s.l., and N 48°45′33.2″ / E 16°34′55.6″, 266 m a.s.l. The succession is tectonically strongly disturbed and imbricated and the Dynów Marlstone occurs in tectonic wedges I (0.00–4.10 m), III (12.50–14.60 m) and XI (38.15–43.05 m) according to RÖGL et al. (2001: p. 317, Fig. 4); ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen).

Derivation of name: Named after the town Dynów, c. 40 km west of the town Przemyśl, Subcarpathia Province, Poland.

Synonyms: Menilitic Formation p.p.

Lithology: In the Waschberg Unit the Dynów Marlstone is a bedded (10–20 cm), white to light grey, partly silicified marl or marlstone (nannoplankton ooze) with brown chert layers. Besides calcareous nannoplankton diatoms occur which cause silicification of distinct layers.

Fossils: The Dynów Marlstone was deposited as calcareous nannoplankton ooze, composed of very few species of calcareous nannoplankton (dominated by *Reticulofenestra ornata*). Characteristic is the occurrence of a small-sized endemic bivalve fauna, the so-called *Janschinella* fauna, together with the CNP species *Transversopontis fibula* and smooth shelled ostracods (Cyprididae). In the Waschberg Unit a high content of diatoms, preserved mainly as casts, occur.

Origin, facies: The high amount of rock forming calcareous nannoplankton is an indication of high productivity in the upper water column, the low diversity points to a decrease in salinity due to increasing fresh water ingressions (BÁLDI, 1984; RÖGL, 1998; SCHULZ et al., 2004). Missing bottom life was caused by anoxic bottom water. The Dynów Marlstone in the Waschberg Unit is strongly influenced by blooms of brackish diatoms, resulting in chert layers by solution of silica (KRHOVSKY et al., 2001).

The unit represents a major break in the Paratethys evolution when the connections to the Mediterranean and Indian Ocean were lost and the Paratethys became isolated, salinity was reduced and widespread endemic biota evolved (Solenovian Event).

Chronostratigraphic age: Early Oligocene, Rupelian (middle Kiscellian).

The deposition of the Dynów Marls can be correlated with the regional Solenovian stage of Eastern Paratethys chronostratigraphy. The occurrence of this very specific unit is also known as "Solenovian Event" which can be traced and correlated Paratethys-wide.

Biostratigraphy: Calcareous nannofossil Zone NP23 (KRHOVSKY, 1981).

Thickness: In the Ottenthal section only a few meters.

Lithostratigraphically higher rank unit: In the Waschberg Unit the Ottenthal Formation.

Lithostratigraphic subdivision: No subdivision in the Waschberg Unit.

Underlying unit(s): In the Waschberg Unit the Galgenberg Member.

Overlying unit(s): Thomasl Formation in erosive contact.

Lateral unit(s): Not recorded in the Waschberg Unit.

Geographic distribution: In the NAFB the Dynów Marlstone is widely distributed from Bavaria, Salzburg, and Upper Austria to the Waschberg Unit in Lower Austria. In some areas (wells) the unit is missing due to submarine erosion (SCHULZ et al., 2004; SACHSENHOFER & SCHULZ, 2006).

Superregionally, the calcareous nannoplankton chalk facies of the Dynów Marl is distributed over the Central Paratethys from Bavaria to the Carpathian arch to the Transylvanian Basin (KRHOVSKY et al., 2001; POPOV et al., 1993, 2004; RÖGL et al., 1997; RUSU et al., 1996) and it extends in the Eastern Paratethys as far as to the North Ustyurt Basin of the Greater Caspian Region in Asia (POPOV et al., 1993).

Remarks: The lithostratigraphic rank and position of the Dynów Marl(stone) is highly inconsistent in respect to its regional occurrence. In the type area it is defined as a member of the Menilite Formation, in the Waschberg Unit it is a member within the Ottenthal Formation (but named Dynów Marlstone). However, the Ottenthal Formation consists of three members – Ottenthal Member, Galgenberg Member, Dynów Marlstone (member) and the latter is on top of the Ottenthal Formation. In Upper Austria the Dynów Marl was raised in rank to a formation (Dynów Formation: WAGNER, 1996b; RUPP, 2008b, 2009a, 2011a; SACHSENHOFER et al., 2010a). In Bavaria, the term "Heller Mergelkalk" is still in use (e.g., DOPPLER et al., 2005). These different treatments need a re-evaluation of the unit, both from a formal perspective (member vs. formation) and also the retention of the same name in very distant geological regions. Due to these problems and until their clarification, the name Dynów Marl(stone) is still be used herein.

Complementary references: KOTLARCZYK & LEŚNIAK (1990), KOTLARCZYK et al. (1991), KRHOVSKY et al. (2001), WESSELY (2006).

Thomasl-Formation / Thomasl Formation

Fred Rögl & Werner E. Piller

Validity: Valid; for middle Oligocene (Egerian) sediments drilled in the Waschberg Unit Papp et al. (1978) introduced the name "Thomasler Schichten"; based on surface outcrops and a restudy of drill cores the unit was revised by Fuchs et al. (2001a) and defined as Thomasl Formation.

Type area: Surface outcrops occur between the villages Ottenthal and Altruppersdorf, WNW–NNW of the town Poysdorf (Lower Austria) and SW of the town Mikulov (Czech Republic). ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 24 Mistelbach, 25 Poysdorf).

Type section: Deep well Thomasl 1, 1,636–1,770 m (core 3: 1,760–1,765 m; Fuchs et al., 2001a), OMV-AG., c. 500 m ENE of the village Thomasl, c. 3.5 km ENE of the marked village Ernstbrunn, Weinviertel district, Lower Austria; N 48°32′01.70″ / E 16°24′15.94″; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach). Only a reduced part of the core is preserved.

Reference section(s): Deep well Poysdorf 2, 2,801–2,892 m (Core 21: 2,813–2,817.5 m; Fuchs et al., 2001a), OMV-AG., c. 2 km NNE of the town Poysdorf, Weinviertel district, Lower Austria; N 48°41′08.22″ / E 16°38′17.62″; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheet 25 Poysdorf). Only a reduced part of the core is preserved; ÖK50-UTM, map sheet 5308 Laa an der Thaya (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 25 Poysdorf).

Surface outcrop "Waldweg section", at the east side of the village Ottenthal in the common "Untere Leithen"; the section includes slumps corresponding to the Šitbořice Event (see below). Section location between N 48°45′34.9″ / E 16°34′53.3″, 261 m a.s.l., and N 48°45′31″ / E 16°34′54″, 266 m a.s.l. The succession is tectonically strongly disturbed and imbricated and the Thomasl Formation occurs in the section in several slices but the basal part (including the Šitbořice Event) occurs between 4.10–12.50 m (Rögl et al., 2001: p. 309, Fig. 4).

Derivation of name: Named after the village Thomasl (and deep drill Thomasl 1), c. 3.5 km ENE of the marked village Ernstbrunn, Weinviertel district, Lower Austria.

Synonyms: Bunte Tone, Pausramer Schiefer, Menilitschiefer, Niemtschitzer Schichten (Jüttner, 1938a, b), Mergel und bunte Tone des Obereozäns p.p. (Grill, 1968: p. 44), Thomasler Schichten (Papp et al., 1978), Ottenthaler Schichten p.p. (Seifert, 1982: p. 139). All mentioned descriptions include variegated shales with a high amount of gypsum, what is characteristic for the Thomasl Formation.

Lithology: Variegated, dark brownish-grey, dark greenish-grey, and black-grey, fissile calcareous shales and clays, with thin sandstone layers and silty bedding planes; occasionally with thin beds of grey marl and whitish calcareous mudstone. Glauconite, pyrite nodules, and gypsum crystals are common. In the surface outcrops pyrite is probably reduced by weathering to jarosite and gypsum (Pupp et al., 2018).

Fossils: In the calcareous shales calcareous nannoplankton is common, in particular with blooms of *Reticulofenestra lockeri* and *R. hesslandii* in the light coloured marly layers. The foraminiferal fauna is diversified in the calcareous shales, commonly with large planktonic forms but also small globigerinids occur. Benthic foraminifera show a distinct amount of deep water agglutinated forms but also calcareous taxa are encountered. Additionally, pyritized diatoms and fish remains occur.

Origin, facies: The deposition of the Thomasl Formation was influenced by periods of dysaerobic bottom water conditions and sedimentation of non-calcareous sediments. The layers of light coloured marls are caused by calcareous nannoplankton blooms and can be compared with those of the Šitbořice Member (Krhovsky & Djurasinovič, 1993). Upsection, diversified foraminiferal faunas demonstrate the re-establishment of full-marine conditions in the Paratethys. Benthic foraminifera indicate a progressive deepening from the outer shelf (e.g., Ottenthal sections) to a deep-water environment of upper to middle bathyal depth in Thomasl 1. A distinct environmental change occurred between the deposition of the Dynów marlstone and the Thomasl Formation. In the lower part of the Ottenthal "Waldweg section" a horizon exists with xenoclasts and pebbles of Dynów Marlstone. This is considered to be an equivalent to a discontinuity with an erosional surface and pebble layer at the base of the Šitbořice Member in the Ždánice Unit, called the Šitbořice Event (Krhovsky & Djurasinovič, 1993).

Chronostratigraphic age: Oligocene, early Rupelian (late Kiscellian) to early Chattian (early Egerian).

Biostratigraphy: Calcareous nannofossil Zones upper NP23 to lower NP25 (?); planktonic foraminifera with *Paragloborotalia opima opima* give a stratigraphic range between Zones P20/O3 to P21b/O5 (Berggren & Pearson, 2005; Wade et al., 2011). For regional correlation benthic foraminiferal assemblages are used (e.g., *Praeglobobulimina bathyalis, Bolivina crenulata, Uvigerina multistriata, U. steyri, Alabamina wolterstorffi, Anomalinoides granosus*).

Thickness: In the type section of deep well Thomasl 1 the formation has a thickness of 127 m, but is tectonically reduced.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): In the Ottenthal sections concordant, partly with a transgressive base, underlain by the Dynow Marlstone of the Ottenthal Formation. Commonly in a tectonic position, e.g., in deep well Thomasl 1 with lower Eocene marls, in Poysdorf 2 with the Upper Cretaceous Klement Formation.

Overlying unit(s): Tectonic contact with lower Miocene (Eggenburgian) "Schieferige Tonmergel".

Lateral unit(s): -

Geographic distribution: The Thomasl Formation is restricted to the Waschberg Unit of Lower Austria (see type area). To the west into the NAFB, the lower part of the Thomasl Formation can be correlated with the Eggerding Formation, the upper part with the Zupfing Formation. In the Ždánice Unit the lower part of the Thomas Formation correlates with the Šitbořice Member of the Menilite Formation and the upper part with the Ždánice-Hustopeče Formation (Krhovsky et al., 2001; Fuchs et al., 2001a; Pupp et al., 2018).

Remarks: -

Complementary references: Rögl et al. (2001, 2009), Roetzel (2002, 2009), Wessely (2006), Berka (2015).

Michelstetten-Formation / Michelstetten Formation

Fred Rögl & Werner E. Piller

Validity: Invalid; Grill (1952) introduced the term "Michelstettener Schichten" for beds with *Vulvulina pennatula* which he considered to be lower Oligocene; in 1953 and 1968, Grill provided more detailed descriptions. Papp (1961) defined a type locality, described the foraminiferal fauna and supposed an Aquitanian age for the "Michelstettener Schichten". Fuchs et al. (1980) described "Michelstettener Schichten" from several drill holes in the Waschburg Unit, Krhovsky et al. (2001) introduced the name Michelstetten Formation and Rögl & Nagymarosy (2004) gave a detailed description of nanno- and microfossils.

Type area: Outcrops occur in the vicinity of the villages Michelstetten, Pyhra, and Klement and the hamlet Haidhof near the market town Ernstbrunn, Weinviertel district, Lower Austria. The formation extends along a tectonic line in SW–NE direction along the outer border of the Klippen belt with Jurassic and Cretaceous rocks (Grill, 1953; Papp, 1961) what is documented in several drill holes (Fuchs et al., 1980). ÖK50-UTM, map sheets 5313 Hollabrunn, 5314 Mistelbach (ÖK50-BMN, map sheets 23 Hadres, 24 Mistelbach).

Type section: Section ca. 1.2 km NW of Michelstetten along a cart road from the village Michelstetten to the village Phyra (Papp, 1961: p. 210), Weinviertel district, Lower Austria. The section was exposed along a cut for about 100 m, N of the common "Am Sand" (eastern end of the section at N 48°35′37″ / E 16°24′56″), but the cart road has been filled. Rögl & Nagymarosy (2004) gained samples by hand drilling in the immediate vicinity of the type section. ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

Reference section(s): -

Derivation of name: Named after the village Michelstetten, 5 km W of the market town Asparn an der Zaya, 11 km WNW of the town Mistelbach, Weinviertel district, Lower Austria.

Synonyms: Michelstettener Schichten (Grill, 1952), Michelstettener Schichten (Pausramer Mergel) (Thenius, 1962), Michelstettener Serie (Brix et al., 1977), Michelstetten beds (Stráník et al., 1981); the sediments of the Michelstetten Formation were probably included in the "Auspitzer Mergel" in the older literature.

Lithology: Light grey, grey-brown, greenish, sandy-silty, micaceous marls with a knobby weathering and dolomite concretions. In deep wells (e.g., Roseldorf), where the complete thickness was drilled, dominating sand, sandstone and gravels with intercalated marls have been recorded (Fuchs et al., 1980).

Fossils: Calcareous nannoplankton from the type area at Michelstetten shows medium high diversity (Krhovsky et al., 2001; Rögl & Nagymarosy, 2004). The foraminiferal fauna shows rich and diversified assemblages with large benthic specimens and a high number of plankton (Papp, 1961), in particular with *Cassigerinella* (Rögl & Nagymarosy, 2004). The later authors also recorded *Uvigerina popescui* as very abundant in some samples, what correlates well with similar occurrences in the Transylvanian Basin and in the Pouzdřany Unit. Macrofossils occur as molluscs as mentioned by Grill (1968).

Origin, facies: The foraminiferal assemblages indicate a deposition in the upper bathyal of a deeper basin. The coarse clastics in deep wells are interpreted either as coastal near deposits (Fuchs et al., 1980) or as transported by mass flows (Rögl & Nagymarosy, 2004). Since the foraminiferal faunas are not different between the fine and coarse clastics mass flow deposits are more probable.

Chronostratigraphic age: Late Oligocene, late Chattian to early Miocene, Aquitanian to early Burdigalian (late Egerian to early Eggenburgian).

Biostratigraphy: In deep wells calcareous nannofossil Zone NP25 is reported, in the outcrops of the type area at Michelstetten only Zones NN1 and NN2 are recorded. The foraminiferal assemblages with *Globorotalia praescitula* indicate Zone N5 and *Uvigerina popescui* indicates an Eggenburgian age for the uppermost part (Krhovsky et al., 2001; Rögl & Nagymarosy, 2004).

Thickness: In deep wells 100–150 m (Fuchs et al., 1980).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Only tectonic contacts.

Overlying unit(s): Only tectonic contacts.

Lateral unit(s): The Michelstetten Formation grades into or interfingers with the Boudky Formation (exposed in the old Ernstbrunn brickyard: Rögl & Nagymarosy, 2004). Such a transitional facies was also exposed W of Haidhof near Ernstbrunn.

Geographic distribution: Restricted to the Waschberg Unit in Lower Austria (see type area). A continuation towards the Pouzdřany Unit is reported for the lower Miocene Boudky Formation (Stráník et al., 1981; Roetzel, 2002).

Remarks: The sediments of the brickyard Ernstbrunn were considered to belong to the "Auspitzer Mergel" (e.g., Grill, 1953) but are now part of the Michelstetten Formation (Rögl & Nagymarosy, 2004).

Complementary references: Thenius (1974), Stráník (1996a), Novák & Stráník (1998), Wessely (2006), Roetzel (2009).

Ždánice-Hustopeče-Formation / Ždánice-Hustopeče Formation

Fred Rögl & Werner E. Piller

Validity: Valid; Rzehak (1881: p. 216) reported "… blauen Thonmergel … bei Auspitz" and "Sandsteine und Mergel des "Auspitzer Berglandes"" and Paul (1891: p. 228) introduced "Steinitzer Sandstein" for beds in the region of Ždánice (german name: Steinitz), Southern Moravia. Kohn (1911) described "blockführende Horizonte" within the

"Auspitzer Mergel". GLAESSNER (1931: p. 10) reported an alternation of "Auspitzer Mergel (Schlierfazies), Steinitzer Sandstein und Blockhorizonten und einzelnen Partien von Menilitschiefer" for Oligocene sediments and united 1937 the so-called "Auspitzer Mergel" with fish remains and the "Steinitzer Sandstein" with interbedded "Blockschichten" (Boulder beds) and conglomerates to the "Steinitzer Serie". For these sediments the descriptive "Schieferige Tone und Tonmergel (Auspitzer Mergel)" was introduced by GRILL (1962b), and he proposed (GRILL, 1968: p. 51) to shorten the term to "Schieferige Tonmergel". Due to great lithological similarities, the "Schieferige Tonmergel" should be considered part of the Ždánice-Hustopeče Formation of the Ždánice Unit (ROETZEL, 2002, 2009: p. 15). This term was introduced by CHMELÍK & MATĚJKA (in KALASEK, 1963: p. 120) subsuming the Hustopeče (Auspitzer) marl and the Ždánice (Steinitzer) sandstone. In this description we will mostly refer to the occurrences in the Lower Austrian Waschberg Unit.

Type area: The type area is located between Ždánice and Hustopeče in Southern Moravia, Czech Republic.

In the Waschberg Unit of Lower Austria it is the most widespread formation: ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5313 Hollabrunn, 5314 Mistelbach (ÖK50-BMN, map sheets 10 Wildendürnbach, 11 Drasenhofen, 23 Hadres, 24 Mistelbach, 25 Poysdorf, 40 Stockerau, 41 Deutsch Wagram).

Type section: No information.

Reference section(s): -

Derivation of name: Named after the towns Ždánice (german name: Steinitz) (N 49°04′02″ / E 17°01′39″), c. 10 km NW of Kyjov, and Hustopeče (german name: Auspitz) (N 48°56′27″ / E 16°44′15″), c. 25 km NW of Břeclav, Southern Moravia, Czech Republic.

Synonyms: Auspitzer Mergel, Steinitzer Sandstein, blockführende Horizonte (PAUL, 1891), Steinitzer Serie (GLAESSNER, 1937), Schiefrige Tone und Tonmergel (Auspitzer Mergel) (GRILL, 1962b), Blockschichten (HOLZER & KÜPPER, 1953), Tonmergelserie (THENIUS, 1962, 1974), Ernstbrunner Tonmergelserie (BRIX & GÖTZINGER, 1964), Ždánicer-Hustopečer-Schichtenfolge (CICHA et al., 1963), Schieferige Tonmergel, Altmannser Grobsande p.p., Ameiser Sand p.p. (GRILL, 1968), Ždánicer-Hustopečer-Schichten (Steinitz-Auspitzer Schichten) (CICHA, 1975), (partim) Blocky Layers (GEBHARDT, 2021).

Remark: The term "Ernstbrunner Tonmergelserie" was proposed by BRIX & GÖTZINGER (1964) for the clays of the Ernstbrunn brickyard, however, the name was considered too similar to the Jurassic Ernstbrunn Limestone ("Ernstbrunner Kalk") (GRILL, 1968: p. 51). Since the clays of Ernstbrunn are now considered part of the Boudky Formation (RÖGL & NAGYMAROSY, 2004) this problem vanished.

Lithology: The formation includes a broad spectrum of lithologies: light grey to greenish-grey, weathered light yellowish-grey, silty clays and clayey marls, well bedded with sandy bedding planes (representing the "Auspitzer Mergel"). In places with thin layers of diatomite and chert (menilite). Intercalated in the marls are micaceous, calcareous sandstone layers from decimeter to meter thickness, commonly graded and with ripple marks (representing the "Steinitzer Sandstein"). In the area of the village Altmanns larger areas with coarse sandstone intercalations were differentiated by GRILL (1968: p. 48) as "Altmannser Grobsande" and in the deep drill Ameis 1 a 200 m-thick alternation of sands and clayey marls were named "Ameiser Sand".

A specific phenomenon are the so-called "Blockschichten" (Boulder beds) which are intercalated in the marls. At the Hollingstein exotic boulders (composed of mica schists, gneiss, amphibolite, granite, marble, flysch sandstone, Hollingstein Limestone) occur within a brown marly-sandy matrix (HOLZER & KÜPPER, 1953). In addition, in the region between Waschberg and Praunsberg giant blocks (several meters length) of granite occur (KOHN, 1911). The "Blockschichten" are depicted as separate lithostratigraphic unit by ROETZEL (2002) in the geological map of Lower Austria (SCHNABEL, 2002a). GEBHARDT (2021: p. 52) reported an intercalation of the "Blocky Layers" with the fine-grained sediments of the Ždánice-Hustopeče-Formation.

Fossils: The sediments of the Ždánice-Hustopeče Formation are very poor in fossils, besides fish scales. GRILL (1968) reported benthic and planktic foraminifers from the deep well Ameis 1. In the marls with diatomitic layers, a small siliceous assemblage was found at the Hollingstein with diatoms, silicoflagellates, ebridiids, few radiolarian and sponge spicules (KRHOVSKY et al., 2001).

Remark: RZEHAK (1888a) reported a small microfauna which he already considered reworked from the underlying Eocene. The rich microfaunas reported by GRILL (1953, 1968) come probably all from the Boudky Formation.

Origin, facies: The pelites and sandstones point to a flysch-type deposition in a deep marine environment with slumping and sliding structures as well as turbidity currents with proximal-distal gradient. The Boulder beds ("Blockschichten") are considered to represent gravitationally transported debris flows (STRÁNÍK et al., 2007; GEBHARDT, 2021).

Chronostratigraphic age: Early Miocene, Aquitanian to Burdigalian (late Egerian to Eggenburgian) for the occurrences in the Ždánice Unit (KRHOVSKY et al., 2001) and early Miocene, Burdigalian (Eggenburgian–Ottnangian) in the Waschberg Unit (KRHOVSKY et al., 2001).

Since reliable biostratigraphic data are missing, the age of this unit is still under discussion.

Biostratigraphy: From the type area of the Ždánice Unit calcareous nannofossil Zones NP24/25–NN2 are reported (CICHA et al., 1971; MOLČÍKOVÁ & STRÁNÍK, 1987; KRHOVSKY et al., 2001), from the Waschberg Unit KRHOVSKY et al. (2001) and GEBHARDT (2021) mention NN2–NN3.

Remark: The clays of the Ernstbrunn brickyard have been the key for GRILL's stratigraphic assignment of the "Schiefrige Tonmergel" to the Eggenburgian. The Ernstbrunn clay is now considered part of the Boudky Formation and represents nannofossil Zone NN2 (RÖGL & NAGYMAROSY, 2004). Since most of the sediments of the Ždánice-Hustopeče Formation are poor in fossils or even barren biostratigraphic data are also very poor.

Thickness: In the deep well Korneuburg 2 near Niederhollabrunn the "Schieferige Tonmergel" extends for 737.60 m (GRILL, 1953) and KOHN (1911) calculated a thickness of

> 600 m between SW of Karnabrunn and NE of Niederhollabrunn. In the type area of the Ždánice-Hustopeče Formation in Southern Moravia, a thickness of about 1,300 m is reported by Stráník et al. (1991) and of 2,500–3,000 m by Chmelík & Matějka (1963: p. 126).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Since the differentiation between pelites, sandstones and boulder beds cannot be consistently used a definition of members is not possible.

Underlying unit(s): Michelstetten Formation and other units in tectonic contact.

Overlying unit(s): Overlying units are only in tectonic contact.

Lateral unit(s): Boudky Formation (?) and probably also Šakvice Formation (from the Ždánice Unit) in the eastern part of Ernstbrunn.

Geographic distribution: Widespread in the Waschberg Unit of Lower Austria.

Remarks: The Ždánice-Hustopeče Formation is part of the so-called "Krosno lithofacies", "Krosno flysch-type sedimentation" or "Krosno-type flysch facies" which represents the youngest flysch sequence on top of the Western Carpathian Flysch Belt (e.g., Picha et al., 2006; Stráník et al., 2007).

In the ASC 2004 (Piller et al., 2004) this unit is depicted as "Schieferige Tonmergel".

Complementary references: Rzehak (1894), Jüttner (1938a, b), Thenius (1974), Brix et al. (1977), Stráník (1997), Wessely (1998, 2006), Picha & Stranik (1999), Gebhardt & Ćorić (2014), Gebhardt (2018a, b).

Boudky-Formation / Boudky Formation

Fred Rögl & Werner E. Piller

Validity: Valid; the first unequivocal record of this unit was given by Rzehak (1895: p. 222) as "Pausramer Mergel" and "Mergel von Baudeck und Pausram" (1895: p. 234). The term "Pausramer Mergel" has been widely used and also "Pouzdřany Marl" in Czech literature. It was formalized by Cicha (1975: p. 200) and he renamed it to "Boudky Schichten" (Boudky Beds) (also defined as faciostratotype for the middle–upper Egerian ($OM_{c(d)}$)).

Type area: The area around the village Pouzdřany, Southern Moravia, Czech Republic, within the Pouzdřany Unit; ZM 50, map sheet 3412.

Type section: A 200 m-long section at the western slope of the hill Kolby (308 m a.s.l.) within a vineyard, N of the village Pouzdřany, c. 8 km W of the Hustopeče**,** Southern Moravia, Czech Republic (Cicha, 1975: p. 200); N 48°56′58″ / E 16°37′54″; ZM 50, map sheet 3412.

Remark: This section was defined by Cicha (1975) also as a faciostratotype of the middle–upper Egerian ($OM_{c(d)}$).

Reference section(s): -

Derivation of name: Named after the former farm house Boudky (german: Baudeck), today a hamlet, c. 1.5 km north of the market town Velké Němčice (german: Groß Niemtschitz), c. 1.5 km SE of the village Nosislav (german: Nußlau), c. 8 km NE of the village Pouzdřany (german: Pausram), Southern Moravia, Czech Republic.

Synonyms: Pausramer Mergel (Rzehak, 1895), Pausramer Schiefer (Jüttner, 1938a), Boudky-Schichten (Cicha et al., 1965), Boudky Marl (e.g., Stráník et al., 1991), Boudeker Schichten (Cicha et al., 1971), Ernstbrunner Tonmergelserie (Brix & Götzinger, 1964), Boudky Formation (Krhovsky et al., 2001).

Remark: In older literature of the Waschberg Unit the Boudky Formation was included in the "Auspitzer Mergel" (now part of the Ždánice-Hustopeče-Formation).

Lithology: Light grey to dark grey, grey-brown, greenish, sandy-silty, fossiliferous micaceous marl and calcareous clay. Occasionally dolomite or calcareous dolomite concretions (5–40 cm) occur.

Fossils: Calcareous nannoplankton with *Helicosphaera ampliaperta, H. scissura,* and *Sphenolithus conicus* (Krhovsky et al., 1995, 2001). Very abundant siliceous microfossils with diatoms, radiolaria, and sponge spicules. A rich benthic foraminiferal assemblage is described by Cicha (1975) and Krhovsky et al. (1995), the planktonic foraminifera from Kolby Hill and Ernstbrunn have been revised in Krhovsky et al. (2001) and Rögl & Nagymarosy (2004).

Origin, facies: Pelagic sediment, deposited in greater water depth, probably in the upper bathyal. The faunal composition with a large amount of siliceous microfossils and floods of small planktonic foraminifera are related to cooler water masses in a strongly subsiding basin in front of the Carpathian nappes. Shallow water foraminifera (i.e., *Ammonia, Elphidium*) are considered to be reworked.

Chronostratigraphic age: Early Miocene, Aquitanian to early Burdigalian (late Egerian to early Eggenburgian).

Biostratigraphy: Calcareous nannofossil Zone NN2; mass occurrences of *Uvigerina popescui* indicate an Eggenburgian age (Krhovsky et al., 2001; Rögl & Nagymarosy, 2004).

Thickness: At the type locality 40 m (Krhovsky et al., 2001), in deep wells 300 m (Cicha et al. (1963), and Chmelík (1963: p. 103) reports 500–600 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Usually only tectonic contacts. A gradational development from the Michelstetten Formation to the Boudky Formation may occur in the Waschberg Unit.

Overlying unit(s): Only tectonic contacts.

Lateral unit(s): A lateral interfingering or transition between the Michelstetten Formation and the Boudky Formation may occur. Such a transitional facies was exposed in a waste deposit W of the Haidhof near Ernstbrunn.

Geographic distribution: In the Pouzdřany Unit of southern Moravia and in isolated places in the Waschberg Unit, Lower Austria.

Remarks: The stratigraphic position of the Boudky Formation varied strongly from the middle to upper Oligocene (Pokorny, 1955) to the Aquitanian (Cicha et al., 1963), finally to the middle to upper Egerian (Cicha, 1975). Recent results by calcareous nannoplankton and foraminifera confirm the age of late Egerian–Eggenburgian as supposed by STRÁNÍK et al. (1981).

Complementary references: JÜTTNER (1938a, b), PICHA & STRÁNÍK (1999), ROETZEL (2002), PICHA et al. (2006), WESSELY (2006), STRÁNÍK et al. (2007), RÖGL et al. (2009).

Křepice-Formation / Křepice Formation

FRED RÖGL & WERNER E. PILLER

Validity: Valid; GRILL (1962b: p. 29) described "Eisenschüssige Tone und Sande am Außenrande der Waschbergzone" (what has been already documented on the map of Korneuburg and Stockerau in GRILL et al., 1957) for sediments which he compared with the "Oncophora-schichten" in the Tulln Basin, Lower Austria. Based on their lithology and tectonic position, ROETZEL (2009: p. 16) considered this sediments part of the Křepice Formation, originally defined in the Pouzdřany Unit in southern Moravia, Czech Republic (CICHA et al., 1963, 1965; KRHOVSKY et al., 1995; PICHA et al., 2006).

Type area: The area around the village Pouzdřany, Southern Moravia, Czech Republic, within the Pouzdřany Unit; ZM 50, map sheet 3412.

In the Waschberg Unit the formation occurs in a small stripe (2–3 km wide) extending from SE Oberolbersdorf – NW Hatzenbach – SE Senning – E Großmugel – Ottendorf – Maisbirnbaum – Merkersdorf, along the external margin of the Waschberg Unit, the so-called Roseldorf-(Sub)Zone (GRÜN, 1984; WESSELY, 1998); ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheets 40 Stockerau, 23 Hadres).

Type section: Abandoned brickyard at the southern slope of the hill Kolby (308 m), NE of the village Pouzdřany, Southern Moravia, Czech Republic (CICHA et al., 1965: p. 94); N 48°56′45″ / E 16°38′20″; ZM 50, map sheet 3412.

Reference section(s): -

Derivation of name: Named after the village Křepice (german: Krepitz) near Hustopeče (N 48°59′51″ / E 16°43′15″), 6.5 km NNW of the town Hustopeče, 3.5 km ENE of the village Velké Němčice, Southern Moravia, Czech Republic.

Synonyms: Oncophora-Schichten (GLAESSNER, 1930), Oncophoraserie (BRIX et al., 1977), Oncophoraschichten (GRÜN, 1984), Oncophora Beds (ANIWANDTER et al., 1990), Eisenschüssige Tone und Sande (GRILL et al., 1957), Krepice-Schichten, Krepicer Schichten (CICHA et al., 1971).

Lithology: Rhythmic alternation of flysch-type, light grey to yellowish grey and brown grey silty clays to claystones with light grey to yellow, micaceous, calcareous, partly graded, silty, fine to medium sands and sandstones (STRÁNÍK, 1996a, 1997; NOVÁK & STRÁNÍK, 1998). Characteristic are limonitic concretions and thin layers of limonitic siltstones. The thickness of the beds ranges between few centimeters to decimeters. In the Roseldorf area the sands reach thickness of some meters (GRILL, 1962b; NOVÁK & STRÁNÍK, 1998).

Fossils: The sediments are nearly barren of fossils, only plant remains have been reported by GRILL (1962b). In the so-called "Oncophoraserie" of deep well Ameis 1 a poor foraminiferal fauna and some calcareous nannoplankton (*Coccolithus pelagicus*) is mentioned by BRIX et al. (1977). An indistinct micro-assemblage with foraminifera, radiolaria, sponge spicules, and fish remains is mentioned by NOVÁK & STRÁNÍK (1998). Only at the outermost margin of the unit, at the western side of Roseldorf, a small foraminiferal fauna and calcareous nannoplankton were identified in grey-brown calcareous shales and yellowish silts interfingering with the sands (KRHOVSKY et al., 2001).

Origin, facies: The flyschoid character of the sediments and the biota (foraminifera, radiolaria, sponge spicules, and fish remains) indicate deep water deposits.

From several locations and authors a link to the "Oncophora Beds" (= now Oncophora Formation in Upper Austria and Traisen Formation in Lower Austria) has been described (e.g., GLAESSNER, 1930; GRILL, 1953, 1962b, 1968; ANIWANDTER et al., 1990). HAMILTON (1997) could show that these "Oncophora Beds", which are widely known in deep drills, are also turbiditic deep water deposits (without any similarity to the brackish-limnic shallow water sediments of the Traisen Formation). These sediments seem also to belong to the Křepice Formation.

At the type area of the Křepice Formation in its upper part layers of diatomite are interbedded in Fe-rich claystones. Similarly, in the Pavlovice Formation of the Ždánice Unit non-calcareous claystones without microfauna were deposited, with rusty siltstone intercalations in the upper part, followed by the deposition of diatomites (KRHOVSKY et al., 2001). The diatomites may indicate dysoxic bottom water conditions and probably also unfavourable surface waters.

Chronostratigraphic age: Early Miocene, Burdigalian (late Ottnangian).

Biostratigraphy: Calcareous nannofossil Zones NN3–NN4 (?) (KRHOVSKY et al., 2001).

Thickness: Some hundred meters estimated, in deep well Ameis 1 354 m (drill depth: 402–756 m) reported (BRIX et al., 1977). In the Pouzdřany Unit of southern Moravia KRHOVSKY et al. (1995) report 300–400 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Mostly tectonic contacts; STRÁNÍK (1996a) and NOVÁK & STRÁNÌK (1998) report a transition from the Michelstetten Formation.

Overlying unit(s): -

Lateral unit(s): To the west it may interfingering with the Ottnangian "Schlier" of the Molasse Basin.

Geographic distribution: In the outermost part (NW margin) of the Waschberg Unit, Roseldorf (Sub)Zone (see above) bound by the Leitzersdorf and Senning Thrusts. This unit continues into the Pouzdřany Unit of Southern Moravia, Czech Republic.

Remarks: In the ASC 2004 (PILLER et al., 2004) this unit is depicted as "Eisenschüssige Tone und Sande".

Complementary references: THENIUS (1962, 1974), CICHA et al. (1963), GRILL (1968), BRIX et al. (1977), PICHA & STRÁNÍK (1999), ROETZEL (2002), WESSELY (2006), STRÁNÍK et al. (2007), GEBHARDT (2018b).

Laa-Formation / Laa Formation

(for descriptions see NAFB north of the Danube)

Vienna Basin, Korneuburg Basin

MATHIAS HARZHAUSER

The Vienna Basin covers large parts of eastern Austria (Lower Austria, Vienna, and Burgenland) and extends into the Czech Republic in the North and the Slovak Republic in the East. It is about 200 km long and 55 km wide, striking roughly SW–NE from Gloggnitz (Lower Austria) in the SSW to Napajedla (Czech Republic) in the NNE (Text-Fig. 7). The Vienna Basin is a rhombic Neogene-age pull-apart basin. Its SW border is formed topographically by the Eastern Alps and to the NW by the Waschberg Unit. To the E it is bordered by Rosalia, Leitha, and Hainburg hills and the Male Karpaty Mountains, all four of which are part of the Alpine-Carpathian Central Zone. The Pieniny Klippen Belt represents an internal boundary of the Outer Carpathian Flysch Belt; sediments of the Magura Unit form the northern margin of the basin. The basement of the basin is formed by Alpine-Carpathian nappes. The maximum thickness of the Neogene basin fill is 5,500 m. The basin is subdivided into a northern, central and southern part. The Spannberg Ridge forms a morphological high, which separates the central from the southern subbasins, which is expressed by partly different depositional environments. Due to the complex fault system, the basin was internally subdivided into a series of horst and graben systems. The uplifted blocks at the margins of the basin are separated from the deeper areas by major faults (e.g., Mistelbach Halfgraben and Steinberg Fault, Moravian central depression and Bulhary Fault in the northern basin, Mödling Block and Leopoldsdorf Fault in the southern basin; Láb-Malacky High and Leitha and Láb Fault Zones). The Mistelbach Halfgraben is an elongate rhombic, SW–NE oriented element along the northwestern margin of the Vienna Basin with a maximum length of c. 60 km and a maximum width of c. 20 km. Its southernmost tip is in the area of Manhartsbrunn and Münichsthal in Austria and the northern spur reaches to Břeclav and Lednice in the Czech Republic. The Schrattenberg Fault forms its western boundary to the Waschberg Unit and the Bisamberg Fault represents its southwestern boundary to the Rhenodanubian Flysch Unit. The Steinberg Fault forms its eastern boundary towards the deeper parts of the Vienna Basin. Marine sedimentation in the Vienna Basin commenced during the Ottnangian (c. 18.1 Ma) and lasted with several interruptions until the late Sarmatian (11.6 Ma). Lacustrine conditions prevailed during the Pannonian from 11.6 Ma to about 8.0 Ma. Pliocene deposits are spotty, reflecting fluvial and limnic environments with paleosol formation. Relibale dating for these depoists is missing throughout.

Many formations of the Vienna Basin are only known from drillings; whereas outcrops along the basin margins represent often only local lithologies. Herein, 31 lithostratigraphic units are listed at group, formation and member rank. Of these, 87 % have been formally established by BARTEK (1989), ČTYROKÝ (2000), ELEČKO & VASS (2001), HARZHAUSER & PILLER (2004b), HARZHAUSER et al. (2019a, 2020) and KOUKAL & WAGREICH (2009).

The Korneuburg Basin is a SSE–NNE elongated halfgraben of 20 km length and a maximum width of 7 km. A swell in the area of Obergänserndorf–Mollmannsdorf separates a southern part of the basin with about 650 m depth from a shallower northern one with about 350 m depth. The basin margins are formed in the northern part by the Waschberg Unit and towards the south by Rhenodanubian Flysch Unit. The Schliefberg Fault forms its western margin. Sedimentation is confined to the early Miocene. None of the herein listed formations distinct to the Korneuburg Basin has been formalized yet.

A synopsis of the Vienna and Korneuburg Basins as well as the Eisenstadt-Sopron and Oberpullendorf basins and their evolution is given in HARZHAUSER et al. (2008a), BERKA (2015) and SIEDL et al. (2020) compiled mainly from DRAGANITS (1998), HARZHAUSER et al. (2002), ZORN (2000), KOVÁČ et al. (2004), STRAUSS et al. (2006), WESSELY (2006) and references therein.

Bockfließ-Formation / Bockfließ Formation

MATHIAS HARZHAUSER

Validity: Valid; PAPP et al. (1973: p. 195) introduced the term “Bockfließer Schichten” (Bockfließ Beds); PILLER et al. (2004) introduced the name Bockfliess-Formation, which was described and formalized by HARZHAUSER et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Matzen 269 (2,245–2,754 m) (N 48°22′59.37″ / E 16°42′22.09″) (HARZHAUSER et al., 2020), c. 5 km N of the town Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Reference section(s): -

Derivation of name: After the village Bockfließ (N 48°21′40.53″ / E 16°36′5.57″), c. 24 km NE of the Vienna city centre, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5320 Wien (ÖK50-BMN, map sheet 42 Gänserndorf).

Text-Fig. 7.
Location of the Vienna und Korneuburg basins (grey shaded).

Synonyms: “brachyhaline Serie” or “brachyhaline facies with *Rzehakia*” (HLADECEK, 1965; KAPOUNEK et al., 1965), Brachyhaline Schichten mit Rzehakia = „Oncophora-Schichten” (PAPP et al., 1973), Bockfließer Schichten (PAPP et al., 1973), Bockfliess-Formation (PILLER et al., 2004).

Lithology: Light and dark grey, mica-rich marly clay with intercalations of marly silt and sand.

Fossils: The Bockfließ Formation is rich in fossils, including calcareous nannoplankton, foraminifers, mollusks and decapods.

Origin, facies: Fully marine, inner neritic lagoonal environments with occasionally stressed bottom conditions.

Chronostratigraphic age: Early Miocene, middle Burdigalian (early Ottnangian); c. 18.1–17.8 Ma.

Biostratigraphy: Nannofossil Zones NN3 to lower NN4.

Thickness: Up to 500 m, but very variable since the Bockfließ Formation fills a paleo-relief and is truncated by erosion.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Rhenodanubian Flysch, Mesozoic nappes of the Northern Calcareous Alps.

Overlying unit(s): Aderklaa Formation south of the Matzen/Spannberg Ridge (Raggendorf–Matzen–Bockfließ–Schönkirchen areas); Badenian units (Matzen Formation, Baden Formation) north of the Matzen/Spannberg Ridge in the Spannberg area.

Lateral unit(s): Lužice Formation in the northern Vienna Basin and Alpine-Carpathian Foredeep. Mistelbach and Kettlasbrunn members of the Lužice Formation in the Mistelbach Halfgraben (HARZHAUSER et al., 2019a).

Geographic distribution: The Bockfließ Formation is restricted to subsurface drillings in the central Vienna Basin and a narrow strip north of the Matzen/Spannberg Ridge; ÖK50-UTM, map sheets 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Lužice-Formation / Lužice Formation

MATHIAS HARZHAUSER

Validity: Valid; described and formalized by HARZHAUSER et al. (2020).

Type area: Northern Vienna Basin.

Type section: OMV deep well Maustrenk West 1 (MTW1) (1,300–1,505 m) (N 48°34′32.08″ / E 16°42′29.77″), c. 10 km E of the town Mistelbach, northern Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5315 Zistersdorf (ÖK50-BMN, map sheet 25 Poysdorf).

Reference section(s): -

Derivation of name: After the village Lužice (german: Luschitz) (N 48°50′27.19″ / E 17°4′17.07″), c. 4.5 km WSW of Hodonín, South Moravia, Czech Republic (northern Vienna Basin); ZM 50, map sheet 3424.

Synonyms: Lužické šlíry (BUDAY & CICHA, 1956), Luschitzer Serie (KAPOUNEK et al., 1960), Neusiedl Schlier (KAPOUNEK et al., 1965), Luzice-Formation (PILLER et al., 2004).

Lithology: Laminated grey calcareous clays, silt and siltstones with intercalations of sands.

Fossils: Rich foraminiferal assemblages with *Bathysiphon*, *Cyclammina*, *Haplophragmoides* and *Trilobatus* (CICHA et al., 1998; HARZHAUSER et al., 2015, 2018).

Origin, facies: Open marine pelagic, partly bathyal environments with high nutrient flux and high sedimentation rates (GRUNERT et al., 2013; HARZHAUSER et al., 2017). A distinct shallowing trend is indicated in the upper part of the Lužice Formation (HARZHAUSER et al., 2017).

Chronostratigraphic age: Early Miocene, middle Burdigalian (Ottnangian); c. 18.1–17.2 Ma.

Biostratigraphy: The Ottnangian age is based on the occurrence of the bivalve *Pecten hornensis* in basal parts (HARZHAUSER et al., 2019a). Early Ottnangian is based on the co-occurrence of *Bathysiphon filiformis*, *Cyclammina bradyi* and *Reticulophragmium karpaticum* (CICHA et al., 1998; HARZHAUSER et al., 2017).

Thickness: Up to a maximum of 1,000 m in the Mistelbach Halfgraben.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Lužice Formation was fully subdivided in the Mistelbach Halfgraben by HARZHAUSER et al. (2019a) in Maustrenk Member, Mistelbach Member, Kettlasbrunn Member, and Hobersdorf Member.

Underlying unit(s): Rhenodanubian Flysch.

Overlying unit(s): Laa Formation in the Mistelbach Halfgraben; Mannsdorf Formation and Baden Formation in the Austrian part of the northern Vienna Basin.

Lateral unit(s): Bockfließ Formation in the central Vienna Basin; Wildendürnbach Formation and Zogelsdorf Formation in the NACFB (ROETZEL, 2009; PALZER-KHOMENKO et al., 2018a, b; HARZHAUSER et al., 2019a).

Geographic distribution: Austrian, Czech and Slovak territories of the northern Vienna Basin and Mistelbach Halfgraben (BUDAY & CICHA, 1956; VASS, 2002; KOVÁČ et al., 2004; HARZHAUSER et al., 2018, 2019a; CSIBRI et al., 2022); ÖK50-UTM, map-sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: PILLER et al. (2004).

Maustrenk-Subformation (Lužice-Formation) / Maustrenk Member (Lužice Formation)

MATHIAS HARZHAUSER

Validity: Valid; described and formalized by HARZHAUSER et al. (2019a).

Type area: Mistelbach Halfgraben.

Type section: OMV deep well Maustrenk West 1 (MTW1) (1,550–1,505 m) (N 48°34′32.08″ / E 16°42′29.77″), c. 10 km E of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5315 Zistersdorf (ÖK50-BMN, map sheet 25 Poysdorf).

Reference section(s): -

Derivation of name: After the village Maustrenk (N 48°34′19.37″ / E 16°42′3.66″), c. 10 km E of the town Mistelbach, northern Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5315 Zistersdorf (ÖK50-BMN, map sheet 25 Poysdorf).

Synonyms: Schlierbasis-Schutt (= "basal Schlier-debris") (VEIT, 1943; JANOSCHEK, 1951).

Lithology: Laminated grey marly claystone, silt and siltstone with intercalations of sandstone and conglomeratic sandstone. Poorly sorted sandstone and gravel with pectinids and celleporid bryozoans occur at the base

Fossils: Celleporid bryozoans and a shallow marine mollusc fauna (*Pecten, Atrina, Ficus*) are reported.

Origin, facies: Gravelly beaches and shallow sublittoral settings in an archipelago-type landscape.

Chronostratigraphic age: Early Miocene, middle Burdigalian (early Ottnangian); c. 18.1–18.0 Ma.

Biostratigraphy: Early Ottnangian is based on the presence of *Pecten hornensis*.

Thickness: Strongly variable, ranging around a few tens of meters.

Lithostratigraphically higher rank unit: Lužice Formation

Lithostratigraphic subdivision: -

Underlying unit(s): Rhenodanubian Flysch.

Overlying unit(s): Mistelbach Member (Lužice Formation).

Lateral unit(s): Chropov, Brezová and Winterberg members in Slovakia and the Czech Republic along the eastern margin of the Vienna Basin (BUDAY, 1955; CICHA et al., 1998; KOVÁČ et al., 2004); Zogelsdorf Formation along the Bohemian Massif (ROETZEL et al., 1999a). The Ritzendorf Formation might be a temporal equivalent in the adjacent Korneuburg Basin.

Geographic distribution: Mistelbach Halfgraben; ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: -

Mistelbach-Subformation (Lužice-Formation) / Mistelbach Member (Lužice Formation)

MATHIAS HARZHAUSER

Validity: Valid; described and formalized by HARZHAUSER et al. (2019a).

Type area: Mistelbach Halfgraben.

Type section: OMV deep well Maustrenk West 1 (MTW1) (1,505–1,300 m) (N 48°34′32.08″ / E 16°42′29.77″), c. 10 km E of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5315 Zistersdorf (ÖK50-BMN, map sheet 25 Poysdorf).

Reference section(s): -

Derivation of name: Named after the town Mistelbach (N 48°34′2.75″ / E 16°34′19.88″), c. 40 km NNE of the city of Vienna, northern Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 24 Mistelbach).

Synonyms: *Bathysiphon-Cyclammina* Schlier (GRILL, 1943).

Lithology: Laminated grey calcareous claystone, silt and siltstone with intercalations of sandstone.

Fossils: Rich foraminiferal assemblages with *Bathysiphon taurinensis, Cyclammina praecancellata*, *Haplophragmoides vasiceki* and *Trilobatus trilobus* (CICHA et al., 1998).

Origin, facies: Open marine pelagic, partly bathyal environments; especially the *Bathysiphon*-dominated faunas were interpreted as indicators for bathyal to middle neritic environments with high nutrient flux and high sedimentation rates (HARZHAUSER et al., 2017, 2019a).

Chronostratigraphic age: Early Miocene, middle Burdigalian (early Ottnangian); c. 18.0–17.8 Ma.

Biostratigraphy: The early Ottnangian age is based on the co-occurrence of *Bathysiphon filiformis, Cyclammina bradyi* and *Reticulophragmium karpaticum* (CICHA et al., 1998; HARZHAUSER et al., 2017).

Thickness: Mostly between ~ 200–240 m.

Lithostratigraphically higher rank unit: Lužice Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Rhenodanubian Flysch, Maustrenk Member (Lužice Formation).

Overlying unit(s): Kettlasbrunn Member (Lužice Formation).

Lateral unit(s): The Hall Formation in the Upper Austrian part of the NAFB is roughly coeval (GRUNERT et al., 2013). In the adjacent Korneuburg Basin, the Ritzendorf beds (HEKEL, 1968) might be temporal equivalents. A full equivalent of this member in the adjacent NACFB was described by CICHA (1997) from the drilling Laa Thermal Süd 1 ("Unterer Teil der Luschitzer Schichtenfolge"; 1,760–1,890 m) as well as the Zellerndorf Formation (1,230–1,747 m).

Geographic distribution: Mistelbach Halfgraben; ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: -

Kettlasbrunn-Subformation (Lužice-Formation) / Kettlasbrunn Member (Lužice Formation)

MATHIAS HARZHAUSER

Validity: Valid; described and formalized by HARZHAUSER et al. (2019a).

Type area: Mistelbach Halfgraben.

Type section: OMV deep well Mistelbach U1 (MisU1) (1,300–1,935 m) (N 48°34′19.39″ / E 16°39′7.32″), c. 6 km E of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 25 Poysdorf).

Reference section(s): -

Derivation of name: After the village Kettlasbrunn (N 48°33′45.35″ / E 16°39′22.21″), c. 6 km E of the town Mistelbach, northern Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 25 Poysdorf).

Synonyms: Elphidium-Cibicides-Schlier (GRILL et al., 1963), Cibicides-Elphidium-Schlier (FUCHS, 1980c).

Lithology: Laminated grey marly claystone, micaceous silt and siltstone with intercalations of fine sandstone.

Fossils: Foraminiferal assemblages with *Ammonia, Porosononion* and *Elphidium*. Mollusc assemblages are dominated by *Corbula gibba* and *Ostrea digitalina*.

Origin, facies: Inner to middle neritic with widespread dysoxic bottom conditions and distinct shallowing trend in the upper part of the unit.

Chronostratigraphic age: Early Miocene, middle Burdigalian (late Ottnangian); c. 17.8–17.4 Ma.

Biostratigraphy: Nannofossil Zone NN3 (KOVÁČ et al., 2004); late Ottnangian is based on the "*Cibicides-Elphidium*" assemblages, typical for the late Ottnangian of the Vienna Basin (CICHA et al., 1998; HARZHAUSER et al., 2017).

Thickness: Up to 550 m.

Lithostratigraphically higher rank unit: Lužice Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Rhenodanubian Flysch, Mistelbach Member (Lužice Formation).

Overlying unit(s): Hobersdorf Member (Lužice Formation).

Lateral unit(s): Zellerndorf Formation in the NACFB (ROETZEL et al., 1999a); Štefanov Member (BUDAY, 1955) in the Slovak part of the Vienna Basin and Hodonín Member in the Czech part of the Vienna Basin (JIŘÍČEK & SEIFERT, 1990).

Geographic distribution: Mistelbach Halfgraben; ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: -

Hobersdorf Subformation (Lužice-Formation) / Hobersdorf Member (Lužice Formation)

MATHIAS HARZHAUSER

Validity: Valid; described and formalized by HARZHAUSER et al. (2019a).

Type area: Mistelbach Halfgraben.

Type section: OMV deep well Mistelbach U1 (MisU1) of (1,300–1,010 m) (N 48°34′19.39″ / E 16°39′7.32″), c. 6 km E of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 25 Poysdorf).

Reference section(s): -

Derivation of name: After the village Hobersdorf (N 48°34′38.23″ / E 16°38′20.28″), c. 5 km ENE of the town Mistelbach, northern Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 25 Poysdorf).

Synonyms: fossilarmer Schlier (impoverished Schlier), Fisch-Schlier (JANOSCHEK, 1951; CICHA et al., 1998).

Lithology: Laminated grey marly claystone, micaceous silt and siltstone with intercalations of sandstone.

Fossils: Fish scales and bones and *Ammonia*-dominated foraminiferal fauna are typical along with the Amoebina genus *Silicoplacentina*.

Origin, facies: Inner neritic paleoenvironment with lowered (but marine) salinity and widespread dysoxic bottom conditions.

Chronostratigraphic age: Early Miocene, middle Burdigalian (late Ottnangian); c. 17.4–17.2 Ma.

Biostratigraphy: No data; the late Ottnangian age is based on its stratigraphic position in the top of the Lužice Formation.

Thickness: Up to 150 m.

Lithostratigraphically higher rank unit: Lužice Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Kettlasbrunn Member (Lužice Formation).

Overlying unit(s): Laa Formation.

Lateral unit(s): Wildendürnbach Formation in the NACFB (PALZER-KHOMENKO et al., 2018a, b).

Geographic distribution: Mistelbach Halfgraben; ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: FUCHS (1980c).

Ritzendorf-Formation / Ritzendorf Formation

Mathias Harzhauser

Validity: Invalid; introduced as "Ritzendorfer Schichten" by Hekel (1968), renamed as Ritzendorf "Formation" by Harzhauser & Wessely (2003) without formalization and used on the geological map by Kreuss (2018) as "Ritzendorf-Formation".

Type area: The region between Ritzendorf and Würnitz, c. 18 km SW of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 41 Deutsch Wagram.

Type section: -

Reference section(s): -

Derivation of name: After the village Ritzendorf (N 48°26′41.07″ / E 16°25′16.08″), c. 18 km SW of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Synonyms: Ritzendorfer Schichten (Hekel, 1968), Ritzendorf "Formation" (Harzhauser & Wessely, 2003).

Lithology: Sand and sandy gravel with subordinate marls and corallinacean limestones.

Fossils: Pectinids (*Pecten hornensis*); foraminiferal fauna with *Heterostegina, Operculina, Uvigerina, Bolivina* (Hekel, 1968).

Origin, facies: Coastal marine, inner neritic paleoenvironment.

Chronostratigraphic age: Early Miocene, Burdigalian (Ottnangian); c. 18.1–17.2 Ma.

Biostratigraphy: The occurrence of *Pecten hornensis* suggests a relation with the Ottnangian Zogelsdorf Formation

Thickness: Few meters.

Lithostratigraphically higher rank unit: No formal higher rank; the Ritzendorf Formation could be treated as member of the Lužice Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Rhenodanubian Flysch.

Overlying unit(s): -

Lateral unit(s): Zogelsdorf Formation along the margin of the Bohemian Massif. Maustrenk Member of the Lužice Formation in the Mistelbach Halfgraben.

Geographic distribution: Small patches between Würnitz and Ritzendorf in the Korneuburg Basin, Lower Austria; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Remarks: Due to the correlation with the Zogelsdorf Formation, the Ritzendorf Formation was considered to be of Eggenburgian age (e.g., Hekel, 1968; Wessely, 2006; Krenmayr & Schnabel, 2002a). However, the Zogeldorf Formation is now placed in the Ottnangian.

Complementary references: Fuchs (1980a), Wessely (1998).

Laa-Formation / Laa Formation

Lakšary-Subformation (Laa-Formation) / Lakšary Member (Laa Formation)

Závod-Subformation (Laa-Formation) / Závod Member (Laa Formation)

(for descriptions see NAFB North of the Danube)

Ginzersdorf-Formation / Ginzersdorf Formation

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2019a).

Type area: Mistelbach Halfgraben.

Type section: OMV deep well Althöflein 1 (342–250 m) (N 48°38′31″ / E 16°45′15″), c. 10 km ESE of Poysdorf, Lower Austria; ÖK50-UTM, map sheet 5309 Hohenau an der March (ÖK50-BMN, map sheet 25 Poysdorf).

Reference section(s): -

Derivation of name: Named after the village Ginzersdorf (N 48°37′33.36″ / E 16°43′20.36″), c. 2 km S of the village Großkrut, c. 13 km NE of the town Mistelbach, Lower Austria; ÖK50-UTM, map sheet 5309 Hohenau an der March (ÖK50-BMN, map sheet 25 Poysdorf).

Synonyms: -

Lithology: Grey to brown micaceous marly clay with intercalations of light grey to beige, moderately bedded, micaceous, fine to middle sand with lignitic plant debris. Clay and marl clasts in sandy matrix are typical in the basal parts.

Fossils: Foraminiferal assemblages with *Uvigerina graciliformis*. Otoliths of lantern fish (Harzhauser et al., 2017).

Origin, facies: Outer neritic to upper bathyal paleoenvironment with suboxic to dysoxic bottom conditions.

Chronostratigraphic age: Early Miocene, late Burdigalian (Karpatian); c. 16.2–16.0 Ma.

Biostratigraphy: The Karpatian age is based on the presence of *Uvigerina graciliformis* (Cicha et al., 1998; Harzhauser et al., 2017).

Thickness: A maximum thickness of 100 m is reported.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Laa Formation.

Overlying unit(s): Baden Group.

Lateral unit(s): Uppermost part of Laa Formation in the NACFB (= Laa Channel of Dellmour & Harzhauser, 2012).

Geographic distribution: Mistelbach Halfgraben between Ginzersdorf, Althöflein and Walterskirchen, Lower Austria; ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: The Ginzersdorf Formation is part of a channel fill, which became largely eroded during the Badenian by the formation of the Mistelbach Canyon. Thus, it represents a Karpatian precursor of the Badenian drainage system from the Vienna Basin into the NACFB. Channel formation was also frequent in the NACFB during the terminal Karpatian (e.g., Laa Channel) (Dellmour & Harzhauser, 2012).

Complementary references: -

Korneuburg-Formation / Korneuburg Formation

Mathias Harzhauser

Validity: Invalid; the term Korneuburg Formation was used by Harzhauser & Wessely (2003) and Zuschin et al. (2014).

Type area: It is restricted to the Korneuburg Basin, Lower Austria; ÖK50-UTM; map sheet 5320 Wien (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Type section: Not defined; Wessely (1998) discussed the 450 m-thick well Korneuburg 1 as typical for the Korneuburg Formation; Zuschin et al. (2014) documented a continuous 445 m-thick succession at Stetten (Austria), which would be a good candidate for a type section. Unfortunately, this outcrop was only exposed during temporary road constructions and is now covered.

Reference section(s): -

Derivation of name: After the town Korneuburg (N 48°20′40.59″ / E 16°19′54.54″), Lower Austria; ÖK50-UTM; map sheet 5320 Wien (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Synonyms: Grunder Schichten (pars) (Rolle, 1859; Vetters, 1910, 1914), Helvet des Korneuburger Beckens (Grill, 1962b), Korneuburger Schichten (Fuchs, 1980a).

Lithology: Rapidly changing succession of fine to middle sand, silt and pelites, occasional root horizons and rare coal seams. The entire formation is tilted about 25° towards the west.

Fossils: More than 650 taxa have been encountered from the Korneuburg Formation. Along with marine foraminifers, ostracods and molluscs, large numbers of terrestrial vertebrates, palynomorphs and plant fossils have been described in the monographs of Sovis & Schmid (1998, 2002). The globally largest fossil oyster reef occurs at the Teiritzberg close to the village Stetten (see also remarks).

Origin, facies: A brackish-marine estuary with shoreface sands, tidal flats, fringes of *Avicennia*-mongroves and extensive *Magallana*-oyster reefs (Harzhauser et al., 2002, 2015). A barrier in the Obergänserndorf area separated a more brackish southern part of the basin from a fully marine northern part (Latal et al., 2006).

Chronostratigraphic age: Early Miocene, late Burdigalian (Karpatian); c. 17.7–16.0 Ma; Zuschin et al. (2014) calculated a duration of 700 ka for the Korneuburg Formation.

Biostratigraphy: Mammal Zone MN5 (Daxner-Höck, 1998; Harzhauser et al., 2002).

Thickness: Up to ~ 450 m (Wessely, 1998; Zuschin et al., 2014).

Lithostratigraphically higher rank unit: - (see remarks).

Lithostratigraphic subdivision: No formal units established; the "Diatomeenschiefer mit Fischresten bei Großrußbach" (= Diatomite with fish remnants at Großrußbach) (Hekel, 1968) are a local facies, which is tentatively correlated with the Korneuburg Formation by Wessely (1998). In contrast, Kreuss (2018) placed this unit in the Ottnangian with question mark.

Underlying unit(s): Rhenodanubian Flysch.

Overlying unit(s): Quaternary deposits.

Lateral unit(s): Závod Member in the Mistelbach Halfgraben; parts of the Schönkirchen Member (Aderklaa Formation) in the central Vienna Basin.

Geographic distribution: Korneuburg Basin; ÖK50-UTM, map sheets 5314 Mistelbach, 5320 Wien (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Remarks: Harzhauser et al. (2019a) considered the Korneuburg Formation a synonym of the Závod Member of the Laa Formation. This would require more information on the Závod Member.

The largest known fossil oyster reef at the Teiritzberg, close to the village Stetten, c. 4 km NE of the town Korneuburg, is the highlight of the geo-entertainment-park Fossilienwelt Weinviertel (www.fossilienwelt.at).

Complementary references: Fuchs & Grill (1984b), Tollmann (1985), Kern et al. (2010).

Aderklaa-Formation / Aderklaa Formation

Mathias Harzhauser

Validity: Valid; described and formalized by Harzhauser et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Schönkirchen T1 (1,980–2,870 m) (N 48°21′30.71″ / E 16°43′05.50″), c. 1.5 km SE of the village Schönkirchen, 2 km N of Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Reference section(s): -

Derivation of name: After the village Aderklaa (N 48°17′07.11″ / E 16°32′18.96″), c. 2.5 km SW of the town Deutsch-Wagram, c. 25 km NE of the Vienna city centre, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Synonyms: schlierähnliche Serie (Janoschek, 1942, 1943), Aderklaaer Schlier (Janoschek, 1951), Liegendserie von Adlerklaa (Grill, 1943), Schichten von Aderklaa (Grill, 1960; Janoschek, 1951), terrestrisch-lacustrische Serie (Hladecek, 1965), limnische Serie (Hladecek, 1965), Gänserndorfer Schichten p.p. (Papp et al., 1973), Aderklaaer Schichten p.p. (Papp et al., 1973), Aderklaa Formation (Weissenbäck, 1996), Aderklaaer Konglomerat (Piller et al., 2004).

Lithology: See Gänserndorf Member and Schönkirchen Member.

Fossils: Terrestrial gastropods, freshwater ostracods and gastropods (see Gänserndorf Member and Schönkirchen Member).

Origin, facies: Alluvial fans, braided river and meandering deposits, wetlands (see Gänserndorf Member and Schönkirchen Member).

Chronostratigraphic age: Early Miocene, late Burdigalian (Karpatian); c. 17.2–16.0 Ma.

Biostratigraphy: The presence of *Globorotalia transsylvanica* and *Globigerinella regularis* excludes an Ottnagnian age according to the ranges given in Cicha et al. (1998) what indicates a Karpatian age.

Thickness: The maximum thickness of 1,258 m is documented from the Schwechat depression.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Aderklaa Formation was completely subdivided into the Gänserndorf Member and the Schönkirchen Member by Harzhauser et al. (2020).

Underlying unit(s): Bockfließ Formation.

Overlying unit(s): Rothneusiedl Formation, Matzen Formation.

Lateral unit(s): Not known.

Geographic distribution: Central Vienna Basin (ÖK50-UTM, map sheets 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: Fuchs (1980c), Tollmann (1985), Piller et al. (2004).

Gänserndorf-Subformation (Aderklaa-Formation) / Gänserndorf Member (Aderklaa Formation)

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Schönkirchen T1 (2,610–2,870 m) (N 48°21′30.71″ / E 16°43′05.50″), c. 1.5 km SE of the village Schönkirchen, 2 km N of Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Reference section(s): -

Derivation of name: After the town Gänserndorf in the central Vienna Basin (N 48°20′26.31″ / E 16°43′03.26″), central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Synonyms: terrestrisch-limnische Schichten (Hladecek, 1965), Gänserndorfer Schichten (Papp et al., 1973), Gänserndorf Formation (Weissenbäck, 1996).

Lithology: Monomictic conglomerates, sandstones, marly silty clays and subordinate breccias (Weissenbäck, 1995).

Fossils: Large freshwater ostracods (Candonidae, Cytherideidae), hydrobiid, planorbid and helicid gastropods and oogonia of Characeae (Hladecek, 1965; Harzhauser et al., 2020).

Origin, facies: Alluvial fans passing into a braided river system with main transport direction from SW to NE (Weissenbäck, 1995).

Chronostratigraphic age: Early Miocene, late Burdigalian (Karpatian); c. 17.2–17.0 Ma.

Biostratigraphy: No biostratigraphic markers are known from the Gänserndorf Member.

Thickness: The maximum thickness is 360 m, but it is laterally very variable.

Lithostratigraphically higher rank unit: Aderklaa Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Bockfließ Formation.

Overlying unit(s): Schönkirchen Member (Aderklaa Formation).

Lateral unit(s): Šaštín Member in the Slovak part of the Vienna Basin (Kováč et al., 2004; Csibri et al., 2022), Lakšary Member of the Laa Formation in the Vienna Basin (Harzhauser et al., 2020) and Závod Formation in the Slovak part of the Vienna Basin, respectively (Csibri et al., 2022).

Geographic distribution: Central Vienna Basin; ÖK50-UTM, map sheets 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: Tollmann (1985), Wessely (2006).

Schönkirchen-Subformation (Aderklaa-Formation) / Schönkirchen Member (Aderklaa Formation)

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Schönkirchen T1 (1,980–2,610 m) (N 48°21′30.71″ / E 16°43′05.50″), c. 1.5 km SE of the village Schönkirchen, 2 km N of Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Reference section(s): -

Derivation of name: After the village Schönkirchen (N 48°21′49.98″ / E 16°42′3.09″), c. 3 km NNW of the town Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Synonyms: Aderklaaer Schlier p.p. (Janoschek, 1951), limnische Serie (Hladecek, 1965), Limnische Schichten mit Congerien (Papp et al., 1973), Aderklaaer Schichten (Papp et al., 1973), Aderklaa Formation (Weissenbäck, 1996), ?Grillenberger Kohleserie (Brix, 1988), ?Hauerbergschichten (Brix, 1988), Láb beds (Láb Member) in Slovakia (Buday, 1955).

Lithology: Monotonous alternation of light grey to greenish sandstones with marly silt and marly clay with rare thin gravel layers (WEISSENBÄCK, 1995).

Fossils: Large freshwater ostracods (Candonidae, Cytherideidae, Hemicytheridae), helicid, hydrobiid and neritid gastropods. Rare marine foraminifers in deep well Matzen 112 (1,805 m).

Origin, facies: Meandering river system with channels and flood plains (WEISSENBÄCK, 1995).

Chronostratigraphic age: Early Miocene, late Burdigalian (Karpatian); c. 17.0–16.0 Ma.

Biostratigraphy: The presence of *Globorotalia transsylvanica* and *Globigerinella regularis* excludes an Ottnagnian age (according to the ranges given in CICHA et al., 1998) what indicates a Karpatian age.

Thickness: The maximum thickness is 1,066 m in the Schwechat depression.

Lithostratigraphically higher rank unit: Aderklaa Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Gänserndorf Member (Aderklaa Formation), Bockfließ Formation.

Overlying unit(s): Rothneusiedl Formation and Matzen Formation (Baden Group).

Lateral unit(s): The Láb beds (= Láb Ostracod member, BUDAY & CICHA, 1956; Láb Member, CSIBRI et al., 2022) are a lateral equivalent in the Slovak part of the Vienna Basin (KOVÁČ et al., 2004, FORDINÁL et al., 2012). The "Grillenberger Kohleserie" and "Hauerbergschichten" (BRIX, 1988) along the southwestern margin of the Vienna Basin might be lateral equivalents. The Závod Member is a time equivalent of upper parts of the Schönkirchen Member in the Mistelbach Halfgraben, the Korneuburg Basin and the Slovak part of the Vienna Basin (KOVÁČ et al., 2004; HARZHAUSER et al., 2019a; CSIBRI et al., 2022).

Geographic distribution: Central Vienna Basin. Only known from subsurface drillings; ÖK50-UTM, map sheets 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: WESSELY (2006).

Baden-Gruppe / Baden Group

MATHIAS HARZHAUSER

Validity: Valid; first named as "Baden-Gruppe" by PILLER et al. (2004), but described and formalized by HARZHAUSER et al. (2020).

Type area: Central Vienna Basin.

Type section: The 102 m long scientific core from the abandoned brick yard Baden/Sooss near the town Baden (Lower Austria), south of Vienna (N 47°59′24″ / E 16°13′44″) is defined as type section (HOHENEGGER et al., 2009a, b, 2014; HOHENEGGER & WAGREICH, 2012); ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt).

Reference section(s): -

Derivation of name: Named after the town Baden (N 48°00′29.00″ / E 16°14′03.72″), central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 58 Baden).

Synonyms: See description of formations.

Lithology: See description of formations.

Fossils: See description of formations.

Origin, facies: See description of formations.

Chronostratigraphic age: Middle Miocene, Langhian to early Serravallian (early to late Badenian); c. 15.4–12.7 Ma.

Biostratigraphy: The Baden Group spans the calcareous nannofossil Zones NN4 (upper part), NN5 and NN6 (KOVÁČ et al., 2004), the planktonic foraminifera Zones M5, M6 and M7 (HOHENEGGER et al., 2014) and comprises the regional benthic foraminiferal eco-biozones Lower and Upper Lagenidae Zone, *Spirorutilus* Zone and *Bulimina-Bolivina* Zone (CICHA et al., 1998).

Thickness: The maximum thickness of the Baden Group, based on the maximum thicknesses of its formations, comes up to 3,300 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Auersthal Formation ("Auersthaler Schichten"), Baden Formation, Leitha Formation, Iváň-Formation, Mannsdorf Formation, Matzen Formation ("Matzen Sand"), Rabensburg Formation, Rothneusiedl Formation ("Rothneusiedler Konglomerat", "Aderklaaer Konglomerat"), Sandberg Member.

Informal lithostratigraphic units used in the literature: Aderklaa bentonite main marker ("Aderklaa Hauptmarker"), Aderklaa Sand ("Aderklaaer Sand"), Andlersdorf conglomerate ("Andlersdorfer Konglomerat"), Devínska Nová Ves Formation, Enzesfeld sand ("Enzesfelder Sande"), Gainfarn breccia ("Gainfarner Bekzie"), Gainfarn sand ("Gainfarner Sande"), Hrušky Formation ("Hrušecké vrstvy"), Iváň Formation, Jakubov Formation ("Jakubovské vrstvy"), Kúty Member ("Kútské vrstvy"), Lab sand, Lanžhot Formation ("Lanžhotské vrstvy"), Lindabrunn conglomerate ("Lindabrunner Konglomerat"), Matzen bentonite main marker ("Matzen Hauptmarker), St. Margarethen limestone ("St. Margarethener Kalksandstein"), Studienka Formation ("Studienské vrstvy"), Vöslau (Baden) conglomerate ("Vöslauer (Badener) Konglomerat"), Žižkov beds ("Žižkovské vrstvy"), Zohor conglomerate, Zwerndorf sand ("Zwerndorfer Sand").

Underlying unit(s): Pre-Neogene units (e.g., Rhenodanubian Flysch, Magura Flysch, Mesozoic nappes of the Northern Calcareous Alps); Bockfließ Formation, Lužice Formation (Ottnangian); Aderklaa Formation (Karpatian).

Overlying unit(s): Holíč Formation (Sarmatian) in most of the distribution area; Quaternary deposits along basin margins and the southern Vienna Basin.

Lateral unit(s): Grund Formation and Mailberg Formation in the Austrian part of the NACFB (ROETZEL, 2009); Baden Clay Formation, Rákos Limestone and Szilàgy Clay Marl Formation in the Hungarian part of the Eisenstadt-Sopron Basin and the Hungarian Kisalföld basins (CSÁSZÁR, 1997); Špačince Formation and Báhoň Formation in the northern Danube Basin in Slovakia (VASS, 2002).

Geographic distribution: Distributed throughout the Vienna Basin; ÖK50-UTM, map sheets 5314 Mistelbach, 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf, 5325 Baden, 5326 Schwechat, 5327 Bruck an der Leitha, 5201 Wener Neustadt, 5202 Eisenstadt, 5203 Neusiedl am See, 5208 Mattersburg (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 26 Hohenau an der March, 41 Deutsch Wagram, 42 Gänserndorf, 43 Marchegg, 58 Baden, 59 Wien, 60 Bruck an der Leitha, 61 Hainburg, 76 Wiener Neustadt, 77 Eisenstadt, 78 Rust, 106 Aspang-Markt, 107 Mattersburg).

Remarks: The "Baden-Gruppe" as shown in the Austrian Stratigraphic Chart (PILLER et al., 2004) is not identical with the Baden Group defined by HARZHAUSER et al. (2020).

Complementary references: -

Rothneusiedl-Formation (Baden-Gruppe) / Rothneusiedl Formation (Baden Group)

MATHIAS HARZHAUSER

Validity: Valid; formalized by HARZHAUSER et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Schönkirchen T2 (1,825–1,980 m) (N 48°21′10.84″ / E 16°41′52.24″), c. 1.2 km S of the village Schönkirchen, 2 km NW of Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 41 Deutsch Wagram).

Reference section(s): -

Derivation of name: Named after the former village Rothneusiedl (N 48°08′27.11″ / E 16°22′28.10″), now a cadastral district at the southern margin of Vienna, central Vienna Basin, Vienna; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Synonyms: Aderklaaer Konglomerat (JANOSCHEK, 1951), Aderklaa Conglomerate (WEISSENBÄCK, 1996), Aderklaa conglomerate Member (KOVÁČ et al., 2004), Rothneusiedler Konglomerat (JANOSCHEK, 1951).

Lithology: Massive, clast-supported, polymict conglomerates composed of poorly to moderately rounded, medium to coarse gravel with frequent cobbles (WEISSENBÄCK, 1995).

Fossils: No fossils are known from the conglomerates but GRILL (1943) documented Badenian fully marine lagenid-assemblages from upper parts of the Rothneusiedl Formation.

Origin, facies: Braided river with numerous amalgamating channels and bars (WEISSENBÄCK, 1995); marine in uppermost parts.

Chronostratigraphic age: Middle Miocene, early Langhian (early Badenian); c. 15.4–15.2 Ma.

Biostratigraphy: Lower Lagenidae Zone (Early Badenian).

Thickness: Up to 360 m in the Schwechat depression; up to 150 m in the central Vienna Basin.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Aderklaa Formation.

Overlying unit(s): Mannsdorf Formation, Matzen Formation, Leitha Formation (all Baden Group).

Lateral unit(s): The Gainfarn breccia (WESSELY et al., 2007) is a proximal equivalent along the western margin of the southern Vienna Basin. The Rust Formation in the Rust Hills may be an equivalent (HÄUSLER, 2010; HÄUSLER et al., 2014) in the Eisenstadt-Sopron Basin.

