

Triassic palynology of the Swiss Belchentunnel - a restudy of the Scheuring samples

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Abstract

Well-preserved Carnian (Late Triassic) palynomorphs are rare in Switzerland, despite sediments include one of the important plant fossil localities, Neue Welt near Basel. Modern detailed palynological studies on Triassic palynomorphs in general and especially in the Carnian are scarce, most palynological studies have been carried out more than fifty years ago. Nevertheless (Late) Triassic sediments still yield surprises for palynological research. Here, we present the results of the re-study of the famous Belchentunnel samples that have been studied and published by Bernhard Scheuring in 1970. The less cheerful result concerns the preservation of slides: more than 60% of the slides are degraded. On the other hand, the restudy of the well-preserved slides showed an unexpected number of algae, acritarch and spore taxa, not described so far. The latter facilitate the correlation with the well-known biostratigraphic schemes established for the Germanic Basin. The distribution of *Porcellispora longdonensis* throughout the Belchentunnel succession is especially striking. The acme just below the Schilfsandstein might suggest the presence of ephemeral ponds.

1. Introduction

The first two Belchen (Bölchen in Scheuring, 1970) tunnels through the Swiss Jura mountains between Hägendorf, Solothurn and Eptingen, Basel-Land were constructed between 1963 and 1966. The opening of a third rehabilitation tunnel recently (July 1, 2022) gave the impetus to re-examine the palynological samples described by Scheuring (1970), taken during the tunnel construction in the 1960s. The succession that had been tunnelled through is one of the few Ladinian–Carnian successions yielding palynomorphs in Switzerland. It is, thus, one of the best places to study the Carnian Pluvial Episode (Simms and Ruffel, 1989), a time of substantial climate and environmental changes accompanied by changes in the composition of the terrestrial and marine ecosystems as well as major originations and radiations among land plants (e.g., Dal Corso et al., 2020). Sedimentologically, this time period is marked by a shift towards siliciclastic dominated facies, as reflected in the Ergolz Member of the Klettgau Formation (Jordan et al., 2016). Palynological assemblages across the Carnian Pluvial Episode are marked by an increase in relative abundance of spores especially *Aulisporites astigosus* and/or *Leschikisporis adunctus* (e.g., Heunisch, 1999; Paterson and Mangerud, 2015; Vigran et al., 2014; Orłowska-Zwolińska, 1985; Roghi et al., 2010).

In Switzerland the Carnian crops out only in few areas. Some of the most famous Carnian plant fossil localities are Neue Welt near Basel and Moderhalde near Pratteln (ca. 20 km NW of Belchentunnel). The plant fossil assemblage are dominated by cycadophytes, ferns, sphenophytes with rare ginkgophytes and conifers (Schlotheim, 1822; Brongniart 1825; Heer, 1865; Leuthardt 1903; 1904; Kräusel 1955; 1959; Kräusel and Schaarschmidt, 1966). Leschik (1955) described numerous spores and pollen (148 species) from Neue Welt. Other Carnian sediments yielding palynomorphs are the Raibl Group of the austroalpine nappes at Fanezfurga (GR), and Iberger Klippen (Sz) (Hochuli and Frank 2000; 2006). They are, however, characterized by a high maturity and low diversity of sporomorphs.

The exceptional preservation and detailed description of the sporomorphs from the Belchentunnel has made the publication by Scheuring (1970) a reference paper for Middle to early Late Triassic palynological taxonomical studies. Scheuring (1970) described in a very detailed and meticulous way various pollen taxa with a special attention also to the variability within single pollen taxa. As detailed his taxonomic work was, the distribution of the various taxa was provided only by simplified information on the vertical distribution of the described forms, including inaccuracies with respect to sample distance and relative abundance (Scheuring, 1970, p. 19). This means that some palynomorph taxa are not included and that the stratigraphic resolution of palynomorph occurrences is vague. In a short biostratigraphic chapter, seven associations (A–G) are described summarily but the exact stratigraphic positions of the boundaries between these associations were not given.

In order to link the palynological assemblages of the Belchentunnel to modern palynological schemes in the Central European Basin and the alpine Triassic, Scheuring's samples are restudied after over fifty years. Despite the preservation of the slides is concerning, the new inventory shows that the curation of fossils, in this case palynological slides, offers the opportunity to discover more taxa and to interpret old and new data on fossils in new contexts.

2. Geological Setting

In northern Switzerland Middle to Upper Triassic sediment outcrops are rare. However, drill cores, such as those drilled by the NAGRA (National Cooperative for the Disposal of Radioactive Waste) provide additional insight and allowed for the formal definition of the Schinznach Formation, the Bänkerjoch Formation, and the Klettgau Formation (Jordan et al., 2016; Pietsch et al., 2016). During construction of the Belchentunnel under the Swiss Jura fold and thrust belt between Hägendorf and Eptingen (Fig. 1), the sedimentary succession of the uppermost part of the Schinznach Formation, the Bänkerjoch Formation and the lower part of the Klettgau Formation was encountered several times due to the tectonic repetition. Especially the northern part is characterized by thrusts. Therefore Scheuring (1970) sampled the Middle and Upper Triassic succession in the southern part of the tunnel which is less affected by thrusts (Fig. 2).

The Asp Member, the uppermost member of the Schinznach Formation, formerly "Lettenkohle" consists of argillaceous marls in the lower part and dolomites in the upper part. Plant and vertebrate fossils are known to occur in the argillaceous marls (Pietsch et al., 2016). The Bänkerjoch Formation consists of an alternation of shales, sulphates, sulphate shale, and shale with nodular sulphate. The Klettgau Formation is subdivided into Ergolz Member, Gansingen Member, Gruhalden Member, and the Belchen Member, the latter was not encountered in the Belchentunnel. The Ergolz Member consist of fluvial sand- and siltstone and is overlain by the dolomites of the Gansingen Member. The succession of the following Gruhalde Member is heterogeneous, consisting of marls, dolomitic marls, and dolomites with varying contribution of sand (Jordan et al., 2016)

3. Materials And Methods

For this study Scheuring's palynological slides, stored in the palaeontological collection at ETHZ, were re-examined. The original Belchentunnel samples were processed according to the scheme in Fig. 3 (Scheuring, 1970, p.8).

According to Scheuring (1970), 89 out of 200 original samples were processed and 45 of them were productive. Productive samples are stored in slides boxes in the palaeontological collection at ETHZ. During a first inspection of the slides, those samples were identified that are still intact enough for a qualitative and quantitative analysis. The target count of 250 sporomorphs was not reached for every sample, because in a few samples the intact area was too small and the spore-pollen yield too low. Samples with counts < 100 are marked by a grey bar in Fig. 4. Miscellaneous palynomorphs, i.e. fungal remains and marine palynomorphs have been counted along spores and pollen. For the relative abundance of the marine fraction, the total amount of marine palynomorphs, spores and pollen was calculated. The Figs. 4 and 5 display all studied by Scheuring (1970), despite not all could be counted. The distribution of the zones or assemblages provided by Scheuring (1970) and their boundaries are given only approximately in Figs. 4 and 5, because no exact stratigraphic position was given in the original paper. Also, all holotype slides were checked for their state of preservation.

