ISSN 0424-7116 | DOI 10.3285/eg.66.1
Edited by the German Quaternary Association
Editor-in-Chief: Margot Böse

E&G

Eiszeitalter und Gegenwart
Quaternary Science Journal

Vol. 66
No 1
2017

LIFE IN DOGGERLAND – PALYNOLOGICAL INVESTIGATIONS OF THE ENVIRONMENT OF PREHISTORIC HUNTER-GATHERER SOCIETIES IN THE NORTH SEA BASIN

SPRING FED RAISED PEAT HUMMOCKS WITH TUFA DEPOSITS AT THE FARBEBERG HILLS (NORTHWEST-GERMANY)

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Eiszeitalter und Gegenwart
Quaternary Science Journal

Volume 66 / Number 1 / 2017 / DOI: 10.3285/eg.66.1 / ISSN 0424-7116 / www.quaternary-science.net / Founded in 1951

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COVER FIGURE
Clay pit „Nightingale" near Höxter
(Klaus-Dieter Meyer, Fig. 5, Page 37)

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E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / 3-13 / DOI 10.3285/eg.66.1.01
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

Life in Doggerland – palynological investigations of the environment of prehistoric hunter-gatherer societies in the North Sea Basin

Sascha Krüger[1], Walter Dörfler[1], Ole Bennike[2], Steffen Wolters[3]

How to cite: Krüger, S., Dörfler, W., Bennike O. & Wolters, S. (2017): Life in Doggerland – palynological investigations of the environment of prehistoric hunter-gatherer societies in the North Sea Basin. – E&G Quaternary Science Journal, 66 (1): 3–13. DOI: 10.3285/eg.66.1.01

Abstract: Analyses of two vibrocores from the sea floor of the submerged Doggerland within the centre of the North Sea provide a record of late Pleistocene and early Holocene vegetation history. Based on two high-resolution pollen diagrams of basal peat, the vegetation development and past environmental conditions were studied. The diagrams show that the vegetation history of Doggerland corresponds to that of the north European Plain during the late glacial and early Holocene. The concentration of micro-charcoal was determined, but no traces of human activity were found.

Leben in Doggerland – palynologische Untersuchungen zur Umwelt urgeschichtlicher Jäger- und Sammlerkulturen im heutigen Nordseebecken

Kurzfassung: Die Analyse zweier Bohrkerne von Grund der Nordsee und dem in Analogie mit Doggerland bezeichneten ehemaligen Nordseefestland boten die Möglichkeit eines besseren Verständnisses pleistozäner und frühholozäner Vegetationsgeschichte. Basierend auf hochauflösenden Pollendiagrammen an Basalen Torfen wurden Vegetationsentwicklungen und Umweltbedingungen untersucht. Die Diagramme zeigen, dass sich die Mitteleuropäische Grundsukzession in weiten Teilen nachverfolgen lässt. Eine Bestimmung der Holzkohlekonzentrationen wurde vorgenommen, jedoch konnten keine sicheren Nachweise für menschliche Aktivität erbracht werden.

Keywords: Doggerland, North Sea Basin, pollen analysis, basal peat, Pleistocene-Holocene Transition, hunter-gatherers

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1. Introduction

The former land area in the North Sea region, named Doggerland by Coles (1998) has for long been considered a potential settlement area of Palaeolithic and Mesolithic hunter-gatherer societies. Regardless of their low number, finds of retouched flint artefacts and harpoons are indisputable evidence of former human presence. Countless mammal bones are witness of a rich and changing environment (Bjerck 1995: 132; Coles 1998: 47; Glimmerveen et al. 2006: 242; Peeters & Momber 2014: 55; Schwabedissen 1951: 76).

A systematic archaeological exploration of Doggerland is obviously impossible because the area is now submerged. However, the history of the region can be studied by palaeoecological methods. Here we used palynology, a particular consideration of non-pollen-palynomorphs and the counting of micro-charcoal of two sediment cores from the bottom of the North Sea (fig. 1) to throw light on the development of this region, where classical archaeological methods are of limited value.

One of the questions we wanted to investigate is what were the living conditions in Doggerland at the Pleistocene–Holocene transition and what was the impact of submergence on potential settlement areas?

The combination of rising temperatures and consequently melting ice sheets during the late glacial and early Holocene resulted in a rise of the sea level. The simultaneously rising groundwater level close to coastal areas caused fen formation in wide areas in the hinterland of the coast, and the so called basal peats developed (Behre 2008: 21; Behre et al. 1979: 94; Firbas 1952: 146; Jansen et al. 1979: 182; Lange & Menke 1967: 30; Overbeck 1975: 46). The permanent rising sea level led inevitably to submergence of coastal fens that hence were often eroded by the sea. Big lumps of peat – the so called *moorlogs* – that once

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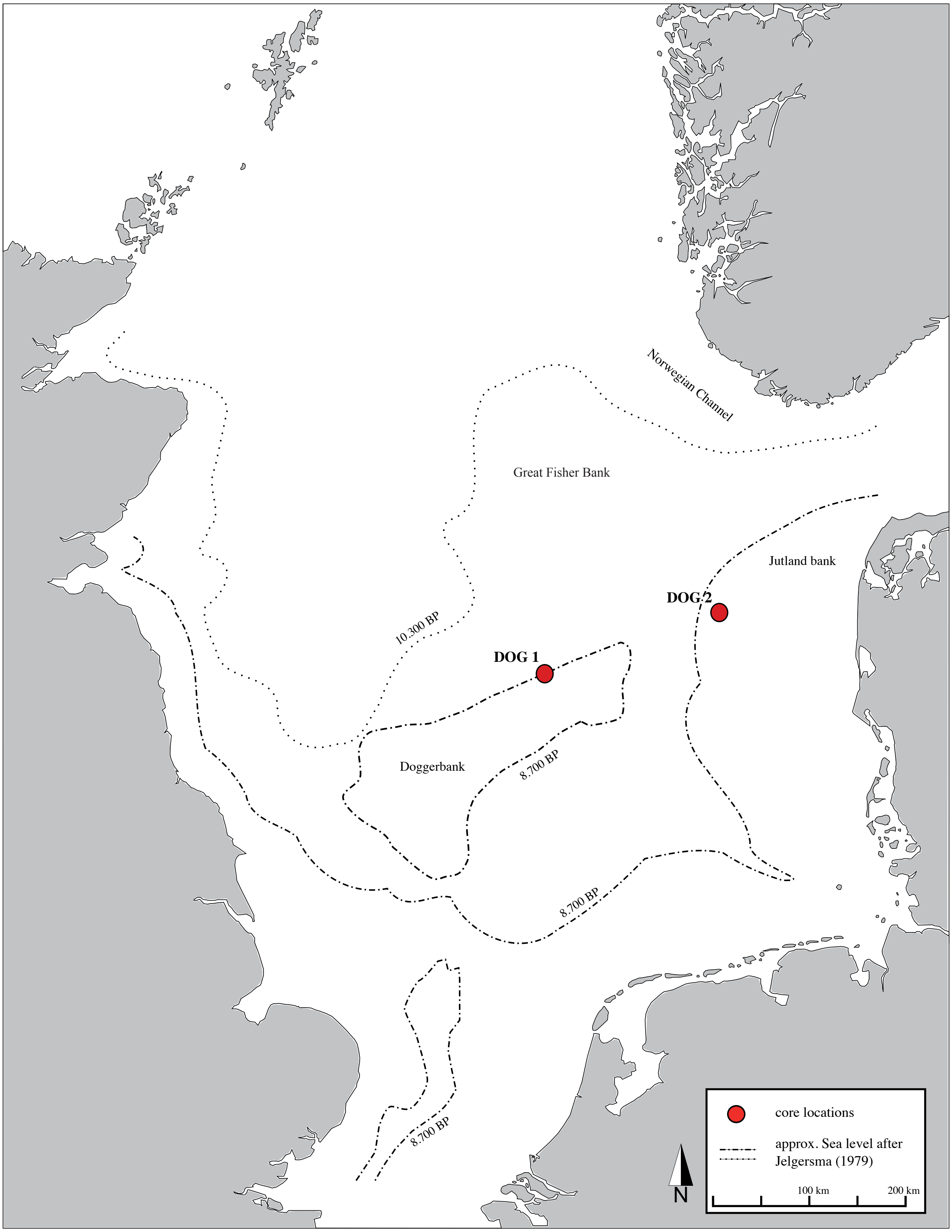

Fig. 1: Geographical setting of the cored locations with estimated sea level for the Preboreal and Boreal period.

Abb. 1: Geografische Position der Bohrstandorte mit ungefährem Verlauf der Küstenlinie während des Präboreals und Boreals.

were part of the basal peat layer are often found in the nets by fishermen. Such lumps of peat may result from erosion of peat layers (Erdtman 1924; Whitehead & Goodchild 1909). An aim of this investigation is to reconstruct the peat formation at the cored locations in order to reason out whether these are basal peats.

Micro-charcoal in pollen samples can shed light on climate induced fires in the natural ecosystem but may also be used to infer man-made changes (Kangur 2002: 289; Moore 1996: 63; Tipping 1996). Assured evidence of human activity during the Mesolithic is mostly associated with high amounts of micro-charcoal in the pollen record. In many parts of Scotland, the Shetland Islands and northern Germany early Holocene forest opening and high quantities of micro-charcoal are correlated and discussed as evidence of anthropogenic activities (Edwards 1996: 34–36; Edwards & Sugden 2009: 15; Innes et al. 2013: 88; Tipping 1996: 45; Robin & Nelle 2014: 62; Welinder 1985). At the Mesolithic site of Hohen Viecheln (Mecklenburg-western Pomerania, Germany) "… finds of micro-charcoal can be referred to fires of Mesolithic people…" (Schmitz 1961: 31). Against this background we wanted to find an explanation for the given signal from micro-charcoal. Is it possible to find evidence of anthropogenic activity and human-environment-interactions based on pollen- and micro-charcoal counting even long before the Neolithic period?

2. Geographical setting

Core DOG 1 (55°44'36.98''N, 3°46'27.88''E) was collected in the centre of the North Sea at the northern edge of the Dogger Bank at a water depth of 38.8 m. The coring position of DOG 2 (56°20.788'N, 6°6.615'E) is located 200 km closer to the west coast of Jylland near the Lille Fisker Banke at a depth of 42.1 m. According to the relative sea-level curves of Behre (2003), Streif (2004) and Jelgersma (1979) both settings must have been flooded during the second phase of the late Weichselian and Holocene North Sea transgression. During this phase areas from about 72 to 25 m below present-day sea level were inundated (fig. 1).

3. Material

Based on a number of pollen analyses (Behre & Menke 1969; Menke 1996; Wolters et al. 2010) and pioneering studies of submerged peat beds (Reid 1913; Whitehead & Goodchild 1909) as well as more recent geological investigations, it is well-known that during the Preboreal and Boreal basal peats were deposited in wetland areas in the North Sea. In some areas such peats have been preserved from erosion during the transgression. In contrast to sandy and clayey sediments, peat provides good conditions for preservation of pollen grains. In both cores preliminary investigations confirmed that pollen grains were well preserved, and hence it was decided to conduct a high-resolution study of the peat deposits. Both sediment cores were sampled with a vibrocorer. Samples from core DOG 1 were provided by the Lower Saxony Institute for Historical Coastal Research (cored by the Federal Institute for Geoscience and Natural Resources within the project Geopotential of the German North Sea – Marine CSEM and provided for further research before) and DOG 2 by the Geological Survey of Denmark and Greenland. The sediment successions extend into the Pleistocene at the bottom of the cores. The sediment stratigraphy of the cores is shown in Table 1 and 2.

Tab. 1: lithological description of DOG 1 (top core edge -38,8 m NN)

Tab. 1: Lithologische Beschreibung des Kerns DOG 1 (Kernoberkante -38,8m NN).

Depth (cm)	Lithology
0–12	Medium to coarse grained sand, interspersed with shells and many small stones, calcareous, 7.5YR N7 olive-grey
12–58	Clayey sediments, calcareous, 5Y 4.1 dark grey
58–62	Clayey sediments and peat, gradual transition to peat below, 10YR 3.1–4.1 very dark grey
62–73	Peat, highly compressed, no organic macro-remains visible, partly sand lenses, 10 YR 2.1 black
73–86	Fine to medium grained sand, sharp transition, 2.5Y 4.2 dark grey-brown
86–100	Fine to medium grained sand, 2.5Y 5.3 light olive-brown

Tab. 2: lithological description DOG 2 (top core edge -42.1 m NN)

Tab. 2: Lithologische Beschreibung des Kerns DOG 2 (Kernoberkante -42,1m NN).

Depth (cm)	Lithology
0–110	Medium-grained homogenous sand, calcareous, with scattered shells of marine molluscs, 5Y 5/2 olive grey. Lower boundary erosive
110–504	Bioturbated clay, calcareous, 5Y 4/1 dark grey. Lower boundary sharp
504–515	Peat, in situ roots from the top to the bottom, 2.5Y N2 black. Lower boundary sharp
515–530	Sandy silt with small sand lenses, 10YR 2.1 black. Lower boundary sharp
530–535	Medium-grained sand, 2.5Y 4.2 dark grey-brown. Lower boundary sharp
535–540	Medium-grained sand with scattered pebbles, 2.5Y 6.2 light brown-grey

4. Methods

4.1 Sampling and sample treatment

Both cores were sub-sampled at 5 mm intervals throughout the peat sections. The clay, silt and sand sections were sampled at least at 2 cm intervals. Sample preparation was carried out according to standard techniques (Fægri & Iversen 1989: 76–84; acetolysis after Erdtmann 1960: 561–62). A *Lycopodium* spore tablet was added to each sample to calculate pollen and charcoal concentrations (Stockmarr 1971). Pollen counting was performed at a total magnification of x400 for routine counting and x1000 for critical objects. A total pollen sum of at least 300 TTP (total terrestrial pollen) and if possible 500 TTP was achieved. Pollen grains were identified with the help of literature, mainly Beug (2004), Fægri (1993) and Moore (et al. 1991). A reference collection at the Institute of Pre- and Protohistoric Archaeology in Kiel was also used. Micro-charcoal was counted as a possible indicator of human activity (Warren et al. 2014: 630; Behre 1988: 637; Tipping 1996: 40). Charcoal particles >10µm were identified by asymmetric shape, deep black colour and sharp fraction edges (Patterson et al. 1987: 9; Wiethold 1997: 48). Considering the multiple fractioning caused during the preparation process sizing was neglected.

The pollen diagrams were constructed using the CountPol software developed by I. Feeser, University of Kiel. Percentage values shown in the diagrams were calculated based on

Depth (cm)	Lab. no	δ¹³C	¹⁴C age	cal. years BP (2σ)
(DOG 1)				
63.0–64.0	POZ-47110	-28,8 ± 0,3	9068 ± 44	10366–10173
72.0–73.0	POZ 47111	-31,6 ± 0,2	9954 ± 52	11620–11240
(DOG 2)				
506.5–507.0	KIA-51169	–27,96 ± 0,17	9547 ± 60	11101–10701
510.5–511.0	KIA-51170	–30,19 ± 0,35	9311 ± 51	10664–10298
513.0–513.5	KIA-51171	–29,43 ± 0,14	9505 ± 51	11083–10593

Tab. 3: radiocarbon ages from DOG 1 and 2

Tab. 3: Radiokarbonalter von DOG 1 und 2.

PAZ	depth (cm)	pollen analytical key features	period
3b	38.0–58.5	Corylus rise, *Pinus* dominates, *Quercus*, *Alnus Ulmus* continuous below 5%, *Sparganium*-type, *Pediastrum*, *Botryococcus* continuously present	Boreal
3a	58.5–62.25	drop of *Corylus*, *Betula* min., *Pinus* increase, *Ulmus*, *Alnus*, *Quercus* < 5 % Chenopodiaceae, *Sparganium*-type, Cyperaceae, *Pediastrum* slowly increase, *Calluna* and *Sphagnum* decrease	Boreal
2b	62.25–65.75	drop of *Betula*, strong rise and max. of *Corylus*, Poaceae min.	Boreal
2a	65.75–73.5	*Betula* max., continuous presence of *Corylus* with an enhanced rise towards the end, *Calluna* and *Sphagnum* increase above 10 %, Poaceae steeply decrease	Preboreal
1	73.5–78.0	decrease of *Pinus*, rise of *Betula* towards the end, Poaceae max., *Calluna* rise	c.f. Younger Dryas

Tab. 4: DOG 1 pollen assemblage zones with key features

Tab. 4: DOG 1 Pollensammelzonen mit Hauptmerkmalen.

PAZ	depth (cm)	pollen analytical key features	period
4b	490.0–495.75	*Pinus* dominant, closed *Quercus* and *Ulmus* curves, *Sparganium*-type, *Pediastrum* and *Botryococcus* curves closed, *Ilex* and *Tilia* occure	Boreal
4a	495.75–505.75	*Pinus* rises and reaches max., *Betula* slowly drops, *Ulmus* and *Quercus* curves partly closed but below 5%, Poaceae increase, *Sparganium*-type, *Equisetum* (partly), *Pediastrum* and *Botryococcus* curves are closed	Boreal
3b	505.75–509.75	slow rise of *Pinus*, *Cyperaceae* max., Poaceae max., *Quercus* and *Ulmus* occure	Boreal
3a	509.75–514.5	*Betula*~30 %, *Pinus* ~20 %, *Corylus* continuous but below 15%, Poaceae increase, *Filipendula* max.	Preboreal/ Boreal
	514.5	Hiatus	
2	514.5–521.0	*Betula* min., no other AP as *Betula*, *Pinus* and *Picea*, Poaceae min., Cyperaceae min.	c.f. Younger Dryas
1	521.0–528.0	*Pinus* max., low values of *Betula*, Poaceae and Cyperaceae (generally bad preservation)	c.f. Younger Dryas

Tab. 5: DOG 2 pollen assemblage zones with key features

Tab. 5: DOG 2 Pollensammelzonen mit Hauptmerkmalen.

the total terrestrial pollen sum. The diagrams were imported to Inkscape (vers. 0.91-1) where zone boundaries were drawn and minor modifications were made. Zone boundaries were placed at marked changes in pollen assemblages.

4.2 ¹⁴C-dating

Two ¹⁴C ages of bulk sediment samples from DOG 1 were available at the beginning of this project. In DOG 2 no suitable seeds or fruits for dating could be found. Hence, three bulk samples were taken. The dates were calibrated using the calibration programme OxCal 4.2 (Bronk Ramsey 2009) and the IntCal13 dataset (Reimer et al. 2013). The results are found in Table 3.

5. Results

5.1 Pollen analysis

The pollen diagram DOG 1 (fig. 2) is based on 33 pollen spectra between 38.0 and 78.0 cm. The diagram was divided into five pollen assemblage zones. DOG 2 includes 55 pollen spectra between 490.0 and 528.0 cm. The diagram DOG 2 (fig. 3) was divided into six pollen assemblage zones. Their main features are compiled in Table 4 and 5.

The pollen diagram DOG 1 spans the chronozones of the Younger Dryas, Preboreal and Boreal. The development of an open birch forest and mass-expansion of hazel are pollen stratigraphical events that allow a chronological classification. The vegetation of the Younger Dryas was dominated by grasses and can be characterized as tundra vegetation. It is conspicuous that juniper (*Juniperus*) and mugwort (*Artemisia*) are underrepresented or not present in this chronozone. The transition to the early Holocene is documented by a shift in vegetation. Tree birches occupied favourable habitats in the region and formed an open forest interspersed with pines during the course of the Preboreal. On a local scale the development of a groundwater influenced wet heathland can be inferred.

The onset of the Boreal is indicated by mass-expansion of hazel and a drop of birch. A conspicuous change in the local vegetation can be observed at the transition from

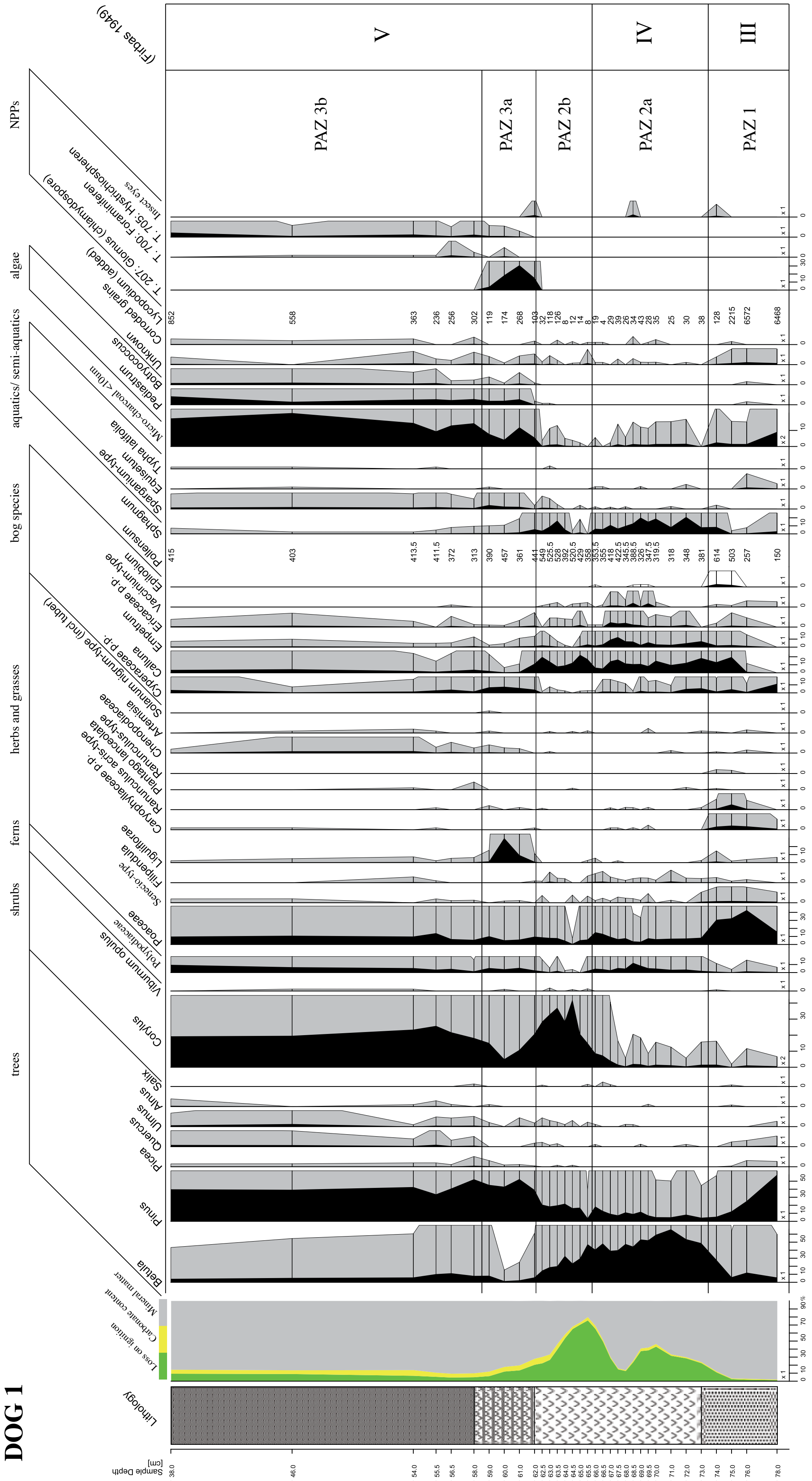

Fig. 2: Percentage pollen diagram from DOG 1, showing selected taxa. The hatched / grey shaded curves indicate a tenfold magnification for improved visualization. All given values are percentage values. TTP sum was used as calculation base.

Abb. 2: Pollenprozentdiagramm von DOG 1 mit ausgewählten Taxa. Grau hinterlegte Kurven zeigen eine 10fache Überhöhung zur verbesserten Sichtbarkeit. Alle angegebenen Werte sind Prozentwerte. Die Landpflanzensumme (TTP) entspricht der Berechnungssumme.

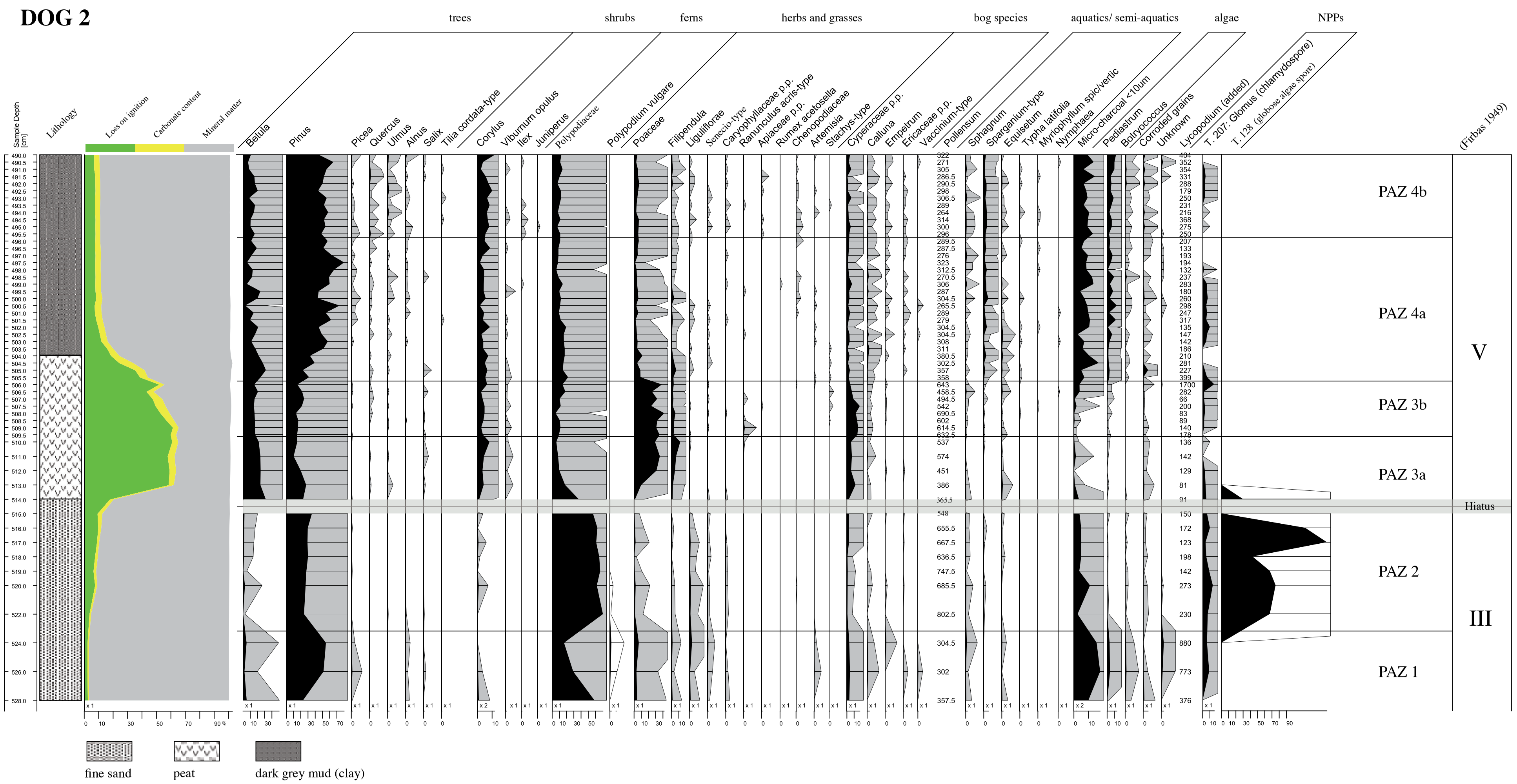

Fig. 3: Percentage pollen diagram from DOG 2, showing selected taxa. The hatched / grey shaded curves indicate a tenfold magnification for improved visualization. All given values are percentage values. TTP sum was used as calculation base.

Abb. 3: Pollenprozentdiagramm von DOG 2 mit ausgewählten Taxa. Grau hinterlegte Kurven zeigen eine 10fache Überhöhung zur verbesserten Sichtbarkeit. Alle angegebenen Werte sind Prozentwerte. Die Landpflanzensumme (TTP) entspricht der Berechnungssumme.

PAZ 2b to PAZ 3a. Heather and peat moss steeply decrease and at the same time lacustrine species such as bur-reed (*Sparganium*-type) and green algae such as *Botryococcus* or *Pediastrum* appear, indicating the formation of a fresh-water lake. Non-pollen-palynomorphs indicating marine influence, such as foraminifera and hystrichospheres are recorded (Bakker & van Smeerdijk 1982: 150), indicating that the marine inundation of the North Sea is seen in the investigated core section.

The pollen diagram DOG 2 most probably spans the chronozones of the Younger Dryas and the Boreal. A hiatus complicates the interpretation. The immigration of species of the mixed oak forest and the continuous presence of hazel are used as pollen stratigraphic events. The early Holocene development with open birch forests and the Boreal hazel maximum is not registered in the pollen diagram.

The local vegetation of the Younger Drays was most probably dominated by ferns, grasses and dwarf shrubs. The high pine pollen percentage values may indicate local pine stands. However, pine pollen are produced in huge numbers and dispersed very well by wind, and it is also possible that the pine pollen represent long-distance transport of pollen from pine forests to the south. In Denmark numerous macrofossil studies of Younger Dryas sediments have failed to show local presence of pine (Mortensen et al. 2014). Nothing can be said about the Preboreal vegetation at this locality due to a hiatus. Also the onset of the Boreal is not recorded, it would be expected between PAZ 2 and PAZ 3. PAZs 3a to 4b is referred to the Boreal because of decreasing birch pollen quantities, a continuous presence of hazel and the presence of elm, oak and alder. Pollen taxa like Poaceae (grasses), Cyperaceae (sedges) and *Salix* (willow) indicate a fen development until PAZ 4a. A marked change in local vegetation during the Boreal period can be seen at the transition between PAZ 3b and PAZ 4a. Lacustrine taxa such as bur-reed, green algae like *Botryococcus* and *Pediastrum* increase and even water lily occur. Again the formation of a fresh-water lake can be assumed. The diagram shows no evidence of the marine inundation.

5.2 Chronology

Peat formation occurred at location DOG 1 mainly during the Preboreal and partly during the Boreal period according to the composition of pollen taxa. The radiocarbon ages confirm this assumption and specify the time of peat formation to between about 11,620 and 10.170 cal. years BP.

At core location DOG 2 the time of peat formation is less clear. On one hand the pollen composition indicates that peat formed during the Boreal period but a hiatus complicates the interpretation of the pollen diagram. On the other hand three radiocarbon samples yielded ages between 11,100 and 10,300 cal. years BP – equivalent to the Preboreal period but the three dates are inverted. However, it is possible that the radiocarbon ages are influenced by a reservoir effect, which can give too old ages. It is also possible that the pollen diagram reflects a very local vegetation development. A large proportion of pollen in peat deposits may come from plants growing at the core site.

In any case the quantity and quality of the ^{14}C dates do not allow the reconstruction of a reliable age-depth model. However, it is clear that peat formation at the core locations occurred during the very early Holocene.

6. Discussion

6.1 Peat formation

As the investigated peat layers are of early Holocene origin, dating as well as lithology and the reconstructed local vegetation reassure the assumption that DOG 1 contained in-situ basal peat. A hiatus and an inversion of ^{14}C dates do not allow the same assertion for DOG 2.

The pollen diagrams DOG 1 and 2 contain indications for the development of fresh-water lakes with bur-reed, green algae or water lilies. In both cases there is a change in the sediment composition from peat to clay at the same time. For both locations it can be assumed that peat developed in coastal depressions which in the course of the Boreal period were flooded by the permanently rising groundwater level before they were covered by marine clay. This process is also seen in the Baltic Sea region in Mecklenburg-western Pomerania, Germany. Here, the Littorina transgression first led to the development of coastal fens. These were subsequently flooded due to the permanent sea level rise (Michaelis 2002: 120). Peats in this case represent an elevation above sea level. Marine influence indicated through inundation and submergence show the vicinity to the sea. Hence, this study provides two more points to the sea-level curve of the southern North Sea.

In the case of DOG 1 and 2 grasses, sedges and species from the goosefoot family can be seen as evidence for coastal influence. Constantly occurring hystrichospheres indicates occasional incursions of seawater into the fresh-water system. However, the permanent presence of green algae and bur-reed that are intolerant to salt water, excludes total marine inundation at both locations during the time of peat deposition.

6.2 The abundance of hazel

The pollen diagram DOG 1 contains maximum values of 40% *Corylus*. Diagrams from surrounding areas show similar maxima. For example, in southern Norway Prøsch-Danielsen (1993) reported 42%, in north-western Denmark Odgaard (1994) reported 40%, in the south-eastern North Sea Basin Menke (1996) reported 42%, Wolters (et al. 2010) 28%, and Overbeck (1975: 447) reported 30–50% on poor sandy soils of the lower moraine area in northern Germany. This peak values are equivalent to the Boreal period in northern Europe (Firbas 1949: 49; Dörfler & Nelle 2008: 56; Lang 1994: 231; Overbeck 1975: 446). The highest values for *Corylus* in diagram DOG 2 are 7%. The high resolution of the diagram excludes the possibility that the hazel maximum was not recorded in the sampling.

PAZ 3a and PAZ 4b of diagram DOG 2 is referred to the Boreal period, based on the occurrence of species of the mixed oak forest. An explanation for the missing Boreal hazel maximum is most probably a hiatus in the sediment record. It is suggested that peat formation was interrupted until the Boreal.

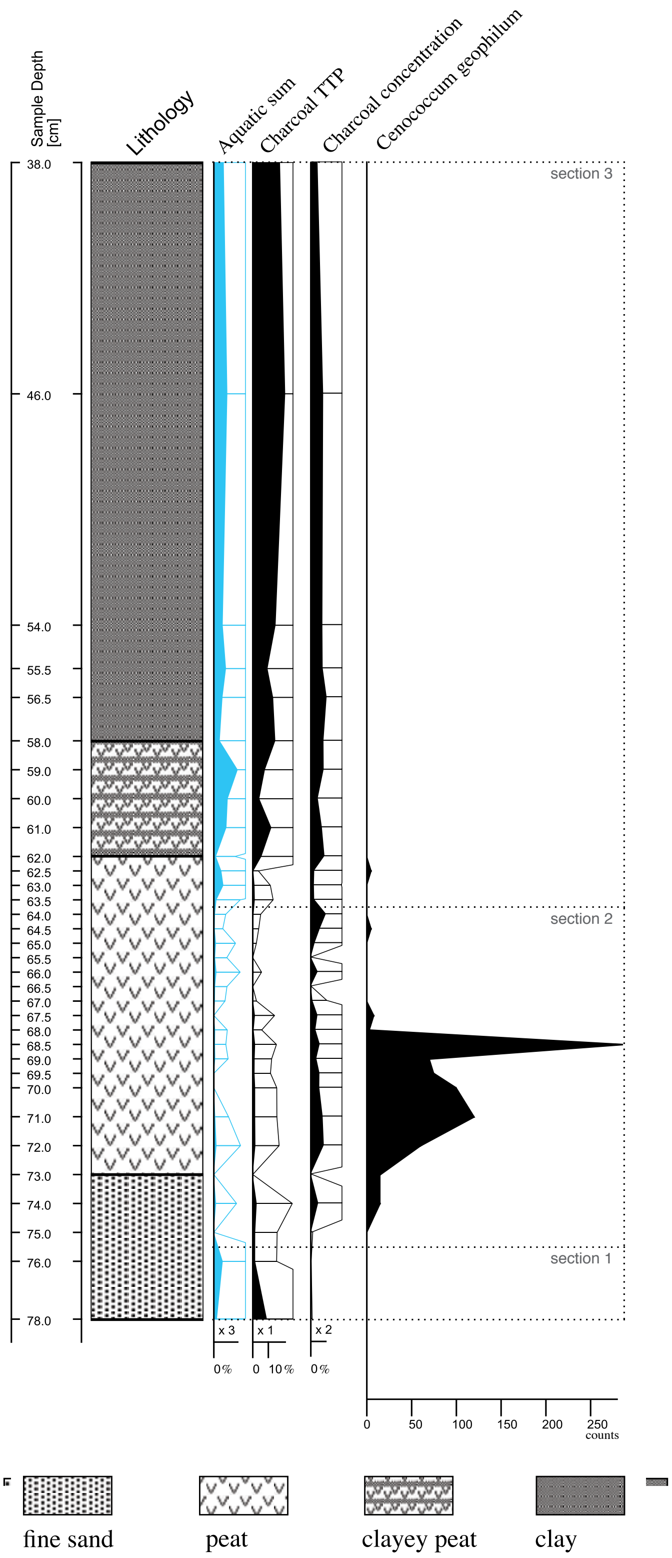

Fig. 4: Composite diagram (DOG 1) for improved interpretation of given charcoal signals. Given charcoal concentration values refer to 1 cm³ sediment.

Abb. 4: Kompositdiagramm (DOG 1) zur besseren Interpretation des Holzkohlesignals. Die angegebenen Prozentwerte der Holzkohle-Konzentration beziehen sich auf je 1cm³ Sediment.

6.3 Micro-charcoal as human indicator

Both pollen diagrams presented in this article show distinct changes in the micro-charcoal record. A comparison with four parameters explains these changes (fig. 4 and 5).