Geographic distribution: Central and southern Vienna Basin; ÖK50-UTM, map sheets 5202 Eisenstadt, 5320 Wien, 5321 Gänserndorf, 5326 Schwechat (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf, 43 Marchegg, 59 Wien, 77 Eisenstadt).

Remarks: -

Complementary references: FUCHS (1980c).

Iváň-Formation (Baden-Gruppe) / Iváň Formation (Baden Group)

MATHIAS HARZHAUSER

Validity: Valid; formalized by ADÁMEK et al. (2003).

Type area: In the area between Novosedly, Hrabětice, Opatovice, southwestern Carpathian Foredeep, Jihomoravský kraj, Moravia, Czech Republic.

Type section: Deep well Iváň-1 (103–164 m) (ADÁMEK et al., 2003).

Reference section(s): -

Derivation of name: After the village Iváň (N 48°55′46.79″ / E 16°34′32.01″), c. 14.5 km NNW of the town Mikulov and c. 30 km S of the town Brno, Jihomoravský kraj, Moravia, Czech Republic.

Synonyms: -

Lithology: Brown-grey marly claystone with intercalations of sandstone.

Fossils: Poor microfauna with *Globigerina praebulloides, Heterolepa dutemplei* and *Cibicidoides*. HARZHAUSER et al. (2017) report *Uvigerina macrocarinata* from the lateral equivalent of the Iváň-Formation in the Mistelbach Canyon.

Origin, facies: Outer neritic to upper bathyal environments within deeply incised canyons (DELLMOUR & HARZHAUSER, 2012; HARZHAUSER et al., 2017, 2019a).

Chronostratigraphic age: Middle Miocene, early Langhian (early Badenian); c. 15.2–14.8 Ma.

Biostratigraphy: Early Badenian based on the occurrence of *Uvigerina grilli, U. macrocarinata* and *Lenticulina americana* (CICHA et al., 1998).

Thickness: The maximum thickness reported is 500 m.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Lužice Formation, Laa Formation, Ginzersdorf Formation.

Overlying unit(s): Baden Formation (discordance).

Lateral unit(s): Rothneusiedl Formation and probably Mannsdorf Formation in the central Vienna Basin. Unnamed clastics in OMV deep well Roggendorf 1, described by Ćorić & Rögl (2004), in the North Alpine-Carpathian Foredeep.

Geographic distribution: The unit is known only subsurface in the northeasternmost part of the NAFB and in a small area of the southwestern part of the Carpathian Foredeep (= Iváň Canyon of Dellmour & Harzhauser, 2012); Mistelbach Halfgraben (= Mistelbach Canyon of Harzhauser et al., 2017, 2019a); ÖK50-UTM, map sheets 5308 Laa an der Thaya, 5314 Mistelbach (ÖK50-BMN, map sheets 10 Wildendürnbach, 24 Mistelbach).

Remarks: -

Complementary references: -

Mannsdorf-Formation (Baden-Gruppe) / Mannsdorf Formation (Baden Group)

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2020).

Type area: Southern Vienna Basin.

Type section: OMV deep well Mannsdorf 1 (2,440–2,575 m) (N 48°09′44″ / E 16°41′07″), c. 2 km NW of the market town Orth an der Donau, Lower Austria; ÖK50-UTM, map sheet 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 60 Bruck an der Leitha).

Reference section(s): -

Derivation of name: After the village Mannsdorf an der Donau (N 48°09′09.90″ / E 16°39′37.05″), c. 3 km WNW of the marke village Orth an der Donau, c. 22 km SE of the city centre of Vienna, in the Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 60 Bruck an der Leitha).

Synonyms: Badener Tegel, Lower Lagenindae Zone p.p.

Lithology: Blue-grey clay, marl and silt, partly with thin silt and fine-sand layers (“Tegel”), sandstone layers; rare tuffitic layers are recorded from OMV deep well Bernhardsthal 4.

Fossils: Foraminiferal assemblages with *Lenticulina inornata*, *Paragloborotalia mayeri, Globigerinella regularis, Tenuitellinata angustiumbilicata, Globoturborotalita druryi, Turborotalia quinqueloba, Lobatula lobatula, Trilobatus trilobus,* and *Globigerina praebulloides* (Harzhauser et al., 2020).

Origin, facies: Outer neritic to upper bathyal paleoenvironment with high nutrient content.

Chronostratigraphic age: Middle Miocene, early Langhian (early Badenian); c. 15.2–14.8 Ma.

Remark: An absolute age is available for a tuff layer in deep well Bernhardsthal 4, which indicates an age of 15.12 ± 0.19 Ma (Sant et al., 2020).

Biostratigraphy: Samples from the Mannsdorf Formation were the base for the description of the Lower Lagenidae Zone (Grill, 1941, 1943).

Thickness: Maximum thickness was recorded with 685 m in well Mühlberg T1; laterally very variable.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Lužice Formation, Rothneusiedl Formation (Baden Group), pre-Neogene basement.

Overlying unit(s): Baden Formation, Matzen Formation, Auersthal Formation (all Baden Group).

Lateral unit(s): Devinska Nová Ves Formation (Fordinál et al., 2012; Rybár et al., 2019) is a terrestrial equivalent at the eastern margin of the Vienna Basin. The Grund Formation represents an age equivalent in the North Alpine Foreland Basin.

Geographic distribution: Northern and central Vienna Basin; no surface outcrops; ÖK50-UTM, map sheets 5309 Hohenau an der March, 5315 Zistersdorf, 5321 Gänserndorf, 5326 Schwechat, 5327 Bruck an der Leitha (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf, 59 Wien, 60 Bruck an der Leitha).

Remarks: -

Complementary references: Csibri et al. (2022).

Auersthal-Formation (Baden-Gruppe) / Auersthal Formation (Baden Group)

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Matzen 269 (1,675–1,730 m) (N 48°22′59.37″ / E 16°42′22.09″), Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Reference section(s): -

Derivation of name: After the market town Auersthal (N 48°22′25.89″ / E 16°38′10.05″), c. 7 km NW of Gänserndorf, central Vienna Basin, Lower Austria.

Synonyms: Auerstaler Konglomerat (Papp et al., 1973), Auersthaler Schichten (Kröll, 1984; Kreutzer, 1986), Auerstal Member (Kováč et al., 2004), Upper Lagenidae Zone p.p.; Slovakia: Kúty Member of the Lanžhot Formation (Fordinál et al., 2012).

Lithology: A succession of conglomerates and sand with marl intercalations.

Fossils: A rich marine microfauna dominated by *Trilobatus trilobus, Spirorutilus carinatus, Heterolepa dutemplei, Lenticulina inornata, Nonion commune, Globigerina bulloides,* and *Orbulina suturalis.*

Origin, facies: A coastal marine delta (Kreutzer & Hlavatý, 1990; Kreutzer, 1993) shedding into an outer neritic marine environment.

Chronostratigraphic age: Middle Miocene, late Langhian (middle Badenian); c. 14.6–13.8 Ma.

Biostratigraphy: Nannofossil Zone NN5 with *Helicosphaera waltrans*; regional foraminiferal eco-biozone Upper Lagenidae Zone (Papp et al., 1973; Kröll, 1984; Kreutzer, 1986). Younger than 14.56 Ma based on the frequent occurrence of *Orbulina*.

Thickness: 40 to 120 m, maximum thickness of about 160 m in OMV deep well Wittau 1.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): The Auersthal Formation has a strong erosive base which is underlain by the Schönkirchen Member (Aderklaa Formation), Rothneusiedl Formation and Mannsdorf Formation (Baden Group).

Overlying unit(s): Matzen Formation, Baden Formation (Baden Group).

Lateral unit(s): The Andlersdorf conglomerate (Kapounek et al., 1965; Kapounek & Papp, 1969) might be a lateral equivalent. The Zohor conglomerate (Vass et al., 1988; Fordinál et al., 2012), the Kúty beds (Kútské vrstvy; Špička, 1966) and the Žižkov Member of Buday (1946) and Fordinál et al. (2012) might represent lateral equivalents in the Slovakian part of the Vienna Basin.

Geographic distribution: Known only from subsurface in the central Vienna Basin; ÖK50-UTM, map sheets 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: -

Matzen-Formation (Baden-Gruppe) / Matzen Formation (Baden Group)

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2020).

Type area: Central Vienna Basin.

Type section: OMV deep well Matzen 269 (1,619–1,673 m) (N 48°22′59.37″ / E 16°42′22.09″), c. 5 km N of the town Gänserndorf, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5321 Gänserndorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Reference section(s): -

Derivation of name: After the village Matzen (N 48°24′4.38″ / E 16°41′42.33″), c. 7 km NNW of Gänserndorf, the central Vienna Basin, Lower Austria.

Synonyms: Matzener Sand (Kröll, 1984), 16. Tortonhorizont (16th Tortonian Horizon) (Kreutzer, 1971), Matzen Sand, Zwerndorf Sand (Weissenbäck, 1996), Matzen sands Member (Kováč et al., 2004), Upper Lagenidae Zone – *Spiroplectammina* Zone p.p., Zwerndorf Member (Kováč et al., 2004), Zizkov-Formation (Matzener Sand) (Piller et al., 2004).

Lithology: Fine to coarse sand, moderately to well sorted, strongly bioturbated, often oil impregnated.

Fossils: A rather low diverse, marine microfauna with *Heterolepa dutemplei, Lenticulina inornata* and *Spirorutilus carinatus*. Macrofossils are poorly preserved including frequent plant debris, pectinid and cardiid bivalves, balanids and tubes of *Ditrupa.*

Origin, facies: Coastal marine environments with sand dunes and shoreface settings of a sand rich braid or fan delta (Fuchs et al., 2001b).

Chronostratigraphic age: Middle Miocene, late Langhian (middle Badenian); c. 14.6–13.8 Ma.

Biostratigraphy: *Spirorutilus* Zone (Kapounek et al., 1965: Sandschalerzone; Kreutzer, 1986: Sandschalerzone, *Spiroplectammina* Zone) or Upper Lagenidae Zone – *Spirorutilus* (*Spiroplectammina*) Zone (Rupp, 1986; Weissenbäck, 1996).

Thickness: 20–70 m; maximum thickness 140 m.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): The Matzen Formation is a transgressive unit overlying older units discordantly: Rhenodanubian Flysch, Bockfließ Formation, Aderklaa Formation, Auersthal Formation (Baden Group).

Overlying unit(s): Baden Formation.

Lateral unit(s): The nearly 300 m thick Zwerndorf Sand is a genetic equivalent of the Matzen Formation. A surface outcrop of an equivalent of the Matzen Formation with huge fossiliferous sand-dunes is exposed in the Eisenstadt-Sopron Basin at Donnerskirchen near Eisenstadt, representing the distal parts of the Hartl Formation (Kroh et al., 2003).

Geographic distribution: Wide subsurface distribution in the central and southern Vienna Basin; ÖK50-UTM, map sheets 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf).

Remarks: -

Complementary references: -

Baden-Formation (Baden-Gruppe) / Baden Formation (Baden Group)

Mathias Harzhauser

Validity: Valid; formalized by Harzhauser et al. (2020).

Type area: Central Vienna Basin.

Type section: The 102 m long scientific core from the abandoned brick yard Baden/Sooss near the town Baden (Lower Austria), south of Vienna (N 47°59′24″ / E 16°13′44″) is defined as type section (Wagreich et al., 2008; Hohenegger & Wagreich, 2012); ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt).

Reference section(s): OMV deep well Ringelsdorf 2 (2,770–3,815 m) (N 48°32′11.32″ / E 16°51′59.90″), c. 8 km E of Zistersdorf, c 8 km SSW of Hohenau an der March, Lower Austria; ÖK50-UTM, map sheet 5315 Zistersdorf (ÖK50-BMN, map sheet 26 Hohenau an der March).

Derivation of name: After the town Baden (N 48°00′29.00″ / E 16°14′03.72″), c. 25 km SSW of the city centre of Vienna, central Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5325 Baden (ÖK50-BMN, map sheet 58 Baden).

Synonyms: Badener Tegel, Badener Serie (KAPOUNEK et al., 1965; PAPP, 1963), Jakubov-Formation, Lanzhot-Formation (PILLER et al., 2004); Slovakia: Lanžhot Formation p.p., Jakubov Formation (FORDINÁL et al., 2012); Baden Clay Formation in the Hungarian part of the Eisenstadt-Sopron Basin (CSÁSZÁR, 1997).

Lithology: Blue-grey to green-grey clay and marl with silt and fine sand intercalations.

Fossils: This formation contains some of the most outstanding fossiliferous localities of the Vienna Basin (see PAPP et al., 1978, and RÖGL et al., 2008, for an overview).

Origin, facies: Inner to middle neritic environments with mean water depth around 250 m (HOHENEGGER et al., 2009a, b). Outer neritic to upper bathyal environments established along tectonically active zones such as the Steinberg Fault (HARZHAUSER et al., 2019a).

Chronostratigraphic age: Middle Miocene, late Langhian (middle Badenian); c. 14.6–13.8 Ma. The type section Baden-Sooss was astronomically tuned to 14.221 and 13.982 Ma by HOHENEGGER & WAGREICH (2012).

Biostratigraphy: The occurrence of the calcareous nannofossil *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta* point at Zone NN5 (ĆORIĆ & HOHENEGGER, 2008), the occurrence of *Orbulina suturalis* indicates planktonic foraminifera Zone M6 (RÖGL et al., 2008). The type section is attributed to the Upper Lagenidae Zone by PAPP & STEININGER (1978).

Thickness: Mostly up to 1,100 m; the maximum thickness of 2,450 m is documented from OMV deep well Zistersdorf Übertief 2Aa.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: No formal subdivision.

Remark: The "Aderklaaer Sand" (Aderklaa sand) is a sand rich intercalation within the Baden Formation. The "Vöslauer (Badener) Konglomerat" (Vöslau (Baden) conglomerate) and the "Gainfarner Bekzie" (Gainfarn breccia) (BRIX, 1988) are local coarse clastic equivalents at the western margin of the Vienna Basin. The "Gainfarner Sande" (Gainfarn sand) and "Enzesfelder Sande" (Enzesfeld sand) are very fossil-rich coastal deposits (BRIX, 1988).

Underlying unit(s): Bockfließ Formation, Lužice Formation; Mannsdorf Formation and Matzen Formation (Baden Group).

Overlying unit(s): Rabensburg Formation (Baden Group), Holíč Formation; the Baden Formation forms the landscape in the Baden region south of Vienna and is partly covered by Quaternary deposits.

Lateral unit(s): The Lanžhot Formation, as described by FORDINÁL et al. (2012) and BRZOBOHATÝ & STRÁNÍK (2012), is a time equivalent. The up to 1,000 m thick pelitic Jakubov Formation (FORDINÁL et al., 2012) is an equivalent of the Baden Formation in the Záhorie Lowlands on Slovak territory. In the Czech part of the Vienna Basin, the Hrušky Formation of PICHA et al. (2006) corresponds to the Baden Formation. The Leitha Formation is an equivalent in the southern part of the Leitha Mountains.

Geographic distribution: Throughout the Vienna Basin (ÖK50-UTM, map sheets 5201 Wiener Neustadt, 5202 Eisenstadt, 5309 Hohenau an der March, 5314 Mistelbach, 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf, 5325 Baden, 5326 Schwechat, 5327 Bruck an der Leitha (ÖK50-BMN, map sheets 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf, 59 Wien, 60 Bruck an der Leitha, 61 Hainburg, 76 Wiener Neustadt, 77 Eisenstadt).

Remarks: The brick yard Sooss (also: Baden-Sooss) was designated by PAPP (1963: p. 229) as type locality of the "Badener Serie" (former: "Tortonian in the Vienna Basin"). Later, PAPP et al. (1978) defined the "Badener Serie" as Badenian Stage. The brickyard Sooss was defined as holostratotype for this regional stage (PAPP & STEININGER, 1978).

Complementary references: HOHENEGGER et al. (2008, 2009a), CSIBRI et al. (2022).

Leitha-Formation (Baden-Gruppe) / Leitha Formation (Baden Group)

MATHIAS HARZHAUSER

Validity: Valid; formalized by HARZHAUSER et al. (2020).

Type area: Leitha Mountains, Burgenland/Lower Austria.

Type section: Fenk quarry, close to Großhöflein (N 47°50′45.78″ / E 16°28′34.60″), c. 4 km W of the town Eisenstadt, Burgenland (Eisenstadt-Sopron Basin); ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt). This section was proposed by STEININGER & PAPP (1978) as faciostratotype of the "Leitha Limestone" and described in detail by RIEGL & PILLER (2000).

Reference section(s): -

Derivation of name: Named after the hill range called "Leitha Mountains" between the river Leitha and Lake Neusiedl (Lower Austria – Burgenland). The name "Leithakalk" was already mentioned by KEFERSTEIN (1828), but he commingled Badenian and Sarmatian limestones.

Synonyms: Leithakalk, Leitha-Kalk, Nulliporenkalk, Nulliporakalk, Lithothamnienkalk, Lithothamnion limestone, Corallinaceenkalk (e.g., KEFERSTEIN, 1828; FUCHS, 1894; WESSELY, 1983; BRIX, 1988; SAUER et al., 1992a, b; PILLER, 1994; PILLER et al., 2004).

Lithology: Whitish to light-yellowish, usually well cemented, corallinacean limestones with coralline red algae in various growth forms, ranging from rhodolite facies to maërl-types.

Fossils: The Leitha Formation is exceptionally rich in fossils. Coralline red algae, such as *Lithothamnion, Spongites, Mesophyllum, Lithophyllum, Phymatolithon*, and *Sporolithon*, are the most important rock-forming elements. Corals are less frequent and usually restricted to small patches or carpets with *Porites* and *Tarbellastrea* (RIEGL & PILLER, 2000). Large sized pectinids such as *Gigantopecten nodosifomis* and echinoderms such as *Clypeaster, Parascutella* and *Echinolampas* occur frequently (KROH, 2005). *Borelis, Amphistegina* and *Planostegina* are important among the larger foraminifera.

Origin, facies: Shallow marine, subtropical carbonate ramps and shoals with coral carpets, sea grass meadows, rhodolite pavements and maërl bottoms. The typical depositional depth ranged from < 10 m down to 60 m in a generally low hydrodynamic setting (RIEGL & PILLER, 2000; WIEDL et al., 2012, 2013).

Chronostratigraphic age: Middle Miocene, late Langhian (middle Badenian); c. 14.6–13.8 Ma.

Biostratigraphy: Nannofossil Zone NN5 and the Upper Lagenidae – *Spirorutilus* zones (WIEDL et al., 2013).

Thickness: A thickness of 50 m based on outcrop data in the southern Leitha Mountains; up to 120 m in drillings.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Austroalpine crystalline and Triassic dolomite in the Leitha Mountains (WIEDL et al., 2013), Triassic dolomite breccias in the area of Bad Vöslau (PILLER & VAVRA, 1991), Rhenodanubian Flysch in the Steinberg area (GRILL, 1968), Hartl Formation in the Eisenstadt area (KROH et al., 2003).

Overlying unit(s): The Leitha Formation forms the surface of the landscape and overlying units have mostly been eroded aside from lower Sarmatian relics ("detrital Leitha Limestone", Holíč Formation, HARZHAUSER & PILLER, 2004a). Rabensburg Formation in subsurface occurrences.

Lateral unit(s): The Baden Formation is a pelitic equivalent in basinal settings. The Jakubov Formation sensu FORDINÁL et al. (2012) is the pelitic equivalent on Slovak territory and the limestones of the Stupava Member of the Jakubov Formation are a full equivalent (HRABOVSKÝ & FORDINÁL, 2013). Coeval corallinacean limestones are the Mailberg Formation in the North Alpine Foreland Basin (MANDIC, 2004a) and the Weißenegg Formation in the Styrian Basin (FRIEBE, 1990, 1991a, b).

Geographic distribution: Southwestern Leitha Mountains; margins of the Vienna Basin; e.g., Wöllersdorf, Baden, Bad Vöslau (Austria), Mikulov (Czech Republic), Borský Mikuláš (Slovakia) (GRILL, 1968; FUCHS & GRILL, 1984a; FORDINÁL et al., 2012); Maustrenk and Prinzendorf in the Steinberg area (GRILL, 1968); ÖK50-UTM, map sheets 5201 Wiener Neustadt, 5202 Eisenstadt, 5315 Zistersdorf, 5325 Baden (ÖK50-BMN, map sheets 25 Poysdorf, 58 Baden, 59 Wien, 60 Bruck an der Leitha, 76 Wiener Neustadt, 77 Eisenstadt).

Remarks: The corallinacean limestones in the northeastern part of the Leitha Mountains (WIEDL et al., 2014) and in the vicinity of St. Margarethen in the Rust Mountains (SCHMID et al., 2001), usually termed Leitha Limestones, do not belong to the Leitha Formation and is called informally "St. Margarthen limestone" in the stratigraphic chart.

Complementary references: TOLLMANN (1985), ZORN (2000), PILLER (2000b, c), KRENMAYR & SCHNABEL (2002a), PILLER et al. (2004).

Rabensburg-Formation (Baden-Gruppe) / Rabensburg Formation (Baden Group)

MATHIAS HARZHAUSER

Validity: Valid; formalized by HARZHAUSER et al. (2020).

Type area: Northern Vienna Basin.

Type section: OMV deep well Rabensburg 1 (690–1,585 m) (N 48°38′53.86″ / E 16°54′43.02″), c. 1 km ESE of the village Rabensburg, c. 5 km N of Hohenau an der March, Lower Austria; ÖK50-UTM, map sheet 5309 Hohenau an der March (ÖK50-BMN, map sheet 26 Hohenau an der March).

Reference section(s): -

Derivation of name: After the village Rabensburg (N 48°38′59.45″ / E 16°54′04.27″), c. 5 km N of Hohenau an der March, northern Vienna Basin, Lower Austria; ÖK50-UTM, map sheet 5309 Hohenau an der March (ÖK50-BMN, map sheet 26 Hohenau an der March).

Synonyms: Badener Serie p.p. (KREUTZER, 1971), *Bulimina-Bolivina* Zone, *Bulimina-Rotalia* Zone, Rotalien-Zone, Studienka Formation (e.g., PILLER et al., 2004).

Lithology: Dark-grey to green-grey, partly laminated clay, marl and silty marl with sand and corallinacean limestone intercalations. Anhydrite was found in cuttings of the basal parts of the formation in the oil field Mühlberg (HARZHAUSER et al., 2018).

Fossils: The Rabensburg Formation is exceptionally rich in marine fossils including numerous foraminifers, mollusks and vertebrates (see HARZHAUSER et al., 2020).

Origin, facies: The Rabensburg Formation comprises a broad range of marine depositional environments. Mudflats and lagoonal conditions are documented from marginal settings; middle to outer neritic settings with dysoxic bottom water conditions prevailed in basinal environments.

Chronostratigraphic age: Middle Miocene, early Serravallian (late Badenian); c. 13.8–12.7 Ma.

Biostratigraphy: Nannofossil Zone NN6 (HUDÁČKOVÁ et al., 2000; JAMRICH & HALÁSOVÁ, 2010).

Thickness: 1,000 m are reported as the maximum thickness.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: No formal subdivision.

Remark: The Sandberg Member of the Studienka Formation along the western margin of the Malé Karpaty (BARÁTH et al., 1994) could be considered part of the Rabensburg Formation (see also remarks).

Underlying unit(s): Baden Formation.

Overlying unit(s): Holíč Formation, Skalica Formation.

Lateral unit(s): HARZHAUSER et al. (2020) list the "Lindabrunner Konglomerat" (Lindabrunn conglomerate) (BRIX, 1988) and the unnamed corallinacean limestones in the northeastern part of the Leitha Mountains and the corallinacean limestones of St. Margarethen in the Rust Mountains (= Rákos Limestone Formation of CSÁSZÁR, 1997) as equivalents of the Rabensburg Formation.

Geographic distribution: Wide subsurface distribution throughout the northern and southern Vienna Basin. Surface outcrops are exposed close to Bratislava (HYŽNÝ et al., 2012); ÖK50-UTM, map sheets 5201 Wiener Neustadt, 5202 Eisenstadt, 5203 Neusiedl am See, 5309 Hohenau an der March, 5314 Mistelbach, 5315 Zistersdorf, 5320 Wien, 5321 Gänserndorf, 5326 Schwechat, 5327 Bruck an der Leitha (ÖK50-BMN, map sheets 25 Poysdorf, 41 Deutsch Wagram, 42 Gänserndorf, 59 Wien, 60 Bruck an der Leitha, 76 Wiener Neustadt, 77 Eisenstadt, 78 Rust).

Remarks: In the Slovak part of the Vienna Basin this formation is termed Studienské vrstvy (Studienka beds) by Špička (1966) and Studienka Formation by Kováč et al. (2004), Fordinál et al. (2012) and Csibri et al. (2022), which was also adopted by Piller et al. (2004) for the Austrian part of the Vienna Basin. A formalization of the Studienka Formation, however, is lacking so far.

The corallinacean limestones in the northeastern part of the Leitha Mountains and in the vicinity of St. Margarethen in the Rust Mountains, usually termed Leitha Limestones, do not belong to the Leitha Formation (see there) and is named informally "St. Margarethen limestone" in the stratigraphic chart.

Complementary references: -

Holíč-Formation / Holíč Formation

Mathias Harzhauser

Validity: Valid; described and formalized by Olečko & Vass (2001) in the Slovak part of the Vienna Basin; this unit is widespread throughout the Vienna Basin and the name Holíč Formation has priority against the wide-spread but informal term "Hernalser Tegel" used by Austrian geologists.

Type area: In the surroundings of the town Holíč, northern Vienna Basin, Slovak Republic.

Type section: Deep well Vrádište-2 (310–154 m) (near N 48°49′10″ / E 17°11′20″) within the town Holíč, c. 21 km NW of the town Senica, Slovak Republic.

Reference section(s): An abandoned gravel pit at the village Unín, c. 10 km SSE of Holíč, Slovak Republic, was chosen by Elečko & Vass (2001) as type section for the Radimov Gravel. As this coarse clastic unit is a member of the Holíč Formation, it may act as reference section for the coarse-grained facies.

Derivation of name: Named after the town Holíč (N 48°48′40.12″ / E 17°09′40.12″), c. 21 km NW of the town Senica, Trnavský kraj, Slovak Republic.

Synonyms: Hernalser Tegel (Suess, 1866b), Cerithien Schichten p.p. (Suess, 1866b), Rissoen Schichten (= Mohrensternien Schichten), Hölleser Schichten (Brix, 1988), *Carychium* beds (Jiříček & Seneš, 1974), Detritärer Leithakalk.

Remark: "Hernalser Tegel" (Marl of Hernals) (Suess, 1866b) consists of blue calcareous clays, which are wide-spread in the entire Vienna Basin; "Cerithien Schichten" (Beds with cerithiids) (Suess, 1866b) are made of yellow sand and sandstone and occur in the entire Vienna Basin; "Rissoen Schichten (= Mohrensternien Schichten)" (Beds with rissoids) are blue clays and marls with shells of the endemic rissoid gastropod genus *Mohrensternia* – this term was used by all geologists during the 19th and early 20th centuries, it corresponds largely to the term "Hernalser Tegel"; "Hölleser Schichten" (Beds of Hölles) (Brix, 1988) represent a sandy marly facies in the central part of the Vienna Basin; "Carychium beds" (Jiříček & Seneš, 1974) represent the fluvial-terrestrial clays of the lowermost part of the formation in the northern Vienna Basin (= Kopčany Member, Elečko & Vass, 2001); "Detritärer Leithakalk" (detrital Leitha limestone) is a frequently used term for marginal lower Sarmatian deposits in the southern Vienna Basin and refers to reworked Badenian corallinacean limestones (Leitha Formation) which form several meter-thick deposits along the northwestern margin of the Leitha Mountains (e.g., Loretto, Mannersdorf).

Lithology: Grey and blue-grey marl, clay and silt with sand intercalations and rare acidic tuff layers. Carbonates consisting of bryozoan-serpulid-algae bioconstructions are typical along the margins of the basin. Thin layers of diatomites occur at Petronell in the southern Vienna Basin (Harzhauser & Piller, 2004a, b).

Fossils: Very rich in marine fossils; most typical is the low-diverse but individual-rich endemic mollusc fauna with the rissoid gastropod *Mohrensternia* and numerous potamidids, cardiids and mactrids. The microfauna is characterized by large-sized elphidiids. Cetaceans and phocids are most outstanding among the marine mammals (see Harzhauser & Piller, 2004a, for references).

Origin, facies: Shallow marine deposits of the Paratethys Sea; deltaic facies is restricted largely to the margins of the basin. The most characteristic facies of the Holíč Formation is represented by the carbonate build-ups consisting of serpulids, bryozoans and microbial mats. These may attain sizes of up to 1–2 m, but are usually preserved only as reworked boulders.

Chronostratigraphic age: Late middle Miocene, late Serravallian (early Sarmatian), c. 12.7–12.1 Ma.

Biostratigraphy: Foraminifera: *Anomalinoides* Zone, *Elphidium reginum* Zone; *Elphidium hauerinum* Zone; Mollusca: *Mohrensternia* Zone; Lower *Ervilia* Zone.

Thickness: Up to 700 m in the Steinberg area; otherwise ranging between 200–400 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Remark: Kopčany Member (Elečko & Vass, 2001): variegated pelites in the Kúty and Kopčany grabens in the northern Vienna Basin (Slovakia); this member is one of the lowermost units of the formation. Radimov Member (Elečko & Vass, 2001): fluvial-deltaic gravel in the northern Vienna Basin (Slovakia); "Brunner Konglomerat" (Brix, 1988): fluvial conglomerates along the western margin of the central Vienna Basin; this unit is intercalated in the upper part of the Holíč Formation; ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt). Raggendorf Fan (Kreutzer, 1974): subsurface; fluvial conglomerates and sand in the central Vienna Basin; ÖK50-UTM, map sheets 5320 Wien, 5321 Gänserndorf, 5314 Mistelbach, 5315 Zistersdorf (ÖK50-BMN, map sheet 42 Gänserndorf). Prottes Fan (Kreutzer, 1974): subsurface; fluvial conglomerates and sand in the central Vienna Basin; ÖK50-UTM, map sheets 5320 Wien, 5321 Gänserndorf, 5314 Mistelbach, 5315 Zistersdorf (ÖK50-BMN, map sheet 42 Gänserndorf).

Underlying unit(s): Austroalpine units along the margins; Baden Group in the basin.

Overlying unit(s): Skalica Formation.

Lateral unit(s): Ziersdorf Formation in the North Alpine Foreland Basin.

Geographic distribution: Entire Vienna Basin.

Remarks: Detailed descriptions and reviews concerning lithology, paleontology and sequence stratigraphy are given in HARZHAUSER & PILLER (2004a, b). VASS (2002) summarizes the lithostratigraphy of the formation in the Slovak part of the Vienna Basin.

Complementary references: KRENMAYR & SCHNABEL (2002a), PILLER et al. (2004).

Skalica-Formation / Skalica Formation

MATHIAS HARZHAUSER

Validity: Valid; defined by ELEČKO & VASS (2001).

Type area: In the surroundings of Holíč, northern Vienna Basin, Slovak Republic.

Type section: Deep well Vrádište-2 (154–5 m) (near N 48°49′10″ / E 17°11′20″) within the town Holíč, c. 21 km NW of the town Senica, Slovak Republic.

Reference section(s): -

Derivation of name: After the town Skalica (N 48°50′44.44″ / E 17°13′30.04″), c. 21 km NNW of the town Senica, Slovak Republic.

Synonyms: Cerithien Schichten (SUESS, 1866b), Atzgersdorfer Stein p.p. (BRIX, 1988), Karlova Ves Member (NAGY et al., 1993).

Remark: "Cerithien Schichten" (Beds with cerithiids) (SUESS, 1866b) are composed of yellow sand and sandstone in the entire Vienna Basin. "Atzgersdorfer Stein" (Beds of Atzgersdorf) is an oolithic sandstone with coquinas; its type area is along the Vienna Basin margin within the city of Vienna where it was used as building stone; however, the name was applied to various oolithic sandstones within the basin (BRIX, 1988).

Lithology: Extraordinary variability of lithologies, ranging from marl and silt to sandstone and gravel but includes also various mixed siliciclastic-carbonatic deposits such as oolites, rock-forming coquinas, and foraminiferal bioconstructions.

Fossils: An endemic mollusc fauna consisting mainly of venerid and cardiid bivalves along with cerithiid and potamidid gastropods is characteristic and may even be rock-forming (e.g., section Nexing). Nonionids with *Porosononion granosum* predominate among foraminifera; in the uppermost part of the formation a horizon with the larger foraminifers *Dentritina* and *Spirolina* is an important marker (see HARZHAUSER & PILLER (2004a) for references). *Sinzowella*-bioherms of up to 1 m height occur in the Wolfsthal Member.

Origin, facies: Shallow marine settings with extended oolite shoals.

Chronostratigraphic age: Late middle Miocene, late Serravallian (late Sarmatian), c. 12.1–11.6 Ma.

Biostratigraphy: Foraminifera: *Porosononion granosum* Zone; Mollusca: Upper *Ervilia* Zone, *Sarmatimactra vitaliana* Zone.

Thickness: Up to 500 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: The Wolfsthal Member (HARZHAUSER & PILLER, 2004a) represents the lower part of the Skalica Formation.

As informal units exist: "Riesenkonglomerat von Windischbaumgarten" (GRILL, 1968): represents boulders of reworked Badenian limestones that formed during a transgression along the coast of the Steinberg block in the northern Vienna Basin; ÖK50-UTM, map sheet 5315 Zistersdorf (ÖK50-BMN, map sheet 25 Poysdorf), "Kottingbrunner Schichten" (Kottingbrunn Beds) (BRIX, 1988): fossiliferous sandy to clayey marls in the central and southern Vienna Basin; ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt).

Underlying unit(s): Holíč Formation.

Overlying unit(s): Bzenec Formation.

Lateral unit(s): Tinnye Formation in Hungary (CSÁSZÁR, 1997).

Geographic distribution: Widespread in the Vienna Basin and the Eisenstadt-Sopron Basin.

Remarks: The Holostratotype of the Sarmatian regional stage at Nexing in Lower Austria (PAPP & STEININGER, 1974) is part of the Skalica Formation (HARZHAUSER & PILLER, 2010).

Complementary references: KRENMAYR & SCHNABEL (2002a), PILLER et al. (2004).

Wolfsthal-Subformation (Skalica-Formation) / Wolfsthal Member (Skalica Formation)

MATHIAS HARZHAUSER

Validity: Valid; described and defined by HARZHAUSER & PILLER (2004a).

Type area: In the area of Hainburg an der Donau and Wolfsthal, southern Vienna Basin, Lower Austria; ÖK50-UTM, map sheets 5327 Bruck an der Leitha, 5328 Preßburg (ÖK50-BMN, map sheet 61 Hainburg).

Type section: 20 m-thick succession in an abandoned quarry in the deer park SW of the village Wolfsthal (N 48°07′47.92″ / E 16°59′28.37″), Lower Austria; ÖK50-UTM, map sheets 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 61 Hainburg).

Reference section(s): -

Derivation of name: After the village Wolfsthal (N 48°8′14.3″ / E 17°0′14.8″), c. 5 km ESE of the town Hainburg an der Donau, Lower Austria; ÖK50-UTM, map sheets 5328 Preßburg (ÖK50-BMN, map sheet 61 Hainburg).

Synonyms: Atzgersdorfer Stein (BRIX, 1988), Karlova Ves Member (NAGY et al., 1993; VASS, 2002) (see HARZHAUSER & PILLER, 2004a for discussion on this member).

Lithology: Oolites, sandy oolites, rock-forming mollusc coquinas, *Sinzowella* bioherms.

Fossils: Enormously rich in shallow marine molluscs (e.g., *Polititapes tricuspis, Obsoletaformis vindobonense, Plicatiforma latesulca, Thericium rubiginosum*), *Sinzowella* bioherms of up to 1 m height may occur.

Chronostratigraphic age: Late middle Miocene, late Serravallian (late Sarmatian), c. 12.1–11.6 Ma.

Biostratigraphy: Molluscs: Upper *Ervilia* Zone and lower parts of the *Sarmatimactra vitaliana* Zone; Foraminifera: *Porosononion granosum* Zone.

Thickness: 20 m.

Lithostratigraphically higher rank unit: Skalica Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Lower Austro-Alpine units; Holíč Formation.

Overlying unit(s): The Wolfsthal Members forms the landscape in many areas of the Vienna Basin; in basinal settings it is overlain by the Bzenec Formation.

Lateral unit(s): "Kottingbrunner Schichten" (Brix, 1988) in the Vienna Basin; the Waltra Member in the Styrian Basin (Friebe, 1994a) is a temporal and facial equivalent of the Wolfsthal Member.

Geographic distribution: Widespread along the margins of the Vienna Basin, including the rock-forming oolitic coquinas of Atzgersdorf (Vienna), Hauskirchen (Lower Austria), and Nexing (Lower Austria); ÖK50-UTM, map sheets 5314 Mistelbach, 5315 Zistersdorf, 5326 Schwechat, 5327 Bruck an der Leitha, 5328 Bratislava (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 58 Baden, 59 Wien, 61 Hainburg).

Remarks: -

Complementary references: Piller & Harzhauser (2005), Harzhauser & Piller (2010).

Bzenec-Formation / Bzenec Formation

Mathias Harzhauser

Validity: Valid; formalized by Čtyroký (2000).

Type area: Area in the surroundings of the town Bzenec, Moravia, Czech Republic (northern Vienna Basin).

Type section: Deep wells Kyj-1 and Kyj-2 in the lignite mine Pokrok, near the village Žeravice, c. 8.5 km ENE of Kyjov, South Moravia, Czech Republic.

Reference section(s): Railway section between Lužice and Mikulčice, SW of the town Hodonín, Czech Republic (Čtyroký, 2000); shaft DV-4 of the lignite mine Dukla at Mistrin, SW of Kyjov, South Moravia, Czech Republic, being the type section of the Kyjov Member which is part of the Bzenec Formation (Čtyroký, 2000).

Derivation of name: Named after the town Bzenec (N 48°58′23.79″ / E 17°16′0.06″), c. 17 km NE of the town Hodonín, South Moravia, Czech Republic.

Synonyms: Congerienschichten, Congerientegel, Brunner Schichten (Krenmayr & Schnabel, 2002a), Inzersdorfer Tegel (Brix, 1988), Pannonium A–E (Papp, 1951), Bzenec-Formation (Inzersdorfer Sch.) (Piller et al., 2004).

Lithology: Silty clays predominate with subordinate sand, gravel and lignites; very rare limestones may occur in marginal positions (e.g., Leobersdorf).

Fossils: The most conspicuous fossils of the Bzenec Formation are the endemic molluscs of Lake Pannon: melanopsid gastropods (e.g., *Melanopsis fossilis*), cardiid bivalves (e.g., *Lymnocardium schedelianum*) and dreissenid bivalves (e.g., *Congeria subglobosa, Mytilopsis spathulata*). Among the rich terrestrial vertebrate fauna, characterized by isolated bones of *Deinotherium, Aceratherium, Miotragocerus* and *Hyotherium*, the first occurrence of the equid genus *Hippotherium* is most important (Harzhauser & Mandic, 2004, 2008; Harzhauser et al., 2004; Daxner-Höck et al., 2016; Bernor et al., 2017).

Origin, facies: Basinal clays of Lake Pannon; deltaic facies may interfinger with the lake deposits.

Chronostratigraphic age: Late Miocene, Tortonian (early to middle Pannonian); c. 11.6–~ 10 Ma.

Biostratigraphy: Molluscs, littoral: *Mytilopsis ornithopsis* Zone, *Mytilopsis hoernesi* Zone and *Lymnocardium conjungens* Zone. Molluscs sublittoral: *Lymnocardium praeponticum* Zone and *Mytilopsis czjzeki* Zone; Pannonian A–E.

Thickness: Up to 700 m; e.g., deep wells Gösting, Eichhorn, Aderklaa.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Not formally defined.

A number of informal units are described: "schiefrige Tonmergel": a 20–50 m thick unit of ostracod-bearing, greengray marly clay in the basal part of the Bzenec Formation (Harzhauser et al., 2004). Kyjov Member (Čtyroký, 2000): lignites and clays in the northern Vienna Basin. "Leobersdorfer Schichten" (Brix, 1988): marginal deposits, consisting of several meters of sand, marly sand and scattered gravel in the southern Vienna Basin. "Großer unterpannoner Sand" [= big Lower Pannonian sand] (Janoschek, 1951): only subsurface, up to 200 m of sand which are a basinal continuation of the deltaic facies of the Hollabrunn-Mistelbach Formation; ÖK50-UTM, map sheet 5314 Mistelbach (ÖK50-BMN, map sheets 24 Mistelbach, 25 Poysdorf, 41 Deutsch Wagram). Leobersdorfer Schichten, Triesting Schotter, Piesting Schotter, Lindenbergkonglomerat (Brix, 1988; Krenmayr & Schnabel, 2002a) represent up to 127 m-thick deltaic systems in the southern Vienna Basin; ÖK50-UTM, map sheet 5201 Wiener Neustadt (ÖK50-BMN, map sheet 76 Wiener Neustadt). Záhorie Member (Vass, 2002): 100–340 m of clay and sand with subordinate gravel and rare lignites. See Harzhauser et al. (2004) for a detailed survey of the informal subdivisions.

Underlying unit(s): Skalica Formation.

Overlying unit(s): Čáry Formation.

Lateral unit(s): Hollabrunn-Mistelbach Formation in the North Alpine Foreland Basin (Nehyba & Roetzel, 2004); Szák Formation in Hungary (Császár, 1997).

Geographic distribution: Widespread in the Vienna Basin and the Eisenstadt-Sopron Basin. Important outcrops are Hennersdorf (Kern et al., 2012a, b) and Mannersdorf (Harzhauser et al., 2004).

Remarks: The holostratotype of the Pannonian regional stage was defined within that unit by PAPP (1985) in the market town Vösendorf near Vienna, southern Vienna Basin, Lower Austria.

Complementary references: PILLER et al. (2004), HARZHAUSER et al. (2004, 2007).

Hollabrunn-Mistelbach-Formation / Hollabrunn-Mistelbach Formation

(see North Alpine Foreland Basin: Lower Austria, North of the Danube and at the Bohemian Massif)

Čáry-Formation / Čáry Formation

MATHIAS HARZHAUSER

Validity: Valid; defined by BARTEK (1989).

Type area: Area between Čáry, Štefanov, Sekule and Závod, Slovak Republic. Slovakian part of the northern Vienna Basin.

Type section: Deep well Gb-1 (68.5–179.8 m) near the village Čáry (N 48°39′17.45″ / E 17°05′07.20″), Slovak Republic.

Reference section(s): -

Derivation of name: Named after the village Čáry, c. 20 km W of Senica, Trnava Region**,** Slovak Republic.

Synonyms: Lignitische Serie (lignitic series) (see HARZHAUSER et al., 2004 for references), Untere Neufelder Schichten (lower Neufeld Beds) (BRIX, 1988), Dubňany Formation (ČTYROKÝ, 2000), Neufeld-Formation p.p. (ZORN, 2000), Cary-Fm. (Neufelder Sch.) (PILLER et al., 2004).

Lithology: Lignites, lignitic clay, silt and sand; rare marly freshwater limestones occur in the southern Vienna Basin (e.g., Richardhof).

Fossils: *Congeria subglobosa* in the lowermost parts; *Mytilopsis zahalkai* in upper parts; freshwater and terrestrial molluscs and small mammals are frequent in the marly limestones along the basin margins (DAXNER-HÖCK, 1996; HARZHAUSER et al., 2004).

Origin, facies: Wetland environments, lakes and swamps; these lakes are already decoupled from Lake Pannon.

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian); c. 10.1–9.6 Ma.

Biostratigraphy: Molluscs: *Mytilopsis neumayri/zahalkai* Zone; top of Zone E and Zone F of PAPP (1951); mammal zone: late MN9.

Thickness: Up to 200 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Sekule Member (BARTEK, 1989): < 100 m, clay and sand, lignites (top of Zone E). Dubňany Member (BARTEK, 1989): 30 m, representing the main lignite seam. Ján Member (BARTEK, 1989): > 100 m, sand, clay, lignites.

Underlying unit(s): Bzenec Formation.

Overlying unit(s): Gbely Formation.

Lateral unit(s): -

Geographic distribution: Vienna Basin and Eisenstadt-Sopron Basin. Most important occurrences in the Austrian part of the Vienna Basin are lignite seams in the area of Sollenau, Dornau, Schönau; ÖK50-UTM, map sheet 5201 Wiener Neustadt (K50-BMN, map sheet 76 Wiener Neustadt) and south of Leobersdorf and their counterparts along the eastern margin at Zillingdorf, Neudörfl, Neufeld an der Leitha and Pöttsching (ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Remarks: The coal seams of Neufeld and Zillingdorf have already been reported by CŽJŽEK (1851); this coal seam is between 8–12 m thick but represents an alternation of sandy silt ("Tegel") and lignite of low quality (RUTTNER, 1952).

Complementary references: STEININGER et al. (1989).

Gbely-Formation / Gbely Formation

MATHIAS HARZHAUSER

Validity: Valid; defined by BARTEK (1989).

Type area: Area between Sekule, Gbely and Brodské, Trnavský kraj, Slovak Republic; Slovakian part of the northern Vienna Basin.

Type section: Deep well Kv-100 at Kúty (5.9–203.0 m), c. 10 km NE of Hohenau an der March (Lower Austria), Slovak Republic (BARTEK, 1989).

Reference section(s): Shaft GV-1 at Dubňany, c. 7.5 km NNW of Hodonín, Czech Republic (ČTYROKÝ, 2000).

Derivation of name: After the village Gbely (N 48°43′06.24″ / E 17°6′53.81″), c. 19 km WNW of the town Senica, Trnavský kraj, Slovak Republic.

Synonyms: Obere Neufelder Schichten (Upper Neufeld beds) (BRIX, 1988), Blaue Serie (= blue series) and Zwischensand (= lower part of the Gbely Formation); Bunte Serie (= variegated series) and Gelbe Serie (= yellow series) (= upper part of the Gbely Formation) (JANOSCHEK, 1951), Neufeld-Formation p.p. (ZORN, 2000).

Lithology: Marl, clay and silt with intercalations of sand, gravel, rare lignites and sporadic freshwater limestones in the top. The limestones of the Eichkogel section (S of the town Mödling, Lower Austria) are a marginal equivalent.

Fossils: Very poor in fossils; only few sections (e.g., Eichkogel, Prottes, Wolkersdorf) yield important vertebrate faunas and rich limnic and terrestrial molluscs (DAXNER-HÖCK, 1996; HARZHAUSER & BINDER, 2004).

Origin, facies: Wetland environments, lakes and swamps; these lakes are already decoupled from Lake Pannon.

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian); c. 9.6–8.0 Ma.

Biostratigraphy: Mammal zones: MN10–11 (HARZHAUSER et al., 2004); Pannonian Zones G–H of PAPP (1951).

Thickness: Up to 450 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Čáry Formation.

Overlying unit(s): Brodské Formation, Quaternary deposits.

Lateral unit(s): -

Geographic distribution: Widespread in the entire Vienna Basin; ÖK50-UTM, map sheet 5321 Gänserndorf, 5201 Wiener Neustadt (ÖK50-BMN, map sheet 42 Gänserndorf, 43 Marchegg, 60 Bruck an der Leitha, 77 Eisenstadt, 78 Rust).

Remarks: -

Complementary references: Krenmayr & Schnabel (2002a), Piller et al. (2004).

Rohrbach-Formation / Rohrbach Formation

Mathias Harzhauser

Validity: Valid; described and formalized by Koukal & Wagreich (2009).

Type area: Area around Neunkirchen – Ternitz, Lower Austria (southern Vienna Basin); ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheets 105 Neunkirchen, 106 Aspang-Markt).

Type section: An approx. 12.5 m-thick section in the Rohrbach Quarry (N 47°43′44.28″ / E 16°03′10.38″) at Rohrbach am Steinfelde, c. 2 km WNW of the town Neunkirchen, Lower Austria; ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheets 105 Neunkirchen).

Reference section(s): Abandoned quarry c. 1.1 km NE of the type section at Rohrbach Quarry (N 47°44′11″ / E 16°03′45″).

Derivation of name: After the village Rohrbach am Steinfelde (now part of the town Ternitz) (N 47°43′22″ / E 16°02′42″), Lower Austria (southern Vienna Basin).

Synonyms: Rohrbacher Konglomerat (Karrer, 1877), “Ternitzer” Konglomerat (Plöchinger, 1967), Rohrbach- und Ternitz Formation (Krenmayr & Schnabel, 2002a), Rohrbach-Konglomerat-Formation (Schnabel, 2008).

Lithology: Red to yellow, polymict, poorly sorted conglomerates and yellow sandstones with high carbonate content.

Fossils: Nearly barren of fossils; rare ostracods, a sparse palynoflora and vertebrate traces are recorded (Thenius, 1974; Koukal & Wagreich, 2009).

Origin, facies: Channels, chutes, gravel bar sediments and overbank fines of a braided river (Koukal & Wagreich, 2009).

Chronostratigraphic age: Late Miocene, Tortonian to Pliocene (late Pannonian).

Biostratigraphy: -

Thickness: Up to 65 m in drillings.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Gbely Formation.

Overlying unit(s): Pleistocene gravel of the “Steinfeldschotter” (Koukal & Wagreich, 2009), Loipersbach Formation (Schnabel, 2008).

Lateral unit(s): Interfingers partly with the Gbely Formation in its lower part and with the “Würflacher Wildbachschotter” (informal lithostratigraphic unit) in its upper part (Brix, 1988).

Geographic distribution: Southern Vienna Basin, from Gloggnitz in the south to Wiener Neustadt in the north; ÖK50-UTM, map sheet 4212 Mürzzuschlag, 5201 Wiener Neustadt, 5207 Neunkirchen (ÖK50-BMN, map sheet 76 Wiener Neustadt, 105 Neunkirchen).

Remarks: -

Complementary references: Küpper et al. (1952), Brix (1988), Piller et al. (2004), Schnabel (2008), Koukal & Wagreich (2009).

Loipersbach-Formation / Loipersbach Formation

Mathias Harzhauser

Validity: Invalid; these sediments were described by Grill (1974b) and Grill & Schmid (1975) without denominating the unit; Krenmayr & Schnabel (2002a) introduced the term “Loipersbach-Formation” without detailed description and formalization; Schnabel (2008) suggested a formalization as “Loipersbach-Formation” or “Loipersbach-Rotlehm-Formation”, however, also without providing the necessary information.

Type area: In the area around the villages Natschbach and Loipersbach, c. 2 km SE of Neunkirchen, Lower Austria (southern Vienna Basin); ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheet 106 Aspang-Markt).

Type section: -

Reference section(s): -

Derivation of name: After the village Loipersbach (N 47°43′5.57″ / E 16°07′6.11″), c. 3 km ESE of the town Neunkirchen, Lower Austria; ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheet 106 Aspang-Markt).

Synonyms: Loipersbacher Rotlehmserie, Loipersbach-Rotlehm-Formation (Schnabel, 2008).

Lithology: Red clay with subordinate quartz and quartzite gravel and boulders.

Fossils: -

Origin, facies: Terrestrial-alluvial environments with repeated paleosol formation.

Chronostratigraphic age: Pliocene; dating is rather tentative.

Biostratigraphy: -

Thickness: Several meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Gbely Formation, Rohrbach Formation.

Overlying unit(s): Quaternary deposits.

Lateral unit(s): Rohrbach Formation.

Geographic distribution: Restricted to the southernmost tip of the Vienna Basin; ÖK50-UTM, map sheet 5207 Neunkirchen (ÖK50-BMN, map sheet 106 Aspang-Markt).

Remarks: The Loipersbach Formation is not shown in the stratigraphic chart because of its uncertain age.

Complementary references: Krenmayr & Schnabel (2002a), Schnabel (2008).

Brodské-Formation / Brodské Formation

Mathias Harzhauser

Validity: Valid; defined by Bartek (1989).

Type area: The area of Brodské, Trnavský kraj, Slovak Republic; Slovakian part of the northern Vienna Basin.

Type section: Deep well Gb-21 (12.3–63.4 m) (N 48°41′53.99″ / E 17°01′36.33″), c. 1 km NE of Brodské, Slovak Republic.

Reference section(s): Deep wells GB-23, Kv-223, Kv-225 between Gbely and Kúty, Trnavský kraj, Slovak Republic.

Derivation of name: After the village Brodské (N 48°41′32.88″ / E 17°00′48.64″), c. 23 km SE of the town Skalica, Trnavský kraj, Slovak Republic.

Synonyms: Rote Lehmserie (Janoschek, 1951; Thenius, 1974), Bunte Lehmserie (Krenmayr & Schnabel, 2002a), Brodske-Formation (Bunte Lehmserie) (Piller et al., 2004).

Lithology: Marl, sandy clay, sand, subordinate gravel and rare lignites.

Fossils: Nearly barren of fossils; rare ostracods (e.g., *Cypris candonaeformis*) are mentioned by Bartek (1989).

Origin, facies: Limnic and alluvial environments with repeated paleosol formation.

Chronostratigraphic age: Early Pliocene, Zanclean (?); datings are rather tentative.

Biostratigraphy: -

Thickness: 50–80 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Gbely Formation.

Overlying unit(s): Quaternary deposits.

Lateral unit(s): Interfingers with the Valtice Gravel in the Czech part of the Vienna Basin (Vass, 2002).

Geographic distribution: Northern Vienna Basin; especially in the Steinberg area between Hohenruppersdorf and Zistersdorf (Grill, 1968); ÖK50-UTM, map sheets 5314 Mistelbach, 5315 Zistersdorf (ÖK50-BMN, map sheets 25 Poysdorf, 42 Gänserndorf).

Remarks: The Brodské Formation is not shown in the stratigraphic chart because of its uncertain age.

Complementary references: Bartek (1989), Piller et al. (2004).

Eisenstadt-Sopron Basin

Mathias Harzhauser

The Eisenstadt-Sopron Basin is more or less triangular and measures about 20 x 20 km in size (Text-Fig. 8). In the north it is limited by the NE–SW trending Leitha Mountains and the associated SE dipping Eisenstadt Fault. In the east, the basin is bordered by the N–S trending Köhida Fault. The Rust-Fertörakos Mountains separate the basin from the Danube Basin in the East. A crystalline ridge, covered by Lower Miocene gravel, extending from the Rosalia Mountains to the Brennberg, defines the southern margin. This topographical barrier separates the Eisenstadt-Sopron Basin from the Oberpullendorf Basin and the Styrian Basin. Its development is closely linked with that of the Vienna Basin, although the thickness of the basin fill is much less (c. 1,500 m). Sedimentation started during the early Miocene and ended during the late Miocene. Only the Hartl Formation has been formalized yet from the herein listed formations distinct to the Eisenstadt-Sopron Basin.

Text-Fig. 8.
Location of the Eisenstadt-Sopron Basin and the Oberpullendorf Basin (grey shaded) on Austrian territory.

Rust-Formation (Baden-Gruppe) / Rust Formation (Baden Group)

Mathias Harzhauser

Validity: Invalid; introduced by Kapounek (1938) as “Rusterschotter”, renamed by Zorn (2000) to “Rust-Formation” without formalization.

Type area: The Rust Hills between the villages Mörbisch and Schützen am Gebirge, Burgenland (Zorn, 2000; Häusler, 2010); ÖK50-UTM, map sheets 5202 Eisenstadt, 5208 Mattersburg (ÖK50-BMN, map sheets 77 Eisenstadt, 78 Rust).

Type section: Not defined; an outcrop in the Schaffgrubenwald (c. N 47°48′05″ / E 16°39′05″), W of the town Rust, described by FUCHS (1965a), might act as type section but is currently covered by vegetation; ÖK50-UTM, map sheets 5202 Eisenstadt (ÖK50-BMN, map sheet 78 Rust).

Reference section(s): -

Derivation of name: After the town Rust (N 47°48′8.29″ / E 16°40′19.69″), Burgenland; ÖK50-UTM, map sheets 5203 Neusiedl am See, 5209 Illmitz (ÖK50-BMN, map sheet 78 Rust).

Synonyms: Rusterschotter (KAPOUNEK, 1938), Burgstall Schotter (TOLLMANN, 1955), Ruster Schotter und Sand (HÄUSLER, 2010).

Remark: The Burgstall Schotter was erroneously included as separate unit by PILLER et al. (2004).

Lithology: Fine to coarse sand with layers of gravel consisting of grey to white quartz, quartzite and gneiss. Angular boulders of more than 1 m diameter and occur especially in the western part of the distribution area; cross bedding is observed in the sandy parts.

Fossils: -

Origin, facies: Fluvial; parts of the Rust Formation seem to have been reworked during the Badenian ingression of the Paratethys Sea into the Eisenstadt-Sopron Basin. TOLLMANN (1955) and FUCHS (1965a) suggest a fluvial system that entered the Eisenstadt-Sopron Basin from the Rosalia Mountains, crossing the basin in S–N direction and entering the southern Vienna Basin across the later Leitha Mountains.

Chronostratigraphic age: Middle Miocene, early Langhian (early Badenian), c. 15.4–15.2 Ma. HÄUSLER (2010) and HÄUSLER et al. (2014) proposed a Karpatian age but HARZHAUSER et al. (2020) suggested a spatial relation with the early Badenian Rothneusiedl Formation.

Biostratigraphy: -

Thickness: 100 m.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement.

Overlying unit(s): Hartl Formation, Leitha Formation.

Lateral unit(s): The Rothneusiedl Formation in the Vienna Basin and the Brennberg Block Flow in the Ödenburg Mountains and the Oberpullendorf Basin might be lateral equivalents.

Geographic distribution: Restricted to the Rust Hills, west of Lake Neusiedl, and the occurrence along the southern margin of the Leitha Mountains, Burgenland; ÖK50-UTM, map sheets 5202 Eisenstadt, 5208 Mattersburg (ÖK50-BMN, map sheets 77 Eisenstadt, 78 Rust, 107 Mattersburg).

Remarks: CŽJŽEK (1852b) first mentioned the gravels in the surrounding of Rust.

The so-called Burgstall gravel along the southern margin of the Leitha Mountains belongs to the Rust Formation.

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004), HÄUSLER (2010).

Hartl-Formation (Baden-Gruppe) / Hartl Formation (Baden Group)

MATHIAS HARZHAUSER

Validity: Valid; formalized by KROH et al. (2003).

Type area: NE of the town Eisenstadt to NE of the village St. Georgen am Leithagebirge, along the Hartl Hill, Burgstall Hill and Hummelbühel Hill, Burgenland; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Type section: At the abandoned sand pit at “Hartllucke” (N 47°51′20″ / E 16°31′34″) an approx. 10 m thick section is exposed, NE of the centre of Eisenstadt, Burgenland; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt) (KROH et al., 2003).

Reference section(s): At the abandoned quarry “Johannesgrotte” (N 47°51′47″ / E 16°31′16″) an approx. 8 m thick section is exposed with predominantly sandy limestones and calcareous sandstones, NE of Eisenstadt, Burgenland; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt) (KROH et al., 2003).

Derivation of name: After the hillside Hartl in the northeastern part of the town Eisenstadt, Burgenland; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Synonyms: Terebratelsande (KAPOUNEK, 1938), Terebratelsande von Eisenstadt, Hartlsande, Eisenstädter Terebratelsand (TOLLMANN, 1955).

Lithology: Coarse calcareous sand to fine gravel grading into bryozoan-corallinacean limestones.

Fossils: Bryozoans, balanids and brachiopods are typical; the type section is one of the most important bryozoan localities in the Neogene of Europe. *Aequipecten* predominates among the molluscs. *Cibicidoides, Heterolepa, Lobatula* and *Amphistegina* are characteristic foraminifera (see KROH et al. (2003) for a detailed discussion).

Origin, facies: Agitated, current dominated foreshore conditions in the lower parts; shallow marine environments with seagrass, corallinacean debris and coral patches in the upper part. A maximum depth of 30–50 m is assumed for the marly parts in the top of the formation (KROH et al., 2003).

Chronostratigraphic age: Middle Miocene, late Langhian (middle Badenian); c. 14.6–13.8 Ma.

Biostratigraphy: Lagenidae Zone; younger than 14.56 Ma based on the frequent occurrence of *Orbulina*.

Thickness: 10–30 m.

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: -

Underlying unit(s): Rust Formation (locally termed Burgstall Gravel) and crystalline basement of the Leitha Mountains.

Overlying unit(s): In few places the Hartl Formation is overlain by middle Badenian corallinacean limestones of the Leitha Formation.

Lateral unit(s): Unclear; marl and clay in the centre of Eisenstadt seem to represent the adjacent basinal facies (KROH et al., 2003).

Geographic distribution: Eisenstadt-Sopron Basin; along the southern flanks of the Leitha Mountains between Eisenstadt and St. Georgen am Leithagebirge. Remnants of the Hartl Formation, with the typical terebratulid brachiopods, are also found as sandstone blocks in the Stotzing bay on the northern side of the Leitha Mountains; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Remarks: -

Complementary references: Tollmann (1985), Zorn (2000), Piller (2000a), Piller et al. (2004).

Baden-Formation (Baden-Gruppe) / Baden Formation (Baden Group)

(for description see Vienna Basin)

Leitha-Formation (Baden-Gruppe) / Leitha Formation (Baden Group)

(for description see Vienna Basin)

„St. Margarethen Kalk“ / “St. Margarethen Limestone”

(see Rabensburg-Formation (Baden-Gruppe) / Rabensburg Formation (Baden Group))

Holíč-Formation / Holíč Formation

(for description see Vienna Basin)

Skalica-Formation / Skalica Formation

(for description see Vienna Basin)

Wolfsthal-Subformation (Skalica-Formation) / Wolfsthal Member (Skalica Formation)

(for description see Vienna Basin)

Bzenec-Formation / Bzenec Formation

(for description see Vienna Basin)

Föllig Schotter / Föllig Gravel

Mathias Harzhauser

Validity: Invalid; introduced by Lueger (1977).

Type area: Föllig hill, c. 2 km SW of Großhöflein near Eisenstadt, Burgenland; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Type section: Not defined, but a possible location is at the southern flank of the Föllig hill (see Lueger, 1980, for map).

Reference section(s): -

Derivation of name: Named after the Föllig hill (N 47°49′17″ / E 16°27′40″), c. 2 km SW of Großhöflein, SW of the town Eisenstadt, Burgenland (Eisenstadt-Sopron Basin); ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Synonyms: Foelik Schotter (Tollmann, 1955), Fölligschotter (Lueger, 1977).

Lithology: Cross bedded gravel and fine-medium sand with gravel components of up to 11 cm diameter (Lueger, 1977). Clay layers are subordinate.

Fossils: A mixed mollusc fauna consisting of limnic Lake Pannon taxa such as *Mytilopsis spathulata, Congeria pancici* and *Congeria subglobosa* accompanied by fluvial taxa such as *Unio atavus* and *Tinnyea escheri*. In addition, a rich ostracod assemblage is described by Lueger (1980).

Origin, facies: Fluvial deposits within a deltaic channel into Lake Pannon.

Chronostratigraphic age: Late Miocene, Tortonian (early to middle Pannonian); c. 11.2–10.3 Ma.

Biostratigraphy: Pannonian Zones C–E of Papp (1951); Mollusc Zones: *Mytilopsis hoernesi* Zone and *Lymnocardium conjungens* Zone.

Thickness: 17–30 m (Lueger, 1980).

Lithostratigraphically higher rank unit: Might represent a member of the Bzenec Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Unknown.

Overlying unit(s): -

Lateral units: Clay of the Bzenec Formation.

Geographic distribution: Restricted to the Föllig hill in the Eisenstadt-Sopron Basin; ÖK50-UTM, map sheet 5202 Eisenstadt (ÖK50-BMN, map sheet 77 Eisenstadt).

Remarks: -

Complementary references: Tollmann (1985), Zorn (2000), Piller et al. (2004).

Oberpullendorf Basin (northern margin)

Mathias Harzhauser

The Oberpullendorf Basin is an about 20 km wide structure (Text-Fig. 8), delimited in the north by the southern slopes of the Rosalia Mountains and the Ödenburg Mountains, by Lower Austro-Alpine metamorphic units of the so-called Bucklige Welt in the west, and by the Penninic units of the Güns Mountains in the south. Towards the east, it is connected to the Pannonian Basin Complex. Herein, only the lower and middle Miocene deposits along the northern margin are considered. None of the herein listed formations distinct to the Oberpullendorf Basin and the Ödenburg Mountains has been formalized yet.

Brennberg-Formation / Brennberg Formation

MATHIAS HARZHAUSER

Validity: Invalid.

Type area: The area of Brennbergbánya along the Austrian/Hungarian border.

Type section: -

Reference section(s): -

Derivation of name: After the Hungarian village Brennbergbánya (= Brennberg) (N 47°39′17.74″ / E 16°29′23.75″), about 7 km WSW of the town Sopron, Hungary; ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Synonyms: Süßwasserschichten von Brennberg (JANOSCHEK, 1931), Brennberger Süßwasserserie mit Kohlenflöz (TOLLMANN, 1985), Brennberger Schichten, kohlenführende Süßwasserschichten von Brennberg (PERESZLÉNYI et al., 1994), Brennberg Lignite Formation (CSÁSZÁR, 1997).

Lithology: Basal breccias consisting of crystalline gravel; above follows a thick lignite of up to 16 m thickness and grey sandy marl, sandstone and fine gravel (JANOSCHEK, 1931).

Fossils: Plant debris and imprints of leaves (*Glyptostrobus*).

Origin, facies: Freshwater lakes and ponds fringed by swamps.

Chronostratigraphic age: Early Miocene, Burdigalian (Ottnangian); c. 18.1–17.2 Ma; dating is tentative. Referred to as Brennberg Sedimentation-Cycle by NEBERT et al. (1980).

Biostratigraphy: -

Thickness: Up to 50 m on Austrian territory, up to 60–180 m in Hungary (JANOSCHEK, 1931; CSÁSZÁR, 1997).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline units.

Overlying unit(s): Lower Auwald Gravel, Upper Auwald Gravel, Hochriegel Formation, Brennberg Block Flow (WEBER & WEISS, 1983).

Lateral unit(s): This formation passes the Austrian/Hungarian border and is termed Brennberg Lignite Formation on Hungarian territory (CSÁSZÁR, 1997). It might be a time equivalent of the Köflach-Voitsberg Formation in the Styrian Basin.

Geographic distribution: Oberpullendorf Basin; a narrow area along the southern slopes of the Rosalia mountains between Schwarzenbach and Oberpetersdorf in the west and Neckenmarkt and Brennbergbánya in the east; ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Remarks: -

Complementary references: KÜPPER (1957), FUCHS (1980c), ZORN (2000), PILLER et al. (2004).

Auwald-Schotter / Auwald Gravel

MATHIAS HARZHAUSER

Validity: Invalid; introduced by VENDL (1933). The term “Schotter und Conglomerat vom Auwald” (= Gravel and conglomerate from the Auwald) was first used by WOLF (1870), who clearly referred to an upper part of the succession which in fact are Badenian deposits with reworked Auwald Gravel.

Type area: The area of Brennbergbánya along the Austrian/Hungarian border. VENDL (1933) described the area between the “Gute Hoffnung-Altbrennberg” open mine and the Barbaraschacht (Barbara mine) at Brennbergbánya as typical. KÜMEL (1940) mentions occurrences in the area of the hillside Reisnerkogel (N 47°41′55.26″ / E 16°22′57.66″), Burgenland; ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg.

Type section: -

Reference section(s): -

Derivation of name: After the alluvial forest (= Auwald) north of the village Sieggraben, Burgenland (WOLF, 1870; KÜMEL, 1940); ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Synonyms: -

Lithology: The basic lithology is gravel with different dominating components in the lower and upper part.

Lower Auwald Gravel: polymict, angular to well rounded, coarse gravel consisting exclusively of crystalline material (gneiss, pegmatite, mica schist) with boulders of up to 2 m^3, derived from the Rosalia Mountains (VENDL, 1933).

Upper Auwald Gravel: well rounded, polymict, coarse gravel and pebbles with intercalations of cross-bedded, poorly sorted sand (HARZHAUSER et al., 2014b). Components derived from the Calcareous Alps and Greywacke Zone with high contribution by limestones and dolostones (JANOSCHEK, 1931; ZORN, 2000).

Fossils: No fossils known from the Lower Auwald Gravel. From the Upper Auwald Gravel: *Chara*-oogonia, gastropods (Helicidae, *Melanopsis*, *Theodoxus*) and bivalves (Dreissenidae, Unionidae) (VENDL, 1973).

Origin, facies: River dominated wetlands with ponds. Note that WOLF (1870) and JANOSCHEK (1931) described various marine fossils (Corallinaceans, Bryozoa, Porites, *Turritella*, *Vermetus*) from the Upper Auwald Gravel. Herein, this part is interpreted as marine reworking of the lower Miocene gravel in basal parts of the Badenian Ritzing Formation In addition, the Upper Auwald Gravel grades without discordance into the limnic Hochriegel Formation (PERESZLÉNYI et al., 1994), what contradicts any marine influence.

Chronostratigraphic age: Early Miocene, upper Burdigalian (Karpatian); c. 17.2–15.9 Ma.

Remark: Corresponds to the lower Miocene Auwald Sedimentation-Cycle of NEBERT et al. (1980).

Biostratigraphy: The mollusc fauna is reminiscent of that from the Aderklaa Formation in the Vienna Basin.

Thickness: 350 m (Lower Auwald Gravel: 100 m, Upper Auwald Gravel: 250 m) (VENDL, 1933).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal subdivision into "Untere Auwald Schotter" (Lower Auwald Gravel) and "Obere Auwald Schotter" (Upper Auwald Gravel).

Underlying unit(s): Brennberg Formation.

Overlying unit(s): Hochriegel Formation, Brennberg Block Flow, Ritzing Formation (Janoschek, 1931; Pascher, 1991; Pereszlényi et al., 1994).

Lateral unit(s): This formation passes the Austrian/Hungarian border and corresponds to the Ligeterdö Gravel Formation of Császár (1997). The Lower Auwald Gravel corresponds to the Alsóligeterdö Gravel Member and the Upper Auwald Gravel corresponds to the Felsöligeterdö Gravel Member of Császár (1997). The Aderklaa Formation might represent an equivalent in the southern and central Vienna Basin. Especially the twofold development (Gänserndorf Member, Schönkirchen Member) is reminiscent of the subdivision of the Auwald gravel.

Geographic distribution: Brennbergbánya area, Oberpullendorf Basin; outcrops occur in a triangle between Sieggraben, Kaisersdorf, Draßmarkt and Oberpullendorf, Burgenland; ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Remarks: -

Complementary references: Küpper (1957), Fuchs (1980c), Tollmann (1985), Piller et al. (2004).

Hochriegel-Formation / Hochriegel Formation

Mathias Harzhauser

Validity: Invalid; introduced by Tauber (1951) and renamed without formalization into "Hochriegel-Formation" by Zorn (2000).

Type area: The northern area of the Oberpullendorf Basin, Burgenland; ÖK50-UTM, map sheets 5208 Mattersburg, 5214 Oberpullendorf (ÖK50-BMN, map sheet 107 Mattersburg).

Type section: -

Reference section(s): -

Derivation of name: After the hill Hochriegel (Hoher-Riegel, 553 m a.s.l.) (N 47°39′0.11″ / E 16°28′0.23″), c. 4.5 km NNW of the village Ritzing, c. 18 km N of the town Oberpullendorf, c. 15 km W–WNW of the market town Deutschkreutz, close to the Austrian/Hungarian border; ÖK50-UTM, map sheets 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Synonyms: Hochriegel Schichten (Tauber, 1951), Blätterton von Weingraben (Küpper, 1957), Hochriegelschichten (Fuchs, 1980c).

Lithology: Grey-blue laminated marl and silty clay with sand, fine gravel and with minor lignites; alginites occur at the village Weingraben, Burgenland.

Fossils: The laminated alginite-clay at Weingraben contains a rich flora of leaves, fruits and seeds. A diverse palynoflora of more than 80 taxa was described by Draxler & Zetter (1991). Green algae (*Botryococcus*) may have formed the alginites (Solti et al., 1994). Insects, bird feathers and limnic ostracods occur as well (Bachmayer et al., 1991; Zorn, 2000).

Origin, facies: Limnic-freshwater settings in wetlands.

Chronostratigraphic age: Early Miocene, uppermost Burdigalian (upper Karpatian); the dating is tentative. According to Pascher (1991) and Pereszlényi et al. (1994), the Hochriegel Formation overlies the Karpatian Upper Auwald Gravel without discordance but is overlain with distinct discordance by the Badenian Brennberg Block Flow.

Biostratigraphy: -

Thickness: Several tens of meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision; *the* "Blätterton von Weingraben" (Küpper, 1957) could be considered a member within the Hochriegel Formation, representing laminated alginite clays with rhythmic alternation of beige to grey silty laminae with dark-brown clay laminae.

Underlying unit(s): Upper Auwald Gravel (Pascher, 1991); the Upper Auwald Gravel develops without discordance into the Hochriegel Formation (Pereszlényi et al., 1994).

Overlying unit(s): Brennberg Block Flow (Pascher, 1991).

Lateral unit(s): -

Geographic distribution: Oberpullendorf Basin; between Ritzing, Sieggraben and Weingraben; ÖK50-UTM, map sheets 5208 Mattersburg, 5214 Oberpullendorf (ÖK50-BMN, map sheet 107 Mattersburg).

Remarks: -

Complementary references: Tollmann (1985), Piller et al. (2004).

Brennberger Blockstrom / Brennberg Block Flow

Mathias Harzhauser

Validity: Invalid; introduced by Vendl (1930) and Janoschek (1931).

Type area: The area around Sieggraben, Oberpullendorf Basin, Burgenland (Janoschek, 1931); ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Type section: -

Reference section(s): -

Derivation of name: After the Hungarian village Brennbergbánya (= Brennberg) (N 47°39′17.74″ / E 16°29′23.75″), about 7 km WNW of the town Sopron, Hungary; ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Synonyms: Brennberger Blockschotter (Küpper, 1957).

Lithology: Poorly sorted gravel and angular boulders of up to 1–2 m size. Subordinate sand and fine gravel may be intercalated. All material seems to be derived directly from the adjacent Rosalia Mountains (e.g., gneiss, granite, marble, quartzite, mica schist). No contribution of lithologies from the Calcareous Alps has been detected (Janoschek, 1931; Küpper, 1957; Pascher, 1991).

Fossils: Nearly barren; rare leaves and terrestrial gastropods (VENDL, 1933).

Origin, facies: Terrestrial and partly fluvial debris flows (JANOSCHEK, 1931; PASCHER, 1991); a semi-arid climate was discussed by JANOSCHEK (1931) and PERÉSZLENYI et al. (1994) based on intercalations of reddish sandy clay.

Chronostratigraphic age: Middle Miocene, early Langhian (early Badenian); c. 15.4–15.2 Ma; the dating is tentative is based on the assumed lateral relation with the Rothneusiedl and Rust formations in the Vienna and Eisenstadt-Sopron basins.

Biostratigraphy: -

Thickness: 150 m (ZORN, 2000).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Hochriegel Formation; a discordance between the Hochriegel Formation and the Brennberg Block Flow was observed at Sieggraben (PERÉSZLENYI et al., 1994).

Overlying unit(s): Ritzing Formation is partly overlaying with distinct discordance (JANOSCHEK, 1931).

Lateral unit(s): The Rust Formation might represent a lateral equivalent in the Eisenstadt-Sopron Basin and the Rothneusiedl Formation might be an equivalent in the southern and central Vienna Basin.