The log has been redrawn and simplified for this study. Results are presented along the current Triassic stratigraphy and chronostratigraphy (Jordan et al., 2016).

4. Results

Over the past 50 + years the microscope slides suffered from degradation. Seventeen out of 46 of Scheuring's original slides could be re-studied. Degradation of microscope slides is an issue not only for palynostratigraphic samples but especially for microscope slides with holotypes (Gravendyck et al., 2021). Therefore, all slides with holotypes were checked for their state of preservation. Preservation of holotype slides is similarly concerning, only ~ 59% of the holotypes could be allocated on intact slides. Especially holotypes described from strew mounts could not be allocated or are degraded (supplementary table, and example in Fig. 4).

For simplicity Scheuring's scheme of 7 distinct palynomorph associations A–G is used here as a basis to present the results. First Scheuring's palynological assemblages are re-called, followed by additional observations and discrepancies encountered during this study.

Association A is dominated by *Triadispora* spp., with prominent contribution of *Striatoabieites aytugii* (*S. balmei* after Scheuring, 1978) and *Protodiploxypinus gracilis*. Rare elements are *Ovalipollis* spp., and *Lunatisporites acutus*. Sporadically *Echinitosporites iliacooides*, *Cucullispora cuneata* and *Retisulcites perforatus* (= *Monosulcites perforatus* Mädlar 1964) are recorded (Scheuring, 1970). Samples 1 and 5 could be restudied. The general description given by Scheuring is verified (Fig. 5). The preservation in sample 1 is rather low, therefore most bisaccate pollen grains could not be identified to genus or species level. Additional elements occurring in low abundances in these assemblages are *Jugasporites* spp.,

including *Jugasporites conmilvinus*, *Alisporites grauvogelii*, *Chordasporites* spp., *Perinopollenites* cf. *elatoides*. and a variety of spore taxa, such as *Deltoidospora* spp., *Calamospora* spp., including *C. tener*, *Punctatisporites* spp., *Aratrisporites* spp., *?Lundbladispora* sp., *Osmundacidites* sp., and undifferentiated spores. Miscellaneous palynomorphs are represented by algal colonies, *Botryococcus* spp., fungal remains (hyphae), *Leiosphaeridia* spp., *Michrhystridium* spp., *Plaesiodictyon mosellanum*, *Tasmanites* spp. and *Veryhachium* spp. In the lowermost samples 1 *Michrhystridium* accounts to almost 40% of the total palynomorph count, excluding fungal remains and *Reduviasporonites* spp. (Fig. 6, 7).

Association B is similar to association A in composition with sporadic occurrences of *Eucommiidites microgranulatus* and *Podosporites amicus*. *Ovalipollis* spp., *Retisulcites perforatus* (= *Monosulcites perforatus* Mädlér 1964), and *Echinitosporites iliacooides* are commonly recorded (Scheuring, 1970). The position of the upper boundary is unclear. Samples 11 and D18 are included, whether D11 and D9 were originally included in Association B is concealed. Samples 11 and D18 provided spore and pollen taxa as mentioned by Scheuring (1970), but also additional taxa such as *Illinites* spp., *Platysaccus* spp., *Cycadopites* spp., monosaccate pollen grains and *Camerosporites secatus*. Scheuring (1970) recorded the latter only from Association C onward. Spores are very rare including *Aratrisporites paraspinosus*, *A. scabratus*, *Densoisporites* spp., and *Apiculatisporis* spp. Additional palynomorphs include algal colonies and fungal remains (hyphae), *Michrhystridium* spp., *Plaesiodictyon mosellanum*, *Reduviasporonites catenulatus*, and *Tytthodiscus* sp. Marine palynomorphs never exceed 10% of the total palynomorph count, excluding fungal remains and *Reduviasporonites* spp. The assemblages in sample 11 is marked by several first appearance data (FAD) and last appearance data (LAD). The LAD's recorded include those of *Cucullispora cuneata*, *Lunatisporites acutus*, *Perinopollenites* cf. *elatooides*, *Osmundacidites* spp. *Apiculatisporis* spp., *Sulcosacispora minuta*, *Falcisporites stabilis*, *Triadispora boelchii?*, and verrucate monosulcate pollen grains occur only in sample D11. The presence of *Cucullispora cuneata* suggests that D11 is probably assignable to Association B (see below). First occurrences are recorded from *Ellipsovelatisporites plicata*, *Sulcatisporites* spp., and *Parillinites* spp. in this sample.

Association C resembles generally associations A and B, but *Cucullispora cuneata* is absent. Instead *Duplicisporites*, *Camerosporites*, and *Paracirculina* (included in *Duplicisporites* Scheuring 1978), and *Infernopollenites* are new elements in this association. The abundance of *Ovalipollis* spp. increases throughout Association C (Scheuring, 1970). Samples D9, D100, 26, 55, and 58 are included in Association C. The list provided by Scheuring (1970) can be complemented by the presence of *Cordaitina* sp. (D9), *Platysaccus* spp. (D100), *Cycadopites* spp. (D100), *Doubingerispora filamentosa* (D100) and *Echinitosporites iliacooides* (D100), and the LAD in sample 58 of *Protohaploxylinus* spp. and *Illinites* spp. *Aratisporites paenulatus* reaches relative abundances of up to ~ 8% in the basal part of Association C. Additional rare element are *Enzonasporites* spp. and *Fossapollenites* cf. *moderatus*, *Aratrisporites scabratus*, *A. paraspinosus*, *Retusotriletes* spp., *Lycospora* sp., and *Punctatisporites* spp. whereas *Infernopollenites* spp. was not recorded. In addition, algal colonies, algal cysts of *Botryococcus* spp., *Cymatiosphaera* spp., *Leiosphaeridia* spp., *Michrhystridium* spp., *Plaesiodictyon mosellanum*, and fungal remains (hyphae and spores) are present. *Leiosphaeridia* spp. are especially abundant in sample 55

accounting to > 50% of the total palynomorph count, excluding fungal remains and *Reduviasporonites* spp. (Fig. 5).