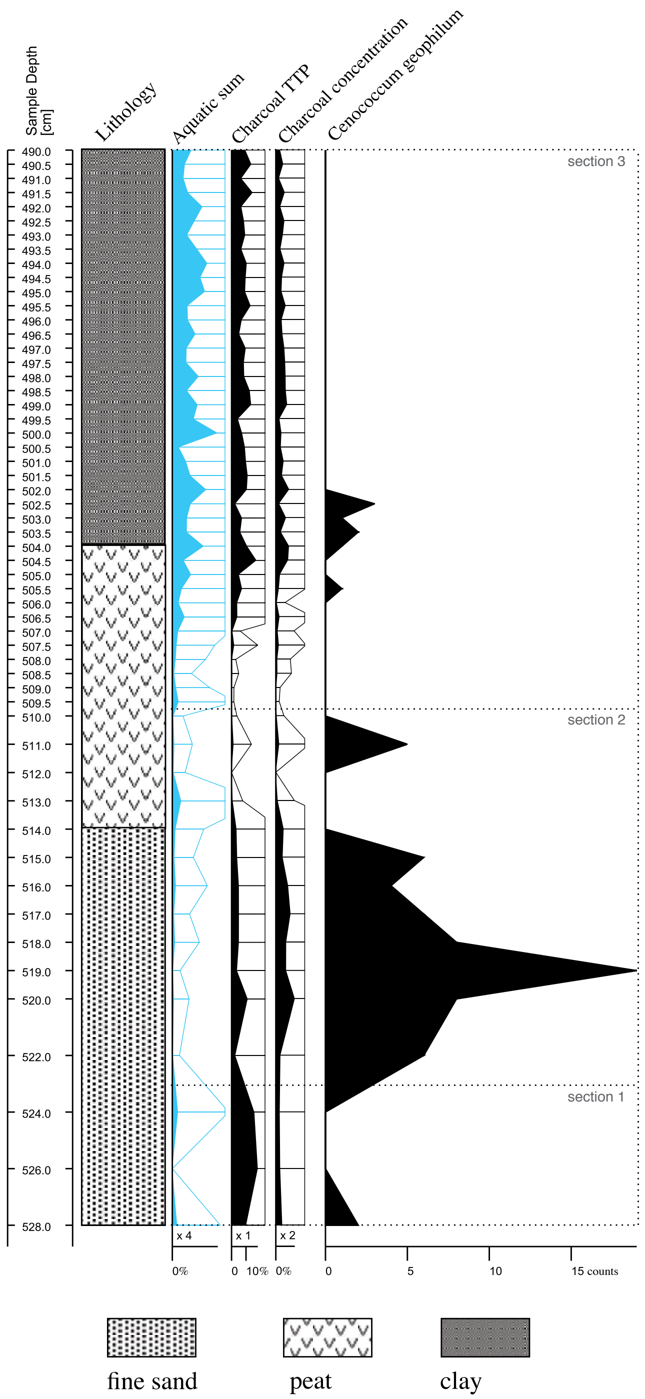

Fig. 5: Composite diagram (DOG 2) for improved interpretation of given charcoal signals. Given charcoal concentration values refer to 1 cm³ sediment.

Abb. 5: Kompositdiagramm (DOG 2) zur besseren Interpretation des Holzkohlesignals. Die angegebenen Prozentwerte der Holzkohle-Konzentration beziehen sich auf je 1cm³ Sediment.

The blue curve shows the sum of aquatic and semi-aquatic species (*Typha latifolia*, *Spagranium*-type, *Equisetum*, *Myriophyllum*, *Nymphaea*), not only pollen but also algae (*Botryococcus*, *Pediastrum*) and other relevant NPPs (foraminifera and hystrichosphers). The next curve displays the micro-charcoal percentage value calculated according to total terrestrial pollen (charcoal TTP). The third curve shows the micro-charcoal concentration per cm³ sediment where *Lycopodium* spores were used for calculation. The fourth curve shows the concentration of *Cenococcum* *geophilum* sclerotia per cm³ sediment. The concentration of sclerotia of this soil fungus can be used as a proxy for soil erosion (Eide et al. 2006: 77; Kroll 1988: 111).

Both profiles presented in the figures can be divided into three sections (1, 2, 3). In section 1 of both diagrams the micro-charcoal TTP-curve shows around 10%. In contrast to that the actual micro-charcoal concentration is below 3 (DOG 2) and 1 % (DOG 1). The micro-charcoal concentration curve indicates that the higher values in the micro-charcoal TTP-curve are the result of a low pollen density[4].

In both second sections (2) the micro-charcoal concentration in the sediment increases – an actual signal is given. In both cases these signals correlate with high concentrations of *Cenococcum geophilum* sclerotia in the sediment. Actually occurring fires might be the reason but most probably soil erosion indicated by Cenococcum geophilum can be assumed as source of secondary micro-charcoal.

The third section (3) shows in both cases the highest values of micro-charcoal TTP and micro-charcoal concentration. The increase in both diagrams corresponds with an increase in the aquatic species sum curve. This is the section when the development of a freshwater lake at both locations starts, as described above. It can be assumed that additionally to input by wind, water transport led to higher micro-charcoal accumulation rates. This assumption is supported by the high pine values. *Pinus* pollen have two air sacs and are hence more easily dispersed by wind and water than other pollen types (Firbas 1952: 148). Simultaneously with the increase in aquatic species the pine values increase in both of the diagrams. Increasing pine values have often been linked to inundation and some kind of bank or shore situation, respectively (Bokelmann et al. 1981: 34).

The Boreal Chronozone is characterized by a dry and continental climate. The vegetation of north-western Europe at that time was dominated by an open birch-pine-forest with strong occurrence of hazel (DOG 1&2; Bokelmann et al. 1981: 33; Dörfler & Nelle 2008: 57; Odgaard 1994: 131; Prøsch-Danielsen 1993: 30; Overbeck 1975: 445). Macro-charcoal from Pleistocene and early Holocene deposits mainly come from pine. The combination of pine-rich forests and dry climate resulted in an increased occurrence of natural fires during the Boreal period (Robin & Nelle 2014: 61). This circumstance and the transition from a peat bog to a shallow lake at both coring locations led to an increase in micro-charcoal.

The micro-charcoal distribution indicates that no local fire events occurred at the investigated sites. Also no phases with distinctly higher values were recorded that could have originated from human induced fires. Of course one cannot exclude anthropogenic activity and human-environment-interactions from the pollen record and the charcoal signal but according to the micro-charcoal record it is unlikely that either Palaeolithic or Mesolithic camp sites existed in the vicinity of the investigated core sites.

7. Conclusion

Even though, artefacts or other evidence for human presence during the Palaeolithic and early Mesolithic are scarce (Coles 1999: 55; Bjerck 1995: 132; Clark 1932: 115; 1936: 15; Louwe Kooijmans 1972: 32) it is today far more than a hypothesis that humans once crossed and lived in Doggerland. Pollen diagrams are important tools for an improved understanding of the development of this submerged region and its suitability for humans.

As suggested by Coles (1998: 63) pollen diagrams from the region show that the vegetation development followed the fundamental succession of forest development in northern central Europe. This implies that the vegetation in Doggerland equates to the vegetation of the northern European Plain during the late glacial and early Holocene. Paludification on Pleistocene mineral-rich sediment caused by a rising groundwater level and finally the development of fresh-water lakes can be inferred from both diagrams described in this paper. The beginning of the marine inundation is indicated by sporadic occurrence of indicators of marine ingressions and finally, marine clay overlies the sequence. Hence, the vicinity of the sea is evident. In addition, the results show that the quantity of micro-charcoal is at a natural level. There is no evidence of anthropogenic changes of the environment based on micro-charcoal at the core sites. Human presence is not excluded from the data but the existence of camp sites of prehistoric hunter-gatherers in the vicinity of the core sites seems unlikely. This result raises the question, what kind of coastal areas of Doggerland were of high importance as potential settlement areas.

8. Outlook

This research investigates cores from the North Sea containing peat sections. The cored sites had been part of the coast of Doggerland in the course of the early Holocene and it is often claimed that a marine orientation of the inhabitants of Doggerland is obvious (Weninger et al. 2008: 14). Subsistence strategies of preboreal and boreal mesolithic hunter-gatherers and fishers and their seasonal exploitation of resources that had been obtainable in Doggerland are known from different sites in the North European Plain as e.g. Duvensee (Bokelmann 1971; 1995; Bokelmann et al. 1981; 1985; Holst 2009; Schwantes et al. 1925). Though, camp sites of late Palaeolithic or early Mesolithic hunter-gatherers could not be proven at any of the investigated sites through the defined human indicator. It might be possible that humans that once roamed the dry North Sea area were living in lacustrine and riverine areas of the morainic landscape rather than at the highly dynamic and shifting coastline. A recent study on stable isotopes of human bones from the Southern North Sea supports this hypothesis (van der Plicht et al. 2016: 117). Hunter-gatherers of Doggerland probably sporadically frequented the seaside depending on season and availability of resources.

Nevertheless, the study area of Doggerland comprises a high potential for Palaeolithic and Mesolithic research. Further investigations, as seismic mapping (Gaffney et al.

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[4] The relation between the counted *Lycopodium* spores and the TTP shows the pollen density (Stockmarr 1971: 615). In the bottom part of e.g. DOG 2 this relation is 6000 to 150.

2007) are both desirable and necessary and can help to spot kettle holes, lagoons and former water bodies – suitable as home ranges of prehistoric people.

9. Acknowledgements

The authors would like to thank two anonymous reviewers for valuable comments on this manuscript. Furthermore we are also grateful to Berit V. Eriksen for her support.

10. References

Bakker, M. & van Smeerdijk, D.G. (1982): A Palaeoecological Study of a Late Holocene Section from “Het Ilperveld”, Western Netherlands. – Review of Palaeoecology and Palynology 36: 95–163.

Behre, K.-E. & Menke, B. (1969): Pollenanalytische Untersuchungen an einem Bohrkern der südlichen Doggerbank. – Deutsche Akademie der Wissenschaften zu Berlin. Beiträge zur Meereskunde 24/25: 122–129.

Behre, K.-E., Menke, B. & Streif, H. (1979): The Quaternary geological development of the German part of the North Sea. Uppsala: Acta Universitatis Upsaliensis, Symposia Universitatis Upsaliensis Annum Quingentiesimum Celbrantis 2: 85–114; Uppsala (Almquist & Wiksell).

Behre, K.-E. (1988): The rôle of man in European vegetation history. – In: Huntley, B. & Webb, T. (eds.): Vegetation history. Handbook of vegetation science, Volume 7: 633–672; Dodrecht (Kluwer).

Behre, K.-E. (2003): Eine neue Meeresspiegelkurve für die südliche Nordsee. Transgressionen in den letzten 10.000 Jahren. – Probleme der Küstenforschung im südlichen Nordseegebiet 28: 9–63.

Behre, K.-E. (2008): Landschaftsgeschichte Norddeutschlands. Umwelt und Siedlung von der Steinzeit bis zur Gegenwart. – 308 S.; Neumünster (Wachholtz).

Beug, H.-J. (2004): Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. – 542 S.; München (Pfeil).

Bjerck, H. B. (1995): The North Sea Continent and the pioneer settlement of Norway. – In: Fischer, A. (ed.): Man and Sea in the Mesolithic. Coastal settlement above and below present sea level. Proceedings of the International Symposium, Kalundborg, Denmark 1993. Oxbow Monograph 53: 131–144; Oxford (Oxbow).

Bokelmann, K. (1971): Duvensee, ein Wohnplatz des Mesolithikums in Schleswig-Holstein und die Duvenseegruppe. – Offa. Berichte und Mitteilungen zur Urgeschichte, Frühgeschichte und Mittelalterarchäologie Bd. 28: 5–26; Neumünster (Wachholtz).

Bokelmann, K. (1995): “Faint flint fall-out”: Duvensee Wohnplatz 19. – Offa. Berichte und Mitteilungen zur Urgeschichte, Frühgeschichte und Mittelalterarchäologie Bd. 52: 45–56; Neumünster (Wachholtz).

Bokelmann, K., Averdieck, F.-R. & Willkomm, H. (1981): Duvensee, Wohnplatz 8. Neue Aspekte zur Sammelwirtschaft im frühen Mesolithikum. – Offa. Berichte und Mitteilungen zur Urgeschichte, Frühgeschichte und Mittelalterarchäologie Bd. 38: 21–40; Neumünster (Wachholtz).

Bokelmann, K., Averdieck, F.-R. & Willkomm, H. (1985): Duvensee, Wohnplatz 13. – Offa. Berichte und Mitteilungen zur Urgeschichte, Frühgeschichte und Mittelalterarchäologie Bd. 42: 13–33; Neumünster (Wachholtz).

Bronk Ramsey, C. (2009): Bayesian analysis of radiocarbon dates. – Radiocarbon 51/1: 337–360.

Clark, J.G.D. (1932): The Mesolithic Age in Britain. – 155 S.; Cambridge (University Press).

Clark, J.G.D. (1936): The Mesolithic Settlement of Northern Europe. A Study of The Food-Gathering Peoples of Northern Europe During The Early Post-Glacial Period. – 284 S.; Cambridge (University Press).

Coles, B.J. (1998): Doggerland: a Speculative Survey. – Proceedings of the Prehistoric Society 64: 45–81.

Coles, B.J. (1999): Doggerland’s loss in the Neolithic. – In: Coles, B., Coles, J. & Jørgensen, M.S. (eds.): Bog Bodies, Sacred Sites and Wetland Archaeology. Proceedings of a conference held by WARP and the National Museum of Denmark, in conjunction with Silkeborg Museum, Jutland, September 1996: 55–57; Exeter (WARP).

Dörfler, W. & Nelle, O. (2008): A summary of the late- and post-glacial vegetation history of Schleswig-Holstein. – Mitteilungen der Arbeitsgemeinschaft für Geobotanik Schleswig-Holstein und Hamburg 65: 45–68.

Edwards, K.J. (1996): A Mesolithic of Western and Northern Isles of Scotland? Evidence from Pollen and Charcoal. – In: Pollard, T. & Morrison, A. (eds.): The Early Prehistory of Scotland: 23–38; Edinburgh (Edinburgh University Press).

Edwards, K.J. & Sugden, H. (2009): Palynological visibility and the Mesolithic Colonisation of the Hebrides, Scotland. – In: Larsson, L. (ed.): Mesolithic on the move: papers presented at the Sixth International Conference on the Mesolithic Europe 04.-08.09.2000 in Stockholm: 11–19; Oxford (Oxbow).

Eide, W., Birks, H.H., Bigelow, N.H., Peglar, S.M. & Birks, H.J.B. (2006): Holocene forest development along the Setesdal valey, southern Norway, reconstructed from macrofossil and pollen evidence. – Vegetation History and Archaeobotany 15: 65–85.

Erdtman, G. (1924): Microanalyses of “moorlog” from the Dogger Bank. – Essex Naturalist XXI: 107–112.

Erdtman, G. (1960): The Acetolysis Method. A Revised Description. – Svensk Botanisk Tidskrift 54/4: 561–564.

Fægri, K. & Iversen, J. (1989): Textbook of Pollen Analysis. IV Edition. – 328 S.; Chichester (Wiley).

Fægri, K. (1993): Bestimmungsschlüssel für die nordwestdeutsche Pollenflora. – 85 S.; Jena (Fischer).

Firbas, F. (1949): Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen, Erster Band: Allgemeine Waldgeschichte. – 480 S.; Jena (Fischer).

Firbas, F. (1952): Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen, Zweiter Band: Waldgeschichte der einzelnen Landschaften. – 256 S.; Jena (Fischer).

Gaffney, V., Thomson, K. & Fitch, S. (2007): Mapping Doggerland. The Mesolithic Landscapes of the Southern North Sea. – 131 S.; Oxford (Archaeopress).

Glimmerveen, J., Mol, D. & van der Pflicht, H. (2006): The Pleistocene reindeer of the North Sea - initial palaeontological data and archaeological remarks. – Quaternary International 142/143: 242–246.

Holst, D. (2009): „Eine einzige Nuss rappelt nicht im Sacke“ - Subsistenzstrategien in der Mittelsteinzeit. – Mitteilungen der Gesellschaft für Urgeschichte 18: 11–38.

Innes, J.B., Blackford, J.J. & Rowley-Conwy, P. (2013): Late Mesolithic and early Neolithic forest disturbance: a high resolution palaeoecological test of human impact hypotheses. – Quaternary Science Reviews 77: 80–100.

Jansen, J.H.F., van Weering, T.C.E. & Eisma, D. (1979): Late Quaternary sedimentation in the North Sea. Uppsala: Acta Universitatis Upsaliensis, Symposia Universitatis Upsaliensis Annum Quingentiesimum Celbrantis 2: 175–188; Uppsala (Almquist & Wiksell).

Jelgersma, S. (1979): Sea level changes in the North Sea basin. Uppsala: Acta Universitatis Upsaliensis, Symposia Universitatis Upsaliensis Annum Quingentiesimum Celbrantis 2: 233–248; Uppsala (Almquist & Wiksell).

Kangur, M. (2002): Methodological and practical aspects of the presentation and interpretation of microscopic charcoal data from lake sediments. – Vegetation History and Archaeobotany 11: 289–294.

Kroll, H. (1988): Das Allerletzte. Cenococcum geophilum. – Archäologische Informationen. Mitteilungen zur Ur- und Frühgeschichte 11/1: 111.

Lang, G. (1994): Quartäre Vegetationsgeschichte Europas. Methoden und Ergebnisse. – 462 S.; Jena (Fischer)

Lange, W. & Menke, B. (1967): Beiträge zur frühpostglazialen erd- und vegetationsgeschichtlichen Entwicklung im Eidergebiet, insbesondere zur Flußgeschichte und zur Genese des sogenannten Basistorfes. – Meyniana 17: 29–44.

Louwe Kooijmans, L.P. (1972): Mesolithic Bone and Antler Implements from the North Sea and from the Netherlands. – Berichten van de Rijksdienst voor het Oudheitkundig Bodermonderzoek 20/21: 27–73.

Ludwig, G., Müller, H. & Streif, H. (1979): Neuere Daten zum holozänen Meeresspiegelanstieg im Bereich der deutschen Bucht. – Deutsche Beiträge zur Quartärforschung in der südlichen Nordsee. Geologisches Jahrbuch A 32: 3–22.

Menke, B. (1996): Palynologische Untersuchungen des Vibrokerns Gauss 1987/5 aus der südlichen Nordsee. – Deutsche Beiträge zur Quartärforschung in der südlichen Nordsee. Geologisches Jahrbuch A 146: 177–182.

Michaelis, D. (2002): Die Talmoorgenese im Bereich der unteren Recknitz (Mecklenburg) - Moore zwischen Ostseeanstieg und autonomen Torfwachstum. – Greifswalder Geographische Arbeiten 26: 167–170.

Moore, P.D., Webb, J.A. & Collinson, M.E. (1991): Pollen Analysis. Second Edition. – 216 S.; Oxford (Blackwell Scientific Publications).

Moore, J. (1996): Damp Squib. How to fire a major deciduous Forest in an inclement Climate. – In: Pollard, T. & Morrison, A. (eds.): The Early Prehistory of Scotland: 62–73; Edinburgh (Edinburgh University Press).

Mortensen, M.F., Henriksen, P.S & Bennike, O. (2014): Living on the good soil: relationships between soils, vegetation and human settlement during the late Allerød time period in Denmark. – Vegetation History and Archaeobotany 23: 195–205.

Munsell Color (Firm). Munsell Soil Color Charts: with genuine Munsell Color Chips. Grand Rapids, MI: Munsell Color, 2010 (Print).

Odgaard, B. V.1994: The Holocene vegetation history of northern West Jutland, Denmark. – Nordic Journal of Botany 14/4: 1–402.

Overbeck, F. (1975): Botanisch-geologische Moorkunde unter besonderer Berücksichtigung der Moore Nordwestdeutschlands als Quelle zur Vegetations-, Klima- und Siedlungsgeschichte. – 719 S.; Neumünster (Wachholtz).

Patterson, W. A., Edwards, K. J., Maguire, D. J. (1987): Microscopic Charcoal as a fossil indicator of fire. – Quaternary Science Reviews 6: 3–23.

Peeters, J.H.M. & Momber, G. (2014): The southern North Sea and the human occupation of northwest Europe after the Last Glacial Maximum. – Netherlands Journal of Geoscience. Geologie en Mijnbouw 93 1/2: 55–70.

Prøsch-Danielsen, L. (1993): Naturhistoriske undersøgelser i Rennesøy og Finnøy kommuner, Rogaland, Sørvest-Norge. Varia 22. – 119 S.; Stavanger (Arkeologisk museum i Stavanger).

Reid, C. (1913): Submerged Forests. – 129 S.; Cambridge (University Press).

Reimer, P. J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I. Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A. Turney, C.S.M. & van der Plicht, J. (2013): IntCal13 and Marine13 radiocarbon age calibration curves, 0–50,000 years cal BP. – Radiocarbon 55/4: 1869–1887.

Robin, V. & Nelle, O. (2014): Contribution to the reconstruction of central European fire history, based on the soil charcoal analysis of study sites in northern and central Germany. – Vegetation History and Archaeobotany 23: 51–65.

Schmitz, H. (1961): Pollenanalytische Untersuchungen in Hohen Viecheln am Schweriner See. – In: Schuldt, E. (ed.): Hohen Viecheln, ein mittelsteinzeitlicher Wohnplatz in Mecklenburg: 14–38; Berlin (Akademie Verlag).

Schwabedissen, H. (1951): Zur Besiedlung des Nordseeraumes in der älteren und mittleren Steinzeit. – In: Kersten, K. (ed.): Festschrift für Gustav Schwantes zum 65. Geburtstag: 59–77; Neumünster (Wachholtz).

Schwantes G., Gripp, K. & Beyle, M. (1925): Der frühmesolithische Wohnplatz von Duvensee. – Prähistorische Zeitschrift 16: 173–177.

Stockmarr, R (1971): Tablets with spores used in absolute pollen analysis. – Pollen et Spores 13: 615–621.

Streif, H. (2004): Sedimentary record of Pleistocene and Holocene marine inundations along the North Sea coast of Lower Saxony, Germany. – Quaternary International 112: 3–28.

Tipping, R. (1996): Microscopic Charcoal Records, inferred human activity and climate change in the mesolithic of northernmost Scotland. – In: Pollard, T. & Morrison, A. (eds.): The Early Prehistory of Scotland: 39–61; Edinburgh (Edinburgh University Press).

van der Plicht, J., Armkreutz, L.W.S.W., Niekus, M.J.L.Th., Peeters, J.H.M. & Smit, B.I. (2016): Surf'n Turf in Doggerland: Dating, stable isotopes and diet of Mesolithic human remains from the southern North Sea. – Journal of Archaeological Science: Reports 10: 110–118.

Warren, G., Davis, S., McClatchie, M. & Sands, R. (2014): The potential role of humans in structuring the wooded landscapes of Mesolithic Ireland: a review of data and discussion of approaches. – Vegetation History and Archaeobotany 23: 629–646.

Wiethold, J. (1997): Studien zur jüngeren postglazialen Vegetations- und Siedlungsgeschichte im östlichen Schleswig-Holstein: mit regionalen Pollendiagrammen aus dem Belauer See, Kr. Plön, dem Treßsee Kr. Schleswig-Flensburg und dem Ilewitter Moor, Kr. Rendsburg-Eckernförde. Dissertation, Universität Kiel. Universitätsforschungen zur Prähistorischen Archäologie 45; Bonn (Habelt Verlag).

Welinder, S. 1985: Mesolithic Forest Clearance in Scandinavia. – In: Bonsall, C. (ed.): The Mesolithic in Europe. Papers presented at the 3rd international Symposium, Edinburgh 1985: 362–366; Edinburgh (Donald).

Weninger, B., Schulting, R., Bradtmöller, M., Clare, L., Collard, M., Edinborough, K., Hilpert, J., Jöris, O., Niekus, M., Rohling, E.J. & Wagner, B. (2008): The catastrophic final flooding of Doggerland by the Storegga Slide tsunami. – Documenta Praehistorica XXXV: 1–24.

Whitehead, H. & Goodchild, H.H. (1909): Some Notes on "Moorlog", a Peaty Deposit from the Dogger Bank in the North Sea. – Essex Naturalist XVI: 51–60.

Wolters, S., Zeiler, M. & Bungenstock, F. (2010): Early Holocene environmental history of sunken landscapes: pollen, plant macrofossil and geochemical analyses from Borkum Riffgrund, southern North Sea. – International Journal of Earth Science 99: 1707–1719

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / 14-31 / DOI 10.3285/eg.66.1.02
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

Spring fed raised peat hummocks with tufa deposits at the Farbeberg hills (Northwest-Germany): Structure, genesis and paleoclimatic conclusions (Eemian, Holocene)

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How to cite: Grube, A. & Usinger, H. (2017): Spring fed raised peat hummocks with tufa deposits at the Farbeberg hills (Northwest-Germany): Structure, genesis and paleoclimatic conclusions (Eemian, Holocene). – E&G Quaternary Science Journal, 66 (1): 14–31. DOI: 10.3285/eg.66.1.02

Abstract: Spring fed raised calcareous peat hummocks in Schleswig-Holstein (Northwest-Germany) were investigated by means of geological methods, pollen analysis and ^{14}C-dates. Artesian water discharges locally cause the growth of hills and ridges consisting of peat, organic / calcareous mud and tufa. Spring discharges at the Northern Farbeberg hill (near Hohenwestedt) are active since at least the beginning of the Eemian. Eemian interglacial deposits with a thickness of more than 7 m are built from massive tufa and yellow lacustrine sequences with varve-like layering. Eemian pollen from zones E-I, E-II, E III, E-IVa, b, and E-VII according to Menke & Tynni (1984) were found. The Eemian deposits occur together in superposition with Holocene carbonate sediments intercalated in peat. Pollen analysis shows Preboreal, Boreal, Atlantic period and Subboreal at the southern Farbeberg; Meiendorf-Interstadial, Preboreal, Boreal, Atlantic period and Subboreal at the northern Farbeberg. Intercalated carbonate deposits indicate a tufa formation also during the Weichselian interstadials, which harmonizes with the idea of a continuously existing talik. Despite unreliably high ^{14}C-ages of the carbonates these generally are in accordance with the pollen age indications. The younger tufa precipitation at the Farbeberg hills begins in the Weichselian Lateglacial and ends in the Preboreal (12,520 until 10,750 cal a BP, southern Farbeberg) at the boundary Boreal / Atlantic (12.520 ^{14}C cal a BP until 8.354 ^{14}C cal a BP, northern Farbeberg). The data indicate an enhanced decalcification of the near-surface sediments in the Lateglacial / Early Holocene and preferred tufa deposition occurring during the climatic optimum phases from Preboreal to Atlantic period.

Quellmoor-Kuppen mit Sinterkalk-Bildungen der Farbeberge (Nordwest-Deutschland): Aufbau, Genese und paläoklimatische Aussagen (Eem-Warmzeit, Holozän)

Kurzfassung: Quellkalkmoor-Hügel in Schleswig-Holstein wurden mittels geologischer Methoden, Pollen- und ^{14}C-Datierungen untersucht. Quellaustritte gespannten Grundwassers führen örtlich zur Bildung von morphologischen Kuppen und Wällen aus Torf, Organik- und Kalk-Mudde sowie Quellkalk. Quellschüttungen am nördlichen Farbeberg sind spätestens seit dem Beginn der Eem-Warmzeit aktiv. Hier treten bis zu 7 m mächtige Eem-warmzeitliche Ablagerungen in Form von massiven Kalksinterbildungen und gelben limnischen Sequenzen, teilweise mit Warven-artiger Schichtung auf. Es wurden die Eem-Pollenzonen E-I, E-II, E III, E-IVa, b, and E-VII nach Menke & Tynni (1984) nachgewiesen. Die Quellablagerungen der Eem-Warmzeit finden sich zusammen mit vergleichbaren Ablagerungen des Holozäns in Superposition. Die Pollenanalyse zeigt Präboreal, Boreal, Atlantikum und Subboreal am südlichen Farbeberg, sowie Meiendorf-Interstadial, Präboreal, Boreal, Atlantikum und Subboreal am nördlichen Farbeberg. Zwischengeschaltete Kalkbildungen in den Weichsel-Ablagerungen weisen auf eine Quellkalk-Sedimentation auch während der Weichsel-Interstadiale hin, was mit der Vorstellung eines kontinuierlich existierenden Taliks im Quellbereich harmoniert. Trotz der hohen ^{14}C-Alter der Kalke ist eine generelle Übereinstimmung mit den Pollendatierungen vorhanden. Die jüngere Kalkausfällung an den Farbebergen beginnt im Weichsel-Spätglazial und reicht bis in das Präboreal (12,520 until 10,750 cal a BP, südl. Farbeberg), bzw. an die Grenze Boreal / Atlantikum (12.520 bis 8.354 ^{14}C a BP, nördl. Farbeberg). Es wird von einer Kombination aus zeitlich begrenzter, verstärkter Entkalkung der oberflächennahen Sedimente im Spätglazial / Frühholozän und klimatisch bevorzugter Kalkausfällung während der Wärmeoptima von Präboreal bis Atlantikum ausgegangen.

Keywords: spring mire, locally elevated calcareous bogs, climate change, Eemian, late Holocene tufa decline, paleohydrogeology

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1. Introduction

Spring fed raised peat hummocks in valleys and bogs of Schleswig-Holstein (Northern Germany) are primarily hydrogeological phenomena associated with the localized more or less vertical entry of confined groundwater or lateral flowing groundwater to the near surface geosphere (Grube & Usinger 2016). Due to the special hydrological conditions and the corresponding nutrient and pH-conditions found at these sites often a rare flora and fauna exists (Martin & Brunke 2012). At such locations, in addition to the most dominant limnic-telmatic sedimentation, deposition of calcareous deposits occurs in the form of massive tufa. This paper is addressed to the spring fed raised peat hummocks of the "Farbeberge" in the area of the stream of the Rüterbek near Nindorf / Hohenwestedt (fig. 1). The term "Farbeberg" means "color hummock" and refers to the digging of calcium carbonate used in the production of color in former times. While the southern Farbeberg is mentioned in the literature (Petersen 1892), the northern Farbeberg was "discovered" during the investigations and examined in greater detail. The latter is of particular importance for the objective of this work. Additionally spring fed raised calcareous peat hummocks in Habernis (Flensburg Fjord) and Curau (near Ahrensbök, Ostholstein; Grube & Usinger, 2016) are discussed. The objectives of this study are to explore the structure and stratigraphic position of the Farbeberge, regarding the genesis of the structures, taking into account the groundwater conditions and the paleoclimatic conditions. The intention is to consider whether the (late) Holocene tufa decline (Goudie, Viles & Pentecost 1993, Pentecost 2005) described elsewhere, can also be found in Northern Germany. This trend is supposed to apply to older interglacials also (Lozek 1965). This is raising the question whether this lack of "replenishment" of calcium carbonate is because of decalcification of near-surface sediment, variable temperature-pressure conditions or changing conditions in the aquifer. Comparison of the carbonate sediments of the Eemian with those of the Holocene – both occur in superposition at the site northern Farbeberg – permits a new study of the processes of formation of tufa sediments.

2. Formation of tufa and spring fed peat / tufa hummocks

There exists a manifold of terms to describe calcareous spring deposits in Germany. The term "Kalktuff"„ (Groschopf 1969) is frequently used. According to Hinze et al. (1989) "Kalktuff„ is referred to as "cellular-porous unconsolidated and/or solid rock, mainly calcite, rarely aragonite, usually with imprints of plants (leaves, stems) and remains of snails, mussels etc.". Here we use the international term "tufa" for solid, limestone-like material; and "calcareous mud" for softer calcareous sediment. The precipitation of calcareous sediments is mainly dependent on the carbon dioxide content of water, key factors are increasing the temperature and a reduction of pressure (Heykes 1931, Jäger & Ložek 1968, Groschopf 1969, Bakalowicz 1990). The photosynthetic activity (CO_2 extraction by algae and other plants) and the built-in calcareous shells of snails, etc. may also play a greater role. Calcite dominates over aragonite as main mineral phase. Generally, calcareous precipitates in peat are limited to small horizons (Moore & Bellamy 1974); massive limestones (tufa) in contrast are rare. The calcium carbonate precipitation is expected to form mainly subaerially. However, according to Sendtner (1854) the formation of "Wiesenkalk" takes place below peats by dissolving snail and mollusc shells by humic acids and subsequent deposition of calcium carbonate under the influence of oxygen-rich groundwater. The opposite is the re-dissolution of limestones by oxidation. Decalcification of the layers during the Holocene is e. g. described by von Vreeken (1981), lower temperatures lead to an increased resolution of carbonate sediments.

To date, little information exists about the absolute ages of calcareous spring deposits in Central Europe. Dobrowolski, Durakiewicz & Pazdur (2002) examined spring fed calcareous hummocks in eastern Poland. Their studies, based on isotope analyses (^{14}C, ^{18}O), showed preferred phases of calcium carbonate precipitation at 10.3 to 9.9; 8.0 to 7.5; 6.7 to 6.5; 6.0 to 5.6; 2.5 to 1.7 and 1.0 to 0.6 ka BP. These periods correspond with relatively warm and rainy phases of the Holocene. Pazur et al. (2002) suggest that the main stage of formation was during the climatic optimum around 5.0 to 6.0 ka B.P. Jäger & Lozek (1968) found a more continuous formation of limestone mostly in the Atlantic / Subatlantic period, after that a discontinuous formation is observed. The beginning of carbonate formation is given here as to be the Preboreal. Laumets, Kalm & Zohar (2010) provide a comparison of different research findings: the main phase of tufa formation is summarized with 9.4 to 7.4 ka BP. The reasons for changing Holocene calcium carbonate precipitation are discussed. In summary, most authors believe in climate-controlled calcium carbonate sedimentation, a corresponding exchange between carbonatic and telmatic sedimentation, or rising groundwater temperatures (Schuster 1926, Goudie et al., Vreeken 1981, Almendinger & Leete 1998, Dramis, Materazzi & Cilla 1999).

The hydrogeological conditions required for the formation of spring fed peat/calcareous hummocks are discussed in various studies. The concepts include sites characterized by glacigenic soft sediments, such as glacilimnic sediments, underlain by confined aquifers, that are locally penetrated (by features such as sand banks or veins). Examples are given for the Midwest USA (Ciolkosz 1965, Wilcox, Shedlock & Hendrickson1986, Thompson & Bettis 1994, Carpenter 1995, Amon et al. 2002, Glaser et al. 1997). Water budgets for such sites are extremely complex and descriptions of such are largely absent (Carpenter 1995).