Geographic distribution: Several outcrops along rivulets between Sieggraben, Oberpetersdorf and Ritzing along the northern margin of the Oberpullendorf Basin, Burgenland; ÖK50-UTM, map sheet 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Remarks: NEBERT et al. (1980) discussed the Sinnersdorf Formation in the Styrian Basin as time equivalent of the Brennberg Block Flow and ZORN (2000) described the Sinnersdorf Formation from the western margin of the Oberpullendorf Basin. See also Sinnersdorf Formation in the Styrian Basin.

Complementary references: FUCHS (1980c), TOLLMANN (1985), KRENMAYR & SCHNABEL (2002a), PILLER et al. (2004).

Ritzing-Formation / Ritzing Formation

MATHIAS HARZHAUSER

Validity: Invalid; described as "Ritzinger Sande" (= Ritzing Sand) by JANOSCHEK (1931) and named "Ritzing-Formation" by HARZHAUSER et al. (2014b).

Type area: The area between Ritzing, Burgenland, and Brennbergbánya, Hungary; ÖK50-UTM, map sheets 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Type section: -

Reference section(s): -

Derivation of name: Named after the village Ritzing, c. 13 km N of the town Oberpullendorf, c. 10 km W–WNW of the market town Deutschkreutz, close to the Austrian/Hungarian border; ÖK50-UTM, map sheets 5208 Mattersburg (ÖK50-BMN, map sheet 107 Mattersburg).

Synonyms: Schichten von Brennberg und Rietzing (pars) (WOLF, 1870), Ritzinger Sande (KÜPPER, 1957), Ritzinger Sande mit Basisflöz (NEBERT et al., 1980), Ritzinger Badenien (TOLLMANN, 1985), Ritzing Formation (HARZHAUSER et al., 2014b).

Lithology: Mainly yellow to white fine to medium sand with layers of quartz pebbles and rare corallinacean limestone beds. Two layers of lignites of 0.3–3.5 m thickness occur in the basal part (WEBER & WEISS, 1983); gravel and cross bedded coarse sand (probably representing reworked Upper Auwald Gravel in basal parts; HARZHAUSER et al., 2014b). A 3 m-thick layer of stromatolites was described by HARZHAUSER et al. (2014b) from the Rabenkropf at Ritzing.

Fossils: Very rich in marine fossils including numerous shallow marine gastropods, bivalves and echinoderms (JANOSCHEK, 1931; SIEBER, 1956c). The stromatolites from the Rabenkropf section are unique for the Paratethys.

Origin, facies: Inner neritic depositional environments with sandy bottoms. Predominately normal marine, agitated. The Rabenkropf section documents a terminal, very shallow, restricted lagoonal phase (HARZHAUSER et al., 2014b).

Chronostratigraphic age: Middle Miocene, late Langhian (middle Badenian); c. 14.6–13.8 Ma.

Biostratigraphy: Upper Lagenidae Zone and *Spirorutilus* Zone (SIEBER, 1956c; MOSTAFAVI, 1978), planktonic foraminifera Zone M6 (HARZHAUSER et al., 2014b).

Thickness: 300 m (KÜPPER, 1957).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Brennberg Block Flow (JANOSCHEK, 1931).

Overlying unit(s): Skalica Formation.

Lateral unit(s): The Auersthal Formation in the central Vienna Basin might be an equivalent of the basal parts with lignites. The Matzen Formation and Baden Formation are equivalents of the main part of the Ritzing Formation in the Vienna Basin and the Hartl Formation is an equivalent in the Eisenstadt-Sopron Basin. The Tauchen Formation is considered an equivalent in the Styrian Basin (NEBERT et al., 1980).

Geographic distribution: Oberpullendorf Basin, Burgenland; ÖK50-UTM, map sheets 5208 Mattersburg, 5214 Oberpullendorf (ÖK50-BMN, map sheets 107 Mattersburg, 108 Deutschkreutz).

Remarks: -

Complementary references: FUCHS (1980c), ZORN (2000).

Skalica-Formation / Skalica Formation

(for description see Vienna Basin)

Bzenec-Formation / Bzenec Formation

(for description see Vienna Basin)

Basalte des Pauliberges und Oberpullendorf-Stoob / Pauliberg and Oberpullendorf-Stoob Basalts

Martin Gross

Validity: Invalid; first mapped by Czjzek & Stur (1851); name adapted after Eppensteiner (2006; see synonyms).

Type area: Southwestern margin of the Oberpullendorf Basin; ÖK50-UTM, map sheet 5214 Oberpullendorf (ÖK50-BMN, map sheets 107 Mattersburg, 138 Rechnitz).

Type section: Not defined.

Remark: Possibly, the still active quarry at the Pauliberg (N 47°35′06″ / E 16°20′34″), c. 3 km NNW Landsee, c. 15 km NW Oberpullendorf might act as type section (e.g., Kümel, 1936; Küpper, 1957; Winkler-Hermaden, 1962; Piso, 1970).

Reference section(s): Not defined.

Remark: The abandoned quarries at the Fenyősch hill in the W of Oberpullendorf (e.g., N 47°30′18″ / 16°29′41″) and 2 km NNW of Oberpullendorf ("Stoob-Süd"; N 47°30′52″ / E 16°29′32″) might act as reference sections (compare e.g., Kümel, 1936; Küpper, 1957; Winkler-Hermaden, 1962; Eppensteiner, 2006).

Derivation of name: After the hill Pauliberg (761 m asl; municipality Landsee) and the towns Oberpullendorf and Stoob (c. 4.2 km NNW Oberpullendorf) in Middle Burgenland.

Synonyms: (partim) Basalt am Pauliberg und Lindberg bei Landsee (Hauer, 1852), […] Basaltmassen […] des Pauliberges, […] Basaltvorkommen […] bei Ober-Pullendorf (Hofmann et al., 1878), Basalt am Pauliberg, Basalt von Pullendorf (Winkler, 1913c), [Basalt] Felső-Pulya, Basalt[…] […] des Pálhegy (Pauliberg) […] (Jugovics, 1916), Basanitgebiet bei Felsőpulya (Oberpullendorf), Basanitoidgebiet von Pauliberg (Schmidt, 1929), Basalt des Pauliberges, Basalt von Oberpullendorf (Kümel, 1936), Basaltkuppe des "Fenyös-erdö", Basalte des Pauliberges (Jugovics, 1939), Basalte des Pauliberges, Basalte von Oberpullendorf-Stoob (Küpper, 1957), Basalt des Pauliberges, Basalt von Stoob, Basalt von Oberpullendorf (Winkler-Hermaden, 1962), Basalte des Pauliberges, Basalte von Stoob-Oberpullendorf (Piso, 1970), Basalt von Oberpullendorf, Pauliberg und Stoob (Zorn, 2000), Basalte des Pauliberges, Basalte von Oberpullendorf-Stoob (Eppensteiner, 2006).

Lithology: Basanite, alkaline basalt and trachybasalt, rarely tuff (Ali & Ntaflos, 2011; compare Schmidt, 1929; Kümel, 1936; Jugovics, 1939; Winkler-Hermaden, 1962; Piso, 1970; Poultidis & Scharbert, 1986; Dobosi et al., 1999); for a mineralogical synopsis see Kolitsch et al., 2009).

Fossils: -

Origin, facies: Alkali basaltic volcanism in form of lava flows and intrusions and (rare) tuff eruptions (Kümel, 1936; Winkler-Hermaden, 1962; Piso, 1970).

Chronostratigraphic age: Middle Miocene, Serravallian (late Sarmatian) to late Miocene, Tortonian (early Pannonian) (Balogh et al., 1994; for earlier age estimations see e.g., Kümel, 1936; Küpper, 1957; Schoklitsch, 1962; Winkler-Hermaden, 1962).

Remark: Radiometric investigations (K/Ar-dating) yielded an age of 11.1 ± 1.2 Ma for the Oberpullendorf Basalt and 12.3 ± 1.1–10.5 ± 1.0 Ma (solidification age most probably around 11.5 Ma) for the Pauliberg Basalt (Balogh et al., 1994).

Biostratigraphy: -

Thickness: About 40–50 m, in drillings up to 80 m (Jugovics, 1916; Kümel, 1936; Winkler-Hermaden, 1962; Eppensteiner, 2006).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement (Pauliberg, Oberpullendorf) or unnamed, fossil free Sarmatian sediments (Stoob; Kümel, 1936; Küpper, 1957; Piso, 1970; compare Müller & Schwaighofer, 1979; for diverging views see Schoklitsch, 1962; Winkler-Hermaden, 1962).

Overlying unit(s): Fossil free, early Pannonian (Stoob) and Quaternary (Oberpullendorf) sediments (Küpper, 1957; Piso, 1970).

Lateral units: -

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: Seiberl (1978), Fuchs (1980c), Tollmann (1985), Ebner & Sachsenhofer (1991), Neubauer & Cao (2021).

Styrian Basin

Martin Gross

The Styrian Basin is located at the SE margin of the Alps and belongs to the Pannonian Basin System (Text-Fig. 9). Its north, west and southwest border is built up by metamorphic Austroalpine units and the Graz Paleozoic. In the northeast, the Güns Mountains (Penninic unit) form its boundary. Towards the east, the South Burgenland Swell separates the Styrian Basin from the Western Pannonian Basin. The Styrian Basin is approximately 100 km long, 60 km wide and basin filling reaches a maximum thickness of up to 4,000 m. The Middle Styrian Swell (Sausal Mountain range) divides it into a Western and an Eastern Styrian Basin. Additionally, subordinate swells and basement spurs cause a complex differentiation in several subbasins and embayments. The basin filling (synrift phase) started in early Miocene times (Ottnangian) with fluvial and limnic sediments in central basin areas (Limnic Series) as well as with alluvial fan, fluvial, deltaic and limnic deposits at the basin margins (Radl Formation, "Lower" Eibiswald Formation, Köflach-Voitsberg Formation, Naas Beds, Zöbern Formation, Mönichkirchen Formation). During the Karpatian

Text-Fig. 9.
Location of the Styrian Basin (grey shaded).

enhanced subsidence as well as a sea level rise led to the deposition of several hundred meters thick offshore clay- and siltstones (Kreuzkrumpl Formation, formerly "Styrian Schlier"). Alluvial/submarine fan, fluvial and deltaic sediments were deposited at marginal basin areas (Sinnersdorf Formation, Conglomerate-rich Group, Stiwoll Formation). Extensional tectonics were accompanied by volcanic activity (Gleichenberg Volcanics), which continued until the early Badenian. Around the early/middle Miocene boundary, a global sea level fall and tectonic movements caused block tilting as well as a major unconformity ("Styrian Tectonic Phase"). In the early Badenian (onset of the postrift phase), the marine environments reached its largest extent. While sedimentation of largely fine clastics (Marl-Silt-Sand-Gravel) prevailed in the central Eastern Styrian Basin, variegated mixed-siliciclastic-carbonatic systems became established on morphologic highs (Kreuzberg Formation, Weißenegg Formation, Tauchen Formation). Lagoonal deposits (Florian Beds) dominate the central Western Styrian Basin, including basaltic intrusions (Weitendorf Basalt) at the transition to the Eastern Styrian Basin. At the western margins of the Western Styrian Basin deltaic (Arnfels Formation, Teichbauer Formation), limnic-deltaic ("Middle" and "Upper" Eibiswald Formation), alluvial fan (Schwanberg Formation), fluvial-limnic (Stallhofen Formation, Rein Formation) and talus sediments (Eggenberg Formation) were deposited. After a marked regression at the Badenian/Sarmatian boundary, late middle Miocene (Sarmatian) sedimentation is characterised by pelitic sediments (Mantscha Formation, Rollsdorf Formation) or bryozoan-serpulid bioconstructions (Grafenberg Formation). A regressive event ("Carinthian Phase") caused basinward progradation of fluvial-deltaic environments (Carinthian Gravel, Gratkorn Formation), followed by cyclic successions of siliciclastics and carbonates (e.g., silt/sand/oolite; Gleisdorf Formation) as well as by limnic-fluvial ("Lower" Coal-bearing Beds of Weiz) and alluvial fan (Puch Gravel) deposits at the northern margin of the Eastern Styrian Basin. The complete isolation of the Central Paratethyan Sea around the middle/late Miocene boundary is accompanied by the evolution of Lake Pannon and significant erosion. Repeated alternations of limnic-deltaic-fluvial environments determined sedimentation throughout late Miocene (Pannonian) times (lower Pannonian: "Upper" Coal-bearing Beds of Weiz, Puch Gravel, Feldbach Formation, Kleinsemmering Formation, Paldau Formation, Ries Formation; middle Pannonian: Loipersdorf-Unterlamm Beds, Stegersbach Beds; upper Pannonian: Oberneuberg Beds, Tabor Gravel, Jennersdorf Beds, Kirchfidisch-Königsberg Freshwater Limestone, Csater-Berg Opalite). Subsequent basin inversion caused considerable erosion and a hiatus (c. 3.5 Ma) ranging up to the early Pliocene. Fluvial clastics are observed below or adjacent (Silberberg Gravel) as well as on top (Postbasaltic Gravel) of variegated alkali basaltic rocks of largely Plio-/Pleistocene age (Basalt and Tuff/Tuffite).

Except the numerous contribution of Winkler-Hermaden (e.g., Winkler-Hermaden, 1957), especially the work of Kollmann (1965), the studies of Kröll et al. (1988) and Ebner & Sachsenhofer (1991; compare Ebner & Sachsenhofer, 1995; Sachsenhofer, 1996; Sachsenhofer et al., 1997) offer detailed data about the basement and basin filling. Gross et al. (2007a) and Berka (2015) provide more recent compilations. Schreilechner & Sachsenhofer (2007) present a sequence stratigraphic framework (Eastern Styrian Basin).

Herein, 65 lithostratigraphic units of the Styrian Basin are treated at formation, member and bed rank. Of these, only 52 % have been validly established by Nebert et al. (1980), Nebert (1989), Stingl (1994), Friebe (1990, 1994a), Ebner et al. (1998) and Gross (2003a, 2015).

Radl-Formation / Radl Formation

Martin Gross

Validity: Valid; established by Stingl (1993); described and formalized by Stingl (1994).

Type area: Southern margin of the Eibiswald embayment of the Western Styrian Basin; ÖK50-UTM, map sheets 4110 Eibiswald, 4111 Leibnitz (ÖK50-BMN, map sheets 206 Eibiswald, 207 Arnfels).

Type section: Not formally defined.

Remark: Stingl (1994) designated no type section but mentioned (Stingl, 1993) the neighbouring outcrops P2a (N 46°39′35″ / E 15°16′20″) and P2b (N 46°39′32″ / E 15°16′30″ = section 5 in Stingl, 1994), c. 3.7 km SE Eibiswald, as "stratotypes".

Reference section(s): -

Remark: Outcrop 3 (N 46°39′34″ / E 15°15′15″) of Stingl (1994 = outcrop 2 in Stingl, 1993), c. 3 km SSE Eibiswald, might act as reference section.

Derivation of name: Radlberg, mountain range, c. 5 km S of the market town Eibiswald, c. 50 km SSW of the city Graz, Styria.

Synonyms: Grits and conglomerates of the Radlberg (Sedgwick & Murchison, 1831), Radeler Conglomerat (Rolle, 1857), (partim) Basisschichten des Radelschutts, Radel-Schutt (Winkler, 1924), Radelkonglomerate, Radelschutt und Basisschichten (Winkler, 1927d), (partim) Schutt von St. Anton (Winkler, 1929b), Radl-Wildbach-Schotter, Radl-Basisschichten, Radlschichten (Winkler-Hermaden, 1943; Kollmann, 1965).

Lithology: Clast- or matrix supported coarse conglomerate, gravel, breccia (boulders up to 8 m in diameter; mainly mica schist, gneiss), sand.

Fossils: Rare plant remains and terrestrial gastropods (Winkler, 1927d; Stingl, 1994).

Origin, facies: Alluvial fan and proximal delta, gravely mass flows.

Chronostratigraphic age: Early Miocene, Burdigalian (? Ottnangian, Karpatian) to middle Miocene, Langhian (Badenian).

Biostratigraphy: -

Thickness: Up to 400 m (Stingl, 1994; Gruber et al., 2003).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal subdivision into "Basisschichten des Radelschutts" (gravel/conglomerate with sandy intercalations; at the southern flank of the Radlberg mountain range in Slovenia) and "Radelschutt" (Winkler, 1924, 1927d).

Underlying unit(s): Crystalline basement.

Overlying unit(s): "Middle" Eibiswald Formation.

Lateral units: "Lower" Eibiswald Formation.

Geographic distribution: Poßruck area, around the Radlberg mountain range (southwestern Styrian downs and Northern Slovenia); ÖK50-UTM, map sheets 4110 Eibiswald, 4111 Leibnitz (ÖK50-BMN, map sheets 206 Eibiswald, 207 Arnfels).

Remarks: The Radl Formation comprises the "*alluvial fan and proximal delta facies groups [...]. The boundary to the [Lower] Eibiswald Formation is drawn below the occurrence of the distal delta facies group and is signalled by the first occurrence of sandy turbidites.*" (Stingl, 1994: p. 819). In Slovenia, the Radl Formation is as Radlje beds (Mioč, 1972) part of the Ivnik beds (Mioč, 1972; Ivnik = Eibiswald in Slovenian language; see also Pavšič & Horvat, 2009).

Complementary references: Fuchs (1980c), Tollmann (1985), Piller et al. (2004).

Köflach-Voitsberg-Formation / Köflach-Voitsberg Formation

Martin Gross

Validity: Invalid; name introduced by Ebner & Stingl (1998) and used in various contributions in Steininger (1998); however, formalization is still pending.

Type area: Köflach-Voitsberg embayment of the Western Styrian Basin; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheets 162 Köflach, 163 Voitsberg).

Type section: -

Remark: Ebner & Stingl (1998) designated no type section. Haas et al. (1998) provide a composite section (outcrops and cores) of the open cast mine Oberdorf, which might act as type section (Oberdorf, c. 1.5 km E Bärnbach, N 47°04′19″ / E 15°08′50″; see Haas, 1997; Daxner-Höck et al., 1998; Steininger et al., 1998). The open cast mines of the Köflach-Voitsberg coal-mining district (Weber & Weiss, 1983) are abandoned and recultivated today.

Reference section(s): -

Derivation of name: After the town Köflach, c. 27 km W of Graz and the town Voitsberg, c. 22 km WSW Graz, Styria.

Synonyms: (partim) Süßwasserbildung von Köflach, Voitsberg, (partim) Planorben-Schichten, (partim) Voitsberg-Köflacher Tertiärgebirge (Rolle, 1856), (partim) Süßwasserschichten von Rein und Köflach (Stur, 1871), Schichten von Köflach (Flügel & Neubauer, 1984), Kohle führende Formation von Köflach/Voitsberg (Ebner & Sachsenhofer, 1991), Köflach-Voitsberg Formation (Ebner & Stingl, 1998).

Lithology: Pelite, gravel, lignite seams, sand, altered tuff (Haas, 1998; Haas et al., 1998; Steininger et al., 1998; Kolcon & Sachsenhofer, 1999).

Fossils: Gastropods, fishes, rich in plant remains (leaves, diaspores, palynomorphs, wood) and vertebrates (amphibians, reptiles, birds, mammals; synopses in Flügel, 1975a and Steininger, 1998; Meller et al., 1999; Kovar-Eder & Meller, 2001; Kovar-Eder et al., 2001; Daxner-Höck & Höck, 2015).

Origin, facies: Alluvial fans, marginal fluvial (flood plain and flood basin deposits, alternating with crevasse splays and channel fillings, paleosols) and limnic; warm-temperate subtropic, humid climate (Ebner & Stingl, 1998; Haas et al., 1998; Stingl, 2003).

Chronostratigraphic age: Early Miocene, Burdigalian (Ottnangian) (Steininger et al., 1998).

Remark: Ebner et al. (2002) report a zircon fission track age of 18.7 ± 0.9 Ma from an altered tuff layer below the Oberdorf lignite seam.

Biostratigraphy: Neogene mammal Zone MN4 (Daxner-Höck et al., 1998; Steininger et al., 1998).

Thickness: Around 200 m (Graszl et al., 1998).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided into the basal "Basis Member" (alluvial fan or limnic deposits) and the coal-bearing "Lignite Member" (Ebner & Stingl, 1998).

Underlying unit(s): Crystalline, Paleozoic or Mesozoic basement.

Overlying unit(s): Unconformably overlain by the Stallhofen Formation (Ebner & Stingl, 1998; Ebner et al., 1998; Stingl, 2003).

Lateral units: -

Geographic distribution: Northwesternmost part of the Western Styrian downs; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheets 162 Köflach, 163 Voitsberg).

Remarks: -

Complementary references: Fuchs (1980c), Tollmann (1985), Piller et al. (2004).

Limnische Serie / Limnic Series

Martin Gross

Validity: Invalid; term introduced by Kollmann (1965).

Type area: Eastern Styrian Basin, southern Gnas and Fürstenfeld Subbasins, area between the villages Petersdorf II (c. 21 km SE Graz), Mitterlabill (c. 25 km SE Graz), Perbersdorf bei St. Veit (c. 40 km SSE Graz), Gosdorf (c. 47 km SSE Graz), Übersbach (c. 48 km ESE Graz) and

Walkersdorf (c. 38 km E Graz; KOLLMANN, 1965; EBNER & SACHSENHOFER, 1991); ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4112 Bad Radkersburg, 5225 Fürstenfeld (ÖK50-BMN, map sheets 166 Fürstenfeld, 191 Kirchbach in Steiermark, 208 Mureck).

Type section: -

Remark: The section of the deep well Übersbach 1 (N 47°01′39″ / E 16°04′05″), c. 2.6 km SSW of the town Fürstenfeld (KOLLMANN, 1965; HOHENEGGER et al., 2009c) might act as type section.

Reference section(s): -

Remark: As reference might act the sections of deep well Perbersdorf 1 (N 46°44′51″ / E 15°40′20″), c. 10.7 km ESE of the town Leibnitz and deep well Petersdorf 1 (N 46°58′54″ / E 15°40′26″; note: c. 2 km SW the village Petersdorf II, c. 14 km SSW Gleisdorf; KOLLMANN, 1965; HOHENEGGER et al., 2009c).

Derivation of name: Refers to the lack of marine biota.

Synonyms: Limnische Serie (KOLLMANN, 1965), Ottnang Helvet s.str. (KOLLMANN, 1980), Ottnang (EBNER & SACHSENHOFER, 1991), Limnic Series (GROSS et al., 2007a), (partim) continental ?Ottnangian Limnic Series, (partim) limno-fluvial Ottnangian (HOHENEGGER et al., 2009c).

Lithology: Red loam, breccia, marl/pelite with coaly, conglomeratic, sandy and tuffitic intercalations (KOLLMANN, 1965; HOHENEGGER et al., 2009c).

Fossils: Rare, gastropod and plant remains (KOLLMANN, 1965).

Origin, facies: Terrestrial, fluvial and limnic (KOLLMANN, 1965), floodplain, lacustrine/swamp and coastal plain deposits (POLESNY, 2003).

Chronostratigraphic age: Early Miocene, Burdigalian (Ottnangian).

Biostratigraphy: -

Thickness: Up to 656 m (deep well Übersbach 1; KOLLMANN, 1965; HOHENEGGER et al., 2009c; for diverging correlations/estimations see EBNER & SACHSENHOFER, 1991; POLESNY, 2003; SCHREILECHNER & SACHSENHOFER, 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided in “Rotlehmserie”, “Serie der bituminösen Mergelsteine mit Glanzkohlen”, “Serie der Tonmergelsteine und Mergelsandsteine”, “[Limnische] “Konglomeratreiche Serie” (KOLLMANN, 1965; see GOLDBRUNNER, 1988; HOHENEGGER et al., 2009c).

Underlying unit(s): Pre-Neogene basement (KRÖLL et al., 1988).

Overlying unit(s): Kreuzkrumpl Formation and Conglomerate-rich Group (KOLLMANN, 1960b, 1965; see GOLDBRUNNER, 1988; SCHREILECHNER & SACHSENHOFER, 2007; HOHENEGGER et al., 2009c).

Lateral unit(s): Perhaps, the Radl Formation, the “Lower” Eibiswald Formation, the Naas Beds, the Zöbern Formation, the Mönichkirchen Formation and the lower (tuff lacking) parts of the Sinnersdorf Formation are surface equivalents of this subsurface unit (KOLLMANN, 1965; EBNER & SACHSENHOFER, 1991; HOHENEGGER et al., 2009c).

Geographic distribution: Corresponds to the type area.

Remarks: The Limnic Series is a subsurface unit, known from deep wells only.

Complementary references: FUCHS (1980c), PILLER et al. (2004).

Schichten von Naas / Naas Beds

MARTIN GROSS

Validity: Invalid; established by FLÜGEL (1961), extended by KRAINER (1987a); see synonyms.

Type area: In the northernmost Weiz embayment (“embayments of Naas and Oberdorf”; KRAINER, 1987a; c. 24 km NE Graz) at the northern margin of the Eastern Styrian Basin; ÖK50-UTM, map sheet 4223 Weiz (ÖK50-BMN, map sheets 135 Birkfeld, 165 Weiz).

Type section: -

Remark: Only KRAINER (1987a) provides a measured section at a lateral ditch of the creek Naasbach (N 47°14′32″ / E 15°36′26″; c. 3 km NNW Weiz), which might act as type or reference section.

Reference section(s): -

Derivation of name: Village Naas, c. 4.4 km NW of the town Weiz, c. 23 km NE Graz, Styria.

Synonyms: (partim) Tertiär von Naas (WAAGEN, 1931), Schichten von Naas (FLÜGEL, 1961), Schichten von Naas-Oberdorf (KRAINER, 1987a), Beds of Naas (GROSS et al., 2007a).

Lithology: General fining-upward succession: the basal, frequently reddish part consists of alternations of consolidated, matrix-supported boulder gravel/debris (with Paleozoic quartz, phyllitic shale, etc. components) and badly sorted clayey sand/silt and silty clay; higher up massive pelite and fine sand with coarse clastic and coal intercalations occur (KRAINER, 1987a). For coal-mining history, see WEBER & WEISS (1983).

Fossils: Plant detritus, proboscidean remains (FLÜGEL & MAURIN, 1957; MOTTL, 1970; KRAINER, 1987a).

Origin, facies: Alluvial fan (debris flows; basal part) to limnic-palustrine (upper part) deposits (KRAINER, 1987a).

Chronostratigraphic age: Early Miocene, Burdigalian (? Ottnangian to ? Karpatian) to middle Miocene (? early Badenian) (FLÜGEL & MAURIN, 1957; FLÜGEL, 1961, 1975a; KOLLMANN, 1965; KRAINER, 1987a).

Biostratigraphy: -

Thickness: At least 80–100 m (KRAINER, 1987a).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Paleozoic basement.

Overlying unit(s): Quaternary talus deposits (KRAINER, 1987a).

Lateral unit(s): Fault bounded to the Coal-bearing beds of Weiz (KRAINER, 1987a). As potential equivalents the Radl

Formation, the ("Lower") Eibiswald Formation, the Zöbern Formation and the Limnic Series are discussed (KOLLMANN, 1965; EBNER & SACHSENHOFER, 1991).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: FUCHS (1980c).

Zöbern-Formation / Zöbern Formation

MARTIN GROSS

Validity: Invalid; term introduced by WINKLER-HERMADEN (1943); named as formation by KRENMAYR & SCHNABEL (2002a); see synonyms.

Type area: The area W of the village Zöbern (c. 10 km NE Friedberg) (WINKLER-HERMADEN, 1933a) and northernmost part of the Friedberg–Pinkafeld embayment; ÖK50-UTM, map sheet 5213 Aspang-Markt (ÖK50-BMN, map sheet 106 Aspang-Markt).

Type section: -

Remark: EBNER & GRÄF (1977b: outcrop "Thalberg/Limbach"; c. 1.9 km NW Dechantskirchen) compared granite gneiss breccias with red matrix, which rest directly upon the basement and are overlain by boulder gravels with the Zöbern Formation (compare HAUSER & NEUWIRTH, 1959). NEBERT (1985: e.g., outcrop "31") reported a similar but unconsolidated sediment c. 3.7 km ENE Sinnersdorf. However, both works provide no section.

Reference section(s): -

Derivation of name: After the village Zöbern, c. 6.9 km E of the market town Mönichkirchen, Lower Austria.

Synonyms: Schuttbreccien der Sinnersdorfer Serie (WINKLER-HERMADEN, 1933a), Zöberner Brekzie (WINKLER-HERMADEN, 1943), Zöbener Brekzie (EBNER & GRÄF, 1977b), Zöbern-Formation (KRENMAYR & SCHNABEL, 2002a).

Lithology: Breccia with red loam-matrix (WINKLER-HERMADEN, 1933a); including also coal fragments (SACHSENHOFER, 1990; EBNER & SACHSENHOFER, 1991).

Fossils: Plant remains (WINKLER-HERMADEN, 1951).

Origin, facies: Debris flow/talus deposits (WINKLER-HERMADEN, 1933a).

Chronostratigraphic age: Early Miocene, Burdigalian (? Ottnangian) (KOLLMANN, 1965; EBNER & SACHSENHOFER, 1990; FUCHS et al., 2008).

Biostratigraphy: -

Thickness: Unclear, probably several hundreds of meters (WINKLER-HERMADEN, 1933a; compare EBNER et al., 1991).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement (WINKLER-HERMADEN, 1933a).

Overlying unit(s): Mönichkirchen and/or Sinnersdorf Formation (WINKLER-HERMADEN, 1933a, 1951; EBNER & GRÄF, 1977b; NEBERT et al., 1980; NEBERT, 1985).

Lateral unit(s): Mönichkirchen Formation.

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: FUCHS (1980c), FLÜGEL & NEUBAUER (1984).

Mönichkirchen-Formation / Mönichkirchen Formation

MARTIN GROSS

Validity: Invalid; term introduced by WINKLER-HERMADEN (1943); named as formation by KRENMAYR & SCHNABEL (2002a); see synonyms.

Type area: The area E of the market town Mönichkirchen, Lower Austria (c. 7.7 km N Friedberg); northernmost part of the Friedberg–Pinkafeld embayment; ÖK50-UTM, map sheet 5213 Aspang-Markt (ÖK50-BMN, map sheets 105 Neunkirchen, 106 Aspang-Markt).

Type section: -

Reference section(s): -

Derivation of name: After the market town Mönichkirchen, c. 24 km SSW of the town Neunkirchen, Lower Austria.

Synonyms: (partim) Stufe von Sinnersdorf (MOHR, 1914), Blockschotter […] der Sinnersdorfer Serie (WINKLER-HERMADEN, 1933a), Mönichkirchner Blockschotter (WINKLER-HERMADEN, 1943), Mönichkirchner Blockschutt (EBNER et al., 1991), Mönichkirchen-Formation (KRENMAYR & SCHNABEL, 2002a), Mönichkirchner Blockschichten (FUCHS et al., 2008).

Lithology: Predominately gneiss boulders (WINKLER-HERMADEN, 1951).

Fossils: -

Origin, facies: Fluvial, torrent deposits (WINKLER-HERMADEN, 1933a, 1951).

Chronostratigraphic age: Early Miocene, Burdigalian (? Ottnangian) (KOLLMANN, 1965; EBNER & SACHSENHOFER, 1991).

Biostratigraphy: -

Thickness: Unclear, probably several hundreds of meters (WINKLER-HERMADEN, 1933a).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Zöbern Formation and/or crystalline basement (WINKLER-HERMADEN, 1933a, 1951; KRENMAYR & SCHNABEL, 2002a).

Overlying unit(s): Zöbern Formation and "Krumbacher Schichten" (WINKLER-HERMADEN, 1951; GOLDBRUNNER, 1993a).

Lateral unit(s): Possibly the "Blockschotter von Kirchberg/Wechsel" and the "Unteren Auwald-Schotter" are lateral equivalents (EBNER et al., 1991; EBNER & SACHSENHOFER, 1991; KRENMAYR & SCHNABEL, 2002a).

Geographic distribution: Corresponds to the type area.

Remarks: In the geological map sheets ÖK50-BMN 136 Hartberg and 137 Oberwart (PAHR, 1984) the Mönichkirchen Formation (and the Zöbern Formation) are not differentiated from the Sinnersdorf Formation (compare "Sinnersdorfer Stufe/Serie"; MOHR, 1914; WINKLER-HERMADEN, 1933a, 1951).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Eibiswalder Schichten / Eibiswald Formation

MARTIN GROSS

Validity: Invalid; name introduced by ROLLE (1856); EBNER & SACHSENHOFER (1995) applied the term formation to the "Middle" and "Upper" part, HANDLER et al. (2006) for the entire unit (see synonyms).

Type area: Eibiswald embayment of the Western Styrian Basin; ÖK50-UTM, map sheets 4110 Eibiswald, 4111 Leibnitz (ÖK50-BMN, map sheets 189 Deutschlandsberg, 190 Leibnitz, 206 Eibiswald, 207 Arnfels).

Type section: -

Remark: NEBERT (1983) described several sections, which provide insight into the lithological development of the Eibiswald Formation: e.g., outcrop 171, c. 2.7 km NNW Wies ("Upper" Eibiswald Formation), outcrop 51, c. 2.6 km NE Eibiswald ("Middle" Eibiswald Formation), outcrops 54 and 55, c. 3.4 km NE Eibiswald ("Pitschgau Conglomerate"), outcrop 68, c. 5.7 km ENE Eibiswald ("Lower" Eibiswald Formation; for other sections see also STINGL, 1993, 1994). For coals see the outcrop ("Wernersdorf coal seam") described by GRUBER et al. (2003), c. 5 km ENE Wies (see also HIESSLEITNER, 1926; NEBERT, 1983). The "Wies coal seam" is open at Aug/Schönegg (N 46°43′03″ / E 15°17′41″; GRUBER et al., 2003; GROSS & MARTIN, 2008). Rather good outcrops ("Upper" Eibiswald Formation) provide the cut banks of the Weiße Sulm river, c. 1 km SE Brunn.

Reference section(s): -

Derivation of name: After the market town Eibiswald, c. 14.5 km SSE Deutschlandsberg, c. 45 km SSW Graz, Styria.

Synonyms: Eibiswalder Schichten (ROLLE, 1856), (partim) Schichten von Eibiswald und Sotzka (STUR, 1871), mitteltertiäre Süsswasserschichten (RADIMSKY, 1875), untere, mittlere und obere Eibiswalder Schichten (WINKLER, 1924), (partim) Lower Eibiswald beds, (partim) Middle and Upper Eibiswald Formation (EBNER & SACHSENHOFER, 1995), Eibiswald Formation (HANDLER et al., 2006), Untere-, Mittlere- und Obere Eibiswalder Schichten (GRUBER et al., 2003).

Lithology: Coarse gravel, sand and pelite ("Lower" Eibiswald Formation), coal seams, pelite, tuffite and gravel intercalations ("Pitschgau Conglomerate"; "Middle" Eibiswald Formation), pelite and sand ("Upper" Eibiswald Formation; NEBERT, 1983, 1989; WEBER & WEISS, 1983; GRUBER et al., 2003).

Fossils: Plant remains, bivalves, gastropods, vertebrates (fishes, reptiles, mammals; ROLLE, 1856; ETTINGSHAUSEN, 1890, 1891; WINKLER, 1927d; MOTTL, 1961a, 1970; KOLLMANN, 1965; HIDEN & STINGL, 1998; GAUDANT, 2000; GROSS, 2003b; GROSS & MARTIN, 2008; MARTIN & GROSS, 2011).

Origin, facies: From bottom to top: fan-delta, limnic deltaic (with low-lying freshwater mire), fluvial (braided river), limnic-deltaic (with low-lying mire), deltaic-coastal (GRUBER et al., 2003).

Chronostratigraphic age: Early Miocene, Burdigalian (? Ottnangian, Karpatian) to middle Miocene (early Badenian).

Remark: $^{40}Ar/^{39}Ar$-datings of tuff layers above the Eibiswald coal seam (= base of the "Middle" Eibiswald Formation) yielded ages of 15.22 ± 0.17 Ma and 15.08 ± 0.9 (GRUBER et al., 2003; HANDLER et al., 2006). SANT et al. (2020) recalibrated these ages to 15.52 ± 0.18 Ma and 15.38 ± 0.10 MIa, respectively.

Biostratigraphy: Partly correlated to Neogene mammal Zones MN4 or MN5 (MOTTL, 1961a, 1970; KOLLMANN, 1965; STEININGER et al., 1996; DAXNER-HÖCK, 2003a, b; GROSS & MARTIN, 2008).

Thickness: Up to 2,500 m (NEBERT, 1983, 1989), up to 1,100 m (GRUBER et al., 2003).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal; "Lower", "Middle" and "Upper" Eibiswald Formation (WINKLER, 1924, 1927d).

Underlying unit(s): Radl Formation or crystalline basement (WINKLER, 1927d).

Overlying unit(s): Florian Beds; possibly the Schwanberg Formation and the Arnfels Formation (HIESSLEITNER, 1926; NEBERT, 1983, 1989; see WINKLER, 1924, 1927d).

Lateral unit(s): Radl Formation (more proximal complement of the "Lower" Eibiswald Formation) and Florian Beds (shallow marine prolongation of the "Upper" Eibiswald Formation; HIDEN & STINGL, 1998; GRUBER et al., 2003).

Geographic distribution: Southwestern Styrian downs and Northern Slovenia; ÖK50-UTM, map sheets 4110 Eibiswald, 4111 Leibnitz (ÖK50-BMN, map sheets 189 Deutschlandsberg, 190 Leibnitz, 206 Eibiswald, 207 Arnfels).

Remarks: In Slovenia, the Ivnik beds (MIOČ, 1972; Ivnik = Eibiswald in Slovenian language) seem to be (at least in part) an equivalent of the Eibiswald Formation. The Ivnik beds also include the Radlje beds (MIOČ, 1972; PAVŠIČ & HORVAT, 2009), which correspond to the Radl Formation

Complementary references: ROLLE (1857), FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Kreuzkrumpl-Formation / Kreuzkrumpl Formation

MARTIN GROSS

Validity: Invalid; described only in the unpublished PhD-thesis of SCHELL (1994).

Type area: Gamlitz embayment and Windische Bühel in Southern Styria (extends southwards into Northern Slovenia); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels) (KOLLMANN, 1965; SCHELL, 1994).

Type section: Outcrop "Kreuzkrumpl" (N 46°38′08″ / E 15°30′00″), c. 4.3 km SE of the town Leutschach, c.

14 km SW of the town Leibnitz (SCHELL, 1994); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Reference section(s): Abandoned brickyard Wagna, c. 3.3 km S of the town Leibnitz (N 46°45′10″ / E 15°32′47″) and outcrop Katzengraben (N 46°42′01″ / E 15°37′52″), ditch c. 0.5 km SW Spielfeld, c. 11 km SE Leibnitz (FRIEBE, 1989, 1990, 1993; HOLZER, 1994; SCHELL, 1994; AUER, 1996; SPEZZAFERRI et al., 2002; LATAL & PILLER, 2003; GROSS et al., 2007a; SOLIMAN & PILLER, 2007; HOHENEGGER et al., 2009c); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheets 190 Leibnitz, 208 Mureck).

Derivation of name: Named after the farmstead Kreuzkrumpl, c. 4.3 km SE Leutschach, c. 48 km S Graz, Styria.

Synonyms: Mittelsteirischer Schlier (WINKLER, 1913b), (partim) ältere Schlierfazies (WINKLER-HERMADEN, 1938), Steirischer Schlier (KOLLMANN, 1965), Kreuzkrumpl-Formation (SCHELL, 1994), Styrian Schlier (STINGL, 1994), Kreuzkrumpel-Formation (PILLER et al., 2004), Wagna-Formation (ĆORIĆ, 2016).

Lithology: Grey, fine sandy silt(-stone) and silty marl with sand(-stone) and rare gravel and tuffitic intercalations (KOLLMANN, 1965; HOHENEGGER et al., 2009c).

Fossils: Plant remains, dinoflagellates, foraminifers, gastropods, bivalves, echinoids, ostracods, trace fossils (WINKLER-HERMADEN, 1938; KOLLMANN, 1965; SCHELL, 1994; RÖGL et al., 2002; SPEZZAFERRI et al., 2002, 2009; SOLIMAN & PILLER, 2007; HOHENEGGER et al., 2009c).

Origin, facies: Deep marine paleoenvironment with turbiditic intercalations.

Chronostratigraphic age: Early Miocene, Burdigalian (Karpatian).

Biostratigraphy: Calcareous nannofossil Zone NN4.

Thickness: More than 600 m (SCHELL, 1994).

Underlying unit(s): Pre-Neogene basement of the Remschnigg-Poßruck (WINKLER-HERMADEN, 1938; SCHELL, 1994) and subsurface, in more central position, the Limnic Series (KOLLMANN, 1965; HOHENEGGER et al., 2009c).

Overlying unit(s): Kreuzberg Formation and Weißenegg Formation.

Lateral unit(s): Until recently, the Arnfels Formation and the Teichbauer Formation were considered as lateral equivalents (e.g., KOLLMANN, 1965; KRAINER, 1989a; SCHELL, 1994); however, due to new biostratigraphic information (ĆORIĆ, 2016) this correlation is no longer sustainable. In the Fürstenfeld Subbasin, the Conglomerate-rich Group is supposed to be a lateral equivalent (KOLLMANN, 1960b, 1965).

Geographic distribution: Type area (including Northern Slovenia) and occurrences on ÖK50-BMN, map sheets 190 Leibnitz (e.g., brickyard Wagna), 208 Mureck (e.g., outcrop Katzengraben; both on ÖK50-UTM, map sheet 4111 Leibnitz); subsurface in the Gnas Subbasin (KOLLMANN, 1965; HOHENEGGER et al., 2009c).

Remarks: SCHELL (1994) described this formation accurately according to common lithostratigraphic guidelines. Moreover, he proposed the famous and well-studied outcrops brickyard Wagna (type locality of the “Styrian Unconformity”) and Katzengraben as reference sections. However, the Kreuzkrumpl Formation is announced in this PhD-thesis only and is therefore not valid. For this reason, the informal terms “Steirischer Schlier” or “Styrian Schlier” are still in use (e.g., HOHENEGGER et al., 2009c, 2014). The Haloze Formation of the adjacent Mura-Zala Basin (Slovenia) is – at least in part – an equivalent of the Kreuzkrumpl Formation (JELEN & RIFELJ, 2011).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Konglomeratreiche Gruppe / Conglomerate-rich Group

MARTIN GROSS

Validity: Invalid; term introduced by KOLLMANN (1960b); see synonyms.

Type area: Fürstenfeld Subbasin, Eastern Styria; ÖK50-UTM, map sheet 5225 Fürstenfeld (ÖK50-BMN, map sheet 166 Fürstenfeld).

Type section: -

Remark: As type section might act the deep well Übersbach 1 (N 47°01′39″ / E 16°04′05″; c. 2.6 km SSW of the town Fürstenfeld) (KOLLMANN, 1960b, 1965; POLESNY, 2003; HOHENEGGER et al., 2009c).

Reference section(s): -

Remark: Potential reference sections are the deep wells Fürstenfeld Thermal 1 (N 47°03′10″ / E 16°04′40″), c. 3.1 km NW Fürstenfeld and Blumau 1a (N 47°07′31″ / E 16°02′46″), c. 9.1 km NNW Fürstenfeld (GOLDBRUNNER, 1988, 1993b; POLESNY, 2003; HOHENEGGER et al., 2009c); ÖK50-UTM, map sheet 5225 Fürstenfeld (ÖK50-BMN, map sheet 166 Fürstenfeld).

Derivation of name: After the predominate lithology (KOLLMANN, 1960b, 1965; GOLDBRUNNER, 1988, 1993b).

Synonyms: Konglomeratreiche Serie marin (KOLLMANN, 1960b), Marine Serie (KOLLMANN, 1965), (partim) Konglomeratreiche Gruppe (KOLLMANN, 1980), Marine Konglomeratreiche Gruppe, (partim) Karpatische Serie – Konglomeratgruppe (GOLDBRUNNER, 1988), (partim) Konglomeratreiche Gruppe (EBNER & SACHSENHOFER, 1991), Conglomerate-rich group (GROSS et al., 2007a), (partim) Karpatian marine (HOHENEGGER et al., 2009c).

Lithology: Alternation of sandy marl-/clay(-stone), polymict conglomerate (largely limestone pebbles) and sandstone, with thin tuffitic intercalations in the upper part; in the deep wells Fürstenfeld Thermal 1 and Blumau 1a the conglomerate proportion predominates (KOLLMANN, 1965; GOLDBRUNNER, 1988).

Fossils: Ichnofossils, plant detritus, foraminifers, bivalves (KOLLMANN, 1965; FRIEBE & POLTNIG, 1991).

Origin, facies: Alluvial to submarine fan systems interfingering with marine environment (POLESNY, 2003; SCHREILECHNER & SACHSENHOFER, 2007).

Chronostratigraphic age: Early Miocene, Burdigalian (Karpatian) (KOLLMANN, 1965).

Biostratigraphy: Planktonic foraminifera Zone M4 (Friebe & Poltnig, 1991; Hohenegger et al., 2009c).

Thickness: Up to 398 m (deep well Übersbach 1), possibly up to 850 m (Kollmann, 1965; Goldbrunner, 1988, 1993b; Ebner & Sachsenhofer, 1991; Polesny, 2003; Schreilechner & Sachsenhofer, 2007; Hohenegger et al., 2009c).

Remark: Diverging thickness indications may derive from the ex- or inclusion of the underlying "Limnische Konglomeratreiche Serie" (= upper part of the Limnic Series; compare Kollmann, 1960b, 1965).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Limnic Series or Paleozoic basement (Kollmann, 1965; Flügel, 1988; Goldbrunner, 1988; Polesny, 2003; Hohenegger et al., 2009c).

Overlying unit(s): Marl-Silt-Sand-Gravel with basal conglomerate (Kollmann, 1965; Goldbrunner, 1988).

Lateral unit(s): Kreuzkrumpl Formation and Sinnersdorf Formation.

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: Fuchs (1980c).

Sinnersdorf-Formation / Sinnersdorf Formation

Martin Gross

Validity: Valid; described and formalized by Nebert et al. (1980; see also Nebert, 1985).

Type area: Friedberg-Pinkafeld embayment of the Styrian Basin and southwestern Oberpullendorf Basin; ÖK50-UTM, map sheets 5213 Aspang-Markt, 5214 Oberpullendorf, 5219 Oberwart (ÖK50-BMN, map sheets 106 Aspang-Markt, 107 Mattersburg, 136 Hartberg, 137 Oberwart, 138 Rechnitz).

Type section: Road cut along the Sparbereggerweg, c. 2.2 km N of the village Sinnersdorf (N 47°25′14″ / E 16°06′09″), c. 15.7 km NW of the town Oberwart; ÖK50-UTM, map sheet 5213 Aspang-Markt (ÖK50-BMN, map sheet 137 Oberwart).

Remark: Nebert et al. (1980) gave only a description of the location (p. 49: "*[...] nördlich von Sinnersdorf, auf dem Weg vom Bahnhof Schäffernsteg nach Sparberegg (Seehöhe 545 m) [...]*". Perhaps this outcrop is (almost) identical with outcrop 24 of Nebert (1985). The type section exposes only lower parts of the Sinnersdorf Formation and is badly preserved today. Nebert et al. (1980) present a "composite-stratotype" based on the type section as well as on the reference sections.

Reference section(s): Outcrop 517, c. 1 km S Oberrabnitz (N 47°29′13″ / E 16°21′26″), outcrop 473, c. 1.7 km SW Weingraben (N 47°30′33″ / E 16°20′34″; both are badly preserved) and further sections described by Nebert et al. (1980) and Nebert (1985); ÖK50-UTM, map sheet 5214 Oberpullendorf (ÖK50-BMN, map sheets 107 Mattersburg, 138 Rechnitz).

Derivation of name: After the village Sinnersdorf (municipality Pinggau), c. 3.7 km NNW of the town Pinkafeld, c. 62 km NE Graz, Burgenland.

Synonyms: Conglomerat[en ...] bei Sinnersdorf (Hoffmann, 1877), Conglomerat von Sinnersdorf (Hilber, 1895), (partim) Stufe von Sinnersdorf (Mohr, 1914), Sinnersdorfer Blockschotter, Sinnersdorfer Konglomerate (Winkler-Hermaden, 1943), Sinnersdorfer Blockschotter und Konglomerate (Kollmann, 1965), (partim) Brennberger Blockschotter (Bachmayer et al., 1991).

Lithology: Alternations of sandstone and badly sorted, matrix-supported (boulder) gravel/conglomerate (mainly quartzite, gneiss and granitic components up to 2–3 m in diameter, sandy to pelitic matrix); tuffitic intercalations, andesitic dikes (Winkler-Hermaden, 1933b; Hauser & Neuwirth, 1959; Ebner & Gräf, 1977b; Nebert et al., 1980; Pahr, 1984; Nebert, 1985).

Fossils: Rare plant remains.

Origin, facies: Mass flow to fluvial deposits.

Chronostratigraphic age: Early Miocene, Burdigalian (? Ottnangian, Karpatian) (Kollmann, 1965; Nebert et al., 1980; Ebner & Sachsenhofer, 1991); maybe extends into the middle Miocene, Langhian (early Badenian) (see Bachmayer et al., 1991).

Biostratigraphy: -

Thickness: Around 200 m (maybe up to 600 m; Nebert et al., 1980; Nebert, 1985).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement (Nebert et al., 1980). Winkler-Hermaden (1933a) mentioned also the Zöbern Formation at the base of the Sinnersdorf Formation (see Ebner & Gräf, 1977b).

Overlying unit(s): Gradational (Nebert et al., 1980; Nebert, 1985) or discordant upper boundary to the Tauchen Formation (Kollmann, 1965; Pahr, 1984) or erosively overlain by Sarmatian sediments or the Rabnitz Formation in the Oberpullendorf Basin (Nebert et al., 1980; Nebert, 1985).

Lateral unit(s): The Brennberg Formation of the northwestern Landsee embayment and the "Krumbacher Schichten" are supposed to be an equivalent (e.g., Nebert et al., 1980; Pahr, 1984). Subsurface, the Conglomerate-rich Group of the central Fürstenfeld Subbasin is correlated with this formation (Goldbrunner, 1988; Schreilechner & Sachsenhofer, 2007).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: Winkler-Hermaden (1951), Fuchs (1980c), Tollmann (1985), Piller et al. (2004).

Stiwoll-Formation / Stiwoll Formation

MARTIN GROSS

Validity: Invalid; first mentioned by WAAGEN (1928); named as formation by EBNER (2001); formalization pending.

Type area: Stiwoll embayment (c. 18 km WNW Graz) of the Western Styrian Basin; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Type section: -

Remark: The outcrop c. 0.7 km NW of the village Stiwoll (N 47°06′27″ / E 15°12′43″) described in EBNER (1983c) could be selected as type section.

Reference section(s): -

Remark: The outcrops along the state road L 336 (c. 0.6 km NNW Stiwoll; N 47°06′27″ / E 15°12′55″), outcrops c. 1.4 km NW Stiwoll (N 47°06′42″ / E 15°12′23″) and road cut at the Södingberg (c. 3.2 km WNW Stiwoll; N 47°06′30″ / E 15°10′39″) where the underlying sediments were exposed (EBNER, 1983c) might act as reference sections.

Derivation of name: Named after the village Stiwoll, c. 17 km WNW of the city Graz, Styria.

Synonyms: Schuttkegel von Södingberg-Stivoll (WAAGEN, 1928), Konglomerat von Stiwoll (WAAGEN, 1937), Konglomerate von Stiwoll (FLÜGEL, 1961), Stiwoller Konglomerat (EBNER et al., 1985), Stiwoll-Formation (EBNER, 2001).

Lithology: Grey to yellowish, coarse, in part graded conglomerate composed of rounded to well rounded, predominantly Paleozoic lime- and dolostone pebbles (subordinately Cretaceous sandstone) with carbonatic matrix consisting largely of rock debris; rare and thin, partly cross-bedded marly sandstone and pelite interlayers (ROLLE, 1856; FLÜGEL, 1961; EBNER, 1983c).

Fossils: -

Origin, facies: Deltaic paleoenvironment (WAAGEN, 1937).

Chronostratigraphic age: Early Miocene, Burdigalian (late Karpatian) (FLÜGEL, 1961; EBNER, 1983c).

Biostratigraphy: -

Thickness: At least 160–170 m (EBNER, 1983c).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Paleozoic and Upper Cretaceous basement with angular unconformity and/or Neogene deposits (red loam/debris and grey pelite with coaly layers, which are possibly equivalents of the Köflach-Voitsberg Formation; FLÜGEL, 1961, 1975a; EBNER, 1983c).

Overlying unit(s): Discordantly overlain by red loam/debris and the Rein Formation and/or the Stallhofen Formation (Eckwirt Member; FLÜGEL, 1961; EBNER, 1983c).

Lateral unit(s): -

Geographic distribution: Corresponds to the type area (EBNER, 1983c).

Remarks: This unit must not be confused with the "Stiwoll-Subformation" (Stiwoll Member) of the Parmasegg Formation (Graz Paleozoic; FLÜGEL, 2000; HUBMANN, 2013).

Complementary references: EBNER & SCHUSTER (2014).

Schwanberg-Formation / Schwanberg Formation

MARTIN GROSS

Validity: Valid; described and proposed as formation by NEBERT (1989).

Type area: Along the eastern slope of the Koralm Massif from W of Stainz (c. 8.8 km NE Deutschlandsberg) in the north, to W of Eibiswald in the south (NEBERT, 1989); ÖK50-UTM, map sheets 4104 Deutschlandsberg, 4110 Eibiswald (ÖK50-BMN, map sheets 189 Deutschlandsberg, 206 Eibiswald).

Type section: Temporary outcrop number 74 (N 46°43′17″ / E 15°10′42″) along the road (Buchenberg); c. 4.3 km SW Schwanberg, c. 7.1 km W Wies, described by NEBERT (1989); section of about 9 m thickness; the lower boundary of the Schwanberg Formation to the crystalline basement was exposed nearby at the valley bottom of the Weiße Sulm river (NEBERT, 1989); ÖK50-UTM, map sheet, 4110 Eibiswald (ÖK50-BMN, map sheet 206 Eibiswald).

Reference section(s): Outcrop number 73 (N 46°43′19″ / E 15°10′37″), forest road cut, section thickness c. 2 m, c. 7.2 km W Wies; and outcrop number 76 (N 46°43′23″ / E 15°10′58″), cut bank of a small tributary (Strutzbach) of the Meßnitzbach and Weiße Sulm river, respectively, section thickness c. 2.5 m, c. 6.7 km W Wies, described by NEBERT (1989); ÖK50-UTM, map sheet, 4110 Eibiswald (ÖK50-BMN, map sheet 206 Eibiswald).

Derivation of name: After the market town Bad Schwanberg, c. 6.7 km SSW Deutschlandsberg, c. 26.3 km W of the town Leibnitz, c. 40 km NW of the city Graz, Styria.

Synonyms: (partim) Schotter- und Sandablagerungen am Fusse der Schwanberger Alpen (ROLLE, 1856), Hangendblockschutt (HIESSLEITNER, 1926), Schwanberger Schutt (WINKLER, 1926), Schwanberger Wildbachschutt (WINKLER, 1927d), Schwanberger Schichten (NEBERT, 1989), Schwanberg Formation (NEBERT, 1989), Schwanberg-Formation (NEBERT, 1983), Schwanberg block debris (PISCHINGER et al., 2008).

Lithology: Badly sorted, coarse boulder debris/gravel (including > m^3 sized, rounded clasts) with partially cross-bedded, grey to yellowish sand and grey, sandy clay interlayers forming rhythmical successions; largely gneiss but also pegmatite and eclogite pebbles (HIESSLEITNER, 1926; NEBERT, 1989).

Fossils: -

Origin, facies: Alluvial fan deposits (debris and stream flow deposits; NEBERT, 1989; GRUBER et al., 2003).

Chronostratigraphic age: Middle Miocene, Langhian–early Serravallian (Badenian) (KOLLMANN, 1965; NEBERT, 1989).

Biostratigraphy: -

Thickness: Up to several hundreds of meters (HIESSLEITNER, 1926; WINKLER, 1926; NEBERT, 1989).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Metamorphic basement of the Koralm Massif or Eibiswald Formation (HIESSLEITNER, 1926; WINKLER, 1929a; NEBERT, 1989; PISCHINGER et al., 2008).

Overlying unit(s): Erosional boundary.

Lateral unit(s): Possibly interfingering with the ("Upper") Eibiswald Formation and the Florian Beds (HIESSLEITNER, 1926; WINKLER, 1929a; NEBERT, 1989).

Geographic distribution: Corresponds to the type area (KOLLMANN, 1965; NEBERT, 1989).

Remarks: -

Complementary references: NEBERT (1984), FUCHS (1980c), TOLLMANN (1985), EBNER & SACHSENHOFER (1991).

Florianer Schichten / Florian Beds

MARTIN GROSS

Validity: Invalid; name introduced by ROLLE (1856; see synonyms).

Type area: Embayment of Groß St. Florian of the Western Styrian Basin; ÖK50-UTM, map sheets 4104 Deutschlandsberg, 4105 Kalsdorf bei Graz, 4110 Eibiswald, 4111 Leibnitz (ÖK50-BMN, map sheets 189 Deutschlandsberg, 190 Leibnitz).

Type section: -

Remark: The outcrops in the ditch 0.4 km NE of the village Pöls an der Wieserbahn (N 46°53′40″ / E 15°24′39″), c. 7.5 km WNW Wildon, c. 19.6 km SSW of the city Graz might serve as type section (KOPETZKY, 1957; FLÜGEL & HERITSCH, 1968; SANT et al., 2020); ÖK50-UTM, map sheet 4105 Kalsdorf bei Graz (ÖK50-BMN, map sheet 190 Leibnitz). Outcrops continuously exposing the Florian Beds are rare. Some authors provide compilations of the isolated and short sections (e.g., KOPETZKY, 1957; HIDEN, 1996a).

Reference section(s): -

Derivation of name: After the market town Groß St. Florian, c. 7.9 km E of the town Deutschlandsberg, c. 29 km SSW Graz, Styria.

Synonyms: (partim) Turritellen-Schichten, (partim) fossilreiche Tegelschichten von St. Florian (ROLLE, 1856), (partim) Florianer Tegel (HILBER, 1878), Florianer Schichten (including, e.g., "Rostellarientegel von Wetzelsdorf", "Pölser Mergel" and, possibly, "Schichten von Dobl"; KOPETZKY, 1957), Florian Formation (HANDLER et al., 2006).

Lithology: Alternations of sand and pelite/marl (sometimes rich in fossils), fine gravel/conglomerate; tuff/tuffite/bentonite intercalations.

Fossils: Plant remains, foraminifers, corals, gastropods, bivalves, cephalopods, ostracods, cirripeds, decapods, echinoids, bryozoans, fishes (elasmobranchii, teleostei; e.g., HILBER, 1878, 1879, 1915b; HOLLER, 1900; BAUER, 1900; GLAESSNER, 1928; WEINFURTER, 1952; KOPETZKY, 1957; EBNER & GRÄF, 1977a; NEBERT, 1989; HIDEN, 1996a, 1997; NOLF & BRZOBOHATÝ, 2009; ESSL, 2013; HYŽNÝ & GROSS, 2016a, b; MESSNER & BERNHARD, 2016, 2017; HARZHAUSER & LANDAU, 2019; HYŽNÝ et al., 2017).

Origin, facies: Marginal, shallow marine (lagoonal) with terrigenous influx.

Chronostratigraphic age: Middle Miocene, Langhian to early Serravallian (early–late Badenian) (HANDLER et al., 2006; SANT et al., 2020).

Remark: $^{40}Ar/^{39}Ar$-datings of tuff layers by HANDLER et al. (2006; for earlier K-Ar age calculations see BALOGH et al., 1994) at the potential type section (see above) yielded ages of 15.75 ± 0.17 Ma. However, analyses by SANT et al. (2020) resulted in notably younger ages (14.31 ± 0.27 and 14.03 ± 0.04 Ma).

Biostratigraphy: The unit comprises the regional benthic foraminiferal eco-biozones Lagenidae Zone to *Bulimina-Bolivina* Zone (KOPETZKY, 1957; KOLLMANN, 1965; FRIEBE, 1990).

Thickness: More than 100 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Subdivided into several informal units (e.g., KOPETZKY, 1957; FRIEBE, 1989; NEBERT, 1989).

Underlying unit(s): Eibiswald Formation (KOLLMANN, 1965; HIDEN & STINGL, 1998).

Overlying unit(s): Erosive upper boundary (KOLLMANN, 1965; FRIEBE, 1989).

Lateral unit(s): To the east the Weißenegg Formation, to the south the "Upper" Eibiswald Formation, to the north(west) the Stallhofen Formation and maybe to the west the Schwanberg Formation (WINKLER, 1924; KOLLMANN, 1965; NEBERT, 1989; FRIEBE, 1990; EBNER & STINGL, 1998; HIDEN & STINGL, 1998; GRUBER et al., 2003).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: WINKLER (1913b), FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Weitendorfer Basalt / Weitendorf Basalt

MARTIN GROSS

Validity: Invalid; first mentioned by ANKER (1830; first mineral report in ANKER, 1827); see synonyms.

Type area: On the eastern side of the Middle Styrian Swell (KOLLMANN, 1965; KRÖLL et al., 1988); ÖK50-UTM, map sheet 4105 Kalsdorf bei Graz (ÖK50-BMN, map sheet 190 Leibnitz).

Type section: Active quarry Weitendorf (N 46°53′44″ / E 15°26′42″), c. 1.6 km W of the village Weitendorf, c. 4.9 km WNW of the market town Wildon (WINKLER-HERMADEN, 1939; FLÜGEL & HERITSCH, 1968; ALKER, 1972; KRAINER, 1987c); ÖK50-UTM, map sheet 4105 Kalsdorf bei Graz (ÖK50-BMN, map sheet 190 Leibnitz).

Reference section(s): -

Derivation of name: Refers to the lithology and to the village Weitendorf, c. 19.3 km SSE of the city Graz, Styria.

Synonyms: le point volcanique [...] sud de Gratz à Weitendorf [...] (ANKER, 1830), trap rocks, [...] west of Weiterdorf [...] (SEDGWICK & MURCHISON, 1831), Basalt von Weitendorf bei Wildon (ROLLE, 1856), Weitendorfer Basalt (FLÜGEL et al., 1952), Weitendorfer Shoshonit (KOLLMANN, 1965), Shoshonit von Weitendorf (FLÜGEL, 1975b).

Lithology: Latite (hawaiite/shoshonite) with xenoliths (MACHATSCHKI, 1927; HERITSCH, 1963a, b, 1967a, b; ALKER, 1972; KRAINER, 1987c; EBNER & SACHSENHOFER, 1991; SLAPANSKY et al., 1999; NIEDERMAYR, 2019).

Fossils: None (only known from sediment lenses forced into the basaltic body; KRAINER, 1987c).

Origin, facies: Mainly volcanic intrusion (sill) close to the sediment-/(sea-)water interface; possibly, in parts, submarine pillow lavas (KRAINER, 1987c; BALOGH et al., 1994).

Chronostratigraphic age: Middle Miocene, Langhian (early to middle Badenian).

Remark: The most recent radiometric investigations (K/Ar-dating) yielded an age of 14.0 ± 0.7 Ma for the Weitendorf Basalt (BALOGH et al., 1994; for earlier analyses see LIPPOLT et al., 1975; STEININGER & BAGDASARJAN, 1977).

Biostratigraphy: The underlying marls are attributed to the Upper Lagenidae Zone; overlying Neogene sediments are of Badenian age (FLÜGEL et al., 1952; KOLLMANN, 1965; FLÜGEL, 1975b; EBNER & GRÄF, 1977a; FENNINGER & WASSERMANN, 1982; KRAINER, 1987c).

Thickness: Around 30–50 m in the quarry Weitendorf (FLÜGEL & HERITSCH, 1968; FLÜGEL, 1975b; KRAINER, 1987c). Geophysical data refer to a thickness of 80–90 m for the basaltic intrusion (WEBER, 1998; see also MAURITSCH, 1975; SLAPANSKY et al., 1999).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): This unit cuts discordantly older units (Pre-Neogene basement, ? Karpatian sediments, and the Florian Beds; WEBER, 1998; WEBER et al., 1999).

Overlying unit(s): Florian Beds (HAUSER & KOLLMANN, 1954; KRAINER, 1987c) or Quaternary sediments (Kaiserwaldterrasse; KOLLMANN, 1965; KRAINER, 1987c).

Lateral unit(s): Intrusion into the Florian Beds (KRAINER, 1987c).

Geographic distribution: Western Styrian downs; only known from the type area.

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Arnfels-Formation / Arnfels Formation

MARTIN GROSS

Validity: Invalid; defined as Arnfels Formation in the unpublished PhD-thesis of SCHELL (1994).

Type area: Area between St. Johann im Saggautal – Arnfels – Maltschach (c. 15 km SW of the town Leibnitz (SCHELL, 1994), southern margin of the Western Styrian Basin; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Type section: Outcrop “Schlossauffahrt unten” (N 46°40′52″ / E 15°24′06″), c. 0.5 km N of the market town Arnfels, c. 15.6 km SW of Leibnitz, along the Schloßbergstraße (driveway to Arnfels castle) of SCHELL (1994; compare WINKLER-HERMADEN, 1938); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Reference section(s): Outcrop “Schlossauffahrt Mitte” (N 46°40′55″ / E 15°24′13″), c. 0.6 km NNE of Arnfels, and further sections described by SCHELL (1994); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Derivation of name: After the market town Arnfels, c. 16 km SW of the town Leibnitz, c. 44 km SSW Graz, Styria.

Synonyms: Arnfelser Schichten (WINKLER, 1924), Arnfelser Konglomerate (WINKLER, 1926), Arnfelser Konglomerat und Sandstein-Serie (WINKLER-HERMADEN, 1938), Arnfels-Formation (SCHELL, 1994).

Lithology: Alternations of up to several meters thick, massive or horizontally bedded conglomerate (predominantly Paleozoic lime- and dolostone pebbles) with massive to bedded sand- and marly siltstone (KRAINER, 1990; SCHELL, 1994; HUBER, 2018).

Fossils: Plant and rare mollusc remains (UNGER, 1847; WINKLER-HERMADEN, 1938; KRAINER, 1990; SCHELL, 1994).

Origin, facies: Deltaic, subaquatic mass flow deposits (SCHELL, 1994).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian) (ĆORIĆ, 2016).

Biostratigraphy: -

Thickness: About 200–300 m (WINKLER, 1929a) or 150 m (SCHELL, 1994).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Possibly basement (at the Remschnigg Mountain) and (“Upper”) Eibiswald Formation (WINKLER, 1927d; KOLLMANN, 1965; KRAINER, 1990; SCHELL, 1994).

Overlying unit(s): Teichbauer Formation and/or Kreuzberg Formation (SCHELL, 1994; STINGL, 2007; ĆORIĆ, 2016).

Lateral unit(s): Teichbauer Formation and Weißenegg Formation towards the E; probably fault bounded towards the W to the Eibiswald Formation (SCHELL, 1994; STINGL, 2007).

Geographic distribution: Type area and hillsides of the Remschnigg (WINKLER, 1927d, 1929a; KRAINER, 1990; SCHELL, 1994).

Remarks: -

Complementary references: KOPETZKY (1957), FUCHS (1980c), TOLLMANN (1985).

Teichbauer-Formation / Teichbauer Formation

MARTIN GROSS

Validity: Invalid; defined in the unpublished PhD-thesis of SCHELL (1994).

Type area: Area between the hillside Türkenkogel, the hamlet Komar and the farmstead Teichbauer, c. 2 km

WNW of the market town Leutschach, c. 14 km SW of the town Leibnitz (SCHELL, 1994), at the southern margin of the Western Styrian Basin; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Type section: Outcrop named "Teichbauer" by SCHELL (1994) along the main road B 69 (N 46°40′10″ / E 15°26′34″), c. 300 m SW of the farmstead Teichbauer, c. 1.9 km W Leutschach; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Reference section(s): Sections denominated and described by SCHELL (1994) as "Cut bank Pößnitzbach" (N 46°40′05″ / E 15°27′05″), "Steinwirt" (N 46°40′05″ / E 15°26′52″) and "Türkenkogel" (N 46°40′26″ / E 15°25′47″) near the type section; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Derivation of name: Named after the farmstead "Teichbauer", c. 1.8 km WNW of the marked town Leutschach, c. 3.4 km ESE of the market town Arnfels, c. 44 km S Graz, Styria.

Synonyms: Leutschacher Sande (WINKLER, 1926), Leutschacher Sand (KOLLMANN, 1965).

Lithology: Massive to indistinctly bedded sand(-stone) with meter-thick, massive or partly horizontally bedded conglomerate intercalations (predominately quartz, lime- and dolostone pebbles) (SCHELL, 1994).

Fossils: Plant detritus, scattered ichnofossils, molluscs, bryozoan, sea urchins and foraminiferan remains (WINKLER-HERMADEN, 1938; SCHELL, 1994).

Origin, facies: Deltaic (marine), subaquatic mass flow deposits (SCHELL, 1994).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian) (ĆORIĆ, 2016).

Biostratigraphy: -

Thickness: Up to 120 m (SCHELL, 1994).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: STINGL (2012) informally proposed the "Montikogel-Subformation", which comprises the conglomeratic portions of the Teichbauer Formation.

Underlying unit(s): Partly the Arnfels Formation (SCHELL, 1994; ĆORIĆ, 2016).

Overlying unit(s): Kreuzberg Formation (SCHELL, 1994; ĆORIĆ, 2016).

Lateral unit(s): Arnfels Formation (SCHELL, 1994).

Geographic distribution: Area between St. Johann im Saggautal – Maltschach – Leutschach and on the hillsides of the Remschnigg (SCHELL, 1994; STINGL, 2012); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Remarks: -

Complementary references: WINKLER (1929a), KOPETZKY (1957), FLÜGEL & HERITSCH (1968), FUCHS (1980c), EBNER & SACHSENHOFER (1991).

Kreuzberg-Formation / Kreuzberg Formation

MARTIN GROSS

Validity: Valid; described and formalized by FRIEBE (1990).

Type area: Western Gamlitz embayment, Southern Styria; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheets 190 Leibnitz, 207 Arnfels, 208 Mureck).

Type section: Not formally defined.

Remark: FRIEBE (1990) designated no type section but mentioned and described several characteristic sections. Here, the outcrop "Labitschberg" (road cut; section thickness c. 4.3 m; N 46°43′43″ / E 15°30′23″), c. 3.7 km WNW of the market town Gamlitz, c. 7 km SSE of the town Leibnitz, is proposed as type section; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels). Neither the lower nor the upper boundary of the Kreuzberg Formation are exposed

Reference section(s): -

Remark: The outcrops "Kranach" (N 46°43′06″ / E 15°30′04″) exposing lower parts of this formation, c. 4 km W Gamlitz, "Urlkogel" (N 46°41′42″ / E 15°33′10″) exposing higher parts of this formation, c. 2.8 km S Gamlitz and "Ratsch an der Weinstraße" (N 46°41′08″ / E 15°34′54″), c. 4.5 km SSE Gamlitz, provide further insights into the lithological development of this formation (FRIEBE, 1990; see also FRIEBE, 1989); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Derivation of name: After the hill Kreuzberg (633 m a.s.l.), c. 4.5 km ENE of the village St. Johann im Saggautal, c. 7.3 km WSW of the market town Gamlitz, c. 40 km S of the city Graz, Styria (WINKLER, 1924).

Synonyms: (partim) Leithakalk-Conglomerat (ROLLE, 1856), Gamlitzer Schotter (STUR, 1871), Kreuzbergschotter, Kreuzbergkonglomerate (WINKLER, 1924), (partim) Urler Blockhorizont, Urler Blockschutt (WINKLER, 1926), (partim) Leithakonglomerate, Leithaschotter (WINKLER-HERMADEN, 1939). For a more detailed listing, see FRIEBE (1989).

Lithology: Alternations of polymict gravel (quartz, crystalline, Paleozoic and Mesozoic pebbles), conglomerate, sand and silt, gravelly to sandy (algal debris) limestone (FRIEBE, 1990; SCHELL, 1994).

Fossils: Coralline red algae, foraminifers, corals, gastropods, bivalves (oysters, pectinids), bryozoans, serpulids, balanids.

Origin, facies: Marginal marine, subaquatic braid delta deposits with sediment gravity flows (FRIEBE, 1990).

Chronostratigraphic age: Middle Miocene, Langhian (early to middle Badenian) (FRIEBE, 1990; ĆORIĆ, 2016).

Biostratigraphy: Calcareous nannofossil Zone NN5; comprises the regional benthic foraminiferal eco-biozones Lower Lagenidae–*Spirorutilus* Zone (former Agglutinated foraminifera Zone) (FRIEBE, 1990; ĆORIĆ, 2016).

Thickness: More than 300 m (KOPETZKY, 1957; FLÜGEL & HERITSCH, 1968).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Ottenberg Member (= basal part of the Kreuzberg Formation that interfingers with the Weißenegg Formation).

Underlying unit(s): Kreuzkrumpl Formation, Arnfels Formation and Teichbauer Formation (FRIEBE, 1990; SCHELL, 1994).

Overlying unit(s): Weißenegg Formation.

Lateral unit(s): Interfingers towards the east with siliciclastics and (rarely) with carbonates of the Weißenegg Formation (FRIEBE, 1990).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: WINKLER (1929a), FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Ottenberg-Subformation (Kreuzberg-Formation) / Ottenberg Member (Kreuzberg Formation)

MARTIN GROSS

Validity: Valid; described and formalized by FRIEBE (1990).

Type area: Area around the market town Gamlitz and the village Ehrenhausen, c. 7.3 km SSE of the town Leibnitz, c. 40 km SSE of the city Graz; ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheets 207 Arnfels, 208 Mureck).

Type section: Not formally defined.

Remark: FRIEBE (1990) considered the outcrop at the "Fuchsmühle" (N 46°43′02″ / E 15°34′58″), c. 1 km SSW Ehrenhausen, and the abandoned quarry at the Gamlitzer Straße (N 46°43′09″ / E 15°34′53″), c. 0.8 km SW Ehrenhausen, as "classical" occurrences of the Ottenberg Member (compare also ROLLE, 1856; WINKLER, 1929a; WINKLER-HERMADEN, 1939; FRIEBE, 1989). A measured section (c. 4.5 m thick) exists only from the quarry at the Gamlitzer Straße (= outcrop number 5 in FRIEBE, 1990 = outcrop number 19 in FRIEBE, 1989), this badly preserved outcrop is proposed here as type section.

Reference section(s): -

Remark: As reference might act the section (c. 4.3 m thick) at the scarp close to the railway Ehrenhausen-Spielfeld (N 46°43′24″ / E 15°35′55″), c. 1 km ESE Ehrenhausen, described by FRIEBE (1990).

Derivation of name: After the village Ottenberg (municipality Ehrenhausen an der Weinstraße), c. 1.9 km SSW of the village Ehrenhausen, c. 8.7 km SSE Leibnitz, c. 40 km SSE Graz, Styria.

Synonyms: Millstone conglomerate (SEDGWICK & MURCHISON, 1831), Leithakalk-Conglomerat (ROLLE, 1856), Leithakonglomerat (WINKLER-HERMADEN, 1938), Leithakonglomerate, Leithaschotter (WINKLER-HERMADEN, 1939). For a more detailed listing, see FRIEBE (1989).