Association D is marked by reduction in *Ovalipollis* spp. and an increase in *Triadispora* spp. (especially *T. aurea* and *T. epigona*). *Echinitosporites iliacooides*, *Retisulcites perforatus* (= *Monosulcites perforatus* Mädlar 1964), *Podosporites amicus*, *T. suspecta* are absent (Scheuring, 1970). Only sample 82 and 85 were still intact to be analysed. The assemblages in these two samples agree with Scheuring's description. LAD's recorded in Association D are those of *Striatoabieites balmei*, *Parillinites* spp., and *Chordasporites* spp. *Staurosaccites* spp. has its first appearance and a single occurrence of *Infernopollenites* sp., is recorded. *Tasmanites* is the only marine palynomorph recorded.

Association E is similar to Association D, but *Eucommiidites microgranulatus* is absent in the former. *Ovalipollis* spp. is again more abundant compared to *Triadispora* spp. (Scheuring, 1970). In addition to the palynomorphs described by Scheuring (1970), assemblages of the two analyzed samples, 97 and 104, included also *?Gordonispora* sp. and *Deltoidospora* sp. Contrastingly, *Eucommiidites microgranulatus* is present in both samples. Numerous LAD's are recorded: the aforementioned *Eucommiidites microgranulatus*, together with *Protodiploxypinus decus*, *Triadispora epigona*, *T. stabilis*, *T. falcata*, *T. plicata*, *Monosulcites perforatus*, *Lunatisporites* spp., and *Doubingerispora filamentosa*. *Vitreisporites* spp., and *Alisporites* spp. disappear as well. Aquatic palynomorphs include *Botryococcus* spp., *Michrhystridium* spp., and *Leiosphaeridia* spp., the latter accounting to ~ 30% of the total palynomorph count, excluding fungal remains and *Reduviasporonites* spp.

Association F is characterized by new elements such as *Patinasporites densus*, *Triadispora verrucata*, and *Paracirculina quadruplicis*. The uppermost part of Association F is marked by a *Porcellispora longdonensis* acme, which disappears thereafter (Scheuring, 1970) (Fig. 5). *Paracirculina* was later revised by Scheuring (1970) and included in *Duplicisporites* (Scheuring, 1978), therefore *Paracirculina quadruplicis* is included in *Duplicisporites* spp. in this study. *Triadispora verrucata* is present in Association B to D, but was not found in assemblages of samples 126, 136, 139, and 142. Instead of *Patinasporites densus*, *Enzonalasporites* spp., including *E. vigenis* and *E. ignaii* occurs commonly. Just one *Michrhystridium* sp. was found in sample 136.

In the uppermost **Association G** *Striatoabieites aytugii* (*S. balmei* after Scheuring, 1978) and *Porcellispora longdonensis* are missing, whereas *Ovalipollis* spp. is dominant. Unfortunately, there are no samples preserved in what is considered the Schilfsandstein. All samples were degraded and could not be reanalysed. The description here is based on data from Scheuring (1970) only.

5. Discussion

5.1 The spores in the assemblages

More than fifty years ago, Bernhard Scheuring described the assemblages of the Belchentunnel with a strong focus on taxonomy of gymnosperm pollen. Only one spore taxon was then described,

Porcellispora longdonensis, which is abundant in the topmost part of the Bänkerjoch Formation (Association F). Despite spores are neither diverse and nor abundant, there are several taxa present in the lower half of the section. These offer additional stratigraphic and ecological information. Sporomorph assemblages are dominated by conifer pollen such as *Triadispora* spp. and *Protodiploxylinus* spp. throughout the studied interval. Pollen of seed ferns (e.g. *Platysaccus* spp.) and pollen with cycadalean affinity (e.g. *Eucommiidites* spp.) are less common. Rare elements are lycophyte spores (e.g. *Aratrisporites* spp.) sphenophyte spores (*Calamospora* spp.), and fern spores (*Punctatisporites* spp.).

The most prominent spore taxon in the assemblages of the Belchentunnel is surely *Porcellispora longdonensis*. Its botanical affinity has long been regarded bryophytic and thus indicating rather humid climatic conditions (Visscher and Van der Zwan, 1981; Baranyi et al., 2019). Currently the affinity of *P. longdonensis* to *Riella* is based on morphological similarities between the fossil spore species *P. longdonensis* and spores of the modern liverwort taxon *Riella* (Reinhardt and Riecken, 2000). In late Pleistocene–early Holocene palaeoecological studies the concentration of *Riella* spores has been used as indication of lake level highs (Djamali et al., 2008). During the last glacial episodes higher spore concentration were deposited in lake sediments of the semi-arid to arid region of Iran. The increase in *Riella* spore concentration could be correlated with lake level highs that allow for brackish to freshwater conditions, i.e. the conditions that favour *Riella* spore germination. The lake level rise during glacial episodes has been explained rather by a reduction in evaporation due to reduced summer temperatures than by an increase in precipitation (Djamali et al., 2008). *Riella* grows as submerged plants in freshwater to brackish, mostly ephemeral ponds in semi-arid climatic conditions with distinct seasonality in precipitation and in rather disturbed environments (Cirujano et al., 1988; Djamali and Segarra-Mortegues, 2021). The plant would, thus, have a very low preservation potential based on their preferred growing environment, whereas the spores have a higher fossilisation potential. Based on these considerations, in recent publications on Late Triassic palynology, *P. longdonensis* has been regarded a xerophytic element (Fijałowska-Mader et al., 2021). In the present study, we included *Porcellispora longdonensis* within the spores, based on its bryophytic affinity. However, for future studies it might be reasonable to emphasis its palaeoecological significance and its potential as an environmental indicator of ephemeral lakes to a greater extent and to group it with aquatic palynomorphs.

5.2 Correlation of assemblages with Upper Triassic palynostratigraphic schemes

Despite the Carnian Pluvial Episode was not recorded by Scheuring (1970), his palynostratigraphic subdivision of Upper Triassic deposits is to date unmatched in terms of resolution (Fig. 8)

Aratrisporites species are especially present in the upper part of the Middle and lower part of the Upper Triassic deposits in the Germanic Basin (Erfurt Formation, and lower part of Grabfeld Formation; Zone GTr 10 and GTr 11 *sensu* Heunisch, 1999, *Heliosaccus dimorphus* Zone *sensu* Kürschner and Hengreen, 2010) and the *Heliosaccus dimorphus* Zone described from the Poland (Orłowska-Zwolińska, 1985) (see also Nowak et al., 2018), which would correspond to Assemblages A to B of Scheuring (1970) in the

Belchentunnel. Diverse *Aratrisporites* and abundant non-taeniate bisaccate pollen are also a common feature of the *Echinitosporites iliacooides* Zone of the Barents Sea area (Vigran et al., 2014, Paterson and Mangerud, 2020), and the assemblage H *sensu* Hochuli et al. (1989). Of the typical elements in the Barents Sea assemblages *Schizaeoisporites worsleyi*, *Staurosaccites quadrifidus*, *Protodiploxypinus ornatus*, *Triadispora verrucata*, *Ovalipollis pseudoalatus*, and monosaccate pollen, the latter three are also present in assemblages A–B in the Belchentunnel. *Heliosaccus dimorphus* and *Echinitosporites iliacooides* are also a characteristic element of the *secatus-dimorphus* phase *sensu* Van der Eem (1983) and their FAD are the marker of the late Fassanian *Heliosaccus dimorphus* zone *sensu* Roghi (1995) of the Dolomites, whereas they have not been described from the Carnian successions of the Julian Alps (Roghi, 2004). This suggests that the assemblages A and B belong to the late Ladinian.