3. Existing knowledge about tufa formation with focus on Northern Germany

Quaternary carbonate precipitation in northern Germany is usually formed in lacustrine environments (Geinitz 1920, Thienemann 1922, Lenz 1924, Schuster 1926, Mende 1956, Strehl 2001, Dörfler et al. 2012). Extensive, thick carbonate sediments typically occur as fine lacustrine detritus calcareous muds partially filling larger depressions. These do not lead to morphological forms such as hummocks on slopes. Typically, carbonates in bogs are most often found in areas with underlying massive limestones, such as the "Thüringer Muschelkalk" area, the chalk on the Rügen island, chalk deposits in East Anglia, Canada and the USA (Succow & Joosten 2001, Paulson 2001, Gilvear et al. 1993, Vreeken 1981, Amon et al. 2002). Alaily et al. (2001) describe tufa from the area Tegel Creek / Blankenfelde, that are very young and occur small scaled and shallow. Spring fed calcareous bogs are a widespread phenomenon in North-West Germany. According to Raabe (1980) these in Schleswig-Holstein occur main-

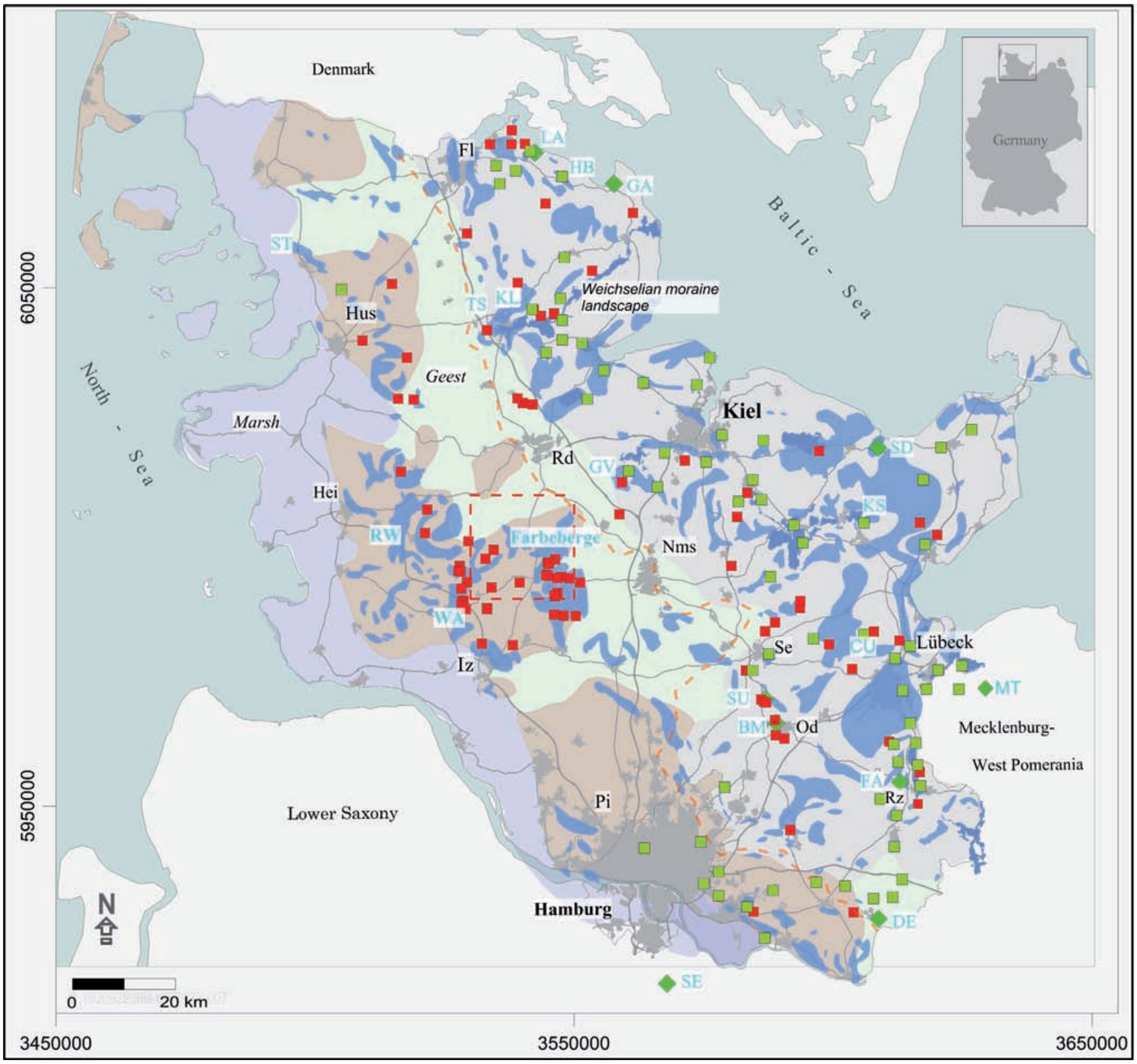

Fig. 1: Occurrence of locally elevated bog spring areas (red; according to Biotope Register Schleswig-Holstein / LLUR SH, supplemented by own survey), calcareous spring mires (green) according to Raabe (1980), position of wider investigation area (fig. 2, with red dashed line) in front of glacitectonically influenced areas (blue, according to Stephan 2004, modified by authors). LGM shown with dashed orange line. Abbr.: CU=Curau, BM=Brenner Moor, DE=Delvenau, FA=Farchau, FB=Farbeberge, GA=Geltinger Au, GV=Groß Vollstedt, HB=Habernis, KS=Kellersee, Kl=Klensby, LA=Langballigau, MT=Maurinetal, Ri=Riesewohld, SD=Sechendorf, ST=Seevetal, SÜ=Sühlen, TS=Tiergarten Schleswig, St=Stollberg, Wa=Wacken.

Abb. 1: Vorkommen von Quellbereichen mit Kuppen-förmiger Ausbildung (rot; nach Biotopkataster Schleswig-Holstein / LLUR SH, ergänzt durch eigene Aufnahmen) und Kalkquellmooren (grün) nach Raabe (1980), Lage des weiteren Untersuchungsgebietes (Abb. 2, rot gestrichelt) vor dem Hintergrund glazitektonischer Stauchungen (blau, nach Stephan 2004, ergänzt durch Autoren). Maximale Ausdehnung der Weichsel-Kaltzeit orange gestrichelt dargestellt. Abkürzungen: CU=Curau, BM=Brenner Moor, DE=Delvenau, FA=Farchau, FB=Farbeberge, GA=Geltinger Au, GV=Groß Vollstedt, HB=Habernis, KS=Kellersee, Kl=Klensby, LA=Langballigau, MT=Maurinetal, Ri=Riesewohld, SD=Sechendorf, ST=Seevetal, SÜ=Sühlen, TS=Tiergarten Schleswig, St=Stollberg, Wa=Wacken.

ly in the eastern hill country (Weichselian moraine landscape; fig. 1). Thienemann (1922) describes the combined occurrence of tufa and calcareous muds. Gripp (1964) lists several spring fed bogs on slopes (Farbeberg at Nindorf, Farchau, Sechendorf, Sühlen).

In the presence of calcium-rich ground waters, morphologically prominent forms can be formed in soft rock areas with Pleistocene sediments, such as till. Spring-fed raised calcareous peat hummocks and other morphological landscape forms containing tufa, have variously been described in the literature from North Germany, and North / Central European region (Weber 1907, Keilhack 1928, von Bülow 1929, Jäger 1966, Kirchner 1971, Succow 1988). Weber (1907) mentions small-scale spring fed raised peat hummocks with calcareous layers frequently occurring in the end moraine areas of Northern Germany. Kirchner (1975) investigated small peat hummocks fed by artesian ground waters in the sandy, today swampy floodplains as exfiltration areas – he mentions the following identifying features: The presence of tufa, a strong peat decomposition, an increased incidence of iron precipitates or ocher as well as the specific type of soil wetness.

Tüxen (1985a, b) reports on peat hummocks and peat walls from Lower Saxony (see also Tüxen 1990). Bremer (1996) describes numerous watch glass formed calcareous spring bogs from the area of the Maurine Valley (Schönberg, Mecklenburg-Vorpommern), which have a height of 1 to 5 m and a diameter of up to a few 100 m. In the top 2 m here, calcareous peats of different compositions occur besides mud-like deposits with calcareous layers, calcium carbonate grains and mollusc remains (see also Dann 2003). The majority of the described hummocks are situated in the valleys, growing from the valley floors. Some appear on valley slopes and ridges of Pleistocene material in peaty areas, or adjacent to these. Deposition of carbonate sediments is explained by the reduced pressure of ground water, warming of the spring water and the contact with oxygen. Succow, Stegmann & Koska (2001) describe examples of hill-shaped bogs as a result of lateral ground water discharge at Prenzlau and Werder / Beseritz (Neubrandenburg). Paulson (2001) reports small scale bulged bog surfaces in karstic peatlands on Rügen. He interprets these as bog initials resulting from a radial bog water dewatering, rather than as spring fed cupolas. Stegmann (2005) examined bogs situated on slopes in the Sernitz valley (Brandenburg) and identifies strongly calcareous peats, moderate calcareous peats and spring fed peats with low $CaCO_3$ content. Hummocks of 20 m in diameter and 2 m in height are also found at Lake Malchin (Mecklenburg-Vorpommern; W. Schulz, personal comm., March 2010).

Observations are also reported from Schleswig-Holstein. Meyn (1848) mentions tufa at Sielbek (presumably near Ratekau / Lübeck), due to solution of underlying “coral sandstone” (Quaternary sands, rich in calcium carbonate). Schuster (1926) describes the massive spring calcareous sediments at the Keller lake (see also Heck 1946b). Schuster (1926) mentions a spring fed swamp delta as a morphological form at the Keller Lake, which was formed by the ground water exfiltration and corresponding calcareous sedimentation. Unfortunately this delta was removed by limestone quarrying (Thienemann 1922, Peters 1955). According to Schuster (1926), the formation of spring-related calcareous sediments at the Keller lake started during the Atlantic period. This author mentions increased rainfall and spring water formation /source activity associated with higher temperatures as reasons for an enhanced formation of spring-related calcareous sediments at this time. The same author sees the Subboreal to hold favorable conditions for the sedimentation of spring-related calcareous sediments, with drier and warmer conditions compared to today’s environments, resulting in more water and less carbon dioxide in the system. Raabe (1980) describes spring-related calcareous hummocks as visible morphological elements from the Curau bog as well as the valleys of Langballigau, Geltinger Au, Delvenau, Steinau and Habernis (fig. 1). These sites are concentrated on the Weichselian moraine landscape with its calcium carbonate-rich sediments, such as tills. With the Prussian Geological Survey calcium carbonate-rich sediments (tufa) were documented at least partially systematically, as with the occurrence in Schleswig Tiergarten and south of Klensby (Heck 1943, fig. 1). The biotope register for Schleswig-Holstein (first version from 1978 to 1994) has systematically mapped a large number of existing spring fed peat hummocks. The main occurrences are in the Weichselian moraine landscape, especially in the valleys. Most of the hills consist of peat, so that calcareous sediments only play a minimal role (Hansen & Martin 2013). Grube & Usinger (2016) report on actual studies of structure and age of peat hummocks at Habernis and Curau bog (fig. 1). All forms from North Germany mentioned are of Holocene age.

So far little information exists about the hydrogeological conditions of spring areas in Schleswig-Holstein (Martin 2004). This situation, as well as the neglect of hydrogeological aspects in the practical implementation of moorland protection programs are also reported from the federal state Mecklenburg-Vorpommern (see Precker 2001, Dann 2003, Kaiser et al. 2012). In summary at least for northern Germany, little recent information is available on the geology-hydrogeology of natural springs and the corresponding tufa.

4. Geological and hydrogeological conditions at the Farbeberge

At the Farbeberge a salt structure in the form of a Keuper-pillow forms the deep geology (Hinsch 1991, Baldschuhn et al. 2001; Reinhold, Krull & Kockel (2008, fig. 1). According to Hinsch (1991) the investigation area is located over a north-south trending buried valley offshoot, ending slightly to the north and being connected to an Elsterian buried valley system cutting >100 m below ground. The area is situated on the western flank of an ice-pushed moraine (see Picard 1962, Stephan 2004), which sweeps from Oldenbüttel over Nindorf towards Tappendorf (fig. 2). Its surface is characterized by a cohesive, chalk rich till of the Middle Saalian (MIS 6; Ehlers et al. 2011). The valley of the Rüterbek down from Nindorf shows a filling of solifluction material, partially covered by peats and subordinate sands. According to Picard (1962) and Stremme (1966) the southern Farbeberg is a fen-area (“Niedermoor”), the northern Farbeberg was mapped as a raised bog-area (“Hochmoor”) (fig. 3). Stremme (1966) mentions the occurrence of bog iron ore adjacent to the peat hummocks. The calcium carbonate deposits at the southern Farbeberg were previously mined for amelioration material and for the production of color raw material. Petersen (1892) observed walls of 5 m high calcareous muds in the former pit, covered by 1 m peat (“Moorerde”; see also Wetzel 1927, Heck 1946a). Petersen (1892) described in great detail the deposits, that obviously were precipitated in association with plants. In the sediments he found a remarkable number of gypsum crystals. Blue iron ore (Vivianite) was also encountered in larger quantities. This author sees leaching of the chalky till as source for the calcareous parts of the peat hummocks. Overviews of groundwater levels are prepared by the LLUR (State Agency for Agriculture, Environment and Rural Regions, Flintbek; H. Angermann). Thereafter the groundwater flow within the subsurface aquifer is directed to west-northwest, the interpolated groundwater levels range between +35 and +30 m a.s.l. at the two hummocks.

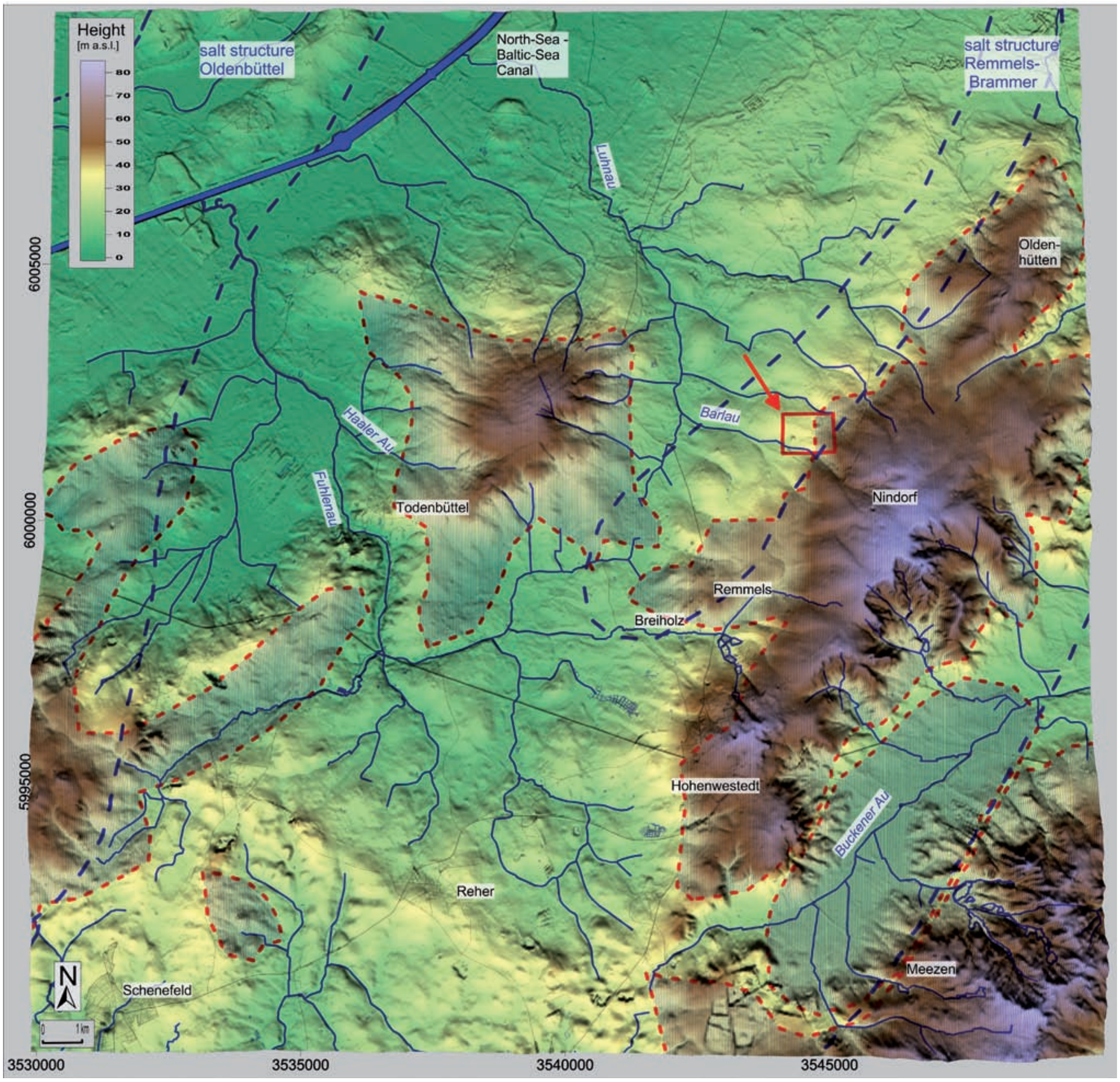

Fig. 2: Large-scaled morphology (DGM). Outline of salt structures according to Reinhold, Krull & Kockel (2008, blue dotted line). Glacitectonically influenced areas shown in hatched signature and red outline (according to Stephan 2004). Detailed study area (fig. 3) is shown as a rectangle (data basis topography: LVermGeo-SH).

Abb. 2: Großräumige Morphologie (DGM). Umrandung der Salzstrukturen nach Reinhold, Krull & Kockel (2008, blau, diagonale Signatur). Glazitektonisch beeinflusste Bereiche (nach Stephan 2004, Kreuzsignatur, rote Umrandung). Das engere Untersuchungsgebiet (Abb. 3) ist als Rechteck dargestellt (Datengrundlage Topographie: LVermGeo-SH).

5. Material und Methods

In addition to the evaluation of archival boring documents (Geological Survey Schleswig-Holstein) several new boreholes were drilled. Hydrogeological information was collected as part of this process. However groundwater monitoring wells are missing in the investigated area, so the groundwater potential distribution and the spatial ascent behavior of groundwater could only be approximated. Nine cores were drilled using the Usinger Drill (Mingram et al. 2007) in order to obtain undisturbed material for palynological investigations and the recovery of materials for ^{14}C- determinations (calcium carbonate, peat, wood) in the years 2011 to 2014. The core drill used was driven by man power, starting at a depth of about 3 metres in very solid sediments on the northern Farbeberg an engine hammer had to be used. This was necessary due to the high ductility of the deposits and the specific mechanical properties (interlocking of the irregularly shaped, tufa deposits). The very high mechanical strength of the underlying deposits partly led to discontinuation of drilling. Cores Fab1-1 and Fab1-2 were supplemented by machine driving core drillings to reach the sediments underlying Eemian organic sediments. The preparation of the pollen samples was carried out at the Institute for Ecosystem Research at the Christian-Albrechts-University of Kiel.

45 soil samples collected in the cores were examined in the Building Materials and Soil Testing Office of the State

Office of Transport Schleswig-Holstein (Kiel) and the State Laboratory in Neumünster (Division 5, environmental monitoring) for grain size distributions (E DIN ISO 11277: 06.1994, DIN 19683 Part 1 + 2, DIN 18123), loss on ignition (organic constituents; DIN ISO 10694: 08.1996) and calcium carbonate content (DIN 18129).

Spring water sampling for chemical analysis was carried out by the LLUR at 2 locations in Habernis, 1 sample from the Wolsroi spring, 2 samples from Curau bog and 2 from the southern Farbeberg. Suitable spring areas on the northern Farbeberg were not available. Basic parameters were recorded on site and the samples tested by the State Laboratory Neumünster on main parameters.

As basis for digital terrain models and their evaluation DGM1 data of the State Office for Surveying and Geoinformation Schleswig-Holstein (LVermGeo-SH) were available with a height resolution of ca. 0.2 m (laser scanning aerial survey from 2005–2007). Morphological analysis was executed with SURFER (Golden Software Inc., Colorado, USA).

The mineralogical investigations were carried out at the Mineralogical-Petrographic Institute of the University of Hamburg (J. Ludwig) by powder diffractometer from Philips (X`pert System) with the following components: Cu fine focus X-ray tube (glass), Wavelength = 1.540598 A; Graphite monochromator secondarily, automatic divergence aperture increment 0.02 ° 2 theta, beat 1sec / step. Samples were taken of two cores of the following depths: Fab1: 0.86 m, 3.6 to 4.00 m, 4.7–5.2 m, 6.70 m, 7.78 m; Fab2: 2.46 m, 3.06 m, 3.10–3.20 m.

Well preserved gastropods from the Eemian tufa were identified by Professor Klaus Bandel (Buchholz / Nordheide).

The ^{14}C AMS datings were carried out at the Leibniz Institute of Kiel University. The samples were treated by Dr. A. Dreves (written message, 2014) as follows: "The peat and mud probes were inspected and freeze-dried. To obtain the carbonate fraction the dried material was hydrolyzed with a 60% H3PO4 at 90 ° C. The CO_2 of all samples was then reduced with H_2 at 600 ° C over an iron catalyst to graphite and pressed the iron-graphite mixture in a sample holder for the AMS measurement. The ^{14}C concentration of the sample is obtained from the comparison of the determined simultaneously ^{14}C, ^{13}C and ^{12}C contents with those of the CO_2 measurement standards (II oxalic acid) as well as suitable effect zero samples. The conventional ^{14}C age is calculated then by Stuiver & Polách (1977) a correction to isotope fractionation using the same measured with AMS ^{13}C / ^{12}C ratio was applied. The translation into calendar ages was made for the organic samples using the OxCal V4.2 program (Bronk Ramsey, C., Radiocarbon 51 (2009), 337–360) and the IntCal13 calibration sets (Reimer, P., et al., Radiocarbon 55 (2013), 1869–1887) ".

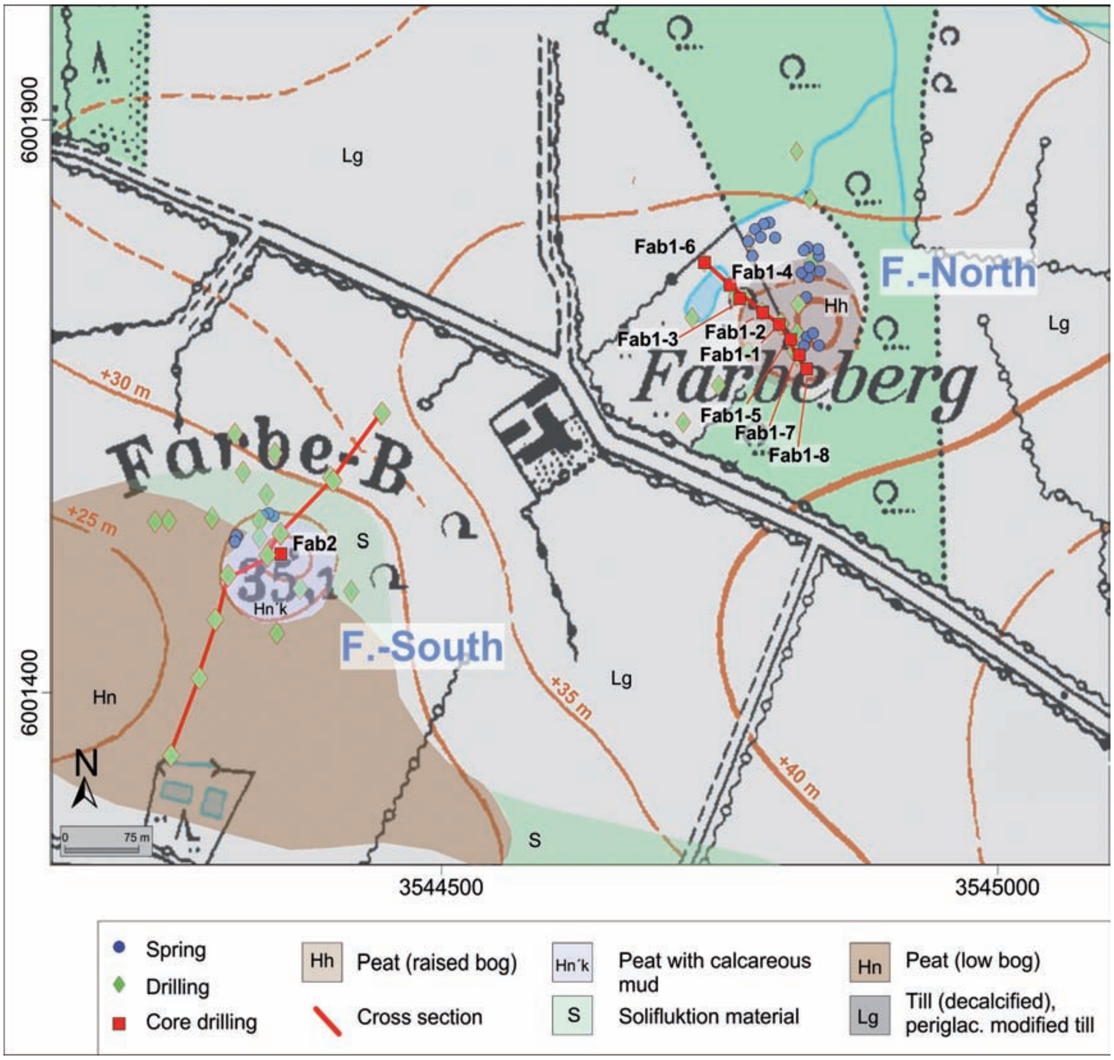

Fig. 3: Map of the investigation area with locally elevated calcareous bogs, position of boreholes, core sampling, geological cross sections and mapped springs (TK25, LVermGeo-SH). Soils according to Picard (1962) and Stremme (1966).

Abb. 3: Lageplan des Untersuchungsgebietes mit Quellkuppen der beiden Farbeberge, Lage der Bohrungen, Kernbohrungen, Profilschnitte und kartierte Quellaustritte (TK25, LVermGeo-SH). Böden nach Picard (1962) und Stremme (1966).

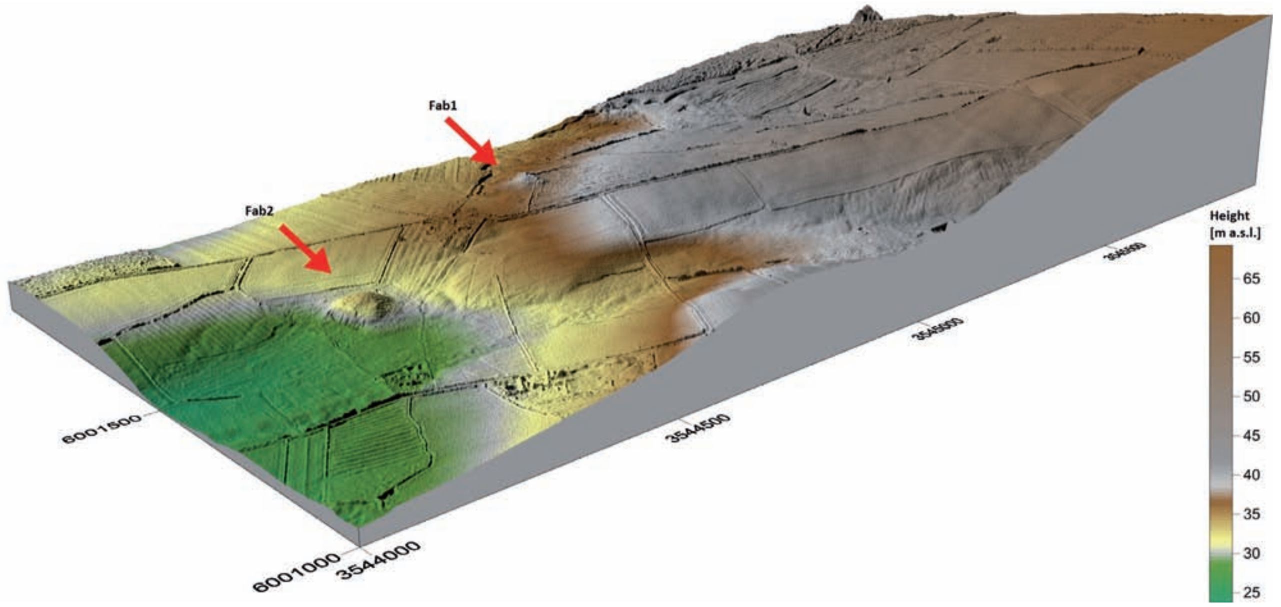

Fig. 4: Digital terrain model (data basis: LVermGeo-SH) with the two prominant peat cupolas Northern and Southern Farbeberg. Distance between coordinate units is 500 m.

Abb. 4: Digitales Geländemodell (Datenbasis: LVermGeo-SH) mit dem südlichen und nördlichem Farbeberg. Die Distanz zwischen Koordinateneinheiten beträgt 500 m.

6. Results

The Farbeberge area comprises two distinct hills of similar size that are located on the northern flank of a wide valley (Rüterbek), most probably formed during the Weichselian. Another round and flat peat hummock is situated east of the northern Farbeberg (see Picard 1962). A lineament is indicated which could pass through the two Farbeberge and another roundish peat area about 300 metres to the east. This linear glacitectonic structure has not yet been adequately explored. The southern Farbeberg has a height of about 3 m (+30.30 to +33.30 m a.s.l.). It is slightly elongated NW-SE perpendicular to the large-scale morphology of the slope (fig. 4). The southern edge of the hummock is characterized by a steep side as a result of the former extraction of carbonate sediments. The original shape of the hummock was changed through the reduction in volume and subsequent slumping (Heck 1946b reports 4.6 m peat). The hill today is mainly used as pasture. The northern Farbeberg has a height of about 2 m; it lies higher (+36.75 to +38.75 m a.s.l.) on the slope than the southern Farbeberg. It is slightly elongate, SE-NW normal to the slope and perpendicular to the large-scale morphology. Two small valleys at the NW' and NE' flanks of the northern Farbeberg (water flows into the Limbrookgraben after 300m) are probably due to strong spring activity during the Holocene. A yet stronger spring activity is assumed under natural conditions. The southern half of the hummock is used as pasture; to the north trees and reed dominate.

6.1 Southern Farbeberg

The geology of southern Farbeberg shows a 3 metres thick sequence of calcareous, clearly layered deposits (fig. 5) on top of glaciofluvial sediments. The younger, Holocene calcium carbonates form mainly calcareous muds with intercalated tufa. Carbonate concentrations are generally more abundant in the lower parts than in the upper. To the top a peat follows, approximately 1 m thick. The geological cross section (fig. 6) shows that the calcareous mud reaches a thickness of more than 1 m. The described conditions are representative for typical tufa/-peat hummocks of North- West Germany. As mentioned above, larger parts of the southern part of the hill were removed (Petersen 1892), thus this part of the hummock information is missing. ^{14}C-ages on the lower tufa range between about 10,750 and 12,520 cal a BP (Tab. 1; lowermost sample is not consistent with upper samples, samples possibly interchanged). Accordingly, the majority of calcium carbonate sedimentation took place during the Preboreal – an interpretation that is supported by the pollen analysis (3.95 m; 3.70 m). Pollen analysis indicates that the Boreal is between 2.95 and 2.35 m, Atlantic between 1.65 and 0.80 m and Subboreal at 0.20 m.

6.2 Northern Farbeberg

6.2.1 Saalian and Eemian deposits

The northern Farbeberg (fig. 7) in contrast, is stratigraphically much older and shows a much more complex structure (fig. 8, 9). The base of the drilled organic sequence is composed of Middle Saalian (MIS 6) till at ca. 11 m depth. The till is relatively soft in the top 2 metre and shows some intercalated sands, which show partial flow structures with a vertical orientation, attributed to artesian groundwater conditions. The sands at the base of the depression show organic constituents in places. These sediments belong to the Saalian lateglacial. The base of the depression is irregular (fig. 9), two steep sided cavities in the profile section can be interpreted as flushing areas of the artesian groundwater. Alternatively a glaci-tectonic influence may be the cause with the sand blocks serving as climbing paths for groundwater.

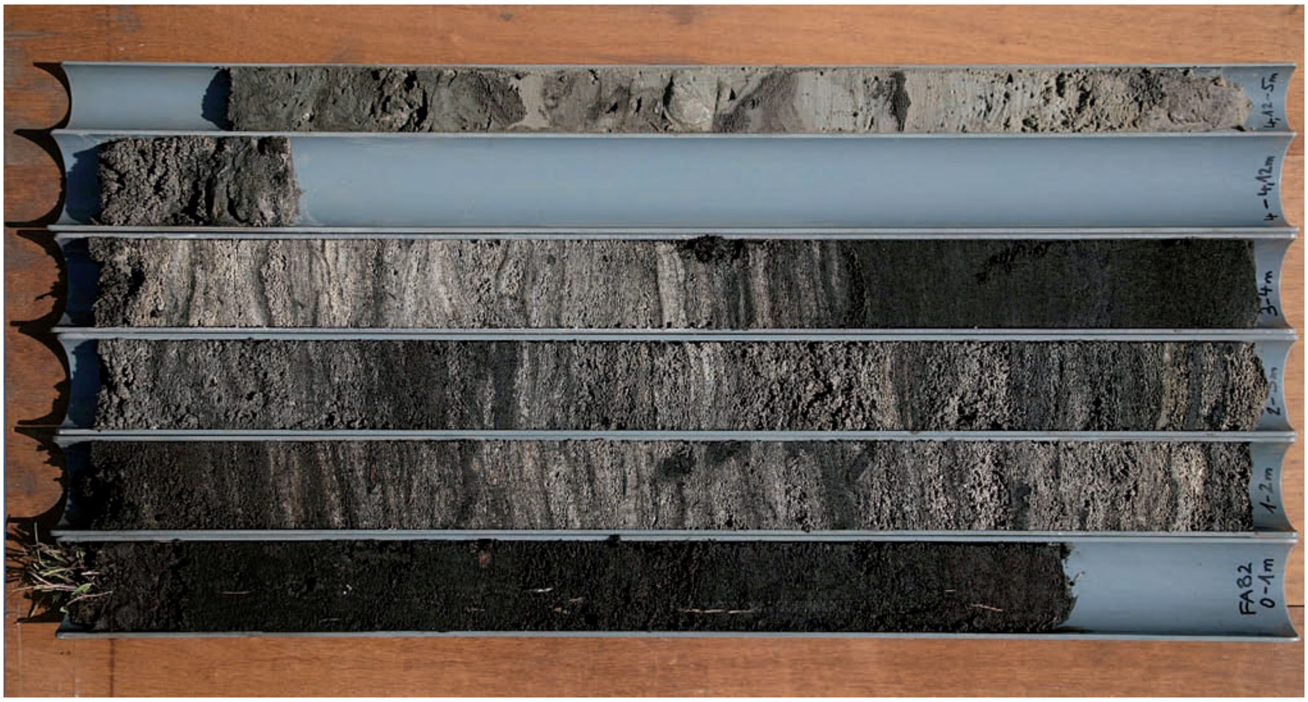

Fig. 5: Photo of drill core from the southern Farbeberg (Fab2). Visible are the peats and intercalating calcareous precipitates (bright colors), the base is built up from sandy deposits of the Pleistocene. Length of a core-liner is 1m.

Abb. 5: Kernphoto des südlichen Farbeberges (Fab2). Erkennbar sind Torfe und Mudden (dunkel) und eingeschaltete Kalkausfällungen (hell), die Basis wird durch sandige pleistozäne Ablagerungen gebildet. Die Länge eines Bohrkernliners beträgt 1m.

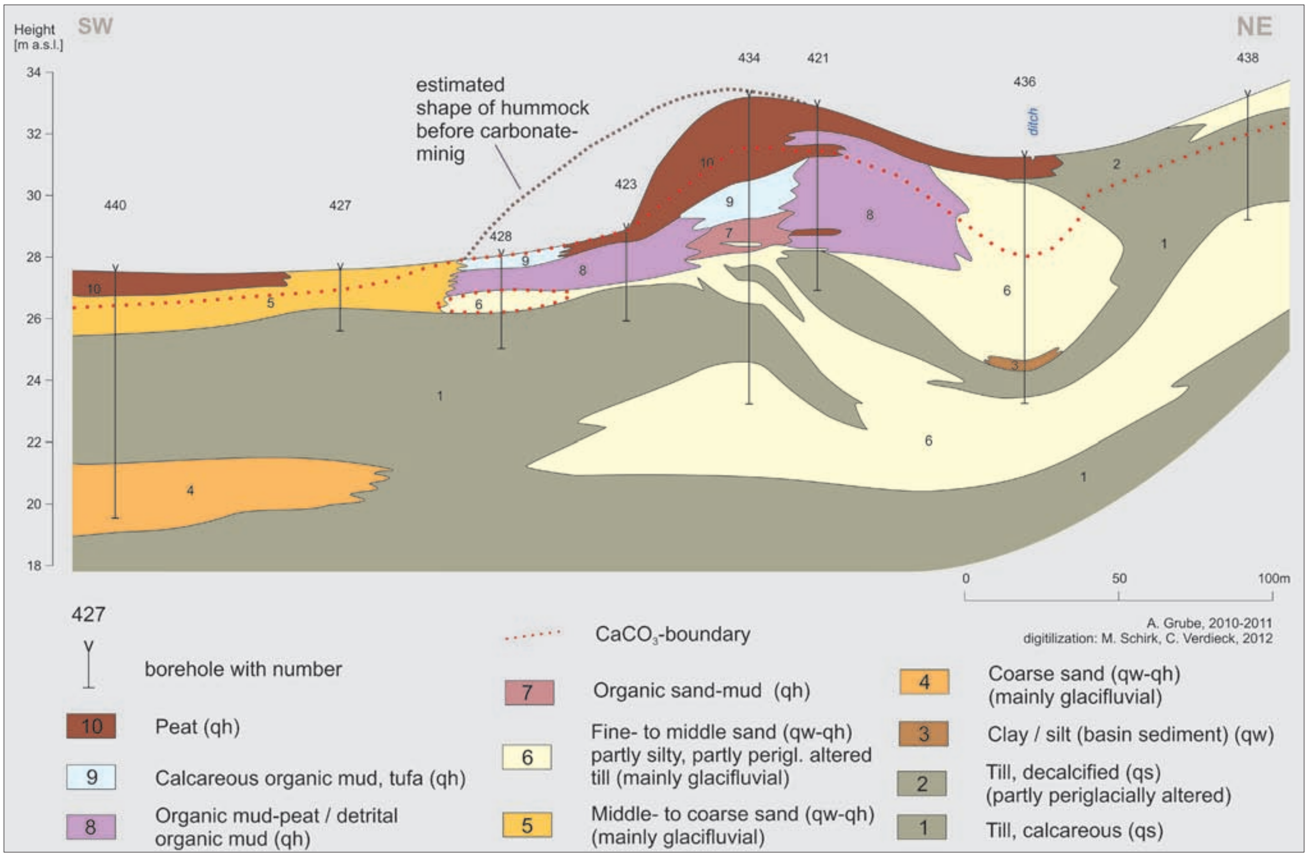

Fig. 6: Simplified geological cross section through the southern Farbeberg (height exaggerated). The shape of the hummock prior to mining of carbonates estimated. Abbreviations: qs=Saalian; qw=Weichselian, qh=Holocene).

Abb. 6: Vereinfachter, stark überhöhter geologischer Profilschnitt durch den südlichen Farbeberg (überhöht). Ungefähre Form der Kuppe vor dem Abbau von Kalken. Abkürzungen: qs=Saale-Komplex; qw=Weichsel-Kaltzeit, qh=Holozän).