Lithology: Corresponds to the Kreuzberg Formation but differs by an increased content of marine fossils; towards the upper boundary (also laterally) continuous increase of coralline red algae debris and decrease in siliciclastics (FRIEBE, 1990).

Fossils: Coralline red algae, foraminifers, corals (rare), gastropods, bivalves (oysters), bryozoans, serpulids, balanids.

Origin, facies: See Kreuzberg Formation (FRIEBE, 1990).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian) (FRIEBE, 1990).

Biostratigraphy: Regional benthic foraminiferal Lagenidae eco-biozone (FRIEBE, 1990).

Thickness: Several meters (> 6 m; WINKLER, 1929a; FRIEBE, 1990).

Lithostratigraphically higher rank unit: Kreuzberg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Kreuzkrumpl Formation.

Overlying unit(s): Weißenegg Formation.

Lateral unit(s): Interfingers with siliciclastics and (rarely) with carbonates of the Weißenegg Formation (FRIEBE, 1990).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: KOLLMANN (1965), FUCHS (1980c).

Weißenegg-Formation / Weißenegg Formation

MARTIN GROSS

Validity: Valid; described and formalized by FRIEBE (1990) as "Weißenegg-Formation" (also spelled "Weissenegg"; e.g., FRIEBE, 1988; HOLZER, 1994).

Type area: Region east of the Sausal mountain, ranging approximately from Wildon (subsurface up to southern Graz) (FLÜGEL, 1975c; GROSS et al., 2007b) in the north to the Austrian/Slovenian borderland (Windische Bühel/Slovenian Hills) in the south (FRIEBE, 1990); ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4111 Leibnitz (ÖK50-BMN, map sheets 190 Leibnitz, 207 Arnfels, 208 Mureck).

Type section: Limestone quarry Weißenegg (N 46°54′11″ / E 15°29′53″), c. 2.1 km NNW Wildon, c. 19.5 km SSE Graz (HILBER, 1913; WINKLER-HERMADEN, 1939; KOPETZKY, 1957; KOLLMANN, 1965; DULLO, 1983; HANSEN et al., 1987; FRIEBE, 1990); ÖK50-UTM, map sheet 4105 Kalsdorf bei Graz (ÖK50-BMN, map sheet 190 Leibnitz).

Reference section(s): Sections in the limestone quarry area of Retznei (N 46°44′37″ / E 15°33′43″), c. 4.6 km SSE Leibnitz; due to active mining the outcrop situation changes rapidly (FRIEBE, 1988, 1990, 1991a, b, 1993; GROSS et al., 2007a; HOHENEGGER et al., 2009c; REUTER & PILLER, 2011; REUTER et al., 2012a, b); ÖK50-UTM, map sheet 4111 Leibnitz (ÖK50-BMN, map sheet 207 Arnfels).

Derivation of name: Named after the castle Weißenegg (municipality Fernitz-Mellach), c. 3 km NNW of the market town Wildon, c. 18.3 km SSE of the city Graz, Styria.

Synonyms: Most notations cover only parts of the Weißenegg Formation; carbonates: Leithakalk, Leithakalk und Leithategel, Nulliporen-Leithakalk (ROLLE, 1855), Aframer Stein (FLÜGEL & NEUBAUER, 1984), Aflenzer Stein, Aflenzer Muschelkalk, Lithothamnienkalk (ZIRKL, 1994); siliciclastics: south of Leibnitz: Gamlitzer Tegel (HILBER, 1877), jüngere Schlier-(marine Mergel)-Fazies (WINKLER-HERMADEN, 1951), Spielfelder Mergel und Sande (KOLLMANN, 1965), Retznei-Formation (ĆORIĆ, 2016); area of Wildon: Tegel von Flammberg (HILBER, 1878), marine Sand- und Tegelfazies (BEER & KOPETZKY, 1951). For a more detailed listing, see FRIEBE (1989).

Lithology: Variegated shallow marine limestones and siliciclastic sediments like algal (corallinacean) debris limestone, rhodolith (debris) limestone, sandy limestone, (coral) patch reefs, marl and fine sand, medium to coarse sand, pebbly marl and conglomerates, scattered tuffitic intercalations (DULLO, 1983; FRIEBE, 1988, 1990, 1993; REUTER & PILLER, 2011; REUTER et al., 2012a; BEDNARIK et al., 2014).

Fossils: Red algae (corallinaceans), green algae, calcareous nannoplankton, dinoflagellates, foraminifers (benthics and planktics; larger foraminifera: *Planostegina*, *Borelis*), corals, gastropods, bivalves, echinoids, decapods, cirripedians, ostracods, serpulids, nautilids, coleoids, bryozoans, brachiopods, fishes (elasmobranchii, teleostei), reptiles (turtles, crocodylians), mammals (sirenians), trace fossils (ROLLE, 1855, 1856; HILBER, 1877, 1878; SCHOUPPÉ, 1949; FRIEBE, 1987; FLÜGEL, 1972, 1977, 1986; HANSEN et al., 1987; VAVRA, 1989; FRITZ & HIDEN, 1996; HIDEN, 1996a, b; FENNINGER & HUBMANN, 1997; SCHULTZ, 2001b, 2004, 2006; SPEZZAFERRI et al., 2002; BOJAR et al., 2004; KROH, 2005; SOLIMAN & PILLER, 2007; GROSS & MARTIN, 2008; HOHENEGGER et al., 2009c; COLLINS, 2014; REUTER et al., 2012b, 2015; HYŽNÝ & GROSS, 2016b; KOŠŤÁK et al., 2016; FEICHTINGER et al., 2022).

Origin, facies: Marine, with carbonate build-ups (patch reefs, rhodolith platforms), tidal, coastal and deltaic sediments; highly influenced by sea-level fluctuations but also by shifting terrigenous influx, tectonic and volcanic events (FRIEBE, 1993; HOHENEGGER et al., 2009c; REUTER & PILLER, 2011; REUTER et al., 2012a).

Chronostratigraphic age: Middle Miocene, Langhian to early Serravallian (Badenian).

Remark: $^{40}Ar/^{39}Ar$-datings of tuff layers in the limestone quarry Retznei (see reference sections) yielded ages of 14.21 ± 0.07 Ma and 14.39 ± 0.12 (HANDLER et al., 2006; compare BOJAR et al., 2004). SANT et al. (2020) recalibrated these ages to 14.39 ± 0.08 Ma and 14.67 ± 0.13, respectively.

Biostratigraphy: Calcareous nannofossil Zones NN4 to NN6; the regional benthic foraminiferal eco-biozones Lower Lagenidae Zone–*Bulimina-Bolivina* Zone were recorded (FRIEBE, 1990; HOHENEGGER et al., 2009c).

Thickness: In the type area in surface outcrops more than 90 m (quarry Weißenegg), approximately 230 m in the area of the Buchkogel S of Wildon (KOPETZKY, 1957; KOLLMANN, 1965).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Fastlkogl Member (local fan delta deposits, with a high amount of Paleozoic schist and carbonate pebbles around the Sausal mountain), Dillach Member (braid delta deposits on top of the Weißenegg Formation; FRIEBE, 1990).

Underlying unit(s): Kreuzkrumpl Formation with angular and erosive boundary ("Styrian Unconformity") or directly on the Pre-Neogene basement.

Overlying unit(s): Erosional upper boundary, overlain by transgressive Sarmatian sediments (Grafenberg and Rollsdorf Formation).

Lateral unit(s): Florianer Beds towards the W, Stallhofen Formation towards the NW, Kreuzberg and Arnfels Formation towards the SW and Marl-Silt-Sand-Gravel in the central Eastern Styrian Basin (KOLLMANN, 1965; FRIEBE, 1990; EBNER & STINGL, 1998; ĆORIĆ, 2016).

Geographic distribution: Corresponds to the type area.

Remark: Similar units are developed around basement highs (South-Burgenland Swell, St. Anna am Aigen-Klapping; Auersbach Swell) and the Miocene Gleichenberg volcanoes (WINKLER, 1927a; KOLLMANN, 1965; FRIEBE, 1990; HARZHAUSER & PILLER, 2004a; SCHREILECHNER & SACHSENHOFER, 2007), which could be considered to be included in the Weißenegg Formation or are already described as separate formations (Tauchen Formation; NEBERT et al., 1980).

Remarks: According to the definition of FRIEBE (1990: p. 225, 227, 234) the Weißenegg Formation comprises shallow marine deposits of the Gnas Subbasin (inclusively the Gamlitz and Flamberg embayments on the eastern side of the Middle Styrian Swell) above the "Styrian Unconformity" and the Kreuzkrumpl Formation, respectively. Several more or less isolated, carbonate dominated occurrences ("Leithakalke") as well as their genetically related siliciclastics are united in the Weißenegg Formation. As demonstrated by HOHENEGGER et al. (2009c) the "Styrian Tectonic Phase" (STILLE, 1924) is a series of tectonic events with several remarkable gaps. However, a distinct angular and erosional discordance with reworked clasts ("Geröllmergel") of the Kreuzkrumpl Formation coincides with the Karpatian/Badenian boundary and is linked with significant environmental changes (deep-water to inner neritic depth; LATAL & PILLER, 2003; HOHENEGGER et al., 2009c, 2014) and characterises the base of the Weißenegg Formation as well (e.g., clay pit Wagna and outcrop Katzengraben). Sandy marls with gravel intercalations with Sarmatian faunas mark the upper boundary (KOLLMANN, 1965; FRIEBE, 1990). In Northern Slovenia, the Hrastovec-Kresnica Member (Špilje Formation) corresponds to the Weißenegg Formation (JELEN & RIFELJ, 2011), in the Vienna Basin and neighbouring areas the equivalent unit is represented by the Leitha Formation of the Baden Group (HARZHAUSER et al., 2020).

Complementary references: WINKLER (1913b), FUCHS (1980c), TOLLMANN (1985), HIDEN (2001), PILLER et al. (2004).

Fastlkogel-Subformation (Weißenegg-Formation / Fastlkogl Member (Weißenegg Formation)

MARTIN GROSS

Validity: Valid; described and formalized by FRIEBE (1990) as "Fastlkogel-Member".

Type area: Area between the Sausal mountain range (Demmerkogel, 671 m a.s.l.; c. 8.5 km E Leibnitz) and the

Kreuzkogel (496 m a.s.l.; c. 2.2 km WNW Leibnitz), about 30 km S Graz; ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4111 Leibnitz (ÖK50-BMN, map sheet 190 Leibnitz).

Type section: Not formally defined.

Remark: Friebe (1989) described two sections of which only the outcrop (section thickness c. 4.3 m) at the wine tavern Schneeberger (N 46°47′13″ / E 15°28′36″), c. 4.9 km WNW Leibnitz, is figured in the publication of Friebe (1990). Here, this section is proposed as type section.

Reference section(s): -

Remark: The section (road cut) at the eastern flank of the Fastlkogel (N 46°47′12″ / E 15°28′50″), c. 4.6 km WNW Leibnitz, described in Friebe (1990) and figured by Friebe (1989) might act as reference section.

Derivation of name: After the hill Fastlkogel (421 m a.s.l.), c. 4.7 km WNW of the town Leibnitz, c. 32 km S of the city Graz, Styria.

Synonyms: Zug groben Schotters (Winkler, 1929a), Schieferschuttbrezien (Winkler-Hermaden, 1943). For more details, see Friebe (1989, 1990).

Lithology: Successions of sand and matrix-rich, coarse conglomerate (polymict: quartz, phyllite, limestone and crystalline pebbles) (Friebe, 1990) and clast-supported phyllite-breccia (reworked basement) (Winkler-Hermaden, 1943; Friebe, 1991a).

Fossils: -

Origin, facies: Marine fan delta deposits (Friebe, 1988, 1990).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian).

Remark: Friebe (1990) assumed an upper Karpatian to early Badenian age (above the “Styrian Tectonic Phase”) for the Fastlkogel Member.

Biostratigraphy: -

Thickness: Possibly up to 100 m based on provisional geological maps (Moser, 2015).

Lithostratigraphically higher rank unit: Weißenegg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Paleozoic basement (Friebe, 1990).

Overlying unit(s): Carbonate rocks of the Weißenegg Formation (Friebe, 1990).

Lateral unit(s): Florian Beds and carbonate rocks of the Weißenegg Formation (Friebe, 1990).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: Ebner & Sachsenhofer (1991).

Dillach-Subformation (Weißenegg-Formation / Dillach Member (Weißenegg Formation)

Martin Gross

Validity: Valid; described and formalized by Friebe (1990) as “Dillach-Member”.

Type area: Region north of castle Weißenegg (c. 18.3 km SSE Graz) and area between the villages Mellach (c. 6.1 km NNE Wildon) and Afram (c. 2.4 km ENE Wildon), respectively (Friebe, 1990); ÖK50-UTM, map sheet 4105 Kalsdorf bei Graz (ÖK50-BMN, map sheet 190 Leibnitz).

Type section: Not formally defined.

Remark: Friebe (1990) described four sections (outcrops at Dillach A, Dillach B, scarp at castle Turmhof and outcrop Afram). Here, the first, Dillach A (N 46°55′06″ / E 15°30′12″), c. 3.5 km NNW Wildon, is chosen as type section.

Reference section(s): -

Remark: The sections Dillach B (N 46°54′52″ / E 15°30′07″), c. 3 km NNW Wildon and at the scarp at castle Turmhof (N 46°56′11″ / E 15°30′31″), c. 5.5 km N Wildon, described by Friebe (1990), are proposed as reference sections.

Derivation of name: After the village Dillach (municipality Fernitz-Mellach), c. 3.8 km NNE of the market town Wildon, c. 17.4 km SSE of the city Graz, Styria.

Synonyms: Grobsand- und Schotterhorizont (Kollmann, 1965), Eckwirt Formation (Friebe, 1989).

Lithology: Alternations of cross- or horizontal bedded sand and gravel, subordinately silt layers (Friebe, 1990).

Fossils: -

Origin, facies: Braid delta deposits (Friebe, 1990, 1991a).

Chronostratigraphic age: Middle Miocene, early Serravallian (late Badenian) (Friebe, 1990).

Biostratigraphy: Regional benthic foraminiferal ecobiozone *Bulimina-Bolivina* Zone (Friebe, 1990).

Thickness: A few meters (Friebe, 1990).

Lithostratigraphically higher rank unit: Weißenegg Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Carbonate rocks of the Weißenegg Formation (Friebe, 1990).

Overlying unit(s): Lower Sarmatian siliciclastics (Kollmann, 1965; Friebe, 1990), equivalents of the Rollsdorf Formation.

Lateral unit(s): Eckwirt Member (Stallhofen Formation) (Friebe, 1990).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: Ebner & Sachsenhofer (1991).

Gleichenberger Vulkanite / Gleichenberg Volcanics

Martin Gross

Validity: Invalid; Buch (1820) described this "Trappformation" first and Steininger & Wessely (2000) used the term "Gleichenberg-vulkanite-Formation"; see synonyms.

Type area: Region around the mountain Gleichenberger Kogel, Gnas Subbasin, Eastern Styrian Basin, Styria; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Type section: -

Remark: As type section might serve the quarry on the western flank of the Gleichenberger Kogel ("Quarry Klause") (N 46°53′31″ / E 15°53′52″), c. 1.6 km NNW of the village Bad Gleichenberg, c. 8.8 km S of the town Feldbach (Winkler-Hermaden, 1939; Heritsch et al., 1964).

Reference section(s): -

Remark: Possible reference sections occur in the abandoned quarry Gossendorf (N 46°53′46″ / E 15°55′09″), c. 2.0 km NNE Bad Gleichenberg (Angel, 1954; Kolmer, 1975; Balogh et al., 1994; Klammer, 1997; Bojar et al., 2008); the abandoned quarry "Schaufelgraben" (N 46°52′55″ / E 15°55′46″), c. 1.5 km NE Bad Gleichenberg (Winkler-Hermaden, 1939; Heritsch et al., 1964; Döhrn, 1992, 1994); and the deep well Bad Gleichenberg StW2, in the park of the spa (N 46°52′23″ / E 15°54′36″) (Hradecký et al., 1999; Elster, 2016).

Derivation of name: The name may be derived from the mountain Gleichenberger Kogel (598 m a.s.l.), c. 7.2 km SSE the town Feldbach or from the village Bad Gleichenberg, c. 8.8 km SSE Feldbach, Styria.

Synonyms: Trappformation (Buch, 1820), Trachytzug von Gleichenberg (Andrae, 1855), Trachyt u. Andesit v. Gleichenberg (Winkler, 1913a; with extensive references to the research history), Trachyt-Andesitkörper von Gleichenberg (Winkler, 1927a), Trachyt-Trachyandesitmassiv von Gleichenberg (Winkler-Hermaden, 1943), Vulkangebiet von Gleichenberg (Kollmann, 1965), Gleichenberg-vulkanite-Formation (Steininger & Wessely, 2000).

Lithology: Variegated latitic to dacitic rocks, partly strongly hydrothermally altered (Heritsch, 1963b; Flügel & Neubauer, 1984; Ebner & Sachsenhofer, 1991; Serri et al., 1996; Klammer, 1997; Hradecký et al., 1999; Slapansky et al., 1999; for mineral content see e.g., Postl et al., 1992; Taucher & Hollerer, 2001).

Fossils: None; reported only in xenoliths (e.g., corallinacean limestone).

Origin, facies: Eruptions of shield volcanoes.

Chronostratigraphic age: Early Miocene, Burdigalian (Karpatian) to middle Miocene, Langhian (early Badenian) (Kollmann, 1965; Balogh et al., 1994; Handler et al., 2006; Bojar et al., 2008, 2013).

Remark: K/Ar datings of rocks from the quarry Klause resulted in 14.6 Ma (Lippolt et al., 1975) and 16.3 ± 0.9 and 15.5 ± 0.1 Ma (recalculated to 16.8–15.4 and 15.8–15.4 Ma by Handler et al., 2006; compare age estimations based on Rb/Sr-isotopes: 22.97 ± 1.93 Ma; Kolmer, 1980a). For the quarry Gossendorf, Bojar et al. (2008) reported K/Ar-ages of 14.9 ± 0.2 and 15.4 ± 0.1 Ma (compare Balogh et al., 1994: 13.2 ± 1.0 Ma).

Volcaniclastic and bentonitic layers found in deep wells and outcrops might hint at a beginning of volcanic activity already in the Ottnangian; however, they may also derive from volcanic centres beyond the Styrian Basin (Steininger et al., 1998; Ebner et al., 2002; Hohenegger et al., 2009c).

Biostratigraphy: Biostratigraphic data from over-/underlying sediments: nannofossil Zone NN4 (? Ottnangian/Karpatian) and foraminiferan Lagenidae Zone (lower Badenian; Kollmann, 1965; Hohenegger et al., 2009c).

Thickness: More than 1,200 m, maybe more than 2,000 m (Kollmann, 1965; Kröll et al., 1988; Ebner & Sachsenhofer, 1991).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision. Several lithological units were differentiated in geological maps, which might achieve the status of members (e.g., Kollmann, 1965; see also Winkler-Hermaden, 1939: "Trachyandesite mit Eruptivbreccie und Tuff", "Trachyt mit Eruptivbreccie und Tuff", "Quarztrachyt", "Traß u. andere Umwandlungsprodukte der Trachyandesite", "Bentonit und Tuff").

Underlying unit(s): This unit cuts discordantly the Pre-Neogene basement and lower/middle Miocene rocks.

Overlying unit(s): Post-eruptive Badenian (Weißenegg Formation and Marl-Silt-Sand-Gravel), Sarmatian (Gleisdorf Formation) and Pannonian (Feldbach and Paldau Formation and Tabor Gravel) sediments.

Lateral unit(s): Interfingers partly with Karpatian (Kreuzkrumpl Formation) and Badenian sediments (Weißenegg Formation and Marl-Silt-Sand-Gravel). Many occurrences of Miocene tuffitic layers in the surroundings are traditionally related to the "Gleichenberg volcanic phase" (Kollmann, 1965; Ebner, 1981; Ebner & Gräf, 1982; Ebner & Sachsenhofer, 1991; Balogh et al., 1994; Ebner & Stingl, 1998; Handler et al., 2006; Reuter & Piller, 2011).

Geographic distribution: Eastern Styrian downs; beside the type area recorded in several deep wells in the Gnas and Fürstenfeld Subbasins (Ebner & Sachsenhofer, 1991).

Remarks: -

Complementary references: Fuchs (1980c), Tollmann (1985), Piller et al. (2004).

Mergel-Silt-Sand-Kies / Marl-Silt-Sand-Gravel

Martin Gross

Validity: Invalid; name used by Gross et al. (2007a) for Badenian deposits in central areas of the Eastern Styrian Basin, which are known from deep wells only (see synonyms).

Type area: Eastern Styrian Basin; ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4111 Leibnitz, 4112 Bad Radkersburg, 4230 Gleisdorf, 5101 Jennersdorf, 5225 Fürstenfeld (ÖK50-BMN, map sheets 165 Weiz, 166 Fürstenfeld, 191 Kirchbach in Steiermark, 192 Feldbach).

Type section: -

Remark: The deep wells Perbersdorf 1 (N 46°44′51″ / E 15°40′20″) c. 10.7 km ESE of the town Leibnitz, and Übersbach 1 (N 47°01′39″ / E 16°04′05″) c. 2.6 km SSW of the town Fürstenfeld, provide insight into the lithological development of this unit (e.g., KOLLMANN, 1965; RÖGL et al., 2002; HOHENEGGER et al., 2009c).

Reference section(s): -

Derivation of name: Refers to the main lithologies of this unit.

Synonyms: For this subsurface unit mainly chronostratigraphic (e.g., "Badener Serie") or biostratigraphic (e.g., "Bulimina-Bolivina-Zone", "Sandschalerzone", "Lagenidenzone") terms or a combination of these are in use (e.g., KOLLMANN, 1965; GOLDBRUNNER, 1988; EBNER & SACHSENHOFER, 1991; FRIEBE & POLTNIG, 1991; RÖGL et al., 2002; HOHENEGGER et al., 2009c). Lithologic terms for this unit are: Tonmergel und Nulliporenkalke, sandige Tonmergel, Sande und Tonmergel, Tonmergel, Konglomerate (FUCHS, 1980c), tonig-mergelige Sed. (HOLZER, 1994), […] Mergel, Tone/Silte/Sande u. "Leithakalke" (GROSS, 2000), Mergel Silt/Sand (PILLER et al., 2004), marl silt/sand gravel (GROSS et al., 2007a), Marl, Silt, Sand (SCHREILECHNER & SACHSENHOFER, 2007).

Lithology: Shale, marl, sandstone; conglomerate, corallinacean limestone and volcaniclastic interlayers.

Fossils: Calcareous nannoplankton, foraminifers, molluscs, ostracods.

Origin, facies: Mainly deep marine.

Chronostratigraphic age: Middle Miocene, Langhian to early Serravallian (Badenian).

Biostratigraphy: Regional eco-biostratigraphy: Lagenidae Zone–*Bulimina-Bolivina* Zone.

Thickness: Several hundred meters, up to more than 1,200 m in the Fürstenfeld Subbasin.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No valid subdivision; mainly subdivided according to biostratigraphic results or geophysical log correlation.

Underlying unit(s): Marine Karpatian sediments (Kreuzkrumpl Formation, Conglomerate-rich Group), in most cases discordant lower boundary ("Styrian Unconformity").

Overlying unit(s): Where preserved lower Sarmatian sediments (equivalents of the Rollsdorf Formation) (KRAINER, 1984; FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a; GROSS et al., 2007b; GROSS, 2015).

Lateral unit(s): Interfingers towards basement highs (Middle Styrian Swell) and at the basin margins with the Weißenegg Formation and the Gleichenberg Volcanics.

Geographic distribution: Eastern Styrian downs, Gnas and Fürstenfeld Subbasin.

Remarks: -

Complementary references: PILLER et al. (2004).

Tauchen-Formation / Tauchen Formation

MARTIN GROSS

Validity: Valid; described and formalized by NEBERT et al. (1980; see also NEBERT, 1985).

Type area: Friedberg-Pinkafeld embayment of the Styrian Basin (NEBERT et al., 1980; NEBERT, 1985; see PAHR, 1984 for diverging boundaries); ÖK50-UTM, map sheets 5213 Aspang-Markt, 5219 Oberwart (ÖK50-BMN, map sheets 136 Hartberg, 137 Oberwart).

Type section: Drilling 1/3-51 (N 47°22′49″ / E 16°13′12″), c. 1.9 km SSW Tauchen, c. 10 km N of the town Oberwart (NEBERT et al., 1980); ÖK50-UTM, map sheet 5219 Oberwart (ÖK50-BMN, map sheet 137 Oberwart).

Reference section(s): Drilling Willersdorf 1/W2 (N 47°22′11″ / E 16°11′32″), in the western part of the community Willersdorf, c. 9.2 km N Oberwart (NEBERT et al., 1980); ÖK50-UTM, map sheet 5219 Oberwart (ÖK50-BMN, map sheet 137 Oberwart).

Remark: The outcrops 38, 39, 58, 59, c. 0.5 km N of the village Wiesfleck, c. 2.3 km NE of the town Pinkafeld, and the outcrop 67, c. 0.5 km NW of the hamlet Gfangen, c. 2 km NW Pinkafeld, of NEBERT (1985; see PAHR, 1984) provide additional information. Especially, the outcrops N Wiesfleck offer a good insight into the lithological development of the Tauchen Formation today.

Derivation of name: After the village Tauchen, c. 2.8 km WSW of the market town Bernstein, c. 7.8 km ENE of the town Pinkafeld, c. 70 km NE of the city Graz, Burgenland.

Synonyms: Tauchener Schichten (WINKLER-HERMADEN, 1943), (partim) Kohle von Tauchen und Schreibersdorf, Marine Sande und Schotter von Wiesfleck mit Nulliporenkalk-Einschaltungen, Marine Sande und Tonmergel von Pinkafeld, Marine Hangendmergel, Sand, Schotter, Schotter von Pinkafeld und Wiesfleck (KOLLMANN, 1965), Baden (Grobsand, Kies, Schotter, Schluff, Feinsand, Riffkalk) (PAHR, 1984).

Lithology: Sand with gravel layers and corallinacean limestone intercalations, sandy pelite and pelite, lignite (lower part: "Tauchen Seams", upper part: "Bubendorf Seams",) with tuffitic intercalations (HAUSER & NEUWIRTH, 1959; EBNER & GRÄF, 1977b; NEBERT et al., 1980; WEBER & WEISS, 1983; NEBERT, 1985).

Fossils: Coralline red algae, plant remains, foraminifers, corals, gastropods, bivalves, ostracods, fishes (HILBER, 1895; LIEBSCHER, 1925; PAHR, 1984; NEBERT, 1985; SCHULTZ, 2004; SCHULTZ & BELLWOOD, 2004).

Origin, facies: Fluvial-limnic, deltaic and shallow marine.

Chronostratigraphic age: Middle Miocene, Langhian (early to middle Badenian).

Biostratigraphy: Regional eco-biostratigraphy foraminifera zones: Lagenidae Zone – *Spirorutilus* Zone (= former Agglutinated foraminifera Zone) (KOLLMANN, 1965; NEBERT et al., 1980; NEBERT, 1985).

Thickness: Up to 200 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal; "Lower" (brown coal, tuff, sand or only sand), "Middle" (sand(stone), gravel layers) and "Upper" part (fine sand, sandy pelites, brown coal) (NEBERT et al., 1980; compare NEBERT, 1985: basin and delta facies).

Underlying unit(s): Sinnersdorf Formation; gradational (NEBERT et al., 1980; NEBERT, 1985) or discordant (KOLLMANN, 1965; PAHR, 1984) lower boundary.

Overlying unit(s): Discordant upper boundary; overlain by Sarmatian, Pannonian or Quaternary sediments (NEBERT et al., 1980; NEBERT, 1985).

Lateral unit(s): NEBERT et al. (1980) suggest the "Ritzinger Sande mit Basisflöz" (see Ritzing Formation) of the Landsee embayment (Burgenland) to be an equivalent of the Tauchen Formation.

Geographic distribution: Northeastern Styria and Middle Burgenland.

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Stallhofen-Formation / Stallhofen Formation

MARTIN GROSS

Validity: Invalid; name introduced by EBNER & STINGL (1998) and used in the various contributions in STEININGER (1998); however, formalization is still pending.

Type area: Köflach-Voitsberg embayment of the Western Styrian Basin; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Type section: -

Remark: EBNER & STINGL (1998) designated no type section. Here, the section at Lobmingberg (N 47°04′36″ / E 15°09′59″), c. 3.5 km NNE Voitsberg, c. 20.6 km W Graz, is proposed as type section. It exposes deposits of the "Fine Basis Member", the Lobmingberg Member and the Eckwirt Member of the Stallhofen Formation (EBNER & GRÄF, 1982; EBNER et al., 1998).

Reference section(s): -

Derivation of name: After the market town Stallhofen, c. 17 km W of the city Graz, Styria.

Synonyms: (partim) Schotter[n] des Eckwirtes (FLÜGEL 1959), (partim) Eckwirt-Schotter (FLÜGEL, 1961), (?partim) Hangendschichten von Zangtal (KOLLMANN, 1965; compare FLÜGEL, 1961; STINGL, 2003; EBNER et al., 2017), (partim) Limnisch-fluviatile Entwicklung (Reiner Schichten, Eckwirtschotter) (EBNER, 1983a).

Lithology: Silt and clay with paleosol horizons; coarse gravel/conglomerate to boulder gravel, subordinately sand and pelite (see Eckwirt Member) and tuff/tuffite/bentonite interlayers (see Lobmingberg Member) (FLÜGEL, 1961; EBNER & GRÄF, 1982; EBNER, 1986a; EBNER & STINGL, 1998; EBNER et al., 1998).

Fossils: Plant and gastropod remains in the "Fine Basis Member"; charcoal within the Lobmingberg Member (FLÜGEL, 1959; MAURIN, 1959; EBNER et al., 1998).

Origin, facies: Fluvial (braided river) and limnic paleoenvironment, partly influenced by volcanic fallout.

Chronostratigraphic age: Middle Miocene, Langhian–Serravallian (early Badenian–early Sarmatian) (FLÜGEL, 1958, 1959, 1997; RIEPLER, 1986, 1988; EBNER et al., 2002; GROSS, 2015).

Biostratigraphy: -

Thickness: Up to 230 m (GROSS, 2015).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Partly subdivided in the invalid "Coarse and Fine Basis Members" and the valid Eckwirt Member and Lobmingberg Member (EBNER & STINGL, 1998; EBNER et al., 1998; GROSS, 2015).

Underlying unit(s): In the type area the Köflach-Voitsberg Formation (erosional or gradational contact; EBNER & STINGL, 1998); in the region of Tobelbad, c. 11.5 km SW Graz, the "Tobelbad Formation" or directly Paleozoic basement (RIEPLER, 1988; FLÜGEL, 1997); in the Rein Basin (13 km NW Graz) the Paleozoic basement, the Rein Formation and Eggenberg Formation (EBNER & GRÄF, 1979; EBNER, 2001; HARZHAUSER et al., 2014a; GROSS, 2015).

Overlying unit(s): In the Thal embayment (NE Stallhofen embayment) the Mantscha Formation or erosive (peneplain) upper boundary (GROSS, 2015).

Lateral unit(s): Interfingers with the Rein and Rollsdorf Formations (EBNER & GRÄF, 1979; RIEPLER, 1986, 1988; FLÜGEL, 1997) as well as with the Florian Beds (EBNER & STINGL, 1998) and the Dillach Member (Weißenegg Formation) (FRIEBE, 1990; GROSS, 2015).

Geographic distribution: Köflach-Voitsberg, Stallhofen, Stiwoll and Thal embayment of the Western Styrian Basin; Rein and western Gratkorn Basin; ÖK50-UTM, map sheets 4104 Deutschlandsberg, 4105 Kalsdorf bei Graz, 4228 Voitsberg, 4229 Graz (ÖK50-BMN, map sheets 163 Voitsberg, 164 Graz, 189 Deutschlandsberg, 190 Leibnitz).

Remarks: In his PhD-thesis, RIEPLER (1988) introduced the "Schichten von Tobelbad" for an about 40 m thick alternation of silt, sand and freshwater limestone temporarily exposed during construction works at the rehabilitation clinic Tobelbad. Later, FLÜGEL (1997) termed these strata "Tobelbad Formation", which are possibly of early to middle Badenian age and could be a lateral equivalent (or even synonym) of the Rein Formation or the Florian Beds (compare discussions in FLÜGEL, 1975c and RIEPLER, 1988).

Complementary references: FUCHS (1980c).

Eckwirt-Subformation (Stallhofen-Formation) / Eckwirt Member (Stallhofen Formation)

MARTIN GROSS

Validity: Valid; established by FLÜGEL (1959); introduced as member of the Stallhofen Formation by EBNER & STINGL (1998); formalized by GROSS (2015).

Type area: Köflach-Voitsberg and Stallhofen embayment of the Western Styrian Basin; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Type section: Section exposed in a ditch at Lobmingberg (N 47°04′36″ / E 15°09′59″), c. 3.5 km NNE Voitsberg, c. 20.6 km W Graz; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Remark: Flügel (1959) and Ebner & Stingl (1998) defined no type section. Gross (2015) selected this outcrop at the Lobmingberg as type section (see also Ebner & Gräf, 1982).

Reference section(s): Gross (2015) indicated the outcrops in the ditch of the Schirningbach (N 47°06′44″ / E 15°13′28″), c. 0.25 km N of the farmstead Eckwirt, c. 17 km NW of Graz, and the sections Triebel (N 47°03′30″ / E 15°19′17″) and Doblwald (N 47°03′45″ / E 15°19′17″), both c. 9 km W of Graz, described by Riepler (1988), as reference sections; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Derivation of name: After the farmstead Eckwirt, c. 1.1 km NNE of the village Stiwoll, c. 17 km NW of the city Graz, Styria.

Synonyms: (partim) Schotter der Mantscha (Aigner, 1917), Schotter[n] des Eckwirtes (Flügel, 1959), Eckwirt-Schotter (Flügel, 1961), Eckwirtschotter (Kollmann, 1965), Eckwirtschotter bzw. Schotter des Unt. Badenian (Ebner & Gräf, 1982), (partim) Eckwirtschotter (Ebner, 1983a), (partim) Eckwirt-Formation (Flügel, 1997), Eckwirt Member (Ebner & Stingl, 1998), ?Zangtal Hangend Abfolge (Stingl, 2003).

Lithology: Yellowish grey, coarse gravel (partly conglomerate) to boulder gravel composed predominantly of quartz and crystalline pebbles, with Eocene and Upper Cretaceous lime-/sandstone pebbles at the base, subordinately horizontal and cross-bedded sand and laminated or massive pelite (Flügel, 1959, 1961, 1997; Ebner, 1986a; Ebner & Stingl, 1998; Riepler, 1986, 1988; Gross, 2015).

Fossils: -

Origin, facies: Braided river deposits (Riepler, 1988; Ebner & Stingl, 1998).

Chronostratigraphic age: Middle Miocene, Langhian–Serravallian (early Badenian–early Sarmatian (Gross, 2015).

Biostratigraphy: -

Thickness: Up to 230 m (Flügel, 1997).

Lithostratigraphically higher rank unit: Stallhofen Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): In the type area the Köflach-Voitsberg Formation (erosional contact) or the "Fine Basis Member" or Lobmingberg Member of the Stallhofen Formation (Ebner & Stingl, 1998); in the region of Tobelbad, c. 11.5 km SW Graz, the "Tobelbad Formation" or directly the Paleozoic basement (Riepler, 1988; Flügel, 1997); in the Rein Basin (13 km NW Graz) the Paleozoic basement, the Rein Formation and Eggenberg Formation (Ebner & Gräf, 1979; Ebner, 2001; Harzhauser et al., 2014a; Gross, 2015).

Overlying unit(s): In the Thal embayment (NE Stallhofen embayment) the Mantscha Formation or erosive (peneplain) upper boundary (Gross, 2015).

Lateral unit(s): Interfingers with the Rein and Rollsdorf Formations (Ebner & Gräf, 1979; Riepler, 1986, 1988; Flügel, 1997) as well as with the Florian Beds (Ebner & Stingl, 1998) and the Dillach Member (Weißenegg Formation) (Friebe, 1990; Gross, 2015).

Geographic distribution: Köflach-Voitsberg, Stallhofen, Stiwoll and Thal embayment of the Western Styrian Basin; Rein and western Gratkorn Basin; ÖK50-UTM, map sheets 4104 Deutschlandsberg, 4105 Kalsdorf bei Graz, 4228 Voitsberg, 4229 Graz (ÖK50-BMN, map sheets 163 Voitsberg, 164 Graz, 189 Deutschlandsberg, 190 Leibnitz).

Remarks: -

Complementary references: Fuchs (1980c), Tollmann (1985), Ebner & Sachsenhofer (1991).

Lobmingberg-Subformation (Stallhofen-Formation) / Lobmingberg Member (Stallhofen Formation)

Martin Gross

Validity: Valid; established by Ebner et al. (1998).

Type area: Area of the Lobmingberg, c. 20 km W of the city Graz in the Köflach-Voitsberg embayment of the Western Styrian Basin; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Type section: Section exposed in a ditch at the Lobmingberg (N 47°04′36″ / E 15°09′59″), c. 3.5 km NNE Voitsberg, c. 20.6 km W Graz (Ebner et al., 1998); ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Remark: This section acts also as type section for the Stallhofen Formation and the Eckwirt Member.

Reference section(s): -

Remark: Further occurrences, a few hundred meters E and SE of the type section in the Bürgerwald are described and figured by Ebner & Gräf (1982), which might act as reference sections.

Derivation of name: After the hill Lobmingberg (municipality Voitsberg), c. 20 km W Graz, Styria.

Synonyms: Tuffe […] auf der Höhe von Lobmingberg (Petrascheck, 1955), Tufflage im Westhang des Lobmingberges (Maurin, 1959), Tuffe des Bürgerwaldes (Flügel, 1961).

Lithology: Grey to whitish tuff and grey-green tuffite/bentonite (Ebner et al., 1998).

Fossils: Maurin (1959) mentioned charcoal within the tuff.

Origin, facies: Subaqueous fallout tephra in a lacustrine/fluvial system (Ebner et al., 1998).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian).

Remark: Ebner et al. (2002; compare Ebner et al., 2000) report a zircon fission track age of 16.0 ± 0.8 Ma from the Lobmingberg Member (compare K/Ar-age of Balogh et al., 1994: 17.5 ± 2.6 Ma).

Biostratigraphy: -

Thickness: About 5 m (MAURIN, 1959; EBNER et al., 1998).

Lithostratigraphically higher rank unit: Stallhofen Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): The invalid "Fine Basis Member" of the Stallhofen Formation compare "fine-grained, lacustrine/fluvial basal member" (EBNER et al., 1998: p. 425).

Overlying unit(s): Eckwirt Member (Stallhofen Formation) (EBNER & GRÄF, 1982).

Lateral unit(s): Eckwirt Member (Stallhofen Formation) (EBNER & GRÄF, 1982).

Geographic distribution: Corresponds to the type area.

Remarks: STINGL (2003: p. 224) correlated occurrences of volcanoclastics in pelitic sediments (including diatom-marls) above the "Zangtal Upper Seam" (Zangtal Depression of the Köflach-Voitsberg embayment; c. 1.6 km ENE Voitsberg) with the "Lobningberg [sic!] Bed of the Stallhofen Formation". However, EBNER et al. (2017) included these deposits as "Zangtal-Subformation" of the Köflach-Voitsberg Formation.

Complementary references: KOLLMANN (1965), FUCHS (1980c).

Rein-Formation / Rein Formation

MARTIN GROSS

Validity: Invalid; first recognized by UNGER (1843); considered as formation by EBNER & GRÄF (1979); named as Rein Formation by EBNER (2001).

Type area: Rein Basin, an embayment of the Western Styrian Basin, c. 13 km NW of the city Graz; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Type section: -

Remark: Despite long-lasting coal mining (WEBER & WEISS, 1983), detailed section descriptions are rare (e.g., borehole descriptions in HILBER, 1893: close to the farmstead "Glöckelanderl", N 47°07′55″ / E 15°18′01″, c. 1 km ESE the Rein Abbey, c. 12.5 km NW of the city Graz; compare BENESCH, 1913; PETRASCHECK, 1922/1924). Drill cores (e.g., EBNER, 1986b: well "GKB 822", N 47°06′08″ / E 15°15′50″), c. 13.7 km WNW Graz, stored in the core repository of the Universalmuseum Joanneum (Graz), could possibly be used to define a type section.

Reference section(s): -

Remark: EBNER & GRÄF (1982) provide sections from the "Upper Rein Beds" ("Weißerdekreuz"; N 47°07′05″ / E 15°16′57″), c. 2.1 km SSW of the village Rein, which might act as reference sections.

Derivation of name: After the village Rein (municipality Gratwein-Straßengel), c. 13.8 km NW of the city Graz, Styria.

Synonyms: (partim) Süßwasser-Formation (UNGER, 1843), Süsswasserschichten von Rein (GOBANZ, 1854), Schichten von Rein (STANDFEST, 1882), (partim) Süsswasserkalk von Reun (PENECKE, 1891), (partim) Schichten von Rein und Köflach (HILBER, 1893), Schichten von Rein-Stiwoll-St. Oswald (FLÜGEL, 1961), Reiner Schichten (EBNER & GRÄF, 1979), Rein-Formation (EBNER, 2001), Rein Layers (BRANDL et al., 2011), Rein Beds (HARZHAUSER et al., 2014a).

Lithology: Predominantly (carbonaceous and carbonatic) pelite and up to 4 m thick brown coal seams with freshwater limestone and bentonite intercalations ("Lower" Rein Formation); alternations of pelite, sandy pelite, sand, freshwater carbonates (limestone/-breccia, dolomite, siliceous limestone, chert) with gravel and bentonite intercalations ("Upper" Rein Formation; e.g., HILBER, 1893; BENESCH, 1913; FLÜGEL, 1961; ALKER, 1979; EBNER & GRÄF, 1979, 1982; WEBER & WEISS, 1983; POSTL et al., 2008; BRANDL et al., 2011).

Fossils: Plant remains, ostracods, molluscs (largely gastropods), vertebrates (turtles, mammals) (e.g., UNGER, 1843, 1850, 1852, 1858; PETERS, 1853; GOBANZ, 1854; STANDFEST, 1882; PENECKE, 1891; HILBER, 1893, 1915a; KUBART, 1924; FLÜGEL, 1961, 1975a; MOTTL, 1969a, 1970; HIDEN & ROTTENMANNER, 2007; POSTL et al., 2008; HARZHAUSER et al., 2014a).

Origin, facies: Limnic (FLÜGEL, 1961; EBNER & GRÄF, 1979; HARZHAUSER et al., 2014a).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian) (FLÜGEL, 1961, 1975a; compare HARZHAUSER et al., 2014a).

Biostratigraphy: -

Thickness: Possibly more than 180 m (PETRASCHECK, 1922/1924; EBNER, 1983a).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal subdivision in the "Lower" (coal-bearing) and "Upper" (coal-lacking) Rein Formation (EBNER & GRÄF, 1979, 1982).

Underlying unit(s): Stiwoll Formation or directly the basement through interposition of the Eggenberg Formation (HILBER, 1893; BENESCH, 1913; EBNER & GRÄF, 1979; EBNER, 1983c; EBNER & SACHSENHOFER, 1991).

Overlying unit(s): Stallhofen Formation (mainly the Eckwirt Member).

Lateral unit(s): Stallhofen Formation (Eckwirt Member) and Eggenberg Formation (HAUSER, 1951; FLÜGEL, 1961; EBNER & GRÄF, 1979).

Geographic distribution: Rein Basin and Stiwoll embayment including the area of St. Bartholomä (c. 13.7 km E Graz) and St. Oswald bei Plankenwart (c. 12.2 km ENE Graz), Western Styria; ÖK50-UTM, map sheet 4228 Voitsberg (ÖK50-BMN, map sheet 163 Voitsberg).

Remarks: -

Complementary references: KOLLMANN (1965), EBNER (1981), TOLLMANN (1985), EBNER & SCHUSTER (2014).

Eggenberg-Formation / Eggenberg Formation

MARTIN GROSS

Validity: Valid; name introduced by HOERNES (1880a); described and formalized by GROSS (2015); see synonyms.

Type area: Eastern slope of the Plabutsch-Buchkogel-Range, c. 4 km WNW of the city centre of Graz; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Type section: Ditch at "Einsiedelei" (N 47°04′34″ / E 15°23′20″), c. 0.5 km NW of Eggenberg Palace, c. 4 km WNW of the city centre of Graz (HANSELMAYER, 1955; GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Reference section(s): -

Derivation of name: Named after Schloss Eggenberg (Eggenberg Palace), c. 3.6 km WNW of the city centre of Graz, Styria.

Synonyms: Eggenberger-Breccie (HOERNES, 1880a), Eggenberger Bresche (CLAR, 1935), Eggenberger Breccie und Roterde (FLÜGEL, 1975a), Roterde, Eggenberger-Brekzie (EBNER & GRÄF, 1979), Rotlehme, Rotschutt, Eggenberger Brekzie (EBNER, 1983a), Eggenberger Brekzie (RIEPLER, 1988), Eggenberg(er)-Formation (FLÜGEL, 1997). For a more detailed list see GROSS (2015).

Lithology: Brick-red to brown-yellow, massive limestone/dolostone breccia and red loam/earth (CLAR, 1935; HANSELMAYER, 1955; FLÜGEL, 1975a; RIEPLER, 1988); bentonitic intercalations (HAUSER, 1951; FLÜGEL, 1959; FLÜGEL & MAURIN, 1961) were identified as residual sediments later (EBNER & GRÄF, 1979).

Fossils: Very rare; silicified wood, one proboscidean molar (RÖSSLER, 1958; FLÜGEL, 1961; MOTTL, 1970).

Origin, facies: Talus deposits (breccia) and residual sediments (red loam/earth; CLAR, 1935; FLÜGEL, 1975a; EBNER & GRÄF, 1979).

Chronostratigraphic age: ? Early Miocene, ? Burdigalian (? Karpatian) to middle Miocene, Langhian–Serravallian (Badenian–Sarmatian); possibly younger (? Late Miocene, ? Tortonian; heterochronous) (CLAR, 1935; HANSELMAYER, 1955; WINKLER-HERMADEN, 1943, 1957; FLÜGEL, 1975a; RIEPLER, 1987, 1988; GROSS, 2015).

Biostratigraphy: -

Thickness: Up to tens of meters (e.g., LORENZ & SCHMID, 2005).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided in red loam/red earth/residual sediments and limestone/dolostone breccia (FLÜGEL et al., 2011).

Underlying unit(s): Paleozoic basement.

Overlying unit(s): Various Neogene and Quaternary units, e.g., Mantscha Formation (FLÜGEL, 1959), Eckwirt Member (Stallhofen Formation) (EBNER & GRÄF, 1979) and Ries Formation (CLAR, 1935).

Lateral unit(s): Interfingers in part with lower Badenian (Rein Formation) and lower Sarmatian (Rollsdorf Formation) fresh-/brackish water limestone breccias (HAUSER, 1951; WINKLER-HERMADEN, 1957; EBNER & GRÄF, 1979; RIEPLER, 1987, 1988).

Geographic distribution: Highland in the surroundings of Graz; ÖK50-UTM, map sheets 4223 Weiz, 4224 Hartberg, 4228 Voitsberg, 4229 Graz (ÖK50-BMN, map sheets 134 Passail, 135 Birkfeld, 163 Voitsberg, 164 Graz, 165 Weiz) (EBNER et al., 1985).

Remarks: -

Complementary references: -

Rollsdorf-Formation / Rollsdorf Formation

MARTIN GROSS

Validity: Valid; introduced and described by KRAINER (1984, 1987a); used in the formation rank by HARZHAUSER & PILLER (2004a); formalized by GROSS (2015).

Type area: Embayment of Weiz, Eastern Styria; ÖK50-UTM, map sheets 4224 Hartberg, 4230 Gleisdorf (ÖK50-BMN, map sheet 165 Weiz).

Type section: Section (temporary excavation pit, c. 9.5 m thick) at the farmstead Steingrub (N 47°13′15″ / E 15°42′42″) (KRAINER, 1984, 1987a) at the S hillside of the Ilzberg (531 m a.s.l.), c. 6.9 km E of town Weiz, c. 26.5 km NE of the city Graz (GROSS, 2015); ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheet 165 Weiz).

Reference section(s): GROSS (2015) denominated the following outcrops, described by KRAINER (1984, 1987a), as reference sections: Pircha, c. 7 km ESE Weiz (N 47°11′51″ / E 15°42′34″), Wohngraben, c. 7.5 km ESE Weiz (section 3: N 47°11′41″ / E 15°42′51″ and section 4: N 47°11′27″ / E 15°42′48″), Rollsdorf, c. 8.3 km SE Weiz (section 5/Hartenstein: N 47°10′39″ / E 15°43′05″ and section 6/Lohnberg: N 47°10′39″ / E 15°42′31″; compare HILBER, 1893: p. 330) and, further, the section at the farmstead Köberl in the Thal embayment (N 47°02′32″ / E 15°21′38″; c. 6.8 km SW Graz; RIEPLER, 1988); ÖK50-UTM, map sheets 4224 Hartberg, 4229 Graz, 4230 Gleisdorf (ÖK50-BMN, map sheets 164 Graz, 165 Weiz).

Derivation of name: After the village Rollsdorf, c. 7.9 km SE of the town Weiz, c. 24 km NE of the city Graz, Styria.

Synonyms: (partim) sarmatische Stufe in Thal (HOERNES, 1878), (partim) Gleisdorf-Schichten (FLÜGEL, 1961), Waldhof-Schichten (FLÜGEL, 1961), Rollsdorfer Schichten (KRAINER, 1984), Rollsdorf-Member (FRIEBE, 1994a), Rollsdorf Formation (HARZHAUSER & PILLER, 2004a). For more details see GROSS (2015).

Lithology: Predominantly fine clastics; yellowish to grey, massive or laminated clay–silt–fine sand-alternations (partly ripple- and cross-bedded) and silty clay; subordinately intercalations of gravel, marl, limestone (breccias) and coal (FLÜGEL, 1975a; FLÜGEL & RIEPLER, 1984; KRAINER, 1984, 1987a; RIEPLER, 1988).

Fossils: Plant remains, foraminifers, molluscs, bryozoans, ostracods, crabs (e.g., FLÜGEL, 1961; KRAINER, 1984, 1987a; RIEPLER, 1988; GROSS et al., 2007b; ZAGYVAI & DEMETER, 2008; HYŽNÝ & GROSS, 2016b); probably rare rhinoceratid remains (HILBER, 1893; MOTTL, 1970; GROSS, 2015).

Origin, facies: Shallow marine (sub- to supratidal), brackish (KRAINER, 1987a).

Chronostratigraphic age: Middle Miocene, Serravallian (early Sarmatian).

Biostratigraphy: Regional eco-biostratigraphic foraminifera zone *Elphidium reginum–Elphidium hauerinum* Zone.

Thickness: 150–200 m (KRAINER, 1987a); in the area of Thal, 6.7 km WNW Graz, about 40 m (RIEPLER, 1988).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision (GROSS, 2015).

Underlying unit(s): In the type area transgressively above crystalline rock debris and basement (KRAINER, 1984, 1987a); in the Thal embayment, W of Graz, the Mantscha Formation (RIEPLER, 1988; FLÜGEL, 1997; GROSS, 2015).

Overlying unit(s): In the Weiz embayment: the Puch Gravel (KRAINER, 1987a); in the area of Graz: the Gratkorn Formation or Gleisdorf Formation (GROSS, 2015).

Lateral unit(s): In the Weiz embayment tectonically bounded. Occurrences in the embayment of Friedberg-Pinkafeld (e.g., Rohrbach an der Lafnitz ("Rissoenschichten"), c. 12.3 km NNE Hartberg (PAPP, 1956; KOLLMANN, 1965; BRANDL, 1979)) are considered as lateral equivalents (GROSS, 2015).

Geographic distribution: A disjunct distribution: Weiz embayment, N and W of Graz and, probably, Friedberg-Pinkafeld embayment; ÖK50-UTM, map sheets 4224 Hartberg, 4228 Voitsberg, 4229 Graz, 4230 Gleisdorf (ÖK50-BMN, map sheets 136 Hartberg, 163 Voitsberg, 164 Graz, 165 Weiz).

Remarks: FRIEBE (1994a) introduced the "Rollsdorf Member" (following KRAINER, 1984: "Rollsdorfer Schichten") within the Gleisdorf Formation but mixed up lower Sarmatian siliciclastics with the mixed-siliciclastic-carbonatic deposits of the upper Sarmatian Gleisdorf Formation. HARZHAUSER & PILLER (2004a) raised the lower Sarmatian, *Mohrensternia*- and oyster-bearing, mainly fine siliciclastics of the "Rollsdorf Member" to the Rollsdorf Formation. GROSS et al. (2007b) and GROSS (2015) used for equivalent deposits ("Waldhof-Schichten") W and N of the city of Graz (Thal embayment) also the term Rollsdorf Formation. Although the "Waldhof Schichten" have been established earlier by FLÜGEL (1961), the name Rollsdorf Formation is preferred, because KRAINER (1984) presented first detailed sections ("Steingrub"; see type section) of this unit. Furthermore, the sections in the Thal embayment are badly exposed.

Complementary references: FUCHS (1980c).

Grafenberg-Formation / Grafenberg Formation

MARTIN GROSS

Validity: Valid; introduced by FRIEBE (1994a) as "Grafenberg Member"; raised to a formation and redefined by HARZHAUSER & PILLER (2004b).

Type area: Region N of the town Hartberg, northeastern Styria; ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheet 136 Hartberg).

Type section: Abandoned quarry Grafenberg (N 47°21′29″ / E 15°59′25″), c. 8.4 km NNE Hartberg, Eastern Styria; ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheet 136 Hartberg).

Remark: The type section is partly backfilled but FLÜGEL (1972) and FRIEBE (1994a, b) provide detailed descriptions of this outcrop, where lower and upper boundaries were exposed.

Reference section(s): Abandoned quarry (N 46°48′44″ / E 15°58′25″) in the forest close to the village Klapping, c. 2 km S of the market town St. Anna am Aigen, southeastern Styria (WINKLER, 1913a, 1927b; KOLLMANN, 1965; HARZHAUSER & PILLER 2004a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Derivation of name: After the village Grafenberg (municipality Grafendorf bei Hartberg), c. 8 km NNE Hartberg, c. 53 km NE Graz, Styria.

Synonyms: Sarmatische Riffkalke (Bryozoen-, Serpuliden- und Algenkalke) (WINKLER v. HERMADEN, 1952), Schichten von Klapping (KOLLMANN, 1965), Bryozoen- und Serpulakalke, Mergel und Konglomerate (EBNER & SACHSENHOFER, 1991).

Lithology: Basal conglomerate and sand with moderately to well-rounded, carbonatic-cemented mica schist and gneiss pebbles; serpulid-bryozoan-foraminiferal framestone (biostrome) with intercalated shell debris, coquinas, microbialites and siliciclastics.

Fossils: Calcareous algae (corallinaceans, dasycladaceans), bryozoans, gastropods (*Mohrensternia*), bivalves (oysters), serpulids (*Hydroides*), foraminifers (*Sinzowella*, miliolids, elphidiids), ostracods (FRIEBE 1994a, b; HARZHAUSER & PILLER, 2004a, b).

Origin, facies: Marginal marine serpulid-bryozoan carbonate build-ups and tidal flats; highly influenced by sea-level fluctuations.

Chronostratigraphic age: Middle Miocene, Serravallian (early Sarmatian).

Biostratigraphy: Regional eco-biostratigraphic foraminifera zone: *Elphidium reginum* Zone; regional eco-biostratigraphic mollusc zone: *Mohrensternia* Zone.

Thickness: In outcrops only some meters but probably considerably thicker (up to 100 m?) as indicated by seismic data (SCHREILECHNER & SACHSENHOFER, 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline basement; erosional, transgressive boundary.

Overlying unit(s): Erosional upper boundary or overlain by the Gleisdorf Formation.

Lateral unit(s): Corresponds to parts of the Holíč Formation of the Vienna and Eisenstadt Basin (HARZHAUSER & PILLER, 2004a).

Geographic distribution: North- and Southeastern Styrian downs (Hartberg, Klapping), close to the basin margin; maybe also in the subsurface of the Southern Fürstenfeld Subbasin (SCHREILECHNER & SACHSENHOFER, 2007); ÖK50-UTM, map sheets 4106 Feldbach, 4224 Hartberg (ÖK50-BMN, map sheets 136 Hartberg, 192 Feldbach).

Remarks: FRIEBE (1994a) amalgamated these lower Sarmatian biostromes (and related sediments) with the upper Sarmatian Gleisdorf Formation. Due to lithological and genetical divergences, HARZHAUSER & PILLER (2004a) proposed the "Grafenberg Member" to be a separate formation.

Complementary references: FLÜGEL & NEUBAUER (1984), PILLER et al. (2004).

Mantscha-Formation / Mantscha Formation

MARTIN GROSS

Validity: Valid; described and formalized by GROSS (2015).

Type area: Thal Basin, W of the city Graz, northern margin of the Western Styrian Basin; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Type section: Section at the farmstead Köberl (N 47°02′32″ / E 15°21′38″), c. 6.8 km SW of the city centre of Graz (RIEPLER, 1988); not accessible anymore; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Reference section(s): -

Derivation of name: After the village Mantscha (municipality Hitzendorf), c. 7.6 km SW of the city centre of Graz, Styria.

Synonyms: (partim) Planorben-Schichten (ROLLE, 1856), limnisch-fluviatile, kohleführende, sandig schottrige Schichtfolge, (partim) Kohleführende Schichten von Webling-Baierdorf (FLÜGEL, 1975c), (partim) Reiner Schichten (EBNER, 1983a).

Lithology: Grey silty to sandy clay (FLÜGEL, 1997); in the embayment of Webling (part of the 16. city district of Graz: Straßgang) also thin coal-layers and grey, marly freshwater limestone (HIDEN, 1996c). For coal-mining history, see WEBER & WEISS (1983).

Fossils: In the area of Webling (Straßgang), SW part of Graz, plant remains, limnic and terrestrial gastropods and rare rhinoceratid remains are recorded (ROLLE, 1856; HILBER, 1893; FLÜGEL, 1959; HIDEN, 1996c; HARZHAUSER et al., 2014a).

Origin, facies: Limnic(-fluvial).

Chronostratigraphic age: Middle Miocene, Serravallian (possibly, around the Badenian/Sarmatian boundary) (FLÜGEL, 1997).

Biostratigraphy: Uncertain.

Thickness: Up to 50 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Stallhofen Formation (Eckwirt Member), in part Eggenberg Formation (FLÜGEL, 1959; HIDEN, 1996c).

Overlying unit(s): Rollsdorf Formation.

Lateral unit(s): Unclear.

Geographic distribution: Type area and Webling embayment, Western Styria; ÖK50-UTM, map sheets 4228 Voitsberg, 4229 Graz (ÖK50-BMN, map sheets 163 Voitsberg, 164 Graz).

Remarks: Due superposition by the lower Sarmatian Rollsdorf Formation and the underlying Badenian to lower Sarmatian Stallhofen Formation (Eckwirt Member), an age around the Badenian/Sarmatian boundary has been assumed for the Mantscha Formation in the type area (FLÜGEL, 1997). For the deposits in the Webling embayment stratigraphic estimations range from the lower Badenian (HOERNES, 1880a; HILBER, 1893; FLÜGEL, 1975a; EBNER, 1983a) to the lower Pannonian (FLÜGEL, 1959; compare GROSS et al., 2007b; GROSS, 2015).

Complementary references: -

Carinthischer Schotter / Carinthian Gravel

MARTIN GROSS

Validity: Invalid; unit established by WINKLER (1926) and used in various combinations afterwards (see Synonyms).

Type area: Region between the market towns Jagerberg, St. Peter am Ottersbach and Straden, c. 38 km SE of the city Graz, Eastern Styria (WINKLER, 1927a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach).

Type section: -

Remark: A gravel pit (N 46°49′42″ / E 15°49′59″; today a waste dump), close to the village Trössing, c. 5 km SSE of the market town Gnas, c. 40 km SE Graz, was mentioned by WINKLER (1914, 1927b) and HANSELMAYER (1969), which might serve as type section. Only the vague sedimentological reports of these works are available up to now. However, there are still good outcrops nearby (N 46°49′57″ / E 15°50′00″ and N 46°49′41″ / E 15°50′20″), which could be used to define a type section.

Reference section(s): -

Derivation of name: The name refers to "exotic" components (e.g., Eocene nummulite limestone pebbles), for which WINKLER (1927b) proposed an origin from the Eocene of Carinthia and postulates a paleodrainage pattern from southwest (SKALA, 1967). Contrary, KOLLMANN (1965) and HANSELMAYER (1967a, 1969) argue for a catchment area in the (north)east.

Synonyms: Sarmato-carinthische[s] Delta (WINKLER, 1926), sarmatocarinthisches Delta (WINKLER-HERMADEN, 1943), Carinthische[r] Schotter (WINKLER VON HERMADEN, 1944), sarmatocarinthische[r] Schotterzug (EBNER & SACHSENHOFER, 1991), Sarmathocarinthian Gravel (EBNER & SACHSENHOFER, 1995), Carinthian Gravel (KOSI et al., 2003).

Remark: The "Carinthischer Schotter" should not be confused with the "carinthischen Delta" (WINKLER, 1926) and the "karinthische[n] Schuttkegel der Arnfelser Konglomerate" (WINKLER, 1929a), respectively.

Lithology: Coarse to medium grained gravel with crystalline (granitoids, pegmatite, gneiss), sandstone, porphyry, limestone, dolomite, chert and Eocene nummulite/corallinacean limestone pebbles, massive to horizontally bedded, imbrication; sand and pelite intercalations (WINKLER, 1927a; HANSELMAYER, 1967a, b, 1969).

Fossils: Rare, only recorded close to the top of these gravels; (allochthonous) terrestrial and marine gastropods, bivalves, foraminifers, mammals (e.g., *Sirenia*), plant remains (WINKLER, 1927b; PAPP, 1958b; KOLLMANN, 1965; MOTTL, 1970).

Origin, facies: Fluvial-deltaic-coastal (WINKLER, 1927b).

Chronostratigraphic age: Middle Miocene, Serravallian (close to the early/late Sarmatian boundary).

Biostratigraphy: Regional eco-biostratigraphic foraminifera zones: *Elphidium hauerinum* and ?basal *Porosononion granosum* Zone; regional mollusc zone: lower and ?upper *Ervilia* Zone.

Thickness: Variable, ranging from several meters to 30 m in outcrops (e.g., Trössing, WINKLER, 1927b). In the deep drilling Übersbach 1, KOLLMANN (1965) reports a thickness of about 100 m. HARZHAUSER & PILLER (2004a) calculate a thickness up to 130 m (SCHREILECHNER & SACHSENHOFER, 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Rollsdorf Formation and Grafenberg Formation (subsurface), erosional lower boundary (WINKLER-HERMADEN, 1957; HARZHAUSER & PILLER, 2004b; GROSS et al., 2007a, b; SCHREILECHNER & SACHSENHOFER, 2007; GROSS, 2015).

Overlying unit(s): Gleisdorf Formation; transgressive upper boundary.

Lateral unit(s): GROSS (2015; see also GROSS et al., 2007b, 2011b, 2014) considered the Gratkorn Formation (ranging from the Gratkorn Basin to the area of Graz) as an equivalent of the Carinthian Gravel.

Geographic distribution: Southeastern Styrian downs and according to WINKLER-HERMADEN (1957) reaching further to the south to the Windische Bühel (Northern Slovenia, down to Lenart).

Remarks: At the end of the early Sarmatian a significant drop in relative sea level is widely recognized in the Eastern Alpine realm. Marked erosion of the underlying strata and basin ward prograding alluvial-deltaic systems developed, leading to the deposition of coarse clastics (Carinthian Gravel, Styrian Basin; Marz Gravel, Eisenstadt-Sopron Basin). Several authors link this regressive phase with an amplified basement uplift and use it as sequence stratigraphic marker for the subdivision of the Sarmatian sediments (e.g., WINKLER-HERMADEN, 1951, 1957; HARZHAUSER & PILLER, 2004a; STRAUSS et al., 2006; SCHREILECHNER & SACHSENHOFER, 2007). Also a strong astronomical forcing of this regression is discussed (e.g., HARZHAUSER & PILLER, 2004a; KOVÁČ et al., 2008; LIRER et al., 2009).

Complementary references: WINKLER VON HERMADEN (1951), FUCHS (1980c), TOLLMANN (1985), HARZHAUSER & PILLER (2004a), PILLER et al. (2004).

Gratkorn-Formation / Gratkorn Formation

MARTIN GROSS

Validity: Valid; described and formalized by GROSS (2015).

Type area: Gratkorn Basin, c. 10 km NW of the city Graz; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Type section: Section (c. 15 m thick), c. 0.2 km SSE of the farmstead “Grubenbauer” (N 47°08′59″ / E 15°21′25″), c. 2 km NE of the market town Gratkorn, c. 11 km NW of the city Graz; neither the lower nor the upper boundary are exposed; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Reference section(s): GROSS (2015) denominated the following outcrops, as reference sections: section (pathway cut) close to the farmstead “Lanz” (N 47°08′21″ / E 15°20′36″), c. 0.4 km NE Gratkorn; St. Stefan clay pit (also named Gratkorn clay pit; N 47°08′14″ / E 15°20′56″), c. 0.7 km E Gratkorn; section Pailgraben (ditch; N 47°07′46″ / E 15°23′06″), c. 3.5 km ESE Gratkorn; and section Bogenhof (ditch; N 47°07′20″ / E 15°23′35″), c. 4.3 km ESE Gratkorn; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Remark: In the outcrops Lanz, Bogenhof and St. Stefan clay pit is the upper boundary to the Gleisdorf Formation exposed (in the pit only temporarily). The section Pailgraben exposes the lower boundary to the Rollsdorf Formation (GROSS et al., 2007b, 2011b, 2014; GROSS, 2015).

Derivation of name: Named after the market town Gratkorn, c. 9.8 km NW Graz, Styria.

Synonyms: (partim) Kristallinschotter (CLAR, 1933), Kristalline Blockschotter von Gratkorn, Frühintrapannonischer Blockschotter und Schotter (WINKLER-HERMADEN, 1957), (partim) Eckwirtschotter (EBNER, 1983a), Eckwirt-Formation (FLÜGEL, 1997), Gratkorn Gravel (GROSS et al., 2011b), Gratkorn Formation (GROSS et al., 2014). For a more detailed list see GROSS (2015).

Lithology: Grey to yellowish, massive, coarse gravel (in part conglomerate) to boulder gravel with sandy or pelitic matrix; subordinately cross- and horizontal bedded sand and fine–medium gravel; frequently weathered gneiss pebbles; polymict (predominantly gneiss, quartz, amphibolite, pegmatite; rarer Paleozoic and Mesozoic lime- and dolostone and “Eocene” pebbles) (FLÜGEL, 1997; GROSS et al., 2014; GROSS, 2015).

Fossils: On top of the Gratkorn Formation a fossiliferous paleosol (plant, gastropod and vertebrate remains) is locally developed (HARZHAUSER et al., 2008c; GROSS et al., 2011b, 2014).

Origin, facies: Fluvial, braided river system, partly influenced by distal alluvial fans (gravel-bed braided river with sediment-gravity-flows; GROSS et al., 2011b).

Chronostratigraphic age: Middle Miocene, Serravallian (around the early/late Sarmatian boundary) (GROSS et al., 2011b).

Biostratigraphy: Correlated to the regional foraminifera zones: *Elphidium hauerinum* and (?) basal *Porosononion granosum* Zones and regional molluscan zones: lower and (?) upper *Ervilia* Zones (HARZHAUSER et al., 2008c; GROSS et al., 2011b, 2014).

Thickness: At the surface 20–30 m, probably more than 100 m (FLÜGEL, 1997).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Rollsdorf Formation.

Overlying unit(s): Gleisdorf Formation.

Lateral unit(s): Carinthian Gravel (GROSS et al., 2007b, 2011b, 2014; GROSS, 2015).

Geographic distribution: Gratkorn Basin and towards the SE into the Graz embayment at the northern margin of the Styrian Basin (FLÜGEL et al., 2011; GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Remarks: Due to lithological similarities, this unit was considered to be equivalent to the lower Badenian to lower Sarmatian Eckwirt Member of the Stallhofen Formation However, the Gratkorn Formation is underlain by the lower Sarmatian Rollsdorf Formation and overlain by the upper Sarmatian Gleisdorf Formation. The Gratkorn Formation is considered as a northwestern equivalent of the Carinthian Gravel. For a comprehensive discussion see GROSS (2015; see also GROSS et al., 2007b, 2011b, 2014).

Complementary references: -

Gleisdorf-Formation / Gleisdorf Formation

MARTIN GROSS

Validity: Valid; described and formalized by FRIEBE (1994a); redefined by HARZHAUSER & PILLER (2004a; see also GROSS, 2015).

Type area: Region around St. Anna am Aigen, c. 48 km SE of Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Remark: FRIEBE (1994a: p. 268) applied the term Gleisdorf Formation for mixed-siliciclastic-carbonatic sediments in the area of "Waltra – St. Anna am Aigen, Löffelbach – Schildbach, Grafenberg und Rollsdorf" (see Waltra Member, Löffelbach Member, Grafenberg Formation and Rollsdorf Formation). However, only the Waltra Member is accepted as valid by HARZHAUSER & PILLER (2004a). Therefore, the area around "Waltra – St. Anna am Aigen" is chosen here as type area.

Type section: Not formally defined by FRIEBE (1994a).

Remark: FRIEBE (1994a) and HARZHAUSER & PILLER (2004a) gave a detailed description of the section (N 46°51′10″ / E 15°57′33″) in a ditch immediately N of the village Waltra, c. 2.3 km NW of the market town St. Anna am Aigen, c. 46 km SE of Graz, which is considered here as type section for the Gleisdorf Formation and the Waltra Member as well.

Reference section(s): Not formally defined by FRIEBE (1994a).

Remark: The section(s) in the ditch of the Pogergraben (N 46°51′08″ / E 15°58′10″), c. 1.9 km NNW St. Anna am Aigen, c. 5.5 km SE Bad Gleichenberg, described by FRIEBE (1994a) as reference section(s) for the Waltra Member are proposed here as reference for the Gleisdorf Formation as well.

Derivation of name: Named after the town Gleisdorf, c. 20 km ENE of the city Graz, Styria.

Synonyms: Obersarmatische Schichten (WINKLER, 1913a), Obersarmat [including the] Gleisdorfer Schichten, Fossilführende Schichten von Spillerhof [Spielerhof], [the] Schichten von Arnwiesen, Fünfing etc., [the] Mühldorfer Schotter, [the] Schichten von Hartberg und Schildbach, Kirchberg a. Walde (KOLLMANN, 1965). For a more detailed list see FRIEBE (1994a) and GROSS (2003a, 2015).

Lithology: Mixed-siliciclastic-carbonatic sediments; alternations of pelite, sand, gravel, marly limestone and oolite (e.g., WINKLER, 1913a, 1927a, b; FRIEBE, 1994a, b; HARZHAUSER & PILLER, 2004a; GROSS, 2015).

Fossils: Ichnofossils, plant remains, foraminifers, gastropods, bivalves, insects, crabs, ostracods, fish and mammal remains (e.g., HILBER, 1893, 1895; WINKLER, 1913a, b, 1927b; PAPP, 1954; MOTTL, 1958a, b, 1970; KOLLMANN, 1965; FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a; GROSS, 2015, cum lit.; HABLY & MELLER, 2017; DOUBRAWA et al., 2018).

Origin, facies: Shallow marine, normal- to hypersaline (FRIEBE, 1994a; PILLER & HARZHAUSER, 2005); in proximal areas marginal marine to limnic with fluvial-deltaic influx (GROSS, 2015).

Chronostratigraphic age: Middle Miocene, late Serravallian (late Sarmatian).

Biostratigraphy: Regional mollusc zones: Upper *Ervilia* Zone and *Sarmatimactra* Zone, regional foraminifera zone: *Porosononion granosum* Zone (KOLLMANN, 1965; FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a; GROSS et al., 2007b)

Thickness: Up to 400 m (KOLLMANN, 1965; EBNER & SACHSENHOFER, 1991; KOSI et al., 2003).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Subdivided into the Waltra Member and Löffelbach Member (HARZHAUSER & PILLER, 2004a); in a proximal position at the northwestern margin of the Styrian Basin it is subdivided into the Peterstal Member and Lustbühel Member (GROSS, 2015).

Underlying unit(s): Carinthian Gravel, Gratkorn Formation or Rollsdorf Formation (FRIEBE, 1994a; GROSS, 2015).

Overlying unit(s): Feldbach Formation, Paldau Formation or Ries Formation (FRIEBE, 1994a; GROSS, 2003a, 2015).

Lateral unit(s): The upper Sarmatian proportions of the Coal-bearing beds of Weiz and of the Puch Gravel are discussed to be – at least in part – lateral equivalents (FLÜGEL, 1975a; MOSER, 1986; KRAINER 1987a; GROSS et al., 2007a, b; GROSS, 2015).

Geographic distribution: Occurs practically in the entire Eastern Styrian Basin (at least subsurface); at the surface it crops out especially in the area of Graz, Gleisdorf, Hartberg, Bad Tatzmannsdorf, Kirchbach, Gnas, Straden, St. Anna am Aigen; ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4112 Bad Radkersburg, 4224 Hartberg, 4229 Graz, 4230 Gleisdorf, 5101 Jennersdorf, 5219 Oberwart (ÖK50-BMN, map sheets 136 Hartberg, 137 Oberwart, 164 Graz, 165 Weiz, 166 Fürstenfeld, 190 Leibnitz, 191 Kirchbach in Steiermark, 192 Feldbach).

Remarks: HARZHAUSER & PILLER (2004a) emended the distribution area of the Gleisdorf Formation and used this term for the whole upper Sarmatian mixed-siliciclastic-oolitic sedimentary sequence of the Styrian Basin (as already discussed by FRIEBE, 1994a). Nevertheless, these authors consider only the Waltra Member of FRIEBE (1994a) as a valid unit due to the original inclusion of Pannonian gravels in the definition of the Löffelbach Member. Furthermore, the inclusion of lower Sarmatian bryozoan-serpulid biostromes ("Grafenberg Member") and fine siliciclastics ("Rollsdorf Member") into the Gleisdorf Formation is refused by HARZHAUSER & PILLER (2004a). The lower Sarmatian "Grafenberg Member" and "Rollsdorf Member" of FRIEBE (1994a, b) are raised to independent formations by these authors (see description of these formations herein). According to HARZHAUSER & PILLER (2004a) only the Waltra and the redefined Löffelbach Member belong to the upper Sarmatian Gleisdorf Formation. In the area of Graz the carbonate content of the Gleisdorf Formation is strongly reduced, which led to the introduction of two additional members (Lustbühel Member, Peterstal Member) by GROSS (2015; see descriptions of these members below).

Complementary references: FUCHS (1980c), PILLER et al. (2004).

Waltra-Subformation (Gleisdorf-Formation) / Waltra Member (Gleisdorf Formation)

MARTIN GROSS

Validity: Valid; introduced by FRIEBE (1994a).