The base of the following younger Zone in the Germanic Basin (*Camerosporites secatus* Zone *sensu* Kürschner and Hengreen, 2010) is marked by the FADs of *Enzonalasporites vigens* as well as the nominating species, and the first common occurrences of *Ovalipollis pseudoalatus*. The latter two feature are observed in assemblage C in the Belchentunnel, whereas *E. vigens* was recorded later in assemblage D. The *C. secatus* Zone is subdivided into two subzone, the base of the lower *Triadispora verrucata* Subzone is marked by the FAD of the nominating species, although in the Swiss section *T. verrucata* is already present in the older assemblage B. Assemblages of the *T. verrucata* Subzone have been correlated with Zones GTr 12 and GTr 13, which are marked by the presence of *E. iliacooides* and *M. perforatus* (recorded as *Retisulcites perforatus*) and numerous *Protodiploxypinus* species, *T. verrucata* and *Ovalipollis pseudoalatus*, *Porcellispora longdonensis* and *C. secatus*. The *T. verrucata* Subzone *sensu* Kürschner and Hengreen (2010) and GTr 12 and GTr 13 *sensu* Heunisch (1999) are, thus, comparable with assemblages D–F *sensu* Scheuring (1970, and this study). Regular occurrences of *P. longdonensis*, diverse *Triadispora* species and Circumpolles are also characteristics of the *P. longdonensis* Zone in Poland (Orłowska-Zwolińska, 1985). The *Aulisporites astigmosus* Composite Assemblages Zone in the Barents Sea (Vigran et al., 2014) includes *Echinitosporites iliacooides*, *Triadispora verrucata*, *Enzonalasporites vigens*, and *Camerosporites secatus* and is, thus, also comparable with the assemblages D–F *sensu* Scheuring (1970). However, there are also differences. The *A. astigmosus* Zone is defined by the FADs of *A. astigmosus*, *Ricciisporites tuberculatus*, *Camazonosporites rudis*, and *Uvaesporites argentaeformis*. These species are not present in the Belchentunnel samples. A refinement of the *A. astigmosus* Zone are provided by the *Semiretisporis hochulii* and *Podosporites vigraniae* zones (Paterson and Mangerud, 2020). These correlate with the Zones G and F of Hochuli et al. (1989). A correlation with the palynological assemblages of the Southern Alps is difficult and based on lithostratigraphic correlation (Roghi et al., 2010). The *Concentricisporites bianulatus* assemblages includes the nominative species, and *Kyrtomispors ervei*, as well. The only species in common is *Duplicisporites verrucosus* (Roghi et al., 2004).

The assemblage G *sensu* Scheuring (1970), corresponds stratigraphically to the Schilfsandstein-facies in the Germanic Basin. However, Scheuring (1970) mentioned only two samples, 150 at the base and 164 at the top of the Schilfsandstein. Unfortunately, both samples are too degraded for a re-assessment. This interval could potentially include also the Carnian Pluvial Episode. In this case a high abundance of either

Aulisporites astigmosus or *Leschikisporis adunctus* or a combination of both would be expected. However, Scheuring (1970) did not mention any specific divergent composition. A resampling would be necessary to understand whether the palynological assemblage resembles the *A. astigmosus* Subzone *sensu* Kürschner and Hengreen, 2010, *A. astigmosus* Zone *sensu* Orłowska-Zwolinska, 1985 (Vigran et al., 2014; Roghi et al., 2010) or *L. adunctus* Zone *sensu* Paterson et al. (2017; Paterson and Mangerud, 2020).

5.2 The Carnian Pluvial Episode

Carnian Pluvial Episode is marked by changes in lithology and vegetation composition due to higher relative humidity in mid Carnian successions in the low latitudes (e.g., Dal Corso et al., 2015; Baranyi et al., 2019). However, records from the Germanic Basin seem to contradict this (Franz et al., 2019; Visscher et al., 1994), since there palaeoclimate proxies indicate rather continuous semi-arid to arid conditions throughout the Carnian. The lithology of Belchentunnel is closely comparable to the Germanic Basin stratigraphy, with some Schilfsandstein-type successions crop out.

The palynological samples from the Belchentunnel do not include the typical marker taxa of the Carnian Pluvial Episode in Europe (*Aulisporites astigmosus* and *Leschikisporis adunctus*), but the spore *Porcellispora longdonensis* has a striking distribution, with a substantial increase in abundance just below what would be considered the Schilfsandstein facies in the Belchentunnel succession. In case *P. longdonensis* would be confirmed to be related to *Riella* plants, and the preferred growing environment would be the same, the increase in relative abundance of *P. longdonensis* spores could be correlated to lake level highs that allow for brackish to freshwater conditions, i.e. the conditions that favour *Riella* spore germination. Lake level rises during glacial episodes have been explained rather by a reduction in evaporation due to reduced summer temperatures than by an increase in precipitation (Djamali et al., 2008). The general climatic conditions between the late Pleistocene-early Holocene and the Late Triassic differ significantly. Climate proxies indicate arid to semi-arid conditions during the latest Longobardian (late Ladinian, Middle Triassic) and the early Carnian with rather high evaporation rates.

Transgressions into the Central European Basin accelerated the hydrological cycle which led to increased runoff and higher groundwater tables (Franz et al., 2019). This favoured the formation of lakes in lowland areas, ideal conditions for plants adapted to grow in ponds under semi-arid conditions, such as *Riella*. The most extensive transgression occurred just before the deposition of the Schilfsandstein (Franz et al., 2019), which would correspond to the *P. longdonensis* acme in the Belchentunnel. These lakes or backswamps created the taphonomic window necessary for the preservation of the pristine fossil flora of e.g., Neue Welt (Franz et al., 2019).

6. Conclusions

With the description of palynomorphs from the Belchentunnel, Bernhard Scheuring published a reference work for Late Triassic palynomorph taxa in 1970. The restudy of his samples shows that the preservation of numerous slides, including the slides with holotypes, is concerning, over 60% are degraded. A positive

aspect, however, is the discovery of aquatic palynomorphs and spores, especially several *Aratrisporites* species that were previously not recorded. The possible botanical affinity of the spore taxon *Porcellispora longdonensis* with *Riella*, a submerged liverwort in semi-arid regions, might indicate ephemeral ponds during deposition of the Schilfsandstein, the sediment facies representing the CPE.