Fig. 7: View of the northern Farbeberg. Visible in the foreground the groundwater exfiltration at the foot area of the locally elevated bog. Two persons for scale.

Abb. 7: Blick auf den nördlichen Farbeberg. Im Vordergrund der nasse Fußbereich des Quellhügels mit Grundwasseraustritten. Zwei Personen als Größenmaßstab.

Fig. 8: Photo of drill core from Farbeberg (Fab1-3). Visible are the underlying stadial and interstadial humic sediments of the late-Saalian, succeeded by yellowish fine sediments and coarse tufa of the Eemian, sandy deposits of the Weichselian (partly brownish oxidized) and finally Weichselian Late Glacial to Holocene peats. The diameter of the drill core is 55 mm, the length of a core-liner is 1m.

Abb. 8: Kernphoto des nördlichen Farbeberges (Fab1-3). Erkennbar sind liegenden stadialen und humosen Interstadial-Lagen der Spät-Saale, im Hangenden gelbliche Feinablagerungen und grobe Quellkalke und des Eems, die liegenden Weichsel-Ablagerungen (teilw. braun oxidiert) sowie die spätglazialen bis holozänen Torfe. Der Durchmesser des Kernrohres beträgt 55 mm, die Länge eines Bohrkernliners 1m.

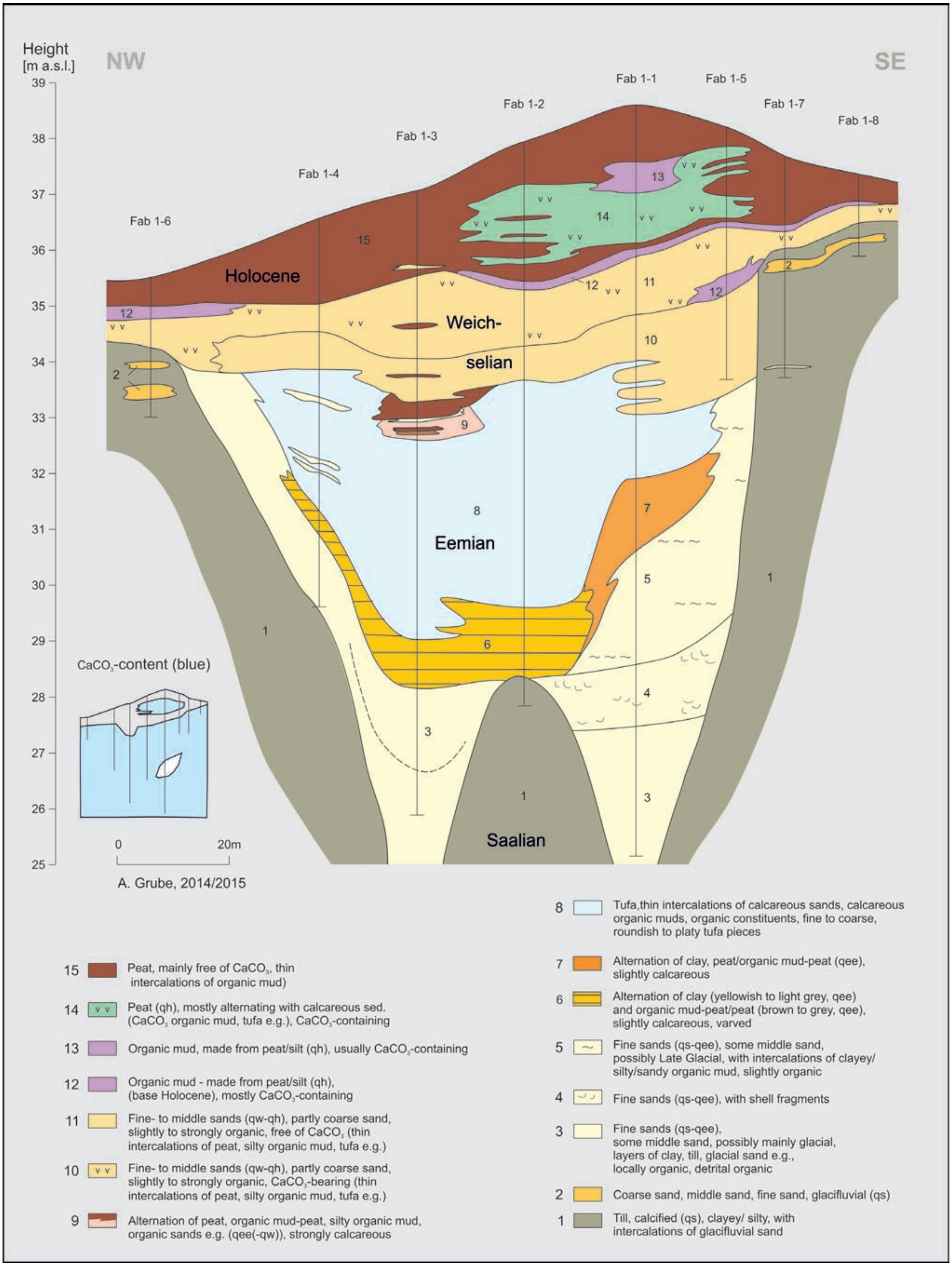

Fig. 9: Geological cross section through the northern Farbeberg (height exaggerated), constructed on the basis of 8 full core drillings. Calcium carbonate dispersal shown in small detail figure.

Abb. 9: Geologischer Profilschnitt durch den nördlichen Farbeberg (überhöht), konstruiert anhand von 8 Kernbohrungen. Kalkverteilung dargestellt in kleiner Nebenabbildung.

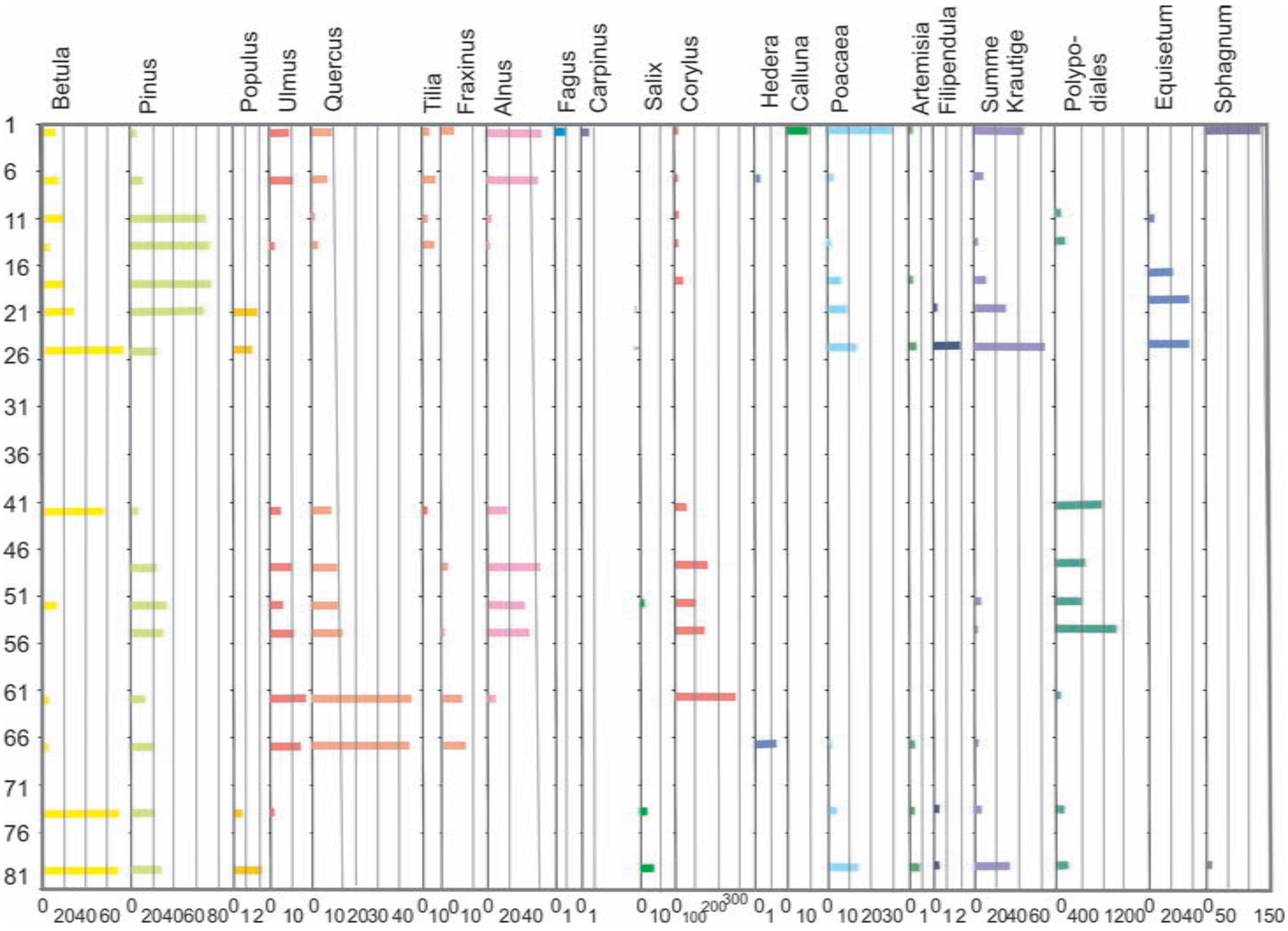

Fig. 10: Pollen diagram Farbeberg-Nord (core Fab1-1). Pollen versus depths.

Abb. 10: Pollendiagramm Farbeberg-Nord (Kern Fab1-1). Teufe gegen Pollenzahl aufgetragen.

Above the glacigenic deposits there is up to ca. 5 m of fine to medium sands and intercalated tufa. In some parts of the hollow massive tufa with a thickness of several metre occurs. In another area the sediments are rhythmically bedded. The pollen diagram for core Fab1-1 (fig. 3) is shown in fig. 10. The Eemian sequence shows pollen zones E-I, E-I-II, E-III and E-IVa, b and E-VII. E-IVb shows a large quantity of reworked material. Zones E-V and E-VI are missing. A higher-resolution pollen analysis is in progress.

The tufa forms the bulk of the sintered calcium carbonate deposits of the section (fig. 8). These are represented by solid white to grey (locally ocher), cellular-porous limestone, often sharp edged, partly roundish, partly with a columnar shape. In many cases, prints of plants can be recognized in the tufa. Larger pieces of several cm in length often show massive, bulbous tufa, which are associated with platy to circular elements that were enclosed by calcium carbonate. Tube-shaped tufa is found in core Fab1-2 between 6.5–7.5 m. The columnar forms are thought to have been formed by calcium carbonate precipitation around reed-caulis. The precipitated material is predominantly calcite, gypsum and pyrite. Aragonite occurs only locally (analysis by R. Ludwig, Univ. of Hamburg). Some well preserved snails and mussels have been found. The gastropods *Bithynia tentaculata*, *Planorbis planorbis*, *Gyraulus cf. laevis* and *Radix peregra / baltica* were identified by Prof. Klaus Bandel (Buchholz i. d. N.).

Partly layered sediments occur, that have a honeycomb-like appearance. The sequence is characterized by an alternation of clayey-silty and fine sand layers. According to the macroscopic investigation this is a sedimentary deposit without major plant and larger animal remnants. The entire sequence is strongly calcareous, and could show an annually layered sediment (e. g. Andrews & Brasier 2005). Several hundred layers are differentiated with sub-millimeter thickness. The thickness of the layers is variable; in the clayey and silty parts they are difficult to differentiate, even under a binocular microscope. While showing yellow colors in a fresh state, the sediments appear as being brown after drying. Sometimes reddish-brown areas are present apparently having a high iron content.

The overall carbonate content in the cores of the northern Farbeberg (Fab1-2, Fab1-3, Fab1-4, Fab1-5) reaches up to 100% (45 samples). The $CaCO_3$ contents in the Eemian deposits are significantly higher than in the Holocene. Total carbon (total C) contents amount to 12–45 cg/g and 9 and 34% by mass. The Eemian sediments have a lower areal extent than the peat formed during the Lateglacial and Holocene, most likely owing to erosion during the Weichselian. Spring areas (fig. 3) are mainly found to the northern side of the northern Farbeberg. They have been destroyed or hidden because of the agricultural as pastures on the southern side.

6.2.2 Weichselian deposits

Medium to fine sand overlies the Eemian carbonates. It is up to 3 m thick and contains gravel with smaller erratics. This layer is assumed to belong to the Weichselian. The horizon is complex in structure and partially organic (fig. 8, 9). In the eastern part, the upper areas show a higher organic content, but overall the proportion of humic content is higher in the bottom half of the total sequence. In the upper sequence (core Fab1-3), there are also thin peat layers. On the basis of the calcium carbonate content a subdivision into a lower and an upper section is possible: The lower part of the sand is calcareous, the upper part is decalcified. The general boundary of calcium carbonate parallels the base of the raised peat hummock and the top of the till. Since the Saalian tills at the east are higher, the boundary of calcium carbonate is higher here also. Local depressions of the boundary can be observed, possibly being a result of a local concentration of organic deposits and a greater influence of humic acids. Locally flow textures can be noticed, that include cone-shaped sink marks, structures resembling cryoturbations and solifluction movements as well as en-echolon offsets. Organic constituents are found floating around erratics (core Fab1-4), possibly being dislocated periglacially. Other dislocations may be a result of flow movements and mass wasting in an environment with a strong vertical ground water activity. Eye catching in this sequence is the brown colouring caused by oxidation, the result of seepage by oxygen-containing groundwater. Sandy intercalations are present, locally possibly due to frost lenses or fluvial input. Calcium carbonates have been dated by ^{14}C method (tab. 1) giving ages from core Fab1-3 of 44,785 + 1819 / -1482 ^{14}C cal a BP (2.46 m below ground), and 8,354 at + 58 / -57 ^{14}C cal a BP (2.85 m below ground). A sample from a depth of 2.12 m below ground gave an age of >51,050 ^{14}C cal a BP years.

6.2.3 Weichselian Lateglacial and Holocene deposits

A limnic-telmatic sequence forms a peat hummock above the Weichselian sediments. This Lateglacial to Holocene sequence is characterized mainly by peat of up to 3 m thickness. The peats are strongly calcareous to decalcified (fig. 8). In the central areas of the northern Farbeberg hummock thicker calcareous deposits are intercalated in the peat. The Holocene calcareous deposits are thinner than those at the southern Farbeberg. Locally wood can be found at the base of peat accumulations. ^{14}C age determinations on the calcium carbonate deposits, taken from depths of 0.86, 1.27 and 2.42 m below surface in core Fab1-1 at the highest point of the hummock (fig. 8; tab. 1) show ages between 12,430 and 11,280 ^{14}C cal a BP. Although these ages are vertically inconsistent, the values are in the transition between Weichselian Lateglacial to Preboreal. Core Fab1-3 is located a few metre further to the west at a more marginal position and shows an age of 11,385 ^{14}C years BP (Preboreal) at 1.51 m below surface and of 8,870 cal a ^{14}C BP (Boreal) at 0.98 m below surface. Even further to the margins of the hummock core Fab1-4 shows an age of 10,004 ^{14}C cal a BP (Boreal) at 1.55 m below surface. Pollen analyses of the upper organic part of core Fab1-1 on top of the dominantly Weichselian material hints to the Meiendorf-Interstadial (2.75 m), covered by Preboreal sediments (fig. 10). The sediments above belong to the Preboreal (2.50 m), transition to the Boreal (2.10 m), Boreal (1.80 m), Atlantic (1.40 m, 1.10 m, 0.70 m) and Subboreal (0.70 m, 0.20 m).

The water table is usually located only a few decimeters below surface. The groundwater is under artesian pressure, presumably being built up under the cohesive till. The recharge areas are expected to be in the hilly, ice pushed areas north and east of the Farbeberge. This idea is supported by the formation of hummocks on the north-

Tab. 1: ^{14}C-values from the Northern Farbeberg (Fab1) and Southern Farbeberg (Fab2).

Tab. 1: Ermittelte ^{14}C-Werte an den Standorten Farbeberg-Nord (Fab1) und Farbeberg-Süd (Fab2).

Core-nr.	Lab.-number	Depths [m b. surface]	cal ^{14}C-age BP [a]	Stand. Deviation [a]	Material	Samples
Fab1-1	KIA48730	0,86 m	11.280	+/- 55	tufa	1
Fab1-1	KIA48731	1,27 m	12.430	+/- 60	tufa	1
Fab1-1	KIA50016	2,41 - 2,42	11.670	+/- 50	tufa	1
Fab1-3	KIA50347	0,98 m	8.870	+/- 35	peat	1
Fab1-3	KIA50348	1,51 - 1,52	11.385	+/- 45	peat	1
Fab1-3	KIA50857	2.46 m	44.785	+ 1819 / -1482	peat / organic mud, leaching residue	1
Fab1-3	KIA50856	2,85 m	8.354	+ 58 / -57	plants from sediment, leaching residue	1
Fab1-4	KIA50349	1,55 m	10.004	+/- 39	wood	4
Fab1-4	KIA50858	2.12 m	> 51.050	-	carbonate*	1
Fab2	KIA 48732	1,77 m	10.995	+/- 55	carbonate *	1
Fab2	KIA 48733	2,46 m	12.110	+/- 60	carbonate *	1
Fab2	KIA 48734	2,78 m	12.520	+/- 60	carbonate *	1
Fab2	KIA 48735	3,38 m	12.230	+/- 60	carbonate *	1
Fab2	KIA 48736	4,08 m	10.750	+/- 45	carbonate *	1

* interpreted as tufa

ern flank of the valley and the very well drained and completely water-filled aquifer in the valley itself with a free ground water surface. Only slightly artesian groundwater conditions were encountered in the boreholes that did not penetrate the confining till. Strong, areal groundwater outflow was observed at the southern artificial flank of the southern Farbeberg at the former mining area. The spring outflows show an anthropogenic influence being located in the area of drainage ditches on the northern Farbeberg. The preferred groundwater outflow at the N / NW slope of the northern Farbeberg is in accordance with the proposed groundwater surface. The same applies to the sources at the northeastern edge of the southern Farbeberg.

7. Discussion

7.1 Geological structure

Raised peat hummocks such as at Nindorf (Farbeberge), Habernis and Curau occur in both Weichselian and Saalian moraine areas and are characterized by the occurrence of peat, organic mud, calcareous mud and tufa. They have diameters of up to 160 m and are up to >3 m high (hummock at Habernis) and lengths of >500 m (peat wall at Curau bog; Grube & Usinger 2016). The hummocks show similar dimensions as those mentioned by Tüxen (1985a, b) from Lower Saxony and Bremer (1996) from Mecklenburg-Vorpommern. The cupolas of the Farbeberge are independent of areal pure carbonate sediments in the deeper subsoil. The hydrogeological conditions show no adjacent contact springs or overflow springs (cf. Von Wichdorff 1904, Von Wichdorff & Range 1906, Von Wichdorff 1914). The groundwater outflows from the Farbeberge are obviously linked to structurally controlled pathways, probably formed glacitectonically with ground water ascending from deeper aquifers.

When comparing the occurrence of spring water hummocks with the distribution of areas influenced by glacitectonism in Schleswig-Holstein, a clear relationship is indicated (fig. 1). Ice pushed areas are often characterized by hydraulic contacts to deeper, artesian aquifers. The dislocation of sediments allow for the built up of stronger artesian pressures and frequent spring outflows. Comparable geological settings with respect to the spring areas are also found in different morphologically high-altitude areas of Schleswig-Holstein, such as the Stollberg and surroundings (Bredstedt, Nordfriesland), where among others, glacitectonically disturbed Miocene mica clays and Holsteinian clays are found, and at the Westensee lake (Rendsburg-Eckernförde). In the Riesewohld area (to the west of Albersdorf, Dithmarschen) on a moraine area (+55 to +60 m a.s.l.) string-like bogs occur, possibly retracing glaci-tectonic structures. In the intensively glaci-tectonically affected area Wacken (Steinburg) numerous springs occur in morphological high positions, which may have partly already existed during the Eemian (Stephan 1981). Spring water outflows in top position on the > +75 m a.s.l. moraine areas northeast of Groß Vollstedt (pers. comm. W. Mevs, LLUR) are likely to be due to glacitectonic deformations.

The chemical composition of the spring waters is very similar at the sites studied (Farbeberge, Habernis and Curau). It is a calcium bicarbonate water with low total mineralization (300 mg/l at the Farbeberge). The temperatures were 10° C, the pH at 7.00 (Farbeberge) to 7.5, the conductivities at 35–50 µS/cm. There is no indication for geogenic salinization of the deep groundwater (e. g. Grube et al. 2000), the NaCl-concentrations are in the order of about 30 mg/l. Influences from agricultural use (nitrate and ammonium) are comparibly low or even missing. Since the studied areas all are regionally situated in agricultural land, it can be assumed that the ascending groundwater comes from moderate or greater depth, the proportion of shallow groundwater is likely to be rather small.

Most Eemian deposits in Schleswig-Holstein are formed in limnic to telmatic environments. Furthermore local diatomite deposits occur, as in central Schleswig-Holstein (Menke & Ross 1967, see also Menke in Stremme & Menke 1980) and western Holstein (Menke & Tynni 1984). Similar deposits have been described from Denmark (Andersen 1965). Eemian tufa has been reported from the Swabian Alb (Dehm 1951). Well known are the Middle Pleistocene tufa from central Germany (Steiner 1981, Kahlke 1984, Mania & Altermann 2004). However, the Eemian tufa and the calcareous honeycomb-like, varved sediments from the northern Farbeberg have not previously been described in Northern Germany. They allow for valuable climatic statements. It has to be further investigated whether annual laminations are present at the varve-like sediments (see Frenzel & Bludau 1987).

The presence of tufa deposits is very diverse at the sites studied. Massive, several metre thick, pure tufa occur at the northern Farbeberg in the lower parts (Eemian). In the Holocene deposits on the northern Farbeberg, in Habernis and the Curau bog calcareous sediments occur as irregular horizons in organic muds and peats, preferably in the lower parts of these sediments. This matches results from other locations, where calcium carbonate precipitates are generally sparsely found in peats, massive calcareous sediment or tufa are but rarely found (Moore & Bellamy 1974). In general, continuation of calcium carbonate sedimentation obviously is very diverse, being rather continuous in Eemian deposits and rather discontinuous in Holocene strata.

At the northern Farbeberg the most massive Holocene carbonate sedimentation are found in the center of the spring fed raised peat hummock, whereas carbonate concentrations are diminishing towards the flanks of the hummock. This can be attributed to stronger dissolution at the flanks due to the stronger percolation of water. The mode of formation of the Holocene carbonates remains uncertain. Though here a subareal genesis is favored, a sub-surface growth of tufa and calcareous muds is – at least in part – generally also possible. An argument for the latter are the peat layers of 1–2 metre thickness that cover the carbonate sediments at the sites Farbeberge, Habernis and Curau. The deposited carbonate could, according to Sendtner (1854), have been formed by humic acids and subsequent re-precipitation by the resolution of snail housings and mussel shells. The massive Eemian tufa shows a precipitation of calcium carbonate around vegetation bodies. This should preferably have occurred subaerial or at least close to the surface or in shallow water. This is also confirmed by the accompanying fauna. The gastropods species composition with *Bithynia tentaculata*, *Planorbis planorbis*, *Gyraulus cf. laevis* and *Radix peregra / baltica* (ident. by Klaus Bandel) argues for small, open water areas with shallow waters during sedimentation. A further differentiation of the several metres thick sediments, mainly consisting of carbonate, with respect to the palaeo-life conditions of the gastropods was thus not possible. The eye catching change of sedimentation style during the Eemian, from yellow-gray, finely layered deposits to almost pure tufa indicates a temporarily altered characteristic of the spring waters. The distinct facies change in sedimentation between clay and tufa could possibly be explained by climatic changes during the Eemian (Dansgaard et al., 1993, Björck et al. 2000, Turner 2000, Müller & Kukla 2004, Müller et al. 2005, Sirocko et al. 2005, Müller 2009).

Presumably, at the northern Farbeberg only a small hummock similar to the present one could have existed during the Eemian, but has since been removed by subsequent erosional processes. Arguments for this are, that zone E-IVb shows a large quantity of reworked material and zones E-V and E-VI are missing; additionally the sequence does not emerge above the surrounding ground. Filling of a small depression – created by erosion of the soft Eemian sediments and / or sagging – during the Weichselian ("6" in fig. 9) by solifluction and periglacial slopewash took place, as well as a possible deposition of calcium carbonate during mid-Weichselian Interstadials. Starting already from the Meiendorf Interstadial (14.500–13.850 a BP) with a probable enhanced spring activity following the reduced occurrence of permafrost led to the deposition of peat and calcium carbonate. The general spatial extension of the Eemian and the Holocene deposits as a result of artesian ground waters at the northern Farbeberg has been constant since the Eemian.

The locations Habernis (Weichselian landscape; Grube & Usinger 2016) and Farbeberge (Saalian landscape, this study) are comparable from a geological point of view with respect to the composition of subsurface geology, since cohesive sediments are dominant at both sites: thick, chalk-rich till (Weichselian and Middle Saalian) has widespread occurrence in the shallow. The decalcification of the glacigenic deposits ($CaCO_3$-content up to >20%) during a warm period such as the Holocene, is low – due to the impermeability of these sediments. However, the till of the middle Saalian at the Farbeberge has – despite its age – hardly been decalcified (decalcification depths only a few decimeter) during the Eemian, though this period was more predestined to leaching of calcium carbonate than the Holocene (Menke 1981; Frenzel, Pecsi & Velichko 1992, Müller 2009).

7.2 Age relationships and climatic aspects

The question why tufa deposition are found in the Eemian sections and in the lower parts of the Holocene sediments, can be answered as follows. The catchment area of the outflowing artesian groundwater at the investigation sites must be large scaled, because a pressure gradient of several decimeters above ground level cannot be set up locally. Anyhow this does not mean that only deeper geological strata are acting as the provenance for the calcium carbonate precipitations. Rather, the artesian setting can be built up in deep aquifer sections, letting surface groundwater be incorporated into the emerging spring water. This can be explained by the hydraulic pressure conditions in aquifers, in which the flow velocities grow upwards. Calcium carbonate is released from the still calcareous layers at greater depths which allows for a sedimentation in the form of tufa during a complete interglacial. A decrease in the Holocene carbonate deposition could be explained with the decreasing decalcification (leaching) in the shallow underground during an interglacial. The decalcification along fissures, where the majority of groundwater flow in the till takes place could also have an influence. The Holocene calcium carbonate precipitation at the Farbeberge shows that the decalcification of the landscape in the Lateglacial may still have had an impact. Especially the disintegration of permafrost must have had an influence, it again allowed an extensive flow through the subsurface pore aquifers. Since the underlying sediments still contain much calcium carbonate and an access of the spring water is expected from a greater depth, also changing temperature conditions, and the following variable hydrogeological conditions as well as impacts of vegetation are likely to have influenced the tufa formation. This is consistent with published literature (Gilvear et al. 1993). In summary it can be said that the sedimentation at the Farbeberge reflects a combination of aging and decalcification of the near-surface sediments occurring during the Lateglacial / Early Holocene – which led to preferred calcification during the climatic optimum phases until the end of the Atlantic period.

The spring discharges are likely to be active since the end of the Middle-Pleistocene. However, the Saalian-Lateglacial deposits on the northern Farbeberg are of telmatic origin, they do not contain calcium carbonate sediments. Anyhow in principle, dissolution of existing sediments from this period is possible.

The calibrated radiocarbon ages of the Lateglacial to Holocene deposits show a heterogeneous signal. The oldest tufa are found on the southern Farbeberg (12,520 ^{14}C years BP), the corresponding deposits on the northern Farbeberg show an age of 11,385 ^{14}C years BP. The Lateglacial activity of the springs is in accordance with sites in Poland (Mazurek et al. 2014). It is noteworthy that the dates from the southern Farbeberg indicate predominantly Weichselian - Lateglacial carbonate sedimentation. The ^{14}C-ages on the northern Farbeberg show a much more complex picture. Parts of carbonate and humic sediments in the center of the hummock give Lateglacial ages at shallow depth. This implies that since then, hardly any sedimentation has occurred – or even removal of material (e.g. volume loss by oxidation). At the margins, at least locally, younger sediments are present. This would represent a sedimentation period of only about 3,500 years. Much of the recent carbonate sediments of the Weichselian Lateglacial and Holocene are thus older than the average sediments mentioned by Laumets, Kalm & Zohar (2010) drawn from different works, thereafter the main phase of tufa formation is summarized with 9.4 to 7.4 ka BP. Accordingly the "late Holocene tufa decline" is irrelevant at the investigated sites.

The dating of carbonates is problematic, due to the hard water effect, possibly even a reservoir effect (Srdoc et al.

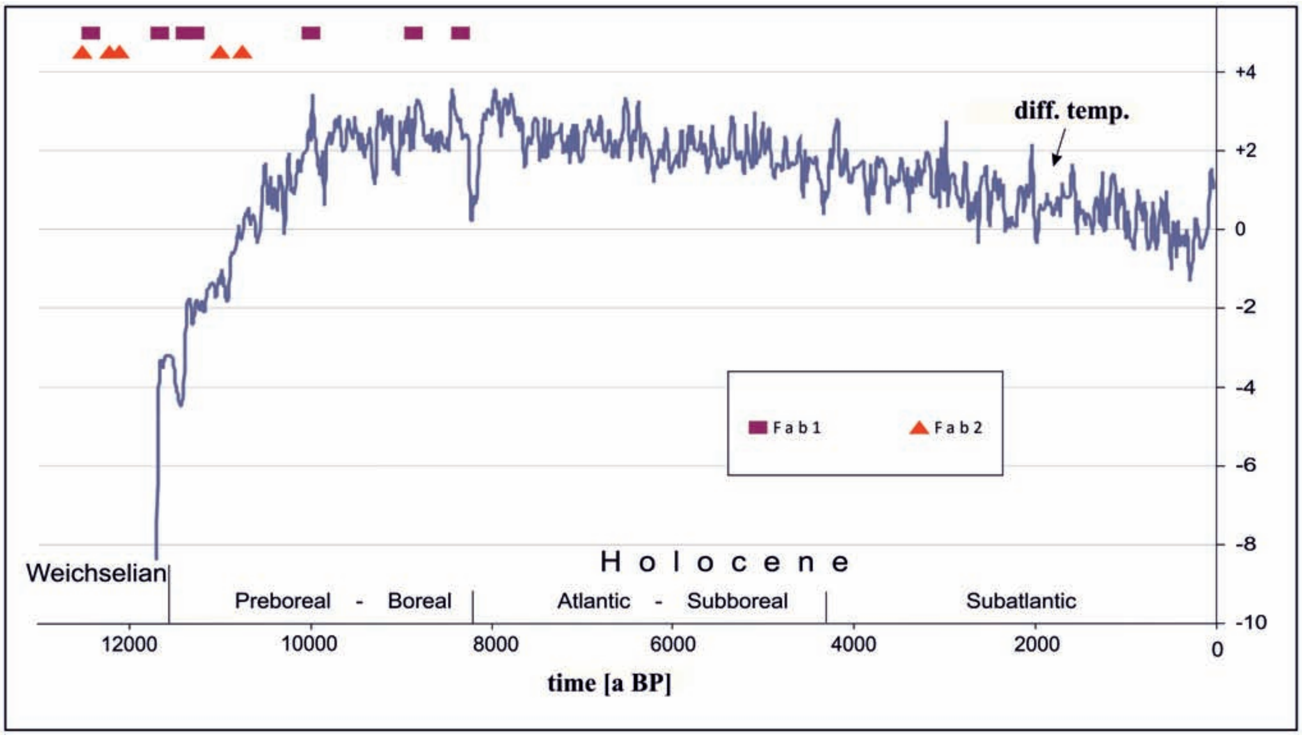

Fig. 11: Climate curve of the Holocene showing the ^{14}C-ages from this study (tufa, peat, wood) in front of climatic curve since the Weichselian Late Glacial (deviation T [°C]; data: ice core Greenland, Vinther *et al. 2009). Absolute ages for Holocene taken from draft Subcommission Quaternary 2015.*

Abb. 11: Klimakurve des Holozäns mit Darstellung der ^{14}C-Alter dieser Studie (Kalke, Torf, Holz) vor dem Hintergrund einer Klimakurve seit dem Spätglazial (Abweichung T [°C]; Daten: Eiskern Grönland, Vinther *et al. 2009). Absolute Altersangaben Holozän nach Entwurf Subkommission Quartär 2015.*

1980, 1983; Wagner 1995; Lowe & Walker 2015). Uncertainties also occur through the use of different dating material (calcareous mud / tufa, peat). Mostly, there are problems in the allocation of the carbonate / tufa deposits in terms of their genesis. Carbonates with a small thickness it cannot be decided without detailed investigation, whether these chronostratigraphically belong to the corresponding unit or are influenced by older calcareous waters moving into a younger peat body. The high ^{14}C-ages even at low depth at the Farbeberge suggest such processes (core Fab1-3 shows an age of 11,385 ^{14}C cal a BP / Preboreal at only 1.51 m below ground). This effect would be expected in principle, on the northern Farbeberg, due to the massive carbonates in the Eemian deposits, which are traversed by the artesian groundwater. However, this aspect can possibly be neglected, because the carbonates on the neighboring southern Farbeberg also show high ages, while massive carbonates of the Eemian here are missing. At the southern Farbeberg the limnic to telmatic sedimentation and tufa sedimentation started already during the Weichselian Lateglacial. At the northern Farbeberg similar ages with 12,520 ^{14}C cal a BP are present. Although the determined ages do not show a continuous age series, the values are similar and provide a plausible picture.

Thickness, type and composition of the Eemian deposits prove a much stronger carbonate sedimentation during the Eemian than during the Holocene. As a result of the higher mean annual temperatures (cf. Menke in Stremme & Menke 1980, Menke 1981, Kühl et al. 2007) higher groundwater temperatures are to be expected, which in turn led to a reduced solubility of $CaCO_3$ in the subsurface. Menke (in Stremme & Menke 1980) sees the quantitative preservation of diatoms, or diatomaceous earth in the Eemian to be an effect of greater supply of silica due to intense weathering and greater seepage (higher precipitation, or leachate). The same is assumed for the solution of $CaCO_3$ from the surface sediments. After the dissemination of climate indicators such as Ilex and Hedera the climate optimum correlates to the Younger Eemian (Menke, in Stremme & Menke 1980 Rundgren, Björck & Hammarlund 2005). This is in accordance with the detected pollen zones (Zones V and VI are missing) at the Farbeberge.

Currently it is unclear whether the ^{14}C-dated carbonates in the intermediate layer between the Eemian and the Holocene sediments are due to an interstadial sedimentation, or go back to solution and re-precipitation of Eemian tufa. The striking age-differences can possibly be explained by contamination of the samples. Anyhow within the closely spaced dates at the northern Farbeberg a carbonate precipitation during Weichselian interstadials seems possible. This is consistent with interpretations of Jäger & Lozek (1968), that mention interstadial carbonates (“impure travertine”) above travertinized Eemian tufa. The drilled carbonates could allow for future investigation of Weichselian carbonate deposition at the Farbeberge site, because carbonate precipitation is not likely in permafrost conditions (Makhnach et al. 2004).

8. Literature

Alaily, F., Brande, A., Facklam, M. & Renger M. (2001): Bodengesellschaften und Genese von Kalktuff im Naturschutzgebiet "Kalktuffgelände am Tegeler Fließ" (Berlin-Blankenfelde). – Sitzungsberichte der Gesellschaft Naturforschender Freunde Berlin (N. F.), 39: 113–127, Berlin.

Almendinger, J. E. & Leete, J. H. (1998): Peat characteristics and groundwater geochemistry of calcareous fens in the Minnesota River Basin, USA. – Biogeochemistry, 43 (1): 17–41.

Amon, J. P., Thompson, C. A., Carpenter, Q. J. & Miner, J. (2002): Temperate zone fens of the glaciated midwestern USA. – Wetlands, 22: 301–317.

Andersen, S. T (1965): Interglacialer og interstadialer I Danmarks Kvaraer. – Meddelelser fra Dansk Geologisk Forening 15: 486–506.

Andrews, J.E. & Brasier, A.T. (2005): Seasonal records of climatic change in annually laminated tufas: short review and future prospects. – Journal of Quaternary Science, 20 (5): 411–421.

Bakalowicz, M. (1990): Geochimie des eaux incustantes, formation des travertins et neotectonique: l'exemple des Corbieres. – Bull. Centre de Geomorphologie du CNRS, 38, Travaux du Groupe Seine, 5: 67–78, Paris.

Baldschuhn, R., Binot, F., Fleig, S. & Kockel, F. (2001): Geotektonischer Atlas von Nordwest-Deutschland und dem deutschen Nordsee-Sektor. – Strukturen, Strukturentwicklung, Paläogeographie. – Geologisches Jahrbuch, A153: 88 p.

Biotopkartierung Schleswig-Holstein – Ersterfassung 1978 bis 1994. – Landesamt für Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein, Flintbek (LLUR) [unpubl.].

Björck, S., Noe-Nygaard, N., Wolin, J., Houmark-Nielsen, M., Hansen, H.J. & Snowball, I. (2000): Eemian lake development, hydrology and climate: a multistratigraphic study of the Hollerup site in Denmark. – Quaternary Science Reviews, 19: 509–536.