Type area: Region around St. Anna am Aigen, c. 48 km SE of Graz (FRIEBE, 1994a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Type section: Section in a ditch immediately N of the village Waltra (N 46°51′10″ / E 15°57′33″), c. 2.3 km NW of the market town St. Anna am Aigen, c. 46 km SE of Graz (FRIEBE, 1994a; compare HARZHAUSER & PILLER, 2004a and Gleisdorf Formation); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Reference section(s): Section(s) in the ditch of the Pogergraben (N 46°51′08″ / E 15°58′10″), c. 1.9 km NNW St. Anna am Aigen, c. 5.5 km SE Bad Gleichenberg (FRIEBE, 1994a; compare Gleisdorf Formation); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Derivation of name: After the village Waltra (municipality St. Anna am Aigen), c. 12.5 km SE of the town Feldbach, c. 46 km SE of the city Graz, Styria.

Synonyms: (partim) Obersarmatische Schichten (WINKLER, 1913a), (partim) Obersarmat (WINKLER, 1927b), (partim) Obere sarmatische Schichten (WINKLER-HERMADEN, 1943), [Obersarmat] mittlere fossilreiche Serie, mittlere[s] fossilreiche[s] Schichtpaket (KOLLMANN, 1965).

Lithology: Mixed-siliciclastic-carbonatic sediments; cyclic succession of massive to laminated silt, ripple bedded silt–sand-alternation, massive to laminated sand and oolite (FRIEBE, 1994a, b; HARZHAUSER & PILLER, 2004a).

Fossils: Plant remains, various gastropods and bivalves, foraminifers (e.g., *Prosononion granosum*) and ostracods (e.g., WINKLER, 1913a, b, 1927a, b; PAPP, 1954; KOLLMANN, 1965; FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a).

Origin, facies: Shallow marine, normal- to hypersaline (PILLER & HARZHAUSER, 2005).

Chronostratigraphic age: Middle Miocene, late Serravallian (late Sarmatian).

Biostratigraphy: Regional mollusc zone: Upper *Ervilia* Zone and *Sarmatimactra* Zone, regional foraminifera zone: *Porosononion granosum* Zone (FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a).

Thickness: More than 20 m, possibly up to 190 m (KOLLMANN, 1965; FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a, b).

Lithostratigraphically higher rank unit: Gleisdorf Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Carinthian Gravel (FRIEBE, 1994a).

Overlying unit(s): Feldbach Formation (FRIEBE, 1994a) or Löffelbach Member of the Gleisdorf Formation (HARZHAUSER & PILLER, 2004a).

Lateral unit(s): See Gleisdorf Formation.

Geographic distribution: Region around St. Anna am Aigen, Bad Gleichenberg, Gnas and S of Feldbach and Paldau (WINKLER, 1927a, b); ÖK50-UTM, map sheets 4106 Feldbach, 5101 Jennersdorf (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach).

Remarks: -

Complementary references: FUCHS (1980c), EBNER & SACHSENHOFER (1991).

Löffelbach-Subformation (Gleisdorf-Formation) / Löffelbach Member (Gleisdorf Formation)

MARTIN GROSS

Validity: Valid; introduced by FRIEBE (1994a); modified by HARZHAUSER & PILLER (2004a).

Type area: Area around the villages Löffelbach and Schildbach, W of the town Hartberg, c. 44 km NE Graz (FRIEBE, 1994a); ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheet 136 Hartberg).

Type section: Abandoned limestone quarry and sand pit Löffelbach (N 47°16′17″ / E 15°56′16″), c. 2.6 km SW Hartberg, c. 44 km NE Graz (FRIEBE, 1994a; compare NEBERT, 1985: outcrop number 187); ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheet 136 Hartberg).

Reference section(s): Abandoned and revegetated quarries of Schildbach (FRIEBE, 1994a; compare NEBERT, 1951; WINKLER VON HERMADEN, 1952).

Derivation of name: After the village Löffelbach (municipality Hartberg Umgebung), c. 2.7 km WSW of the town Hartberg, c. 44 km NE of the city Graz, Styria.

Synonyms: (partim) calcareous formation (SEDGWICK & MURCHISON, 1831), Sarmatische Stufe (HILBER, 1895), Sarmat südwestlich von Hartberg (BRANDL, 1931), Schichten von Hartberg und Schildbach, […] (KOLLMANN, 1965), Erster Sedimentationszyklus des Sarmatien (NEBERT, 1985). For a more detailed listing, see FRIEBE (1994a).

Lithology: Marly limestone with only scattered ooids, laminated silt and fine sand, ripple and cross-bedded sand (FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a).

Fossils: Ichnofossils, foraminifers, various gastropods and bivalves, ostracods, fish and mammal remains (e.g., HILBER, 1892, 1895; BRANDL, 1931; NEBERT, 1951, 1985; MOTTL, 1958a; FRIEBE, 1994a).

Origin, facies: Fluvial-deltaic and shallow marine (FRIEBE, 1994a).

Chronostratigraphic age: Middle Miocene, late Serravallian (late Sarmatian).

Biostratigraphy: Regional mollusc zone: *Sarmatimactra* Zone, regional foraminifera zone: *Porosononion granosum* Zone (FRIEBE, 1994a; HARZHAUSER & PILLER, 2004a).

Thickness: More than 10 m (NEBERT, 1951; HARZHAUSER & PILLER, 2004a).

Lithostratigraphically higher rank unit: Gleisdorf Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Waltra Member (Gleisdorf Formation) (HARZHAUSER & PILLER, 2004a; compare WINKLER VON HERMADEN, 1952).

Overlying unit(s): Feldbach Formation and Paldau Formation (FRIEBE, 1994a; GROSS, 2003a).

Lateral unit(s): See Gleisdorf Formation.

Geographic distribution: Type area and region around St. Anna am Aigen; ÖK50-UTM, map sheets 4106 Feldbach, 4224 Hartberg (ÖK50-BMN, map sheets 136 Hartberg, 192 Feldbach).

Remarks: -

Complementary references: FUCHS (1980c), EBNER & SACHSENHOFER (1991).

Peterstal-Subformation (Gleisdorf-Formation) / Peterstal Member (Gleisdorf Formation)

MARTIN GROSS

Validity: Valid; introduced by FLÜGEL (1997) as Peterstal-Formation; formalized as Peterstal-Subformation by GROSS (2015; compare GROSS et al., 2007b).

Type area: Eastern Gratkorn Basin and area of the city Graz, E of the Mur river; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz; GROSS, 2015).

Type section: About 15 m thick section in the St. Stefan (also called Gratkorn) clay pit (N 47°08′14″ / E 15°20′56″), c. 0.7 km E of the market town Gratkorn, c. 10 km NNW of the city Graz, where the lower boundary to the underlying Gratkorn Formation was exposed (e.g., GROSS et al., 2011b, 2014; GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz.

Reference section(s): -

Derivation of name: After the valley of the Petersbach, a brook in the 8. city district (St. Peter) of Graz, c. 4.2 km ESE of the city centre of Graz, Styria.

Synonyms: (partim) untere Süßwasserschichten (HILBER, 1893), (partim) Gleisdorfer Schichten mit limnischen Ostracoden (KOLLMANN, 1965), Peterstal-Formation (FLÜGEL, 1997), Peterstal Member (GROSS et al., 2007b). For a more detailed list, see GROSS (2015).

Lithology: Grey, frequently laminated or massive pelite, subordinately sand and gravel layers (GROSS, 2015).

Fossils: Plant remains, molluscs, insects, freshwater crabs, ostracods, fish remains (e.g., HILBER, 1893; KNOLL, 1902; CLAR, 1927; KOLLMANN, 1965, GROSS et al., 2007b, 2011b, 2014; GROSS, 2008; KLAUS & GROSS, 2010; HABLY & MELLER, 2017; GEIER et al., 2022) and, probably, rhinoceratid, suid and bovid remains (GROSS, 2015).

Origin, facies: Limnic (freshwater), in part with fluvial-deltaic influx (GROSS, 2015).

Chronostratigraphic age: Middle Miocene, late Serravallian (late Sarmatian).

Biostratigraphy: -

Thickness: Variable; about 5–25 m (GROSS, 2015).

Lithostratigraphically higher rank unit: Gleisdorf Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Gratkorn Formation or Rollsdorf Formation (GROSS, 2015).

Overlying unit(s): Lustbühel Member (Gleisdorf Formation) (GROSS, 2015).

Lateral unit(s): See Gleisdorf Formation.

Geographic distribution: Corresponds to the type area.

Remarks: The predominantly pelitic Peterstal Member is underlain by coarse clastics of the Gratkorn Formation. Where these gravels are missing (e.g., in the city area of Graz), the differentiation to the also largely pelitic Rollsdorf Formation is difficult (GROSS, 2015). While KOLLMANN (1965) attributed the deposits of the Peterstal Member to the uppermost Sarmatian, GROSS et al. (2007b) placed them into the basal upper Sarmatian (corresponds biostratigraphically to the regional mollusc zone: Upper *Ervilia* Zone; compare GROSS, 2015).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Lustbühel-Subformation (Gleisdorf-Formation) / Lustbühel Member (Gleisdorf Formation)

MARTIN GROSS

Validity: Valid; introduced by FLÜGEL (1997) as Lustbühel-Formation; formalized as Lustbühel-Subformation by GROSS (2015; compare GROSS et al., 2007b).

Type area: Area of the city Graz, E of the Mur river; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz; GROSS, 2015).

Type section: Log of a drilling in the abandoned and backfilled brickyard Eustacchio (N 47°03′40″ / E 15°28′30″) in the 8. city district (St. Peter) of Graz, c. 3 km SE of the city centre of Graz (GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz.

Remark: The Lustbühel Member is frequently exposed due to construction works; however, thicker, well-documented sections are missing (Flügel, 1997; Gross et al., 2007b). For this reason, Gross (2015) selected this drilling, described in Flügel (1997), as type section.

Reference section(s): Section roughly described by Winkler-Hermaden (1957) from the abandoned brickyard Wolf (N 47°05′55″ / E 15°26′11″) in the 12. city district (Andritz) of Graz, c. 3 km N of the city centre of Graz, where the boundary between the Lustbühel Member to the underlying Peterstal Member was exposed (Gross et al., 2007b; Gross, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz.

Derivation of name: After the Lustbühel castle in the 9. city district (Waltendorf) of Graz, c. 4.2 km E of the city centre of Graz, Styria (Gross, 2015).

Synonyms: (partim) Untermiozäne Süßwasserschichten (Clar, 1927), (partim) Fossilführende Schichten von Spillerhof [Spielerhof] bei Raaba (Kollmann, 1965), Ton/Sand/Kies-Wechselfolge (Untersweg, 1986), Lustbühel-Formation (Flügel, 1997), Lustbühel Member (Gross et al., 2007b).

Lithology: Alternations of yellowish-grey, massive or cross-bedded gravel and sand and massive or laminated pelite; very rare occurrences of thin oolite layers (Gross et al., 2007b; Gross, 2015).

Fossils: Rare; plant remains, foraminifers, molluscs, ostracods (Gross et al., 2007b) and, probably, rhinoceratid and proboscidean remains (Gross, 2015).

Origin, facies: Marginal marine with fluvial influx (Gross, 2015).

Chronostratigraphic age: Middle Miocene, late Serravallian (late Sarmatian).

Biostratigraphy: Regional foraminifera zone: *Porosononion granosum* Zone (Gross et al., 2007b).

Thickness: Variable; about 20–40 m (Flügel, 1997; Gross et al., 2007b).

Lithostratigraphically higher rank unit: Gleisdorf Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Peterstal Member (Gleisdorf Formation); if no differentiation in Lustbühel and Peterstal Member is possible: the Gratkorn Formation or Rollsdorf Formation (Gross, 2015).

Overlying unit(s): Ries Formation (Gross, 2015).

Lateral unit(s): See Gleisdorf Formation.

Geographic distribution: Corresponds to the type area.

Remarks: The Lustbühel Member comprises the upper Sarmatian mixed-siliciclastic deposits, which are encountered frequently at the hills in the eastern city area of Graz. Due to pelitic intercalations in its basal proportions and gravel layers in its upper part a differentiation to the underlying Peterstal Member and the overlying Ries Formation remains difficult (Gross et al., 2007b; Gross, 2015).

Complementary references: Flügel (1975c), Gross et al. (2011b, 2014).

Kohleführende Schichten von Weiz / Coal-bearing beds of Weiz

Martin Gross

Validity: Invalid; name introduced by Flügel (1961).

Type area: Weiz embayment at the northern margin of the Eastern Styrian Basin, c. 23.5 km NE of the city Graz, Styria; ÖK50-UTM, map sheets 4223 Weiz, 4224 Hartberg, 4229 Graz, 4230 Gleisdorf (ÖK50-BMN, map sheet 165 Weiz).

Type section: -

Remark: The outcrop at the cut bank of the Ilzbach (N 47°12′54″ / E 15°41′27″), c. 5.1 km E of the town Weiz, as described by Krainer (1987a), could be proposed as type section.

Reference section(s): -

Remark: As reference sections might serve the localities “Pichl” (N 47°11′49″ / E 15°40′30″), c. 4.5 km SE of the town Weiz and “Höllgraben” (N 47°10′51″ / E 15°41′17″), c. 6 km SE of the town Weiz, described in Krainer (1987a) and Kovar-Eder & Krainer (1988).

Derivation of name: Named after the characteristic lithology and the town of Weiz, c. 21.4 km NE of the city Graz, Styria.

Synonyms: (partim) kohleführenden Tegelgebilde (Rolle, 1856; compare Andrae, 1854), (partim) unteren Süsswasserschichten am Gebirgsrand zwischen Graz und dem Kulm (Hilber, 1893), (partim) grundgebirgsnahe unterpannone Süßwasserschichten (Hübl, 1942), obere [und untere] Lignitniveau östlich von Weiz (Winkler-Hermaden, 1957), Untere [und Obere] Kohleführende Schichten von Weiz (Flügel, 1961), Untere [und Obere] Kohleführende Serie von Weiz (Kollmann, 1965), Kohleführenden Schichten von Weiz (Krainer, 1987a), Lower [and Upper] coal-bearing Beds of Weiz (Gross et al., 2007a).

Lithology: Alternations of massive or laminated pelite and ripple- and cross-bedded sand with intercalated brown coal seams, sporadic marl(stone), freshwater limestone (close to the basement) and quartz-dominated gravel layers (in more distal position; Krainer, 1987a). For coal mining history, see Weber & Weiss (1983).

Fossils: Plant remains (pollen, leaves), foraminifers (rare), ostracods, gastropods, bivalves, fish and proboscidean remains (e.g., Andrae, 1854; Hoernes, 1880b; Granigg, 1910; Hilber, 1893, 1915a; Winkler von Hermaden, 1951; Flügel & Maurin, 1957; Flügel, 1961, 1975a; Mottl, 1970; Krainer, 1987a; Kovar-Eder & Krainer, 1988).

Origin, facies: Limnic (brackish) to fluvial (fluvial coastal plain; Krainer, 1987a).

Chronostratigraphic age: Middle Miocene, late Serravallian (late Sarmatian) to late Miocene, Tortonian (early Pannonian) (Flügel, 1961, 1975a; Krainer, 1987a).

Biostratigraphy: Regional mollusc Zone “A/B” (*Melanopsis impressa*/*Mytilopsis ornithopsis* Zone Krainer, 1987a; Kovar-Eder & Krainer, 1988) only documented for the “Upper” Coal-bearing beds of Weiz sensu Flügel (1961).

Thickness: More than 140 m, probably 200–300 m (Krainer, 1987a).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informal; traditionally subdivided into the "Lower" (upper Sarmatian) and "Upper" (lower Pannonian) Coal-bearing beds of Weiz (e.g., Winkler-Hermaden, 1957; Flügel, 1961, 1975a; Kollmann, 1965). Krainer (1987a) differentiated the sediments above ground in a "lower" (greyish; gravel lacking; more limnic) and an "upper" (yellowish-grey; with gravel; more fluvial) package. Both packages are separated by gravelly channel fillings, cross-bedded sand or fossil-rich calcareous marl and are of Pannonian age.

Underlying unit(s): Directly upon the basement (Krainer, 1987a); possibly also the Rollsdorf Formation (Krainer, 1989b) and Gleisdorf Formation (or an equivalent; Granigg, 1910; Kollmann, 1965).

Overlying unit(s): Quaternary sediments; possibly also Puch Gravel (Krainer, 1987a, 1989b).

Lateral unit(s): The Puch Gravel (Krainer, 1987a), the Gleisdorf Formation (for the "Lower" Coal-bearing beds of Weiz) as well as the Kleinsemmering Formation and the Feldbach Formation (for the "Upper" Coal-bearing beds of Weiz) are considered as possible lateral equivalents (e.g., Kollmann, 1965; Flügel, 1997; Gross, 2003a, 2015).

Geographic distribution: Corresponds to the type area including the coal mines of Oberdorf bei Thannhausen (also "Oberdorf bei Weiz"; Petrascheck, 1922/1924; Winkler von Hermaden, 1951; Weber & Weiss, 1983; Krainer, 1987a).

Remarks: -

Complementary references: Fuchs (1980c), Tollmann (1985), Ebner & Sachsenhofer (1991).

Pucher Schotter / Puch Gravel

Martin Gross

Validity: Invalid; name introduced by Krainer (1984, 1987a).

Type area: Weiz embayment at the northern margin of the Eastern Styrian Basin, c. 24 km NE Graz (Krainer, 1987a); ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheets 135 Birkfeld, 165 Weiz).

Type section: -

Remark: The abandoned sand pit "Hohenilz" (N 47°14′18″ / E 15°41′45″), c. 2.7 km NW of the village Puch bei Weiz, c. 6 km ENE of the town Weiz, could be selected as type section.

Reference section(s): -

Remark: The abandoned gravel pit "Puch" (N 47°13′23″ / E 15°43′02″), c. 0.6 km WSW of the village Puch bei Weiz, may act as reference section described in Krainer (1987a).

Derivation of name: Named after the village Puch bei Weiz, c. 7.8 km E of the town Weiz, c. 28 km NE of the city Graz, Styria.

Synonyms: (partim) Feinkiese und Sande von Hohenilz (Flügel, 1961), Pucher Schotterfolge (Krainer, 1984), Pucher Schotter (Krainer, 1987a), Puch Gravel (Ebner & Sachsenhofer, 1995), ?Puch-Fm (Gross, 2003a), Puch Gravels (Gross et al., 2007a).

Lithology: Alternations of massive, cross- or horizontally bedded gravel and sand (subordinately ripple- or horizontally bedded sand and laminated pelite/fine sand successions); predominantly quartz components; towards the basement increase in grain size (up to boulder gravels), pelitic matrix and gneiss components (Krainer, 1987a, b).

Fossils: Rare, coaly plant fragments.

Origin, facies: Prograding alluvial fan with clear proximal–distal differentiation, ranging from debris flows (proximal) to braided channel and sheet flood deposits (Krainer, 1987a, b).

Chronostratigraphic age: Middle Miocene, Serravallian (late Sarmatian) to late Miocene, Tortonian (early Pannonian) (Krainer, 1987a, b).

Biostratigraphy: -

Thickness: Up to 250 m (Krainer, 1987a, b).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided in "proximal and middle fan" and "distal fan" (Krainer, 1987a).

Underlying unit(s): Crystalline and Paleozoic basement or basal "Kristalliner Blockschutt" or Rollsdorf Formation (Krainer, 1987a, b).

Overlying unit(s): Quaternary sediments (alluvium, alluvial fan and talus deposits; Krainer, 1987a).

Lateral unit(s): The lower Pannonian Paldau Formation and Ries Formation, the upper Sarmatian Gleisdorf Formation, the Coal-bearing beds of Weiz and the "Grobschotter von Trog" (Flügel, 1961; Krainer, 1987a, b; Gross, 2003a, 2015; Schuster et al., 2016).

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: -

Feldbach-Formation / Feldbach Formation

Martin Gross

Validity: Valid; name introduced by Sauerzopf (1950); established as formation by Gross (1999); described and formalized by Gross (2003a; compare Gross, 2000).

Type area: Region S of the town Feldbach and the market town Paldau, c. 30 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach).

Type section: Section (c. 16 m thick) in the ditch of the brook Eisengrabenbach (N 46°56′31″ / E 15°51′55″) with the lower boundary to the Gleisdorf Formation exposed (Gross, 2003a), c. 2.3 km SW Feldbach, c. 35 km SE Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Remark: Acts also as type section for the Eisengraben Member (GROSS, 2003a).

Reference section(s): Section (acre bank close to the farmstead "Grabenhof") GR 24 (N 46°55′56″ / E 15°48′49″), c. 1.6 km SE Paldau, c. 6.2 km WSW Feldbach, where the upper boundary to the Paldau Formation (Kapfenstein Member) was exposed (GROSS, 2003a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: The Mataschen clay pit (N 46°54′15″ / E 15°57′16″), c. 2.4 km NW Kapfenstein, c. 7.5 km SE Feldbach, where the lower boundary to the Gleisdorf Formation and the upper boundary to the Paldau Formation (Mayerhanselberg Member) is at least sporadically exposed, has been considered by GROSS (2004b) as reference section.

Derivation of name: After the town Feldbach, c. 30 km SE Graz, Styria.

Synonyms: (partim) Inzersdorfer Schichten (STOLICZKA, 1863), Congerienschichten (HOERNES, 1878), (partim) Unterpontikum (WINKLER, 1927b), Schichten von Feldbach (SAUERZOPF, 1950), (partim) Zone B des Unterpannons (KOLLMANN, 1965). For a detailed list, see GROSS (2003a).

Lithology: Grey, massive or laminated silt/clay to marl, frequently with mass occurrences of dreissenid bivalves; up section successively increase in ripple-, cross- or horizontal bedded (fine-)sand layers, leading to dm-thick pelite-sand-alternations; sporadically stub horizons and thin lignite seams (GROSS, 1998a, 2003a).

Fossils: Plant remains (pollen, diaspores, leaves), calcareous nannoplankton, dinoflagellates, gastropods (e.g., melanopsids), bivalves (e.g., dreissenids, *Mytilopsis ornithopsis*), ostracods (e.g., candonids, cytherideids, loxoconchids, hemicytherids), insects, vertebrates (fish remains, amphibians, reptilians (turtles), birds, mammals (div. fam.) (e.g., HOERNES, 1878; HILBER, 1893; STINY, 1924; WINKLER, 1927a, b; SAUERZOPF, 1950, 1952; KOLLMANN, 1960a, 1965; FLÜGEL & HERITSCH, 1968; MOTTL, 1970; NEBERT, 1985; FRIEBE, 1994a; GROSS, 1994, 1997, 2000, 2004a, cum lit.; KOVAR-EDER & HABLY, 2006; GROSS et al., 2008a, b, 2011a; ENGEL & GROSS, 2008; KERN et al., 2012a; SOLIMAN et al., 2013; GITTER et al., 2015).

Origin, facies: Limnic-deltaic (brackish; GROSS, 2003a; GROSS et al., 2011a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "B" (*Mytilopsis ornithopsis* Zone; GROSS, 2004a; GROSS et al., 2011a).

Thickness: 30–50 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Eisengraben Member (lower, mainly pelitic part), Sieglegg Member (upper, pelitic to sandy part) (GROSS, 2003a).

Underlying unit(s): Gleisdorf Formation (GROSS, 2003a).

Overlying unit(s): Paldau Formation; erosional boundary (GROSS, 2003a).

Lateral unit(s): The "Upper" Coal-bearing beds of Weiz and the Kleinsemmering Formation are considered as possible lateral equivalents (e.g., KOLLMANN, 1965; GROSS, 2003a, 2015).

Geographic distribution: Occurs practically in the entire Eastern Styrian Basin (at least subsurface); at the surface it crops out especially in the area from Kirchbach to Feldbach to St. Anna am Aigen, in the region of Gleisdorf, Markt Hartmannsdorf and Sinabelkirchen, in the area of Hartberg and Bad Tatzmannsdorf (KOLLMANN, 1965; GROSS, 2003a); ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4224 Hartberg, 4230 Gleisdorf, 5219 Oberwart (ÖK50-BMN, map sheets 136 Hartberg, 137 Oberwart, 165 Weiz, 166 Fürstenfeld, 191 Kirchbach in Steiermark, 192 Feldbach).

Remarks: The Feldbach Formation was introduced by GROSS (1999, 2000) and later on formalized (GROSS, 2003a) as homage to the "Schichten von Feldbach" of SAUERZOPF (1950) and the location of the type section in order to replace lithostratigraphically invalid terms like "Congerienschichten" or "Zone B des Unterpannons". Equivalent strata in the Pöllau and Friedberg-Pinkafeld embayments (KOLLMANN, 1965; PAHR, 1984; NEBERT, 1985; FRIEBE, 1994a), which were originally not formally assigned to the Feldbach Formation, are integrated in this formation here. For more details see GROSS (2000, 2003a).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Eisengraben-Subformation (Feldbach-Formation) / Eisengraben Member (Feldbach Formation)

MARTIN GROSS

Validity: Valid; name introduced by GROSS (1999); described and formalized by GROSS (2003a; compare GROSS, 2000).

Type area: Region S of the town Feldbach and the market town Paldau, c. 30 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach).

Type section: Section (c. 16 m thick) in the ditch of the brook Eisengrabenbach (N 46°56′31″ / E 15°51′55″) with the lower boundary to the Gleisdorf Formation exposed (GROSS, 2003a), c. 2.3 km SW Feldbach, c. 35 km SE Graz (compare Feldbach Formation); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Reference section(s): -

Remark: The Mataschen clay pit (N 46°54′15″ / E 15°57′16″), c. 2.4 km NW Kapfenstein, c. 7.5 km SE Feldbach, might act as reference section. There, the lower boundary to the Gleisdorf Formation and the upper boundary to the Sieglegg Member (Feldbach Formation) is at least temporarily exposed (GROSS, 2004b).

Derivation of name: After the ditch of the brook Eisengrabenbach, c. 2 km SW Feldbach, Styria.

Synonyms: Congerientegel (WINKLER, 1913a), tiefere[s] Schichtpaket der Zone B (KOLLMANN, 1965). For a detailed list, see GROSS (2003a).

Lithology: Grey, massive or laminated silt/clay to marl, frequently with mass occurrences of dreissenid bivalves; up section successively increase of grey (fine-)sand layers.

Fossils: Plant remains, calcareous nannoplankton, dinoflagellates, gastropods (e.g., melanopsids), bivalves (e.g., dreissenids, *Mytilopsis ornithopsis*), ostracods (e.g., cytherideids, loxoconchids, hemicytherids), insects, vertebrates (fish remains, amphibians, reptilians (turtles), birds, mammals (div. fam.) (e.g., HOERNES, 1878; HILBER, 1893; STINY, 1924; WINKLER, 1927a, b; SAUERZOPF, 1950, 1952; KOLLMANN, 1960a, 1965; FLÜGEL & HERITSCH, 1968; MOTTL, 1970; NEBERT, 1985; FRIEBE, 1994a; GROSS, 1994, 1997, 1998c, 2000, 2004a, cum lit.; GROSS et al., 2008a, b, 2011a; ENGEL & GROSS, 2008; KERN et al., 2012a; SOLIMAN et al., 2013; GITTER et al., 2015).

Origin, facies: Limnic (brackish; GROSS, 2003a; GROSS et al., 2011a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "B" (*Mytilopsis ornithopsis* Zone) (GROSS, 2004a; GROSS et al., 2011a).

Thickness: 10–20 m (GROSS, 2003a).

Lithostratigraphically higher rank unit: Feldbach Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Gleisdorf Formation (GROSS, 2003a).

Overlying unit(s): Sieglegg Member (Feldbach Formation) (GROSS, 2003a).

Lateral unit(s): See Feldbach Formation.

Geographic distribution: See Feldbach Formation.

Remarks: The boundary between the Eisengraben Member and the Sieglegg Member has been defined by the "first occurrence of thicker, sandy intercalations" (GROSS, 2003a: p. 25), which could not be shown by a section in the original definition of these members. However, the herein proposed reference section at the Mataschen clay pit exposes this boundary (GROSS, 2004b).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Sieglegg-Subformation (Feldbach-Formation) / Sieglegg Member (Feldbach Formation)

MARTIN GROSS

Validity: Valid; name introduced by GROSS (1999); described and formalized by GROSS (2003a; compare GROSS, 2000).

Type area: Region S of the town Feldbach and the market town Paldau, c. 30 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach).

Type section: About 23 m thick section ED 17–18 (N 46°55′15″ / E 15°48′05″) in a side ditch of the brook Edelsbrunngrabenbach, c. 2.3 km SSE of the market town Paldau, c. 7.7 km SW of the town Feldbach; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: At the type section only the upper boundary to the Paldau Formation (Mayerhanselberg Member) is exposed (GROSS, 2003a).

Reference section(s): -

Remark: The Mataschen clay pit (N 46°54′15″ / E 15°57′16″), c. 2.4 km NW Kapfenstein, c. 7.5 km SE Feldbach, can be considered as reference section as already proposed by GROSS (2003a). There, the lower boundary to the Eisengraben Member and the upper boundary to the Paldau Formation (Mayerhanselberg Member) are exposed (GROSS, 2004b).

Derivation of name: After the hamlet Sieglegg (municipality Paldau), c. 2.3 km SSE Paldau, c. 32 km SE Graz, Styria.

Synonyms: Höhere[s] Schichtpaket der Zone B (KOLLMANN, 1965).

Lithology: Grey, laminated fine sand to silt, alternating in dm-scale with grey or yellowish/orange (fine-)sand; up section increase in thickness of the layers consisting of ripple-, cross- or horizontal bedded fine sand and greyish, massive to laminated silt/fine sand, frequently coaly plant remains and thin lignite seams especially in the upper part (GROSS, 1997, 1998a, 2003a).

Fossils: Frequently plant remains (pollen, diaspores, leaves), rare ostracod remains (e.g., candonids, cytherideids, loxoconchids) (KOLLMANN, 1965; GROSS, 2004b; MELLER & HOFMANN, 2004; GROSS et al., 2008b, 2011a; KOVAR-EDER & HABLY, 2006).

Origin, facies: Limnic-deltaic (slightly brackish) (GROSS et al., 2011a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "B" (*Mytilopsis ornithopsis* Zone) (GROSS, 2004a; GROSS et al., 2011a).

Thickness: 20–30 m (GROSS, 2003a).

Lithostratigraphically higher rank unit: Feldbach Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Eisengraben Member (Feldbach Formation) (GROSS, 2003a).

Overlying unit(s): Paldau Formation (GROSS, 2003a).

Lateral unit(s): See Feldbach Formation.

Geographic distribution: See Feldbach Formation.

Remarks: Due to new fossil finds (especially of *Mytilopsis hoernesi*) (STRAHLHOFER, 2009) the deposits cropping out at the cut banks of the Feistritz river near Maierhofen and Altenmarkt bei Fürstenfeld, W of the town Fürstenfeld (locality named also "Buchberge" or "Unterbuchberg"; WINKLER, 1921, 1927b; SAUERZOPF, 1950, 1952; KOLLMANN, 1965) belong biostratigraphically to the regional mollusc Zone "C". Hence, these limnic-deltaic sediments and, possibly, the "Kalsdorfer Schichten" (KOLLMANN, 1939, 1965; SAUERZOPF, 1952), c. 5.5 km NW Unterbuchberg, c. 9.7 km NW Fürstenfeld, can be considered as lateral, more distal and much thicker equivalent of the Münzengraben Bed (Mayerhanselberg Member, Paldau Formation) and does not belong to the Sieglegg Member (GROSS, 2003a).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Kleinsemmering-Formation / Kleinsemmering Formation

MARTIN GROSS

Validity: Valid; most recently investigated by MOSER (1986); name introduced by FLÜGEL (1997); described and formalized as formation by GROSS (2015).

Type area: In the area of the villages Wenisbuch, Niederschöckl, Kumberg and Kleinsemmering, c. 6–17 km NE of the city centre of Graz at the northwestern margin of the Eastern Styrian Basin (GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Type section: Section Hofmühle (c. 38 m thick; N 47°10′19″ / E 15°31′25″) in a ditch of a NE–SW-trending tributary of the Rabnitz, c. 1.5 km NW Kumberg, c. 12.9 km NE of the city centre of Graz (HÜBL, 1942; MOSER, 1986; GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Remark: Acts also as type section for the Hofmühle Member. Neither the lower nor the upper boundary of the Kleinsemmering Formation is exposed.

Reference section(s): As reference act the type and reference sections of the Hofmühle Member and Gstauda Member (GROSS, 2015).

Derivation of name: Named after the village Kleinsemmering (municipality Gutenberg-Stenzengreith), c. 4.5 km SW of the town Weiz, c. 17 km NE Graz, Styria.

Synonyms: (partim) Braunkohlen des oberen Tegels [Congerienschichten] (STUR, 1855), (partim) lacustre[…] Miocaenschichten (HILBER, 1893), (partim) Untermiozäne Süßwasserschichten (HERITSCH, 1921), (partim) kohlenführende […] Serie von Klein-Semmering (KOLLMANN, 1965), kohlenführende Schichten von Weinitzen, Niederschöckl, Kumberg, Gschwendt und Klein-Semmering (EBNER, 1983a).

Lithology: Laterally and vertically variable; alternation of grey to brown or yellowish, laminated or massive silt and (fine) sand; dark-grey, coal-rich pelite; grey, marl and marly limestone; partly cross-bedded sand and rare debrite intercalations; brown coal seams (MOSER, 1986). For details of coal-mining see WEBER & WEISS (1983) and MOSER (1986). Further information on grain size, heavy mineral and coal petrological analyses in MOSER (1986).

Fossils: Rare, except plant remains; characean gyrogonites, gastropods, bivalves, ostracods, fish remains (UNGER, 1849; ANDRAE, 1854; ETTINGSHAUSEN, 1893; HILBER, 1893; HÜBL, 1942; MOSER, 1986).

Origin, facies: Deltaic to limnic (brackish) deposits (MOSER, 1986).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zones "B/C" (*Mytilopsis ornithopsis/hoernesi* Zones; MOSER, 1986).

Thickness: Variable; probably more than 40 m (MOSER, 1986).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Completely subdivided in the Hofmühle Member (lower, silty–fine sandy part with brown coal) and Gstauda Member (upper, silty–sandy part with marl and marly limestone) (GROSS, 2015).

Underlying unit(s): Weathered basement and red earth (HÜBL, 1942; FLÜGEL, 1975a; EBNER, 1983b; MOSER, 1986).

Overlying unit(s): Ries Formation, with erosive base; in part covered by Quaternary terrace sediments and loam on planation surfaces.

Lateral unit(s): Toward the E and SE the "Upper" Coal-bearing beds of Weiz (FLÜGEL, 1975a, 1997) and the Feldbach Formation (GROSS, 2003a, 2015).

Geographic distribution: Corresponds to the type area.

Remarks: MOSER (1986; compare HÜBL, 1942) suggested a transition of delta plain deposits (Hofmühle Member) towards the open basin into delta front, prodelta and limnic sediments (Gstauda Member). Index fossils are largely lacking in the Kleinsemmering Formation. Only at the sections Gschwendt (Hofmühle Member) and Gschwendt-Kleinsemmering (Gstauda Member) the found ostracods indicate an early Pannonian age (regional mollusc Zone "B/C", MOSER, 1986; most probably Zone "B"). The mentioned finds of Sarmatian molluscs (WINKLER, 1913b; CLAR, 1927; WINKLER VON HERMADEN, 1951; WINKLER-HERMADEN, 1957) within the Kleinsemmering Formation remain unconfirmed. For more details see MOSER (1986) and GROSS (2015).

Complementary references: FUCHS (1980c), EBNER & SACHSENHOFER (1991).

Hofmühle-Subformation (Kleinsemmering-Formation) / Hofmühle Member (Kleinsemmering Formation)

MARTIN GROSS

Validity: Valid; described and formalized by GROSS (2015).

Type area: Corresponds to the type area of the Kleinsemmering Formation.

Type section: Section Hofmühle; c. 38 m thick (N 47°10′19″ / E 15°31′25″), in a ditch of a NE–SW-trending tributary of the Rabnitz, c. 1.5 km NW Kumberg, c. 12.9 km NE of the city centre of Graz (HÜBL, 1942; MOSER, 1986; GROSS, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Remark: Acts also as type section for the Kleinsemmering Formation. Neither the lower nor the upper boundary of the Hofmühle Member is exposed in the type and reference sections.

Reference section(s): The sections Wenisbuch (ditch SSW Wenisbuch; N 47°06′56″ / E 15°28′35″; c. 1.5 km NW Mariatrost), Hinterholzbachgraben (ditch SE Ebersdorf; N 47°09′58″ / E 15°30′54″; c. 1.6 km WNW Kumberg; compare HÜBL, 1942), Gschwendt (ditch NE Gschwendt; N 47°10′58″ / E 15°34′46″; 1 km SSE Kleinsemmering; compare HÜBL, 1942) and the section of the abandoned and recultivated loam pit Höf (N 47°08′11″ / E 15°29′31″; 1 km SW Niederschöckl), described by MOSER (1986) are indicated by GROSS (2015) as reference sections; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Derivation of name: After the farmstead Hofmühle (municipality Kumberg), c. 1.5 km NW of the market town Kumberg, Styria.

Synonyms: Untersarmatische Tone mit Cardien (HERITSCH, 1921), (partim) Unterpannone Feinsedimente (grundgebirgsnahe Fazies) (HÜBL, 1942), untere […] kohleführende Schichten von Weiz (WEBER & WEISS, 1983), Silte und Feinsande des ?Obersarmat/Unterpannon; kohleführende, grundgebirgsnahe Fazies (MOSER, 1986).

Lithology: Alternation of grey to yellowish, laminated or massive silt and fine sand; dark-grey, coal-rich pelite; partly cross-bedded sand; up to 2 m thick brown coal seams; rare and thin intercalations of unsorted crystalline debris with pelitic matrix; grey marl and marly limestone only at the transition to the Gstauda Member (section Gschwendt; MOSER, 1986). For details of coal-mining see WEBER & WEISS (1983) and MOSER (1986). Further information on grain size, heavy mineral and coal petrological analyses in MOSER (1986).

Fossils: Rare, except plant remains; gastropods, bivalves, ostracods, fish remains (UNGER, 1849; ANDRAE, 1854; ETTINGSHAUSEN, 1893; HILBER, 1893; HÜBL, 1942; MOSER, 1986).

Origin, facies: Variegated delta plain sediments (marsh, levee, crevasse splay, distributary channel, interdistributary bay but also debris flow deposits) (MOSER, 1986).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian) (MOSER, 1986).

Biostratigraphy: Regional mollusc Zones "B/C" (*Mytilopsis ornithopsis*/*hoernesi* Zones) (MOSER, 1986).

Thickness: Variable; probably more than 40 m (MOSER, 1986).

Lithostratigraphically higher rank unit: Kleinsemmering Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): See Kleinsemmering Formation.

Overlying unit(s): See Kleinsemmering Formation.

Lateral unit(s): The Gstauda Mb and, toward the E and SE, the "Upper" Coal-bearing beds of Weiz (FLÜGEL, 1975a, 1997) and the Feldbach Formation (GROSS, 2003a, 2015).

Geographic distribution: Corresponds to the type area of the Kleinsemmering Formation.

Remarks: -

Complementary references: -

Gstauda-Subformation (Kleinsemmering-Formation) / Gstauda Member (Kleinsemmering Formation)

MARTIN GROSS

Validity: Valid; described and formalized by GROSS (2015).

Type area: Corresponds to the type area of the Kleinsemmering Formation.

Type section: Section Gschwendt-Kleinsemmering, c. 29 m thick road cut (N 47°10′56″ / E 15°33′45″) at the hamlet Gstauda, c. 1.4 km SW Kleinsemmering, c. 15.6 km NE Graz (MOSER, 1986); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Remark: The section is not accessible anymore. Neither the lower nor the upper boundary were exposed.

Reference section(s): -

Derivation of name: After the hamlet Gstauda (municipality Kumberg), c. 1.4 km SW of the village Kleinsemmering, c. 15.6 km NE Graz, Styria.

Synonyms: (partim) Unterpannone sandige Tegel (Beckenfazies) (HÜBL, 1942), Silte und Feinsande des ?Obersarmat/Unterpannon; kohlefrei (MOSER, 1986).

Lithology: Alternations of grey to olive brown or yellowish, massive or laminated silt and (fine) sand; dark-grey, coal-rich pelite; grey marl and marly limestone; thicker coal seams are lacking (MOSER, 1986).

Fossils: Rare; plant remains, characean gyrogonites, gastropods, ostracods, fish remains (MOSER, 1986).

Origin, facies: Delta front, prodelta and limnic (brackish) deposits (MOSER, 1986).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian) (MOSER, 1986).

Biostratigraphy: Regional mollusc Zones "B/C" (*Mytilopsis ornithopsis*/*hoernesi* Zones; MOSER, 1986).

Thickness: Variable; probably more than 40 m (MOSER, 1986).

Lithostratigraphically higher rank unit: Kleinsemmering Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): See Kleinsemmering Formation.

Overlying unit(s): See Kleinsemmering Formation.

Lateral unit(s): The Hofmühle Member and, toward the E and SE, the "Upper" Coal-bearing beds of Weiz (FLÜGEL 1975a, 1997) and the Feldbach Formation (GROSS, 2003a, 2015).

Geographic distribution: Corresponds to the type area of the Kleinsemmering Formation.

Remarks: -

Complementary references: -

Paldau-Formation / Paldau Formation

MARTIN GROSS

Validity: Valid; name introduced by GROSS (1999); described and formalized by GROSS (2003a; compare GROSS, 2000).

Type area: Central Gnas and southern Fürstenfeld Subbasin of the Eastern Styrian Basin (GROSS, 2003a); ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4230 Gleisdorf, 5225 Fürstenfeld (ÖK50-BMN, map sheets 165 Weiz, 166 Fürstenfeld, 191 Kirchbach in Steiermark, 192 Feldbach).

Type section: Abandoned gravel pit "Monscheinkiesgrube" (N 46°56′17″ / E 15°48′37″), section BE 1-2, at the Wagenhoferberg, c. 1 km ESE of the market town Paldau, c. 31 km SE of the city Graz, where neither the lower nor the upper boundary are exposed (GROSS, 2003a; compare GROSS, 1997, 1998b; GROSS et al., 2000); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: Acts also as type section for the Kapfenstein Member (GROSS, 2003a).

Reference section(s): Section (acre bank close to the farmstead "Grabenhof") GR 24 (N 46°55′56″ / E 15°48′49″), c. 1.6 km SE Paldau, c. 6.2 km WSW Feldbach, where the lower boundary to the Feldbach Formation (Sieglegg Member) was exposed (GROSS, 2003a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: At the Mataschen clay pit (N 46°54′15″ / E 15°57′16″), c. 2.4 km NW Kapfenstein, c. 7.5 km SE Feldbach, the lower boundary to the Feldbach Formation (Sieglegg Member) is exposed (GROSS, 2004b).

Derivation of name: Named after the market town Paldau, c. 7 km WSW of the town Feldbach, c. 31 km SE of the city Graz, Styria.

Synonyms: (partim) Belvedereschichten, thrazische Stufe (HERITSCH, 1921), Kapfensteiner Schotterzug & Sedimente des Mittelpontikums (WINKLER, 1927b), Unterpannon Zone C (KOLLMANN, 1965). For a detailed list see GROSS (2003a).

Lithology: Variegated siliciclastics, laterally and vertically variable; grey to yellowish, quartz-dominated, well-rounded, massive or cross- or horizontal bedded, sandy gravel; yellowish or grey, cross-, ripple- or horizontal bedded sand; alternations of yellowish or grey, cross-, ripple- or horizontal bedded or massive (silty) sand und grey or yellowish, laminated or massive (sandy) silt; yellowish to grey, massive or thin laminated silt/clay, frequently with plant remains; intercalations of blue grey, massive marl with gastropods, bivalves and ostracods and dm- to m-thick lignite seams (e.g., Paldau, Ilz; GROSS, 2003a). For data to heavy mineral spectra see NEBERT (1985, 1988) and HANSELMAYER & KOTSIS (1976, 1977), to component analyses HANSELMAYER (1958, 1959, 1960a, 1966, 1968, 1971, 1978, 1979), to sedimentary structures, paleocurrent and facies analyses SKALA (1968), KRAINER (1987b), KOVAR-EDER & KRAINER (1990, 1991), GROSS (1997, 1998b, c) and GROSS et al. (2000). For coal-mining history see ANDRAE (1854), PETRASCHECK (1922/1924), WEBER & WEISS (1983), NEBERT (1988) and GROSS (1998a).

Fossils: Plant remains, characean gyrogonites, gastropods, bivalves (e.g., *Mytilopsis hoernesi*), insects, ostracods, vertebrates (fishes, reptiles, various mammals; e.g., "*Hipparion*") (HILBER, 1893; WINKLER, 1921, 1927a, b; SAUERZOPF, 1950, 1952; MOTTL, 1954a, b, 1955a, b, c, 1961b, 1966a, b, 1969b, 1970; KOLLMANN, 1960a, 1965; NEBERT, 1985, 1988; KOVAR-EDER & KRAINER, 1990, 1991; FRITZ, 1996b; GROSS, 1997, 1998c, 2000; KRENN, 1998; ENGEL & GROSS, 2008, 2009, 2012; NEL et al., 2017). For more details, see lithostratigraphically lower rank units and GROSS (2003a).

Origin, facies: Fluvial (gravel-bed and/or gravel-sand, meandering river) and limnic-deltaic (in part slightly brackish) (KRAINER, 1987b; GROSS, 1998b, 2003a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: 100–160 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Partly subdivided into fluvial (the Kapfenstein Member, Kirchberg Member, Karnerberg Member and the invalid Schemerl Gravel) and limnic-deltaic members (Mayerhanselberg Member, including the Münzengraben Bed; GROSS, 2003a).

Underlying unit(s): The lower boundary to the Feldbach and Gleisdorf formations is marked by coarse siliciclastics above an erosive surface (Kapfenstein Member) or by the distinct onset of thick sands, respectively (Mayerhanselberg Member; GROSS, 2003a; KOSI et al., 2003).

Overlying unit(s): Loipersdorf-Unterlamm Beds or Tabor Gravel; erosional boundary (GROSS, 2003a).

Lateral unit(s): Ries Formation (GROSS, 2015) and Puch Gravel (KRAINER, 1987a, b). To what extent "Blockschotter" ("Boulder Gravels") at the northern margin of the Eastern Styrian Basin (e.g., "Blockschichten von Pöllau", "Vorauer Serie", "Friedberger Schotter") are lateral equivalents remains unclear (e.g., MOHR, 1914; BRANDL, 1931; WINKLER-HERMADEN, 1933a, 1951; NEBERT, 1952, 1985; KOLLMANN, 1965; WEINHANDL, 1971; EBNER & GRÄF, 1977b; SCHUSTER et al., 2016).

Geographic distribution: Corresponds to the type area and occurrences in the area of Hartberg (NEBERT, 1985); ÖK50-UTM, map sheet 4224 Hartberg (ÖK50-BMN, map sheet 136 Hartberg).

Remarks: Within the Paldau Formation, members of fluvial and limnic-deltaic genesis are differentiated. GROSS (1998b, c) interpreted the Kapfenstein Member (and in analogy the Kirchberg Member and Karnerberg Member) as deposits of gravel-bed and/or gravel-sand meandering rivers, where longitudinal meander belts segue laterally and vertically into limnic-deltaic environments. Towards the basin margin, the meandering river systems grade into braided river (Ries Formation) and alluvial fan (Puch Gravel) deposits, where a separation of above mentioned members is not possible (GROSS, 2003a; compare also KOLLMANN, 1965; KRAINER, 1987b). For a comprehensive discussion see GROSS (2000, 2003a, 2015).

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Kapfenstein-Subformation (Paldau-Formation) / Kapfenstein Member (Paldau Formation)

MARTIN GROSS

Validity: Valid; name introduced by WINKLER (1927b); established as "Kapfenstein-Subformation" by GROSS (1999); described and formalized by GROSS (2003a; compare GROSS, 2000).

Type area: Region S of the market town Paldau, the town Feldbach and the village Kapfenstein, c. 30 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach) (Gross, 2003a).

Type section: Abandoned gravel pit “Monscheinkiesgrube” (N 46°56′17″ / E 15°48′37″), section BE 1-2, at the Wagenhoferberg, c. 1 km ESE of the market town Paldau, c. 31 km SE of the city Graz, where neither the lower nor the upper boundary are exposed (Gross, 2003a; compare Gross, 1997, 1998b; Gross et al., 2000); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: Acts also as type section for the Paldau Formation (Gross, 2003a).

Reference section(s): Section (acre bank close to the farmstead “Grabenhof”) GR 24 (N 46°55′56″ / E 15°48′49″), c. 1.6 km SE Paldau, c. 6.2 km WSW Feldbach, where the lower boundary to the Feldbach Formation (Sieglegg Member) was exposed (Gross, 2003a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: Acts also as reference section for the Paldau Formation (Gross, 2003a).

Derivation of name: After the village Kapfenstein, c. 10 km SE Feldbach, c. 46 km SE Graz, Styria.

Synonyms: (partim) Kapfensteiner Schotterzug (Winkler, 1927b), (partim) Kapfensteiner Schotter (Winkler-Hermaden, 1939). For a detailed list, see Gross (2003a).

Lithology: Laterally and vertically variable; grey or yellowish, quartz-dominated, well-rounded, massive or cross- or horizontal bedded, sandy gravel; yellowish or grey, cross-, ripple- or horizontal bedded sand; alternations of yellowish, ripple-bedded or massive (silty) sand and grey or yellowish, laminated (sandy) silt; yellowish or grey, massive or thin laminated silt/clay, frequently with plant remains (Gross, 1998b, c, 2003a; Gross et al., 2000). Further data to heavy mineral spectra in Nebert (1985, 1988), to component analyses in Hanselmayer (1971).

Fossils: Plant remains (leave, seed and root remains), gastropods (e.g., planorbids), bivalves (e.g., unionids), insects, vertebrates (fish remains, mammals (div. fam.)) (Winkler, 1927a, b; Kollmann, 1965; Mottl, 1970; Gross, 1997, 1998c, 2000; Krenn, 1998; Engel & Gross, 2008, 2009, 2012; Nel et al., 2017).

Origin, facies: Fluvial (gravel-bed and/or gravel-sand, meandering river (Gross, 1998b, 2003a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone “C” (*Mytilopsis hoernesi* Zone).

Thickness: 20–40 m (Gross, 2003a).

Lithostratigraphically higher rank unit: Paldau Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Feldbach Formation or Gleisdorf Formation; erosional boundary (Gross, 2003a; Kosi et al., 2003).

Overlying unit(s): Mayerhanselberg Member (Paldau Formation (Gross, 2003a).

Lateral unit(s): Mayerhanselberg Member (Paldau Formation), Ries Formation and Puch Gravel (Gross, 2003a, 2015).

Geographic distribution: Corresponds to the geographic distribution of the Paldau Formation.

Remarks: The Kapfenstein Member comprises the fluvial parts of the Paldau Formation above the Feldbach Formation. The lower boundary of the Kapfenstein Member is marked by the occurrence of sandy gravels (“Kapfensteiner Schotter”). The upper boundary cannot by shown by sections till now and is, however, defined by the shift from fluvial to limnic-deltaic sedimentation (Mayerhanselberg Member (Gross, 2003a).

Complementary references: Winkler-Hermaden (1943), Fuchs (1980c), Tollmann (1985).

Mayerhanselberg-Subformation (Paldau-Formation) / Mayerhanselberg Member (Paldau Formation)

Martin Gross

Validity: Valid; introduced by Gross (1999); described and formalized by Gross (2003a; compare Gross, 2000).

Type area: Region S of the market town Paldau, c. 30 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheets 191 Kirchbach in Steiermark, 192 Feldbach; Gross, 2003a).

Type section: About 18 m thick section MA 10 (N 46°56′05″ / E 15°47′42″) in a side ditch of the brook Ahlgrabenbach, c. 0.6 km SSW of the market town Paldau, c. 7.5 km WSW of the town Feldbach; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: At the type section neither the lower nor the upper boundary is exposed. The reference section (see below) exposes the lower boundary to the Feldbach Formation (Sieglegg Member). For the upper boundary of the Mayerhanselberg Member a section is lacking (Gross, 2003a).

Reference section(s): About 23 m thick section ED 1718 (N 46°55′15″ / E 15°48′05″), the type section of the Sieglegg Member (Feldbach Formation), in a side ditch of the brook Edelsbrunngrabenbach, c. 2.3 km SSE of the market town Paldau, c. 7.7 km SW of the town Feldbach; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: The Mataschen clay pit (N 46°54′15″ / E 15°57′16″), c. 2.4 km NW Kapfenstein, c. 7.5 km SE Feldbach, can be considered as further reference section. There, the lower boundary to the Feldbach Formation (Sieglegg Member) is exposed (Gross, 2004b).

Derivation of name: After the hamlet Mayerhanselberg, c. 0.9 km S Paldau, c. 7.3 km WSW Feldbach, Styria.

Synonyms: (partim) Congerienstufe, Belvedersand[...] (STUR, 1867), (partim) Sedimente des Mittelpontikums (WINKLER, 1927b), (partim) Zwischenserie zwischen Kapfensteiner und Kirchberger Schotter (KOLLMANN, 1965), (partim) Erste Limnische Zwischenserie (FUCHS, 1980c). For a detailed list see GROSS (2003a).

Lithology: At the base yellowish or grey, cross-, ripple- or horizontal bedded sand; up section, dm- or m-scale alternations of yellowish, cross-, ripple- or horizontal bedded (silty) sand and grey, laminated or massive silt to fine sand; intercalations of dm- to m-thick lignite seams and blue-grey, massive marl, rich in bivalves, gastropods and ostracods (GROSS, 2003a; compare WEBER & WEISS, 1983; NEBERT, 1988; GROSS, 1997, 1998a).

Fossils: Plant remains (leaves, cones, pollen), gastropods (e.g., melanopsids), bivalves (e.g., *Mytilopsis hoernesi*), ostracods (e.g., candonids, cytherideids, hemicytherids, loxoconchids), insects, fish remains, mammals (div. fam.) (e.g., WINKLER, 1927b; SAUERZOPF, 1950, 1952; KOLLMANN, 1960a, 1965; NEBERT, 1988; GROSS, 1997, 1998c, 2003a; ENGEL & GROSS, 2008).

Origin, facies: Limnic-deltaic (in part slightly brackish (GROSS, 2003a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: 40–50 m (GROSS, 2003a).

Lithostratigraphically higher rank unit: Paldau Formation.

Lithostratigraphic subdivision: Within the Mayerhanselberg Member the Münzengraben Bed is intercalated (GROSS, 2003a).

Underlying unit(s): Feldbach Formation (Sieglegg Member) (GROSS, 2003a).

Overlying unit(s): The Kirchberg Member (Paldau Formation) with erosional boundary or sandy deposits of a further still undefined member of the Paldau Formation (GROSS, 2003a).

Lateral unit(s): Kapfenstein Member (Paldau Formation) and, possibly, the Ries Formation (GROSS, 2003a, 2015).

Geographic distribution: Region stretching from about the market town Paldau to the villages Frauenbach, Dörfla (near Kirchbach in Steiermark) and Empersdorf and area S of Ilz; ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4229 Graz, 4230 Gleisdorf (ÖK50-BMN, map sheets 166 Fürstenfeld, 191 Kirchbach in Steiermark).

Remarks: The Mayerhanselberg Member comprises the limnic-deltaic sediments above the Feldbach Formation and below the Kirchberg Member. The lower part of the Mayerhanselberg Member interfingers with the Kapfenstein Member The upper boundary of the Mayerhanselberg Member is marked by the coarse clastics of the Kirchberg Member or by sandy intercalations of a further, not yet defined member of the Paldau Formation (GROSS, 2003a).

Complementary references: TOLLMANN (1985), EBNER & SACHSENHOFER (1991).

Münzengraben-Bank (Mayerhanselberg-Subformation, Paldau-Formation) / Münzengraben Bed (Mayerhanselberg Member, Paldau Formation)

MARTIN GROSS

Validity: Valid; introduced by GROSS (1999); described and formalized by GROSS (2003a; compare GROSS, 2000).

Type area: In the area of the Münzengraben, a small valley c. 1.4 km S of the market town Paldau, c. 32 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark (GROSS, 2003a).

Type section: About 33 m thick section MA 3538 (N 46°55′47″ / E 15°48′03″) at the valley head of the brook Münzengrabenbach, c. 1.2 km SSE Paldau, c. 7.3 km SW of the town Feldbach (GROSS, 2003a); ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: The lower and upper boundary of the Münzengraben Bed are exposed there.

Reference section(s): -

Remark: Aside the type section, this bed was observed only at a nearby landside (N 46°55′36″ / E 15°47′49″) locality ED 5 of GROSS (1997, 2000, 2003a).

Derivation of name: After the valley of the brook Münzengrabenbach, c. 1.4 km S Paldau, c. 7.4 km SW Feldbach, Styria.

Synonyms: -

Lithology: Grey, massive marl, rich in bivalves, gastropods and ostracods (GROSS, 1997, 2000, 2003a).

Fossils: Gastropods (e.g., melanopsids), bivalves (dreissenids, lymnocardiids), ostracods (e.g., candonids, hemicytherids, cytherideids, loxoconchids), fish remains (GROSS, 1997, 2000, 2003a).

Origin, facies: Limnic (slightly brackish (GROSS, 2003a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: 0.2 m (GROSS, 2003a).

Lithostratigraphically higher rank unit: Mayerhanselberg Member (Paldau Formation) (GROSS, 2003a).

Lithostratigraphic subdivision: -

Underlying unit(s): The Münzengraben Bed is an intercalation within the Mayerhanselberg Member (Paldau Formation) (GROSS, 2003a).

Overlying unit(s): See Underlying unit(s).

Lateral unit(s): See underlying unit(s) and remarks.

Geographic distribution: Corresponds to the type area.

Remarks: The fauna of Münzengraben Bed indicates an ingression of Lake Pannon (e.g., MAGYAR et al., 1999a; HARZHAUSER & MANDIC, 2008) during the regional mollusc Zone "C", reaching well into the southern Gnas Subbasin (area of Paldau) (GROSS, 1997, 2000, 2003a; compare also

Kosi et al., 2003). Other indications for this ingression derive from fossil finds close to the South Burgenland Swell (area S of Kapfenstein) and in the southern Fürstenfeld Subbasin (area S of Ilz and Maierhofen and Altenmarkt bei Fürstenfeld; see Kollmann, 1965: p. 591–592, cum lit. and remarks to the Sieglegg Member (Feldbach Formation)).

Complementary references: -

Kirchberg-Subformation (Paldau-Formation) / Kirchberg Member (Paldau Formation)

Martin Gross

Validity: Valid; name introduced by Kollmann (1960b); established as "Kirchberg-Subformation" by Gross (1999); described and formalized by Gross (2003a; compare Gross, 2000).

Type area: Region around the village Kirchberg an der Raab, c. 26 km SE of the city Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark) (Gross, 2003a).

Type section: Section Langwald, about 8 m thick in an abandoned gravel pit (N 46°59′33″ / E 15°44′13″), c. 2.1 km WNW Kirchberg an der Raab, c. 12 km WNW Feldbach; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 191 Kirchbach in Steiermark).

Remark: Neither the lower nor the upper boundary of the Kirchberg Member are exposed at the type section. Boundary stratotypes for this member have not been described so far (Gross, 2003a).

Reference section(s): -

Remark: Gross (2003a) mentioned the gravel-sand pits at Wörth bei Kirchberg an der Raab (N 46°58′32″ / E 15°46′16″), c. 1.5 km SSE Kirchberg an der Raab (Kovar-Eder & Krainer, 1990), at Reith near Unterstorcha (N 46°57′34″ / E 15°48′05″), c. 6.6 km W Feldbach (Kovar-Eder & Krainer, 1991) and at Minireith (N 47°04′20″ / E 15°50′18″ and N 47°04′35″ / E 15°50′11″; pits number 33 and 34 of Nebert, 1988), c. 2.3 km N Markt Hartmannsdorf, as reference, which, however, are recultivated today.

Derivation of name: After the village Kirchberg an der Raab (municipality Kirchberg an der Raab), c. 10 km NW Feldbach, c. 26 km SE Graz, Styria.

Synonyms: (partim) Kapfensteiner Schotterzug (Winkler, 1927b), (partim) Kirchberger Schotter (Kollmann, 1960b), Kirchberger Schotter (Hanselmayer, 1966), (partim) Kirchberger Schotter, Zweite Limnische Zwischenserie (Fuchs, 1980c). For a detailed list, see Gross (2003a).

Lithology: Laterally and vertically variable; grey to brownish, quartz-dominated, massive or cross-bedded sandy gravel; yellowish or grey, ripple-, cross- or horizontal bedded sand; alternations of yellowish, laminated or ripple-bedded fine sand and grey, massive or laminated silt; blue-grey, massive or thin laminated silt/clay; frequently with plant remains (Hanselmayer, 1966, 1968; Skala, 1968; Nebert, 1988; Kovar-Eder & Krainer, 1990, 1991; Gross, 2003a).

Fossils: Plant remains (pollen, leaves, seeds and root remains), characean gyrogonites, gastropods, bivalves, ostracods, fish and mammal remains (div. fam.) (Winkler, 1927b; Kollmann, 1965; Mottl, 1970; Kovar-Eder & Krainer, 1990, 1991).

Origin, facies: Fluvial (gravel-bed and/or gravel-sand, meandering river (Krainer, 1987a, b; Gross, 1997, 2003a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: 20–30 m (Gross, 2003a).

Lithostratigraphically higher rank unit: Paldau Formation (Gross, 2003a).

Lithostratigraphic subdivision: -

Underlying unit(s): Mayerhanselberg Member (Paldau Formation) (Gross, 2003a).

Overlying unit(s): Probably limnic-deltaic, fine clastic deposits of another, hitherto undescribed member of the Paldau Formation (Gross, 2003a).

Lateral unit(s): Possibly the Ries Formation (Gross, 2003a, 2015).

Geographic distribution: Region roughly encircled by the market town Paldau, the villages Lichendorf and Breitenbuch, the hills Sengerberg and Schemerlhöhe, the villages Goggitsch, Studenzen and Paurach (Kollmann, 1965); ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4229 Graz, 4230 Gleisdorf (ÖK50-BMN, map sheets 165 Weiz, 191 Kirchbach in Steiermark).

Remarks: Similar to the Kapfenstein Member, the basal gravels ("Kirchberger Schotter") of the Kirchberg Member are not continuously developed and restricted to meander belts. Laterally (where the basal gravels are missing) and above the Kirchberg Member follow fine clastic, probably limnic-deltaic sediments (analogously to the Mayerhanselberg Member), which cannot be shown by sections until now. The upper boundary of the Kirchberg Member is defined by the end of fluvial deposition (Gross, 2003a). In more proximal basin areas (approximately in the region of Laßnitzhöhe and Markt Hartmannsdorf), a differentiation between the Kirchberg and Kapfenstein Formation is not possible (Kollmann, 1965; Gross, 2003a).

Complementary references: Tollmann (1985), Ebner & Sachsenhofer (1991).

Karnerberg-Subformation (Paldau-Formation) / Karnerberg Member (Paldau Formation)

Martin Gross

Validity: Valid; name introduced by Winkler (1927a); established as "Karnerberg-Subformation" by Gross (1999); described and formalized by Gross (2003a; compare Gross, 2000).

Type area: Region c. 2.8 km SW (Karnerberg) and c. 2.3 km NE (Ober- and Unterlembach) of the market town Riegersburg, c. 36 km ESE of the city Graz; ÖK50-UTM, map sheets 4106 Feldbach, 4230 Gleisdorf (ÖK50-BMN, map sheets 192 Feldbach, 166 Fürstenfeld; Gross, 2003a).

Type section: Section Unterlembach (N 47°00′46″ / E 15°57′48″), about 13 m thick in an abandoned gravel pit, c. 2.5 km NE Riegersburg, c. 8.6 km NE Feldbach; ÖK50-UTM, map sheet 4230 Gleisdorf (ÖK50-BMN, map sheet 166 Fürstenfeld).

Remark: Neither the lower nor the upper boundary of the Karnerberg Member are exposed at the type section. Clear boundary stratotypes (see reference sections) for this member have not been described so far (GROSS, 2003a).

Reference section(s): -

Remark: GROSS (2003a) figured the sections Oberlembach (N 47°01′01″ / E 15°56′48″), about 8 m thick in an abandoned gravel pit, c. 2.0 km NNE Riegersburg and Lemberg (N 47°01′21″ / E 15°57′32″), about 6 m thick in an abandoned gravel pit, c. 3.0 km NE Riegersburg to provide further lithological information on the Karnerberg Member. Due to poor outcrop conditions, it is not clear if the lower boundary of the Karnerberg Member (to a further still undefined Member of the Paldau Formation) is exposed at the section Oberlembach (GROSS, 2003a).

Derivation of name: After the hill Karnerberg (395 m a.s.l.), municipality Riegersburg, c. 4 km NNE Feldbach, c. 36 km ESE Graz, Styria.

Synonyms: (partim) Die mittleren Lagen des oststeirischen Pontikums (WINKLER, 1921), Karnerberger Schotter (WINKLER, 1927a), Karnerbergniveau (WINKLER, 1927b), Karnerberg-Schotter (WINKLER-HERMADEN, 1943), (partim) Karnerbergschotter und […] Hangendschichten, Schotter v. Riegersburg und Ob. Lembach (KOLLMANN, 1965). For a detailed list see GROSS (2003a).

Lithology: Laterally and vertically variable; yellowish to grey, quartz-dominated, well-rounded, massive, cross- or horizontal bedded sandy gravel, in part rich in grey silt intraclasts; grey to red brown, ripple-, cross- or horizontal bedded sand, in part epsilon-crossbedding and nodules; alternations of green-grey, laminated (sandy) silt and grey to yellowish, ripple- or horizontal bedded (silty) fine sand, frequently convolute-bedding, in part with plant remains (HANSELMAYER, 1968; HANSELMAYER & KOTSIS, 1976; GROSS, 2003a)

Fossils: Plant remains, gastropods, reptiles (trionychids, testudinids) and various mammal finds (including "*Hipparion*") (MOTTL, 1954a, 1966a, b, 1969b, 1970; KOLLMANN, 1965; GROSS, 2003a).

Origin, facies: Fluvial (gravel-bed and/or gravel-sand, meandering river) (GROSS, 2003a).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: More than 15 m (GROSS, 2003a).

Lithostratigraphically higher rank unit: Paldau Formation (GROSS, 2003a).

Lithostratigraphic subdivision: -

Underlying unit(s): Fine clastic deposits of another, hitherto undescribed member of the Paldau Formation; erosive lower boundary (GROSS, 2003a).

Overlying unit(s): Fine clastic deposits of another, hitherto undescribed member of the Paldau Formation (GROSS, 2003a).

Lateral unit(s): Possibly the Ries Formation and the Schemerl Gravel (KOLLMANN, 1965; GROSS, 2003a, 2015).

Geographic distribution: Region roughly encircled by the villages Johnsdorf, Raabau, Fladnitz im Raabtal, St. Marein bei Graz, Krumegg, Goggitsch, Eichkögl, Auersbach, Breitenfeld an der Rittschein and Rittschein (KOLLMANN, 1965); ÖK50-UTM, map sheets 4106 Feldbach, 4229 Graz, 4230 Gleisdorf, 5225 Fürstenfeld (ÖK50-BMN, map sheets 165 Weiz, 166 Fürstenfeld, 191 Kirchbach in Steiermark, 192 Feldbach).

Remarks: WINKLER (1921) described in the region of Riegersburg–Ober-/Untertiefenbach fluvial gravels. WINKLER (1927a, b) recognized them as separate unit above the "Kapfensteiner Schotter" (see Kapfenstein Member) and introduced the name "Karnerberger Schotter". Later, KOLLMANN (1960b, 1965) determined an additional fluvial intercalation, the "Kirchberger Schotter" (see Kirchberg Member) between the "Kapfensteiner Schotter" and the "Karnerbergschotter". Towards proximal basin areas (approximately the region around Laßnitzhöhe) grain-size and abundance of carbonate clasts increase (HANSELMAYER, 1968), which complicates a differentiation of the "Karnerbergschotter" from the "Schemerl-Schotter" (KOLLMANN, 1960b, 1965).

Complementary references: FUCHS (1980c), TOLLMANN (1985), EBNER & SACHSENHOFER (1991).

Schemerl Schotter (Paldau-Formation) / Schemerl Gravel (Paldau Formation)

MARTIN GROSS

Validity: Invalid; name introduced by KOLLMANN (1960b); not formally defined as member of the Paldau Formation (GROSS, 2000, 2003a; see synonyms).

Type area: Region E of the market town Laßnitzhöhe (Bucklberg, Schemerlhöhe, Nestelbach bei Graz) to the SW of the town Gleisdorf, c. 19 km E of the city Graz (KOLLMANN, 1965); ÖK50-UTM, map sheets 4229 Graz, 4230 Gleisdorf (ÖK50-BMN, map sheet 165 Weiz).

Type section: -

Remark: Possibly the former gravel pit Griessl (also "Grießl" or "Griehsl"; N 47°04′19″ / E 15°35′35″), c. 0.9 km SE Laßnitzhöhe, c. 12 km E Graz, might act as type locality, which is well recognized due to rich vertebrate finds (MOTTL, 1954a, 1955a, b, c, 1970; KOLLMANN, 1965). MOTTL (1954a) and HANSELMAYER (1959; compare HANSELMAYER, 1958, 1960a) provide a coarse description of the 12–15 m thick section. However, the pit is recultivated today.

Reference section(s): -

Remark: As reference section might act the abandoned gravel pit Adler (N 47°02′59″ / E 15°37′43″), c. 100 m SE of the castle Erkoschlößl, c. 14.7 km ESE Graz, of which MOTTL (1954a) gave a short description and where still about 4 m of sediment (sandy gravel – sand – fine sand) are exposed (compare MOTTL, 1954b, 1955a, b, 1970; HANSELMAYER 1958, 1979).

Derivation of name: After the hill Schemerlhöhe (500 m a.s.l.), municipality Nestelbach bei Graz, c. 3.1 km SE Laßnitzhöhe, c. 13 km ESE Graz, Styria.

Synonyms: ?Belvedereschotter (Hilber, 1893), Pannonische […] Schotter […] von […] Laßnitzhöhe-Schemmerl (Hanselmayer, 1958), Schotter vom Schemerl (Kollmann, 1960b), Schemerl-Schotter [including the "Hangendserie mit Kies und Schotter"] (Kollmann, 1965), Schemerlschotter (Hanselmayer, 1966), Schemerl Schotter (Ebner & Sachsenhofer, 1991), Schemmerl-Subformation (Gross, 1999), Schemmerl-Schotter (Gross, 2003a).

Lithology: Alternations of grey, sandy, fine to coarse gravel (mainly quartz but frequently also limestone pebbles) and grey or yellowish, in part cross-bedded sand and dm-thick (sandy) pelite layers (Mottl, 1954a; Hanselmayer, 1958, 1959, 1960a, 1979; Kollmann, 1965).

Fossils: Plant, gastropod and various mammal remains (Mottl, 1954a, b, 1955a, b, c, 1961b, 1970; Hanselmayer, 1959).

Origin, facies: Fluvial (possibly gravel-bed meandering river).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian).

Biostratigraphy: Regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: More than 15 m (Hanselmayer, 1959).

Lithostratigraphically higher rank unit: Paldau Formation.

Lithostratigraphic subdivision: -

Underlying unit(s): Fine clastic deposits of another, hitherto undescribed member of the Paldau Formation (compare Kollmann, 1965).

Overlying unit(s): Erosional upper boundary; probably in part Pliocene denudation plains (compare Flügel et al., 2011; Wagner et al., 2011).

Lateral unit(s): The Ries Formation and, possibly, upper parts of the Karnerberg Member (Kollmann, 1965; Gross, 2003a, 2015).

Geographic distribution: Corresponds to the type area.

Remarks: Gross (2003a) proposed an integration of the Schemerl Gravel (in the rank of a member) in the Paldau Formation, which has been followed here with reservation. The "Hangendserie mit Kies und Schotter" of Kollmann (1965), above the Schemerl Gravel, is also included in this unit herein.

Complementary references: Flügel (1975a), Fuchs (1980c), Tollmann (1985).

Ries-Formation / Ries Formation

Martin Gross

Validity: Valid; introduced as formation by Flügel (1997); described and formalized by Gross (2015).

Type area: NW-margin of the Eastern Styrian Basin ranging from the city Graz towards the NE from the villages Wenisbuch, Niederschöckl, Kumberg to Kleinsemmering (c. 6–17 km NE of the city centre of Graz) and towards the E approximately to Laßnitzhöhe (c. 10 km E of the city centre of Graz) and Gratkorn Basin; ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Type section: Abandoned gravel pit "Schreiner-Stattegger" (N 47°06′22″ / E 15°27′33″), c. 1 km SW of the hillside Platte (651 m a.s.l.; Stefanien lookout), c. 4.2 km NE of the city centre of Graz (Hanselmayer, 1960b; Gross, 2015); ÖK50-UTM, map sheet 4229 Graz (ÖK50-BMN, map sheet 164 Graz).

Reference section(s): -

Derivation of name: Named after Ries, 10. city district of Graz, c. 4.6 km ENE of the city centre of Graz, Styria.

Synonyms: (partim) Belvedereschichten (Heritsch, 1921), (partim) Belvedereschotter (Clar, 1927), Schotter der Ries mit Sand- und Tonlagen (Kollmann, 1965), (partim) Pannon C (Ebner, 1983a), Ries-Formation (Flügel, 1997), Ries Formation (Gross et al., 2007b). For a more detailed list, see Gross (2015).

Lithology: Grey to yellowish, quartz-dominated, massive, cross- or horizontal bedded, sandy, fine to coarse gravel (partly conglomerate) with cross-, ripple- or horizontal bedded sand layers; subordinately laminated or massive silt and clay layers; rare limestone pebbles, frequently heavily altered gneiss pebbles (Flügel, 1951, 1997; Hanselmayer, 1960b; Gross, 2015).

Fossils: Rare; leaf and indeterminable mollusc remains and vertebrates (Kollmann, 1965; Mottl, 1970; Gross, 2015).

Origin, facies: Fluvial (braided to gravel-bed meandering river).

Chronostratigraphic age: Late Miocene, Tortonian (early Pannonian) (Kollmann, 1965).

Biostratigraphy: Correlated to the regional mollusc Zone "C" (*Mytilopsis hoernesi* Zone).

Thickness: Up to 140 m (Ebner, 1983a); highly variable due to erosive lower and upper boundaries.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Gleisdorf Formation, Kleinsemmering Formation and Eggenberg Formation or pre-Neogene basement; erosive lower boundary (Gross, 2015).

Overlying unit(s): In part, deeply weathered denudation plains (Wagner et al., 2011).

Lateral unit(s): Paldau Formation (Gross, 2003a, 2015) and Puch Gravel (Krainer, 1987a).

Geographic distribution: Corresponds to the type area.

Remarks: For a comprehensive discussion see Gross (2015).

Complementary references: Gross et al. (2014).

Schichten von Loipersdorf-Unterlamm / Loipersdorf-Unterlamm Beds

MARTIN GROSS

Validity: Invalid; name introduced by KOLLMANN (1965); see synonyms.

Type area: Styrian-Burgenland border area between the towns Fürstenfeld (Eastern Styria) and Jennersdorf (Southern Burgenland), c. 50 km ESE Graz; ÖK50-UTM, map sheets 5101 Jennersdorf, 5225 Fürstenfeld (ÖK50-BMN, map sheets 166 Fürstenfeld, 167 Güssing, 192 Feldbach, 193 Jennersdorf).

Type section: -

Reference section(s): -

Derivation of name: Named after the village Bad Loipersdorf, c. 4.5 km SSE of the town Fürstenfeld and the village Unterlamm, c. 8.3 km SSW Fürstenfeld, c. 50 km ESE Graz, Styria.