Resampling and restudy at high resolution with special attention to the upper part of the succession are important to get insights into the traces left by the CPE in Swiss successions.

Declarations

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Availability of data and material

Palynological slides are stored in the Palaeontological Collection of ETH Zurich. All other data are included in the text and in the supplementary material.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ESH had the idea to restudy Scheuring's slides from the Belchentunnel and analysed the slides. EK added palaeogeographic and palaeoclimatic context. Both authors wrote and proofread various versions of the text and approved the final manuscript.

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Figures

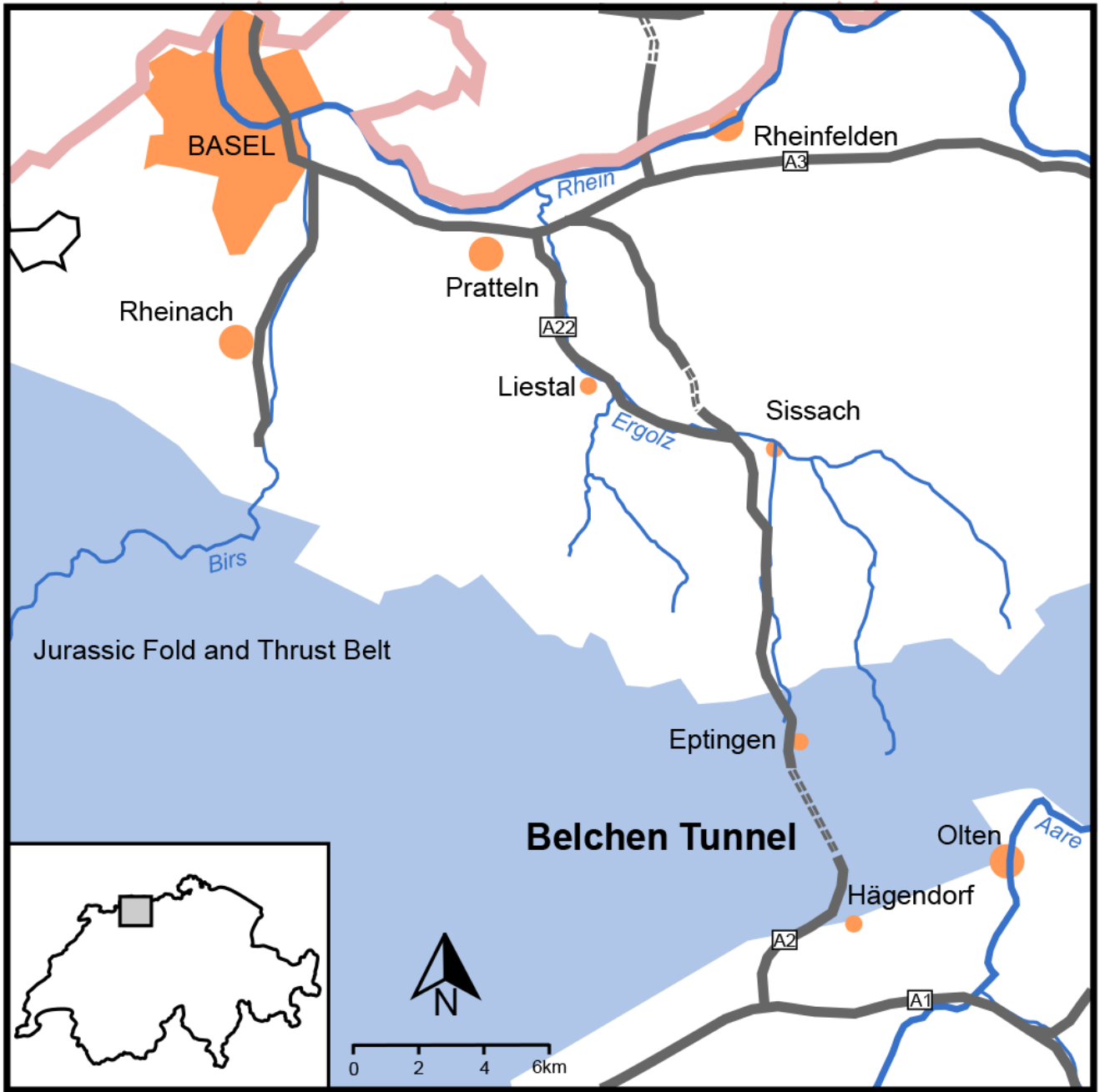


Figure 1

Geographical overview of the Belchentunnel location. Blue area indicates roughly the extend of the Jurassic thrust and fold belt.

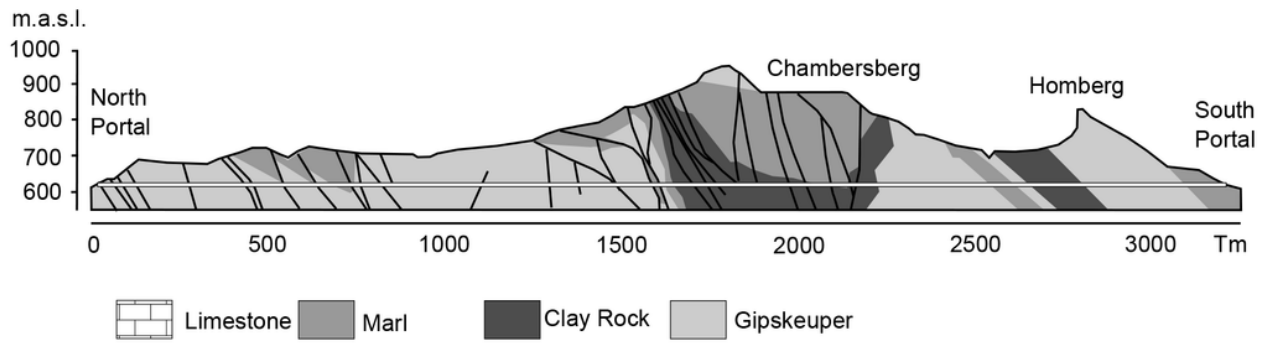


Figure 2

Geological cross section along the Belchentunnel after Amann et al., 2014.