Bremer, F. (1996): Geologische Karte von Mecklenburg-Vorpommern 1:25 000; 2131 Schönberg. – mit Beiträgen von Hanetschak, M., Haupt, J., Lückstädt, M. & Müller, U.; Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern [Ed.], Güstrow.

Bülow, K., von (1929): Allgemeine Moorgeologie. – 308 p., Berlin (Gebr. Borntraeger).

Carpenter, Q. J. (1995): Toward a new definition of calcareous fen for Wisconsin (USA). – Diss, Univ. of Wisconsin, Madison, 295 p.

Ciolkosz, E. J. (1965): Peat mounds of southeastern Wisconsin. – Soil Science Survey, 1:15–17.

Dann, T. (2003): Die Moore in Mecklenburg-Vorpommern – Eine Übersicht unter besonderer Berücksichtigung der hydrogeologischen Verhältnisse. – Schriftenreihe des Landesamtes für Umwelt, Naturschutz und Geologie, 3: 17–26.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjornsdottir, A. E., Jouzel, J., & Bond, G. (1993): Evidence for general instability of past climate from a 250-kyr ice-core record. – Nature, 364: 218–220.

Dehm, R. (1951): Mitteldiluviale Kalktuffe und ihre Molluskenfauna bei Schmeichen nahe Blaubeuren (Schwäb. Alb). – Neues Jahrbuch Geologie und Paläontologie, Abh., 93: 247–276.

Dörfler, W., Feeser, I., van den Bogaard, C., Dreibrodt, S., Erlenkeuser, H., Kleinmann, H., Merkt, J. & Wiethold, J. (2012): A high-quality annually laminated sequence from Lake Belau, Northern Germany: Revised chronology and its implications for palynological and tephrochronological studies. – The Holocene, 22: 1413–1426.

Dobrowolski, r. Durakiewicz, t. & Pazdur, A. (2002): Calcareous tufas in the soligenous mires of eastern Poland as an indicator of the Holocene climatic changes. – Acta Geologica Polonica, 52 (1): 63–73

Dramis, F., Materazzi, M. & Cilla, G. (1999): Influences of climatic changes on freshwater travertine deposition: a new hypothesis. – Physics and Chemistry of the Earth, (A)24: 893–897.

Ehlers, J., Grube, A., Stephan, H.-J. & Wansa, S. (2011): Pleistocene Glaciations of North Germany – New Results. – In: Developments in Quaternary Science 15: 149–162, Amsterdam [e.g.], Elsevier.

Frenzel, B. & Bludau, W. (1987): On the duration of the interglacial transition at the end of the Eemian interglacial (deep sea stage 5e): botanical and sedimentological evidence. – In: Berger, W.H. and Labeyrie, L.D. [Eds.]: Abrupt climatic change – evidence and implications, New York (Gustav Fischer Verlag), 151–62.

Frenzel, B., Pecsi, M. & Velichko, A.A. (1992): Atlas of Paleoclimates and Paleoenvironments of the Northern Hemisphere, Late Pleistocene – Holocene. – Geographical Research Institute, Hungarian Academy of Sciences, Budapest; 153 p., Stuttgart, Jena, New York (Fischer).

Geinitz, E. (1920): Das Diluvium Deutschlands. – 206 p., Stuttgart (E. Schweizerbart).

Glaser, P. H., Siegel, D. I., Romanowicz, E. A. & Shen, Y. P. (1997): Regional linkages between raised bogs and climate, groundwater, and landscape of north-western Minnesota. – Journal of Ecology, 85: 3–16.

Gilvear, D. J., Andrews, R., Tellam, J. H., Loyd, J. W. & Lerner, D. N. (1993): Quantification of the water balance and hydrogeological processes in the vicinity of a small groundwater-fed wetland, East Anglia, UK. – Journal of Hydrology, 144: 311–344.

Goudie, A. S., Viles, H. A. & Pentecost, A. (1993): The late Holocene tufa decline in Europe. – The Holocene, 3: 181–186.

Gripp, K. (1964): Erdgeschichte von Schleswig-Holstein. – 411 p., Neumünster (Wachholtz).

Groschopf, p. (1969): Zur Genese und Systematik limnischer Kalksedimente. – Mitteilungen Internationale Vereinigung Limnologie, 17: 219–225.

Grube, A. & Usinger, H. (2016): Zur Bildung von Quellmoor-Kuppen mit Quellkalk-Bildungen bei Habernis und Curau (nördliches und mittleres Schleswig-Holstein). – E&G Quaternary Science Journal, 65 (2): 156–173.

Grube, A., Wichmann, K., Hahn, J. & Nachtigall, K.H. (2000): Geogene Grundwasserversalzung in den Poren-Grundwasserleitern Norddeutschlands und ihre Bedeutung für die Wasserwirtschaft. – Veröffentlichungen aus dem Technologiezentrum Karlsruhe, 9: 1–203.

Hansen, M. & Martin, P. (2013): Kalktuffquellen – Allgemeine Charakterisierung und Stand der Dinge in Schleswig-Holstein, Deutschland und der Europäischen Union. – Deutsche Gesellschaft für Limnologie (DGL), erweiterte Zusammenfassungen der Jahrestagung 2012 (Koblenz), Hardegsen 2013, 98–102.

Heck, H.-L. (1943): Erläuterungen zur Geologischen Karte des Deutschen Reiches 1:25.000, Blätter Schleswig, Brodersby, Sieseby und Dorotheenthal. – Reichsamt für Bodenforschung [Ed.], 36 p., Berlin.

Heck, H.-L. (1946a): Farbeberg bei Nindorf. – Aktenvermerk, Geological Survey of Schleswig-Holstein, LLUR, 3 p. [unpubl.].

Heck, H.-L. (1946b): Geologische Auskunft über verschiedene Kalkvorkommen. – Aktenvermerk, Nr. III 2 / 682, Geological Survey of Schleswig-Holstein, LLUR, 2 p. [unpubl.].

Heykes, K. (1931): Entstehung von Quellkalken. – In: Stoller, J., Bülow, von, K. & Dienemann, W. et. al.; Handbuch der vergleichenden Stratigraphie, Preuss. Geolog. Landesanst. [Eds.], pp. 38–39, Berlin.

Hinsch, W. (1991): Karte des präquartären Untergrundes von Schleswig-Holstein 1:200.000. – Ed. Geologisches Landesamt Schleswig-Holstein, Kiel.

Hinze, C., Jerz, H., Menke, B. & Staude, H. (1989): Geogenetische Definitionen quartärer Lockersedimente für die Geologische Karte 1:25.000 (GK 25). – Geologisches Jahrbuch, A 112: 243 p.

Jäger, K.-D. (1966): Holozäne Binnenwasserkalke und ihre Aussage für die nacheiszeitliche Klima- und Landschaftsentwicklung im südlichen Mitteleuropa: Grundlagen und Grundzüge einer vergleichenden Stratigraphie unter besonderer Berücksichtigung Thüringens. – Jena, 1966: Teilband 1: 161 gez. Bl., Teilband 2: gez. Bl. 162–399, Jena, Univ., Diss.

Jäger, K.-D. & Ložek, V. (1968): Beobachtungen zur Geschichte der Karbonatdynamik in der holozänen Warmzeit. – Ceskoslovensky Kras, 19: 7–22, Praha.

Kahlke, H.-D. (1984): Das Pleistozän von Weimar. Die Travertine im Stadtgebiet. – Quartärpaläontologie / Abhandlungen und Berichte Institut für Quartärpaläontologie Weimar., 5, 432 p, Berlin.

Kaiser, K., Lorenz, S., Germer, S., Juschus, O., Küster, M., Libra, J., Bens, O. & Hüttl, R.F. (2012): Late Quaternary evolution of rivers, lakes and peatlands in northeast Germany reflecting past climatic and human impact – an overview. – E&G Quaternary Science Journal 61, 103–132.

Keilhack, K. (1928): Bericht der Moorkommission. – Veröffentlichungen der Zentralstelle für Balneologie, 7: 23–29.

Kirchner, A. (1971): Ein Beitrag zur Klassifizierung von Niedermoorstandorten in den drei Nordbezirken der DDR unter für die Melioration bedeutungsvollen hydrologischen Gesichtspunkten. – 110 p., Dissertation, W.-Pieck-Universität, Rostock.

Kirchner, A. (1975): Zum Auftreten von Druckwasser in Niedermooren. – Archiv Acker- und Pflanzenbau und Bodenkunde, 19: 613–617, Berlin.

Kühl, K., Litt, T., Schölzel, Chr. & Hense, A. (2007): Eemian and Early Weichselian temperature and precipitation variability in northern Germany. – Quaternary Science Reviews, 26: 3311–3317.

Laumets, L., Kalm, V. & Sohar, K. (2010): Postglacial period of intensive Tufa precipitation in the region of Scandinavian glaciation. – Abstracts 35. Hauptversammlung der Deutschen Quartärvereinigung DEUQUA e. V., Greifswald, pp. 47–48.

Lenz, F. (1924): Quellkreide im Großen Plöner See. – Verhandlungen der Internationalen Vereinigung für Limnologie, Innsbruck, 2: 359–376.

Lowe, K. J. J. & Walker, M. J. C. (2015): Quaternary Environments. – 3. Aufl., London e.g. Routledge).

Ložek, V. (1965): The relationship between the development of soils and faunas in the warm Quaternary phases. – Anthropozoikum 3: 7–51, Praha.

Mania, D. & Altermann, M. (2004): Zur Geologie des altpaläolithischen Fundhorizontes von Bilzingsleben (Thuringen) unter Berücksichtigung des geologischen Wirkfaktors „Mensch". – Hercynia, N.F., 37: 143–184.

Makhnach, N., Zernitskaja, V., Kolosov, I. & Simakova, G. (2004): Stable oxygen and carbon isotopes in Late Glacial-Holocene freshwater carbonates from Belarus and their palaeoclimatic implications. – Palaeogeography, Palaeoclimatology, Palaeoecology, 209: 73–101.

Martin, P. (2004): Hydromorphologische und physikochemische Erhebung von Quellen in verschiedenen Naturräumen Schleswig-Holsteins. – Report for Landesamt für Natur und Umwelt Schleswig-Holstein (LANU).– 6. p. + appendix [unpubl.].

Martin, P. & Brunke, M. (2012): Faunal typology of lowland springs in northern Germany. – Freshwater Science, 31(2): 542–562.

Mazurek, M., Dobrowolski, R., Osadowski, Z. (2014): Geochemistry of deposits from spring-fed fens in West Pomerania (Poland) and its significance for palaeoenvironmental reconstruction. – Géomorphologie 20: 323–342.

Mende, R. (1956): Eis – Wasser – Wind. – Eine allgemein verständliche Eiszeitgeologie der Hamburger Gegend. – Hamburg (Christians), 344 p.

Menke, B. (1981): Vegetation, Klima und Verwitterung im Eem-Interglazial und Weichsel-Frühglazial Schleswig-Holsteins. – Verhandlungen Naturwissenschaftlicher Verein Hamburg (NF), 24 (2): 123–132.

Menke, B. & Ross, P.-H. (1967): Der erste Fund von Kieselgur in Schleswig-Holstein bei Brokenlande, südlich von Neumünster (Mit einem Beitrag zur Biostratigraphie des „Saale-Spätglazials"). – Eiszeitalter und Gegenwart, 18: 113–126.

Menke, B. & Tynni, R. (1984): Das Eeminterglazial und das Weichselfrühglazial von Redderstall/Dithmarschen und ihre Bedeutung für die mitteleuropäische Jungpleistozän-Gliederung. – Geologisches Jahrbuch, A76: 3–120.

Meyn, L. (1848): Geognostische Beobachtungen in den Herzogthümern Schleswig und Holstein. – Amtl. Bericht über die XL. Versammlung dt. Land- und Forstwirthe zu Kiel, pp. 3–65, Altona.

Mingram, J., Negendank, F. W., Brauer, A., Berger, D., Hendrich, A., Köhler, M. & Usinger, H. (2007): Long cores from small lakes – recovering up to 100 m-long lake sediment sequences with a high-precision rod-operated piston corer (Usinger-corer). – Journal Paleolimnology, 37: 517–528.

Moore, P. D. & Bellamy, D. J. (1974): Peatlands. – 1. Ed., London (Elek Science).

Müller, U. C. (2009) Eemian (Sangamonian) Interglacial. – In: Gornitz, V. (Eds.) Encyclopedia of Paleoclimatology and Ancient Environments. pp. 302–307, Dordrecht (Springer).

Müller, U. C., Klotz, S., Geyh, M. A., Pross, J. & Bond, G. C. (2005): Cyclic climate changes during the Eemian interglacial in Central Europe. – Geology, 33 (6): 449–452.

Müller, U. C. & Kukla, G. J. (2004): North Atlantic Current and European environments during the declining stage of the last interglacial. – Geology, 32: 1009–1012.

Paulson, C. (2001): Die Karstmoore in der Kreidelandschaft des Nationalparks Jasmund auf der Insel Rügen. – Greifswalder Geographische Arbeiten, 21: 1–296.

Pazur, A., Dobrowolski, R., Durakiewicz, T., Mohanti, M., Piotrowska, N. & Das, S. (2002): Radiocarbon time scale for deposition of holocene calcareous tufa from Poland and India (Orissa). – Geochronometria, 21: 85–96.

Peters, G. (1955): Alte und Neue Kalkhütte am Kellersee. – Blätter für Heimatkunde, 1 (18): 70–72, Eutin.

Petersen, J. (1892): Über den Wiesenkalk des Farbeberges bei Nindorf. – Mitteilungen mineralogisches Institut der Universität Kiel, 1–4: 104–110.

Pentecost, A. (2005): Travertine. – 445 p., Springer.

Picard, K. (1962): Geologische Landesaufnahme 1:25000, Blatt 1824 Holtdorf. – Aufnahme 1952–1953; Geologisches Landesamt Schleswig-Holstein [Ed.], Kiel.

Precker, A. (2001): Die Regenmoore Mecklenburg-Vorpommerns – Vorläufig abschliessende Auswertung der Untersuchungen zum Regenmoor-Schutzprogramm des Landes Mecklenburg-Vorpommern. – TELMA, 31: 53–63.

Raabe, E. W. (1980): Der Wandel der Pflanzenwelt unserer Kalk-Quell-Moore. – Die Heimat, 87 (3): 41–49.

Reinhold, K., Krull, P. & Kockel, F. (2008): Salzstrukturen Norddeutschlands 1:500 000. – Bundesanstalt für Geowissenschaften und Rohstoffe, Berlin/Hannover.

Rundgren, M., Björck, S. & Hammarlund, D. (2005): Last interglacial atmospheric CO2 changes from stomatal index data and their relation to climate variations. – Global and Planetary Change 49: 47–62.

Schuster, O. (1926): Postglaziale Quellkalke Schleswig-Holsteins und ihre Molluskenfauna in Beziehung zu den Veränderungen des Klimas und der Gewässer. – Archiv für Hydrobiologie, 16: 1–73.

Sendtner, O. (1854): Die Vegetationsverhältnisse Südbaierns nach Grundsätzen der Pflanzengeographie und mit Bezugnahme auf Landeskultur geschildert. – Lit.-art. Anst., München, 910 p.

Sirocko, F., Seelos, K., Schaber, K., Rein, B., Dreher, F., Diehl, M., Lehne, R., Jäger, K., Krbetschek, M. & Degering, D. (2005): A late Eemian aridity pulse in central Europe during the last glacial inception. – Nature letters, 436: 833–836.

Srdoc, D., Obelic, B., Horvatincic, N. & Sliepcevic, A. (1980): Radiocarbon dating of calcareous tufa: How reliable results can we expect? – Radiocarbon, 22 (3): 858–862.

Srdoc, D., Horvatincic, N., Obelic, B. & Sliepcevic, A. (1983): Radiocarbon dating of tufa in palaeoclimatic studies. – Radiocarbon 25 (2): 421–427.

Stegmann, H. (2005): Die Quellmoore im Sernitztal (NO-Brandenburg) – Genese und anthropogene Bodenveränderungen. – Math.-Nat.-Fak., Ernst Moritz Arndt Universität Greifswald. Dissertation: 94 p., appendix.

Steiner, W. (1981): Der Travertin von Ehringsdorf und seine Fossilien. – Die Neue Brehm-Bücherei Band 522 (200 p.), 2. Ed., Wittenberg-Lutherstadt.

Stephan, H.-J. (1981): Erläuterungen zur Ingenieurgeologischen Planungskarte 1: 5 000, Wacken (Blatt 1922). – 69 p., Geologisches Landesamt Schleswig-Holstein, Kiel [Ed.].

Stephan, H.-J. (2004): Karte der Stauchgebiete und Haupt-Gletscherrandlagen in Schleswig-Holstein 1:500.000. – Meyniana, 56: 149–154.

Strehl, E. (2001): Über ein Vorkommen von Quellkalk bei Lütjenburg. – Jahrbuch für Heimatkunde im Kreis Plön, 31: 166–168.

Stremme, H. E. (1966): Bodenkarte von Schleswig-Holstein 1:25 000, Blatt 1824 Holtdorf. – Aufnahme Stremme 1956/1960; Geologisches Landesamt Schleswig-Holstein [Ed.], Kiel.

Stremme, H. E. & Menke, B. (1980): Quartär-Exkursionen in Schleswig-Holstein. – Geologisches Landesamt Schleswig-Holstein [Ed.], Führer zur 7th Session Int. Geol. Correlation Programme, Project 24, Schleswig-Holstein, Germany, 132 p., Kiel.

Succow, M. (1988): Landschaftsökologische Moorkunde. – 340 p., Lizenzausgabe für Gebrüder Borntraeger, Berlin, Stuttgart, VEB Gustav Fischer Verlag, Jena.

Succow, m. & joosten, h. [Eds.] (2001): Landschaftsökologische Moorkunde. – 2. Auflage. 622 p., Stuttgart (Schweizerbart).

Succow, M., Stegmann, H. & Koska, I. (2001): Quellmoore. – In: Succow, M. & Joosten, H. (Eds.): Landschaftsökologische Moorkunde: 353–365; Stuttgart (Schweizerbart).

Thienemann, A. (1922): Hydrobiologische Untersuchungen an Quellen (I–IV). – Archiv für Hydrobiologie, 14: 151–190.

Thompson, C. A. & Bettis, E. A. (1994): Development and Evolution of Iowa Fens. – Journal of the Iowa Academy of Science, 10: 73–77.

Tüxen, J. (1985a): Moore. – in: Höfle, H.-Chr. (1985): Erläuterungen zu Blatt Nr. 2726 Hanstedt, Geologische Karte 1:25000 von Niedersachsen, 107 p., Niedersächsisches Landesamt für Bodenforschung Hannover [Ed.], pp. 64–66.

Tüxen, J. (1985b): Moore. – in: Meyer, K.-D. (1985): Erläuterungen zu Blatt Nr. 2626 Stelle, Geologische Karte 1:25000 von Niedersachsen, 95 p., Niedersächsisches Landesamt für Bodenforschung Hannover [Ed.], pp. 52–59.

Tüxen, J. (1990): Grundzüge einer Geologie der Moore im niedersächsischen Flachland. – In: Niedersächsische Akademie der Geowissenschaften (1990): Moor und Torf in Niedersachsen, 5, 84 p.

Turner, C. (2000): The Eemian interglacial in the North European plain and adjacent areas. – Geologie en Mijnbouw / Netherlands Journal of Geosciences, 79 (2/3) 217–231.

Vinther, B. M., Buchardt, S.L., Clausen, H. B., Dahl-Jensen, D., Johnsen, S. J., Fisher, D. A., Koerner, R. M., Raynaud, D., Lipenkov, V., Andersen, K. K., Blunier, T., Rasmussen, S. O. Steffensen, J. P. & Svensson, A. M. (2009): Holocene thinning of the Greenland ice sheet. – Nature, 461: 385–388.

Vreeken, W. J. (1981): Distribution and chronology of freshwater marls between Kingston and Belville, Ontario. – Canadian Journal or Earth Science, 18: 1228–1239.

Wagner, G. A. (1995): Altersbestimmung von jungen Gesteinen und Artefakten. – 277 p., Stuttgart (Enke).

Weber, C. A. (1907): Aufbau und Vegetation der Moore Norddeutschlands. – Botanisches Jahrbuch für Systematik, Pflanzengeschichte und Pflanzengeographie, Beiblatt Nr. 90: 19–34; Leipzig.

Wetzel, W. (1927): Farbeberg bei Nindorf. – Die Heimat, p. 24–25.

von Wichdorff, H. (1904): Erster Bericht über die Aufnahme auf Blatt Kerschken im Jahre 1904. – Geologisches Jahrbuch für 1904: 827–829.

von Wichdorff, H. (1914): Zur weiteren Kenntnis der Quellmoore in Norddeutschland. – Geologisches Jahrbuch für 1912, XXXIII. II, 319–341.

von Wichdorff, H. & Range, P. (1906): Über Quellmoore in Masuren (Ostpreußen). – Jahrbuch der Königlich-Preußischen Geologischen Landesanstalt, 27/1: 95–106.

Wilcox, D., Shedlock, R.J. & Hendrickson, W.H. (1986): Hydrology, water chemistry, and ecological relations in the raised mound of Cowles Bog. – Journal of Ecology, 74: 1103–1117.

Acknowledgements

The work was partly carried out by the first author during his employment at the Geological Survey Schleswig-Holstein (LLUR). My first thanks go to PD Dr. Hartmut Usinger (Kiel, †) for our friendly cooperation for many years. Special thanks we owe to Ms. Dr. J. Stahl for discussion of pollen diagrams, Mr. J. Ludwig (Univ. Hamburg) for powder diffractometer determination, Prof. K. Bandel (Buchholz) for identifying gastropods, Ms. K. Krauss (Altenholz) for a data query in the LLUR-biotope register and Ms. J. Dannarth (Inst. for Ecosystem Research, University of Kiel) for the treatment of pollen samples. Thanks also go to Dr. Werner Schulz (Schwerin), Hr. Dr. A. Brande (TU Berlin) for information on peat hummocks, the team of the Leibniz Laboratory in Kiel (Drs. A.Z. Rakowski, A. Dreves, M. Hüls) for ^{14}C-dating of samples, Dr. J. Merkt (Herbertingen) for discussion, Ms. M. Kairies, Mr. V. Hildebrand, Mr. W. Petersen and Mr. J. Beller (all LLUR) for help and references. Ms. I. Köller (Hamburg), Vierth family (Remmels) and Kiessling family (Farbeberg) are acknowledged for the access to the study area. Ms. M. Schirk and Ms. Chr. Verdieck are thanked for help on fig 6 and 8. Last not least thanks to Mrs. W. Mevs, E. Krug, K. Peters, A. Preuss and H. P. Henningsen for the exhausting field work. Special thanks go to Prof. Jim Rose and Dr. Jörg Elbracht for the constructive review.

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / 32-43 / DOI 10.3285/eg.66.1.03
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

Pleistozäne (elster- und saalezeitliche) glazilimnische Beckentone und -schluffe in Niedersachsen/NW-Deutschland

Klaus-Dieter Meyer

How to cite: Meyer, K.-D. (2017): Pleistozäne (elster- und saalezeitliche) glazilimnische Beckentone und-schluffe in Niedersachsen/NW-Deutschland. – E&G Quaternary Science Journal, 66 (1): 32–43. DOI: 10.3285/eg.66.1.03

Kurzfassung: Die niedersächsischen glazilimnischen Beckentone und-schluffe werden im Überblick geschildert. Sie unterscheiden sich beträchtlich in Verbreitung und Mächtigkeit von den mitteldeutschen, insbesondere fehlen weitgehend die dort flächenhaft bekannten Bändertone. Im niedersächsischen Bergland sind elsterzeitliche Beckenbildungen ausgesprochen selten, im Flachland dagegen als Füllung der tiefen subglazialen Rinnen erreichen sie Maximalmächtigkeiten bis zu 170 m. Saalezeitliche Beckenschluffe, darunter auch Bändertone, sind in geringer Verbreitung bei Alfeld im Leinetal und an der Weser bei Rinteln seit langem bekannt. Zur Ausbildung großer und tiefer Stauseen ist es in beiden Flussgebieten jedoch nicht gekommen. Im Flachland sind insbesondere in Nordostniedersachsen Beckenschluffe bis zu einigen 10er m Mächtigkeit und mehrere 100 m Ausdehnung nicht selten. Die Ursachen für diese unterschiedlichen Verhältnisse sind vermutlich in den topographischen Gegebenheiten und im unterschiedlichen Verlauf der Vereisungen zu suchen.

Pleistocene (Elsterian and Saalian) glaciolacustrine clays and silts in Lower Saxony, NW Germany

Abstract: A short account is given of the glaciolacustrine clays and silts of Lower Saxony. They show considerable differences from those of Central Germany with regard to their distribution and thickness; in particular the extensive varved clays, well known in Central Germany, are more or less absent. Elsterian glaciolacustrine deposits are very rare in the Lower Saxony hilly areas, although in the lowlands they fill deep subglacial channels and attain a thickness of up to 170 m. Saalian glaciolacustrine silts with minor varved clays have long been known near Alfeld in the Leine valley and near Rinteln on the River Weser. However, no large or deep proglacial lakes developed in either of these two river systems. In the lowlands, particularly in NE Lower Saxony, glaciolacustrine silts several tens of metres thick and several 100 m in extent are by no means rare. The contrasting glacial geology in Lower Saxony and Central Germany is probably due to the different topography and the course oft the glaciation.

Keywords: Nordwestdeutschland, Niedersachsen, Elster- und Saale-Vereisung, Stauseen, Beckenton und -schluff

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1. Einführung

Glazilimnische Sedimente gehören mit glazifluviatilen Sanden und Kiesen zu den wichtigsten Schmelzwasserablagerungen Norddeutschlands; zwischen beiden vermittelnd stehen feinkörnige, oft schluffige Beckensande. Während letztere namentlich im Küstengebiet noch als Füllsande oft im Nassabbau gewonnen werden, stellen die bindigen Schichten oftmals eher lästigen Abraum dar, wogegen sie früher zu den wichtigsten Ziegelrohstoffen gehörten. Heute werden nur noch an wenigen Stellen pleistozäne Tone abgebaggert, womit auch der Großteil der Aufschlüsse verloren geht, teils durch Absaufen oder Rekultivierung.

Neben der Bedeutung als Rohstoff verdienen die bindigen Quartärsedimente auch Aufmerksamkeit wegen ihrer ingenieurgeologisch problematischen Eigenschaften, namentlich der Rutschungsgefährdung. Die hydrogeologische Bedeutung solcher schwer durchlässigen Schichten braucht nicht weiter betont werden, obgleich dieselben trotz manchmal größerer Mächtigkeit vergleichsweise geringe Ausdehnung besitzen.

Trotz der oft relativ geringen Ausdehnung kommt den Beckenablagerungen auch eine stratigraphische Bedeutung zu, insbesondere dem Lauenburger Ton, der im Unterelbe-Unterwesergebiet ein guter Leithorizont ist, zumal er direkt von Holstein-interglazialen Schichten überlagert wird. Auch von diesem international wichtigen Leithorizont gibt es kaum noch Aufschlüsse in Niedersachsen, ein Grund mehr, die jetzige Situation zusammenfassend darzustellen.

Obgleich glazilimnische Sedimente praktisch in allen Abschnitten des Mittelpleistozäns vorkommen, gibt es noch zwei Bereiche, in denen sie besonders stark vertreten sind, und zwar zu Beginn (Vorstoß-Beckenbildungen) und am Ende (Rückzugs-Beckenbildungen) einer Vereisungsphase. Allerdings sind dieselben in den einzelnen Ländern bzw. Landesteilen unterschiedlich stark verbreitet, worauf hier aber nur kurz verwiesen werden kann. Die Felduntersuchungen und Probenahmen erfolgten hauptsächlich im

Rahmen der Geologischen Landesaufnahme beim früheren Niedersächsischen Landesamt für Bodenforschung (NLfB) / Hannover, jetzt LBEG, in den Jahren 1963–2001. Bezüglich der Lage der im Text zitierten Spezialkarten sei auf die Geologische Übersichtskarte 1 : 200 000 und die Quartärgeologische Übersichtskarte von Niedersachsen und Bremen 1 : 500 000 verwiesen.

2. Elster-Kaltzeit

2.1 Niedersächsisches Bergland

Zur Elster-Kaltzeit sind die Gletscher in die Leipziger Tieflandsbucht und in das Thüringer Becken weiter als in der nachfolgenden Saale-Kaltzeit vorgedrungen, von welcher ihre Sedimente einerseits stark erodiert wurden, andererseits aber auch bei Bedeckung erstaunlich gut erhalten sind, wie in den riesigen Braunkohle-Tagebauen gut zu sehen ist, was auch für die südlichen Landesteile Brandenburgs und Sachsen-Anhalts gilt. Im Leipziger Raum liegt unter den beiden Elster-Grundmoränen (Zwickauer und Markranstädter Phase; Eissmann 1975) flächenhaft ein meist geringmächtiger Bänderton, wie im Thüringischen (Unger 1974) mit speziellen Namen belegt. Es sind Vorstoß-Bändertone, während die Rückzugsbildungen hauptsächlich an die Becken- und Rinnenstrukturen gebunden sind (Junge 1998).

In Niedersachsen gestalten sich die Verhältnisse abweichend: weitflächige glazilimnische Vorstoßbildungen sind unbekannt, vermutlich weil wegen des Fehlens großer Tieflandsbuchten die geomorphologischen Voraussetzungen zum Aufstau solcher größerer Seen nicht gegeben waren. Aber auch in den größeren Tälern wie denjenigen von Weser und Leine fehlen elsterzeitlich-glazilimnische Sedimente weitestgehend, was nicht allein auf spätere Ausräumung zurückgeführt werden kann. Zwar ist die Reichweite des Elster-Eises nur ungefähr bekannt, aber nach einem Fund nordischer Gerölle in einer Lößfolge bei Ahlshausen (Jordan 1986; Jordan & Schwartau 1993) reichte das Elster-Eis vermutlich bis in den Raum Einbeck.

Ein kleines Vorkommen von elsterzeitlichem Beckenton beschrieb Herrmann (1958, 1968) aus dem Innern der Hilsmulde SSE Wallensen in 165–190 m Höhe als Ablagerung eines vom Eis gegen den Berghang gestauten Schmelzwasserbeckens. Es mag sein, dass unter anderen, bislang undatierten Vorkommen im niedersächsischen Bergland sich weitere elsterzeitliche befinden.

2.2 Niedersächsisches Flachland

Im nördlichen Niedersachsen sind mit dem Lauenburger Ton (Schucht 1912) glazilimnische Ablagerungen in großer Mächtigkeit bekannt, deren Areal sich vom Unterelbe- über das Unterwesergebiet zur Ems erstreckt, von dort bis in die Niederlande („Potklei“); jenseits der Elbe nach Hamburg, Schleswig-Holstein und nach Brandenburg. Früher wurde der Ton von vielen Ziegeleien abgegraben, heute arbeiten nur noch im Oldenburgischen wenige Werke. Zur Zeit der Neukartierung des Geestanteils der GK 25 Lauenburg Nr. 2629 (Meyer 1965) war die große Tongrube nördlich der Stadt noch in Betrieb, wo gestauchter Ton unter einer dünnen Schicht von Geschiebemergel erschlossen war (Abb. 1). Die stratigraphisch hangenden Sedimente des Holstein-Interglazials konnten in den verfallenen Gruben am östlichen Geesthang nur noch erschürft bzw. am Elbsteilufer erbohrt werden.

Abb. 1: Lauenburger Ton (qL), gestaucht, Geschiebemergel (qD 2 // Mg) der Jüngeren Drenthe. Tongrube ca. 2 km NNW Lauenburg, GK 25 Nr. 2629 Lauenburg. Foto K.-D. Meyer 1963.

Fig. 1: Lauenburg Clay below Younger Drenthian Till. Old clay pit 2 km NNW Lauenburg.

Das Holstein überlagert in mariner Ausbildung im Unterelbe-Gebiet entweder direkt den Lauenburger Ton (Linke 1993) oder es schalten sich dazwischen einige Meter spätelsterzeitliche Feinsande und limnische Bildungen wie in Bossel bei Stade (Müller & Höfle 1994) und Breetze bei Bleckede (Benda & Meyer 1973).

Petrographisch handelt es sich beim „Lauenburger Ton“ um eine Abfolge von fetten Tonen, Schluffen und Feinsanden, sodass auch von einem „Komplex des Lauenburger Tons“ gesprochen wird. Der Tongehalt kann 80 % erreichen, wie in Lauenburg selbst (Bohrung 182, Meyer 1965, Abb. 1) sowie anderen Lokalitäten, während im gesamten Verbreitungsgebiet die Tongehalte oft um 50 % liegen (Tab. 1). Nicht selten handelt es sich um tonige bis schwach tonige Schluffe. Der Karbonatgehalt liegt in der Regel um 10 %, mitunter ist der Ton gut geschichtet, wie Abb. 115 und 116 bei Dewers et al. 1941 zeigen. Einmal sind auch in einem warvenartigen Ton im Oldenburgischen Lebensspuren gefunden worden (Dahm & Otto 1953).

Die Mächtigkeit des Lauenburger Tons erreicht in der Bohrung 145 bei Lauenburg 96 m. In der Reeßelner Rinne östlich Lüneburg, wo mit 502 m die größte Quartärmächtigkeit in Niedersachsen erbohrt wurde, entfallen 150 m auf den Ton, und mit einigen sandigen Zwischenlagen in der Bohrung UWO 6 sind es 170 m (Kuster & Meyer 1979: 142). Ähnlich große Mächtigkeiten kennt man aus Hamburg. Diese großen Tonmächtigkeiten sind an die elsterzeitlichen Rinnen gebunden, die in Norddeutschland tief in das Tertiär eingeschnitten sind, mit der bislang größten erbohrten Quartärmächtigkeit von 584 m in der Hagenower Rinne im südwestlichen Mecklenburg. Über ihre Entstehung durch druckhafte subglaziale Schmelzwässer besteht heute weitgehend Einigkeit, da das von Eissmann (1967, 1975, 1987) vorgestellte Modell der „Glazihydrodynamischen Struktu-

Tab. 1: Korngrößenanalysen (Gew. -%, φ in μ) von elsterzeitlichem Beckenton und -schluff (Lauenburger Ton) im Unterelbe- und Unterweser-Gebiet

Tab. 1: Grain size analyses of Elsterian clays and silts in Lower Saxony

Probe Nr.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Tiefe in m unter Gelände	22 - 24	24 - 26	20 - 30	30 - 45	36 - 60	4,5 - 5	1,7 - 2	30 - 32	4 - 8	8 - 15
gS	**2.000 - 1.000**				0,2						
	1.000 - 630				0,7					0,1	
mS	**630 - 315**			1,2	1,3			0,3			
	315 - 200			3	3,1	0,3		0,9	0,3		0,1
fS	**200 - 125**			8,4	6,4	0,3		1,8	0,6	1,1	0,2
	125 - 63	12,4	4,6	20,1	11,7	4,2	5,8	4	2,4	7	2,4
U	**63 - 20**	0,7	1,8	19,7	6,1	17	39,8	3,8	8,8	17,1	8,9
	20 - 6,3	0,9	2,1	2,9	6,7	14,2	23,2	4,3	9,5	19,1	9,8
	6,3 - 2	2,5	12,5	5,1	10,8	17,1	9,4	7,5	17,6	13,5	17,4
T	**< 2**	83,5	79	38,9	53	46,6	21,8	77,4	60,8	42,1	61,2

T = Ton, U = Schluff, fS = Feinsand, mS = Mittelsand, gS = Grobsand.

Probe 1 und 2:	"Bohrung 181 Wasserwerk Lauenburg [Meyer 1965, Abb. 1] GK 25 Nr. 2629 Lauenburg, R 44 03 030, H 59 16 520."
Probe 3 und 4:	"Drillbohrung GE 30, SW Bretze [Meyer 2004, Tab. 9] GK 25 Nr. 2730 Bleckede, R 44 13 640, H 59 04 230."
Probe 5:	"Drillbohrung GE 55, 2 km SSW Stelle [Meyer 1985, Tab. 2] GK 25 Nr. 2626 Stelle, R 35 73 360, H 59 15 720."
Probe 6:	"Handbohrung C 231, alte Lehmgrube S Drangstedt GK 25 Nr. 2318 Neuenwalde, R 34 83 570, H 59 42 030."
Probe 7:	"Handbohrung C 340, alte Tongrube E Drangstedt [Meyer & Schneekloth 1973, Tab. 1] GK 25 Nr. 2318 Neuenwalde, R 34 84 510, H 59 42 280."
Probe 8:	"Drillbohrung D 17, 5 km SSW Rastede [Meyer 2012, Tab. 1] GK 25 Nr. 2715 Rastede, R 34 45 870, H 58 97050."
Probe 9 und 10:	Drillbohrung D 6, 2 km E Rastede, R 34 48 700, H 59 02 430.

ren“ bestens mit den Verhältnissen übereinstimmt. Im Unterelbegebiet sind die Rinnen besonders gut in Hamburg in ihrem Verlauf bekannt (Grube 1979) und der Mechanismus der Verfüllung untersucht (Ehlers & Linke 1989, Janszen et al. 2013).