Synonyms: (partim) Mittelpontikum (WINKLER, 1927a), Mittelpannon, Zonen D und E, Schichten von Loipersdorf und Unterlamm (KOLLMANN, 1965), Beds of Loipersdorf/Unterlamm (GROSS et al., 2007a).

Lithology: Alternations of pelite, sand and subordinate gravel, occasionally with thin (maximal around 1 m thick) coal seams intercalated towards the top (e.g., close to the villages Schiefer, c. 12.5 km SSW Fürstenfeld and Henndorf im Burgenland, c. 5 km N Jennersdorf) (WINKLER, 1927b; KOLLMANN, 1965; WEBER & WEISS, 1983).

Fossils: Rare; gastropods (melanopsids), bivalves (dreissenids), ostracods, mammals (e.g., *Aceratherium incisivum*, *Hyotherium* cf. *soemmeringi*, *Tragocerus* sp.); see compilations by KOLLMANN (1965) and MOTTL (1970).

Origin, facies: Limnic-fluvial.

Chronostratigraphic age: Late Miocene, Tortonian (middle Pannonian).

Biostratigraphy: Regional mollusc Zones "D–E" (*Lymnocardium conjugens* Zone) (KOLLMANN, 1965).

Thickness: About 100–140 m (EBNER & SACHSENHOFER, 1991).

Underlying unit(s): With erosional lower boundary above the Paldau Formation (KOSI et al., 2003; SCHREILECHNER & SACHSENHOFER, 2007).

Overlying unit(s): Jennersdorf Beds and Tabor Gravel, erosional boundary.

Lateral unit(s): KOLLMANN (1965) suggested a correlation with the Stegersbach Beds based on ostracods.

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Stegersbacher Schichten / Stegersbach Beds

MARTIN GROSS

Validity: Invalid; name introduced by WINKLER-HERMADEN (1943; see synonyms).

Type area: Area between the market towns Burgau (Eastern Styria) and Stegersbach (Southern Burgenland), c. 16 km SSW of the town Oberwart; ÖK50-UTM, map sheet 5225 Fürstenfeld (ÖK50-BMN, map sheet 167 Güssing).

Type section: -

Reference section(s): -

Derivation of name: After the market town Stegersbach, c. 14 km NE of the town Fürstenfeld, c. 15.5 km SSW of the town Oberwart, c. 56 km ENE Graz, Burgenland.

Synonyms: Inzersdorfer Schichten bei Stegersbach (STOLICZKA, 1862), Schichten mit Congeria subglobosa hemiptycha (KOLLMANN, 1939), Stegersbacher Sch. m. Cong. subglobosa-hemyptycha (WINKLER-HERMADEN, 1943), Schichten von Stegersbach (SAUERZOPF, 1950), Mittelpannon, Zonen D und E, Schichten von Stegersbach (KOLLMANN, 1965), Ton-Sand-Folge (up_4) (NEBERT, 1979), Stegersbacher Schichten (KOVAR-EDER, 1988), Beds of Stegersbach (GROSS et al., 2007a).

Lithology: Sand, pelite and gravel (SAUERZOPF, 1950).

Fossils: Plant remains, various gastropods (e.g., melanopsids), bivalves (e.g., dreissenids, lymnocardiids), ostracods, mammal remains (STOLICZKA, 1862, 1863; KOLLMANN, 1939, 1960a; SAUERZOPF, 1950, 1952, 1953a, b; PAPP, 1951; MOTTL, 1955b, c; KOVAR-EDER, 1988; MAGYAR et al., 1999b).

Origin, facies: Limnic (littoral).

Chronostratigraphic age: Late Miocene, Tortonian (middle Pannonian).

Biostratigraphy: Regional mollusc Zones "D–E" (*Lymnocardium conjugens* Zone) (SAUERZOPF, 1952; KOLLMANN, 1965; MAGYAR et al., 1999b).

Thickness: 100–120 m (SAUERZOPF, 1950).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision; SAUERZOPF (1950, 1952) differentiated three horizons (the two lower ones are dominated by sands, the upper one is mainly pelitic).

Underlying unit(s): Paldau Formation (erosional contact) or directly upon the Paleozoic basement.

Overlying unit(s): The Oberneuberg Beds or Tabor Gravel.

Lateral unit(s): KOLLMANN (1965) suggested a correlation with the Loipersdorf-Unterlamm Beds based on ostracods.

Geographic distribution: Corresponds to the type area and occurrences on ÖK50-UTM, map sheet 5219 Oberwart (ÖK50-BMN, map sheet 167 Güssing) in Southern Burgenland (SAUERZOPF, 1950).

Remarks: SZTANÓ et al. (2016) consider the Újfalu Formation as an equivalent to the Stegersbach Beds in Hungary.

Complementary references: FUCHS (1980c), TOLLMANN (1985), SAUERZOPF (1998), EBNER & SACHSENHOFER (1991), PILLER et al. (2004), SCHREILECHNER & SACHSENHOFER (2007).

Schichten von Oberneuberg / Oberneuberg Beds

MARTIN GROSS

Validity: Invalid; name introduced by WINKLER-HERMADEN (1943); slightly modified here (see synonyms).

Type area: Area between the village Neumarkt im Tauchental, the market town Rotenturm an der Pinka and the villages Oberdorf im Burgenland and Neuberg im Burgenland, W of the South Burgenland Swell in the northeastern Styrian Basin (WINKLER-HERMADEN, 1943; SAUERZOPF, 1950; KÜMEL, 1957; NEBERT, 1979); ÖK50-UTM, map sheets 5219 Oberwart, 5220 Rechnitz, 5225 Fürstenfeld, 5226 Kohfidisch (ÖK50-BMN, map sheets 137 Oberwart, 138 Rechnitz, 167 Güssing, 168 Eberau).

Type section: -

Remark: Possibly, the log of the drilling R4 (N 47°16′51″ / E 16°21′24″) in the village Zuberbach, c. 6.9 km SW of the market town Rechnitz, c. 10.6 km E of the town Oberwart, described by PAPP & RUTTNER (1952; compare RUTTNER, 1952; NEBERT, 1979) might act as type section.

Reference section(s): -

Remark: Possible reference sections might be the logs of the deep wells Neuhaus K1 (N 47°12′56″ / E 16°16′32″; c. 1.1 km ESE Neuhaus in der Wart, c. 4.2 km SW Großpetersdorf), Bachselten 1 (N 47°12′24″ / E 16°17′38″; c. 0.55 km NW Großbachselten, c. 4 km SW Großpetersdorf) and Mischendorf K1 (N 47°11′27″ / E 16°19′00″; c. 0.5 km SE Mischendorf, c. 5.3 km S Großpetersdorf), described by KÜMEL (1957), which penetrated the lower (all wells) and the upper boundary (well Mischendorf) of the Oberneuberg Beds (compare also KOLLMANN, 1965; KRÖLL et al., 1988). At the surface (aside the "*Congeria*" *neumayri*-bearing sites of SAUERZOPF, 1950: Neumarkt im Tauchental, Oberdorf im Burgenland, Rotenturm; compare HILBER, 1895; HERRMANN, 1974; SAUERZOPF, 1985, 1998), the no longer accessible outcrops close to Badersdorf (N 47°12′06″ / E 16°22′19″; SAUERZOPF, 2000) and Eisenberg an der Pinka (N 47°10′33″ / E 16°25′43″; NEBERT, 1979) provided insight into the lithology of this unit.

Derivation of name: After the nowadays informal part "Oberneuberg" of the village Neuberg im Burgenland, c. 13.5 km SSE of the town Oberwart, Burgenland.

Synonyms: Schichten bei Oberneuberg (WINKLER-HERMADEN, 1943), (partim) Ober-Pannon Zone F, lignitführende[n] Schichten des Oberpannon (Zone F) (PAPP & RUTTNER, 1952), Schwarze Serie (KÜMEL, 1957), (partim) basaloberpannonische[r] Horizont (F-Hor.) (WINKLER-HERMADEN, 1957), (partim) Kohle von Oberneuberg, Congerienschnäbelhorizont (Oberdorf) (KOLLMANN, 1965), Ton-Sand-Folge (op_1) [and] Lignit-Folge (op_2) des Pont (NEBERT, 1979), "Congerienschnäbel-Horizont" von Oberdorf, Tone und Sande mit Ligniten von Oberneuberg (RÖGL & STEININGER, 1989).

Lithology: Yellowish, cross-bedded sand with fine gravel interlayers; alternations of yellowish or grey, laminated sandy pelite and pelite; blue-grey or blackish, lignite-rich clay; up to m-thick lignite seams (KÜMEL, 1957; PAPP & RUTTNER, 1952; NEBERT, 1979, 1981; SAUERZOPF, 2000).

Fossils: Green algae, plant remains (spores, pollen, twigs), gastropods, bivalves (e.g., "*Congeria*" *neumayri*), ostracods, fish remains (SAUERZOPF, 1950, 1952, 1953a; PAPP & RUTTNER, 1952; KÜMEL, 1957; ZETTER, 1988, 1990; ZETTER & KERI, 1989; ZETTER & FERGUSON, 2001; HOFMANN & ZETTER, 2005; KOVAR-EDER et al., 2005).

Origin, facies: Fluvial, limnic (in part slightly brackish) and swamp deposits (PAPP & RUTTNER, 1952; NEBERT, 1979).

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian).

Biostratigraphy: Regional mollusc Zone "F"; possibly also the upper part of Zone "E" and the lower part of Zone "G" (SAUERZOPF, 1950, 1952; PAPP & RUTTNER, 1952; KÜMEL, 1957; NEBERT, 1979, 1981).

Thickness: Up to 350 m thick (PAPP & RUTTNER, 1952; NEBERT, 1979).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided into the lower "Ton-Sand-Folge (op_1)" with "*Congeria*" *neumayri* and the upper "Lignit-Folge (op_2)" with lignite seams (NEBERT, 1979, 1981; compare KÜMEL, 1957; WEBER & WEISS, 1983).

Underlying unit(s): The Stegersbach Beds or directly upon the basement (KÜMEL, 1957; PAPP & RUTTNER, 1952; NEBERT, 1979).

Overlying unit(s): The Tabor Gravel (erosive boundary; NEBERT, 1979, 1981; SAUERZOPF, 2000) and/or the "Blaue Serie" (KÜMEL, 1957; compare Gbely Formation of the Vienna Basin), a possible lateral equivalent of the Jennersdorf Beds).

Lateral unit(s): The lower part of the Čáry Formation (synonym: Neufeld Formation; see HARZHAUSER et al., 2004) of the southern Vienna Basin is proposed to be a synchronous equivalent (PAPP & RUTTNER, 1952; NEBERT, 1979).

Geographic distribution: Extends from the type area over the South Burgenland Swell into the Westpannonian Basin (e.g., at the surface around the village Eisenberg an der Pinka, subsurface at the villages Edlitz and Eberau) (PETRASCHECK, 1922/1924; WINKLER-HERMADEN, 1943; SAUERZOPF, 1950; KÜMEL, 1957; NEBERT, 1979); ÖK50-UTM, map sheets 5219 Oberwart, 5220 Rechnitz, 5225 Fürstenfeld, 5226 Kohfidisch (ÖK50-BMN, map sheets 137 Oberwart, 138 Rechnitz, 167 Güssing, 168 Eberau).

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), EBNER & SACHSENHOFER (1991).

Taborer Schotter / Tabor Gravel

MARTIN GROSS

Validity: Invalid; name introduced by WINKLER (1927b).

Type area: Area between the rivers Lafnitz and Raab NW, N and NE of the town Jennersdorf (c. 56 km ESE of the city Graz) and region SW and S of Jennersdorf (to about Grad in northern Slovenia); ÖK50-UTM, map sheet 5101 Jennersdorf (ÖK50-BMN, map sheets 192 Feldbach, 193 Jennersdorf).

Type section: -

Reference section(s): -

Remark: Possible reference sections are the section (landslide) described by WINKLER (1921: p. 9, fig. 2, section 6; compare WINKLER, 1927b) at Hirzenriegel (N 46°54′40″ / E 16°03′01″), c. 7.5 km WSW Jennersdorf and the road cut and abandoned gravel pit (N 46°53′05″ / E 16°01′42″) at Tabor castle, c. 10.5 km SW of Jennersdorf (WINKLER, 1927b). The Tabor castle rests directly upon the Tabor Gravel. Gravel pits at Schüttlgreut (N 46°53′29″ / E 16°01′27″), c. 10.3 km SW Jennersdorf still provide insight into the development of the Tabor Gravel (see KOLLMANN, 1965: "Schüttlgreith").

Derivation of name: After the Tabor castle (municipality Neuhaus am Klausenbach), c. 10.5 km SW Jennersdorf, c. 49 km SE Graz, Burgenland.

Synonyms: Basalschotter des Höherpontikums (WINKLER, 1927a), Taborer Schotter (WINKLER, 1927b), Basalschotter der Sand-Folge (op_3) (NEBERT, 1979), Neuberger Schotter (NEBERT, 1981), Tabor Gravel (EBNER & SACHSENHOFER, 1995).

Lithology: Medium to coarse gravels, subordinate sand and pelite layers, mainly quartz components, subordinately crystalline pebbles, carbonate components are missing (KOLLMANN, 1965).

Fossils: Rare (mentioned only from the probably equivalent "Schotter des Mühlsteinbruchs"): silicified plant remains (wood, cones), one mammal record (UNGER, 1854; RÖSSLER, 1937; THENIUS, 1952b; MOTTL, 1970; CICHOCKI, 1987).

Origin, facies: Fluvial.

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian).

Biostratigraphy: Regional mollusc Zone "G" (KOLLMANN, 1965).

Thickness: 40–50 m (WINKLER-HERMADEN, 1957).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Erosional lower boundary; in the type area the Paldau Formation and the Loipersdorf-Unterlamm Beds; in the Großpetersdorf embayment, close to the South Burgenland Swell, the Oberneuberg Beds or directly upon the basement (NEBERT, 1979; SAUERZOPF, 2000).

Overlying unit(s): Jennersdorf Beds, gradational.

Lateral unit(s): Partly interfingering (at the basal part) with the Jennersdorf Beds (WINKLER, 1927b).

Geographic distribution: Probably ranging from the type area around Jennersdorf to the north up to the Eisenberg area (SAUERZOPF, 1950, 1985; WINKLER-HERMADEN & RITTLER, 1949; WINKLER-HERMADEN, 1957; NEBERT, 1979). WINKLER (1927a, b) suggested that the "Schotter des Mühlsteinbruchs" (area of Bad Gleichenberg) are an equivalent, erosional relict of the Tabor Gravel (WINKLER-HERMADEN, 1957). NEBERT (1952; compare HADITSCH & YAMAC, 1977; NEBERT, 1985) correlated the "Hofkirchener Schotter" in the Pöllau embayment with the "Tabor Gravel".

Remarks: -

Complementary references: FUCHS (1980c), WEBER & WEISS (1983), TOLLMANN (1985), PILLER et al. (2004), GROSS et al. (2007a), SCHREILECHNER & SACHSENHOFER (2007).

Jennersdorfer Schichten / Jennersdorf Beds

MARTIN GROSS

Validity: Invalid; name introduced by KOLLMANN (1965); see synonyms.

Type area: Area between the village Gillersdorf, c. 7.2 km SE of the town Fürstenfeld and the town Jennersdorf (KOLLMANN, 1965); ÖK50-UTM, map sheet 5101 Jennersdorf (ÖK50-BMN, map sheet 193 Jennersdorf).

Type section: -

Reference section(s): -

Remark: WINKLER (1927b) briefly described a section at the abandoned and backfilled brickyard Jennersdorf (N 46°56′21″ / E 16°07′55″).

Derivation of name: After the town Jennersdorf, c. 18 km E of the town Feldbach, c. 55 km SE of the city Graz, Burgenland.

Synonyms: Höherpontische Sand- und Tonbildungen (WINKLER, 1927b), Schichten von Jennersdorf, Blaugrüne Serie (KOLLMANN, 1965), Jennersdorf Formation (EBNER & SACHSENHOFER, 1995), Jennersdorf Beds, Beds of Jennersdorf (GROSS et al., 2007a).

Lithology: Alternations of blue-green (fine) sand (partly with gravel intercalations) and pelites.

Fossils: -

Origin, facies: Limnic (WINKLER, 1927a, b; WINKLER-HERMADEN, 1957).

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian).

Biostratigraphy: Regional mollusc Zone "G" (KOLLMANN 1965).

Thickness: 150 m (WINKLER, 1927a, b).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Tabor Gravel, gradational boundary.

Overlying unit(s): Silberberg Gravel, erosive boundary (peneplain, sometimes with red loam) (WINKLER, 1927a, b; KOLLMANN, 1965).

Lateral unit(s): Partly interfingering (at the basal part) with the Tabor Gravel (WINKLER, 1927b).

Geographic distribution: Eastern margin of the Styrian and Southern Burgenland downs; ÖK50-UTM, map sheet 5101 Jennersdorf (ÖK50-BMN, map sheets 192 Feldbach, 193 Jennersdorf); extends into the Pannonian Basin.

Remarks: The "Blaue Serie" of KÜMEL (1957) (compare Gbely Formation) and the "Sand-Folge (op_3)" of NEBERT (1979) in the area around the Eisenberg Mountain, c. 17 km SE of the town Oberwart, could be – at least partly – a lateral equivalent of the Jennersdorf Beds.

Complementary references: FUCHS (1980c), EBNER & SACHSENHOFER (1991), PILLER et al. (2004), SCHREILECHNER & SACHSENHOFER (2007).

Süßwasserkalk von Kirchfidisch und Königsberg / Kirchfidisch-Königsberg Freshwater Limestone

MARTIN GROSS

Validity: Invalid; name introduced by KOLLMANN (1960b); see synonyms.

Type area: Area around the Eisenberg Mountain (415 m a.s.l.), c. 17 km SE of the town Oberwart, Southern Burgenland; ÖK50-UTM, map sheets 5220 Rechnitz, 5226 Kohfidisch (ÖK50-BMN, map sheet 168 Eberau).

Type section: -

Reference section(s): -

Remark: Possible reference sections might be the localities mentioned by WINKLER (1927c), SAUERZOPF (1950, 1990), KÜMEL (1957), NEBERT (1979) and SCHÖNLAUB & SAUERZOPF (2000): at the hillside of the Hohensteinmaißberg (N 47°08′36″ / E 16°21′00″), c. 1.8 km S Kirchfidisch, at the abandoned Quarry Hohensteinmaißberg (Baron von Kottwitz Quarry; N 47°08′55″ / E 16°21′01″), c. 1.3 km S Kirchfidisch, at the overgrown quarry W Georgshof (N 47°09′43″ / E 16°23′38″), c. 3.1 km ENE Kirchfidisch and at the southern hillside of the Königsberg Mountain (N 47°13′01″ / E 16°23′08″), c. 1.5 km SSE Hannersdorf.

Derivation of name: After the village Kirchfidisch (municipality Kohfidisch), c. 18 km SE Oberwart and the Königsberg hill (350 m a.s.l.) in the municipality Hannersdorf, c. 6.8 km NNE Kirchfidisch, both c. 71 km ENE Graz, Burgenland.

Synonyms: Süßwasserkalk (WINKLER, 1927c), Süßwasserkalk von Kirchfidisch und Königsberg (KOLLMANN, 1960b), (partim) Blaue Serie (KÜMEL, 1957), (partim) Sand-Folge (op_3) (NEBERT, 1979).

Lithology: Yellowish to grey limestone and marl.

Fossils: Various freshwater and terrestrial gastropods, rare micro-mammals (SAUERZOPF, 1950, 1952, 1953a, b; KÜMEL, 1957; NEBERT, 1979); note the close-by cave and fissure fillings of Kohfidisch with its rich vertebrate fauna (e.g., BACHMAYER & ZAPFE, 1969; RÖGL et al., 1993; DAXNER-HÖCK, 2004b; ZIEGLER & DAXNER-HÖCK, 2005; VISLOBOKOVA, 2007; DAXNER-HÖCK et al., 2016).

Origin, facies: Limnic (littoral).

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian).

Biostratigraphy: Regional mollusc Zone "H" (SAUERZOPF, 1950, 1952; KOLLMANN, 1965).

Thickness: Several meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Paleozoic basement, erosional contact (conglomerates, breccias).

Overlying unit(s): Erosional boundary.

Lateral unit(s): KÜMEL (1957) correlated the Kirchfidisch-Königsberg Freshwater Limestone with the Csater-Berg Opalite (see below and compare HARZHAUSER et al., 2019b).

Geographic distribution: Beside the type area, SAUERZOPF (1990) referred to an occurrence in the area of Rudersdorf in Southern Burgenland, c. 3 km ENE Fürstenfeld; ÖK50-UTM, map sheet 5225 Fürstenfeld (ÖK50-BMN, map sheet 167 Güssing).

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Opalite vom Csater-Berg / Csater-Berg Opalite

MATHIAS HARZHAUSER

Validity: Invalid; described as opalite from Csatherberg or Tschaterberg by BENDA (1929), KÜMEL (1957), HARZHAUSER et al. (2019b).

Type area: Not defined; three isolated occurrences exist on the Klein-Csater-Berg (365 m a.s.l.) and the Hoch-Csater-Berg (341 m a.s.l.), c. 3 km E of the village Kohfidisch (N 47°10′29″ / E 16°21′31″), Burgenland; ÖK50-UTM, map sheet 5226 Kohfidisch (ÖK50-BMN, map sheet 168 Eberau).

Type section: -

Derivation of name: After the hill Hoch-Csater-Berg (N 47°10′30″ / E 16°23′38″), E of the village Kohfidisch, Burgenland.

Synonyms: Süßwasseropal der Csatherberge, Opalfels (KÜMEL, 1957).

Lithology: Whitish to brownish, glossy and dense opalite and granulose-porous, lustreless opalite with numerous tube-like cavities of dissolved stalks.

Fossils: Silicified wood, terrestrial and freshwater gastropods (HARZHAUSER et al., 2019b).

Remark: Fossil wood from the "Tschaterberg Opalit" was already described by CLUSIUS (1583) representing the first scientific description of an Austrian fossil.

Origin, facies: Short-lived, shallow lake or pond with rich reed vegetation and peat formation.

Chronostratigraphic age: Late Miocene, Tortonian (late Pannonian), c. 8.9–8.0 Ma (SACCHI & HORVÁTH, 2002).

Biostratigraphy: Based on the mollusc fauna the opalite is correlated to Pannonian Zone H (HARZHAUSER et al., 2019b). The closeby mammal locality Kohfidisch is correlated with the lower Turolian European Mammal Zone MN11 (DAXNER-HÖCK & HÖCK, 2015).

Thickness: < 1 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Serpentinite of the Eisenberg crystalline (GRATZER, 1985).

Overlying unit(s): -

Lateral unit(s): The Kirchfidisch-Königsberg Freshwater Limestone might represent a time equivalent.

Geographic distribution: Csater hills E of Kohfidisch, Burgenland; ÖK50-UTM, map sheet 5226 Kohfidisch (ÖK50-BMN, map sheet 168 Eberau).

Remarks: -

Complementary references: -

Silberberg Schotter / Silberberg Gravel

MARTIN GROSS

Validity: Invalid; unit introduced by WINKLER (1921); see synonyms.

Type area: Area around Srebrni breg (= Silberberg in German), hill in northeastern Slovenia, c. 0.5 km NW of the village Martinje (municipality Gornji Petrovci), c. 9.9 km S of the town Jennersdorf; ÖK50-UTM, map sheet 5101 Jennersdorf (ÖK50-BMN, map sheet 193 Jennersdorf).

Type section: -

Reference section(s): -

Derivation of name: After the hill Silberberg (= Srebrni breg, 404 m a.s.l.), former Austrian territory, today in the Republic of Slovenia, in the Austrian/Slovenian/Hungarian-borderland, c. 9.9 km S Jennersdorf, c. 59 km SE Graz.

Synonyms: Schotter des Silberberg (WINKLER, 1921), Silberberger Schotter (WINKLER, 1927a), Jungpontikum, Silberbergschotter (WINKLER, 1927b), Präbasaltische (Silberberg-) Schotter, ältere Silberbergschotter (WINKLER-HERMADEN, 1957), Präbasaltische Schotter (Silberbergsch.) (KOLLMANN, 1960b).

Lithology: Coarse quartz-gravel with coarsening upward trend, rare siliceous slate, gneiss- and schist pebbles (WINKLER, 1927a, b; KRALJ, 2011).

Fossils: -

Origin, facies: Fluvial, alluvial fan (KRALJ, 2011).

Chronostratigraphic age: Early Pliocene, Zanclean (WINKLER-HERMADEN, 1943, 1957; WINKLER VON HERMADEN, 1951; see also WAGNER et al., 2011).

Biostratigraphy: -

Thickness: 80 m (WINKLER, 1927a, b).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Erosive (peneplain, sometimes with red loam) lower boundary above the Jennersdorf Beds; sometimes above the Gleisdorf Formation, Feldbach Formation and Paldau Formation (at Klöch and Stradner Kogel) (WINKLER, 1927a, b; WINKLER VON HERMADEN, 1951; KOLLMANN, 1965).

Overlying unit(s): Basalt and Tuff/Tuffite (at Klöch and Stradner Kogel; WINKLER, 1927a, b), erosive (peneplain) upper boundary.

Lateral unit(s): In Slovenia, these coarse clastics are integrated in the Mura Formation (KRALJ & KRALJ, 2000; KRALJ, 2006, 2011).

Geographic distribution: Type area and at the base of the Plio-/Pleistocene volcanic rocks at Klöch and Stradner Kogel in southeastern Styria. WINKLER (1927b) suggested a much wider distribution based on pebble-inclusions in tuffites ranging from the Feldbach–Riegersburg and Fürstenfeld–Fehring area in the Styrian Basin further eastwards into the Pannonian Basin (compare also WINKLER-HERMADEN, 1957); ÖK50-UTM, map sheets 5101 Jennersdorf, 5107 Sicheldorf (ÖK50-BMN, map sheets 192 Feldbach, 193 Jennersdorf).

Remarks: -

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Basalt und Tuff/Tuffit / Basalt and Tuff/Tuffite

MARTIN GROSS

Validity: Invalid; the discovery of these volcanic rocks is attributed to ANKER (1809; see BUCH, 1820); the current term is adopted from ANDRAE (1855) and KOLLMANN (1965); see synonyms.

Type area: Southeastern Styria and Southern Burgenland, area between the town Fürstenfeld in the north and the market town Klöch in the south and Feldbach in the west and Jennersdorf in the east; ÖK50-UTM, map sheets 4106 Feldbach, 4112 Bad Radkersburg, 4230 Gleisdorf, 5101 Jennersdorf, 5225 Fürstenfeld (ÖK50-BMN, map sheets 166 Fürstenfeld, 167 Güssing, 192 Feldbach, 193 Jennersdorf).

Type section: -

Remark: The sections around the village Altenmarkt bei Riegersburg (N 47°00′18″ / E 15°54′40″), c. 6 km NNE of the town Feldbach, c. 37 km ESE Graz, might be used to define this unit due to the exposure of a wide range of volcanic rock variations (FRITZ, 1996a, b, 2000, 2015).

Reference section(s): -

Remark: For the tuffitic part and the also included maar lake sediments the sections around the hamlet Beistein (N 46°54′36″ / E 16°00′51″), c. 2.6 km SSE of the town Fehring, at the village Burgfeld (N 46°55′07″ / E 16°00′25″), c. 2 km SSW Fehring and the market town Gnas (N 46°52′16″ / E 15°50′24″), c. 10 km SW of the town Feldbach may serve as reference sections (BERTOLDI et al., 1983; PÖSCHL, 1991; GROSS et al., 2007a).

Derivation of name: Refers to the lithology.

Synonyms: This unit is mentioned in the literature either by using chronostratigraphic/genetic terms, e.g., Jungpontische Eruptivgesteine (WINKLER, 1927a), Jungpliozäner basaltischer Zyklus (KOLLMANN, 1965), Plio-/Pleistozäne Vulkanite (EBNER & SACHSENHOFER, 1991) or geographic names for each volcanic area/section, e.g., Basaltdecke des Hochstraden (WINKLER, 1913a), Volcaniclastic deposits at Beistein near Fehring (PÖSCHL, 1991), Volcanic area of Altenmarkt near Riegersburg (FRITZ, 1996a). ANKER (1809) reported about minerals found in these volcanics; BUCH (1820) named these occurrences "basaltische Conglomeratberge", ANDRAE (1855) subsumed these rocks as "Basalt, Basalttuff und Basaltconglomerat" and KOLLMANN (1965) as "Basalte, Basalttuffe und Tuffite".

Lithology: Diverse volcanics or genetically associated rocks like various basanites, scoriaceous basanites, tephra, different types of tuffs and tuffites, xenoliths and pelites, fine sands and conglomerates (e.g., WINKLER 1913a, 1927a; WINKLER-HERMADEN, 1957; HERITSCH & HÜLLER, 1975; HERITSCH, 1976; KURAT et al., 1980; PÖSCHL, 1991; FRITZ, 1996a; VASELLI et al., 1996; DOBOSI et al., 1999; FALUS et al., 2000; MOGESSIE et al., 2005; COLTORTI et al., 2007; GROSS et al., 2007a; TÖRÖK et al., 2014).

Fossils: Rare; wood and leaf remains, insects, freshwater gastropods, bivalves and ostracods in pyroclastic rocks and/or maar lake deposits (e.g., WINKLER, 1927a; MEIXNER, 1938; WINKLER-HERMADEN, 1939; KORITNIG & MEIXNER, 1989; GROSS et al., 2007a).

Origin, facies: Alkali basaltic volcanism in form of lava ex- and intrusions, phreatomagmatic eruptions and crater (maar) lake deposits (WINKLER, 1913a; WINKLER-HERMADEN, 1957; MURBAN, 1939; PÖSCHL, 1991; FRITZ, 1996a; KRALJ, 2000a, b; GROSS et al., 2007a; see also SEGHEDI et al., 2004a).

Chronostratigraphic age: Pliocene, Zanclean–Piacenzian; possibly ranging from the late Miocene, Tortonian (7.51 ± 0.09 Ma) to the Early Pleistocene (1.71 ± 0.72 Ma; BALOGH et al., 1994; SEGHEDI et al., 2004b; BOJAR et al., 2013; SCHNEPP et al., 2021).

Biostratigraphy: -

Thickness: More than 100 m in outcrops (e.g., Steinberg, Klöch, Stradner Kogel, Riegersburg, Kapfenstein).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): This unit cuts the older units discordantly (Pre-Neogene basement, Miocene volcanics (Gleichenberg Volcanics), Miocene and Pliocene sediments) and rests upon or interlocks with them. It overlies mainly Sarmatian and Pannonian sediments. Occasionally, the Pliocene Silberberg Gravel is observed at the lower boundary (WINKLER, 1927a, b).

Overlying unit(s): Postbasaltic Gravel, erosive upper boundary.

Lateral unit(s): Lithologically and genetically similar rocks occur outside the Styrian Basin east of the South Burgenland Swell in the area of Güssing in Southern Burgenland and at Grad (formerly Oberlimbach; c. 10 km SE St. Anna am Aigen) in northeastern Slovenia (WINKLER, 1913a; SAUERZOPF, 1986; KRALJ, 2006, 2011). They might be included in a formalized formation later on. KRALJ (2006) used the term "Grad Member" (Mura Formation) and JELEN & RIFELJ (2011) "Popovšček Member" (Ptuj-Grad Formation) for occurrences in northeastern Slovenia.

Geographic distribution: Southeastern Styrian and Southern Burgenland downs and in the Goričko region in northeastern Slovenia (compare BOJAR et al., 2013); ÖK50-UTM, map sheets 4106 Feldbach, 4112 Bad Radkersburg, 4230 Gleisdorf, 5101 Jennersdorf, 5225 Fürstenfeld (ÖK50-BMN, map sheets 166 Fürstenfeld, 167 Güssing, 192 Feldbach, 193 Jennersdorf).

Remarks: A huge amount of literature exists dealing with mineralogic and petrologic aspects of this unit (e.g., TAUCHER et al., 1989; POSTL et al., 1992; TAUCHER & HOLLERER, 2001; VASELLI et al., 1996; DOBOSI et al., 1999; COLTORTI et al., 2007). However, at least for the basaltic part of this unit a concise geologic description is still lacking. The geology of these volcanics is still based on various publications of WINKLER-HERMADEN (e.g., WINKLER, 1913a, 1927a; WINKLER-HERMADEN, 1939, 1957).

Complementary references: FUCHS (1980c), TOLLMANN (1985), PILLER et al. (2004).

Postbasaltische Schotter / Postbasaltic Gravel

MARTIN GROSS

Validity: Invalid; name introduced by WINKLER (1921); see synonyms.

Type area: Stradner Kogel, hill (609 m a.s.l.) in southeastern Styria, c. 12 km SSE Feldbach, c. 45 km SE Graz; ÖK50-UTM, map sheet 4106 Feldbach (ÖK50-BMN, map sheet 192 Feldbach).

Type section: -

Reference section(s): -

Derivation of name: Name refers to gravel above the Basalt and Tuff/Tuffite.

Synonyms: Nachbasaltische Schotterüberdeckung (WINKLER, 1921), Postbasaltische Lehme und Sande am Hochstraden (WINKLER, 1927a), nachbasaltische Schotterbedeckung (WINKLER, 1927b), höhere Silberbergschotterserie (WINKLER-HERMADEN, 1957), postbasaltische Schotter (KOLLMANN, 1960b), post-basaltic Gravel (GROSS et al., 2007a).

Lithology: Fine to coarse gravels (quartz pebbles), but also loams and residual soils.

Fossils: -

Origin, facies: Fluvial.

Chronostratigraphic age: Pliocene, Zanclean–Piacenzian; possibly even Early Pleistocene according age datings of the underlying volcanic rocks (BALOGH et al., 1994; WAGNER et al., 2011).

Biostratigraphy: -

Thickness: Occurs only in form of scattered pebbles, more or less embedded into loams and residual soils. WINKLER (1927a) reports a thickness of several meters and postulates an original thickness of several tens of meters (WINKLER-HERMADEN, 1957).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Rests with erosional lower boundary on the intensively weathered Basalt and Tuff/Tuffite.

Overlying unit(s): Erosional upper boundary.

Lateral unit(s): In neighbouring Slovenia, these coarse clastics are integrated in the Mura Formation (Kralj & Kralj, 2000; Kralj, 2006) or Ptuj-Grad Formation (Jelen & Rifelj, 2011).

Geographic distribution: Eastern Styrian downs, at the plateaus of volcanic hills (e.g., Stradner Kogel, Seindl, Steinberg, Gleichenberger Kogel, Zinsberg) (Winkler, 1927a; Winkler-Hermaden, 1943, 1957; Pöschl, 1991).

Remarks: -

Complementary references: Kollmann (1965), Fuchs (1980c), Tollmann (1985), Ebner & Sachsenhofer (1991), Piller et al. (2004).

Fohnsdorf Basin

Martin Gross

The Fohnsdorf Basin is the largest of a series of intramontane basins (Noric Depression) within the Eastern Alps. This c. 22 km long, 11 km wide and more than 2,000 m deep basin is situated upon Austroalpine metamorphic complexes and formed at the crossing point of the sinistral NE-trending Mur-Mürz- and the dextral SE-trending Pöls-Lavanttal-fault system (Text-Fig. 10). During an initial pull-apart phase around the early/middle Miocene boundary, fluvio-deltaic sediments with an up to 15 m thick coal seam on top were deposited (Fohnsdorf Formation). Increased subsidence caused the development of lacustrine (partly brackish) and deltaic environments in early and middle Badenian times (Ingering Formation). Subsequently, the strike-slip basin turned into a half-graben and alluvial sedimentation (Apfelberg Formation) dominated in the middle to late Badenian.

In depth information to the Fohnsdorf Basin are given by e.g., Polesny (1970), Sachsenhofer et al. (2000a, b, 2003, 2010b), Strauss et al. (2001, 2003), Hölzel & Wagreich (2004) and Wagreich & Strauss (2005).

All three lithostratigraphic units at formation rank of the Fohnsdorf Basin have been formalized by Strauss et al. (2003).

Fohnsdorf-Formation / Fohnsdorf Formation

Martin Gross

Validity: Valid; name introduced by Strauss & Wagreich (1999); formalized by Strauss et al. (2003).

Type area: In the area of the town Fohnsdorf and at the northern margin of the Fohnsdorf Basin (Strauss et al., 2003); ÖK50-UTM, map sheets 4220 Pöls, 4221 Knittelfeld (ÖK50-BMN, map sheets 161 Knittelfeld, 162 Köflach).

Text-Fig. 10.
Location of the Fohnsdorf and Lavanttal basins (grey shaded).

Type section: Abandoned open cast mine Dietersdorf (N 47°12′40″ / E 14°39′20″), c. 1.7 km WNW Fohnsdorf, c. 4.8 km NNW Judenburg (Strauss et al., 2003; compare Weber & Weiss, 1983; Sachsenhofer et al., 2000a; Gruber et al., 2012); ÖK50-UTM, map sheet 4220 Pöls (ÖK50-BMN, map sheet 161 Knittelfeld).

Reference section(s): -

Remark: The abandoned calcareous sinter quarry Maria Buch, c. 3.6 km SE Judenburg (N 47°09′08″ / E 14°42′14″) (Sachsenhofer et al., 2000a; Strauss et al., 2003; Gruber et al., 2012) could act as reference section; compare also the log of the well Gabelhofen Thermal 1 (N 47°11′38″ / E 14°40′30″; c. 1.7 km SSW Fohnsdorf) in Sachsenhofer et al. (2000a, b, 2003, 2010b).

Derivation of name: After the town Fohnsdorf, c. 4.7 km NNE of the town Judenburg, c. 60 km WNW of the city Graz, Styria.

Synonyms: (partim) Conglomerat von Fohnsdorf, Kohlenflötz von Fohnsdorf (Stur, 1864), Liegend-Breccie, Liegendsandstein, Fohnsdorfer Kohle (Petrascheck, 1922/1924), Basisbrekzie, Liegendsandstein mit Konglomeratlagen, Kohle: Fohnsdorfer Horizont (Polesny, 1970), Lower complex (Liegendserie) and Coal seam (Sachsenhofer et al., 2000b).

Lithology: Coarse clastics (basal breccia, conglomerate, sand and coal seams up to 12–15 m thickness) with general fining-upward trend; tuff layers in the upper part (Sachsenhofer et al., 2000b, 2010b; Bechtel et al., 2001; Gruber & Sachsenhofer, 2001).

Fossils: Plant remains, gastropods, bivalves, reptiles, mammals (Mottl, 1961a, 1970; Weber & Weiss, 1983; Gross, 2003b).

Origin, facies: Debris flow, fluvial, deltaic and limnic deposits; probably some brackish/marine influx (Sachsenhofer et al., 2003; Strauss et al., 2003).

Chronostratigraphic age: Early Miocene, Burdigalian (?early to late Karpatian) to middle Miocene, Langhian (early Badenian) (Strauss et al., 2003).

Remark: The zircon fission track age (17.1 ± 0.7 Ma) of a tuff layer at Laas (c. 10.3 km NE Knittelfeld), however, outside the Fohnsdorf Basin s.str., might indicate an onset of deposition of the Fohnsdorf Formation already in the early Karpatian (Ebner et al., 2002; Sachsenhofer et al., 2010b).

Biostratigraphy: Probably Neogene mammal Zone MN5 (compare MOTTL, 1961a, 1970; POLESNY, 1970; GAUDANT, 2010).

Thickness: Up to 800 m (SACHSENHOFER et al., 2000b).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided into “Basisbrekzie”, “Liegendsandstein mit Konglomeratlagen”, “Kohle: Fohnsdorfer Horizont” (POLESNY, 1970; WEBER & WEISS, 1983; SACHSENHOFER et al., 2000b).

Underlying unit(s): Rests discordantly on the crystalline basement.

Overlying unit(s): Ingering Formation (sapropelitic pelites or *Congeria*-debris layers).

Lateral unit(s): -

Geographic distribution: Fohnsdorf and Seckau Basin (Upper Mur Valley); ÖK50-UTM, map sheets 4220 Pöls, 4221 Knittelfeld, 4226 Judenburg, 4227 Zeltweg (ÖK50-BMN, map sheets 131 Kalwang, 132 Trofaiach, 161 Knittelfeld, 162 Köflach).

Remarks: Mining of the coal seam started in the year 1675 and the mine was closed 1977 (WEBER & WEISS, 1983; SACHSENHOFER et al., 2000a).

Complementary references: TOLLMANN (1985), STRAUSS et al. (2001).

Ingering-Formation / Ingering Formation

MARTIN GROSS

Validity: Valid; name introduced by STRAUSS & WAGREICH (1999); formalized by STRAUSS et al. (2003).

Type area: Valley of the creek Ingeringbach and northern margin of the Fohnsdorf Basin (STRAUSS et al., 2003); ÖK50-UTM, map sheets 4220 Pöls, 4221 Knittelfeld (ÖK50-BMN, map sheet 161 Knittelfeld).

Type section: Cut banks of the creek Ingeringbach (N 47°13′25″ / E 14°46′55″), c. 3.8 km WNW of the town Knittelfeld (STRAUSS et al., 2003; compare HÖLZEL & WAGREICH, 2004; HÖLZEL et al., 2006; for early mentions see MORLOT, 1848; STUR, 1864); ÖK50-UTM, map sheet 4221 Knittelfeld (ÖK50-BMN, map sheet 161 Knittelfeld).

Remark: In the type section only the lower part of the formation is exposed (HÖLZEL & WAGREICH, 2004).

Reference section(s): -

Remark: Additional lithological information provide the sections c. 0.3 km N of the village Sillweg (N 47°13′11″ / E 14°42′04″; c. 2.1 km NE Fohnsdorf) and c. 0.5 km WNW of the village Flatschach (N 47°13′08″ / E 14°44′46″; c. 3.4 km NNW Zeltweg) (SACHSENHOFER et al., 2000a, 2010b; STRAUSS et al., 2003; GRUBER et al., 2012) and the logs of the wells in SACHSENHOFER et al. (2000b, 2003).

Derivation of name: After the creek Ingeringbach, tributary of the Mur River merging SW of the town Knittelfeld, c. 49 km NW of the city Graz, Styria.

Synonyms: (partim) Hangendmergel, Mergelschiefer, etc. (PETRASCHECK, 1922/1924), (partim) Fohnsdorfer Muschelkalk (KIESLINGER, 1953), Hangendschichten (inclusively “Brandschiefer”, “Fohnsdorfer Muschelkalk (Congerienbank I)”, “Hangendmergel”, “Congerienbank II”, “Tonige Hangendschichten mit Sandstein- und Feinschotterlagen”) (POLESNY, 1970), Upper complex (Hangendserie) (SACHSENHOFER et al., 2000b).

Lithology: Pelite, sand, conglomerates (coarsening-upward); tuffitic and coquinoid limestone intercalations (STRAUSS et al., 2003; HÖLZEL & WAGREICH, 2004).

Fossils: Algae and plant remains (leaves, cones, pollen), gastropods, bivalves, ostracods, fishes, rarely reptiles and mammals (ETTINGSHAUSEN, 1853b; STUR, 1864; MOTTL, 1970; POLESNY, 1970; WEBER & WEISS, 1983; HIDEN, 2002; HÖLZEL & WAGREICH, 2004; GAUDANT, 2010).

Origin, facies: Limnic (with some brackish/marine influence), prodelta, delta front and delta plain succession (SACHSENHOFER et al., 2000b, 2003; STRAUSS et al., 2001, 2003; HÖLZEL & WAGREICH, 2004).

Chronostratigraphic age: Middle Miocene, Langhian (early to middle Badenian) (SACHSENHOFER et al., 2000b; STRAUSS et al., 2003). EBNER et al. (2002; compare EBNER et al., 2000) report a zircon fission track age of 14.9 ± 0.7 Ma for the uppermost tuff horizon in the Ingering Formation (section Flatschach; see reference sections).

Biostratigraphy: Probably Neogene mammal Zone MN5 (compare MOTTL, 1961a, 1970; POLESNY, 1970; GAUDANT, 2010).

Thickness: Up to 2,000 m (STRAUSS et al., 2003).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision; informal subdivision of the “Hangendschichten” in the synonyms (POLESNY, 1970).

Underlying unit(s): Coals of the Fohnsdorf Formation.

Overlying unit(s): Apfelberg Formation (discordant hanging wall boundary) or Quaternary sediments.

Lateral unit(s): -

Geographic distribution: Fohnsdorf and Seckau Basin (Upper Mur Valley); ÖK50-UTM, map sheets 4220 Pöls, 4221 Knittelfeld and subsurface 4226 Judenburg, 4227 Zeltweg (ÖK50-BMN, map sheets 131 Kalwang, 132 Trofaiach, 161 Knittelfeld, 162 Köflach).

Remarks: -

Complementary references: TOLLMANN (1985).

Apfelberg-Formation / Apfelberg Formation

MARTIN GROSS

Validity: Valid; name introduced by STRAUSS & WAGREICH (1999); described and formalized by STRAUSS et al. (2003).

Type area: Southeastern margin of the Fohnsdorf Basin (STRAUSS et al., 2003); ÖK50-UTM, map sheets 4221 Knittelfeld, 4227 Zeltweg (ÖK50-BMN, map sheets 161 Knittelfeld, 162 Köflach).

Type section: Composite-stratotype; section of the clay pit of the brickyard Apfelberg (N 47°11′51″ / E 14°50′27″),

c. 1.9 km SSE of the town Knittelfeld and forest road cuts (N 47°13′11″ / E 14°54′20″), c. 0.7 km NW of the village Rachau, c. 5.8 km E Knittelfeld (Strauss et al., 2003; compare Sachsenhofer et al., 2000a; Wagreich & Strauss, 2005; Gruber et al., 2012); ÖK50-UTM, map sheets 4221 Knittelfeld, 4227 Zeltweg (ÖK50-BMN, map sheet 162 Köflach).

Reference section(s): -

Remark: The sections in the ditch of the brook Fötschachbach (N 47°14′51″ / E 14°55′09″; c. 7.8 km NE Knittelfeld), of the forest road cut (N 47°09′47″ / E 14°50′36″), c. 0.4 km SSW of the farmhouse Gföller (c. 5.7 km SSE Knittelfeld) and at the Sulzberg (N 47°15′32″ / E 14°52′31″), c. 6.1 km NE Knittelfeld, might act as reference sections. At Fötschachbach and Gföller the contact to the basement and at Sulzberg the contact to the Ingering Formation were exposed (Strauss et al., 2003; compare Gruber et al., 2012).

Derivation of name: Named after the brickyard Apfelberg (municipality Knittelfeld), c. 1.9 km SSE of the town Knittelfeld, c. 47 km WNW of the city Graz, Styria.

Synonyms: (partim) Belvedere-Schotter (Stur, 1864), Blockschotter (Polesny, 1970), Boulder gravel (Blockschotter) (Sachsenhofer et al., 2000b).

Lithology: Coarse conglomerates, boulder gravels and gravel layers; subordinately sand, coal and tuffitic layers (Strauss et al., 2003).

Fossils: Plant remains, gastropods, vertebrates (amphibians, reptiles, mammals) (Strauss et al., 2003).

Origin, facies: Mainly mass flows on alluvial fans but also flood plain and lacustrine fan delta environment (Strauss et al., 2003).

Chronostratigraphic age: Middle Miocene, Langhian to early Serravallian (middle to late Badenian) (Strauss et al., 2003). Fission track dating of a tuff-layer in the brickyard Apfelberg yielded an age of 15.5 ± 0.8 Ma (Ebner et al., 2002) which is older than the age estimation based on mammals (< 14.9 Ma).

Biostratigraphy: Neogene mammal Zone MN6 (Strauss et al., 2003).

Thickness: Around 1,000 m (Strauss et al., 2003).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: No formal subdivision; Strauss et al. (2003; see Wagreich & Strauss, 2005; see also Polesny, 1970) distinguished a northeastern “Rachau fan” and a south-western “Apfelberg fan” based on lithological and facial differences (NE: sandy matrix and large boulders derived from the gneiss and amphibolite dominated hinterland; SW: higher pelite content and smaller clasts derived from micaschist and marble source areas).

Underlying unit(s): Overlies discordantly the Ingering Formation or crystalline basement (Strauss et al., 2003).

Overlying unit(s): Erosive upper boundary or overlain by Quaternary sediments.

Lateral unit(s): -

Geographic distribution: Corresponds to the type area and occurrences at the hills Zuckenhut (756 m a.s.l.) and Sulzberg (711 m a.s.l.; about 5.5 km NE Knittelfeld; note: “Eichberg-Zuckerhut” and “Sülzberg” in Strauss et al., 2003); ÖK50-UTM, map sheets 4221 Knittelfeld, 4227 Zeltweg (ÖK50-BMN, map sheets 132 Trofaiach, 161 Knittelfeld, 162 Köflach).

Remarks: -

Complementary references: Tollmann (1985), Strauss et al. (2001), Sachsenhofer et al. (2003, 2010b).

Lavanttal Basin

Martin Gross

The Lavanttal Basin is an up to 28 km long, maximal 12 km wide and up to 2,000 m deep pull-apart basin, which is located in the eastern part of Carinthia between the metamorphic mountain ranges of the Saualpe and the Koralpe (Text-Fig. 10). Basin formation is intimately linked with the still active dextral Lavanttal-fault system, which connects the Noric Depression in the North with the Periadriatic Lineament in the South. In early Miocene times (?Ottnangian) basin filling started in the south-western part in the W–E-trending Granitztal Subbasin with fluvial and limnic sediments (Granitztal Formation). Around the early/middle Miocene boundary the depocentre changed into a NW–SE orientated basin. Lacustrine and marine environments evolved (Mühldorf Formation), which were influenced by early Badenian sea level changes as well as by basaltic intrusions and pyroclastic eruptions (Kollnitz Basalt). Lacustrine-fluvial, fine clastics (Lower Freshwater Beds) were deposited subsequently (late Badenian). Fluvial gravels (Dachberg Formation) interfinger with these strata and with lower Sarmatian, limnic-swampy and partly marginal marine sediments (Fresh- and Brackish Water Beds). Above an unconformity, non-marine, limnic-swampy conditions became established in the late Sarmatian (Kuchl Beds) and turned into fluvial-limnic and alluvial fan facies (Upper Freshwater Beds) in early Pannonian times. During the late Pliocene to earliest Pleistocene, alluvial fan and fluvial sediments (Reideben Gravel) were deposited.

Particularly, the publications of Winkler-Hermaden (1937), Beck-Mannagetta (1952), Ebner & Sachsenhofer (1991), Reischenbacher et al. (2007) and Reischenbacher & Sachsenhofer (2013) provide comprehensive data for the Lavanttal Basin.

None of the nine herein listed lithostratigraphic units (at formation rank) of the Lavanttal Basin have been formalized yet.

Granitztal-Formation / Granitztal Formation

Martin Gross

Validity: Invalid; first mentioned by Lipold (1854); name introduced by Beck (1928); used as formation by Reischenbacher et al. (2007).

Type area: South-eastern foothills of the Saualpe (downs between the market towns Griffen and St. Paul im Lavanttal) and downs NE St. Paul im Lavanttal, Carinthia; ÖK50-UTM, map sheet 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheets 204 Völkermarkt, 205 Sankt Paul im Lavanttal).

Type section: -

Reference section(s): -

Remark: Beck-Mannagetta (1952) mentioned several outcrops (e.g., at the main road between St. Andrä im Lavanttal and Griffen in the area of Langegg; see also Dreger, 1907; Beck-Mannagetta, 1951). Reischenbacher et al. (2007) provide logs through the upper part of the Granitztal Formation.

Derivation of name: Named after the valley of the creek Granitzbach, c. 5 km WNW St. Paul im Lavanttal, western tributary of the river Lavant, Carinthia.

Synonyms: Schotter und Conglomerate [...] an dem Gebirgsrücken zwischen dem Granitzthale und der Griffener Ebene (Lipold, 1854), Granitztalschotter (Beck, 1928), Granitztaler Schichten (Winkler-Hermaden, 1937), Granitztaler Schotter (Winkler-Hermaden, 1943), (partim) Blockschotter von St. Marein-St. Margarethen (Winkler-Hermaden, 1943), Granitztaler Schichten [including the “Blockschotter des Pichlingkogels und Herzogberges”] (Beck-Mannagetta, 1952), (partim) St. Margarethener Schotter (Beck-Mannagetta, 1952), (partim?) Schichten von Schönweg (Beck-Mannagetta, 1952), Granitztaler Schichten und Basisschichten im Lavanttal (Fuchs, 1980c), St. Margarethen Gravel (Reischenbacher et al., 2007), Granitztal Beds, St. Margarethen Gravel (Reischenbacher & Sachsenhofer, 2013).

Lithology: Boulder gravel, gravel/conglomerate, sand, pelite, coal (with fining-upward trend).

Fossils: Plant remains, freshwater gastropods and bivalves, fish remains (Beck-Mannagetta, 1952).

Origin, facies: Fluvial, limnic, debris flows.

Chronostratigraphic age: Early Miocene, Burdigalian (?Ottnangian–Karpatian) to middle Miocene, Langhian (early Badenian) (Beck-Mannagetta, 1952; Fuchs, 1980c; Reischenbacher et al., 2007).

Biostratigraphy: See remarks.

Thickness: Up to 800 m (Beck-Mannagetta, 1952; Ebner & Sachsenhofer, 1991; Reischenbacher et al., 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided into the “Lower Granitztal Beds” (mainly coarse clastics) and “Upper Granitztal Beds” (mainly sandy sediments; Beck-Mannagetta, 1952; Ebner & Sachsenhofer, 1991).

Underlying unit(s): Crystalline and Mesozoic basement.

Overlying unit(s): Mühldorf Formation.

Lateral unit(s): Beck-Mannagetta & Draxler (1987) consider the “Schichten von Schönweg” as equivalents of the Mühldorf Formation (see remarks). Beck-Mannagetta (1952) discussed a correlation to the “Schwanberger Schotter” (Schwanberg Formation) and the “Kreuzbergschotter und Urler Blockschutt” (Kreuzberg Formation) of the Styrian Basin (see also Winkler-Hermaden, 1937, 1943; Ebner & Sachsenhofer, 1991; Reischenbacher & Sachsenhofer, 2013).

Geographic distribution: In the type area and NW (N of St. Margarethen im Lavanttal) and SW (W of St. Marein) of the town Wolfsberg, Eastern Carinthia; ÖK50-UTM, map sheets 4103 Wolfsberg, 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheets 187 Bad Sankt Leonhard im Lavanttal, 204 Völkermarkt, 205 Sankt Paul im Lavanttal).

Remarks: The quite fossil-rich, freshwater “Schichten von Schönweg” with the “Schotter v[on]. Schönweg” and the “Tone u[nd]. Mergel v[on]. Schönweg” (Beck-Mannagetta, 1952), c. 7.5 km NW St. Paul im Lavanttal, are questionably assigned here to the (“Upper”) Granitztal Formation (compare Ebner & Sachsenhofer, 1991). However, it is possible that only the “Schotter von Schönweg” (formerly exposed in the pit Schönweg-“Brüchl”; N 46°44′37″ / E 14°48′01″; Klaus & Gross, 2010; Hyžný & Gross, 2016b; Prieto et al., 2016, 2019, 2021, 2022) can be related to the Granitztal Formation. Perhaps, the “Tone und Mergel von Schönweg” with an intercalated brown coal seam and a tuff layer are an equivalent of the Mühldorf Formation (Beck-Mannagetta & Draxler, 1987; for fossil content see, e.g., Hofmann, 1929; Beck-Mannagetta, 1952; Berger, 1955b; Mottl, 1967; Knobloch, 1977; Rauscher, 1984; Rabeder, 1984, 1986; Wank, 1991). The mammalian faunas of the “Schichten von Schönweg” are biostratigraphically allocated to the Neogene mammal Zone MN5 (late Karpatian to early Badenian; Daxner-Höck & Höck, 2015; Prieto et al., 2016).

Complementary references: Tollmann (1985).

Mühldorf-Formation / Mühldorf Formation

Martin Gross

Validity: Invalid; name introduced by Höfer (1892); used as formation by Reischenbacher et al. (2007).

Type area: Region at the southern slopes of the Dachberg, N of the market town St. Paul im Lavanttal, Carinthia; ÖK50-UTM, map sheet 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheet 205 Sankt Paul im Lavanttal).

Type section: -

Remark: As type section can be considered the section at the cut banks of the creek Hahntrattenbach (Gemmersdorferbach in Beck-Mannagetta, 1952), c. 4.2 km NNE St. Paul im Lavanttal (N 46°44′04″ / E 14°51′48″) (Höfer, 1892; Beck-Mannagetta, 1952).

Reference section(s): -

Remark: Reischenbacher et al. (2007) provide logs through the Mühldorf Formation.

Derivation of name: After the village Mühldorf, c. 4.1 km NNW St. Paul im Lavanttal, Carinthia.

Synonyms: (partim?) Tegel vom Dachberg (LIPOLD, 1854), Blaugraue Mergel mit Badener Versteinerungen (STUR, 1855), (partim) Tegel mit *Pecten cristatus* (PENECKE, 1886), (partim) Mühldorfer Schlier, Mühldorfer Schichten (HÖFER, 1892), Mühldorfer Schichten [including "Cardienbank" and "Cardienmergel"] (BECK-MANNAGETTA, 1952), Schichten von Mettersdorf (PAPP, 1952), Mühldorf Formation [inclusively the "*Cardia* marl" and "Microfauna with *Ammonia beccarii*"] (REISCHENBACHER et al., 2007).

Lithology: Lower part (lacustrine "Fish shale"): laminated mudstone, shaly marl with silt and fine-grained sand layers; upper part ("marine upper part"): mudstone, shaly marl, silt and sand layers (coarsening-upward trend), tuffite and coal layers (BECK-MANNAGETTA, 1952; REISCHENBACHER et al., 2007).

Fossils: Plant remains, calcareous nannoplankton, foraminifers, corals, gastropods, bivalves, scaphopods, nautilids, bryozoans, ostracods, decapods, insects, echinoids, fishes, reptiles, birds (BECK-MANNAGETTA, 1952; WEINFURTER, 1952; KÜHN, 1963; SCHMID, 1974; WANK & STOJASPAL, 1980; REISCHENBACHER et al., 2007; NOLF & BRZOBOHATÝ, 2009; MELLER et al., 2015; HARZHAUSER et al., 2016; SCHÄDEL & LECHNER, 2017; HOFMANN & LICHTENWAGNER, 2020; HAPP et al., 2022).

Origin, facies: Lower part ("Fish shale"): limnic with anoxic conditions and some brackish water influx; upper part ("marine upper part"): marine (outer shelf) to marginal marine (shallowing upward trend) (REISCHENBACHER et al., 2007).

Chronostratigraphic age: ?Early Miocene, Burdigalian (?Karpatian) to middle Miocene, Langhian (early–middle Badenian).

Biostratigraphy: Foraminifera zone: upper part of Zone M5b (Central Paratethyan Ecobiozone Lower Lagenidae Zone), nannofossil Zone NN5, ostracod Zone NO7 (for the "marine upper part"; REISCHENBACHER et al., 2007).

Thickness: About 270 m (REISCHENBACHER et al., 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided into a lower lacustrine part ("Fish shale") and a "marine upper part".

Underlying unit(s): Granitztal Formation.

Overlying unit(s): Lower Freshwater Beds (BECK-MANNAGETTA, 1952; REISCHENBACHER et al., 2007).

Lateral unit(s): BECK-MANNAGETTA & DRAXLER (1987) regard the "Schichten von Schönweg" as equivalents of the Mühldorf Formation (see remarks to the Granitztal Formation). REISCHENBACHER et al. (2007) discuss a possible correlation of the lowermost parts of the Weissenegg Formation (Styrian Basin) with the "marine upper part" of the Mühldorf Formation and probably coeval strata of the Mura-Zala Basin in Northern Slovenia (see HOHENEGGER et al., 2009c; compare also WINKLER-HERMADEN, 1937; BECK-MANNAGETTA, 1952).

Geographic distribution: Lavanttal, Eastern Carinthia; ÖK50-UTM, map sheet 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheet 187 Bad Sankt Leonhard im Lavanttal, 205 Sankt Paul im Lavanttal).

Remarks: According to REISCHENBACHER et al. (2007), the "marine upper part" of the Mühldorf Formation is of early Badenian age and the lower part ("Fish shale") is possibly of Karpatian age. Later, REISCHENBACHER & SACHSENHOFER (2013) allocate the Mühldorf Formation entirely to the early Badenian.

Complementary references: FUCHS (1980c), TOLLMANN (1985).

Kollnitzer Basalt / Kollnitz Basalt

MARTIN GROSS

Validity: Invalid; first mention by KEFERSTEIN (1829).

Type area: Only known from one isolated outcrop NW of the market town St. Paul im Lavanttal, Carinthia; ÖK50-UTM, map sheet 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheet 205 Sankt Paul im Lavanttal).

Type section: -

Remark: The Kollnitz Basalt crops out only in the abandoned quarry at the village Hundsdorf (N 46°42′47″ / E 14°51′08″), c. 2.2 km NW St. Paul im Lavanttal (e.g., WINKLER-HERMADEN, 1954).

Reference section(s): -

Derivation of name: After the former farmstead near the quarry (actual name: "Kampach") of the "Kollnitzer" dynasty, c. 2.2 km NW St. Paul im Lavanttal, Carinthia.

Synonyms: [...] schmücken die Ruinen des alten verfallenen Schlosses Gollnitz einen Berg, der aus Basalt bestehet, [...] (KEFERSTEIN, 1829), Basalt [...] bei Kollnitz (ROSTHORN & CANAVAL, 1853), [...] nächst dem Kollnitzer Meierhofe bei St. Paul eine kleine Basaltkuppe [...] (LIPOLD, 1856), Basalt von Kollnitz (PROHASKA, 1886), Basalt vom Lavant-Tal (LIPPOLT et al., 1975), basaltischer Andesit von Kollnitz (EBNER & SACHSENHOFER, 1991), Kollnitz basalt (REISCHENBACHER et al., 2007).

Lithology: Basalt/basaltic andesite and tuffite (SCHOKLITSCH, 1933; MEIXNER, 1953; ZIRKL, 1962; KOLMER, 1980b; SERRI et al., 1996).

Fossils: None; only in the form of xenoliths (plant remains, marine molluscs; KAHLER, 1928; HOFMANN & KAHLER, 1938; WINKLER-HERMADEN, 1954).

Origin, facies: Basaltic intrusion and pyroclastic eruptions (WINKLER-HERMADEN, 1954).

Chronostratigraphic age: Middle Miocene, Langhian (early Badenian) (LIPPOLT et al., 1975; REISCHENBACHER et al., 2007; REISCHENBACHER & SACHSENHOFER, 2013; for diverging discussion see WINKLER-HERMADEN, 1937, 1943, 1954; BECK-MANNAGETTA, 1952). K/Ar-datings of the Kollnitz Basalt yielded an age of 14.9 ± 0.9 Ma (LIPPOLT et al., 1975; compare HANDLER et al., 2006).

Biostratigraphy: -

Thickness: Around 30 m at the surface (WINKLER-HERMADEN, 1954).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Granitztal Formation (Beck-Mannagetta, 1952; Winkler-Hermaden, 1954).

Overlying unit(s): Discordant upper boundary, Quaternary sediments (Beck-Mannagetta, 1952; Winkler-Hermaden, 1954).

Lateral unit(s): Tuffitic layers in the Mühldorf Formation (and the Ingering Formation of the Fohnsdorf Basin) are discussed to be related with the magmatic activity at Kollnitz (Reischenbacher et al., 2007).

Geographic distribution: Corresponds to the type area.

Remarks: In Piller et al. (2004), the Kollnitz Basalt was erroneously placed into the Pliocene.

Complementary references: Fuchs (1980c), Tollmann (1985).

Dachberg-Formation / Dachberg Formation

Martin Gross

Validity: Invalid; name introduced by Höfer (1892); used as formation by Reischenbacher et al. (2007).

Type area: Region around the hill Dachberg, c. 3.5 km SE of the town St. Andrä im Lavanttal, Carinthia; ÖK50-UTM, map sheet 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheets 188 Wolfsberg, 205 Sankt Paul im Lavanttal).

Type section: -

Remark: The abandoned and partly revegetated sand pit N of the village Messensach (N 46°44′59″ / E 14°51′21″), c. 3.0 km SE of the town St. Andrä im Lavanttal, Carinthia, described by Beck-Mannagetta (1952), can be considered as type section.

Reference section(s): -

Remark: The small outcrop at the eastern flank of the Dachberg (N 46°44′51″ / E 14°52′12″) could be considered as reference section (Winkler-Hermaden, 1937; Beck-Mannagetta, 1952).

Derivation of name: After the hill Dachberg (552 m a.s.l.), c. 3.9 km SE St. Andrä im Lavanttal, Carinthia.

Synonyms: Schotter [...] des [...] Dachberges (Höfer, 1892), Schotter des Dachberges (Winkler-Hermaden, 1937), Dachbergschotter (Beck-Mannagetta, 1952), Dachberg Gravel (Reischenbacher & Sachsenhofer, 2013).

Lithology: Sandy (quartz) gravels with carbonate (in southern parts) and crystalline components (in the northern parts) (Beck-Mannagetta, 1952).

Fossils: Plant remains, gastropods, rare vertebrates (Beck-Mannagetta, 1952).

Origin, facies: Fluvial.

Chronostratigraphic age: Middle Miocene, Serravallian (late Badenian to early Sarmatian).

Biostratigraphy: -

Thickness: About 400 m (Beck-Mannagetta, 1952; Reischenbacher et al., 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Mühldorf Formation.

Overlying unit(s): The lower Sarmatian Fresh- and Brackish Water Beds or discordantly Plio-/Pleistocene boulder gravels ("Quarz- und Blockschotter vom Dachberg" [sic!]; see Reideben Gravel) and Quaternary sediments (Beck-Mannagetta, 1952).

Lateral units: Interfingers with the upper Badenian Lower Freshwater Beds and the lower Sarmatian Fresh- and Brackish Water Beds (Beck-Mannagetta, 1952; Bechtel et al., 2007; Reischenbacher et al., 2007).

Geographic distribution: Lavanttal, Eastern Carinthia; ÖK50-UTM, map sheets 4103 Wolfsberg, 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheets 187 Bad Sankt Leonhard im Lavanttal, 188 Wolfsberg, 205 Sankt Paul im Lavanttal).

Remarks: -

Complementary references: Winkler-Hermaden (1943), Fuchs (1980c), Tollmann (1985).

Untere Süßwasserschichten / Lower Freshwater Beds

Martin Gross

Validity: Invalid; introduced by Beck-Mannagetta (1952).

Type area: Area on the eastern slopes of the mountain Saualpe, NW and SW of the town Wolfsberg (between the villages St. Margarethen im Lavanttal in the north and Siegelsdorf in the south) and subsurface occurrences in the southern part of Wolfsberg (district Gries) (e.g., drilling Oppersdorff VI) and St. Stefan (e.g., drilling Großedling F1) (Beck-Mannagetta, 1949, 1952); ÖK50-UTM, map sheet 4103 Wolfsberg (ÖK50-BMN, map sheets 187 Bad Sankt Leonhard im Lavanttal and 188 Wolfsberg).

Type section: -

Reference sections: -

Remark: The drillings "Marein (M)" (c. 1.0 km SE St. Marein), "Wolkersdorf I (W_1)" (c. 1.8 km S St. Stefan), "Wolkersdorf III (W_3)" (c. 1.9 km SSE St. Stefan) and "Großedling ($G = F_1$)" (c. 0.9 km S St. Stefan) provide insight into the lithological development of this unit below the "Totz Seam" of the Fresh- and Brackish Water Beds (Beck-Mannagetta, 1952).

Derivation of name: Named after the depositional environment (Beck-Mannagetta, 1952).

Synonyms: (partim?) Cypridinenmergel von Siegelsdorf (Zwanziger, 1882), Untere Süßwasserschichten [including the "Oppersdorf[f]er- und Siegelsdorfer Flöze [and] Hattendorfer Sandstein"] (Beck-Mannagetta, 1952), Süßwassermergel mit Blattabdrücken (Tollmann, 1985), (partim?) Siegelsdorfer Schichten (Beck-Mannagetta & Draxler, 1987), Freshwater beds: Marl, sandstone + 2 minor seams (Reischenbacher et al., 2007).

Lithology: Mainly pelite (marl, shaly marl) and sandstone with intercalated thin coal seams (Siegelsdorf Seam and Oppersdorf[f] Seam; Beck-Mannagetta, 1952; Reischenbacher & Sachsenhofer, 2013).

Fossils: Plant remains, freshwater and terrestrial molluscs, freshwater ostracods, fish remains (Beck-Mannagetta, 1952; Berger, 1955b; Reischenbacher et al., 2007; see also Meller et al., 2015).

Origin, facies: Lacustrine-fluvial (Beck-Mannagetta, 1952; Reischenbacher et al., 2007).

Chronostratigraphic age: Middle Miocene, Serravallian (late Badenian) (Beck-Mannagetta, 1952).

Biostratigraphy: -

Thickness: Up to 700 m (Beck-Mannagetta, 1952).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Mühldorf Formation (Beck-Mannagetta, 1952).

Overlying unit(s): Fresh- and Brackish Water Beds (Beck-Mannagetta, 1952); erosional boundary (Reischenbacher & Sachsenhofer, 2013).

Lateral unit(s): Dachberg Formation (Beck-Mannagetta, 1952).

Geographic distribution: Corresponds to the type area.

Remarks: Probably also the drillings KB D16/01 (N 46°44′22″ / E 14°52′08″) and KB D15/01 (N 46°44′27″ / E 14°52′17″), both c. 4.6 km SE St. Andrä im Lavanttal in the Dachberg area (ÖK50-UTM map sheet 4109 Sankt Paul im Lavanttal; ÖK50-BMN, map sheet 205 Sankt Paul im Lavanttal), penetrated deposits of the Lower Freshwater Beds (Reischenbacher et al., 2007).

Complementary references: -

Süß- und Brackwasser-Schichten / Fresh- and Brackish Water Beds

Martin Gross

Validity: Invalid; described sufficiently first by Beck-Mannagetta (1952); name used here adapted from Bechtel et al. (2007) and Reischenbacher et al. (2007), respectively.

Type area: Subsurface in the area around St. Stefan in the north to the area east of St. Andrä in the south, Lavanttal, Carinthia; ÖK50-UTM, map sheets 4103 Wolfsberg, 4109 Sankt Paul im Lavanttal (ÖK50-BMN 187 Bad Sankt Leonhard im Lavanttal, 188 Wolfsberg).

Type section: -

Reference section(s): -

Remark: As reference sections might act the logs of the wells (e.g., "Wolkersdorf I (W_1)", c. 1.8 km S St. Stefan; "Wolkersdorf III (W_3)", c. 1.9 km SSE St. Stefan; "Großedling (G = F_1)", c. 0.9 km S St. Stefan) provided by Beck-Mannagetta (1952) and Bechtel et al. (2007).

Derivation of name: Named after the depositional environment.

Synonyms: (partim) (obere) kohleführende Schichtfolge im unteren Lavanttal, (partim) tieferer Flözzug (Winkler-Hermaden, 1943), (partim) Rissoen-Elphidienfazies [including "Totzer Flöz, Mergel usw., Liegendflöz, Mergel usw., Hangendflöz, Mergel und Sande, […] Phosphorite und Diatomeenschiefer", (partim) Pirenellenfazies (Beck-Mannagetta, 1952), (partim) St. Stefaner Flöze (Totzerflöz, Liegendflöz, Hangendflöz) (Weber & Weiss, 1983), Totzer Flöz, u.a., *Mohrensternia* Tone (Piller et al., 2004), Freshwater and brackish beds incl.: Upper Seam, Lower Seam, Totz Seam) [and] Brackish ("*Pirenella*") Beds (Bechtel et al., 2007).

Lithology: Coal seams ("Totz Seam", up to 1 m thickness, "Lower Seam", up to 2.9 m thickness, "Upper seam", up to 3.3 m thickness) separated by 30–45 m thick pelite/marl/sapropelitic shale interlayers; sapropelite with phosphorite nodules and diatomite and sand- and gravel-intercalations above the "Upper Seam" (Beck-Mannagetta, 1952; Bechtel et al., 2007; see also Petrascheck, 1922/1924; Herzog & Kahler, 1978; Weber & Weiss, 1983; Grímsson et al., 2011).

Fossils: Plant remains, diatoms, foraminifers, sponges, gastropods, bivalves, ostracods, fish remains, mammals, primates (*Dryopithecus fontani*) (Beck-Mannagetta, 1952; Mottl, 1957; Papp, 1957; Begun et al., 2006; Grímsson & Zetter, 2011; Grímsson et al., 2011, 2015, 2016, 2020; Fuss et al., 2018).

Origin, facies: Limnic swampy environment (fresh- and brackish waters) with some fluvial influx, topogenous mires, partly marginal marine (Beck-Mannagetta, 1952; Bechtel et al., 2007).

Chronostratigraphic age: Middle Miocene, Serravallian (early Sarmatian).

Biostratigraphy: Regional mollusc zone: *Mohrensternia* Zone (Beck-Mannagetta, 1952; Reischenbacher & Sachsenhofer, 2013).

Thickness: Up to 265 m (Beck-Mannagetta, 1952; Bechtel et al., 2007).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided by coal seams (the lowermost "Totz Seam", the "Lower Seam" and the "Upper Seam") and/or in the lower "Rissoen-Elphidienfazies" and the upper "Pirenellen(Cerithien)-Fazies" (Beck-Mannagetta, 1952).

Underlying unit(s): Lower Freshwater Beds and Dachberg Formation (Beck-Mannagetta, 1952).

Overlying unit(s): Discordantly overlain by the Kuchl Beds (Beck-Mannagetta, 1952; Reischenbacher et al., 2007).

Lateral unit(s): Interfingers towards the south with the upper part of the Dachberg Formation.

Geographic distribution: Lavanttal, Eastern Carinthia; ÖK50-UTM, map sheets 4103 Wolfsberg, 4109 Sankt Paul im Lavanttal (ÖK50-BMN 187 Bad Sankt Leonhard im Lavanttal, 188 Wolfsberg, 205 Sankt Paul im Lavanttal).

Remarks: -

Complementary references: Fuchs (1980c), Tollmann (1985).

Kuchler Schichten / Kuchl Beds

MARTIN GROSS

Validity: Invalid; the unit was first described in the current sense by BECK-MANNAGETTA (1952) and termed "Kuchler Horizont". Since the terminology used in the literature (see synonyms) is lithostratigraphically not adequate and also not unambiguous (see remarks) we use here the name Kuchl Beds ("Kuchler Schichten").

Type area: Subsurface in the area around St. Stefan in the north to the area east of St. Andrä in the south, Lavanttal, Carinthia; ÖK50-UTM, map sheets 4103 Wolfsberg, 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheet 188 Wolfsberg).

Type section: -

Reference section(s): -

Remark: As reference sections might act the logs of the wells in the area of St. Stefan (S Wolfsberg; e.g., "Großedling (G = F_1)", c. 0.9 km S St. Stefan) provided by BECK-MANNAGETTA (1952).

Derivation of name: Named after the farmstead "Kuchler" (N 46°48′31″ / E 14°51′35″; Paildorferstraße 65) in the village St. Stefan (municipality Wolfsberg), 3.7 km SSE of the town Wolfsberg, Lavanttal, Carinthia.