- 1) Zerkleinern (< 1 mm), Vorwaschen und Aufweichen
- 2) HCl (wenn nötig: Aufwärmen), Waschen
- 3) HF (in Kupfertiegel, wenn nötig: Aufwärmen), Waschen
- 4) HCl (heiss), Waschen
- 5) Chlorieren (Na_2ClO_3 in Eisessig und mit einigen Tropfen HCl conc. im Wasserbad erwärmen). Zum Entfernen von Pyrit und organischen Resten, Waschen
- 6) Azetolysieren (Konzentration je nach Bedarf), Waschen
- 7) Schwereretrennung der mineralischen Überreste mittels Bromoform oder einem gesättigten Gemisch von $\text{CdJ} + \text{KJ} + \text{H}_2\text{O}$, Waschen.

Die Streupräparate wurden – wie üblich – mit Glyzerin-gelatine hergestellt. Nagellack diente zu ihrer Umrandung.

Über die Haltbarkeit solcher Präparate liegen uns noch keine Erfahrungen vor. LESCHIKS Präparate von Neuwelt bei Basel sind zum Teil mit Kanadabalsam verdichtet worden. Dieser wird nach einer gewissen Zeit brüchig, weshalb einzelne seiner Präparate schon unter Luftzutritt stehen.

Figure 3

Preparation scheme applied by Scheuring. 1) crushing, washing, and soaking, 2) HCl (warm-up if necessary), washing, 3) HF (in copper pot, warm-up if necessary), washing, 4) HCl (hot), washing, 5) Chlorination (warming up Na_2ClO_3 in glacial acetic acid with few droplets of conc. HCl in water bath) In order to remove pyrite and organic residuals, washing 6) Azetolyze (concentration as required), washing, 7) Density separation to remove mineral remains using bromoform or a saturated mixture of $\text{CdJ} + \text{KJ} + \text{H}_2\text{O}$, washing. Strew mounts prepared using glycerine jelly and nail polish.

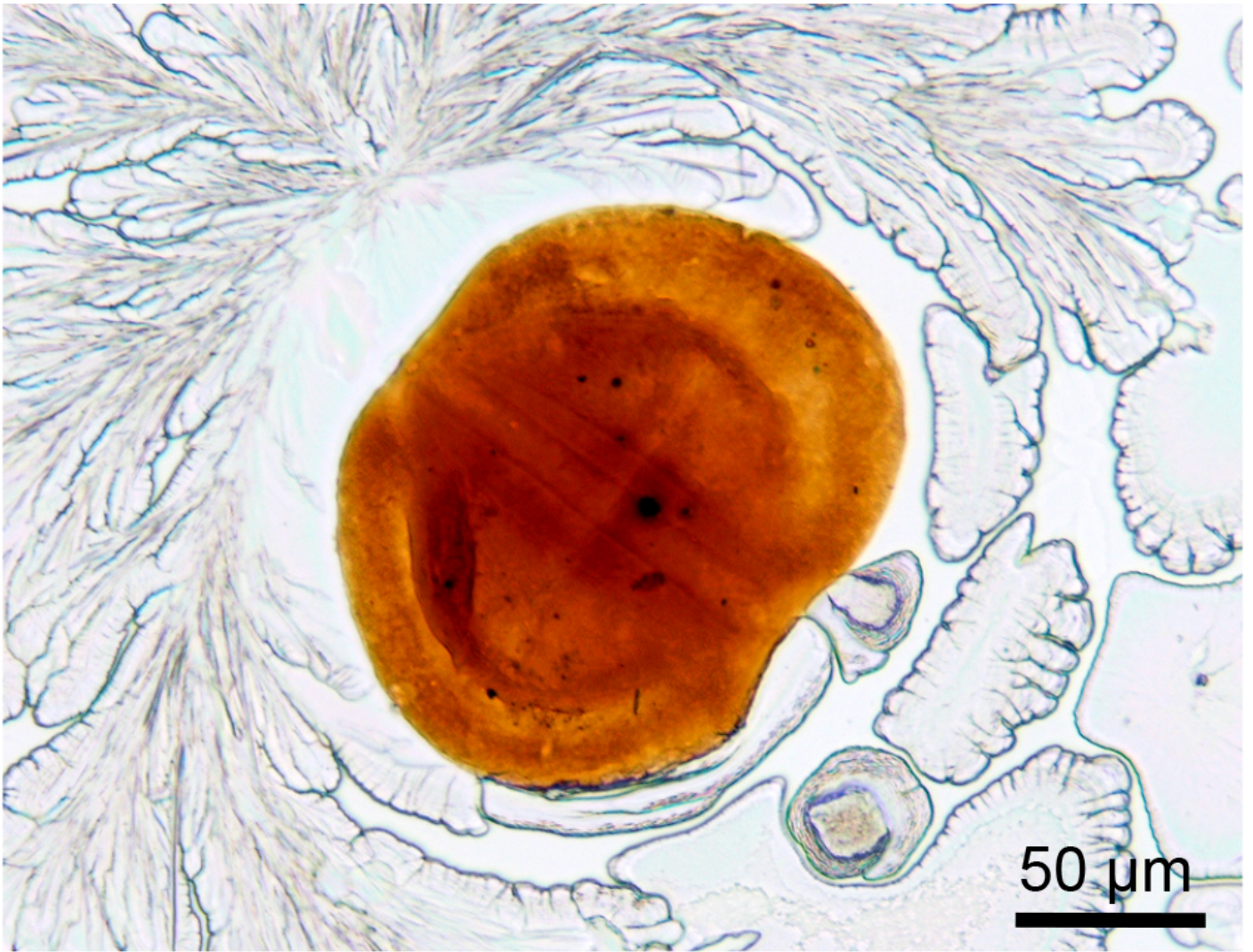


Figure 4

Holotype of *Parillinites pauper* (Scheuring, 1970) threatened by degradation.