Im Bereich der Rinnen wurde durch die starke Strömung der Schmelzwässer die elsterzeitliche Grundmoräne weitestgehend zerstört, die auf den „Rinnenschultern“ erhalten ist, wie das z.B. auf dem Profil durch die Buxtehuder und Wintermoorer Rinne auf Bl. GK 25 Nr. 2524 gut zu sehen ist (Kuster & Meyer 1979, Abb. 10). In beiden Rinnen schwillt die Mächtigkeit des Tones übrigens kaum an, der ansonsten fast flächenhaft auf dem Blattgebiet verbreitet ist. Gleiches trifft für die Nordhälfte der GK 25 Stelle Nr. 2626 zu (Meyer 1985).

An der Basis der Rinnen sammelt sich das Grobkorn der zerspülten Grundmoränen an, wovon allenfalls verstürzte Teilschollen erhalten bleiben (Eissmann 1987, Abb. 1; Ehlers et al. 1984, Fig. 6). Wenn, wie im Tagebau Schöningen bei Helmstedt, ein intakter elsterzeitlicher Geschiebemergel von gut 10 m Mächtigkeit (Meyer 2012) über die ganze Abbauwand erhalten war, kann es sich dort nicht um eine subglaziale Rinne gehandelt haben, wie Lang & Winsemann (2012) annehmen. Damit in Einklang steht, dass in Schöningen elsterzeitliche glazilimnische Ablagerungen im Hangenden der Grundmoräne nur geringe Verbreitung haben (Urban et al. 1988, Elsner 2003). Mitunter zeigt der Ton eine diskrete Schichtung, die in den oberen 57 m der Forschungsbohrungen qho 4 HH-Dockenhuden (Linke 1993: 55) so regelmäßig war, dass eine Jahresschichtung gefolgert wurde mit einem Ablagerungszeitraum von ca. 2000–2500 Jahren. Der Tongehalt in diesem Abschnitt stieg bis auf 40 %. Die unteren 56 m (bis 208 m u. Gelände) waren mehr schluffig-sandig entwickelt.

Auch in NW-Niedersachsen wurde gelegentlich gut gebänderter Lauenburger Ton erschlossen, wie im Hangenden einer Sandgrube bei Hahn, TK 25 Nr. 2714 Wiefelstede, Abb. 2 (NW Oldenburg). Solche geringmächtigen, auskeilenden Vorkommen wurden mehrfach im Unterwesergebiet im Raum Bremen sowie zwischen Oldenburg und Wilhelmshaven gefunden, sie können dort direkt die extrem sandig ausgebildete („Geschiebesand“) Jüngere Elster-Grundmoräne überlagern. Dies war beispielsweise in der großen Sandgrube bei Freißenbüttel (TK 25 Nr. 2718 Osterholz-Scharmbeck) gut zu sehen (Abb. 3), ein Schlüsselprofil, da hier im tieferen Teil der Grube auch noch die Els-

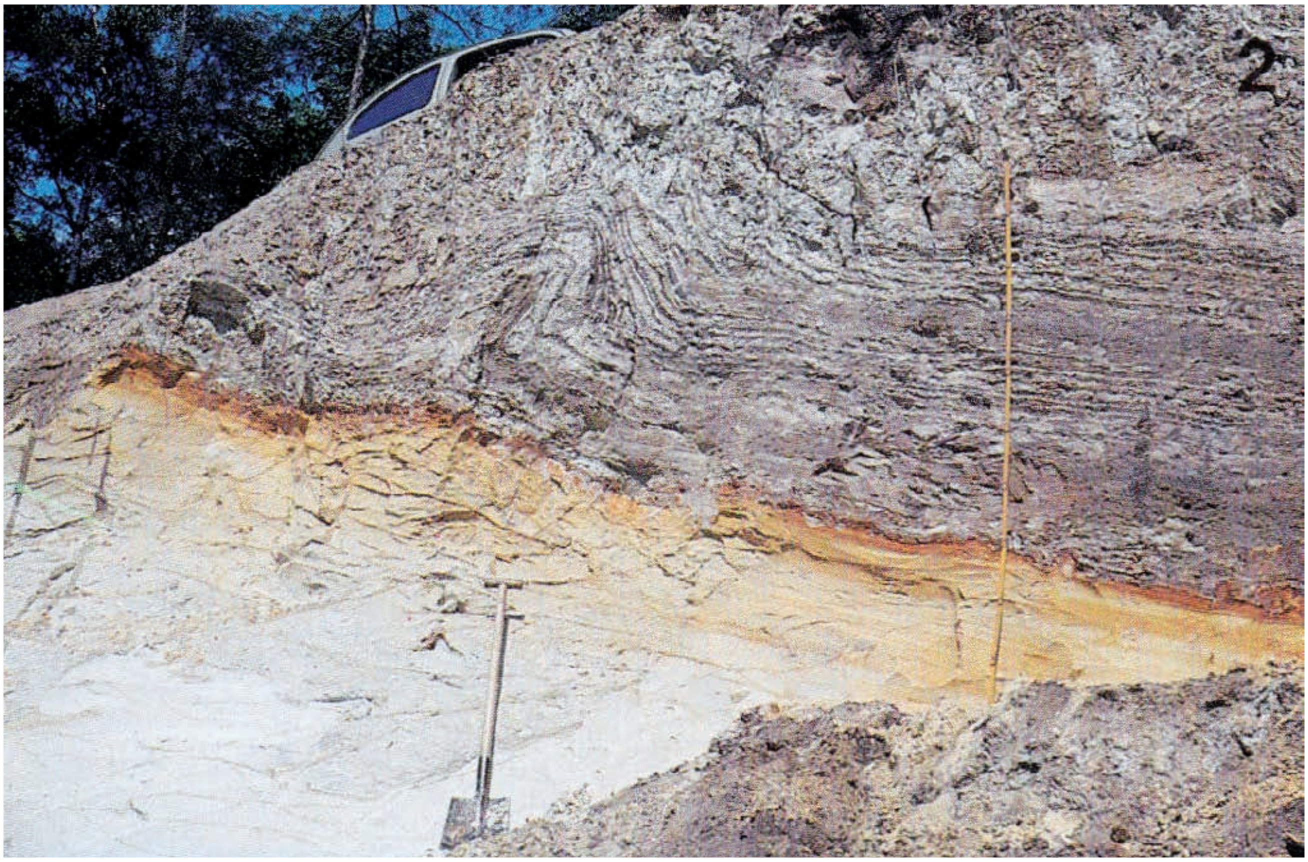

Abb. 2: Lauenburger Ton (qL), warwig geschichtet, verfaltet, über elsterzeitlichen Schmelzwassersanden (qe / S / gf). Sandgrube 2 km WNW Hahn, TK 25 Nr. 2714 Wiefelstede. Foto K.-D. Meyer 1968.

Fig. 2: Lauenburg Clay, varved, overlain elsterian fluvioglacial sand. Sandpit 2 km WNW Hahn.

Abb. 3: Lauenburger Ton (qL), direkt Geschiebesand (qe // Sg) der Jüngeren Elster-Grundmoräne überlagernd. Zuoberst Geschiebelehm der Drenthe-Hauptmoräne (qD // Lg). Sandgrube Freißenbüttel, TK 25 Nr. 2718 Osterholz-Scharmbeck. Foto K.-D. Meyer 1995.

Fig. 3: Lauenburg Clay, below Younger Elsterian sandy Till. Sandpit Freißenbüttel.

ter-Hauptmoräne aufgeschlossen war sowie zuoberst die Drenthe-Moräne (Feldmann & Meyer 1998). Leider waren alle Bemühungen, einen Abschnitt dieses geowissenschaftlich einmaligen Profils zu erhalten, trotz Zusage des Landkreises vergebens (Meyer 1997).

Auf die zum Lauenburger Ton-Komplex gehörenden Feinsande soll hier nicht weiter eingegangen werden, da sie weit seltener als die bindigen Schichten aufgeschlossen waren und in Bohrungen auch schlechter zu identifizieren sind. Besonders im Raum Oldenburg-Ostfriesland enthalten sie häufig lagenweise umgelagerte Braunkohle (Abb. 4) mit nicht wenig Bernstein (Alexander 2002). Allein eine im Nassabbau betriebene Sandgrube bei Altjührden (TK 25 Nr. 2614 Varel) hat bis zu ihrer Stilllegung schätzungsweise ½ t Bernstein geliefert, der vermutlich zumindest teilweise (ebenso wie die Kohle) mitsamt dem durch Eisschmelzwasser ausgespültem Rinnenmaterial aus Mitteldeutschland entstammt und auf dem Wege zum Nordseebecken unterwegs deponiert wurde.

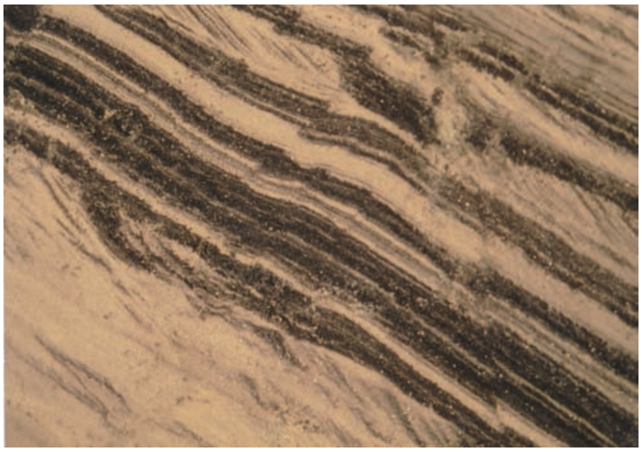

Abb. 4: Elsterzeitlicher Beckensand (qe /S /b) mit umgelagerter tertiärer Braunkohle, Bernstein-führend. Ehemalige Sandgrube Altjührden, TK 25 Nr. 2614 Varel.

Fig. 4: Elsterian fluvioglacial sand with redeposited tertiary lignite, containing Amber. Old sandpit Altjührden.

3. Saale-Kaltzeit

3.1 Niedersächsisches Bergland

Wie zur Elster-Kaltzeit transgredieren die saalezeitlichen Grundmoränen in Mitteldeutschland über Bändertone, die auch hier mit speziellen Ortsbezeichnungen versehen sind (Bettenstaedt 1934, Schulz 1962, Eissmann 1975). Vergleichbare flächenhafte Sedimente fehlen in Niedersachsen, immerhin kam es am nordwestlichen Harzrand zur lokalen Ausbildung von Stauseen, die Pilger (1991) zusammenfassend dargestellt hat. Es sind insgesamt sieben nicht sehr ausgedehnte Vorkommen.

3.1.1 Leinebergland

Im westlich des Harzes anschließenden Leine-Gebiet sind bei Alfeld Bändertone in einer Mächtigkeit bis zu 3 m seit langem bekannt (Lüttig 1960, Abb. 1); wie in Mitteldeutschland auf Mittelterrasse liegend und ihrerseits von Grundmoräne überlagert. Nach Jordan (1994, Abb. 10 und 11) kommt lokal auch über der Moräne Bänderschluff in einer Höhenlage von ca. 100 m vor.

Vom östlichen Nachbarblatt beschreibt Harms (1983) aus einer Baugrube einen ca. 50 cm mächtigen tonig-feinsandigen feingeschichteten Beckenschluff, Mittelterassen-Kies der Leine überlagernd. Dieses Vorkommen liegt ca. 1 km SE der Fredener „Endmoräne“, in der ebenfalls zeitweise örtliche Schlufflagen aufgeschlossen waren.

Weiter das Leinetal aufwärts sind keine glazilimnischen Bildungen mehr nachgewiesen, lediglich 10 km SE Freden in einem Nebental der Gande östlich Orxhausen, wo Jordan (1993) Beckentone bis Schluff über Schmelzwassersanden fand und in einem Profil (Abb. 6) darstellte, vgl. auch Kaltwang 1986; 1992: 59 und 137. Auch Rausch (1977) erwähnt in seinen Aufschlussbeschreibungen keine derartigen Sedimente über der Mittelterrasse der Leine.

Die Stauseen im Leinetal samt ihren Nebentälern sind also von sehr begrenzter Ausdehnung gewesen, es gibt keine Beweise für einen riesigen „glacial Lake Leine“ (Winsemann et al. 2011) mit einer maximalen Seespiegelhöhe von 200 m + NN. Die von diesen Autoren auf Fig. 3 dargestellten „Fine grained bottom sediments“ sind teils älter als saalezeitlich (unter Mittel- und Oberterasse lagernd), teils sind es mächtige Absätze in Subrosionssenken, wie auf den GK 25 Nr. 4125 Einbeck (Jordan 1993: 45), Nr. 4225 Northeim West (Jordan 1986: 44) oder Nr. 4325 Nörten-Hardenberg (Jordan 1984:46). Selbst Interglaziale wurden einbezogen wie die cromerzeitlichen von Bilshausen und Sohlingen. Manche dieser Sedimentfüllungen sind einige 10er m mächtig, maximal 50 m. Selbst wenn Stauseesedimente im oberen Leinetal existiert haben sollten, wären solche Mächtigkeiten wenig plausibel, noch weniger in Nebentälern wie dem der Rhume.

3.1.2 Weserbergland

Auch für das Wesergebiet wird von Winsemann et al. (2011) ein großer saalezeitlicher Stausee („Glacial Lake Weser“) angenommen, dabei eine Vorstellung von Thome (1983) aufnehmend. Im Wesertal sind im Bereich zwischen der Porta und Hameln seit langem Stauseeablagerungen bekannt, von Spethmann (1908) einem „Rintelner Eisstausee“ zugeordnet, dessen Sedimente auf der betreffenden Talstrecke im Bereich der GK 25 Nr. 3719, 3819, 3820, 3821 und 3822 nachgewiesen wurden. Auch auf dem westlichen Anschlussblatt Herford Nr. 3818 tritt unter Grundmoräne Beckenschluff und -ton auf (Deutloff 1995); die Verhältnisse in Nordrhein-Westfalen (Meinsen et al. 2011) sind jedoch nicht Gegenstand dieser Arbeit.

Die Mächtigkeit des Rintelner Beckentons liegt meist bei einigen m. Kulle (1985) hat die damals auf GK 25 Hess. Oldendorf Nr. 3821 in den Ziegeleigruben Helpensen und Heeslingen in je 2,5 Meter Mächtigkeit aufgeschlossenen Bändertone untersucht, die jeweils von mehreren m Grundmoräne überlagert waren. Dabei ist die Überlagerungsgrenze messerscharf, ohne dass Störungen der Bändertone erkennbar waren, ein auch in Mitteldeutschland nicht ungewöhnlicher Fall (Junge & Eissmann 2000). In Helpensen wurden 51 Warven gezählt, in Heeslingen 66. Obwohl natürlich mit einer gewissen Erosion und damit einer entsprechenden Schichtlücke zu rechnen ist, so ist von einem Ablagerungszeitraum für den Beckenton von rund 100 Jahren auszugehen.

Interessant ist ferner, dass unter den von Kulle (1985) gezählten Dropsteinen etwa ¾ nordischer Herkunft waren. Zusammen mit den Ergebnissen der Schwermineralanalyse deutet das klar auf eine dominierende nordische Herkunft des Materials. Dabei ist zu fragen, was aus dem damals von Süden in das Staubecken transportierten Material geworden ist.

Auf dem westlich an Bl. Hess. Oldendorf anschließenden Blatt Rinteln Nr. 3820 hat Rausch (1975) in einem südlich Krankenhagen damals abgebauten Staubeckenschluff ebenfalls reichlich eingestreute nordische Geschiebe beschrieben, wobei er das Fehlen von Buntsandstein und Kieselschiefer betont. Das von Rausch als „Bögerhofton" bezeichnete Sediment hat eine Basishöhe von über 100 m. In diesem Zusammenhang ist auch auf ein Profil in der aufgelassenen Kiesgrube westlich Möllenbeck zu verweisen, in der drei, z.T. allerdings nur eng begrenzte Schluffschichten auftraten. Die Position des Bögerhoftons zur Grundmoräne ist unklar; vermutlich handelt es sich um eine Bildung während des Eisrückzugs.

Flussaufwärts von Hameln sind keine Vorkommen des Rintelner Tones mehr bekannt, obwohl die vorhandenen Mittelterrassenflächen genügend Platz geboten hätten und der Ton auch außerhalb der Reichweite der Gletscher vor Erosion hätte verschont bleiben können. Bei allen anderen von Winsemann et al. (2011) im Wesereinzugsgebiet dargestellten Vorkommen von „Fine-grained lake bottom sediments" handelt es sich um Fehlinterpretationen. Die nördlich Holzminden eingetragenen Vorkommen sind nach der GK 25 Nr. 4022 Ottenstein feinkörnige Einlagerungen in der Mittelterrasse. Auf GK 25 Nr. 4322 Höxter wird am N-Hang der Nethe, einem Seitental der Weser, unter Löß ein geringmächtiger Ton angegeben, undatiert und ohne Beziehung zur Weser. Das Vorkommen im Bereich der GK 25 Nr. 4322 Karlshafen bleibt unklar.

Der letzte an der Weser gelegene Punkt auf GK 25 Nr. 4323 Uslar (Lepper 1977) bei Bodenfelde nahe der Schwülme-Mündung liegt oberhalb der Mittelterrasse und ist eine zur Oberterrasse gehörende periglaziale Schluff-Sand-Wechselfolge (Preuss & Rohde, in Lepper 1977, S. 46/47).

Ebenfalls auf GK 25 Uslar liegt in etwa 200 m NN (= 90 m über der Mittelterrasse) am Hang des Ahle-Tales das zum Cromer-Komplex gehörende Sohlingen-Interglazial (Homann & Lepper 1994).

Als letztes verbleibt ein Punkt auf GK 25 Nr. 4421 Borgenteich, wo bei Daselburg am W-Hang des Eggeltales, einem Nebental der Diemel, in ca. 180 m Seehöhe in einer alten Ziegeleigrube 4 m kaltzeitlicher Ton abgegraben wurde. Eine verlässliche Datierung liegt nicht vor. Es ist wenig glaubhaft, dass im gesamten Diemeltal, sofern es tatsächlich vom „Lake Weser" bedeckt gewesen wäre, nicht noch weitere Vorkommen erhalten geblieben wären, zumal vom Diemeltal eine ausführliche Untersuchung von Wortmann (1937) vorliegt, der auch ein exzellenter Kenner des Wesersystems war.

Weiterhin wird von Winsemann et al. (2011) im Einzugsgebiet der Weser (merkwürdigerweise nicht auch der Leine) „Ice rafted debris" angegeben. Kein Fund davon wurde in situ gemacht, weshalb eine Verdriftung als nicht erwiesen gelten muss, zumal alle Punkte im Bereich des früher vereisten Gebietes liegen (Kaltwang 1992), mit zwei Ausnahmen. Eine davon bezieht sich auf die Angabe von Grupe (1923), dem Fund eines angeblich nordischen Quarzits in den interglazialen Tonschichten der Zeche Nachtigall bei Höxter, GK 25 Nr. 4122 Holzminden. Dazu schreibt Lüttig 1955, S. 83: „Diese Angabe ist von verhängnisvollem Einfluß vor allem auf die seither herausgegebenen Kartenwerke gewesen und muß endlich korrigiert werden. Ich kann Grupe in keiner Weise folgen und halte den „kambrischen Quarzit" entweder für eine Fehlbestimmung oder ein verschlepptes Geschiebe."

Dem ist hinzuzufügen, dass auch Mangelsdorf (1981) in den Tonen zwar Weser-Kiese als Driftmaterial fand, darunter aber kein einziges nordischer Herkunft. Eigene Aufsammlungen während der Neubearbeitung (in Rohde et al. 2012: 139) können das bestätigen. Die Probe stammt von der Nordwand des damaligen Aufschlusses aus dem Schluff über der untersten Torfbank (Abb. 5) und war garantiert frei von nordischen Komponenten. Nur Stücke

Abb. 5: Ziegeleitongrube „Zeche Nachtigall" bei Höxter (Saale-Komplex), Blick nach Westen, GK 25 Nr. 4122 Holzminden. An N-Wand rechts im Bild der Proben-Entnahmepunkt der „Dropsteine" aus dem Schluff über dem untersten Torfband, Rohde & Lepper 2012, S. 139. Foto K.-D. Meyer 1997.

Fig. 5: Interglacial (Saalian complex) Clay pit „Nightingale" near Höxter, containing Weser-river dropstones.

Abb. 6: Zeche Nachtigall, Höxter, Buntsandstein-Dropstein in situ im Schluff über dem untersten Torf. Foto K.-D. Meyer 1.9. 1997.

Fig. 6: Nightingale clay-pit: Buntsandstein-dropstone in situ.

aus dem sicheren Anstehenden wurden entnommen, wie Abb. 6 zeigt. Im Übrigen gibt es keine roten kambrischen Quarzite; möglicherweise war es ein Buntsandstein. Wie auch immer, die Position in den interglazialen Tonen macht das fragliche Geschiebe als Kronzeuge für einen frühdrenthezeitlichen Bänderton unbrauchbar.

Das zweite Vorkommen von angeblichem „Ice-rafted debris" liegt auf GK 25 Nr. 4523 Hann. Münden, wo bereits in den Erläuterungen von Feuersteinen berichtet wurde, die über die Werra aus Thüringen dorthin gelangt sein sollen. Wiegers (1955) hat das Thema erneut aufgegriffen, was von Unger (1974) dahingehend korrigiert wurde, dass es sich um umgelagertes elsterzeitliches Material aus dem Thüringer Becken handelt. Jedenfalls zeugen auch diese beiden angeblichen Fundpunkte von „Ice-rafted debris" weit außerhalb der Vereisungsgrenze in keiner Weise für die Existenz eines großen Stausees.

Im Leine- und Wesergebiet sind, außer den in unmittelbarer Nähe des Eisrandes abgelagerten, lange bekannten Staubeckensedimenten wie die von Alfeld und Rinteln, keine weiteren Vorkommen nachweisbar. Sämtliche von Winsemann et al. 2011, Fig. 2 aufgeführten Vorkommen, soweit sie Verf. nicht z.T. seit über 50 Jahren bekannt waren, wurden anhand von Bohrungen oder geol. Karten überprüft und erwiesen sich als unrichtig datiert oder undatierbar. Die Existenz großer und bis 200 m Höhe aufgestauter Stauseen muss also als unbewiesen gelten und daher auch der subaquatische Charakter der „Fan and delta complexes" von der Porta bis zum Harzrand bei Bornhausen. In diese aus glazifluviatilem Sand und Kies aufgebauten, früher oft (Grupe 1930, Stach 1930) als Kames-Bildungen gedeuteten Körper sind zwar gelegentlich auch Schluffbänke und flow till-Lagen eingeschaltet, aber das ist in dieser Position nicht ungewöhnlich. Im Übrigen sei auf die vorliegenden Bearbeitungen dieser Körper verwiesen: Porta: Attig 1965, Röhm 1985; Emme: Merkt 1980, Rakowski 1990; Freden: Harms 1983; Möllenbeck-Krankenhagen: Wellmann 1990; 1998; Coppenbrügge: Lüttig 1960; Bornhausen: Uebersohn 1990.

3.2 Niedersächsisches Flachland

Im niedersächsischen Flachland sind saalezeitliche glazilimnische Tone und Schluffe erheblich weiter verbreitet als im Bergland; kaum eine GK 25, wo dieselben nicht an der Oberfläche oder in Bohrungen vorkommen. Das trifft besonders für Nordostniedersachsen zu, wohl weil dort die jüngeren Eisvorstöße für ein unruhigeres Relief und damit für geeignete Ablagerungsräume sorgten. Am deutlichsten wird das im Uelzener Becken, wo früher viele Ziegeleien noch bis in die 60/70er Jahre des 20. Jhd. Einblick gewährten, aber heute sämtlich stillgelegt sind. Auch gut gewarvte Bändertone waren dabei wie in Emmendorf, GK 25 Nr. 2929, wobei der Jahresschichten-Charakter nicht erwiesen, aber aufgrund der sehr regelmäßigen Ausbildung gut möglich ist (Dewers et al. 1941, Abb. 46 bis 47). In Emmendorf, wo direkt über dem Bänderton eine rote ostbaltische Moräne liegt, wäre ein solcher Nachweis besonders interessant (Gauger & Meyer 1970), weil damit eine Zeitmarke für den Ablagerungszeitraum dieses mutmaßlich von einem Eisstrom abgelagerten Geschiebemergels gegeben wäre (Meyer & Roland 2016).

Die Mächtigkeit der saalezeitlichen Beckensedimente reicht nicht an die elsterzeitlichen heran, da es keine vergleichbar tiefen Rinnenstrukturen gab. Immerhin sind einige 10er m nicht außergewöhnlich. Die Ausdehnung der Vorkommen an der Oberfläche geht meist nicht über 1 km hinaus, oft sind es nur wenige 100 m bis 10er m. Die Verteilung ist sehr ungleichmäßig, z.B. häufen sich die Vorkommen wie im SW und in der Mitte der GK 25 Nr. 2830 Dahlenburg (Meyer 2009), was sowohl morphologische wie geologische Gründe haben kann, wie z.B. das Vorkommen von tonigem Geschiebemergel als geeignetes Abdichtungsmittel (ehemalige Grundmoränenseen), zusammen mit diesen auch für nachfolgende warmzeitliche Sedimente dienend.

Auf anderen Blättern, wo an der Oberfläche kaum Beckenbildungen vorkommen, sind sie im Untergrund durchaus vorhanden, wie das Profil der GK 25 Nr. 2524 Buxte-

Tab. 2: Korngrößenanalysen (Gew. -%, φ in μ) von saalezeitlichen Beckenschluffen in NE-Niedersachsen.

Tab. 2: Grain size analyses of Saalian glaciolacustrine silts in NE Lower Saxony

Probe Nr.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Tiefe in m unter Gelände	7	5,5	4	12	3	10	48 - 53	1	2	3
gS	**1.000 - 630**	0,3	0,2								
mS	**630 - 315**	0,7	1,3					1			
	315 - 200	1,7	4,5					2,1	0,1		
fS	**200 - 125**	2,1	6,5		2,9			3,8	0,4		0,4
	125 - 63	6,4	5,5	7,2	20,2	2	0,8	3,9	2,9	8,2	3,8
U	**63 - 20**	51	6,4	34,2	48,4	28,2	12,6	13,2	28,4	70,3	29,6
	20 - 6,3	16,5	14,9	26,6	11,6	40	45	17	14,4	21,9	14,6
	6,3 - 2	6,5	21,9	5,3	2,8	9,2	22,6	19	13,1	1,8	17,3
T	**> 2**	15,1	39,5	26,7	14,1	20,6	19	40,1	40,3	5,6	34

T = Ton, U = Schluff, fS = Feinsand, mS = Mittelsand, gS = Grobsand.

Probe 1:	"Beckenschluff, bis 3 m mächtige, seitlich auskeilende Einschaltung in drenthezeitliche Vorschüttsande. Tagebau Schöningen, S-Wand des "Bahnpfeilers" 2009. GK 25 Nr. 3731 Schöningen, R 44 30 820, H 57 79 280."
Probe 2:	"Brockenmergel", in 2 - 3 dm Stärke den hangenden Geschiebemergel überlagernd. Fundpunkt wie Probe 1 (Meyer 2012).
Probe 3:	"Beckenschluff, feingeschichtet, steilstehend und die Drenthe-Hauptmoräne überlagernd. (Meyer 1965, Taf. 1) GK 25 Nr. 2629 Lauenburg, R 44 02 960, H 59 16 510."
Probe 4:	"Beckenschluff, über Jüngerer-Drenthe-Moräne, Elbsteilufer Lauenburg, GK 25 Nr. 2526, R 44 02 865, H 59 16 510."
Probe 5:	"Beckenschluff, Jüngere-Drenthe-Moräne unterlagernd, alte Mergelkuhle 1 km SSW Breetze (Meyer 2004, Tab. 9) GK 25 Nr. 2730 Bleckede, R 44 13 240, H 59 03 310."
Probe 6:	"Beckenschluff-Lage in Drenthe-Schmelzwassersand, Kiesgrube E Breetze (Meyer 2004, Tab. 9) GK 25 Nr. 2730 Bleckede, R 44 14 840, H 59 04 320."
Probe 7:	"Beckenschluff, Drillbohrung G 19 (Meyer 2009, Tab. 3) GK 25 Nr. 2830 Dahlenburg, R 44 12 450, H 59 92 540."
Proben 8 bis 10:	"Beckenschlufff, alte Ziegeleigrube Scharmbeck (Meyer 1985, Tab. 4) GK 25 Nr. 2626 Stelle, R 35 75 640, H 59 13 200."

hude zeigt, obgleich sie hier auch in Sandgruben in einer Ausdehnung von m bis 10er m vorkommen (Meyer 1982).

Petrographisch handelt es sich meist um schwach bis sehr stark tonige Schluffe mit Tongehalten bis 40 % (Pr. 7 und 8, Tab. 2), während fette Tone eher selten sind. Beim Schluff gibt es große Unterschiede, manchmal dominiert der Mittelschluff (Pr. 6 mit 45 %), manchmal der Grobschluff (Pr. 4 mit 48 %).

Die Beckenschluffe kommen in allen Etagen der saalezeitlichen Abfolge vor, d.h. als Einschaltungen in Schmelzwassersande, oft nur in geringer Mächtigkeit und Ausdehnung wie im Tagebau Schöningen, wo an der Südwand des „Bahnpfeilers" im Jahre 2009 ein bis zu 9 m mächtiger, seitlich schnell auskeilender gelblicher Beckenschluff aufgeschlossen war, teils direkt von der Drenthe-Hauptmoräne überlagert (Meyer 2012, Abb. 14 und 15). Die Korngrößenanalyse (Pr. 1, Tab. 2) zeigt mit 51 % das deutliche Überwiegen des Grobschluffs.

Solche Schluffe sind Stillwassersedimente in lokal nur kurzfristig existierenden Depressionen innerhalb der normalen Vorschüttsedimente, die andererseits auch Grobkiesbänke enthielten, welche in Schöningen Leitgeschiebezählungen ermöglichten (Meyer 2012, Tab. 2). Im gleichen Profil wurde direkt über der Drenthe-Grundmoräne ein 2–3 dm mächtiger, rötlich-brauner, stark toniger (39,5 % T) Schluff (Pr. 2, Tab. 2) mit brecciösen Strukturen aufgeschlossen, als „Brockenschluff" bezeichnet. Vermutlich gehen solche Strukturen auf periglaziale Einwirkungen nach der Abschmelzphase zurück. Möglicherweise handelt es sich um ähnliche Erscheinungen, wie sie von Junge et al. (1999) aus Bändertonen des Tagebaus Delitzsch-SW im Hangenden der ersten Saale-Grundmoräne beschrieben wurden, in ähnlicher Position wie in Schöningen, auch wenn es sich hier nicht um Bändertone handelt und eine Gleichsetzung nicht erwiesen ist. Mit dem „Brockenschluff" endet in Schöningen die Schmelzwasser-Tätigkeit in der Abschmelzphase. Ein größerer Stausee mit mächtigen Ablagerungen, wie von Lang & Winsemann 2013 angenommen, kann hier nicht existiert haben, dafür gab es auch in frühen Abbau-Schnitten in Schöningen keine Hinweise (Elsner 2003).

Wie im Profil Schöningen, kommen Beckenschluffe bevorzugt im unmittelbaren Liegenden und Hangenden der

Drenthe-Grundmoräne vor, insofern an die Verhältnisse in Mitteldeutschland erinnernd, auch wenn im Flachland keine flächenhaft auftretenden Bändertone bekannt sind.

Ebenfalls die Drenthe-Hauptmoräne direkt überlagernd und mit dieser zusammen gestaucht (Meyer 1965), steht am Elbsteilufer von Lauenburg in steiler Lagerung ein 20 m mächtiger, hellgelblicher Beckenschluff an (Abb. 7). Es ist ein toniger Grob- bis Mittelschluff (Pr. 3, Tab. 2), ziemlich homogen und ähnelt der Pr. 1 von Schöningen. Die Schicht konnte am Elbsteilufer in Bohrungen und Schürfen etwa 1 km weiter elbabwärts verfolgt werden.

Am Lauenburger Steilufer ist ein weiterer, jüngerer Beckenschluff aufgeschlossen, allerdings nur die Eemtorf-Mulden auskleidend und mit diesen auf Profil I bei Meyer 1965 zusammengefasst. Vom unteren gelben Beckenschluff ist er durch die Kreidekalk-reiche Jüngere Drenthe-Moräne und deren Vorschüttsanden getrennt. Der 1–2 m mächtige Schluff ist von grauer Farbe; seine Korngrößenzusammensetzung (Pr. 4, Tab. 2) ähnelt, abgesehen von einem etwas höheren Feinsandgehalt, der Pr. 1, Tab. 2, von Schöningen.

Ein toniger, lagenweise feinsandiger Mittelschluff (40 %, Pr. 5, Tab. 2) ist in einer alten Mergelkuhle 1 km SW Breetze aufgeschlossen, muldenförmig Jüngeren Drenthe-Geschiebemergel unterlagernd (Meyer 2004, Abb. 4). Mit 20,1 % ist sein Karbonat-Gehalt relativ hoch, weshalb er zur Zeit der Kartierung (1988/90) noch gelegentlich abgegraben wurde. Sehr ähnlich ist die Analyse (Pr. 6, Tab. 2) einer Schluffbank aus der aufgelassenen Kiesgrube östlich Breetze, nur ist hier der Grobschluff zugunsten des Feinschluffs erniedrigt. Der Karbonat-Anteil ist mit 19 % fast identisch mit Pr. 5.

Im Bereich des Blattes Bleckede wurden ferner mehrfach unter den dort sehr häufigen Eem-Vorkommen (insg. 37) lokale Beckenschluffe erbohrt, die ihrerseits in Grundmoräne eingetieft sind. Bemerkenswert ist, dass auch im Hangenden des Interglazials Beckenschluffe bis zu einigen m Mächtigkeit vorkommen können, und dies in einer heute rein sandigen Umgebung. Dies bedeutet, dass noch zur frühen Weichsel-Kaltzeit mehr oder weniger schluffige Substrate ausgespült und in den betreffenden Depressionen deponiert werden konnten, und somit nicht alle limnischen Sedimente auf der Geest auch glazilimnisch sind.

Auf dem südlich an Bleckede anschließenden Blatt GK 25 Nr. 2830 Dahlenburg sind sowohl an der Oberfläche wie im Untergrund Beckenschluffe in Mächtigkeiten über 20 m weit verbreitet. Der Tongehalt kann 40 % erreichen, weshalb sie gern verziegelt wurden. Ihre Häufung ist einmal durch die Position im Dahlenburger Becken bedingt, andererseits durch die Anlehnung der Grundmoräne an den Moränenrücken im SW des Blattes, wo sich auch hier Eem-Vorkommen häufen (insg. 36). Damit sind auf den beiden Blättern 73 Eem-Vorkommen bekannt, es könnten gut doppelt soviel sein, da nicht nur in den Trockentälern weitere Vorkommen völlig überschüttet wurden, wenn auch nur von sehr geringer Ausdehnung. Jedenfalls dürfte die Gegend nach Abschmelzen des letzten Saale-Eises von Toteislöchern überzogen gewesen sein, jedoch nicht so lückenlos wie in den jetzigen Jungmoränen-Gebieten, wo auf den Quadrat-km bis zu 10 Toteislöcher entfallen können – die zehnfache Menge wie hier.

Teils oberflächennah unter Bedeckung von Schmelzwassersand, teils unmittelbar an der Oberfläche anstehend und von km-langer Ausdehnung sind einige Beckenschluff-Vorkommen auf GK 25 Stelle Nr. 2626 (Meyer 1985, Tab. 4). Die noch Anfang der 80er Jahre arbeitende Ziegelei Scharmbeck betrieb eine flache Grube, aus der die Pr. 8–10 der Tab. 2 entnommen wurden. Während die Pr. 8 und 10 sehr hohe Tongehalte (40,3 bzw. 34 %) zeigten, ging derselbe in Pr. 2 auf 5,5 % zurück, dafür stieg der Grobschluff auf 70,3 % an, bei ungewöhnlich niedrigem Feinsandgehalt. Der Kalkgehalt war mit 8,4 % relativ niedrig. Die Mächtigkeit des Schluffs nimmt außerhalb des Vorkommens offenbar rasch ab, wogegen derselbe in dem zwischen Scharmbeck und Ashausen gelegenen Gebiet in der Drillbohrung G 84 mit 50 m nicht durchteuft wurde. Ebenfalls auf Blatt Stelle war in der NW-Ecke desselben beim Autobahn-Neubau im Jahre 1974 gut gebänderter, sandstreifiger Beckenschluff in stark verfaltetem Zustand angeschnitten, diskordant z.T. mit Steinsohle an der Basis von Schmelzwassersand überlagert (Abb. 8). Das Profil ist in den Erläuterungen auf Abb. 5 dargestellt sowie in etwas veränderter Form von Grube & Ehlers 1975 beschrieben.

Westlich der Hamburger Berge wurden größere Beckenschluff-Vorkommen mehrfach durch Bohrungen im Liegenden der Drenthe-Hauptmoräne nachgewiesen wie auf GK 25 Buxtehude Nr. 2424 (Meyer 1982) und GK 25 Hollenstedt Nr. 2524 (Höfle 1982). Vom südlichen Anschlussblatt Nr. 2725 Tostedt beschrieb Harms 1986, Abb. 7 und 8 zwei kleinere Vorkommen an der Oberfläche nahe Tostedt: eines von Jüngerer Drenthe-Moräne überlagert, ein anderes direkt im Hangenden derselben aufgeschlossen an der Bundesbahn-Ausbaustrecke am Bahnhof Tostedt. Es sind feingeschichtete Schluffe mit Feinsandlagen (Foto-Abb. 8 in Harms 1986).