Synonyms: (partim) Kuchler Flöz (PETRASCHECK, 1922/1924), oberer ("Kuchler Flöz") [Zug] (WINKLER-HERMADEN, 1943), Kuchler Horizont (BECK-MANNAGETTA, 1952), Kuchler Horizont (FUCHS, 1980c), sandig-mergelige Süßwasser-Folge mit dem Kuchler Flözhorizont (EBNER & SACHSENHOFER, 1991), Süßwasserserie (PILLER et al., 2004), Freshwater beds (sand, marl; 30 m) [incl.] Kuchl Coal Horizon (REISCHENBACHER et al., 2007), Freshwater Beds [incl.] Kuchl Horizon with 2 coal seams (REISCHENBACHER & SACHSENHOFER, 2013).

Lithology: Shaly to sandy marl, sand; including two coal seams: the "Lower Kuchl Seam" (1.3–1.7 m thick) and the "Upper Kuchl Seam" (2.5–5 m thick) (BECK-MANNAGETTA, 1952; WEBER & WEISS, 1983; BECHTEL et al., 2007; REISCHENBACHER & SACHSENHOFER, 2013).

Fossils: Plant remains (BECK-MANNAGETTA, 1952).

Origin, facies: Limnic-swampy environment.

Chronostratigraphic age: Middle Miocene, Serravallian (late Sarmatian).

Biostratigraphy: -

Thickness: Around 30 m, up to 75 m (BECK-MANNAGETTA, 1952).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: Informally subdivided into the "Lower" and "Upper Kuchl Coal Seams".

Underlying unit(s): Fresh- and Brackish Water Beds with an unconformity (BECK-MANNAGETTA, 1952; REISCHENBACHER et al., 2007).

Overlying unit(s): Upper Freshwater Beds (BECK-MANNAGETTA, 1952).

Lateral unit(s): The "Andersdorfer Flöze", c. 4.2 km NE St. Paul im Lavanttal, and associated sediments are correlated with the Kuchl Beds (BECK-MANNAGETTA, 1952).

Geographic distribution: Corresponds to the type area.

Remarks: In PILLER et al. (2004), this unit was named "Süßwasserserie", however, lacking the coal mark. In order to avoid confusions with the Badenian Lower Freshwater Beds and the Pannonian Upper Freshwater Beds, this unit is termed here Kuchl Beds following the name "Kuchler Horizont" of BECK-MANNAGETTA (1952).

Complementary references: TOLLMANN (1985).

Obere Süßwasserschichten / Upper Freshwater Beds

MARTIN GROSS

Validity: Invalid; the term "Obere Süßwasserschichten" has been introduced by BECK-MANNAGETTA (1952).

Type area: At the hills NE and E of St. Andrä im Lavanttal, Carinthia; ÖK50-UTM, map sheet 4109 Sankt Paul im Lavanttal (ÖK50-BMN, map sheet 188 Wolfsberg).

Type section: -

Reference section(s): -

Remark: Possible reference sections might be a gravel pit and outcrops NE of the Taubenkogel ("Mittertalkogel") (c. N 46°47′22″ / E 14°52′12″), c. 4.5 km NE St. Andrä im Lavanttal mentioned by BECK-MANNAGETTA (1952).

Derivation of name: Refers to the non-marine facies.

Synonyms: Süßwasserschichten im Hangenden der kohleführenden Schichten (BECK-MANNAGETTA, 1980b), obere kalkfreie Süßwasserschichten (FUCHS, 1980c), Sande, Schotter (PILLER et al., 2004), Freshwater Beds (sand, gravel, clay) (BECHTEL et al., 2007).

Lithology: Interbedded layers of sand, gravel and clay (BECK-MANNAGETTA, 1952; BECHTEL et al., 2007; REISCHENBACHER & SACHSENHOFER, 2013).

Fossils: -

Origin, facies: Fluvial-limnic; braided and meandring river systems, in the upper part interfingering with alluvial fans (REISCHENBACHER & SACHSENHOFER, 2013).

Chronostratigraphic age: Late Miocene, Tortonian (?early Pannonian) (BECK-MANNAGETTA, 1952).

Biostratigraphy: -

Thickness: Around 250 m, possibly up to 400 m (BECK-MANNAGETTA, 1952) or up to 900 m (EBNER & SACHSENHOFER, 1991; REISCHENBACHER & SACHSENHOFER, 2013).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Kuchl Beds.

Overlying unit(s): Discordantly overlain by the Plio-/Pleistocene Reideben Gravel and its potential equivalents (e.g., "Quarz- und Blockschotter vom Dachberg" [sic!], "Schotter der Wölch"; BECK-MANNAGETTA, 1952).

Lateral unit(s): -

Geographic distribution: Corresponds to the type area.

Remarks: -

Complementary references: TOLLMANN (1985), REISCHENBACHER et al. (2007).

Reidebener Schotter / Reideben Gravel

MARTIN GROSS

Validity: Invalid; name introduced by WINKLER-HERMADEN (1937) as "Grobschotter […] bei Riegelsdorf–Reideben" and renamed "Reidebener Schotter" by BECK-MANNAGETTA (1948).

Type area: Area around the castle Reideben and the village Riegelsdorf, c. 6 km SE Wolfsberg, Lavanttal, Carinthia; ÖK50-UTM, map sheet 4103 Wolfsberg (ÖK50-BMN, map sheet 188 Wolfsberg).

Type section: -

Reference sections: -

Derivation of name: Named after the castle Reideben (municipality Wolfsberg), c. 6 km SE of the town Wolfsberg, Lavanttal, Carinthia (BECK-MANNAGETTA, 1954).

Synonyms: Schotterablagerungen […] bei Riegelsdorf (PETRASCHECK, 1922/1924), Grobschotter […] bei Riegelsdorf–Reideben (WINKLER-HERMADEN, 1937), Reidebener Blockschutt (BECK-MANNAGETTA, 1952), (partim) Gravel (BECHTEL et al., 2007).

Lithology: Coarse to boulder gravel (predominantly crystalline pebbles) with loamy matrix (PETRASCHECK, 1922/1924; BECK-MANNAGETTA, 1948).

Fossils: -

Origin, facies: Alluvial fan to fluvial deposits (BECK-MANNAGETTA, 1952).

Chronostratigraphic age: Late Pliocene to earliest Pleistocene (BECK-MANNAGETTA, 1952, 1954).

Biostratigraphy: -

Thickness: Up to more than 100 m (BECK-MANNAGETTA, 1952).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Upper Freshwater Beds (above an unconformity) or crystalline basement (BECK-MANNAGETTA, 1948, 1952, 1954).

Overlying unit(s): Quaternary sediments (terrace and fan deposits; BECK-MANNAGETTA, 1948, 1952).

Lateral unit(s): "Quarz- und Blockschotter vom Dachberg" (BECK-MANNAGETTA, 1952; not to be confused with the Dachberg Formation!), the "Schotter der Vorderwölch" (BECK-MANNAGETTA, 1948; also "Schotter der Wölch"; BECK-MANNAGETTA, 1952) and further isolated gravel/boulder gravel occurrences in the upper Lavanttal, N of Wolfsberg (e.g., Preitenegg, Schiefling) are discussed to be lateral equivalents (WINKLER-HERMADEN, 1937; BECK-MANNAGETTA, 1948, 1952; FUCHS, 1980c).

Geographic distribution: Western slopes of the Koralm Massif (see type area) and, possibly (see lateral units), south of the Packalpe (BECK-MANNAGETTA, 1980b).

Remarks: -

Complementary references: BECK-MANNAGETTA (1951), EBNER & SACHSENHOFER (1991), REISCHENBACHER et al. (2007), REISCHENBACHER & SACHSENHOFER (2013).

Quaternary System

Preface

DIRK VAN HUSEN & JÜRGEN M. REITNER

The stratigraphic subdivision of the sedimentary archive of Austria attributed to the Quaternary (the last 2.58 Ma; GIBBARD et al., 2009) represents a big challenge at least for two reasons. First, very different former environments (ranging from glacial, fluvio-glacial, to lacustrine and eolian) and facies associations whose sedimentary record is fragmentary and discontinuous, are documented in the Austrian landscape for the Pleistocene (2.58–0.01 Ma BP). Such a complex setting leads to the second reason for problems in establishing a homogeneous stratigraphic approach. Only few sedimentary units in inneralpine, mostly glacially shaped basins can be classified according to the principles of lithostratigraphy (STEININGER & PILLER, 1999; SALVADOR, 1994), i.e. using lithic characteristics and the Law of Superposition. Thus, at present, we do not follow efforts of standardisation (see PILLER et al., 2003) which elsewhere result in a plethora of lithostratigraphic subdivisions (e.g., British Isles; BOWEN, 1999a), which are partly "*not amenable to systematic and widespread mapping away from their stratotypes*" (BOWEN, 1999b). However, it is evident that fluvio-glacial or fluvial deposits in the Alpine Foreland, having more or less the same lithic content during all Quaternary phases of sedimentation but occurring in different but contiguous terrace levels and documenting different phases of aggradation followed by incision, represent discontinuity-bound units in the sense of allo-stratigraphy (NACSN, 2005). As these units cannot be treated according to the lithostratigraphic criteria mentioned above, any stratigraphic subdivision within this setting has to rely on a mixture of different criteria for discriminating lithic units mappable at least at the scale of 1:10,000.

The Eastern Alps and their foreland resemble the type-area for the classical Alpine stratigraphy according to PENCK & BRÜCKNER (1909). It is based on the concept of "Glaziale Serie" (glacial sequence) genetically linking tongue basins with subglacial till, terminal moraine deposits and terraces consisting of proglacial outwash and climatically induced gravel accumulation along the rivers. In the Northern Alpine Foreland of Austria and along the Danube this system was only affected by a uniform slow uplift. Due to this, the clear differentiation in the elevation of the four terraces was established.

This stratigraphic scheme which is reduced by some authors (e.g., Bowen, 1978) to include solely the element of morphological correlation, classifying it as morphostratigraphy, has been extended and adapted in the sense of climate-based stratigraphy. However, the deposits of most glacials and also some interglacials, stadials and interstadials do not cover geological time without gaps, which would be required for a (regional) chronostratigraphy (Gibbard & West, 2000). Thus, no regional chronostratigraphy subdivision sensu stricto exists for the Quaternary sediments of Austria, with the exception of the Würm glacial period which was officially classified as a regional stage by the Subcommission on European Quaternary Stratigraphy (SEQS; Chaline & Jerz, 1984). It is subdivided into three substages: early, middle and late Würm based on palynological and lithological criteria evident in the respective stratotypes. The other glacials and at least the last interglacial (Riß/Würm-Interglacial), which represents the Alpine equivalent of the Eemian (Grüger, 1979) are informally used in the sense of stages. The Marine Isotope Stages (MIS; see Gibbard & Cohen, 2008; Cohen & Gibbard, 2011) provide the framework within which the climate-based units (e.g., Günz glacial) are correlated (van Husen, 2000a; Reitner, 2022) based on the existing geochronological and biostratigraphic constraints, whose quality and precision decreases in most cases with the age of the deposit. In the case of the Chibanian glaciations Günz and Mindel, which fall into the Brunhes polarity chron (van Husen, 2000a), it is inferred that they are concurrent with phases of global excess 100-kyr ice as a result of unusually long intervals of low summer insolation, which are followed by major terminations as evident in the $\delta^{18}O$ record (Raymo, 1997; Lisiecki & Raymo, 2005). Such a situation is based on geochronological data at least for the other major glaciations during Riß (MIS 6) and Würm (MIS 2). With the knowledge on the course of these two major climatic deteriorations and their impact on the Alpine sedimentary record, a correlation of the older glaciations with the marine $\delta^{18}O$ stratigraphy seems possible. It is based on the relation between type and magnitude of the global climate signal and the amount of reconstructed sediment production in very short timespans (van Husen & Reitner, 2011a).

Short outline of the Quaternary Stratigraphy as linked to landscape development

The description of the system of Quaternary sedimentary units of the Middle to Late Pleistocene is based on the succession of cold (glacial) and warm (interglacial) periods shown by the $\delta^{18}O$ record (Raymo, 1997; Lisiecki & Raymo, 2005; van Husen & Reitner, 2011a). All these varying global climatic conditions had an impact on processes shaping the landscape of the Alps in relation to the respective magnitude of the climate signal. Thus, expansion of permafrost, strong congelifraction and the vegetation cover changed simultaneously with growing and shrinking of the valley glaciers. These changes occurred in higher or lower parts of the Alps or in the foreland depending on the degree of climatic deterioration (van Husen, 2000a). Beside the great events (glaciations) resulting in glacier expansion into the foreland, climatic deteriorations are often documented in loess profiles only (e.g., Krems Schießstätte). The corresponding gravel beds, if ever formed and preserved, have not been recognized so far. Periglacial debris production and gravel accumulation prograded successively from the inneralpine areas to the foreland during climatic deterioration finally forming extended terraces along the rivers (Danube and tributaries) probably only during the four climax periods. The parallelization of separated bodies of terminal moraines of the former network of valley glaciers and transient glaciers was done in consideration of the laws of ice dynamic. Isolated terraces have been correlated according to their surface gradient as well as to their base level in relation to the recent river. In both cases this is supported by lithology, sedimentary facies, morphology, development of weathering and loess cover (Piller et al., 2003).

According to these principal climatically controlled sedimentary and erosional processes it is possible to trace the four terraces (Penck & Brückner, 1909) along the Danube and the tributaries down-stream to the Vienna Basin due to a uniform and quite stable tectonic situation. Within the Vienna Basin such a tectonic setting seems to be present only in the westernmost part (the city of Vienna). East of the Leopoldsdorf Fault and at the centre of the Vienna Basin recent tectonic subsidence has taken and is taking place (Decker et al., 2005) influencing the deposits of the two youngest glaciations (Gänserndorf and Prater Terrace) north of the river Danube and forming the “Mitterndorfer Senke” (Mitterndorf Basin) south of it. Between these two areas of active subsidence a zone of less tectonic influence runs parallel to the river (“Rauchenwarter Platte – Maria Ellender Hügelland – Prellenkirchener Terrasse”) where the gravel accumulations of Lower Pleistocene and Chibanian seem to be in accordance with the terraces west of the Vienna Basin (Fuchs, 1985a, b, c).

For the period of the Early Pleistocene no traces of glaciations have been found. However, the succession of cool and warm periods during this time had an effect on landscape evolution especially in the Alpine forelands in the North and Southeast. Thus, gravel accumulation along the rivers combined with loess deposition in the surrounding area took place more or less in the same way but under slightly warmer conditions as during the Middle Pleistocene, Chibanian (van Husen, 2000a). Some remnants of these sediments, which belong to this long period before the major glaciations began, are depicted in the Stratigraphic Chart.

Beside the specific situation of the “Tullner Feld” and “Prater Terrasse”, which were – after accumulation at the climax of the last glaciation (MIS 2) – reworked up to the Holocene, Termination I is documented by glacial activity within the Eastern Alps. This includes huge gravel accumulation at the main valleys as the outcome of the downwasting of the large valley glaciers, as well as two short distinct glacier advances of comparably small Alpine glaciers in immediate response to well defined climatic signals such as Heinrich 1 event and Younger Dryas. In this context it has to be emphasized, that for example the youngest phase of the Quaternary (the last 20,000 years) is documented in geological maps not by stratigraphic units but mostly by lithogenetic units defined by their depositional origin as manifested by material properties (STEINBICHLER et al., 2019).

This review aims to present the currently used Quaternary stratigraphic subdivision based on mappable bodies of sediments. In addition, three major long sections (Stranzendorf, Krems Schießstätte and Mitterndorf Basin) and an important area with fossil rich cave sediments are presented which are crucial for the understanding of Quaternary landscape evolution and have the potential to serve as reference sections for future local subdivisions.

The chronostratigraphic framework for the Quaternary is given by the major chronostratigraphic subdivisions according to the standards presented by GIBBARD et al. (2009). It correlates with the Early/Middle Pleistocene boundary at the Matuyama-Brunhes paleomagnetic Chron boundary following the recommendation by RICHMOND (1996) and HEAD & GIBBARD (2005) and the Chibanian/Late Pleistocene boundary at the beginning of the Eemian (GIBBARD, 2003) roughly identical with the MIS 6/5 boundary. In addition, the record of the Marine Isotope Stages serves as a global stratigraphic reference.

It is important to note that the Austrian landscape is subdivided into major elements like the Alps, the Northern Alpine Foreland drained by the river Danube and its southern tributary rivers (Inn, Traun, Enns, Ybbs and Traisen), the Vienna Basin and the Styrian Basin located in the southeast drained by the river Mur and its tributaries. The stratigraphic subdivisions with their interrelationships and the correlations – partly well established, partly inferred – with the chronostratigraphic frame are summarized in the included stratigraphic chart.

Geiersberg Schotter / Geiersberg Gravel

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by GRAUL (1937).

Type area: North of the hillsides Kobernaußerwald and the Hausruck, Upper Austria.

Type section: Not defined, the former pits are closed, occasional outcrops occur.

Reference section(s): -

Derivation of name: Village of Geiersberg (N 48°12′03″ / E 13°34′51″), 7 km ESE Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: -

Lithology: The gravel deposits are dominated by clasts made up of quartz and quartzite with some crystalline and a few limestone. The heavily oxidized and weathered coarse gravel shows interbedding of thick sand layers. It consists of eroded and redeposited material of the Neogene Hausruck Formation.

Fossils: -

Origin, facies: Reworked river gravel of the Hausruck Formation and Kobernaußerwald Formation (Neogene). Old valley fills; braided river beds.

Chronostratigraphic age: probably Early Pleistocene, Gelasian; during cold periods.

Biostratigraphy: -

Thickness: Up to 10 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above Neogene deposits of the North Alpine Foreland Basin.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: Close to the north rim of Hausruck preserved along ridges; ÖK50-UTM, map sheets 3322 Braunau am Inn, 3323 Ried im Innkreis, 3324 Grieskirchen, 3328 Mattighofen, 3329 Vöcklabruck (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Remarks: -

Complementary references: RUPP (2008a, b).

Federnberg Schotter / Federnberg Gravel

DIRK VAN HUSEN, JÜRGEN M. REITNER

Validity: Invalid; introduced by GRAUL (1937).

Type area: North of the hillsides Kobernaußer Wald and Hausruck, Upper Austria.

Type section: -

Reference section(s): -

Derivation of name: The name originates from a local ridge named Federnberg (N 48°12′16″ / E 13°23′66″) located approximately 6–7 km west of the town of Ried im Innkreis, Upper Austria; ÖK50-UTM, map sheet 3329 Vöcklabruck (ÖK50-BMN, map sheet 47 Ried im Innkreis).

Synonyms: -

Lithology: The deposit consists of predominantly rounded and well-rounded sand-bearing coarse gravel. They are poorly sorted and more or less horizontally bedded with intensive cross-bedding typical for braided river deposits. The clast lithology is dominated by quartz and quartzite. Pebbles of crystalline rocks are rare and limestone pebbles are very rare. The gravel is weathered and strongly oxidized.

Fossils: -

Origin, facies: The material is eroded and redeposited gravel and sand of the coarse deposits of the Neogene Hausruck Formation and Kobernaußerwald Formation Old extended valley fills, braided river deposits.

Chronostratigraphic age: probably Early Pleistocene, Gelasian; during cold periods.

Remark: Older than the “Eichwald Schotter”.

Biostratigraphy: -

Thickness: Up to 20 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above Neogene deposits of the North Alpine Foreland Basin.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: North of the Kobernaußer Wald und Hausruck; mostly on long ridges. ÖK50-UTM, map sheets 3322 Braunau am Inn, 3323 Ried im Innkreis, 3324 Grieskirchen, 3328 Mattighofen, 3329 Vöcklabruck (ÖK50-BMN, map sheets 29 Schärding, 30 Neumarkt im Hausruckkreis, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck).

Remarks: -

Complementary references: Rupp (2008a, b).

Langenloiser Terrasse / Langenlois Terrace

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; recognized as Gobelsburger Terrasse by Piffl (1959), introduced by Fink & Piffl (1976c).

Type area: NE of the city of Krems an der Donau (N 48°24′44″ / E 15°36′7″), Lower Austria.

Type section: -

Reference section(s): -

Derivation of name: Named after the town Langenlois (N 48°28′24″ / E 15°40′38″), Lower Austria.

Synonyms: Gobelsburger Terrasse (Piffl, 1959).

Lithology: The unit consists of coarse sand-bearing gravel. The clasts mainly consist of crystalline rocks, quartz and quartzite (c. 70–80 %) mixed with limestone and sandstone (30–20 %) in the non-weathered parts, typical for fluvial deposits of the river Danube. The gravel deposits are strongly weathered and covered by thick loess deposits interrupted by paleosols.

Fossils: -

Origin, facies: Gravel of river Danube; braided river deposits.

Chronostratigraphic age: Early Pleistocene, Gelasian–Calabrian.

According to paleomagnetic data the gravel and loess accumulation took place in the upper part of the Matuyama Chron (possibly around the Olduvai Event) (Piffl, 1976).

Biostratigraphy: -

Thickness: 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above Neogene deposits of the North Alpine Foreland Basin, partly also directly on crystalline rocks of the Bohemian Massif.

Overlying unit(s): Covered by loess.

Lateral unit(s): -

Geographic distribution: Terrace north of the river Danube between the city of Krems an der Donau and the river Kamp, Lower Austria; ÖK50-UTM, map sheet 4318 Langenlois (ÖK50-BMN, map sheet 38 Krems an der Donau).

Remarks: -

Complementary references: -

Eichwaldschotter / Eichwald Gravel

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; recognition by Graul (1937) as “Aichberg-Geinberg Verschotterung”, introduced by Weinberger (1955).

Type area: Area NE of the town Mattighofen (N 48°06′35″ / E 13°08′44″), Upper Austria; ÖK50-UTM, map sheet 3328 Mattighofen (ÖK50-BMN, map sheet 46 Mattighofen).

Type section: -

Reference section(s): -

Derivation of name: Field name after an oak forest.

Synonyms: Aichberg-Geinberg Verschotterung (Graul, 1937).

Lithology: The sediment consists predominantly of rounded and well-rounded coarse sand-bearing gravel deposits. The lithological composition of the gravel is quite similar to that of the younger terrace gravel along the rivers Inn and Salzach in front of the terminal moraines of the “Salzachgletscher”, bearing limestones, dolostone, sandstones and crystalline rocks such as gneiss, quartzite and schists. The gravel is strongly weathered.

Fossils: -

Origin, facies: Gravels of the rivers Mattig and Salzach; braided river deposits.

Chronostratigraphic age: Early Pleistocene, Calabrian.

Remark: The chronostratigraphic age assigned to a cold period older than Günz. Based on the similarity in facies and lithology with the typical fluvioglacial sediments of Chibanian age (e.g., “Ältere Deckenschotter” of the Günz glaciation) the “Eichwaldschotter” may represent the beginning of major Alpine glaciations at MIS 22 around 870 ka as recorded in the southern Alpine area and foreland (Muttoni et al., 2003).

Biostratigraphy: -

Thickness: 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above Neogene deposits of the North Alpine Foreland Basin.

Overlying unit(s): Covered by loess.

Lateral unit(s): -

Geographic distribution: Along the NW rim of hilly Molasse Zone N of the town Mattighofen; ÖK50-UTM, map sheets 3322 Braunau am Inn, 3323 Ried im Innkreis, 3328 Mattighofen (ÖK50-BMN, map sheets 29 Schärding, 46 Mattighofen, 47 Ried im Innkreis).

Remarks: -

Complementary references: MUTTONI et al. (2007).

Kiese von Reuharting-Schnelling / Gravels of Reuharting-Schnelling

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by KOHL & KRENMAYR (1997).

Type area: A hilly area around Reuharting (N 48°02′10″ / E 13°55′56″) and Schnelling (N 48°02′50″ / E 13°57′21″), Upper Austria. ÖK50-UTM, map sheet 3330 Attnang-Puchheim (ÖK50-BMN, map sheet 49 Wels).

Type section: -

Reference section(s): -

Derivation of name: Two hamlets. SW of the city of Wels (N 48°09′28″ / E 13°01′36″).

Synonyms: -

Lithology: Unit consists of coarse sand-bearing gravel deposits. The clast lithology is made up of sub-rounded quartz, quartzite and crystalline rocks as well limestone and dolostone from the Alps. Gravels are deeply weathered.

Fossils: -

Origin, facies: Reworked gravel of the Hausruck Formation and gravel derived from the Alps transported by rivers from the south (Traun, Alm, Krems); braided river deposits.

Chronostratigraphic age: Early Pleistocene, Calabrian.

The age is assumed as cold periods older than Günz and may correlate with MIS 22 according to arguments mentioned for the “Eichwaldschotter” unit.

Biostratigraphy: -

Thickness: 20–30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above Neogene deposits of the North Alpine Foreland Basin.

Overlying unit(s): Partly covered with a residual clay deposit and loess.

Lateral unit(s): -

Geographic distribution: Northerly part of “Traun-Enns-Platte” south of river Traun; ÖK50-UTM, map sheets 3330 Attnang-Puchheim, 4325 Wels, 4326 Steyr (ÖK50-BMN, map sheets 49 Wels, 50 Bad Hall, 51 Steyr).

Remarks: A similar gravel remnant preserved at Forstholz an area around (N 48°12′21″ / E 14°20′11″) (KRENMAYR, 1996c).

Complementary references: -

Amstettener Bergland / Amstetten hill range

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by KRENMAYR & SCHNABEL (2002b).

Type area: Hills between the rivers Enns, Danube, Ybbs and Urlbach, W of the town Amstetten (N 48°07′30″ / E 14°52′10″), Lower Austria.

Type section: -

Reference section(s): -

Derivation of name: Hill range W of the town Amstetten, Lower Austria.

Synonyms: Strengberg Schlierriedelland and Ybbs-Erlauf-Melk-Schlierriedelland (FISCHER, 1979).

Lithology: Unit consists of fine to coarse sand and clay containing gravel deposits. The gravels mainly consist of quartz, quartzite and crystalline rocks, mixed with limestone and sandstone clasts supplied by the southern tributaries of the River Danube. In the highest elevated terrace these materials are mostly weathered while in the lower situated terraces only the upper part (30–40 %) of the sediment is weathered.

Fossils: -

Origin, facies: Former terraces formed by the river Danube; braided river deposits.

Chronostratigraphic age: Early Pleistocene, probably Calabrian.

Biostratigraphy: -

Thickness: Up to 20 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlay unconformably Neogene deposits of the North Alpine Foreland Basin.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Hill range W of the town Amstetten, Lower Austria; ÖK50-UTM, map sheets 4326 Steyr, 4327 Amstetten (ÖK50-BMN, map sheets 51 Steyr, 52 St. Peter in der Au, 53 Amstetten).

Remarks: -

Complementary references: -

Maria Ellender-Arbesthaler Hügelland / Maria Ellend-Arbesthal hilly area

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; described by KRENMAYR & SCHNABEL (2002b).

Type area: A chain of hills between Königsberg (260 m a.s.l., N 48°05′19″ / E 16°37′29″) and Wartberg (231 m a.s.l., N 48°05′14″ / E 16°46′38″), Lower Austria; ÖK50-UTM, map sheets 5326 Schwechat, 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 60 Bruck an der Leitha).

Type section: -

Reference section(s): -

Derivation of name: After the villages Maria Ellend (N 48°06′42″ / E 16°40′49″) and Arbesthal (N 48°03′48″ / E 16°42′29″), Lower Austria.

Synonyms: -

Lithology: The unit consists of fine to coarse sand bearing gravel interbedded with up to 20 m thick sand layers. The gravel is mainly rounded to well-rounded and composed of c. 80–90 % quartz and quartzite pebbles and crystalline rocks mixed with limestone and sandstone. The chemical weathering and oxidation of the deposits is very well developed and reaches down to the base of the gravel.

Fossils: -

Origin, facies: Remnants of former extended gravel deposits by the river Danube; braided river deposits.

Chronostratigraphic age: Early Pleistocene, Calabrian (FUCHS, 1985c).

Biostratigraphy: -

Thickness: 30–40 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlay unconformably Neogene deposits of the Vienna Basin.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: East of the river Fischa a hilly ridge 4 km south and parallel to the river Danube; ÖK50-UTM, map sheets 5326 Schwechat, 5327 Bruck an der Leitha (ÖK50-BMN, map sheets 60 Bruck an der Leitha, 61 Hainburg).

Remarks: -

Complementary references: -

Rauchenwarther Platte / Rauchenwarth gravel sheet

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by KÜPPER (1968).

Type area: The extended hilly area between the Vienna Airport (N 48°07′16″ / E 16°33′29″) in the North and the market town Himberg (N 48°04′59″ / E 16°26′39″) and the village Ebergassing (N 48°02′45″ / E 16°31′06″) in the South, Lower Austria; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Type section: -

Reference section(s): -

Derivation of name: After the village of Rauchenwarth (N 48°05′01″ / E 16°31′40″), Lower Austria.

Synonyms: -

Lithology: The unit consists of fine to coarse sand-bearing gravel deposits interbedded with sand layers. The gravel is mainly rounded to well-rounded and composed of 80–90 % quartz, quartzite and crystalline rocks mixed with some limestone and sandstone. The chemical weathering of the deposits is intensive and may reach down to the base of the gravel.

Fossils: -

Origin, facies: Accumulation by the river Danube; braided river deposits.

Chronostratigraphic age: Early Pleistocene, Calabrian (FUCHS, 1985d).

Older than Günz and may probably correlate with MIS 22.

Biostratigraphy: -

Thickness: Up to 15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlay unconformably Neogene deposits of the Vienna Basin.

Overlying unit(s): Loess.

Lateral unit(s): -

Geographic distribution: Central part of the plateau between the rivers Schwechat, Danube and Fischa; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheets 59 Wien, 60 Bruck an der Leitha).

Remarks: -

Complementary references: -

Laaerberg Terrasse / Laaerberg Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by SCHAFFER (1902); detailed description by FINK & MAJDAN (1954) and KÜPPER (1968).

Type area: Recreation area "Bömischer Prater" in the 10th district (Favoriten) of the city of Vienna (N 48°10′01″ / E 16°23′50″), Vienna; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Type section: -

Reference section(s): -

Derivation of name: Named after the hillside "Laaerberg" (251 m a.s.l.) at the southern margin of the city of Vienna, part of the 10th district, Vienna.

Synonyms: -

Lithology: Coarse sand-bearing gravel dominated by crystalline clasts (mostly quartz and quartzite). The gravel deposits have a reddish matrix as a result of intense weathering and show cryoturbation structures.

Fossils: -

Origin, facies: Deposited by the river Danube; braided river deposits.

Chronostratigraphic age: Early Pleistocene, Calabrian; probably MIS 22.

Biostratigraphy: -

Thickness: 3–4 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlay unconformably Neogene deposits of the Vienna Basin.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: SE part of the 10th district of the city of Vienna; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Remarks: -

Complementary references: PFLEIDERER (2008), GRUPE et al. (2021).

Günz End- und Grundmoräne und Vorstoßschotter / Günz terminal moraine, subglacial till and proglacial gravel

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: Iller-Lech Platte, at the river Günz, Bavaria (Swabia), Germany.

Type section: -

Reference section(s): -

Derivation of name: River Günz, Bavaria (Swabia), Germany.

Synonyms: -

Lithology: Terminal moraine: consists of diamictons of coarse sand-bearing gravel with boulders. Often a varying content of silt and clay can be noticed. Locally indistinct bedding can be found. The clast composition of the deposits reflects the lithology in the catchment area (e.g., gneisses, quartzites, amphibolites, limestones, dolostones, flysch sandstones) according to the resistance of the material against glacial and fluvial abrasion.

Subglacial till: consists of an over consolidated massive, matrix-supported diamicton with the same clast composition. The till is normally deeply weathered to an average depth of 5–6 m.

The Günz subglacial till often covers a few meters thick gravel bed, which reflects sedimentary transition to the till. These gravel deposits called "Vorstoßschotter" in German were formed in front of the advancing glacier by fluvial action and were covered by till immediately after deposition. In some tributary valleys, fine grained (glacio-) lacustrine sediments are occasionally preserved below the subglacial till. These silty to sandy deposits are the infill of ephemeral ice-dammed lakes during glacier advance and are consequently a part of the "Vorstoßschotter".

Fossils: -

Origin, facies: Deposit of valley and piedmont glaciers; glacial sediment.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably correlated to MIS 16 (VAN HUSEN, 2000a; VAN HUSEN & REITNER, 2011a, b).

Biostratigraphy: -

Thickness: Up to 10 m but variable.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformable contact to pre-Quaternary bedrock as well as older Pleistocene sediments.

Overlying unit(s): Partly covered by loess.

Lateral unit(s): -

Geographic distribution: The unit is widespread in Salzburg and Upper Austria; ÖK50-UTM, map sheets 3206 Gmunden, 3328 Mattighofen, 4325 Wels (ÖK50-BMN, map sheets 46 Mattighofen, 67 Grünau im Almtal, 49 Wels).

Remarks: Salzach glacier at Siedelberg, west of Uttendorf, Salzburg (N 48°09′50″ / E 13°07′13″) (WEINBERGER, 1955), Traun glacier at Berg, SE Lindach, Upper Austria (N 47°59′33″ / E 13°52′38″) (EGGER & VAN HUSEN, 2007); Krems glacier around Sattledt, Upper Austria (N 48°04′20″ / E 14°03′26″) (KOHL, 2000; VAN HUSEN & DRAXLER, 2011).

Complementary references: WEINBERGER (1955).

Älterer Deckenschotter / Older gravel sheet

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: Iller-Lech Platte at the river Günz, Bavaria (Swabia), Germany.

Type section: -

Reference section(s): -

Derivation of name: Old extended gravel deposits in the Northern Alpine Foreland. In some areas distribution is not following the modern river courses.

Synonyms: Terrace N Hochstraßberg (N 48°12′02″ / E 15°15′54″) (FUCHS, 1964b), "Enns-Ybbs Schotterplatte" (FISCHER, 1979), "Traun-Enns Platte" (KOHL, 2000).

Lithology: The lithology shows coarse sand-bearing gravel typified by a poor sorting and bedding. The lithology of the clasts corresponds to the sources in the catchment areas of the rivers. Along the River Traun and at the "Traun-Enns Platte" (between the rivers Traun and Enns) the material in the upper part of the sequence predominantly derived from the Alps (limestone, dolostone, and flysch sandstones). In the lower part the clast spectrum shows a great amount of quartz, quartzite and crystalline rocks indicating reworked Neogene gravel of the Hausruck Formation (KOHL, 2000; KRENMAYR & SCHNABEL, 2006; VAN HUSEN & DRAXLER, 2011). At the "Enns-Ybbs Schotterplatte" (between the rivers Enns and Ybbs) the gravel was supplied by the river Enns (FISCHER, 1979). Distinct gravel layers may show a good cementation. Intensive weathering is evident on the top of the gravel. Frequently occurring pipe-like weathering features ("Geologische Orgeln") exist throughout the whole sequence (VAN HUSEN, 1999).

Fossils: -

Origin, facies: Climatically induced gravel accumulation along main rivers during climax of Günz glaciation with older gravel (Early–Middle Pleistocene) in the lower parts; braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably correlated to MIS 16 in the upper parts (VAN HUSEN, 2000a; VAN HUSEN & DRAXLER, 2011; VAN HUSEN & REITNER, 2011a).

Biostratigraphy: -

Thickness: 10–30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrocks.

Overlying unit(s): Up to 10 m thick weathered loess.

Lateral unit(s): -

Geographic distribution: Larger areas in the Alpine Foreland in Upper and Lower Austria; ÖK50-UTM, map sheets 3206 Gmunden, 3330 Attnang-Puchheim, 4201 Kirchdorf an der Krems, 4325 Wels, 4326 Steyr, 4327 Amstetten (ÖK50-BMN, map sheets 49 Wels, 50 Bad Hall, 51 Steyr, 52 Amstetten, 66 Gmunden, 67 Grünau im Almtal, 68 Kirchdorf an der Krems).

Remarks: -

Complementary references: RUPP et al. (2011).

Wienerberg Terrasse / Wienerberg Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by FINK & MAJDAN (1954).

Type area: Around "Spinnerin am Kreuz" (N 48°10′11″ / E 16°21′01″) in the 10th district (Favoriten) of the city of Vienna; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Type section: -

Reference section(s): -

Derivation of name: Named after the hillside "Wienerberg" (244 m a.s.l.) at the southern margin of the city of Vienna, part of the 10th district, Vienna.

Synonyms: -

Lithology: Lithologically it consists of coarse sand-bearing gravel of mainly quartz, quartzite and crystalline rocks containing also sand-, dolo- and limestones which were deposited by the river Danube. In the upper parts subangular flysch gravel, so called "Plattelschotter", frequently occurs. The gravel deposits are weathered in the upper part. Cryoturbation is frequent.

Fossils: Remnants of elephants (*E. planifrons*) (KÜPPER, 1968).

Origin, facies: Deposit by the river Danube and the tributary river Wien; braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably MIS 16.

Biostratigraphy: -

Thickness: About 10 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlay unconformably Neogene deposits of the Vienna Basin.

Overlying unit(s): Weathered loess.

Lateral unit(s): -

Geographic distribution: Along the ridge of the Wienerberg, W and E of "Spinnerin am Kreuz", Vienna; ÖK50-UTM, map sheet 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Remarks: -

Complementary references: PFLEIDERER (2008), GRUPE et al. (2021).

Prellenkirchener Terrasse / Prellenkirchen Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by WESSELY (1961) as "Petronell-Prellenkirchner Terrasse".

Type area: Extended terrace W and E of Petronell-Carnuntum (N 48°06′45″ / E 16°52′01″), c. 7 km SW of the town Hainburg an der Donau, Lower Austria; ÖK50-UTM, map sheet 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 61 Hainburg).

Type section: -

Reference section(s): -

Derivation of name: Village of Prellenkirchen (N 48°04′31″ / E 16°56′58″), c. 8 km SE of Petronell-Carnuntum, Lower Austria.

Synonyms: -

Lithology: Coarse gravel and sand mainly deposited by the river Danube. The gravel consists of rounded to well-rounded clasts. The clast spectrum shows a predominance of quartz, quartzite and crystalline rocks (c. 80 %) mixed with limestone, dolostone and sandstones (c. 20 %). Material is strongly weathered.

Fossils: -

Origin, facies: Gravel of rivers Danube and Leitha, braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably correlates with MIS 16.

Biostratigraphy: -

Thickness: About 10 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Neogene deposits of the Vienna Basin.

Overlying unit(s): Weathered loess.

Lateral unit(s): -

Geographic distribution: A 2 km wide area direct south of river Danube in a 2 km wide area between Regelsbrunn and Prellenkirchen between Regelsbrunn and Prellenkirchen; ÖK50-UTM, map sheet 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 61 Hainburg).

Remarks: -

Complementary references: FUCHS (1985b).

Parndorf-Formation / Parndorf Formation

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Valid; introduced by HÄUSLER et al. (2021).

Type area: Area NE of Lake Neusiedl, S of the river Leitha, between Parndorf and Nickelsdorf, Burgenland.

Type section: Abandoned gravel pit E Parndorf (N 47°59′16″ / E 16°55′23″), Burgenland; ÖK50-UTM, map sheet 5203 Neusiedl am See (ÖK50-BMN, map sheet 79 Neusiedl am See).

Reference section(s): Abandoned gravel pit c. 3 km NW Gattendorf (N 48°01′33″ / E 16°56′20″); ÖK50-UTM, map sheet 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 61 Hainburg); and a gravel pit c. 1 km NNW Nickelsdorf (N 47°57′01″ / E 17°03′48″).

Derivation of name: Village of Parndorf (N 47°59′35″ / E 16 51′29″), Burgenland.

Synonyms: Parndorfer Platte as the continuation of the “Prellenkirchener Terrasse” (WESSELY, 2006).

Lithology: Fine to coarse sand-bearing gravel deposits mainly of the river Danube. The gravel is rounded to well-rounded and predominantly composed of quartz, quartzite and crystalline rocks (c. 90 %) mixed with lime-, dolo- and sandstones (c. 10 %). The sandy gravels show partly horizontal layering or cross bedding. The gravels, which are strongly weathered and partly covered with loess deposits show partly intensive cryoturbation (HÄUSLER, 2007; HÄUSLER et al., 2021).

Fossils: -

Origin, facies: All deposits are gravel of the rivers Danube and Leitha representing braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian.

Accumulation during two glacial periods (Günz, Mindel, cf. FUCHS, 1985a, b; HÄUSLER, 2007). Thus, the chronostratigraphic age correlates with MIS 16 and MIS 12. According to the mapping of FUCHS (1985a) a small part between Gattendorf and Zurndorf was deposited during MIS 6 (Riß).

Biostratigraphy: -

Thickness: 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above fine-grained Pannonian (upper Miocene) deposits.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: Between Parndorf, Neusiedl am See, and Nickelsdorf; ÖK50-UTM, map sheets 5203 Neusiedl am See, 5204 Nickelsdorf, 5327 Bruck an der Leitha (ÖK50-BMN, map sheets 61 Hainburg, 79 Neusiedl am See).

Remarks: -

Complementary references: -

Kaiserwaldterrasse / Kaiserwald Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: South of the city of Graz between lower terrace “Leibnitzer-Grazer Feld” of the river Mur and the river Kainach; Styria.

Type section: -

Reference section(s): -

Derivation of name: Named after the “Kaiserwald” (imperal forest) S of the city of Graz, Styria.

Synonyms: -

Lithology: Coarse sand-bearing gravel deposits with intensive cross bedding. Gravels are quartz, quartzite and crystalline rocks, lime-, dolo- and sandstones.

Fossils: -

Origin, facies: Gravels of the rivers Mur and Kainach; braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably MIS 16.

Biostratigraphy: -

Thickness: Up to 15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Florianer Beds and Eckwirt Member (Stallhofen Formation) (Miocene, Neogene).

Overlying unit(s): Up to 10 m of weathered loess.

Lateral unit(s): -

Geographic distribution: Forested terrace around of Unter- and Oberpremstätten (N 46°58′04″ / E 15°23′54″); ÖK50-UTM, map sheet 4105 Kalsdorf bei Graz (ÖK50-BMN, map sheet 190 Leibnitz).

Remarks: -

Complementary references: WINKLER VON HERMADEN (1955), FINK (1961), EBNER (1983a).

Weiße Nagelfluh / White Conglomerate

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by ANGERER (1909), detailed description by KOHL (1977).

Type area: Southern part of the "Traun-Enns-Platte" along the rivers Alm and Krems, Upper Austria.

Type section: Not defined. Main section is described from the former quarry Lärchenwald (N 48°03′12″ / E 14°07′13″), within the village Kremsmünster, Upper Austria; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 50 Bad Hall). The outcrop does not exist anymore.

Reference section(s): The abandoned quarries in the hamlet Wolfgangstein (N 48°04′00″ / E 14°08′48″), NE of Kremsmünster, and the village Egenstein (N 47°58′43″ / E 13°57′35″), c. 4 km SE of the market town Vorchdorf, Upper Austria, could act as reference sections; ÖK50-UTM, map sheets 3206 Gmunden, 4325 Wels (ÖK50-BMN, map sheets 50 Bad Hall, 67 Grünau im Almtal).

Derivation of name: From white colour according to high content of bright Triassic carbonate rocks.

Synonyms: "Kremsmünsterer Nagelfluh" as a name for a local building stone KOHL (1986).

Lithology: The deposit is made up of massive well cemented conglomerates. The clasts are predominantly rounded limestone, dolostone and some sandstone (Flysch).

Angular to sub-angular boulders, probably transported by ice floes, occur frequently. The sediments are poorly sorted with intensive cross bedding and small foresets (channel fill). The uppermost part shows weathering with layers of reddish clay indicating interglacial conditions (KOHL & KRENMAYR, 1997).

Fossils: -

Origin, facies: According to the gravel composition the "Weiße Nagelfluh" was deposited by the river Alm in the style of a wide alluvial fan covering an older landscape (KOHL, 2000). It reached also the adjacent valleys of rivers Krems and the modern Laudach (EGGER & VAN HUSEN, 2007; EGGER et al., 2007a); overall braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; MIS 14.

Biostratigraphy: -

Thickness: 5–30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Partly unconformably overlain by Neogene deposits (Haller Schlier); partly weathered gravels and Günz subglacial till (KOHL, 2000).

Overlying unit(s): Around Kremsmünster "Graue Nagelfluh" and Mindel subglacial till on top of a weathering horizon (KOHL, 1977).

Lateral unit(s): -

Geographic distribution: Southern part of the "Traun-Enns-Platte" between the rivers Laudach and Krems; ÖK50-UTM, map sheets 3206 Gmunden, 4201 Kirchdorf an der Krems, 4325 Wels (ÖK50-BMN, map sheets 49 Wels, 67 Grünau im Almtal, 68 Kirchdorf an der Krems).

Remarks: -

Complementary references: -

Graue Nagelfluh / Grey Conglomerate

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by KOHL (1977).

Type area: In combination with "Weißer Nagelfluh" around Kremsmünster.

Type section: Not defined. Description is from the former quarry Lärchwand (N 48°03′20″ / E 14°07′15″) within the village Kremsmünster, Upper Austria; ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 50 Bad Hall).

Reference section(s): -

Derivation of name: It originates from the dark greyish colour due to a high content of Flysch sandstones and marls.

Synonyms: "Jüngerer Deckenschotter in Kremstalfacies" (KOHL & KRENMAYR, 1997).

Lithology: The lithology of the unit is described as coarse sand-bearing gravel with weak bedding. Clasts consist of limestone, dolostone and sandstone and are irregularly cemented. Frequent cross bedding and transition into the overlying Mindel subglacial till is evident.

Fossils: -

Origin, facies: The unit was probably deposited by a braided river in front of the advancing Mindel glacier in the Krems valley.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably correlates with MIS 12 (VAN HUSEN, 2000a; VAN HUSEN & REITNER, 2011b).

Biostratigraphy: -

Thickness: 5–10 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably the weathered "Weiße Nagelfluh".

Overlying unit(s): Till of piedmont glacier of Kremstal.

Lateral unit(s): -

Geographic distribution: The Krems valley around the creeks Aiterbach and Rindbach, Upper Austria (KOHL, 2000); ÖK50-UTM, map sheet 4325 Wels (ÖK50-BMN, map sheet 49 Wels).

Remarks: -

Complementary references: -

Mindel End- und Grundmoräne und Vorstoßschotter / Mindel terminal moraine, subglacial till and proglacial gravel

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: Type area is the Iller-Lech-Platte, along the river Mindel, Bavaria (Swabia), Germany.

Type section: -

Reference section(s): -

Derivation of name: River Mindel.

Synonyms: Graue Nagelfluh in the area of Kremsmünster (KOHL, 1977).

Lithology: The unit consists of diamictons (till) of coarse sand-bearing gravel with boulders. Often a varying content of silt and clay can be noticed. Locally indistinct bedding is evident. The clast composition of the gravel deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of subglacial till on the up-flow side of the terminal moraine are highly consolidated. Subglacial till ("Grundmoräne"), is an over-consolidated massive matrix-supported diamicton with occasional shear planes. The till is normally deeply weathered to an average depth of 3–5 m.

The Mindel subglacial till often covers a few meters thick gravel bed, which reflects sedimentary transition to the till. These gravel deposits called "Vorstoßschotter" in German were formed in front of the advancing glacier by fluvial action and were covered by till immediately after deposition. In some tributary valleys, fine grained (glacio-) lacustrine sediments are occasionally preserved below the subglacial till. These silty to sandy deposits are the infill of ephemeral ice-dammed lakes during glacier advance and are consequently a part of the "Vorstoßschotter".

Fossils: -

Origin, facies: Genetically, the Mindel terminal moraine was (overwhelmingly) deposited as a dump moraine by a stationary glacier during the climax conditions. Subglacial till can be classified as a subglacial traction till (EVANS et al., 2006).

Chronostratigraphic age: Middle Pleistocen, Chibanian; probably correlates with MIS 12 (VAN HUSEN, 2000a; VAN HUSEN & REITNER, 2011a).

Biostratigraphy: -

Thickness: Up to some tens of meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlays unconformably deposits of pre-Quaternary bedrock as well as older Pleistocene sediments.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: In general, it occurs at the tongues of Salzach, Traun and Krems glaciers; ÖK50-UTM, map sheets 3204 Salzburg, 3205 Mondsee, 3206 Gmunden, 3327 Burghausen, 3328 Mattighofen, 3329 Vöcklabruck, 3330 Attnang-Puchheim, 4201 Kirchdorf an der Krems, 4325 Wels (ÖK50-BMN, map sheets 45 Ranshofen, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels, 50 Bad Hall, 64 Straßwalchen, 65 Mondsee, 66 Gmunden, 67 Grünau im Almtal, 68 Kirchdorf an der Krems).

Remarks: -

Complementary references: WEINBERGER (1955), DEL NEGRO (1969), KOHL (2000), VAN HUSEN (1977), EGGER & VAN HUSEN (2007).

Jüngerer Deckenschotter / Younger gravel sheet

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: "Iller-Lech-Platte", Bavaria (Swabia), Germany.

Type section: -

Reference section(s): -

Derivation of name: Gravel deposits slightly incised in the "Ältere Deckenschotter" now following the modern river course.

Synonyms: Terrasse von Lehen, Terrasse S Ornding (FUCHS, 1964b).

Lithology: Coarse sand-bearing gravel deposits with weak layering. The material reflects the lithology of the catchment areas of the supplying rivers. In contrast to the "Älteren Deckenschotter" along the rivers Traun and Enns, all the material of the "Jüngerer Deckenschotter" originates from the Alps as is demonstrated by the content of limestone, dolostone, and flysch sandstone. In some layers the gravel is well cemented. The gravel deposits are intensively weathered at the top. Pipe-like weathering features ("Geologische Orgeln") occur frequently.

Fossils: -

Origin, facies: Climatically induced gravel accumulation along main rivers during climax of Mindel glaciation; braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably correlates with MIS 12 (VAN HUSEN, 2000a; VAN HUSEN & REITNER, 2011a).

Biostratigraphy: -

Thickness: Up to 40 m near the terminal moraines.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock.

Overlying unit(s): Mostly loess.

Lateral unit(s): Pre-Quaternary bedrock.

Geographic distribution: Along the rivers more or less extended remnants; ÖK50-UTM, map sheets 3205 Mondsee, 3206 Gmunden, 3327 Burghausen, 3328 Mattighofen, 3329 Vöcklabruck, 3330 Attnang-Puchheim, 4201 Kirchdorf an der Krems, 4202 Ternberg, 4325 Wels, 4326 Steyr, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg (ÖK50-BMN, map sheets 45 Ranshofen, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels, 50 Bad Hall, 51 Steyr, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf, 56 St. Pölten, 64 Straßwalchen, 65 Mondsee, 66 Gmunden, 67 Grünau im Almtal, 68 Kirchdorf an der Krems, 69 Großraming).

Remarks: Adenberg (N 48°08′35″ / E 12°58′22″) (WEINBERGER, 1955), S Lindach (N 48°00′02″ / E 13°51′02″)

(KOHL, 2000; EGGER & VAN HUSEN, 2007). Additional remnants "Jüngerer Deckenschotter" occur along the Danube and its southern tributaries (KRENMAYR & SCHNABEL, 2006; SCHNABEL, 2002a; SCHNABEL et al., 2012; ĆORIĆ et al., 2016).

Complementary references: -

Mönchsberg Nagelfluh / Mönchsberg Conglomerate

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by BOUÉ (1830a).

Type area: The mountain Mönchsberg (N 47°48′00″ / E 13°02′00″) in the city centre of Salzburg; ÖK50-UTM, map sheet 3210 Hallein (ÖK50 BMN, map sheet 63 Salzburg).

Type section: -

Reference section(s): -

Derivation of name: Named after the "Mönchsberg" (508 m a.s.l.).

Synonyms: "Salzburger Nagelfluh" as well-known building stone (KIESLINGER, 1964).

Lithology: Coarse sand-bearing gravel deposits which are in part well-cemented to conglomerate. The gravel composition is similar to that of the modern gravel of the river Salzach. Layers are dipping 20–30° in western to northeastern directions. Apart from a few layers with open work structures the conglomerates show predominantly a sand matrix.

Fossils: -

Origin, facies: Kame. Foreset-beds of a Gilbert-Type delta deposits which was formed in an ephemeral small lake, during the initial phase of down-melting of the Salzach glacier at the end of the Mindel glaciation (Termination V).

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably correlates with MIS 12 (VAN HUSEN, 2000a; VAN HUSEN & REITNER, 2011b).

Biostratigraphy: -

Thickness: Up to 80 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Terrace in the centre of the city of Salzburg; ÖK50-UTM, map sheets 3204 Salzburg, 3210 Hallein (ÖK50 BMN, map sheets 63 Salzburg, 94 Hallein).

Remarks: Similar deposits: Adneter Riedl, c. 1 km SSW of the village Adnet (N 47°41′11″ / E 13°07′30″), Georgenberg (N 47°38′06″ / E 13°09′35″), near the hamlet Lacher (N 47°36′09″ / E 13°08′39″), c. 1.8 km WNW of Golling an der Salzach, Salzburg (PLÖCHINGER, 1987; VAN HUSEN, 1990).

Complementary references: MORLOT (1847), PENCK & BRÜCKNER (1909), GÖTZINGER (1936c).

Arsenal Terrasse / Arsenal Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by SCHAFFER (1902), detailed description by FINK & MAYDAN (1954) and KÜPPER (1968).

Type area: Around the main railway station of the city of Vienna (N 48°11′08″ / E 16°22′39″), 10th district of Vienna (Favoriten); ÖK50-UTM, map sheet 5326 Schwechat (ÖK50 BMN, map sheet 59 Wien).

Type section: -

Reference section(s): -

Derivation of name: After the former military complex "Arsenal".

Synonyms: -

Lithology: Coarse sand-bearing gravel deposits. The gravel is mainly composed of quartz, quartzite and crystalline rocks and limestones from the rivers Danube and Wien. It contains angular boulders (SUESS, 1862) in the lower parts which were obviously transported by ice floes. In the upper parts layers with subangular flysch gravel ("Plattelschotter") deposited by river Wien are dominant. The top of the gravel deposits is heavily weathered. Cryoturbations are frequent.

Fossils: -

Origin, facies: Rivers Danube and Wien; braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; probably MIS 12.

Biostratigraphy: -

Thickness: Up to 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Overlay unconformably Neogene deposits of the Vienna Basin.

Overlying unit(s): Loess.

Lateral unit(s): -

Geographic distribution: Vienna Basin; ÖK50-UTM, map sheets 5321 Gänserndorf, 5326 Schwechat (ÖK50-BMN, map sheets 43 Marchegg, 59 Wien, 61 Hainburg).

Remarks: "Schloßhofer Platte" is a loess-covered 15 m thick gravel sheet on top of an isolated base of Neogene, more or less in a comparable elevation like the Arsenal Terrace (WESSELY, 2006). Weathered gravel of river Danube with frequent cryoturbation features. Lithology is identical with the Prellenkirchen Terrace south of the river Danube (FINK, 1955).

Complementary references: PFLEIDERER (2008), GRUPE et al. (2021).

Höttinger Brekzie / Hötting Breccia

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by ESCHER VON DER LINTH (1846) and MORLOT (1847).

Type area: North of the city of Innsbruck, north of the river Inn between Höttingergraben (N 47°17′00″ / E 11°22′20″)

and Mühlauergraben (N 47°18′00″ / E 11°24′50″), Tyrol; ÖK50-UTM, map sheet 2223 Innsbruck (ÖK50-BMN, map sheet 118 Innsbruck).

Type section: -

Reference section(s): -

Derivation of name: Hötting (N 47°16′20″ / E 11°23′13″), a district of the city of Innsbruck, Tyrol.

Synonyms: -

Lithology: The lithology is a well-cemented breccia containing angular Triassic carbonate rocks, silt-sandstone and some associated crystalline erratics. The predominantly coarse talus contains some fine-grained layers. Based on the colour two types of breccias can be recognized in the lower parts of the slope: the White Breccia and the Red Breccia. The colour results from the bedrock colour that influences the matrix (Ampferer, 1936).

Fossils: Plant fossils crop out on one spot at Rossfall-Lahner (N 47°17′30″ / E 11°22′40″). The flora is rich in taxa indicating warm interglacial conditions (e.g., *Rhododendron, Vitis*) (von Ettingshausen, 1885; von Wettstein, 1892; Gams, 1936; Denk, 2006).

Origin, facies: The origin and facies of the unit is a talus formed mostly by debris and mud flows but also by rock fall and grain flow (Sanders et al., 2009). The latter formed laminated silt deposits in distal puddles (Sanders & Ostermann, 2006; Sanders, 2010).

Chronostratigraphic age: Middle Pleistocene, Chibanian, between MIS 12 and 6.

Remark: It represents the period Mindel/Riß "Großes Interglazial" (Penck, 1921; Ampferer, 1936) and probably covers the full time-span from MIS 11 to MIS 7 (van Husen, 2000a). Breccia was already lithified and fractured 167 ± 2 ka ago (U/Th age; Spötl et al., 2015). A correlation with MIS 5 is discussed (Sanders & Ostermann, 2006). Such a young age is supported by luminescence ages which suggest an early to middle Würm deposition of the Hötting Breccia (Gemmel & Spötl, 2009).

Biostratigraphy: -

Thickness: Up to more than 100 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Older till (Mindel) and Triassic bedrock.

Overlying unit(s): Riß and Würm subglacial tills separated by gravel deposits (Ampferer, 1936).

Lateral unit(s): -

Geographic distribution: Lower southern slope of the mountain range "Nordkette" north of Innsbruck and along the south rim of the Northern Calcareous Alps, Tyrol; ÖK50-UTM, map sheets 3217 Hallstatt, 3218 Bad Mitterndorf, 4207 Windischgarsten, 4211 Neuberg an der Mürz, 4212 Mürzzuschlag, 4214 Trieben, 4215 Eisenerz (ÖK50 BMN, map sheets 100 Hieflau, 101 Eisenerz, 103 Kindberg, 104 Mürzzuschlag, 126 Radstatt, 127 Schladming).

Remarks: All these similar breccias are more or less induced by the underling Early Triassic Werfen Formation or other ductile rocks (van Husen, 2000a) and common also within the Northern Calcareous Alps (e.g., Windischgarsten) (van Husen & Draxler, 2011). These lithified talus deposits were especially developed on the southern rim of the Northern Calcareous Alps from Innsbruck eastwards to the easternmost Alpine margin, e.g., on the southern flank of the Dachstein plateau (Mandl et al., 2014), at the Gesäuse (Ampferer, 1935) and at the Schneeberg (Cornelius, 1936, 1941, 1951).

Complementary references: -

Riß End- und Grundmoräne und Vorstoßschotter / Riß terminal moraine, subglacial till and proglacial gravel

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Penck & Brückner (1909).

Type area: Eastern rim of piedmont tongue of the former Rhine glacier at Biberach an der Riß (N 48°05′53″ / E 09°47′19″), Baden-Württemberg, Germany.

Type section: -

Reference section(s): -

Derivation of name: River Riß, Baden-Württemberg, Germany.

Synonyms: Salzach glacier (Weinberger, 1955), Traun glacier (van Husen, 1977).

Lithology: Lithologically the unit consists of diamictons (till) of coarse sand-bearing gravel with boulders. Often a varying content of silt and clay can be noticed. Locally indistinct bedding is evident. The clast composition of the gravel deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of subglacial till on the upflow side of the terminal moraine are highly consolidated. The till shows advanced weathering, averaging a depth of 1 to 2 m.

The Riß subglacial till often covers a few meters thick gravel bed, which reflects sedimentary transition to the till. These gravel deposits called "Vorstoßschotter" in German were formed in front of the advancing glacier by fluvial action and were covered by till immediately after deposition. In some tributary valleys, fine grained (glacio-) lacustrine sediments are occasionally preserved below the subglacial till. These silty to sandy deposits are the infill of ephemeral ice-dammed lakes during glacier advance and are consequently a part of the "Vorstoßschotter".

Fossils: -

Origin, facies: Genetically, the Riß terminal moraine was overwhelmingly deposited as a dump moraine by a stationary glacier during climax conditions.

Chronostratigraphic age: Middle Pleistocene, Chibanian; correlated with MIS 6 (van Husen, 2000a; van Husen & Reitner, 2011a).

Remark: This assumption is backed by the "Mondsee Deltakomplex" (N 47°51′24″ / E 13°20′44″) (van Husen, 2000c) where Riß subglacial till is superimposed in a continuous sequence by Riß/Würm interglacial lake deposits (Drescher-Schneider, 2000), correlated with the Eemian –

MIS 5e. Luminescence dating of glaciofluvial deposits in the Ybbs valley of Lower Austria (BICKEL et al., 2015a) with ages 150 ± 14 ka (pIRIR225) and 129 ± 14 ka (OSL) proof the correlation of Riß glaciation with MIS 6.

Biostratigraphy: -

Thickness: Up to some tens of meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock or older Quaternary sediments.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: North rim of the Alps and the Alpine Foreland in Salzburg and Upper Austria; ÖK50-UTM, map sheets 3204 Salzburg, 3205 Mondsee, 3206 Gmunden, 3327 Burghausen, 3328 Mattighofen, 4201 Kirchdorf an der Krems, 4202 Ternberg (ÖK50-BMN, map sheets 45 Ranshofen, 46 Mattighofen, 64 Straßwalchen, 65 Mondsee, 66 Gmunden, 67 Grünau im Almtal, 68 Kirchdorf an der Krems, 69 Großraming).

Remarks: Terminal morains: Salzach glacier around Gilgenberg (N 48°7′45″ / E 12°56′43″) (WEINBERGER, 1955) and Kühberg (N 47°58′21″ / E 13°10′10″) (EGGER & VAN HUSEN, 2003), Traun glacier around the glacier tongues at lake Irrsee at Sommerholz (N 47°55′34″ / E 13°16′45″), Attersee and Traunsee (VAN HUSEN, 1989; EGGER, 1996; EGGER & VAN HUSEN, 2003, 2007), Krems glacier around Wartberg an der Krems (N 47°59′21″ / E 14°07′07″) KOHL (2000) and Enns glacier Großraming (PENCK & BRÜCKNER, 1909; VAN HUSEN, 1968, 2011).

Complementary references: KRENMAYR & SCHNABEL (2006), RUPP et al. (2011).

Bürser Konglomerat / Bürs Conglomerate

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by AMPFERER (1908).

Type area: Brandner Valley at Bürs (N 47°09′06″ / E 09°48′14″), and Gamperdona Valley at Nenzing (N 47°11′11″ / E 09°42′18″), Vorarlberg; ÖK50-UTM, map sheet 1230 Bludenz (ÖK50-BMN, map sheet 141 Feldkirch).

Type section: -

Reference section(s): -

Derivation of name: Village of Bürs (N 47°09′06″ / E 09°48′14″), Vorarlberg.

Synonyms: -

Lithology: Partly well cemented cobbly, coarse sandy gravel manly of Mesozoic sedimentary rocks. Clasts are predominately sub- to well-rounded. The "Bürser Konglomerat" shows very well rounded clasts in the lower and more subangular and subrounded ones in upper parts. At Gamperdona successions of unconformities are evidence for repeatedly interrupted delta accumulation. Packages bottomset-to-topset, few of meters thick are frequent. At Bürs: the conglomerate is arranged in indistinct, roughly symmetrical upward-coarsening to upward-fining packages that are vertically separated by thin intervals of arenite (HEISSEL, 1961; HEISSEL et al., 1965); the cyclic packages are, however, locally truncated and incomplete. The accumulation of the Bürs Conglomerate probably results from a rise of local base-level during glaciation. "*The succession may represent an aggrading braid plain that formed during advance or during retreat of the Ill glacier*" (OSTERMANN et al., 2006: p. 34).

Fossils: -

Origin, facies: Filling of the two tributary valleys (the creeks Alvier and Meng) due to the blocking of glacier in the main Ill valley. Gilbert-type delta deposits in temporary lakes with no constant lake levels.

Chronostratigraphic age: Middle Pleistocene, Chibanian; MIS 6.

Remark: According to ^{230}Th/^{234}U dates of 129 ± 6.5 ka (Gamperdona Valley) and 128 ± 10 ka (Brandner Valley) MIS 6 + Termination II (OSTERMANN et al., 2006).

Biostratigraphy: -

Thickness: 140 m at Bürs, up to 400 m at Gamperdona (AMPFERER, 1908).

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock.

Overlying unit(s): -

Lateral unit(s): Pre-Quaternary bedrock.

Geographic distribution: Ill valley, Vorarlberg; ÖK50-UTM, map sheet 1230 Bludenz (ÖK50-BMN, map sheets 169 Gaschurn, 142 Schruns).

Remarks: -

Complementary references: DE GRAAFF (1996).

Hochterrasse / High Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: "Iller-Lech-Platte", along the river Riß, Baden-Württemberg, Germany.

Type section: Former gravel pit (N 48°04′55″ / E 09°48′04″) at southern margin of the town Biberach an der Riß (N 48°05′44″ / E 09°47′21″), Baden-Württemberg, Germany.

Reference section(s): -

Derivation of name: Means, in comparison to the "Niederterrasse" (Low Terrace), the higher of the extensive continuous valley terraces following the modern river course.

Synonyms: -

Lithology: Coarse, sand-bearing gravel with weak bedding. Gravel composition displays the lithology of the catchment area of the respective rivers. Along the Danube material from the Alps in the South (limestone, dolostone, flysch, sandstones) is mixed with the gravel from the tributaries originating in the Bohemian Massif. The gravel deposits show only locally weak cementation. Well-developed weathering occurs at the top just below the loess cover. The onset of pipe-like weathering ("Geologische Orgeln") can locally be recognized.

Fossils: -

Origin, facies: Climatically induced fluvial gravel deposits were mainly accumulated by braided rivers which were directly connected to the Riß terminal moraines. High terraces are also developed in unglaciated valleys.

Chronostratigraphic age: Middle Pleistocene, Chibanian; MIS 6.

Remark: Inn Valley at Gunderding (N 48°15′14″ / E 13°11′15″) has been dated by optically stimulated luminescence (OSL) between c. 200 and 140 ka (MEGIES, 2006). Such a result is supported by U/Th-dating of a calcitic cement from the same gravel pit providing a minimum age of 113.4 ± 4.4 ka (TERHORST et al., 2002). Luminescence ages of gravel pits in the Traun valley at Desselbrunn, Unterhart, Trindorf (Upper Austria), in the Krems valley at Oberrohr (Upper Austria), in the Steyr valley at Sierninghofen (Upper Austria), in the Enns Valley at Dörfling (Upper Austria) and in the Ybbs valley (Lower Austria) provided ages for the Hochterrasse indicating MIS 6 (BICKEL et al., 2015b).

Biostratigraphy: -

Thickness: 20–50 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock.

Overlying unit(s): Partly loess.

Lateral unit(s): Older terrace bodies and Pre-Quaternary bedrock.

Geographic distribution: Extended units of "Hochterrasse" are present along the Danube and its southern tributaries starting from the terminal moraines. Also along river Mur and the rivers east of it. Some remnants of the unit occur in non-glaciated valleys also.

ÖK50-UTM, map sheets 3205 Mondsee, 3206 Gmunden, 3317 Passau, 3321 Altötting, 3322 Braunau am Inn, 3323 Ried im Innkreis, 3327 Burghausen, 3328 Mattighofen, 3329 Vöcklabruck, 3330 Attnang-Puchheim, 4201 Kirchdorf an der Krems, 4202 Ternberg, 4203 Waidhofen an der Ybbs, 4319 Linz, 4320 Perg, 4323 Sankt Pölten, 4324 Herzogenburg, 4325 Wels, 4326 Steyr, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg, 4330 Neulengbach, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 28 Altheim, 29 Schärding, 31 Eferding, 32 Linz, 38 Krems an der Donau, 39 Tulln, 40 Stockerau, 44 Ostermiething, 45 Ranshofen, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels, 50 Bad Hall, 51 Steyr, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf, 56 St. Pölten, 64 Straßwalchen, 65 Mondsee, 66 Gmunden, 67 Grünau im Almtal, 68 Kirchdorf an der Krems, 69 Großraming, 70 Waidhofen an der Ybbs, 71 Ybbsitz, 72 Mariazell).

River Mur and SE Styria: ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4111 Leibnitz, 4112 Bad Radkersburg, 4229 Graz, 4230 Gleisdorf, 5101 Jennersdorf, 5219 Oberwart, 5225 Fürstenfeld, 5226 Kofidisch (ÖK50-BMN, map sheets 137 Oberwart, 138 Rechnitz, 164 Graz, 165 Weiz, 166 Fürstenfeld, 167 Güssing, 168 Eberau, 189 Deutschlandsberg, 190 Leibnitz, 191 Kirchbach in Steiermark, 192 Feldbach, 193 Jennersdorf, 206 Eibiswald, 207 Arnfels, 208 Mureck, 209 Bad Radkersburg).

Remarks: Salzach glacier (WEINBERGER, 1955), Traun glacier (EGGER, 1996; EGGER & VAN HUSEN, 2003, 2007, 2009b; EGGER et al., 2007a, 2009; VAN HUSEN, 1989; VAN HUSEN & EGGER, 2014), Danube (KRENMAYR & SCHNABEL, 2006; SCHNABEL, 2002a). The terraces: "Terrasse westlich Seyring" (GRILL, 1951), "Gänserndorfer Terrasse" (FINK, 1955), "Theresianumterrasse" (KÜPPER, 1968), "Stadtterrasse, Simmeringer Terrasse" (SCHAFFER, 1902) are equivalent to "Hochterrasse".

Complementary references: -

Torrener Nagelfluh / Torren Conglomerate

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PIPPAN (1957).

Type area: Salzachtal near Golling an der Salzach, Salzburg.

Type section: Quarry near the village Torren (N 47°35′41″ / E 13°09›02″), c. 1.2 km W of the market town Golling an der Salzach, Salzburg; ÖK50-UTM, map sheet 3216 Bischofshofen (ÖK50-BMN, map sheet 94 Hallein).

Reference section(s): -

Derivation of name: Village Torren W of the market town Golling an der Salzach, Salzburg.

Synonyms: -

Lithology: The unit is typified by partly well-cemented sand-bearing gravel. The deposit is dominated by carbonate pebbles from local sources which are mixed with crystalline clasts. Only a few layers show well-developed cementation. Layers with clay coating of the pebbles are poorly cemented. The lower sediment layers of the sequence show clinoforms with a dip of 30° to the North. The upper part shows horizontal layering with cross bedding. The uppermost part (c. 2 m) is in part intensively weathered.

Fossils: -

Origin, facies: The sequence is formed as a Gilbert-Type delta complex with fore- and topsets in a lake probably between stagnant ice and the slope (kame terrace).

Chronostratigraphic age: Middle Pleistocene, Chibanian; MIS 6.

Remark: Initial phase of down-melting at the end of the Riß glaciation Termination II, MIS 6 (VAN HUSEN, 2000a; VAN HUSEN & REITNER, 2011b) supported by BICKEL et al. (2015b) with an OSL age of 131 ± 18 ka.

Biostratigraphy: -

Thickness: About 30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock.

Overlying unit(s): -

Lateral unit(s): Pre-Quaternary bedrock.

Geographic distribution: Restricted to the type area at the village Torren, Salzburg; ÖK50-UTM, map sheet 3216 Bischofshofen (ÖK50-BMN, map sheet 94 Hallein).

Remarks: Conglomerate is used as building stone (KIESLINGER, 1964).

Complementary references: -

Stadtterrasse / City Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by SCHAFFER (1902).

Type area: At the centre of the city of Vienna around St. Stephen's cathedral (N 48°12′31″ / E 16°22′22″), 1st district of Vienna (Innere Stadt); ÖK50-UTM, map sheet 5320 Wien (ÖK50-BMN, map sheet 59 Wien).

Type section: -

Reference section(s): -

Derivation of name: Named after the city of Vienna.

Synonyms: -

Lithology: Coarse gravel deposits with sand showing weak layering. The gravel is rounded to well-rounded and is composed of c. 80 % quartz and crystalline rocks, c. 20 % pebbles of limestone and flysch sandstone. This material was deposited by the Danube. Angular boulders of 1 m and more in diameter are mainly found in the lower part of the deposit (KÜPPER, 1951). They were transported and deposited by ice floes during glacial climatic conditions. At the mouth of tributaries like river Wien originating from the Vienna Woods thick layers of predominant subangular flysch material ("Plattelschotter") interdigitate at the top with the Danube terrace deposits (KÜPPER, 1968; FINK, 1973).

Fossils: -

Origin, facies: Deposit of river Danube, braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; MIS 6.

Biostratigraphy: -

Thickness: 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Neogene of Vienna Basin.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: City of Vienna; ÖK50-UTM, map sheets 5320 Wien, 5326 Schwechat (ÖK50-BMN, map sheet 59 Wien).

Remarks: Equvivalent terrasses are "Simmeringer Terrasse" (SCHAFFER, 1902) and "Theresianum Terrasse" (KÜPPER, 1968).

Complementary references: FINK & MAJDAN (1954), PFLEIDERER (2008), GRUPE et al. (2021).

Gänserndorfer Terrasse / Gänserndorf Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by FINK & MAJDAN (1954).

Type area: Vienna Basin North of the river Danube.

Type section: -

Reference section(s): -

Derivation of name: Town of Gänserndorf (N 48°20′26″ / E 16°43′03″), Lower Austria.

Synonyms: Terrace W of Seyring (N 48°19′57″ / E 16°29′12″).

Lithology: Coarse gravel deposits of rounded to well-rounded clasts which consist of about 80 % quartz, quartzite and crystalline rocks and about 20 % limestone and flysch-sandstone. The uppermost part of the unit is weathered and shows strong oxidation of iron (hydroxides). The upper 3–4 m of the unit was affected by ice wedges and intensive cryoturbation which included also soil and loess material.

Fossils: -

Origin, facies: Deposited by the river Danube; braided river deposits.

Chronostratigraphic age: Middle Pleistocene, Chibanian; MIS 6.

It is a part of the "Hochterrasse" along the river Danube. A recent luminescence-date of 120 ± 10 ka confirmed this age (BRAUMANN et al., 2019).

Biostratigraphy: -

Thickness: 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Neogene of Vienna basin.

Overlying unit(s): Partly loess.

Lateral unit(s): -

Geographic distribution: Vienna basin N of river Danube; ÖK50-UTM, map sheets 5320 Wien, 5321 Gänserndorf (ÖK50-BMN, map sheets 41 Deutsch Wagram, 42 Gänserndorf, 43 Marchegg, 59 Wien, 60 Bruck an der Leitha, 61 Hainburg).

Remarks: In part the terrace body is tectonically subsided at Aderklaa (N 48°17′07″ / E 16°32′15″), Obersiebenbrunn (N 48°15′52″ / E 16°42′25″), and Lassee (N 48°13′26″ / E 16°49′25″) (FUCHS & GRILL, 1984a; DECKER et al., 2005).

Complementary references: -

Illmitz-Formation / Illmitz Formation

Dirk van Husen & Jürgen M. Reitner

Validity: Valid; introduced by Häusler et al. (2021).

Type area: The area called "Seewinkel" east of Lake Neusiedl, Burgenland.

Type section: A drillhole (N 47°45′15″ / E 16°50′54″) E of the village Illmitz, Burgenland; ÖK50-UTM, map sheet 5209 Illmitz (ÖK50-BMN, map sheet 79 Neusiedl am See).

Reference section(s): A gravel pit (N 47°44′14″ / E 16°57′05″) NE Wallern im Burgenland and a drillhole (N 47°45′50″ / E 16°46′51″) at the SW shore of "Illmitzer Zicklacke" (Illmitz Pond); ÖK50-UTM, map sheet 5209 Illmitz (ÖK50-BMN, map sheet 78 Rust).