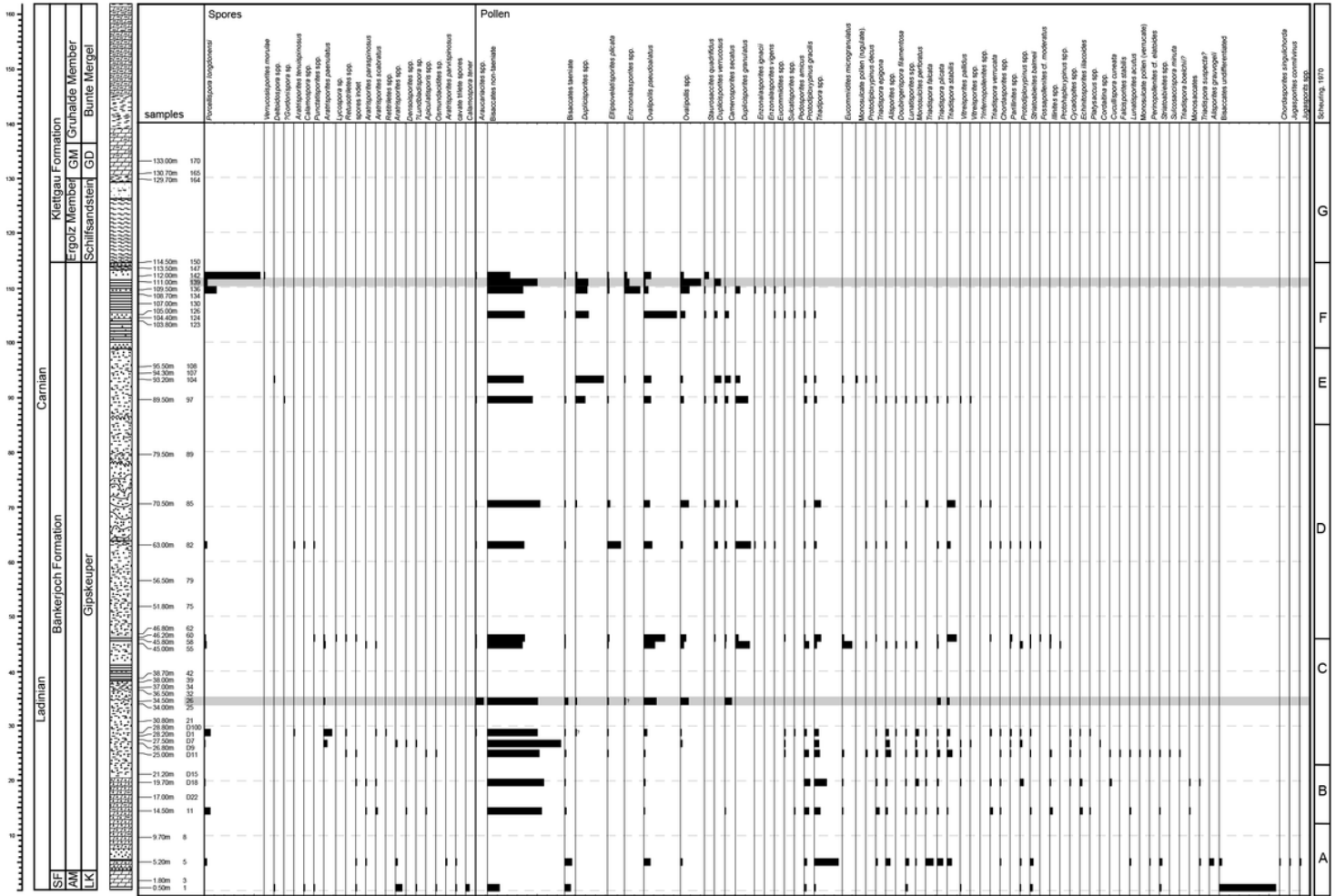


Figure 5

Relative abundances of terrestrial palynomorphs in the Belchentunnel samples. Arranged according to the stratigraphic last occurrence of the taxa.

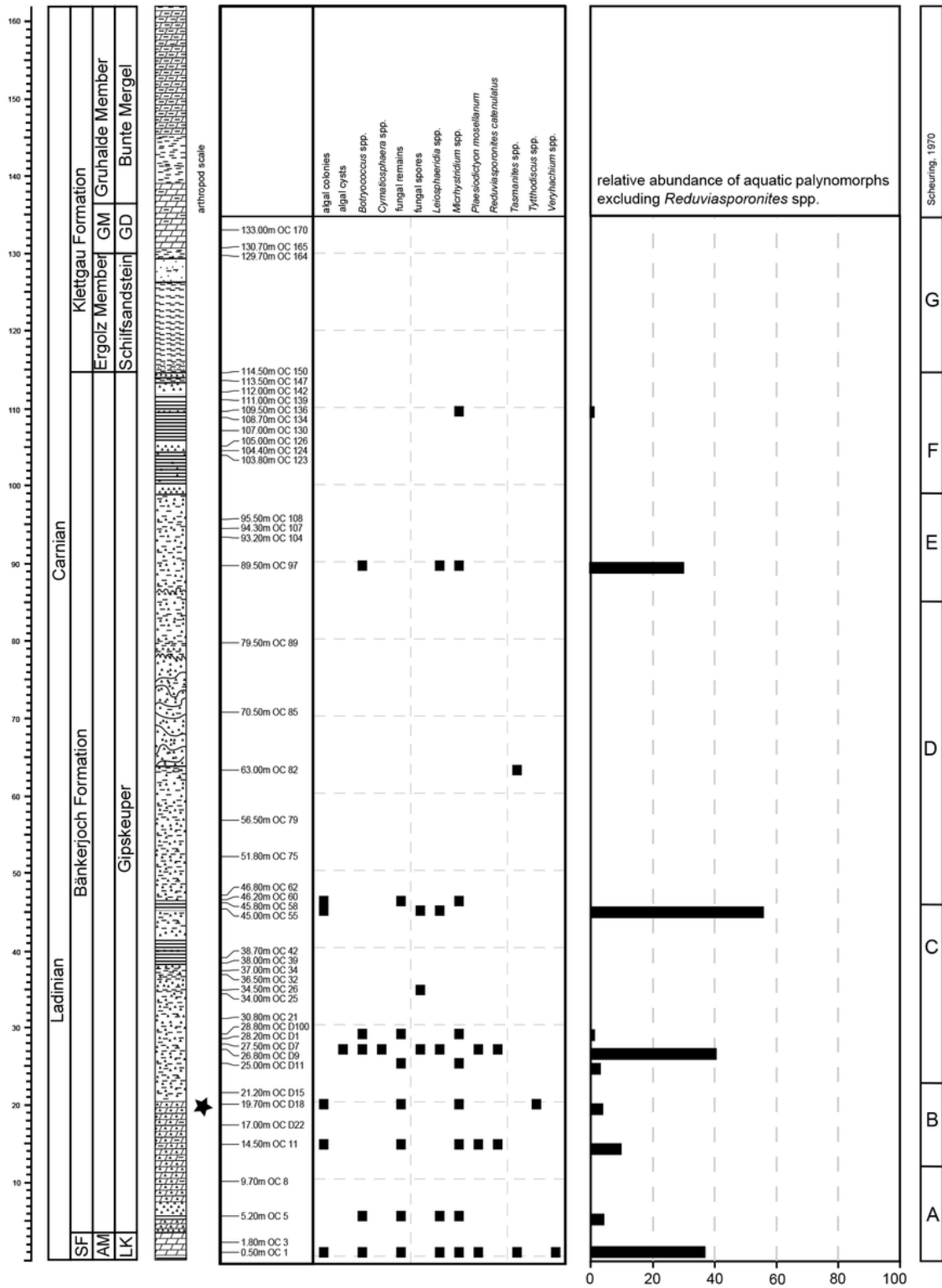


Figure 6

Miscellaneous palynomorphs in the Belchentunnel samples calculated using the total of palynomorphs counted excluding *Reduviasporonites*.