Mächtige Beckenschluffe, vielleicht nicht zufällig über einer mit Lauenburger Ton gefüllten elsterzeitlichen Rinne liegend, stellte Höfle (1995) auf dem Profil der Grundkarte des Blattes 2826 Egestorf dar, ebenfalls die Drenthe-Hauptmoräne unterlagernd und ihrerseits im Luhetal bei Schwindebeck von eemzeitlicher Kieselgur überlagert.

Von den zahlreichen früheren Ziegeleien namentlich im Uelzener Becken liegen kaum Untersuchungen vor, und die alten Erläuterungen sind für stratigraphische Bewertungen nicht ausreichend. Das ist besonders deshalb bedauerlich, als hier mit warthezeitlichen Beckenablagerungen zu rechnen ist. Da warthezeitliche Vorschüttsande und Kiese selten sind, wären zwischen Warthe- und Drenthe-Grundmoräne eingeschaltete Beckenschluffe wie offenbar im bereits erwähnten Emmendorf ein wichtiger Hinweis für einen Eisrückzug oder zumindest Stillstand zwischen beiden Vorstößen bzw. Eisströmen.

Es ist die gleiche Fragestellung wie in der benachbarten Altmark, wo der auf den alten GK 25 dargestellte warthezeitliche „Rote Altmärker Geschiebemergel“ so enge Beziehungen zu Beckenbildungen zeigt, dass warthezeitliches Alter auch für letztere wahrscheinlich ist. Die Häufung saalezeitlicher Beckenschluffe in NE-Niedersachsen wird auf der quartärgeologischen Übersichtskarte 1 : 500 000 von Niedersachsen und Bremen deutlich, ebenso deren Seltenheit in den übrigen Gebieten. Eine gewisse Ausnahme bilden die GK 25 3125 Bergen, 3224 Westenholz, 3121 Husum und 3422 Neustadt, wo sandig-tonige Schluffe zumeist unter der saalezeitlichen Grundmoräne liegen. Dazu treten auch schluffige Feinsande. Über die Mächtigkeiten dieser Bildungen ist wenig bekannt.

Abb. 7: Beckenschluff, steilgestellt, zwischen Drenthe-Hauptmoräne und Jüngerer Drenthe-Moräne, 20 m mächtig. Elbsteilufer Lauenburg, GK 25 Nr. 2629, Lauenburg. Foto K.-D. Meyer 1963.

Fig. 7: Drenthian glaciolacustrine silt, steep folded. Bluffs oft he Elbe River W Lauenburg.

Abb. 8: Bänderschluff, gestaucht, diskordant von Schmelzwassersand überlagert. Autobahn-Einschnitt, N-Seite, bei Karoxbostel, GK 25 Nr. 2626 Stelle. Foto K.-D. Meyer 1974.

Fig. 8: Drenthian Varved silt, folded, overlain by fluvioglacial sand. Construction pit Karoxbostel.

4. Schlussfolgerungen

In Niedersachsen sind glazilimnische Tone und Schluffe in den einzelnen Regionen und auch stratigraphisch sehr unterschiedlich verbreitet. Sehr selten sind Bändertone, die in Mitteldeutschland eine so große Rolle spielen. Elsterzeitliche Beckenbildungen sind im Bergland kaum bekannt, spielen dafür im Flachland eine desto größere Rolle, besonders als Füllung in den höheren Abschnitten der tiefen subglazialen Rinnen, wo sie mit dem Lauenburger Ton maximal 170 m Mächtigkeit erreichen können.

Zur Saale-Eiszeit erreichte das Eis den Harznordrand und es kam zum Aufstau lokaler Becken bis in einige Täler hinein. Dies war auch im Leine- und Weser-Bergland der Fall, in beiden Tälern mit Absatz von Bändertonen auf der frühdrenthezeitlichen Mittelterrasse. Anschließend kam es zur Überfahrung durch den Drenthe-Gletscher und Überlagerung mit dessen Grundmoräne, wobei Schmelzwasser-Aufschüttungen einschließlich lokaler Beckenbildung noch etwas über die Maximalgrenze des Eises hinausgegangen sein können wie im Raum Gandersheim.

Zur Ausbildung großer Stauseen, die weit in die Nebentäler des Leine- und Wesersystems hineinreichten mit einer Seehöhe von über 200 m ist es jedoch offensichtlich nicht gekommen. Bei den namentlich im Leinegebiet von Winsemann et al. (2011) angegebenen Fundpunkten von „lake bottom sediments“ handelt es sich entweder um stratigraphisch ältere Schichten oder die Füllung von Subrosionssenken, auch um Interglazialsedimente wie von Bilshausen und Sohlingen.

Kein Beweis für große Stauseen ist auch das angeblich von Eisschollen verdriftete Material, da die Punkte ausschließlich innerhalb des ehemals vergletscherten Gebietes liegen und alle nicht autochthon sind, mit Ausnahme sehr zweifelhafter Funde oberhalb Holzminden und bei Hann.-Münden.

Hätte es tatsächlich so große Stauseen gegeben, müsste man auch entsprechende Ablagerungen finden. Da diese bis auf die Randgebiete der Vergletscherung fehlen, ist auch die angeblich subaquatische Bildung der großen Sandfächer von der Porta bis zum Harzrand nicht akzeptabel.

Im Gegensatz zum Bergland sind Beckenschluffe im Flachland weit verbreitet, besonders in Nordost-Niedersachsen, wo sie nicht selten in km^2-großen Vorkommen bis zu einigen 10er m-Mächtigkeit verbreitet sind, in geringerer Mächtigkeit auch in Tagesaufschlüssen, wo sie früher in zahlreichen Ziegeleien abgebaut wurden.

5. Danksagung

Für kritische Durchsicht des Manuskript und Hinweise dankt der Autor Frau M. Böse, Berlin und den Herren J. Elbracht, Hannover, F. Junge, Leipzig und S. Wansa, Halle. Für die Korngrößenanalysen ist den Mitarbeitern des Sedimentlabors des früheren NLfB zu danken, ebenso anderen Kollegen dieser Dienststelle sowie denjenigen benachbarter Geologischer Landesämter und Institute. Das Abstract erstellte Herr H. Toms, Celle.

Literaturverzeichnis

Alexander, I. (2002): Bernstein-Vorkommen in Niedersachsen. Untersuchungen zu geologischer Altersstellung, Herkunft und Transportmechanismen. – Dipl.-Arbeit F. B. Geowissenschaften (unveröff.), 81 S., 106 Abb., 2 Tab., Anhang; Bremen.

Attig, K. (1965): Das Quartär südöstlich der Porta Westfalica unter besonderer Berücksichtigung der glazifluviatilen Sedimente. – Dipl.-Arb. u. Karte: 43. S., 3 Taf., 2 Prof., 3Kt.; Braunschweig (unveröff.).

Benda, L. & Meyer, K.-D. (1973): Das Holstein-Interglazial von Breetze bei Bleckede / Elbe. – Geologisches Jahrbuch, A 9: 21–40, 3 Abb., 2 Tab.; Hannover.

Bettenstaedt, F. (1934): Stauseebildung und Vorstoß des diluvialen Inlandeises in seinem Randgebiet bei Halle a. S. – Jahrbuch des Halleschen Verbandes, N. F., 13: 241–313, 16 Abb., 2 Taf.; Halle.

Dahm, D. & Otto, W. (1953): Über Lebensspuren in Bändertonen Nordwestdeutschlands. – Freiburger Forschungshefte, C5: 39–40, 3 Abb.; Berlin.

Deutloff, O. (1995): Geologische Karte Nordrhein-Westfalen 1 : 25000, Erl. Blatt 3818 Herford, 2. Aufl.: 182 S., 13 Abb., 17 Tab., 2 Taf.; Krefeld.

Dewers, F., Gripp, K. & Overbeck, F. (1941): Das Känozoikum in Niedersachsen. – Geologie und Lagerstätten Niedersachsens, 3; Schriften der Wirtschaftswissenschaftlichen Gesellschaft zum Studium Niedersachsens e.V., N. F. 3, 503 S., 216 Abb., 15 Tab., 1 Taf.; Oldenburg.

Ehlers, J., Meyer, K.-D. & Stephan, H.-J. (1984): The Pre-Weichselian Glaciations of North-West Europe. – Quaternary Science Reviews, 3: 1–40, 11 Abb., 1 Tab., 3 Taf.; Oxford.

Ehlers, J. & Linke, G. (1989): The origin of deep buried channels of Elsterian age in Northwest-Germany. – Journal of Quaternary Science, 4 (3): 255–265, 7 Fig.; Harlow.

Eissmann, L. (1967): Glaziäre Destruktionszonen (Rinnen, Becken) im Altmoränen-Gebiet des Norddeutschen Tieflandes. – Geologie, 16 (7): 804–833, 19 Abb., 1 Tab.; Berlin.

Eissmann, L. (1975): Das Quartär der Leipziger Tieflandsbucht und angrenzender Gebiete um Saale und Elbe. – Schriftenreihe für geologische Wissenschaften, 2: 263 S., 58 Abb., 23 Tab., 17 Taf.; Berlin.

Eissmann, L. (1987): Lagerungsstörungen im Lockergebirge. Exogene und endogene Tektonik im Lockergebirge des nördlichen Mitteleuropa, Geophysik und Geologie. – Geophysikalische Veröffentlichungen der Karl-Marx-Universität Leipzig, 3. Ser.; III (4): 7–77, 35 Abb.; Berlin.

Elsner, H. (2003): Verbreitung und Ausbildung Elster-zeitlicher Ablagerungen zwischen Elm und Flechtiger Höhenzug. – Eiszeitalter und Gegenwart, 52: 91–116, 6 Abb., 1 Tab.; Hannover.

Feldmann, L. & Meyer, K.-D. (Hrsg.) (1998): Quartär in Niedersachsen. Exkursionsführer zur Jubiläums-Hauptversammlung der Deutschen Quartärvereinigung in Hannover. – 205 S., 88 Abb., 9 Tab.; Hannover.

Gauger, W. & Meyer, K.-D. (1970): Ostbaltische Geschiebe (Dolomite, Old Red-Sandsteine) im Gebiet zwischen Lüneburg und Uelzen. – Der Geschiebesammler, 5 (1): 1–12, 1 Abb., 2 Tab.; Hamburg.

Grube, F. (1979): Übertiefte Täler im Hamburger Raum. – Eiszeitalter und Gegenwart, 29: 157–172, 11 Abb.; Hannover.

Grube, F. & Ehlers, J. (1975): Pleistozäne Flußsedimente im Hamburger Raum. –Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg, 44: 353–382, 6 Abb.; 1 Taf., Hamburg.

Grupe, O. (1923): Über die Ausdehnung der ältesten (drittletzten) Vereisung in Mitteldeutschland. – Jahrbuch der Preussischen Geologischen Landesanstalt zu Berlin. [für 1921], 42: 161–174, 1 Abb.; Berlin.

Grupe, O. (1930): Die Kamesbildungen des Weserberglandes. – Jahrbuch der Preussischen Geologischen Landesanstalt zu Berlin. , 51: 350–370, 6 Taf., 1 Abb.; Berlin.

Harms, F. – J. (1986): Zur Geologie saalezeitlicher Sedimente am Rand des Leinetals zwischen Imsen und Freden. – Beiträge zur Naturkunde Niedersachsens, 36 (2): 53–69, 14 Abb., 3 Tab.; Hannover.

Harms, F. – J. (1986): Geol. Karte Niedersachsen 1 : 25000. Erl. Blatt 2724 Tostedt. – 117 S., 24 Abb., 7 Tab., 8 Kt.; Hannover.

Herrmann, R. (1958): Eisrandablagerungen und Fließerden am Nordrand des Leineberglandes. – Geologisches Jahrbuch, 76: 309–320, 6 Abb.; Hannover.

Herrmann, R. (1968): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 3923 Salzhemmendorf. – 133 S., 10 Abb., 5 Tab., 3 Taf., 1 Kt.; Hannover.

Höfle, H.-Chr. (1982): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 2624 Hollenstedt. – 75 S., 6 Abb., 7 Tab., 7 Kt.; Hannover.

Höfle, H.-Chr. (1995): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 2826 Egestorf. – 116 S., 5 Abb., 4 Tab., 8 Kt.; Hannover.

Homann, M. & Lepper, J. (1994): Das Cromer-Profil von Sohlingen (Süd-Niedersachsen). – Geologisches Jahrbuch., A 134: 211–228, 5 Abb., 1 Tab.; Hannover.

Janszen, A., Moreau, J., Moscariello, A., Ehlers, J., Kröger, J. (2013): Time-transgressive tunnel-valley inftill revealed by a three-dimensional sedimentary model, Hamburg, north-west Germany. – Sedimentology, 60 (3): 693–719, 10 Fig., 2 Tab.; Oxford.

Jordan, H. (1984): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 4325 Nörten-Hardenberg: 148 S., 12 Abb., 13 Tab., 8 Kt.; Hannover.

Jordan, H. (1986): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 4225 Northeim West. – 144 S., 13 Abb., 13 Tab., 7 Kt.; Hannover.

Jordan, H. (1993): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 4125 Einbeck: 107 S., 12 Abb., 18 Tab., 6 Kt.; Hannover.

Jordan, H. (1994): Geol. Karte Niedersachsen 1 : 25000, Erl. Blatt 4024 Alfeld: 126 S., 17 Abb., 13 Tab., 7 Kt.; Hannover.

Jordan, H. & Schwartau, W. (1993): Das Lößprofil von Ahlshausen und weitere tiefe Quartäraufschlüsse entlang der Bundesbahn-Neubaustrecke bei Northeim. – Eiszeitalter und Gegenwart, 43: 110–122, 9 Abb., 3 Tab.; Hannover.

Junge, F. W. (1998): Die Bändertone Mitteldeutschlands und angrenzender Gebiete – ein regionaler Beitrag zur quartären Stausee-Entwicklung im Randbereich des elsterglazialen skandinavischen Inlandeises. – Altenburger Naturwissenschaftliche Forschungen, 9: 3–210, 58 Abb., 40 Bilder, 31 Tab.; Altenburg.

Junge, F. W. & Eissmann, L. (2000): Postsedimentäre Deformationsbilder in mitteldeutschen Vorstoßbändertonen – Hinweise auf den Bewegungsmechanismus des quartären Inlandeises. – Brandenburgische Geowissenschaftliche Beiträge, 7: 21–28, 6 Abb.; Kleinmachnow.

Junge, F. W., Böttger, T. & Siegert, Ch. (1999): Die Stauseesedimente des Bruckdorfer Horizontes: Ergebnis der Eisrandoszillation des saaleglazialen skandinavischen Inlandeises in Mitteldeutschland. – Mauritiana, 17 (2): 257–276, 3 Abb., 9 Bilder; Altenburg.

Kaltwang, J. (1986): Geologische Kartierungen im Raum Bad Gandersheim (Blatt Bentierode, DGK Nr. 4126/13). – 32 S., 3 Abb., 1 Anl.; unveröff., Anhang: Tief- u. Handbohrungen (Univ. Hannover).

Kaltwang, J. (1992): Die pleistozäne Vereisungsgrenze im südlichen Niedersachsen und im östlichen Westfalen. – Mitteilungen aus dem Geologischen Institut der Universität Hannover, 33: 161 S., 7 Abb., 38 Tab., 49 Kt.; Hannover.

Kulle, S. (1985): Drenthe-stadiale Staubeckensedimente (Pleistozän) und ihr Lagerungsverband aus zwei Aufschlüssen im Wesertal zwischen Rinteln und Hameln. unveröff. Dipl.-Arb., 82 S., 18 Abb., 8 Tab., 4 Taf., 3 Anl.; Hannover.

Kuster, H. & Meyer, K.-D. (1979): Glaziäre Rinnen im mittleren und östlichen Niedersachsen. – Eiszeitalter und Gegenwart, 29: 135–156, 5 Abb., 3 Tab., 1 Kt.; Hannover.

Lang, J. & Winsemann, J. (2012): The 12 II DB outcrop section at Schöningen: sedimentary facies and depositional architecture. – in: K. –E. Behre (Hrsg.): Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen: 39–59, 11 Fig.; 1 Tab.; Mainz.

Lang, J. & Winsemann, J. (2013): Lateral and vertical relationships of bedforms deposited by aggrading supercritical flows: from cyclic steps to humpback dunes. – Sedimentary Geology, 296: 36–54; Amsterdam.

Lepper, J. (1977): Geologische Karte Niedersachsen 1 : 25000, Erl. Blatt 4323 Uslar: 129 S., 14 Abb., 13 Tab., 10 Taf., 7 Kt.; Hannover.

Linke, G. (1993): Zur Geologie und Petrographie der Forschungsbohrungen qho 1-5, der Bohrung Hamburg-Billbrook und des Vorkommens von marinem Holstein im Gebiet Neuwerk-Scharhörn. – Geologisches Jahrbuch, A 138: 35–76, 23 Abb., 7 Tab.; Hannover.

Lüttig, G. (1955): Alt- und mittelpleistozäne Eisrandlagen zwischen Harz und Weser. – Geologisches Jahrbuch., 70: 43–125, 16 Abb., 1 Taf.; Hannover.

Lüttig, G. (1960): Neue Ergebnisse quartärgeologischer Forschung im Raume Alfeld – Hameln – Elze. – Geologisches Jahrbuch, 77: 337–390, 11 Abb., 5 Tab., 3 Taf.; Hannover.

Mangelsdorf, P. (1981): Quartärgeologische und paläobotanische Untersuchungen der Schichtenfolge der Tongrube „Nachtigall" N Höxter / Weser. – Dipl.-Arb., 63 S., 12 Abb., 6 Tab., 3 Taf.; Hannover (unver.)

Meinsen, J., Winsemann, J., Weitkamp, A., Landmeyer, N., Lenz, A. & Dölling, M. (2011): Middle Pleistocene (Saalian) lake outburst floods in the Münsterland Embayment (NW Germany): impacts and magnitudes. – Quaternary Science Reviews 30, S. 1–29, 24 Fig.; Amsterdam.

Merkt, J. (1980): Zur Bildung der Quellmoore: Die geologischen Voraussetzungen. – Mitteilungen der floristisch-soziologischen Arbeitsgemeinschaft, N. F. 22: 135–138, 3 Abb., Göttingen.

Meyer, K.-D. (1965): Das Quartärprofil am Steilufer der Elbe bei Lauenburg. – Eiszeitalter und Gegenwart, 16: 47–60, 3 Abb., 1 Taf.; Öhringen / Württ.

Meyer, K.-D. (1982): Geol. Karte Niedersachsen 1: 25 000. Erl. Blatt 2524 Buxtehude. –120 S., 22 Abb., 8 Tab., 7 Kt.; Hannover.

Meyer, K.-D. (1985): Geol. Karte Niedersachsen 1: 25 000. Erl. Blatt 2626 Stelle. – 95 S., 9 Abb.,7 Tab., 8 Kt.; Hannover.

Meyer, K.-D. (1997): Schutzwürdige Zeugnisse der Eiszeiten in Niedersachsen. – Schriftenreihe der Deutschen Geologischen Gesellschaft, 5: 98–100, 8 Taf.; Hannover.

Meyer, K.-D. (2004): Geol. Karte Niedersachsen 1: 25 000. Erl. Blatt 2730 Bleckede: 136 S., 14 Abb., 14 Tab., 3 Kt.; Hannover.

Meyer, K.-D. (2009): Geol. Karte Niedersachsen 1: 25 000. Erl. Blatt 2830 Dahlenburg: 33 S., 5 Abb., 4 Tab., 1 Kt.; Hannover.

Meyer, K.-D. (2012): Stratigraphie des Saale-Komplexes in Niedersachsen und die Schöninger Profile. – in: K.-E. Behre (Hrsg.): Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen. Forschungen zur Urgeschichte aus dem Tagebau von Schöningen, 1: 61–76 S., 19 Abb., 2 Tab.; Mainz.

Meyer, K.-D. & Schneekloth, H. (1973): Geol. Karte Niedersachsen 1 : 25000. Erl. Blatt Neuenwalde Nr. 2318. – 80 S., 1 Kt., 12 Abb., 1 Tab., 3 Taf.; Hannover.

Meyer, K.-D. & Roland, N. W. (2016): Eisströme – Dynamik und Sedimente. An Beispielen des Quartärs von Norddeutschland. Geologisches Jahrbuch.; A 161: 120 S., 34 Abb., 6 Tab.; Hannover.

Müller, H. & Höfle, H.-Ch. (1994): Die Holstein-Interglazialvorkommen bei Bossel westlich von Stade und Wanhöden nördlich Bremerhaven. – Geologisches Jahrbuch, A 134: 71–116, 13 Abb., 5 Tab.; Hannover.

Pilger, A. (1991): Die nordischen Gletscher am nordwestlichen Harzrand und ihre Stauseen. – (mit Beitr. v. P. Mocha, B. Petzold u. A. Rösler) Clausthaler Geologische Abhandlungen, 48: 159 S., Abb; Köln.

Rakowski, B. (1990): Aufbau und Genese der „Emme" – eines Schmelzwasser-Schwemmfächers auf der Südseite des Wesergebirges bei Kleinenbremen (Bückeburg). – Dipl. Arb. Univ. Hannover, 95 S.; Hannover (unveröff.).

Rausch, M. (1975): Der „Dropstein-Laminit" von Bögerhof und seine Zuordnung zu den Drenthe-zeitlichen Ablagerungen des Wesertals bei Rinteln. – Mitteilungen aus dem Geologischen Institut der Universität Hannover, 12: 51–84, 8 Abb., 1 Taf.; Hannover.

Rausch, M. (1977): Fluß-, Schmelzwasser- und Solifluktionsablagerungen im Terrassengebiet der Leine und der Innerste. – Mitteilungen aus dem Geologischen Institut der Universität Hannover, 14: 84 S., 16 Abb., 4 Tab., 1 Taf.; Hannover.

Rohde, P., Lepper, J. & Thiem, W. (2012): Younger Middle Terrace – Saalian pre-Denthe deposits overlying MIS 7 Nachtigall interglacial strata near Höxter / Weser, NW-Germany. – Eiszeitalter und Gegenwart, 61 (2): 133–145, 6 Abb., 2 Tab.; Hannover.

Röhm, H. (1985): Bau und Zusammensetzung Saale-eiszeitlicher Sedimentkörper im Raum Hausberge-Veltheim / Weser. – Unveröff. Dipl.-Arbeit u. Kartierung, 107 S., 53 Abb., 7 Anl.; Hannover.

Schucht, F. (1912): Der Lauenburger Ton als leitender Horizont für die Gliederung und Altersbestimmung des nordwestdeutschen Diluviums. – Jahrbuch der Preussischen Geologischen Landesanstalt zu Berlin. 29 II [für 1908] 130–150, 1 Taf.; Berlin.

Schulz, W. (1962): Die Gliederung des Pleistozäns in der Umgebung von Halle (Saale). – Geologie, Beih., 36, 69 S., 31 Abb., 1 Tab.; Berlin.

Spethmann, H. (1908): Glaziale Stillstandslagen im Gebiet der mittleren Weser. – Mitteilungen der Geographischen Gesellschaft in Lübeck, 22: 1–17, 1 Abb.; Lübeck.

Stach, E. (1930): Die Eisrandbildung an der Porta Westfalica. Jahrbuch der Preussischen Geologischen Landesanstalt zu Berlin. 51: 174 –187, 2 Abb., 3 Taf.; Hannover.

Thome, K. N. (1983): Gletschererosionen und -akkumulationen im Münsterland und angrenzenden Gebieten. – Neues Jahrbuch für Geologie Paläontologie, Abh.; 166: 116–138, 2 Abb.; Stuttgart.

Uebersohn, D. (1990): Aufbau und Alter pleistozäner Lockersedimente bei Bornhausen (Nord-Westliches Harzvorland). – 57 S., 19 Abb., 8 Tab., Anl.; unveröff. Dipl.-Arb. F. B. Erdwiss. Univ.; Hannover.

Unger, K. P. (1974): Die Elstervereisung des zentralen Thüringer Keuperbeckens. – Zeitschrift für geologische Wissenschaften, 2 (7) 791–800. 3 Abb.; Berlin.

Urban, B., Thieme, H. & Elsner, H. (1988): Biostratigraphische, quartärgeologische und urgeschichtliche Befunde aus dem Tagebau „Schöningen", Ldkr. Helmstedt. – Zeitschrift der deutschen geologischen Gesellschaft, 139: 123–154, 9 Abb., 1 Taf.; Hannover.

Wellmann, P. (1990): Aufbau und Genese des Saale-eiszeitlichen Kies- / Sandkörpers von Krankenhagen-Möllenbeck. – Dipl.-Arb. Univ. Hannover, 84 S., 45 Abb., 1 Tab., 13 Anl.; Hannover (unveröff.).

Wellmann, P. L. (1998): Kies-/Sandkörper im Wesertal zwischen Rinteln und Porta Westfalica. – Mitteilungen aus dem Geologischen Institut der Universität Hannover, 38: 203–212, 6 Abb.; Hannover.

Wiegers, F. (1952): Nordische Feuersteine im diluvialen Terrassenschotter der Werra. – Zeitschrift der deutschen geologischen Gesellschaft, 103: 78–82, 1 Abb.; Hannover.

Winsemann, J., Brandes, Ch., Polom, U. & Weber, Ch. (2011): Depositionale architecture and palaeogeographic significance of Middle Pleistocene glaciolacustrine ice marginal deposits in northwestern Germany: a synoptic overview. – Eiszeitalter und Gegenwart, 60 (2/3): 212–235, 16 Fig.; Hannover.

Wortmann, H. (1937): Die Terrassen der Diemel zwischen Sauerland und Weser. Jahrbuch der Preußischen Geologischen Landesanstalt zu Berlin, 57: 359–413, 6 Abb., = Taf.; Berlin.

Wortmann, H. (1968): Die morphogenetische Gliederung der Quartärbasis des Wiehengebirgsvorlandes in Nordwestdeutschland. – Eiszeitalter und Gegenwart, 19: 227–239, 4 Abb., 1 Tab., 1 Taf.; Öhringen/ Württ.

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / 44-56 / DOI 10.3285/eg.66.1.04
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

The morphological units between the end moraines of the Pomeranian phase and the Eberswalde ice-marginal valley (Urstromtal), Germany – a critical examination by means of a high-resolution DEM

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How to cite: Krambach, M., Böse, M. (2017): The morphological units between the end moraines of the Pomeranian phase and the Eberswalde ice-marginal valley (Urstromtal), Germany – a critical examination by means of a high-resolution DEM. – E&G Quaternary Science Journal, 66 (1): 44–56. DOI: 10.3285/eg.66.1.04

Abstract: The area between the Pomeranian end moraine and the town of Eberswalde, located in the Torun-Eberswalde ice marginal valley (IMV), has long been considered to represent a sequence of proglacial landforms in good agreement with the model of the glacial series of Penck & Brückner (1901–1909). The most prominent geomorphological feature in the area is the Pomeranian end moraine which was formed at about 20 ka. However, the meltwater deposits in the research area were not only formed by meltwaters from the Pomeranian ice margin but also by those draining the Parstein and the Angermünde subphases of the retreating Scandinavian Ice Sheet (SIS). The main meltwater discharge was assumed to have followed a major valley structure, which today forms a gap in the end moraine ridge. The analysis of the landforms, their altitudes as well as the surface features, by means of a high-resolution digital elevation model (DEM) based on light detection and ranging (LiDAR) data now allow a new interpretation. The newly reconstructed relative chronology of meltwater drainage in the area shows a much more complex picture: The Britz Forest, the highest glaciofluvial landform which was formerly considered to be a sandur of a recessional subphase, is now interpreted as a pre-Pomeranian meltwater deposit, because of its altitude and its smoothened surface. The Ragöse Sandur, the Stadtforst and the Mönchsheide, as well as the Amtsweg Sandur were previously considered to be either sandurs of the Pomeranian phase, partly underlain by dead ice, or to represent sandur of a recessional subphases. However, DEM analysis clearly shows that Ragöse sandur lacks any fluvial pattern and consists of sedimentary lobes perpendicular to the front of the end moraine. A similar structure can be identified on the Amtsweg sandur. Both are therefore attributed to several small meltwater outlets at the Pomeranian end moraine. The Klosterbrücke Sandur was formed by different successional processes but its initial formation is also now attributed to the Pomeranian phase of the SIS. In contrast, the Stadtforst and the Mönchsheide show a distinct east-west directed fluvial pattern, and are therefore not sandur deposits of the Pomeranian phase. The Stadtseerinne and Neuhütter Rinne can be traced across the IMV and their origin can therefore be attributed to a pre-Pomeranian ice advance and subsequent conservation by dead ice during the Pomeranian phase and the following subphases. According to the DEM based landform analysis, a lower meltwater discharge than that derived from previous reconstructions is very likely. In addition, the landforms are likely to have experienced a longer and more complex genesis then previously assumed. The DEM analyses also support the assumption that at least in parts, transformation of the landscape by periglacial processes also played a significant role.

Die geomorphologischen Einheiten zwischen der Endmoräne des Pommerschen Stadiums und dem Eberswalder Urstromtal (Deutschland) – eine kritische Überprüfung mittels eines hochaufgelösten Digitalen Geländemodells

Kurzfassung: Die Geländeformen im Gebiet zwischen der Pommerschen Endmoräne und der Stadt Eberswalde, die im Thorn-Eberswalder Urstromtal (IMV) liegt, sind lange Zeit als eine typische proglaziale Abfolge im Sinne der Glazialen Serie von Penck & Brückner (1901–1909) gedeutet worden. Die deutlichste morphologische Erscheinung ist die Pommersche Endmoräne, die um 20 ka gebildet wurde. Die Schmelzwasserablagerungen gehören jedoch nicht nur zur Pommerschen Eisrandlage sondern wurden auch durch die Abflüsse der jüngeren Parsteiner und Angermünder Staffeln während des Abschmelzens des Skandinavischen Inlandeises gebildet. Es wurde davon ausgegangen, dass der Hauptabfluss durch einen Taldurchbruch, der heute eine Lücke in dem Endmoränenrücken bildet, erfolgte. Die Analyse der Geländeformen hinsichtlich ihrer Höhenlagen und ihrer Oberflächenformen mittels eines LiDAR-gestützten Höhenmodells (DGM) erlaubt nun eine neue Interpretation. Die neue, relative Chronologie der Schmelzwasserabflüsse in dem Gebiet zeigt ein deutlich komplexeres Bild: Der Britzer Forst, die am höchsten gelegene glazifluviale Geländeform, wurde bisher als ein Sander einer Rückzugsstaffel angesehen; nun wird das Gebiet als eine prä-Pommersche Schmelzwasserablagerung gedeutet. Diese Interpretation basiert auf der Höhe und der geglätteten Oberfläche. Der Ragöse Sander, der Stadtforst, die Mönchsheide und auch der Amtsweg Sander wurden entweder als Sander des Pommerschen Stadiums, die teilweise von Toteis unterlagert waren, oder als Sander von Rückzugsstaffeln beschrieben. Aber in dem DGM wird deutlich, dass die Oberfläche des Ragöse Sanders keine fluvialen Muster aufweist, sondern aus sedimentären Loben besteht, die von der Endmoräne ausgehen. Ein ähnlicher Aufbau kennzeichnet auch den Amtsweg Sander. Beide werden daher auf viele kleine Schmelzwasser-Ausflüsse an der Endmoräne zurückgeführt. Der Klosterbrücke Sander ist durch mehrere aufeinander folgende Prozesse gebildet worden, aber seine Anlage wird auf Schmelzwässer der Pommmerschen Eisrandlage zurückgeführt. Im Gegensatz dazu zeigen der Stadtforst und die Mönchsheide eine deutlich ost-west ausgerichtete fluviale Oberflächenstruktur und sind daher keine Sanderablagerungen vor der Pommerschen Eisrandlage. Die Stadtseerinne und die Neuehütter Rinne können quer durch das Urstromtal verfolgt werden, ihre Entstehung wird daher auf einen prä-Pommerschen Eisvorstoß zurückgeführt mit anschließender Konservierung durch Toteis während des Pommerschen Stadiums und der folgenden Rückzugsstaffeln. Aufgrund der Reliefanalyse auf der Basis des DGM wird nunmehr davon ausgegangen, dass die Schmelzwasserabflüsse geringer waren als bisher angenommen. Außerdem haben die Geländeformen offensichtlich eine längere und komplexere Entstehungsgeschichte. Die Reliefinterpretation auf der Basis des DGM stützt auch die Annahme, dass die Veränderung der Landschaft durch periglaziale Prozesse eine bedeutende Rolle gespielt habt.

Keywords: Pomeranian phase, meltwater deposits, ice-marginal valley, glacial geomorphology, Germany

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1 Introduction

The end moraines northeast of Eberswalde are prominent landforms of the Weichselian glaciation. They belong to the Pomeranian phase (qw2) (Terms according to Symbolschlüssel Geologie 2015), which is considered to be a glacial re-advance from the Baltic Sea depression. The Pomeranian phase followed the down-wasting of the of the Brandenburg phase ice lobe (qw1), the latter representing the maximum Weichselian ice advance (Lippstreu 1995, Lüthgens & Böse 2011).

After their first description by Berendt (1888), these end moraines and the areas surrounding them played major roles in establishing and discussing theories concerning the glaciation history of northern Central Europe. The research area itself focusses on the morphological units adjacent to the end moraines between the Pomeranian ice-marginal position and the Toruń-Eberswalde IMV (see Fig.1). The research area has been considered as a classical model for the glacial series landform concept of Penck & Brückner (1901–1909), extending beyond the glacier's front. Nevertheless it has been under controversial discussion concerning sedimentary and drainage patterns. In addition, there are different opinions on the development and the timing of the meltwater flow in the IMV in relation to the Oder valley. Liedtke (1956/57; 2001) postulates that the continuous east-west flow in the IMV was only possible from the Angermünder subphase onwards, as dead ice in the Oder basin (Oderbruch) blocked it during the Pomeranian phase and the meltwater streams flowed to the Warsaw-Berlin IMV. According to Liedtke (1956/57) the lower lying Oder valley was preserved by dead ice whereas Brose (1978) attributes the distinct lower valley bottom to Late Glacial-Early Holocene fluvial erosion. Börner (2007, Fig. 64) postulates an east-west flow through the IMV during the Angermünde subphase. All theories imply the formation of a pre-Pomeranian IMV which has been transformed during the Pomeranian phase. The research area was also influenced by meltwater streams from more northerly ice margins of the qw2 Parstein and Angermünde (qw2AN) subphases.

The main end moraine is a defining part of the Pomeranian phase and has been dated to about 20 ka by means of Optically Stimulated Lumincescence (OSL) (Lüthgens et al. 2011). In addition, Heine et al. (2009) dated the main end moraine by Surface Exposure Dating (SED) with ^{10}Be of erratic

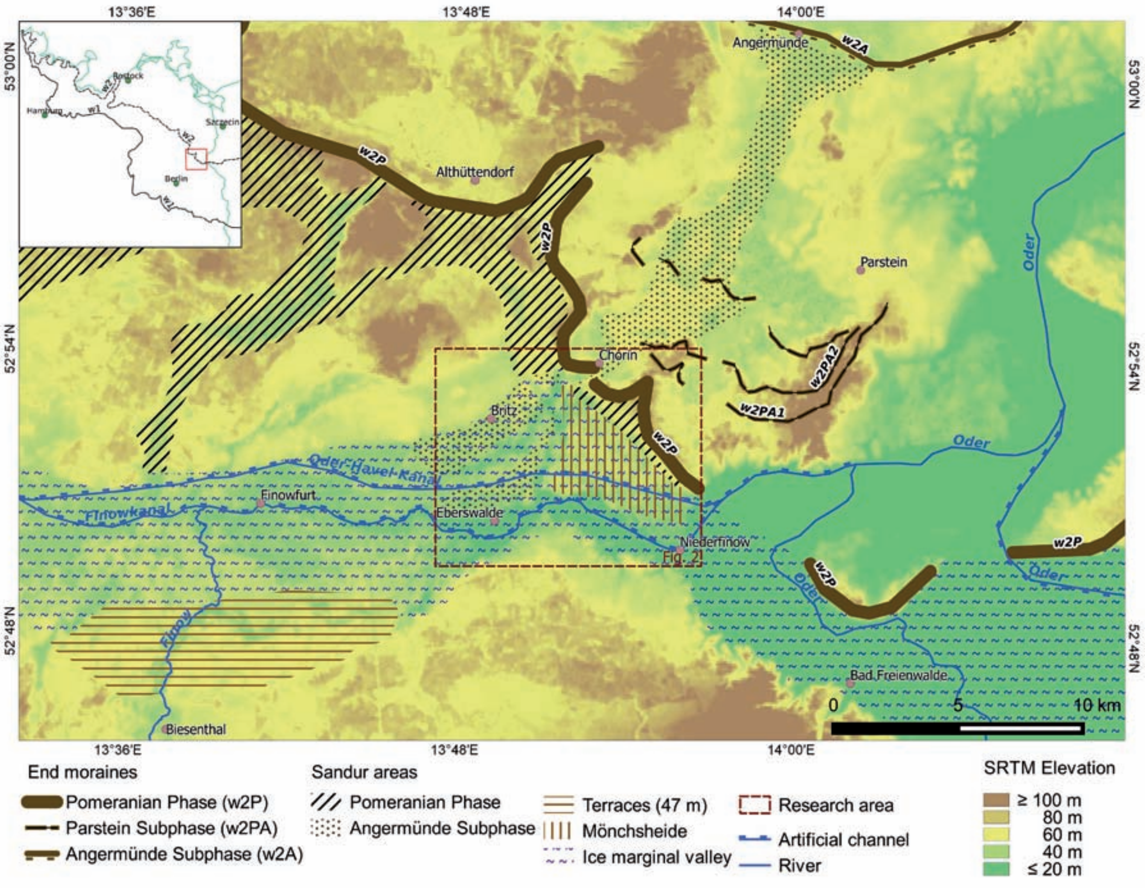

Fig.1: The location of the research area and the geomorphological units according to the classification of Liedtke (1956/57) and Brose (1978) (simplified).