Derivation of name: Village of Illmitz (N 47°45′44″ / E 16°48′01″), Burgenland.

Synonyms: "Seewinkelschotter" (Fuchs, 1985a; Herrmann et al., 1993; Pascher, 1999).

Lithology: Gravel with a high content of sand, silt and clay predominated by well-rounded quartz pebbels mixed with lime- and dolostones. Fine grained layers are common.

Fossils: -

Origin, facies: Fluvial gravel beds with intensive lateral as vertical change of grain size distribution. Deposits of anastomosing rivers (Häusler et al., 2021).

Chronostratigraphic age: Middle Pleistocene, Chibanian and Late Pleistocene.

Remark: According to the tectonic subsiding at the margin of the "Kleine Ungarische Tiefebene" (Kisalföld) accumulation occurred for the first time in Middle Plistocene (MIS 6) and again in Late Pleistocene (MIS 2) (Häusler et al., 2021).

Biostratigraphy: -

Thickness: Up to 30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above fine-grained Pannonian (Upper Miocene) deposits.

Overlying unit(s): Partly salt soils and the Osli Formation in the South (Häusler et al., 2021).

Lateral unit(s): -

Geographic distribution: "Seewinkel" south of "Parndorfer Platte" and east of Lake Neusiedl; ÖK50-UTM, map sheets 5203 Neusiedl am See, 5204 Nickelsdorf, 5209 Illmitz, 5210 Andau (ÖK50-BMN, map sheets 78 Rust, 79 Neusiedl am See, 109 Pamhagen).

Remarks: -

Complementary references: -

Deltakomplex Mondsee / Mondsee delta deposits

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced as "Mondsee Interglazial" by Klaus (1975, 1987).

Type area: The slope north of the market town of Mondsee at around the farmhouse Steiner (N 47°51′56″ / E 13°20′48″), Upper Austria.

Type section: Steinerbach (N 47°51′54″ / E 13°20′37″) as still accessable location may serve as the type section.

Reference section(s): An artificial ditch at Pichlergraben (N 47°51′40″ / E 13°20′40″), Kohl (1978). Three drillholes (N 47°51′54″ / E 13°20′38, N 47°51′55″ / E 13°20′39″, N 47°51′56″ / E 13°20′40″), Krenmayr (2000a), van Husen (2000c).

Derivation of name: After the market town Mondsee (N 47°51′22″ / E 13°20′59″), Upper Austria.

Synonyms: -

Lithology: The unit superposes subglacial till (Riß). The sequence starts with laminated clay, silt and lake marls, which were deposited during the Eemian interglacial period. This lower part is overlain by a coarsening upward sequence of clay, silt and sand layers (Krenmayr, 2000a). The whole package is covered by subglacial till (late Würm).

Fossils: The unit is rich in pollen which document the vegetation development from the late glacial period of the Riß (Termination II, MIS 6) to middle Würm (MIS 3) (Drescher-Schneider, 2000; Oeggl & Unterfrauner, 2000).

Origin, facies: The preserved sequence evolved as a Gilbert-type delta with bottom-, fore- and top-sets deposited in an ancient Lake Mondsee with a lake level of about 60 m above the present-day level (van Husen, 2000c).

Chronostratigraphic age: Middle Pleistocene, Chibanian to Late Pleistocene; MIS 6 to 3.

Biostratigraphy: -

Thickness: About 60 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Probably pre-Quaternary bedrock only.

Overlying unit(s): -

Lateral unit(s): Pre-Quaternary bedrock.

Geographic distribution: At the western shore of lake Mondsee; ÖK50-UTM, map sheet 3205 Mondsee (ÖK50-BMN, map sheet 65 Mondsee).

Remarks: -

Complementary references: Kohl (1978), van Husen (2000b).

Schieferkohle von Nieselach / Nieselach Lignite

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Fritz (1971).

Type area: Escarpment to the river Gail south of the village St. Stefan an der Gail (N 46°37′05″ / E 13°30′59″), Carinthia.

Type section: At the escarpment to the river Gail c. 500 m WNW of the hamlet Nieselach (N 46°36′25″ / E 13°30′34″), Carinthia.

Reference section(s): -

Derivation of name: Named after the hamlet Nieselach (N 46°36′25″ / E 13°30′34″) c. 1.3 km SSW of the village St. Stefan an der Gail, Carinthia.

Synonyms: -

Lithology: The sequence consists of horizontally bedded sandy, silty, occasionally gravelly sediments with lignite in the uppermost part; this conformably overlays banded clay (lake deposits after Riß deglaciation). The lignite is unconformably overlain by coarse gravel, which is regarded to represent "Vorstoßschotter", i.e. proglacial fluvial sediments deposited during the glacier advance phase of the late Würm glaciation.

Fossils: The unit is rich in pollen which document the vegetation at the end of the Eemian (DRAXLER, 2000); and pieces of wood of willows and other bushes.

Origin, facies: The predominantly coarse sand with thin gravel and silt layers were deposited in a meandering river with during a low-energy stream regime. Layers of massive or banded clay document sedimentation in oxbow lakes, which finally got filled with wood (willows and other bushes) and peat, the source material of the lignite.

Chronostratigraphic age: Late Pleistocene.

Remark: According to paleomagnetic data (presence of the Blake event within the sequence) a correlation to MIS 5e is possible (SCHOLGER, 2000). U/Th dating of the lignite (113,000 ± 2,000 BP; GEYH et al., 1998) and the palynological record provide also arguments for a correlation with the Eemian (MIS 5e) as well as with the 1st Würm Interstadial (MIS 5c).

Biostratigraphy: -

Thickness: Around 6–8 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Banded clay representing the filling of the tongue basin of River Gail at the end of MIS 6.

Overlying unit(s): "Vorstoßschotter" and subglacial till of MIS 2 (Würm).

Lateral unit(s): Pre-Quaternary bedrock.

Geographic distribution: Escarpment of the terrace SSW of St. Stefan an der Gail; ÖK50-UTM, map sheets 3111 Spittal an der Drau, 3117 Nötsch im Gailtal (ÖK50-BMN, map sheet 199 Hermagor).

Remarks: -

Complementary references: VAN HUSEN & DRAXLER (1982), VAN HUSEN (2000a).

Kitzbüheler Terrasse / Kitzbühel Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by UNGER (1836).

Type area: Vicinity of of the town Kitzbühel (N 47°26′50″ / E 12°23′26″), Tyrol; ÖK50-UTM, map sheet 3214 Kitzbühel (ÖK50-BMN, map sheet 122 Kitzbühel).

Type section: -

Reference section(s): -

Derivation of name: After the town of Kitzbühel, Tyrol.

Synonyms: -

Lithology: The sequence consists of a subglacial till (attributed to MIS 6) overlain by massive and banded silts with no pollen content which show a coarsening-upward into sand-bearing gravel deposits (REITNER & DRAXLER 2002; REITNER, 2005; HEINISCH et al., 2015). The gravel is overlain by a laminated organically rich clayey silt deposit and three meters thick lignite (former peat).

Fossils: The unit is rich in pollen which document the vegetation of a cool period. Aditional pieces of wood of willows and other bushes.

Origin, facies: The coarsening-upward sequence is regarded to represent a phase of rapid sedimentation during deglaciation. From the organic-bearing upper part of this and other locations with wood remnants or lignite within the extensive Kitzbühel Terrace it is concluded that during an interstadial phase an elevated valley floor with prograding alluvial fans and swampy intercone deposits existed.

Chronostratigraphic age: Late Pleistocene.

Remark: Pollenanalyses by DRAXLER (2005) and BORTENSCHLAGER (2015) together with a U/Th age of 90 ± 8 ka (REITNER, 2005) indicate that the peat was formed during the first Würm Interstadial (MIS 5c). Thus, the valley infill of the Kitzbühel Terrace supposedly covers the timespan from end of the Riß glaciation (Termination II, MIS 6) to the early Würm.

Biostratigraphy: -

Thickness: Around 40 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Probably pre-Quaternary bedrock.

Overlying unit(s): Unconformable overlain by subglacial till (MIS 2).

Lateral unit(s): -

Geographic distribution: Vicinity of the town of Kitzbühel; ÖK50-UTM, map sheet 3214 Kitzbühel (ÖK50-BMN, map sheet 122 Kitzbühel).

Remarks: Similar sediments of early Würm age consisting of lignites intercalated in up to 100 m thick gravel beds are found in the area of Hopfgarten/Brixental (N 47°26′58″ / E 12°09′27″), Tyrol (REITNER, 2005; REITNER & DRAXLER, 2002).

Complementary references: OHNESORGE (1917).

Bänderton von Baumkirchen / Banded clay of Baumkirchen

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by FLIRI et al. (1970).

Type area: Vicinity of the village Baumkirchen (N 47°18′02″ / E 11°33′49″), Tyrol.

Type section: Abandoned clay pit (N 47°18′25″ / E 11°34′12″) c. 1 km NE of the village Baumkirchen, Tyrol.

Reference section(s): -

Derivation of name: Village Baumkirchen, c. 2 km WNW of the market town Wattens, Tyrol.

Synonyms: -

Lithology: Uniform banded clay deposits.

Fossils: Branches of pine, alder, and buckthorn.

Origin, facies: Bottomset of a greater lake in the area. According to pollen content high sedimentation rate under cool conditions (Bortenschlager & Bortenschlager, 1978; Barret et al., 2017).

According to a new detailed investigation by a drill hole the lake existed over a time span of 50 ka from c. 80 ka to 30 ka with a gap of c. 10 ka around 50 ka. This was probably caused by climatic deterioration combined with an interruption of the lake phase and erosional activity (Barret et al., 2017). In addition, two stadials and two interstadials were identified in the MIS 3 section (Barret et al., 2018). The interstadials show a well-developed open vegetation with some stands of trees.

Chronostratigraphic age: Late Pleistocene.

Remark: From MIS 5 to 3 according to luminescence dating of Barrett et al. (2018) and cal.^{14}C-dates of 34 to 35 ka of Spötl et al. (2013).

Biostratigraphy: -

Thickness: More than 250 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Probably older Quaternary deposits.

Overlying unit(s): Gravel and Würm subglacial till.

Lateral unit(s): Pre-Quaternary bedrock. Alluvial fan at Fritzens (N 47°18′20″ / E 11°35′24″).

Geographic distribution: Slope N of the village Baumkirchen, Tyrol; ÖK50-UTM, map sheet 2223 Innsbruck (ÖK50-BMN, map sheet 118 Innsbruck).

Remarks: Can be correlated with the upper part of a sequence of coarse gravel and talus intercalated with banded clay, age 49,290 ± 5,030–26,130 ± 230 at Nesseltalgraben (N 47°39′31″ / E 13°02′57″) (Mayr et al., 2017, 2019). Located in the basin of Berchtesgaden, Bavaria, Germany.

Complementary references: Fliri (1973).

Ausseer Konglomerat / Aussee Conglomerate

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Götzinger (1935).

Type area: Basin around city of Bad Aussee (N 47°36′32″ / E 13°46′05″), Styria.

Type section: Not defined. As a type section can serve the location on both sides of Altausseer Traun at the "PVA Reha-Zentrum" (N 47°36′36″ / E 13°46′53″) (van Husen, 1977).

Reference section(s): -

Derivation of name: After the town Bad Aussee (N 47°36′32″ / E 13°47′05″), Styria.

Synonyms: -

Lithology: Mostly coarse sandy gravel reflecting the composition of the catchment area. In the blocked tributaries coarser gravel layer show often foreset structures and intercalate with sand, massive as well as banded clay layers.

Fossils: -

Origin, facies: Climatically induced sedimentation in front of the advancing glaciers. Partly coarse fluviatile sedimentation at valley floor in front of advancing glacier as braided river deposits. Partly lacustrine deposits with thick layers of banded clay in blocked tributaries at other locations (see remarks).

Chronostratigraphic age: Late Pleistocene; MIS 2.

Biostratigraphy: -

Thickness: Up to 30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Subglacial till (Riß).

Overlying unit(s): Subglacial till (Würm).

Lateral unit(s): Haselgebirge Formation (Lower Triassic).

Geographic distribution: Around the town Bad Aussee; ÖK50-UTM, map sheet 3212 Bad Aussee, 3218 Bad Mitterndorf (ÖK50-BMN, map sheet 96 Bad Ischl).

Remarks: Sediments of the final phase of the climatic decay during MIS 2 are documented from several places all over the Eastern Alps.

Tyrol: Fieberbrunn (N 47°28′43″ / E 12°32′49″) (Heinisch et al., 2015); Wildschönau (N 47°24′27″ / E 12°2′19″) (Menzis & Reitner, 2016); Gravel on top of "Bänderton von Baumkirchen" (N 47°18′25″ / E 11°34′12″) (Fliri et al., 1970); Steinberg am Rofan (N 47°30′45″ / E 11°47′53″) $U^{234}U^{230}$/Th age of 29.7 ± 1.8 ka (Sanders et al., 2014).

Salzburg: Basin of Abtenau (N 47°33′52″ / E 13°20′48″), coarse gravel below the till of the Last Glacial Maximum (Würm) contains a tusk of *Mammuthus primigenius,* cal. age BP 31,140–30,950 (Plöchinger, 1982; Krutter, 2019).

Upper Austria: Gimbach – Offensee (N 47°46′02″ / E 13°46′07″), Langbath valley (N 47°49′32″ / E 13°44′38″) (van Husen, 1977).

Carinthia: gravel on top of the Nieselach Lignite forming the terrace of St. Stefan an der Gail (N 46°37′05″ / E 13°30′59″) (Schönlaub, 1989; van Husen, 2000a).

Complementary references: Spengler & Götzinger (1936).

Würm End- und Grundmoräne und Vorstoßschotter / Würm terminal moraine, subglacial till and proglacial gravel

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Penck & Brückner (1909).

Type area: The precursor of the modern lake Starnberger See known as "Würm Lake" and its outlet the river Würm (N 47°59′59″ / E 11°21′25″), Bavaria, Germany.

Type section: -

Reference section(s): -

Derivation of name: River Würm, Bavaria, Germany.

Synonyms: -

Lithology: The Würm terminal moraine unit, in general, consists of massive diamicton (till) of coarse-grained sand-bearing gravel with boulders and an often varying content of silt and clay. Locally, indications of weak bedding can be found. The clast composition of the gravel deposits reflects the lithology in the catchment area according to the resistance of the material against glacial abrasion. Only the remnants of subglacial till on the up-flow side of the terminal moraine are highly consolidated. Subglacial till ("Grundmoräne") is an overconsolidated massive matrix-supported diamicton with occasional shear planes. The till is normally slightly weathered to depths of max. 1 m.

The Würm subglacial till often covers a few meters thick gravel bed which reflects a sedimentary transition to the till. These gravel deposits called "Vorstoßschotter" in German were formed in front of the advancing glacier by fluvial action and were covered by till immediately after deposition. In some tributary valleys, fine grained (glacio-) lacustrine sediments are occasionally preserved below the subglacial till. These silty to sandy deposits are the infill of ephemeral ice-dammed lakes during glacier advance and are consequently a part of the "Vorstoßschotter".

Fossils: -

Origin, facies: Genetically, the Würm terminal moraine was (overwhelmingly) deposited as a dump moraine by a stationary glacier during the climax conditions. Subglacial till can be classified as a subglacial traction till (EVANS et al., 2006).

Chronostratigraphic age: Late Pleistocene; MIS 2 (REUTHER et al., 2011).

Biostratigraphy: -

Thickness: Up to some tens of meters.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Quaternary sediments or pre-Quaternary bedrock.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Würm terminal morains occur – beside small cirque glaciers in the easterly parts of the Eastern Alps – more or less in all formerly glaciated valleys. ÖK50-UTM, map sheets 3106 Radenthein, 3204 Salzburg, 3205 Mondsee, 3206 Gmunden, 3327 Burghausen, 3328 Mattighofen, 4101 Gurk, 4102 Althofen, 4107 Klagenfurt, 4108 Sankt Veit an der Glan, 4109 Sankt Paul im Lavanttal, 4113 Ferlach, 4114 Bad Eisenkappel, 4115 Bleiburg, 4207 Windischgarsten, 4208 Spital am Phyrn, 4210 Mariazell, 4211 Neuberg an der Mürz, 4212 Mürzzuschlag, 4226 Judenburg (ÖK50-BMN, map sheets 44 Ostermiething, 45 Ranshofen, 46 Mattighofen, 64 Straßwalchen, 65 Mondsee, 66 Gmunden, 67 Grünau im Almtal, 98 Liezen, 99 Rottenmann, 100 Hieflau, 101 Eisenerz, 102 Aflenz-Kurort, 103 Kindberg, 104 Mürzzuschlag, 161 Knittelfeld, 184 Ebene Reichenau, 185 Straßburg, 186 St. Veit an der Glan, 202 Klagenfurt, 203 Maria Saal, 204 Völkermarkt, 211 Windisch Bleiberg, 212 Vellach, 213 Bad Eisenkappel).

Remarks: Special St. Radegund in the Salzach valley N of the city of Salzburg (N 48°05′55″ / E 12°45′51″) (WEINBERGER, 1955); "Traun See" city of Gmunden (N 47°55′18″ / E 13°48′10″) (VAN HUSEN, 1977); "Drau valley at Ruden" E of Klagenfurt (N 46°39′33″ / E 14°46′14″). "Würm-Moräne" occurs more or less in all formerly glaciated valleys of the Eastern Alps. Very often below Würm terminal and basal till deposits so called "Vorstoßschotter" can be found. These fluvial gravel deposits whose facies indicates deposition in the proglacial area (sensu lato) of glaciers advancing to their maximum extent during the Würm Pleniglacial. Around the terminal moraines, such sediments below subglacial till are typically gravel beds of some meters thickness (PENCK & BRÜCKNER, 1909). Within the Alpine valleys up to 100 m thick sediment sequences of such coarse sand-bearing gravel are preserved (VAN HUSEN, 2000a). Proglacial gravel at the Salzach glacier was deposited 29 ± 4 ka (SALCHER et al., 2015).

Complementary references: -

Niederterrasse / Low Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: "Iller-Lech-Platte", Bavaria (Swabia), Germany.

Type section: -

Reference section(s): -

Derivation of name: Means the lower of the extensive continuous valley terraces following the modern river course (compare High Terrace).

Synonyms: -

Lithology: Coarse, sand-bearing gravel with weak bedding. Gravel composition displays the lithology of the catchment area of the respective rivers. Along the Danube material from the Alps in the South (e.g., limestone, dolostone, flysch and sandstones beside crystalline rocks) is mixed with the gravel (e.g., granites) from the tributaries originating in the Bohemian Massif. The gravel is usually not cemented and the weathering horizon on the top of the sequence is up to 50 cm. At escarpments to the river incomplete cementation ("Talrandverkittung") occurs often.

Fossils: -

Origin, facies: Based on the model of the "Glaziale Serie" PENCK & BRÜCKNER (1909) the Low Terrace is directly connected with Würm terminal moraines in more or less all the valleys in the Eastern Alps which were affected by former glaciers. These deposits are more or less everywhere, coars sandy gravels accumulated by braided rivers.

Chronostratigraphic age: Late Pleistocene.

Remark: The final proglacial aggradation of the "Niederterrasse" linked to LGM terminals of the Salzach Glacier occurred at Duttendorf at a cal. age of 25,900 ± 590 BP (TRAUB & JERZ, 1975), respectively, at an OSL age of 21 ± 3 ka (STARNBERGER et al., 2008, 2011). Deposition probably began in MIS 3, mainly MIS 2.

Biostratigraphy: -

Thickness: Varies between 10–100 m near the terminal moraines.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock.

Overlying unit(s): -

Lateral unit(s): Older Quaternary sediments; pre-Quaternary bedrock.

Geographic distribution: Around the Eastern Alpes more or less in all valleys.

Danube and tributaries: ÖK50-UTM, map sheets 3204 Salzburg, 3205 Mondsee, 3206 Gmunden, 3317 Passau, 3321 Altötting, 3322 Braunau am Inn, 3323 Ried im Innkreis, 3324 Grieskirchen, 3327 Burghausen, 3328 Mattighofen, 3329 Vöcklabruck, 3330 Attnang-Puchheim, 4201 Kirchdorf an der Krems, 4202 Ternberg, 4203 Waidhofen an der Ybbs, 4204 Gaming, 4205 Sankt Aegyd am Neuwalde, 4207 Windischgarsten, 4208 Spital am Phyrn, 4209 Hieflau, 4210 Mariazell, 4211 Neuberg an der Mürz, 4319 Linz, 4320 Perg, 4323 Sankt Pölten, 4324 Herzogenburg, 4325 Wels, 4326 Steyr, 4327 Amstetten, 4328 Scheibbs, 4329 Wilhelmsburg, 4330 Neulengbach, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 28 Altheim, 29 Schärding, 31 Eferding, 32 Linz, 38 Krems an der Donau, 39 Tulln, 40 Stockerau, 44 Ostermiething, 45 Ranshofen, 46 Mattighofen, 47 Ried im Innkreis, 48 Vöcklabruck, 49 Wels, 50 Bad Hall, 51 Steyr, 52 St. Peter in der Au, 53 Amstetten, 54 Melk, 55 Ober-Grafendorf, 56 St. Pölten, 64 Straßwalchen, 65 Mondsee, 66 Gmunden, 67 Grünau im Almtal, 68 Kirchdorf an der Krems, 69 Großraming, 70 Waidhofen an der Ybbs, 71 Ybbsitz, 72 Mariazell, 73 Türnitz, 98 Liezen, 99 Rottenmann, 100 Hieflau, 101 Eisenerz, 102 Aflenz-Kurort, 103 Kindberg).

River Mur, SE Styria and S Burgenland: ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4106 Feldbach, 4111 Leibnitz, 4112 Bad Radkersburg, 4216 Bruck an der Mur, 4217 Kindberg, 4221 Knittelfeld, 4222 Leoben, 4223 Weiz, 4226 Judenburg, 4227 Zeltweg, 4228 Voitsberg, 4229 Graz, 4230 Gleisdorf, 5101 Jennersdorf, 5219 Oberwart, 5225 Fürstenfeld, 5226 Kofidisch (ÖK50-BMN, map sheets 132 Trofaiach, 133 Leoben, 134 Passail, 137 Oberwart, 138 Rechnitz, 160 Neumarkt in Steiermark, 161 Knittelfeld, 162 Köflach, 163 Voitberg, 164 Graz, 165 Weiz, 166 Fürstenfeld, 167 Güssing, 168 Eberau, 189 Deutschlandsberg, 190 Leibnitz, 191 Kirchbach in Steiermark, 192 Feldbach, 193 Jennersdorf, 206 Eibiswald, 207 Arnfels, 208 Mureck, 209 Bad Radkersburg).

Rivers Gurk and Drau: ÖK50-UTM, map sheets 4101 Gurk, 4102 Althofen, 4109 Sankt Paul im Lavanttal, 4115 Bleiburg (ÖK50-BMN, map sheets 184 Ebene Reichenau, 185 Straßburg, 186 St. Veit an der Glan, 204 Völkermarkt, 205 Sankt Paul im Lavanttal, 213 Bad Eisenkappel).

Remarks: At the Salzach glacier (Weinberger, 1955) and Traun glacier (van Husen, 1989; Egger, 1996; Schnabel, 2002a; Krenmayr & Schnabel, 2006; Egger et al., 2007a) the lower terraces are directly connected with the terminal moraines.

Due to climate controlled congelifraction the Low Terrace is also developed in non-glaciated areas. Evidence for deposition in a non-glaciated area is found at Neurath (N 46°53′26″ / E 15°14′41″), Styria, where a gyttja interbedded in gravel beds provided ^{14}C ages of 19,720 ± 390 ka BP and 21,270 ± 230 ka BP which mark the end of sedimentation under periglacial conditions (Draxler & van Husen, 1991). These sediments can be interpreted as braided river deposits.

Complementary references: -

Tullner Feld Terrasse / Tulln Field Terrace

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Piffl (1971).

Type area: In the “Tullnerfeld” (Tulln Basin) around the town Tulln an der Donau. The “Tullnerfeld” extends along the river Danube between the city of Krems an der Donau in the W and the town Klosterneuburg in the E. The southern margin is built by the Vienna Woods and hills made of Ottnangian beds (“Molassezone”), the northern margin is marked by the Wagram a hillside parallel to the river Danube made of loess, Lower Austria.

Type section: -

Reference section(s): -

Derivation of name: Named after the town Tulln an der Donau (N 48°19′52″ / E 16°03′17″), Lower Austria.

Synonyms: -

Lithology: Sand-bearing coarse gravel. The material is predominantly rounded and well-rounded. It was deposited by the river Danube. In particular, a high content of quartz and crystalline rocks mixed with limestone, dolostone and sandstone is mainly at the debouchment of tributaries in the southern part of the distributional area. The gravel deposits are horizontally layered with cross bedding. Widespread layers of sand occur particularly north of the Danube. Weathering is restricted to about the uppermost 50 cm. Gravel deposits south of the Danube display permafrost features like cryoturbation and ice wedges. Large and usually angular boulders of > 1 m in diameter, transported by ice flows occur frequently at the base of the gravel deposits near the underlying bedrock.

Fossils: Tree trunks of *oak, elm, poplar, willow.*

Origin, facies: Gravel deposit of the river Danube. Sedimentological characteristics of braided river type, permafrost structures, and poor weathering in the area south of the Danube point to accumulation of the deposits during glacial conditions (Piffl, 1971). In contrary, the gravel deposits in the area north of the Danube show sediment structures typical for meandering rivers as a result of complete re-working of the glacial terrace by the river Danube. Such process took place without lowering of the surface and basal erosion level compared to that of the glacial terrace in the sense of the Low Terrace. This re-working without incision by the river Danube resulted from the large debris load supplied from the tributaries while they eroded their local Low Terrace deposits (van Husen, 2000a).

Chronostratigraphic age: Late Pleistocene (MIS 2) to Early Holocene.

Remark: The sediments of the "Tullnerfeld" are correlated with MIS 2 for the area south of the Danube and with the Early Holocene for the area north of the Danube (PIFFL, 1971). The latter is supported by ^{14}C dates of about 9–9.7 ka BP which are obtained from tree trunks of *oak*, *elm*, *poplar*, and *willow*. See also Prater Terrace.

Biostratigraphy: -

Thickness: 10–20 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably above Neogene deposits of the North Alpine Foreland Basin.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Occurs in the "Tullnerfeld" (see Type area); ÖK50-UTM, map sheets 4324 Herzogenburg, 5313 Hollabrunn, 4318 Langenlois, 5319 Tulln an der Donau (ÖK50-BMN, map sheets 38 Krems an der Donau, 39 Tulln, 40 Stockerau).

Remarks: -

Complementary references: -

Prater Terrasse / Prater Terrace

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by SCHAFFER (1902), detailed description in FINK & MAJDAN (1954), KÜPPER (1968) and FINK (1973).

Type area: Prater Terrace, the island between Danube and Danube canal (a former arm of the Danube) in the 2nd (Leopoldstadt) and 20th district (Brigittenau) of Vienna (SCHAFFER, 1902) and Marchfeld (N of the Danube).

Type section: -

Reference section(s): -

Derivation of name: "Prater" is the public recreation area in the eastern part of the island between Danube and Danube canal, characterized by meadows and forest.

Synonyms: -

Lithology: Coarse gravel and sand with predominantly rounded and well-rounded components transported by the river Danube. A high content of quartz and crystalline rocks mixed with limestone, dolostone and sandstone is observed particularly around the mouths of tributaries. In the "Marchfeld", the terrace north of the River Danube, the gravel shows horizontal layering and cross bedding while intercalated wide-spread layers of sand occur frequently. At some locations at the north rim permafrost features like cryoturbations and ice wedges were described (FINK & MAJDAN, 1954). At the base and partly also within the gravel deposits near the bedrock large and mostly angular boulders of up to > 1 m in diameter occur frequently (KÜPPER, 1950). These were transported and deposited by ice floes under glacial conditions. The about uppermost 50 cm of the deposits are affected by weathering.

Fossils: Tree trunks of *oak*, *elm*, *poplar*, and *willow*.

Origin, facies: Gravel deposit of the river Danube. According to braided river sediment structures and permafrost features as well as poor weathering the Prater Terrace in narrow northern part of the "Marchfeld" was considered to represent glacial conditions (FINK & MAJDAN, 1954; KÜPPER, 1968; FINK, 1973). In contrast, the gravel deposits in the southern, the main part of the "Marchfeld", are partly characterized by sediment structures of meandering rivers. The Danube has there only the material of the glacial terrace reworked without lowering the elevation of the surface by erosion. This was due to the debris load the Danube had to carry from the tributaries, eroding their Low Terrace ("Niederterrasse") deposits (VAN HUSEN, 2000a).

Chronostratigraphic age: Late Pleistocene (MIS 2) to Early Holocene.

Remark: The northernmost parts of the Prater Terrace are correlated with the late Würm (CHALINE & JERZ, 1984) and MIS 2. Reworked terrace sediments south of it are considered to be Early Holocene. Tree trunks (*oak*, *elm*, *poplar*, *willow*) in the "Marchfeld" north of the Danube were dated at about 8,500–7,000 ^{14}C years BP (FINK, 1973).

Biostratigraphy: -

Thickness: 10–20 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformably Neogene deposits of the Vienna Basin.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Vienna Basin north of the Danube and between the Danube and the Danube Canal, Vienna and Lower Austria; ÖK50-UTM, map sheets 5320 Wien, 5321 Gänserndorf, 5326 Schwechat, 5327 Bruck an der Leitha (ÖK50-BMN, map sheets 59 Wien, 60 Bruck an der Leitha, 61 Hainburg).

Remarks: -

Complementary references: PFLEIDERER (2008), GRUPE et al. (2021).

Grazer-Leibnitzer Feld / Graz-Leibnitz Field (terrace)

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by PENCK & BRÜCKNER (1909).

Type area: Mur valley between the cities of Graz and Leibnitz, Styria.

Type section: -

Reference section(s): -

Derivation of name: City of Graz (N 47°04′21″ / E 15°26′35″) and town Leibnitz (N 46°46′56″ / E 15°32′26″), Styria.

Synonyms: -

Lithology: The coarse sandy gravel consists mainly of quartz, quartzite, amphibolite, gneisses, limestone, dolostone and contains boulders. The sediment shows intensive cross bedding.

Fossils: -

Origin, facies: Gravel deposit of River Mur; braided river deposits.

Chronostratigraphic age: Late Pleistocene; MIS 2.

Biostratigraphy: -

Thickness: About 15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Neogene sediments.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Terrace along the river Mur south of Graz.ÖK50-UTM, map sheets 4105 Kalsdorf bei Graz, 4111 Leibnitz, 4229 Graz (ÖK50-BMN, map sheets 164 Graz, 190 Leibnitz, 207 Arnfels).

Remarks: -

Complementary references: Winkler von Hermaden (1955), Fink (1961).

Höhlen- und Spaltenfüllungen in Hundsheim und Deutsch-Altenburg / Cave and fissure fillings at Hundsheim and Deutsch-Altenburg

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; Hundsheim introduced by Toula (1902), Deutsch-Altenburg by Freudenberg (1914).

Type area: Pfaffenberg, c. 1 km E of the market town Bad Deutsch-Altenburg, which belongs to the “Hainburger Berge” (Hainburg Mountains), Lower Austria.

Type section: Quarry Hollitzer at Bad Deutsch-Altenburg (N 48°08′05″ / E 16°55′00″), “Hundsheimer Spalte” (N 48°07′16″ / E 16°56′11″).

Reference section(s): -

Derivation of name: Village of Hundsheim (N 48°07′03″ / E 16°56′08″) and market town Bad Deutsch-Altenburg (N 48°08′04″ / E 16°54′22″), Lower Austria.

Synonyms: -

Lithology: Cave sediments like talus cemented by sinter, fluvial sand, loess, and transported soil material.

Fossils: A comprehensive and detailed description of the fossils is given by Frank & Rabeder (1997b, c).

Origin, facies: Cave sediment and fillings of crevasses.

Chronostratigraphic age: Late Pliocene, Piacenzian to Middle Pleistocene, Chibanian.

Remark: According to biostratigraphic data (Frank & Rabeder, 1997b, c), which was confirmed by numerical dating (Neuhuber et al., 2020).

Biostratigraphy: -

Thickness: Narrow fissures and caves.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): -

Overlying unit(s): -

Lateral unit(s): Middle Triassic dolomite and limestone, Jurassic breccia.

Geographic distribution: Between Bad Deutsch-Altenburg and Hundsheim, Lower Austria; ÖK50-UTM, map sheet 5327 Bruck an der Leitha (ÖK50-BMN, map sheet 61 Hainburg).

Remarks: -

Complementary references: Ehrenberg (1929), Wessely (2006).

Schotter und Löß von Stranzendorf / Gravel and loess of Stranzendorf

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Fink & Piffl (1976b).

Type area: Village of Stranzendorf, c. 13.5 km N of the town Tulln an der Donau, Lower Austria.

Type section: Former gravel pit (today a football ground) (N 48°27′06″ / E 16°05′05″) at the eastern margin of the village Stranzendorf, Lower Austria.

Reference section(s): -

Derivation of name: Village of Stranzendorf (N 48°27′14″ / E 16°04′52″), Lower Austria.

Synonyms: -

Lithology: Coarse, partly cemented gravel deposits containing quartz and crystalline rocks mixt with limestone, dolomite and sandstone. Covered by a loess sequence with paleosols (Fink & Piffl, 1976b; Rabeder & Verginis, 1987).

Fossils: Rich in mollusks (*Cochlicopa* sp., *Vertigo* sp., *Makrogasta* sp. and many others) and vertebrates (*Mimomys* sp., *Pusillomimus* sp., *Borsodia* sp., *Equus* cf.) (Frank & Rabeder, 1997a).

Origin, facies: Deposits of the Danube with a strong influence of a tributary from the South (Fink & Piffl, 1976b; Frank & Rabeder, 1997a); warmer climatic conditions.

Chronostratigraphic age: Early Pleistocene, Gelasian–Calabrian.

According to the mollusk fauna the loess deposit comprehends the whole Early Pleistocene from 2.7–1.7 Ma (Frank & Rabeder, 1997a). At the same result pointed a preliminary paleomagnetic investigation (Fink & Piffl, 1976b).

Biostratigraphy: See above.

Thickness: 30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Laa-Formation.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Restricted to the escarpment east of the village Stranzendorf, Lower Austria; ÖK50-UTM, map sheet 5313 Hollabrunn (ÖK50-BMN, map sheets 39 Tulln, 40 Stockerau).

Remarks: -

Complementary references: -

Krems Schießstätte / Krems shooting range

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Penck (1903).

Type area: Eastern slope of Wachtberg, northern margin of the town of Krems (N 48°24′38″ / E 15°36′04″), Lower Austria.

Type section: Rifle range (N 48°25′01″ / E 15°35′48″), northern margin of the city of Krems, Lower Austria; ÖK50-UTM, map sheet 4317 Krems an der Donau (ÖK50-BMN, map sheet 38 Krems an der Donau).

Reference section(s): -

Derivation of name: -

Synonyms: "Kremser Verlehmungszone" (Götzinger, 1936d).

Lithology: Thick loess profile with a sequence of paleosols.

Fossils: Molluscs of warm and cold periods (Ložek, 1976); remnants of small mammals (Rabeder, 1976).

Origin, facies: Loess deposit in a lee position.

Chronostratigraphic age: Early Pleistocene, Calabrian to Middle Pleistocene, Chibanian.

Remark: According to paleomagnetic data (Kočí & Kukla, 1976), the deposition started to develop at the end of the Olduvai Event and continued through Matuyama to the Brunhes Chrons (Fink & Kukla, 1977).

Biostratigraphy: -

Thickness: 40 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Crystalline bedrock.

Overlying unit(s): -

Lateral unit(s): -

Geographic distribution: Eastern slope of Wachtberg, Krems; ÖK50-UTM, map sheet 4317 Krems an der Donau (ÖK50-BMN, map sheet 38 Krems an der Donau).

Remarks: -

Complementary references: Hoernes (1903), Fink & Piffl (1976a), Sprafke (2016).

Mitterndorfer Senke / Mitterndorf Basin

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Suess (1862).

Type area: Southern and central part of the Vienna Basin south of the river Danube; Lower Austria.

Type section: -

Reference section(s): -

Derivation of name: Village Mitterndorf (N 47°59′58″ / E 16°28′24″) SE of Vienna, Lower Austria.

Synonyms: -

Lithology: The Mitterndorf Basin, a strike-slip graben (Decker et al., 2005), was filled by two alluvial fans, the Piesting River fan in the north (formerly called "Wöllersdorfer Schotterfächer"; Brix, 1988) and the Schwarza River fan (formerly called "Neunkirchner Schotterfächer") in the south. Both alluvial fans show a characteristic alluvial fan cyclic sequence development of up to about 2 m thick fine clastic sequences which are alternating with massive, fine to coarse gravel (Salcher & Wagreich, 2010). The uppermost coarse gravel unit of the whole sequence is called "Steinfeldschotter". The thickness of the whole sequence is up to 170 m consisting of different units with thicknesses reaching up to 35 m.

The fine clastic facies assemblage is recognized in the lithology of a drill hole as brown to red brown loam or sandy loam with varying gravel content. These loamy sequences are laterally extensive and can be correlated between wells across an area larger than 100 km². Such correlations allow the evidence of vertical tectonic movements. Massive, coarse sediments of alluvial fans are sheet flood dominated (bed load sheets). Close to the mountain front they are debris flow dominated. Coarse sediment deposition on the fan surface is supposed to occur during rather cold periods where intensified periglacial influence leads to increased sediment supply (Salcher & Wagreich, 2010). Analogues from outcrops and a scientific cored drill hole (scientific THER-1) suggest that the loamy sequences represent overbank fines in most cases.

The "Mitterndorfer Becken" was finally filled by alluvial fans of river Piesting ("Wöllersdorferschotter") and river Schwarza ("Steinfeldschotter"). The sedimentation was dominated by coarse sheet flood deposits intercalated more and more with fine grained over-bank deposits and paleosols to the north (Salcher & Wagreich, 2010). This upper layer of c. 35 m covers the c. 170 m thick primarily Miocene filling of the basin (Salcher et al., 2017).

Fossils: The fine clastic deposits are rich in terrestrial mollusks which point to climatically rather warm periods (Küpper, 1951; Salcher & Wagreich, 2010; Salcher et al., 2017).

Origin, facies: Coarse alluvial fans and fine grained overbank deposits in the active subsiding graben called "Mitterndorfer Senke".

Chronostratigraphic age: Middle Pleistocene, Chibanian to Late Pleistocene.

Remark: According to the comprehensive investigation (paleosols, fossils, paleomagnetism, luminescence dating), the onset of the tectonic subsidence and thus the formation of the Quaternary Mitterndorfer Basin occurred during MIS 9 and 11. The uppermost coarse gravel layer represents MIS 2 (SALCHER et al., 2017). Thus, the infill comprises a unique Chibanian to Late Pleistocene sequence of coarse to fine fluvial deposits in superposition. The youngest coarse gravel unit, the "Steinfeldschotter" is correlated with the late Würm and with MIS 2.

Biostratigraphy: -

Thickness: The thickness of the whole sequence is up to 170 m consisting of different units with thicknesses reaching up to 35 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Unconformable Neogene sediments of the Vienna Basin.

Overlying unit(s): -

Lateral unit(s): Along the faults Neogene sediments of the Vienna Basin. Partly older pre-Quaternary deposits.

Geographic distribution: Southern and central part of Vienna Basin south of river Danube. ÖK50-UTM, map sheets 5201 Wiener Neustadt, 5202 Eisenstadt, 5326 Schwechat (ÖK50-BMN, map sheets 58 Baden, 59 Wien, 60 Bruck an der Leitha, 76 Wiener Neustadt, 77 Eisenstadt, 105 Neunkirchen, 106 Aspang-Markt).

Remarks: -

Complementary references: STINY (1932).

Ainet Einheit / Ainet Unit

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; introduced by REITNER et al. (2016).

Type area: Valley of the river Isel, NW of the town of Lienz (N 46°49′42″ / E 12°45′41″), Eastern Tyrol.

Type section: Delta deposits in the lower Daber Valley at Ainet (N 46°52′06″ / E 12°42′40″) (REITNER et al., 2016; REITNER & MENZIES, 2020).

Reference section(s): -

Derivation of name: Village Ainet (N 46°51′50″ / E 12°41′40″), c. 7 km NW of the town Lienz, Eastern Tyrol.

Synonyms: Westendorf terrace (MAYR & HEUBERGER, 1968; REITNER, 2007).

Lithology: Delta deposits (coarse gravel, sand) and glaciolacustrine deposits (laminated to massive silt and clay, diamictons), often up to tens of meters thick. Clast composition is according to the catchment area of the tributary valley and the reworked till of the glacier in the main valley.

Fossils: -

Origin, facies: Infill of ephemeral lakes on the margin of rapidly decaying glaciers. Further collapse of the ice led to a blocking of main valleys and basins by stagnant glacier and dead-ice bodies and accumulation of reworked debris as huge kame complexes in ice-dammed lakes. The infill is made up of deltaic and glaciolacustrine deposits with intercalations of subaquatic mass flows. At some localities short oscillation of adjacent glacier tongues got in contact with this deposits resulting in till beds (e.g., Steinach) on top of or interfingering with the Ainet Unit.

Chronostratigraphic age: Late Pleistocene; MIS 2.

Remark: MIS 2 at the beginning of Termination I (Alpine Late glacial) defined as a phase of ice decay (REITNER, 2007). OSL age 18.7 ± 1.7 ka from delta deposits of the Westendorf terrace at former clay pit Rahmstätt (N 47°27′33″ / E 12°09′02″), Hopfgarten im Brixental, Tyrol (KLASEN et al., 2007).

Biostratigraphy: -

Thickness: Up to more than 100 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock and Würm subglacial till.

Overlying unit(s): Occasionaly Steinach basal till.

Lateral unit(s): Pre-Quaternary bedrock, glacial deposits.

Geographic distribution: Principally in all great valleys of the Eastern Alps: ÖK50-UTM, map sheets 2223 Innsbruck, 2229 Fulpmes, 3103 Lienz, 3109 Oberdrauburg, 3111 Spittal an der Drau, 3112 Villach, 3212 Bad Aussee, 3213 Kufstein (ÖK50-BMN, map sheets 96 Bad Ischl, 121 Neukirchen am Großvenediger, 148 Brenner, 178 Hopfgarten in Defereggen, 179 Lienz, 196 Obertilliach, 199 Hermagor, 200 Arnoldstein, 201 Villach).

Remarks: Tyrol: Sill valley North of Steinach up to the mouth into the Inn Valley (ROCKENSCHAUB & NOVOTNY, 2009), Brixener Ache around Itter (N 47°28′14″ / E 12°08′18″), Westendorf (N 47°25′56″ / E 12°12′52″), Scheffau (N 47°31′45″ / E 12°14′59″), Ellmau (N 47°30′49″ / E 12°18′10″) (REITNER, 2007). Carinthia: Drau valley east of Lienz (N 46°49′42″ / E 12°45′41″) (LINNER et al., 2013), Malta valley around Gmünd (N 46°54′24″ / E 13°32′05″), Seeboden (N 46°49′08″ / E 13°31′01″) (PESTAL et al., 2006), Drau valley around Villach (N 46°36′52″ / E 13°50′44″), Paternion (N 46°42′45″ / E 13°38′13″), Gassen (N 46°43′37″ / E 13°32′17″) (ANDERLE, 1977a, b; SCHÖNLAUB, 1989).

Complementary references:

Steinach Grundmoräne / Steinach subglacial till

DIRK VAN HUSEN & JÜRGEN M. REITNER

Validity: Invalid; first recognition by KERNER VON MARILAUN (1894).

Type area: Valley of the river Sill around Steinach am Brenner (N 47°05′32″ / E 11°28′01″), Tyrol.

Type section: Plateau near Steinach am Brenner (N 47°05′35″ / E 11°26′55″), Tyrol (MAYR & HEUBERGER, 1968); ÖK50-UTM, map sheet 2229 Fulpmes (ÖK50-BMN, map sheet 148 Brenner).

Reference section(s): -

Derivation of name: Named after the market town Steinach am Brenner (N 47°05′29″ / E 11°28′01″), Tyrol.

Synonyms: Jochwand Stand, Bad Goisern (N 47°39′05″ / E 13°36′06″) (van Husen, 1977), Daber unit, Ainet (N 46°51′50″ / E 12°41′40″) (Reitner et al., 2016; Reitner & Menzies, 2020), Galitzen unit near Amlach (N 46°48′50″ / E 12°45′43″) (Reitner et al., 2016).

Lithology: Subglacial till consists of an over consolidated massive, matrix-supported diamicton. Clast lithology represents the catchment area of the local glacier in rare cases moraine ridges coarse blocky diamicton.

Fossils: -

Origin, facies: Till of local glaciers which showed short advances overriding the infill of ice-dammed lakes (Ainet Unit). Such glacier oscillations occurred during the formation of the Ainet Unit (Reitner, 2007; Reitner et al., 2016). Coarse boulder-rich debris was deposited on the lateral part of debris-covered glaciers tongues. There are no indications of end moraines indicating a longer lasting stabilisation of the glacier tongues after the advance. It can be also due to calving into the lakes (Reitner et al., 2016).

Chronostratigraphic age: Late Pleistocene; MIS 2.

Remark: Early late glacial phase of ice decay in Termination I (Reitner, 2005, 2007). Age is given also by the OSL age of the Westendorf terrace of 18.7 ± 1.7 ka (Klasen et al., 2007) and the ^{10}Be surface exposure age at beginning of lowering of the LGM-Ice surface about between 19 and 18 ka (oldest date 18.6 ± 1.4 ka) (Wirsig et al., 2016).

Biostratigraphy: -

Thickness: As a subglacial till in general 2 m, occasionally up to 20 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Mostly Ainet Unit, Pre-Quaternary bedrock.

Overlying unit(s): -

Lateral unit(s): Pre-Quaternary bedrock, Ainet Unit.

Geographic distribution: ÖK50-UTM, map sheets 2223 Innsbruck, 2229 Fulpmes, 3103 Lienz, 3109 Oberdrauburg, 3212 Bad Aussee, 3213 Kufstein (ÖK50-BMN, map sheets 96 Bad Ischl, 121 Neukirchen am Großvenediger, 122 Kitzbühel, 148 Brenner, 178 Hopfgarten in Defereggen, 179 Lienz, 196 Obertilliach).

Remarks: At the southern flank of the mountain range Wilder Kaiser: Wegstein Alm (N 47°32′54″ / E 12°15′45″), Wochenbrunn Alm (N 47°32′28″ / E 12°19′10″), (Reitner, 2007). In the Kitzbüheler Alpen at Aurach (N 47°24′55″ / E 12°25′54″) (Heinisch et al., 2015).

Complementary references: von Klebelsberg (1948, 1949), Senarclens-Grancy (1956, 1958), Mayr & Heuberger (1968).

Gschnitz Endmoräne und Schotter / Gschnitz end moraine and gravel

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; introduced by Penck & Brückner (1909).

Type area: Valley of the Gschnitz river, a tributary of the Wipp river merging at Steinach am Brenner, Tyrol.

Type section: Terminal moraine linked to outwash gravel at the village Trins (N 47°05′03″ / E 11°25′07″), c. 4 km W of Steinach am Brenner, c. 20 km south of the city of Innsbruck, Tyrol.

Reference section(s): -

Derivation of name: After Gschnitz Valley where the village Trins (N 47°05′03″ / E 11°25′07″) is located.

Synonyms: Gerlos (N 47°13′37″ / E 12°01′55″) (Patzelt, 1975), Goiserer Stand (N 47°38′27″ / E 13°37′01″) where till is overlying and connected to fluvial deposits (van Husen, 1977), Kunig unit (N 46°53′19″ / E 12°43′19″) (Buchenauer, 1990; Reitner et al., 2016).

Lithology: Terminal moraines consist of boulder-rich diamictons. Large boulders occur frequently at the top of the end moraine ridges. Subglacial till is mostly well consolidated. Lithological composition of clasts depends on the respective catchment only. In some locations till overlays glaciofluviale gravel from the advance phase. A glacial sequence consisting of a terrace made up of coarse outwash gravel linked to the terminal moraine exist at Bad Goisern and Malta see above.

Origin, facies: Glacial deposits of a distinct readvance of the glaciers when the valleys where free of dead-ice in the glacier forefield. Larger dendritic glaciers in higher still glaciated areas of the central Eastern Alps. Small valley and cirque glaciers in lower, today unglaciated areas. In some valleys glacial deposits are connected to outwash gravels forming locally terrace bodies (glacial sequence). Terminal moraines deposited as a dump moraine by a stationary glacier.

Chronostratigraphic age: Late Pleistocene; MIS 2.

Remark: Early phase of Termination 1 (Alpine Late glacial), after the formation of the Ainet Unit and Steinach Grundmoräne and before the Bølling/Allerød-Interstadial (van Husen, 1977; Reitner et al., 2016; Drescher-Schneider & Reitner, 2018). Moraine of the long-lasting stabilisation gave at Trins a ^{10}Be age of 16.8 ± 1.7 ka (Ivy-Ochs et al., 2006a, 2008) and at Norbertjagdhütte (Reißeckgruppe) (N 46°53′18″ / E 13°21′23″) a ^{10}Be surface exposure age of 15.8 ± 0.8 ka what linked it to the oldest dated rock glacier deposits of the Eastern Alps (Steinemann et al., 2020).

Biostratigraphy: -

Thickness: 10–30 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bedrock, glacial deposits.

Overlying unit(s): Fluvial and lacustrine sediments, peat deposits with pollen of the Bølling/Allerød-Interstadial.

Lateral unit(s): Pre-Quaternary bedrock, glacial deposits.

Geographic distribution: All over the central part of the Eastern Alps as far as to "Wölzer Tauern" in the east. Additional at highest ranges in the east of the Calcareous Alps. ÖK50-UTM, map sheets 2229 Fulpmes, 3103 Lienz, 3104 Obervellach, 3105 Millstatt, 3108 Sillian, 3206 Gmunden, 3211 Bad Ischl, 3212 Bad Aussee, 3219 Neukirchen, 3221 Zell am See, 4210 Mariazell (ÖK50-BMN, map sheets 66 Gmunden, 95 St. Wolfgang im Salzkammergut, 96 Bad Ischl, 97 Mitterndorf, 102 Aflenz Kurort, 121 Neukirchen am Großvenediger, 123 Zell am See, 124 Saalfelden am Steinernen Meer, 148 Brenner, 179 Lienz, 180 Winklern, 181 Obervellach, 182 Spittal an der Drau, 195 Sillian).

Remarks: Malta Valley near the village of Malta (N 46°57′17″ / E 13°30′28″) where end moraines are also linked to outwash terraces (Schuster et al., 2006), Hieburg in Neukirchen am Großvenediger (N 47°14′49″ / E 12°14′40″) (Patzelt, 1975), Fusch (N 47°12′55″ / E 12°49′58″) (Cornelius & Clar, 1935, Clar & Cornelius, 1936), Schober Gruppe, Unterfercher (N 46°54′36″ / E 12°38′56″) (Buchenauer, 1990), Lienzer Dolomiten, Klammbrückl (N 46°47′22″ / E 12°45′56″) (Reitner et al., 2016), Karnische Alpen, Erschbaumer Tal (N 46°42′45″ / E 12°31′20″) and Schuster Tal (N 46°43′25″ / E 12°28″54″) (Schönlaub, 2000), Hochschwab, Grübel (N 47°39′15″ / E 15°13′18″) and Fadenloch (N 47°38′08″ / E 15°17′11″) (Bryda et al., 2020).

Complementary references: Mayr & Heuberger (1968), Ivy-Ochs et al. (2006b), Rockenschaub & Novotny (2009), Dippenaar (2016), Drescher-Schneider & Reitner (2018), Reitner et al. (2018).

Egesen Endmoräne und Grundmoräne / Egesen end moraine and subglacial till

Dirk van Husen & Jürgen M. Reitner

Validity: Invalid; “Egesen” was originally defined by Kinzl (1929, 1932) as a substage of the Daun stadial as defined by Penck & Brückner (1909) with the moraine at the mouth of Langental (N 47°01′17″ / E 11°13′38″) in the Stubai Valley, Tyrol, and redefined by Mayr & Heuberger (1968). The original type section at Glamergrube (N 47°00′45″ / E 11°07′35″) in the Mutterbergtal, north of the Egesengrat, Stubaier Alpen (Kinzl, 1929, 1932) does not longer represent the current use of Egesen!

Remark: Actually Egesen includes those moraines from the most extended glaciers formerly attributed to the Daun stadial (Reitner et al., 2016) to the smallest glacier extents attributed to Egesen (Kartell end moraines in the Verwallgruppe) (N 47°03′19″ / E 10°15′17″) (Fraedrich, 1979; Sailer, 2001; Ivy-Ochs et al., 2006b, 2009).

Thus, Egesen – as the name – now is in use for the multiple moraines formed during the Younger Dryas or Greenland stadial 1 in the Alps (Kerschner, 2009).

Type area: Uppermost part of the Stubai Valley with the river Ruetz, the largest tributary valley of the Wipp Valley, Tyrol.

Type section: Glamergrube (N 47°00′45″ / E 11°07′35″) in the Mutterbergtal, north of Egesengrat, Stubaier Alpen, Tyrol; ÖK50-UTM, map sheet 2228 Neustift im Stubaital (ÖK50-BMN, map sheet 147 Axams).

Reference section(s): -

Derivation of name: Named after the Egesengrat (2,631 m a.s.l.), a mountain ridge in the Stubaier Alpen, Tyrol.

Synonyms: Debant unit, Schober Gruppe, Eastern Tyrol (Reitner et al., 2016), comprises the multiple moraines of the Gaimberg Alm stade (N 46°55′19″ / E 12°46′01″) and Lienzer Hütte stade defined by Buchenauer (1990).

Kolm Saigurn, south of Rauris in the Hüttwinkl Valley (N 47°04′30″ / E 12°59′07″) where subglacial till and multiple end moraines overly a rockslide deposit of the Allerød-Interstadial covered by a rock avalanche deposit of the Early Holocene (Bichler et al., 2016).

Lithology: Terminal moraines consist of boulder-rich diamictons. Large boulders occur frequently at the top of the end moraine ridges. Subglacial till consists of an overconsolidated massive, matrix-supported diamicton. Ablation till consists of clast supported diamictons with mostly angular clasts of gravel to boulder size. Lithological composition of clasts depends on the respective catchment only.

Fossils: -

Origin, facies: Glacial deposits of a distinct readvance of the glaciers to their maximum position followed by multiple recessional halts. Occasional dendritic glaciers in higher still glaciated areas of the central Eastern Alps. Small valley and cirque glacier in lower, today, unglaciated areas. Boulder-rich ablation tills were formed by strongly debris-covered glaciers. End moraines deposited as a dump moraine by a stationary glacier.

Chronostratigraphic age: Late Pleistocene; MIS 2. Greenland Stadial 1, Younger Dryas (12.9–11.7 ka).

Biostratigraphy: -

Thickness: 10–15 m.

Lithostratigraphically higher rank unit: -

Lithostratigraphic subdivision: -

Underlying unit(s): Pre-Quaternary bed rock and landslide deposits.

Overlying unit(s): -

Lateral unit(s): In some places peat deposits.

Geographic distribution: At all still glaciated mountains around of the main crest of the Eastern Alps “Hohe Tauern” and also “Niedere Tauern” as far as the “Wölzer Tauern”. ÖK50-UTM, map sheets 2101 Gaschurn, 2102 Pfunds, 2103 Vent, 2104 Sölden, 2105 Sterzing, 2106 Sand in Taufers, 2220 Elbigenalp, 2221 Imst, 2226 Landeck, 2227 Längenfeld, 2228 Neustift im Stubaital, 2229 Fulpmes, 2230 Mayerhofen, 3101 Sankt Jakob in Defereggen, 3102 Hopfgarten in Defereggen, 3103 Lienz, 3104 Obervellach, 3217 Hallstatt, 3223 Radstadt, 3224 Schladming, 3225 Sankt Peter in Ahrn, 3226 Matrei in Osttirol, 3227 Großglockner, 3228 Bad Hofgastein, 3229 Sankt Michael im Lungau, 4219 Oberwölz (ÖK50-BMN, map sheets 95 St. Wolfgang im Salzkammergut, 96 Bad Ischl, 114 Holzgau, 115 Reutte, 116 Telfs, 126 Radstadt, 127 Schladming, 128 Gröbming, 129 Donnersbach, 144 Landeck, 145 Imst, 146 Ötz, 147 Axams, 148 Brenner, 149 Lanersbach, 150 Zell am Ziller, 151 Krimml, 152 Matrei in Osttirol, 153 Großglockner, 154 Rauris, 155 Markt Hofgastein, 156 Muhr, 170 Galtür, 171 Nauders, 172 Weißkugel, 173 Sölden, 174 Timmelsjoch, 175 Sterzing, 176 Mühlbach, 177 St. Jakob in Defereggen, 178 Hopfgarten in Defereggen, 179 Lienz, 180 Winklern, 181 Obervellach).

Remarks: Schönverwall, SW Konstanzer Hütte, Verwall mountain group (N 47°04′04″ / E 10°11′12″) (Sailer, 2001; Ivy-Ochs et al., 2006b, 2009); Kaunertal (Kerschner, 1979); Seebensee, Mieminger Kette (N 47°22′23″ /

E 10°56′06″) (Moran et al., 2016); Silvretta (Hertl, 2001; Braumann et al., 2022); Ötz Valley, Gaislachalm (N 46°56′13″ / E 11°00′02″) and SSE Sölden (N 46°57′22″ / E 11°01′18″) (Patzelt et al., 1996); Küharn Stand, valley of the Kelchsauer Ache, Kitzbühel Alps (N 47°19′11″ / E 12°06′33″) (Dippenaar, 2016); Kerschbaumer Alm unit, Lienz Dolomites (N 46°45′34″ / E 12°45′53″) (Linner et al., 2013; Reitner et al., 2016); Trogalm, Heiligenblut, Möll Valley (N 47°03′02″ / E 12°47′09″) (Cornelius & Clar, 1935).

Complementary references: -

List of abbreviations

ASC 2004 – Austrian Stratigraphic Chart 2004

a.s.l. – above sea level

ATK25 – official topographic map of Bavaria 1:25,000

BMN – Bundesmeldenetz, Austrian map grid

BP – before present

CCx – Cretaceous Calcareous Nannofossil Biozones

CCD – Calcite Compensation Depth

CNPx, CNEx, CNOx, etc. – Calcareous Nannofossil Zones (Paleocene, Eocene, Oligocene)

CNP – Calcareous Nannoplankton

GK25 – Geological map of Bavaria 1:25,000

GTS 2020 – Geological Time Scale 2020

ICC – International Chronostratigraphic Chart

IUGS – International Union of Geological Sciences

K/Pg – boundary – Cretaceous/Paleogene boundary

LBF – Larger Benthic Foraminifera

LGM – Last Glacial Maximum

MIS x – Marine Isotope Stages

MNx – Neogene Mammal Biozones

NACFB – North Alpine-Carpathian Foreland Basin

NAFB – North Alpine Foreland Basin

NCA – Northern Calcareous Alps

Ng.Z.x – Neogene Floral Zone

NNx – Neogene Calcareous Nannofossil Zone

NPx – Paleogene Calcareous Nannofossil Zone

ÖK50 – Austrian topographic map 1:50,000

OSL – Optically stimulated luminescence (dating method)

OSM – Upper Freshwater Molasse

PF – Planktonic Foraminifera

PFZ – Planktonic Foraminifera Zone

PGZx – Pollen Zone

Pg.Z.x – Paleogene Floral Zone

pIRIR225 – post infrared, infrared stimulated luminescence signal at 225 °C (dating method)

Px, Ex, Ox, etc. – Planktonic Foraminifera Biozones

RDFU – Rhenodanubian Flysch Unit

SBZx – Shallow Benthic Zone, biostratigraphic zonation based on Larger Benthic Foraminifera

TK25 – topographic map 1:25,000 (herein for Germany)

TOC – total organic carbon

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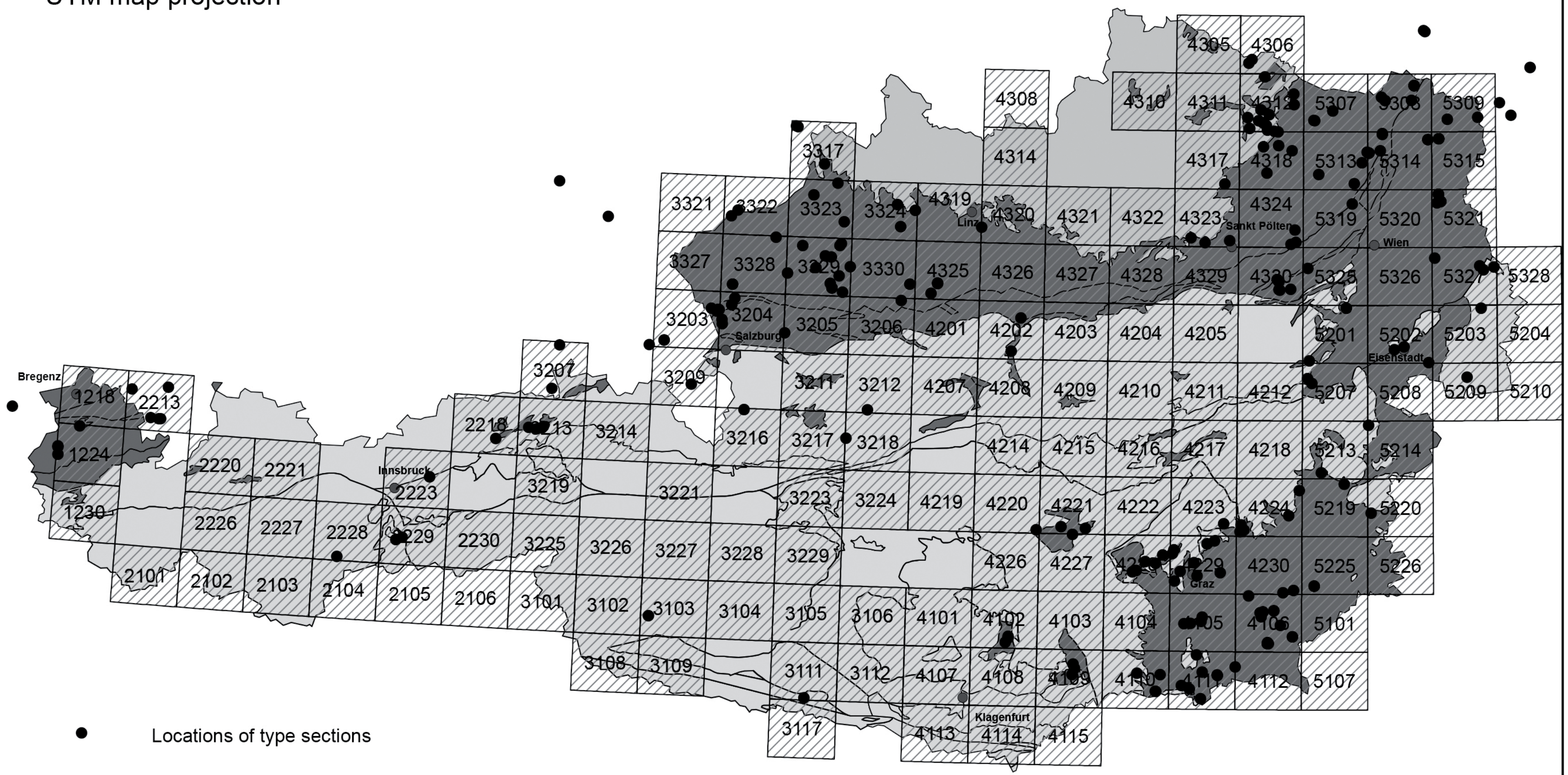
Lithostratigraphische Einheiten / Lithostratigraphic Units

Synonyme / Synonyms

Appendix 1.

Location of map sheets and type sections
UTM map projection



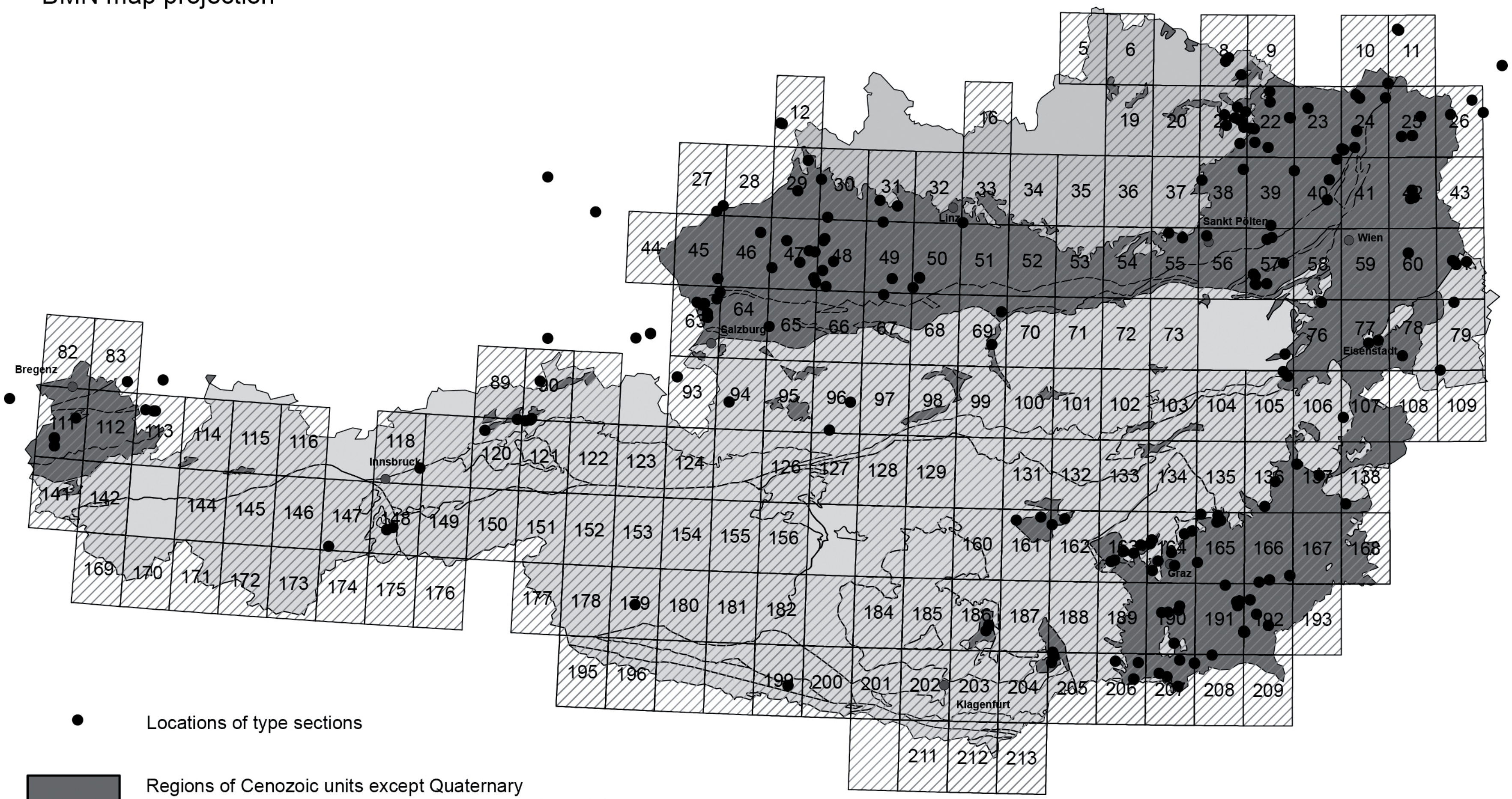
● Locations of type sections

Regions of Cenozoic units except Quaternary
(small areas of Cenozoic units are missing due to scale)

Mapsheets containing Cenozoic units according to the Stratigraphic Chart 2004

Appendix 2.

Location of map sheets and type sections
BMN map projection



● Locations of type sections

Regions of Cenozoic units except Quaternary
(small areas of Cenozoic units are missing due to scale)

Mapsheets containing Cenozoic units according to the Stratigraphic Chart 2004


ABHANDLUNGEN
BAND 66
2014
THE LITHOSTRATIGRAPHIC UNITS OF THE AUSTRIAN STRATIGRAPHIC CHART 2004 (SEDIMENTARY SUCCESSIONS)
WERNER E. PILLER [ED.]
CENOZOIC
MESOZOIC
PALEOZOIC
PERMIAN
LOPINGIAN
GUADALUPIAN
CISURALIAN
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
UPPER
MIDDLE
LOWER
SILURIAN
PRIDOLI
LUDLOW
WENLOCK
LLANDOVERY
ORDOVICIAN
UPPER
MIDDLE
LOWER
CAMBRIAN
UPPER
MIDDLE
LOWER
Vol. I
THE PALEOZOIC ERA(THEM)
2nd EDITION
Authors:
Bernhard Hubmann [Coordinator] (Graz),
Fritz Ebner (Leoben), Annalisa Ferretti (Modena),
Erika Kido (Graz), Karl Krainer (Innsbruck),
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Geologische Bundesanstalt

GBA Thesaurus –
a web based controlled vocabulary of geoscientific terms as used by the Geological Survey of Austria.

The Geological Survey of Austria has developed an online thesaurus of controlled vocabularies for the geoscientific community.

A controlled vocabulary provides the potential to clarify expert knowledge and terminology in the form of thematic vocabulary concepts (terms) at a scientific level. The GBA Thesaurus provides a standardised set of such terms and definitions to describe and classify different types of e.g. geological units, rock formations, mineral deposits and geological structures. Furthermore, this thesaurus is an indispensable tool for geoscientists, researchers and students as it helps to ensure consistency and accuracy in the classification and definition of geological units.

The GBA Thesaurus can be used free of charge and is based on the fundamental standards of the Semantic Web (RDF; SPARQL; SKOS). This is in line with the goals of Linked Open Data (LOD) to make our geoscientific data more findable, reusable and shareable. This modern technology supports semantic harmonisation initiatives, where the harmonisation of different datasets is based on matching the meanings of the data objects used (entities, relationships, attributes). Thus, the GBA Thesaurus is also a necessary tool to implement the legal requirements, e.g. the semantic harmonisation of data, of the EU Directive INSPIRE and the corresponding Austrian law (GeoDIG).

GBA Thesaurus: https://thesaurus.geolba.ac.at/

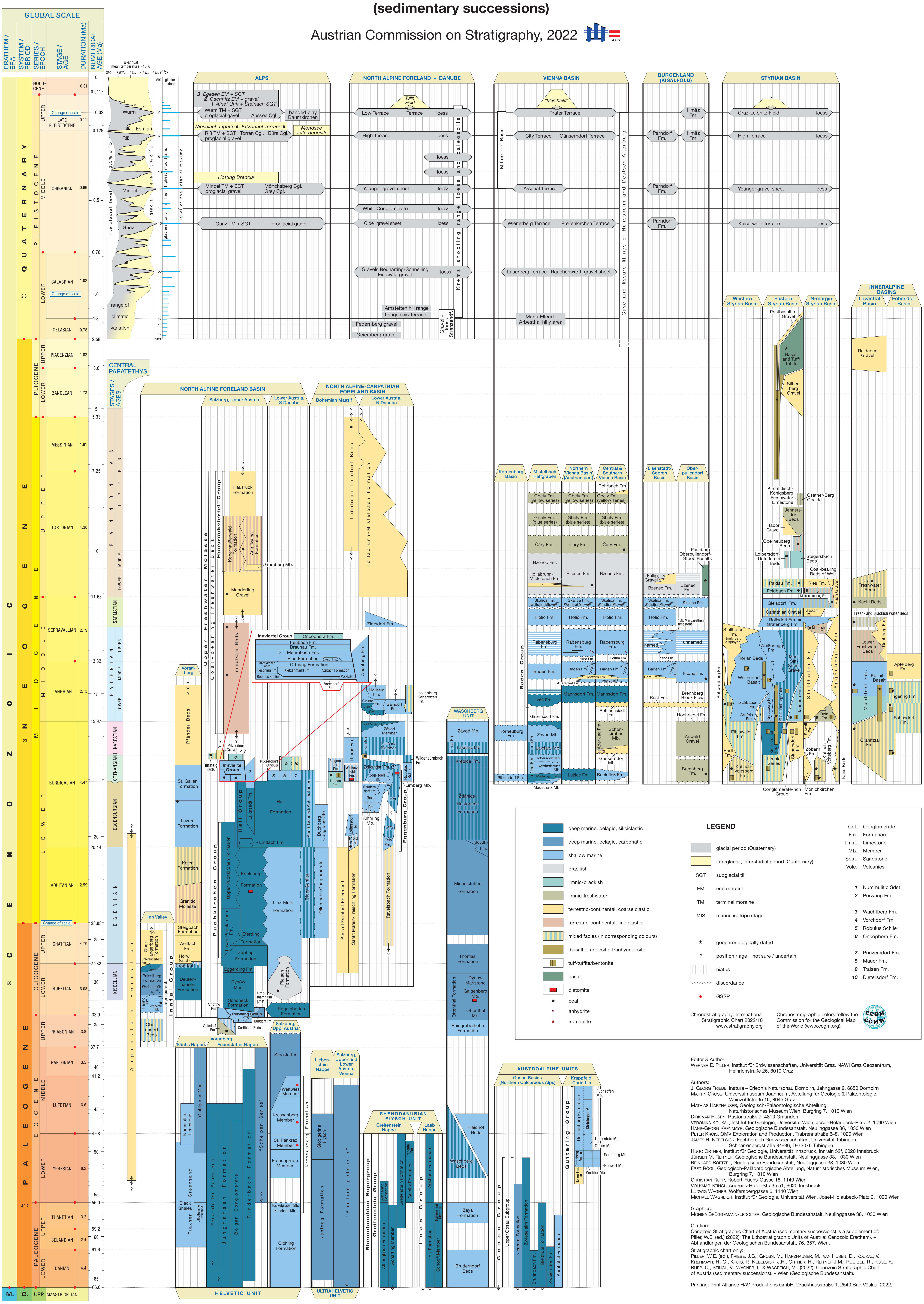
Most of the content of this publication – The lithostratigraphic units of Austria: Cenozoic Era(them) – will be included in the Thesaurus.

ISSN 0378-0864
ISBN 978-3-903252-14-1

CENOZOIC STRATIGRAPHIC CHART OF AUSTRIA

(sedimentary successions)

Austrian Commission on Stratigraphy, 2022



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Citation:
Cenozoic Stratigraphic Chart of Austria (sedimentary successions) is a supplement of:
Piller, W.E. (ed.) (2022): The Lithostratigraphic Units of Austria: Cenozoic Era(them). – Abhandlungen der Geologischen Bundesanstalt, 76, 357, Wien.

Stratigraphic chart only:
Piller, W.E. (ed.), Friebe, J.G., Gross, M., Harzhauser, M., van Husen, D., Koukal, V., Krenmayr, H.-G., Krois, P., Nebelsick, J.H., Ortner, H., Reitner J.M., Roetzel, R., Rögl, F., Rupp, C., Stingl, V., Wagner, L. & Wagreich, M., (2022): Cenozoic Stratigraphic Chart of Austria (sedimentary successions). – Wien (Geologische Bundesanstalt).

Printing: Print Alliance HAV Produktions GmbH, Druckhausstraße 1, 2540 Bad Vöslau, 2022.