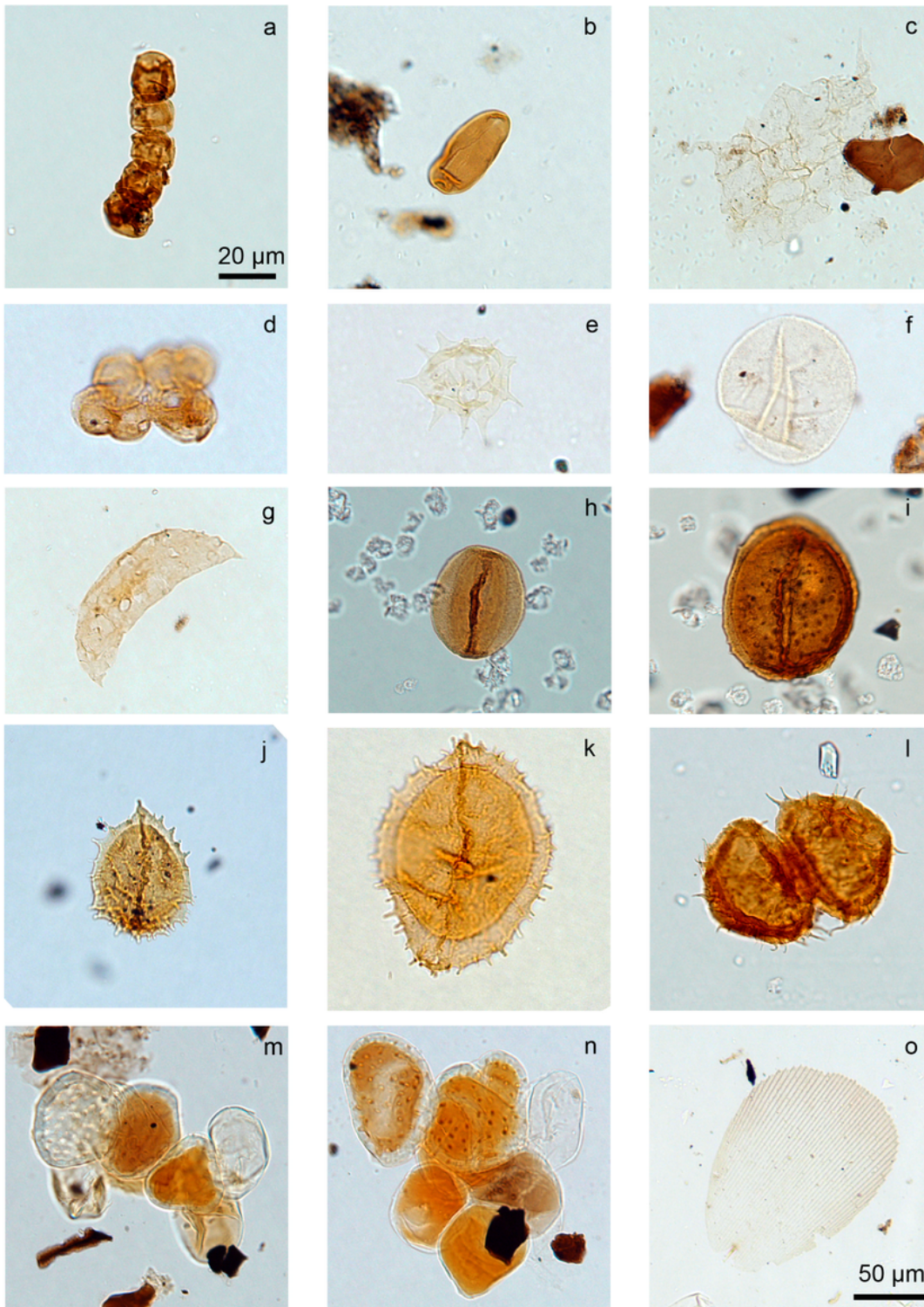


Figure 7

Palynomorphs from the Belchentunnel, scale bar 20 µm except otherwise indicated. Palynomorph followed by sample number and Englandfinder coordinates. **a** *Reduviasporonites catenulatus*, 11, L 29; **b** fungal remain «jelly bean», D9, S 36/3; **c** *Plaesiodictyon mosellanum*, D9, Q 38/3; **d** algal cluster, 11, H 34; **e** *Michystridium pentagonale?*, 26, N39/1; **f** *Thyttodiscus* sp., 1, T37/4; **g** algal cyst, D9, R44/1; **h** *Aratrisporites scabratus*, D100, 2. slide, K 49; **i** *Aratrisporites paenulatus*, D100, 2. slide Q 34; **j**

Aratrisporites paraspinosus, 11, J 46/1; **k** *Aratrisporites parvispinosus*, 5, Q28/4; **l** *Aratrisporites tenuispinosus*, 82, Q 41/2; **m**, **n** immature spore masses?, 1, M 39, M44/3; **o** arthropod scale, D18, V41/1

Stratigraphy Germany (STGC 2022)	Kürschner & Herengreen 2010	Heunisch, 1999	Scheuring 1970 and this study	Stratigraphy CH old	Stratigraphy CH Jordan et al., 2006	Orłowska- Zwolinska 1985	Vigran et al., 2014	Paterson et al., 2017	Paterson & Mangerud, 2019	Hochuli et al., 1989	Roghi et al., 2010	Roghi et al., 2004
	subzone											
Schilfsand- stein (Stuttgart Fm)	<i>Aulisporites astigosus</i>	GTr 14		<i>Schilfsand- stein</i>	Ergolz Mb, Klettgau Fm	<i>Aulisporites astigosus</i>		<i>Leschiki- sporites adunctus</i>	<i>Leschiki- sporites adunctus</i>	D,E	<i>Aulisporites astigosus</i>	<i>Duplici- sporites continuus</i>
upper Grabfeld	<i>Camero- sporites secatus</i>	GTr 13	D, E, F?		Bänkerjoch Fm and Asp	<i>Porcellispora longdonensis</i>	<i>Aulisporites astigosus</i>	<i>Podosporites cf amicus</i>	<i>Podosporites vigraniae</i>	F		<i>Concentrici- sporites bianulatus</i>
lower Grabfeld and Erfurt Fm	<i>Heliosaccus dimorphus</i>	GTr 12	C?	Gipskeuper and Lettenkohle	Mb, Schinznach Fm			<i>Echinito- sporites iliacoides</i>	<i>Echinito- sporites iliacoides</i>	G		
		GTr 11	A-B?							H		
		GTr 10										

Figure 8

Correlation of the Belchentunnel assemblages with palynozones from the Central European Basin, Tethys, and the Barents Sea.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [DataTable.xlsx](#)