Fig. 1: -Die Lage des Untersuchungsgebietes und der geomorphologischen Einheiten nach Liedtke (1956/57) und Brose (1978) (vereinfacht).

boulders. The results gave a wide range of ages, mainly in the Weichselian Late Glacial (15.6 ±0.7, 17.1±0.9 and 14.7±0.5 ka). Recently the surface exposure data published by Heine et al. (2009) have been recalculated by Hardt & Böse (2016), giving slightly older ages and therefore confirm the OSL results.

The area has been studied by Berendt 1888, Liedtke (1956/ 57), Brose (1978), Gärtner et al. (1995), Börner (2007), Lüthgens et al. (2011) and Pisarska-Jamroży (2013). The numerical dating work by means of OSL and SED of the Pomeranian main advance and the Angermünde retreat phase by Lüthgens et al. (2011), Heine et al. (2009), and Hardt & Böse (2016) provides the above-mentioned temporal framework.

The inconsistencies between the recent numerical data and the older geomorphological interpretations led to the present study, for which a geomorphological approach has been adopted. Using newly available data, which promise better insights on the surface in combination with an interpretation of sediment archives known from literature, new aspects of the relative chronology of the processes involved are revealed.

2 Methods

The DEM consists of data acquired and preprocessed by the *Landesvermessung und Geobasisinformation Brandenburg* (LGB) via airborne LiDAR in March 2011. The horizontal resolution is set at 5 m, the vertical accuracy is estimated at ± 0.3m. Data outside the research area were obtained from the topographical map 1:25.000.

The DEM was then processed to reveal slope, surface flow and hillshade, which were afterwards analysed visually with the help of profiles taken from the DEM. The main regional focus of the work lies in densely forested areas that were only scantily surveyed in the past.

The DEM results were compared with lithological properties given in literature, and the genesis of the landforms was then interpreted in a relative chronology.

3 The research area

The research area is almost triangular in form and lies between the Chorin village to the north and the part of the IMV west of the Oderbruch depression and east of the city of Eberswalde (Fig. 2).

The end moraine of the Pomeranian phase, marking the northeastern edge of the area, is a very distinct ridge with relative altitudes reaching 60 to 70 m a.s.l. A well visible gap in the end moraine ridge as part of a glaciofluvial channel system is caused by repeated locally concentrated meltwater flows from northerly directions. In this gap, the ruins of the Chorin monastery are located, therefore this morphological distinct interruption in the end moraine will be named the Chorin gap in the following text. The possible sandurs have been attributed to different phases of meltwater activities belonging the Pomeranian phase, the Parstein subphase and

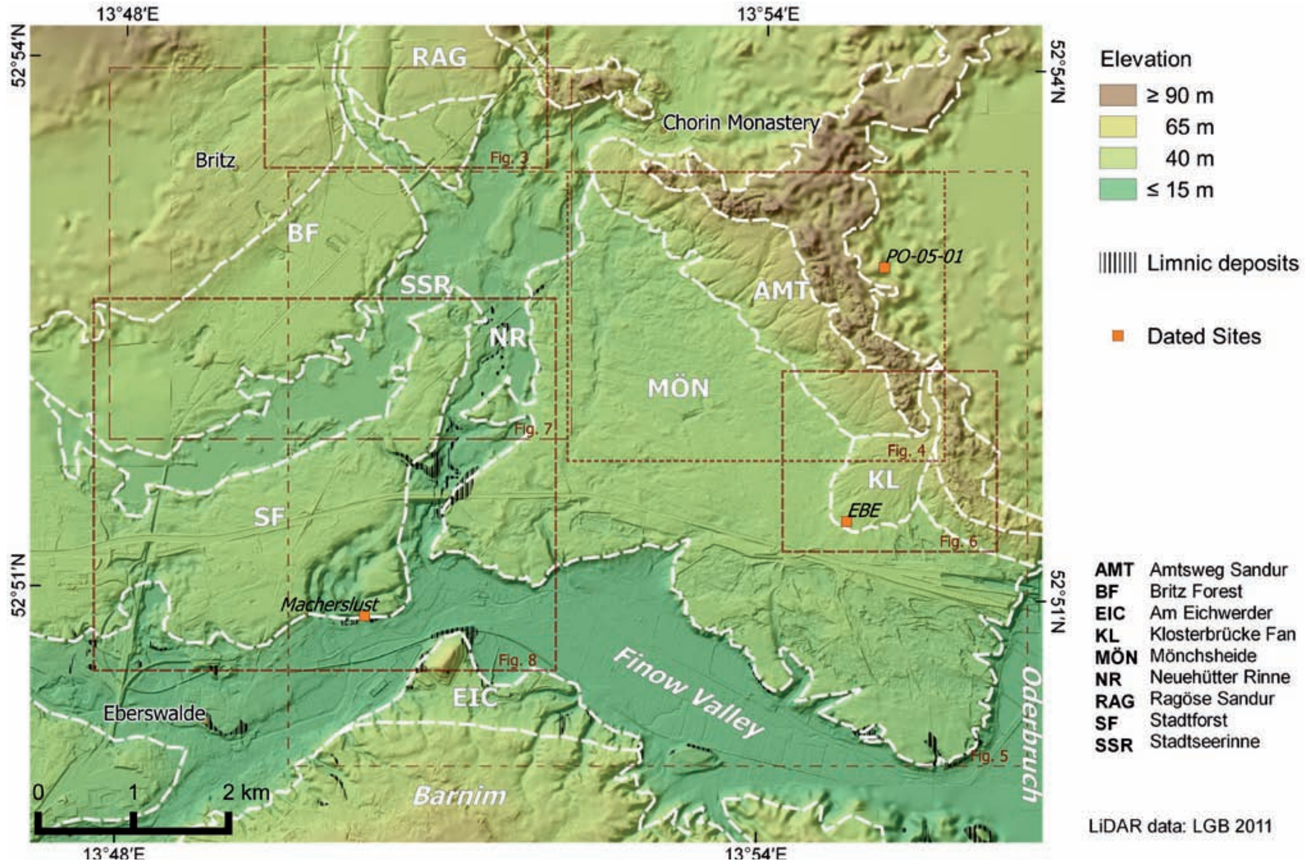

Fig. 2: Elevation model with hillshade (5-fold exaggerated), names of the main geomorphological units and sites of geochronological samples (PO-05-01 (Heine et al. 2009), EBE (Lüthgens et al. 2011), Macherslust (Schirrmeister 2004, Lüthgens et al. 2011, Pisarska-Jamroży 2013).

Fig. 2: Höhenmodell mit Schummerung (5fach überhöht), Namen der wichtigsten geomorphologische Einheiten und Lage der Probenentnahmestellen für geochronologische Datierungen (PO-05-01 (Heine et al. 2009), EBE (Lüthgens et al. 2011), Macherslust (Schirrmeister 2004, Lüthgens et al. 2011, Pisarska-Jamroży 2013).

the Angermünde subphase (Liedtke 1956/57, Brose 1978, Marcinek & Brose 1987, Brose 1995, Börner 2007).

It is thought that the IMV was not active as a continuous stream when the glacier formed the Pomeranian end moraine (Liedtke 1956/57, Kozarski 1966). The main discharge of the IMV has been rerouted through southern overflows, because the Oderbruch depression was blocked by dead ice at this time (Liedtke 1956/57). The occurrence of this is barrier is controversial (cf. the discussion by Liedtke (2001) vs. Brose et al. (2003)). The latter authors consider the Oderbruch as a fluvial erosional feature formed after deglaciation, having a higher valley bottom at the time of the IMV.

For the research area itself the main qw2 glaciofluvial sediments were thought to be represented by the Ragöse Sandur, derived from the north, described as a sandur valley originating at Althüttendorf, north of the research area (Liedtke 1956/57:11; Fig.1). The Amtsweg Sandur links directly to the terminal moraines and is of similar age; this phase corresponds to accumulation of terrace deposits at 47 m a.s.l. southwest of Eberswalde (Liedtke 1956/57) (Fig.1).

Following the glacial retreat from the Pomeranian ice-marginal position, the IMV became active in an east-west direction, albeit for a short period. The glaciofluvial breakthrough at the terminal moraines east of Oderberg, east of the research area, marks the end of the IMV activity. The meltwaters then followed the modern Oder valley towards the Noteć-Randow IMV further north (Marcinek & Brose 1987, Börner 2007).

Therefore, the Eberswalde IMV should have been occupied during the Angermünde subphase (qw2AN) (Liedtke 1956/57, Kozarski 1966). At that time, meltwaters from the north-northeast followed a channel through the Chorin gap, a transverse valley in the end moraine of Pomeranian phase. To the south, the alluvial fan merges with the main terraces of the IMV at Eberswalde at about 37.5 m a.s.l.,i.e. the "main terrace" level of Liedtke (1956/57).

Brose (1978) and Marcinek & Brose (1987) introduced an additional subphase between the Pomeranian phase and the Angermünde subphase, the Parstein subphase (qw2PA). The meltwater deposits related to this still stand correspond to terrace surfaces at 40–42 m a.s.l. (Marcinek & Brose 1987) in the IMV. The waters passed through the gap at the Chorin monastery and another gap at Klosterbrücke to merge with the main terraces at an unspecified location.

In addition, banded lake deposits, documented and dated in terrace outcrops east of Eberswalde gave ages of Late Glacial time and represent the youngest Weichselian deposits in this area.

According to the high-resolution DEM showing the relief in detail and permitting altitudinal profiles, the following questions arise:

1. Do the Ragöse Sandur, the Stadtforst and the Mönchsheide really represent the deposits of a meltwater stream from the Althüttendorf area according to Liedtke (1956/57)?
2. What is the relative age of the the Britz Forest terrace in relation to the other landforms located in the northern part of the IMV?
3. What could be the origin of the Amtsweg Sandur and the Klosterbrücke Sandur just in front of the Pomeranian end moraine?
4. What is the relative age of the formation and conservation of the Stadtseerinne and Neuhütter Rinne?
5. What is the relation of Late Glacial lake deposits in the IMV to the other landforms?

4 The morphological units in the research area – description on based on the DEM

Despite the previous research, differences emerge in the genetic interpretation and chronological positioning of landscape units in the foreland of the Pomeranian end moraine. Surface structures and differences in altitudes can be evaluated. The landscape units are represented by distinct landforms with local names cited in the above mentioned literature (Fig. 2).

The DEM derived from LiDAR data offers new possibilities to reveal the detailed morphology in a spatial context. This is particularly so in forested areas, as recently shown on the Barnim till plain, where a succession of ice-marginal fans has been detected using a LiDAR DEM (Hardt et al. 2015).

4.1 The Ragöse Sandur

The name of this sandur was derived from a Holocene stream incised into the glaciofluvial deposits. In all previous publications, the Ragöse Sandur is linked to the glaciofluvial activities of the Pomeranian phase at Althüttendorf, to the northwest of the research area. It is considered by Liedtke (1956/57) to be of the same age as the Amtsweg Sandur east of the Chorin gap. However, there is no direct continuation of these two units. At its southern margin, the Ragöse San-

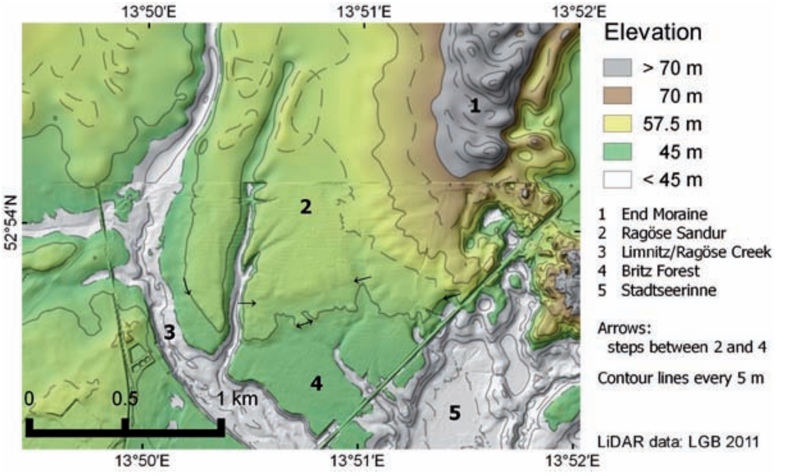

Fig. 3: The Ragöse Sandur (2), lying at the northwestern edge of the research area (northern part DEM based on topographic map 1:25000, southern part DEM based on LiDAR data; hillshade with 5-fold exaggeration). The end moraines of Pomeranian phase are clearly visible to the east (1). The steps to the Britz Forest (4) are marked with arrows. The present-day Limnitz-Ragöse valley (3) is incised into Ragöse Sandur and Britz Forest.

Fig. 3: Der im Nordwesten des Untersuchungsgebietes liegende Ragöse- Sander (nördlicher Teil DGM aus der topographischen Karte 1:25000, südlicher Teil DGM auf der Basis von LiDAR Daten, Schummerung mit 5facher Überhöhung). Deutlich erkennbar ist die östlich anschließende Pommersche Endmoräne (1) und der stufenartige Übergang zum Britzer Wald im Süden (4). Die Stufen sind mit Pfeilen markiert. Das heutige Limnitz-Ragöse-Tal (3) ist sowohl in Ragösesander als auch in den Britzer Wald eingeschnitten.

dur is separated by a step from the lower lying Britz Forest plain and the northernmost part of the Stadtseerinne, a glaciofluvial channel to the east of the former (Fig. 3).

The sandur is dissected by the present-day Ragöse-Limnitz valley system, which will be described below.

4.2 The Amtsweg Sandur

The Amtsweg Sandur is a fringe of glaciofluvial sediments in front of the end moraine, southeast of the Chorin gap. It is separated by a distinct change in the inclination from the end moraine and a step from the Mönchsheide, a forested area stretching to the southwest.

Taking into account the whole area between the end moraine slope and the Mönchsheide, several topographical units can be differentiated (Fig. 4).

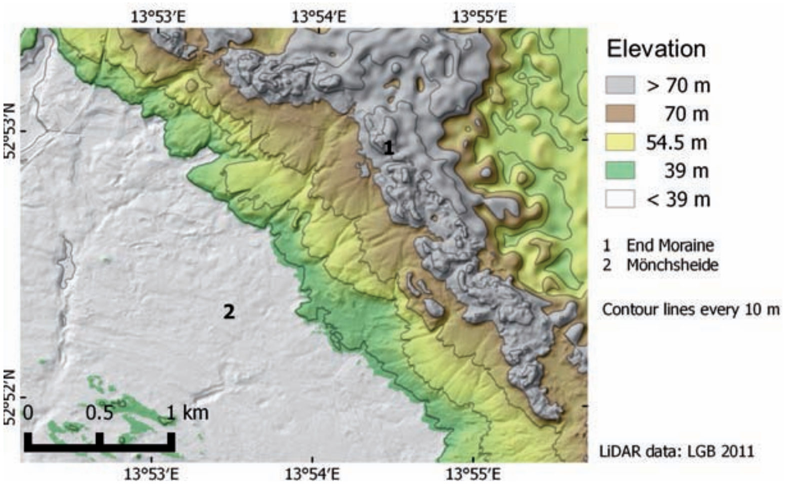

Fig. 4: Morphology of the Amtsweg Sandur. This sandur has a distinct gradient towards the southwest and a step in the profile. This morphological unit in total has a sharp border to the Mönchsheide (2).

Fig. 4: Morphologie des Amtswegsanders. Der Sander hat eine deutliche Neigung nach Südwesten und eine Stufe in seinem Längsprofil. Die Mönchsheide (2) ist deutlich gegen diese morphologische Einheit abgegrenzt.

The upper area represents a sandur formed by merged sedimentary fans. It can be clearly separated from the end moraine in terms of slope and elevation. The end moraine has slope angles of 10° to 30°, whereas the sandur shows a gradient of less than 5°. The dividing line between end moraine and sandur is at about 70 m a.s.l., and the sandur gently declines to about 55 m a.s.l. This upper part is separated by a step, running in a straight line from southeast to northwest, from the lower area. This lower area consists of four overlapping sedimentary fans, of which the proximal parts are indistinct. The lower limit to the Mönchsheide is very clearly visible as an irregularly curved margin formed by a distinct step at 42 m a.s.l. Nevertheless, the step is formed by the depositional front of the fans and doesn't show any erosional undercutting.

Brose (1978) classified the Amtsweg sandur as a sandur belonging to the end moraine. Liedtke (1956/57) described two different genetic phases involved in its' formation: the upper part from the end moraine itself to the step at about 60 m a.s.l. is a sandur, the lower part between the sandur *sensu stricto* and the Mönchsheide, consisting of fans, is interpreted by Liedtke (1956/57) as periglacial fan deposits.

4.3 Mönchsheide

The adjacent area to the southwest is the Mönchsheide which has an apparently irregular surface; the altitudes vary between 32–42 m a.s.l. and can be separated into the "37.5 m" or into the "40–42 m" levels when discussing terraces of the IMV.

According to Liedtke (1956/57), the Mönchsheide forms part of the Pomeranian sandur complex, which was deposited onto dead ice. According to his interpretation, late melting of the dead ice potentially explains the slope change observed towards the Amtsweg sandur and the irregular surface of the Mönchsheide.

Following Brose (1978), the Mönchsheide is classified as a sandur of a later subphase that originated at the breakthrough at the Chroin gap. It is attributed to the Angermünde (Brose 1978) or Parstein subphases (Marcinek & Brose 1987).

Scamoni (1975) questions the interpretation of the area as originating as a sandur, and points out that the Mönchsheide rather resembles gravelly fluvial valley sediments. That corresponds to the signatures of the 1:25000 geological map (Berendt & Schröder 1899).

The DEM provides some new insights for the interpretation. The area shows a surface that reflects a fluvial shallow channel pattern that discharged from southeast to west-northwest as part of a bend in a braided river system. It follows the mean direction of the IMV with a slope of about 0.6‰. The discharge used several channels with ridges between them, reaching from several centimetres to two meters in altitude. Excluding local dead-ice kettle holes the fluvial pattern is continuous through the Mönchsheide (Fig. 5).

There is no indication of an inclination from north to south, as would be expected in the case of a sandur fan (Fig. 5), nor is there evidence of a gradient towards the southwest as a prolongation of the Amtsweg Sandur (Fig 5c). The northern part of the Mönchsheide is even lies somewhat lower, at about 33–36 m a.s.l., than the southern part. The main area of the Mönchsheide is structured by west-trending depression lines. Some minor elevations up to 41.5 m a.s.l. are preserved, thus 3 m higher than the bottom of the nearby depression. The southern part of the Mönchsheide around the Kahlenberg, at the margin of the deepest section of the valley, the present-day Finow valley, reaches up to 42 m a.s.l. The Kahlenberg has been considered as an erosional residual of a former higher landscape (Scamoni 1975).

The Mönchsheide is dissected by a small north-south trending channel that cuts the fluvial structures, with an irregular floor and a blind end to the south. A second channel is directed from north-east to south-west, but it is not continuous and is only partly visible in its northern part.

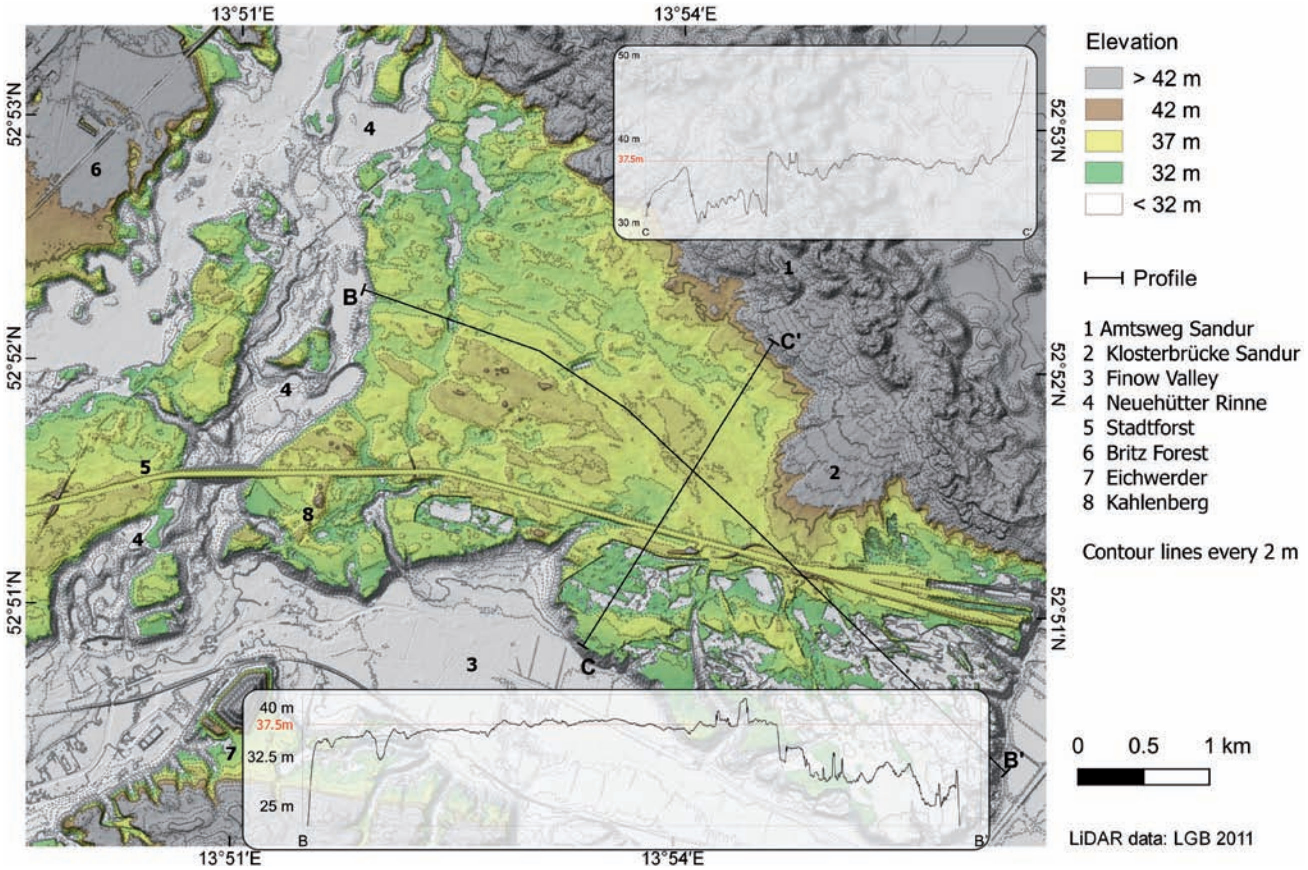

Fig. 5: Morphology of the Mönchsheide, sharply separated from the Amtsweg- Sandur (1), the Finow valley (3) and the Neuehütter Rinne (4). – B: The WNW-ESE orientated profile is the longitudinal profile according to the supposed fluvial pattern. – C: A profile perpendicular to the supposed fluvial pattern, showing that the Mönchsheide has no gradient from the end moraine to the central part of the meltwater valley. Dashed line indicates the 37.5 m level, the main terrace level according to Liedtke *(1956/57).*

Fig. 5: Die Morphologie der Mönchsheide, deutlich abgesetzt gegen Amtswegsander (1), Finowtal (3) und Neuehütter Rinne (4) – B: Das WNW-OSO ausgerichtete Profil entspricht dem Längsprofil des als fluvial interpretierten Oberflächenmusters. – C: Ein Querprofil über das als fluvial interpretierte Oberflächenmuster, das zeigt, dass die Mönchsheide keine Neigung von der Endmoräne zum zentralen Teil des Urstromtales aufweist. Die gestrichelte Linie markiert das 37,5 m – Niveau, nach Liedtke *(1956/57) die Höhe der Hauptterrasse.*

4.4 Klosterbrücke Fan

The prominent fan at Klosterbrücke (Fig. 6) has been described as a sandur deposited during the Parstein subphase (Brose 1978) or was formed as periglacial formation (Scamoni 1975). Its position is linked with a small breakthrough in the end moraines, a valley which abruptly ends at the hinterland of the end moraine (Fig. 2; Fig.6: A). There is no connection to any landscape feature north of the end moraine. Conflicting opinions concerning whether this sedimentary fan is younger or older than the adjacent Mönchsheide have been voiced by Liedtke (1956/57) and Brose (1978).

OSL data from a sand pit in the distal part of the Klosterbrücke fan provided an average age of three very consistent determinations of 19.4 ± 2.4 ka, while four samples collected from the sandur deposits in front of the end moraine of Pomeranian phase close to Althüttendorf gave an average OSL age of 20.1 ± 1.6 ka (Lüthgens et al. 2011). Therefore the formation of the main ice margin and that of the Klosterbrücke sandur fan can be considered contemporaneous. The sediments of the Klosterbrücke fan are classified as well sorted fine to medium sand at the OSL sampling site (Dörschner 2008, cited in Lüthgens 2011), nevertheless the fan is covered by “Geschiebedecksand”, a cover sediment characterised by clasts (including ventifacts) in a sandy matrix, also described by Liedtke (1956/57).

The fan at Klosterbrücke shows several steps in its topography. On the western and eastern sides, a definite step separates the fan from the lower lying Mönchsheide, whereas in the southwest a gentle transition to the Mönchsheide occurs. Four fan generations can be deduced from these steps:

The first generation was undercut at about 55 m a.s.l. (Fig. 6: U). This corresponds to the step in the Amtsweg Sandur, stretching in a northwesterly direction. This step is only partly preserved in the Klosterbrücke fan, mainly in the northwestern part.

1) The second generation, with a broader extent, is separated from the Mönchsheide at about 42 m a.s.l. (Fig. 6: L) and has apparently almost concealed the first step.

2) The most distal part, stretching in southwesterly direction, does not show the distinct step (L) to the Mönchsheide.

3) A younger incision, probably of periglacial origin, dissects the northern part of the Klosterbrücke fan.

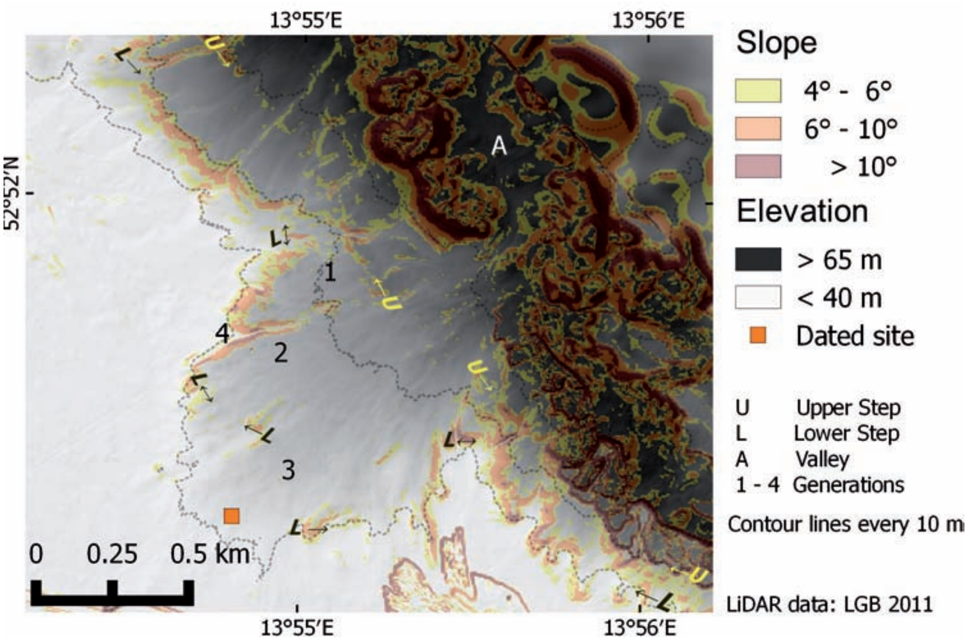

Fig. 6: Depositional generations of the Klosterbrücke Sandur and the dating site of Lüthgens et al. (2011). Combined elevation and slope; arrows marking distinct steps.

Fig. 6: Ablagerungsgenerationen des Klosterbrückesanders und Lage des datierten Profils von Lüthgens et al. (2011). Kombination aus Höhen- und Hangneigungsdarstellung, Pfeile markieren deutliche Stufen.

4.5 The Britz Forest

The Britz Forest is a flat, slightly inclined area in the western part of the research area (Fig.7). The plain, at present showing no distinct natural structure at its surface, is separated by steps (up to 8 m high) from the till plain in the west, the Ragöse Sandur in the north, and the Stadtseerinne in the east. It is considered to be the part of a meltwater stream related to the Angermünde subphase (Liedtke 1956/57:25). The plain is inclined to the southwest, the elevation is about 48 m in the north and about 37.5 m in the south; the gradient is slightly steeper than at the rest of the Angermünde valley sandur (Liedtke 1956/57).

The NE-SW inclination is indeed exceptionally regular and steeper than typical IMV terraces (2.3‰).

The hypothetical prolongation of the Britz Forest plain to the northeast shows no direct connection to the Chorin gap. The Britz Forest plain is definitely higher than Mönchsheide and Stadtforst on the other side of the Stadtseerinne.

4.6 Stadtforst

Another prominent plain is that at Stadtforst, between the Britz Forest and the Mönchsheide, separated from them by channel landforms. The Stadtforst has a similar altitude as the southern part of the Britz Forest, but with a less regular surface. Altitudes here vary between 35 m and 40 m. Whether the surface in the smaller northern part represents the continuation of the fluvial pattern at the surface of the Mönchsheide is not clear but likely (a in Fig. 8). The southern part, separated from the northern part by a small valley, shows two east-west extending elevations, but the rest of the plain is strongly influenced by artificial constructions, including the Oder-Havel-channel. Nevertheless the southernmost part (b in Fig. 8) is a somewhat lower (about 2 m), corresponding to a small isolated remnant further east in the Neuehütter Rinne (c in Fig. 8). The latter areas may be attributed to the IMV terrace system. On the opposite side of the IMV, a terrace remnant (Eichwerder), has a similar altitude and has been mapped as "*Talsand*" (fluvio-glaciofluvial deposit) already by Berendt & Schröder (1899).

4.7 Stadtseerinne and Neuehütter Rinne

The Stadtseerinne and Neuehütter Rinne are deeper lying, elongated, channel-like landforms, separating the before described landforms Britz Forest, Stadtforst and Mönchsheide from each other. Both channels are broad, irregular and interfere with each other (Fig. 9).

4.7.1 Stadtseerinne

The Stadtseerinne is a northeast-southwest trending elongate landform at about 24.5–25 m a.s.l.. The steep but irregular margins to the neighbouring plains, the Britz Forest plain and the Stadtforst are striking. Spurs at the edge of the Britz Forest protrude into the Stadtseerinne. The floor itself is full of depressions, some of which are filled by lakes.

This landform can be traced to the north beyond the Chorin gap, while further to the south it is following parallel to the IMV in a westerly direction. In this area it can be traced by depressions and marshy areas at least as far as Finowfurt.

4.7.2 Neuehütter Rinne

The Neuehütter Rinne occurs at an even lower elevation and is also characterized by an irregular topography and several branches. Some depressions are infilled by lakes. The Ragöse stream crosses the Stadtseerinne and then follows the western branch of the Neuehütter Rinne, having formed terraces at several levels between 15–26m a.s.l.

The depression itself has a different origin. It begins further north at the Chorin gap, in the end moraine. Further south, in the area of the IMV terrace, the channel subdivides into two parts. The Neuehütter Rinne can be traced southwards across the IMV and the Finow valley to the Barnim till plain. Its name here is the Schwärzerinne.

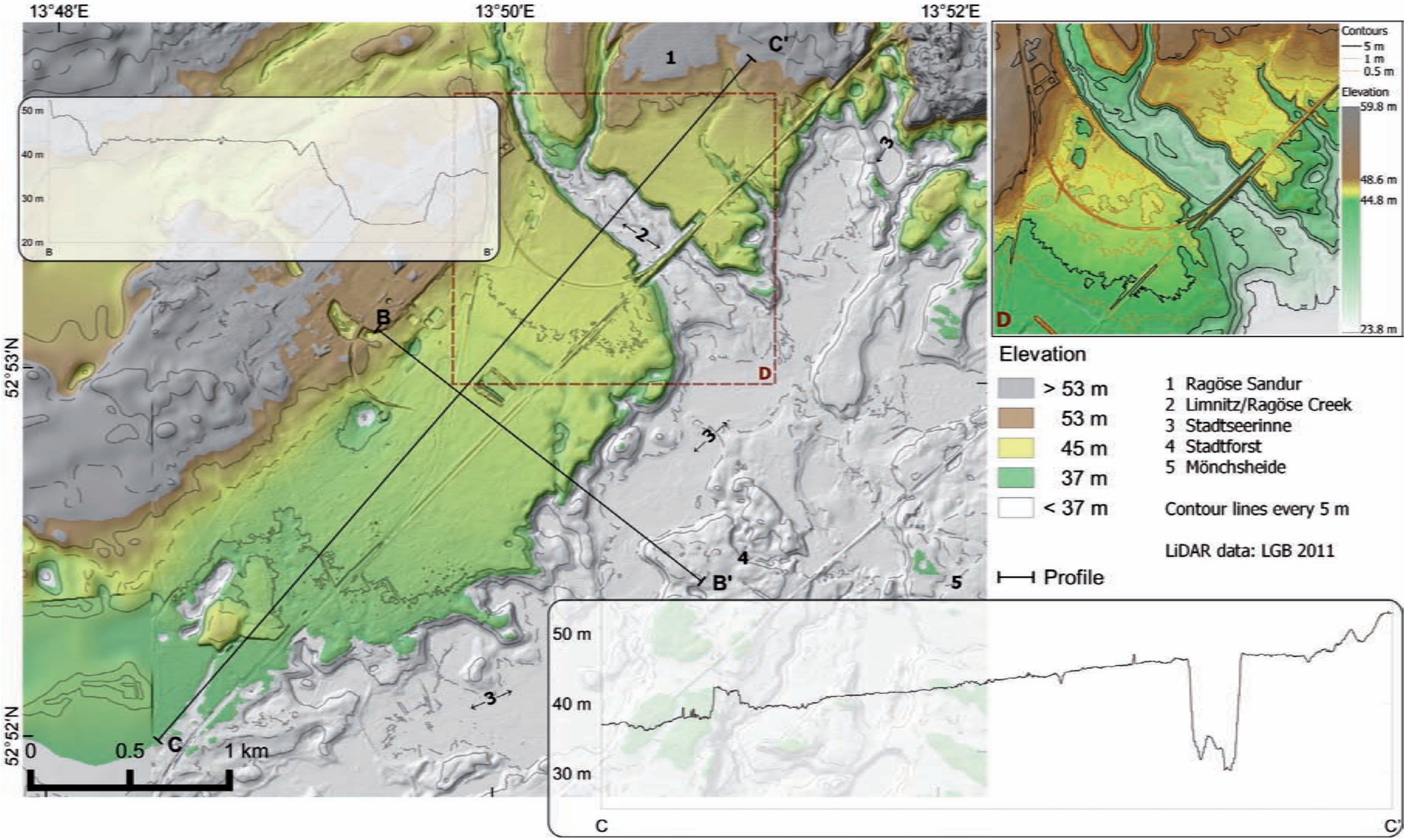

Fig. 7: Morphology of the Britz Forest. – B: WNW-ESE cross profile of the Britz Forest, the Stadtseerinne (3) and into the Stadtforst (4), showing the distinctiveness of the units and their height differences. – C: NNE-SSW longitudinal profile of the Britz Forest showing the gentle gradient (2.3‰) towards the Eberwalde IMV. – D: Detail view of the small alluvial fan on top of the Britz forest.

Fig. 7: a: Morphologie des Britzer Forsts. – B: WNW-OSO-Querprofil über den Britzer Forst, durch die östlich angrenzende Stadtseerinne und in den Stadtforst. Die scharfen Grenzen und klaren Höhenunterschiede zwischen den Einheiten werden hier verdeutlicht. – C: NNO-SSW-Längsprofil des Britzer Forsts, das die schwache Neigung (2,3‰) Richtung SSW hin zum Eberswalder Urstromtal zeigt. – D: Detailansicht des kleinen Schwemmfächers auf dem Britzer Wald.

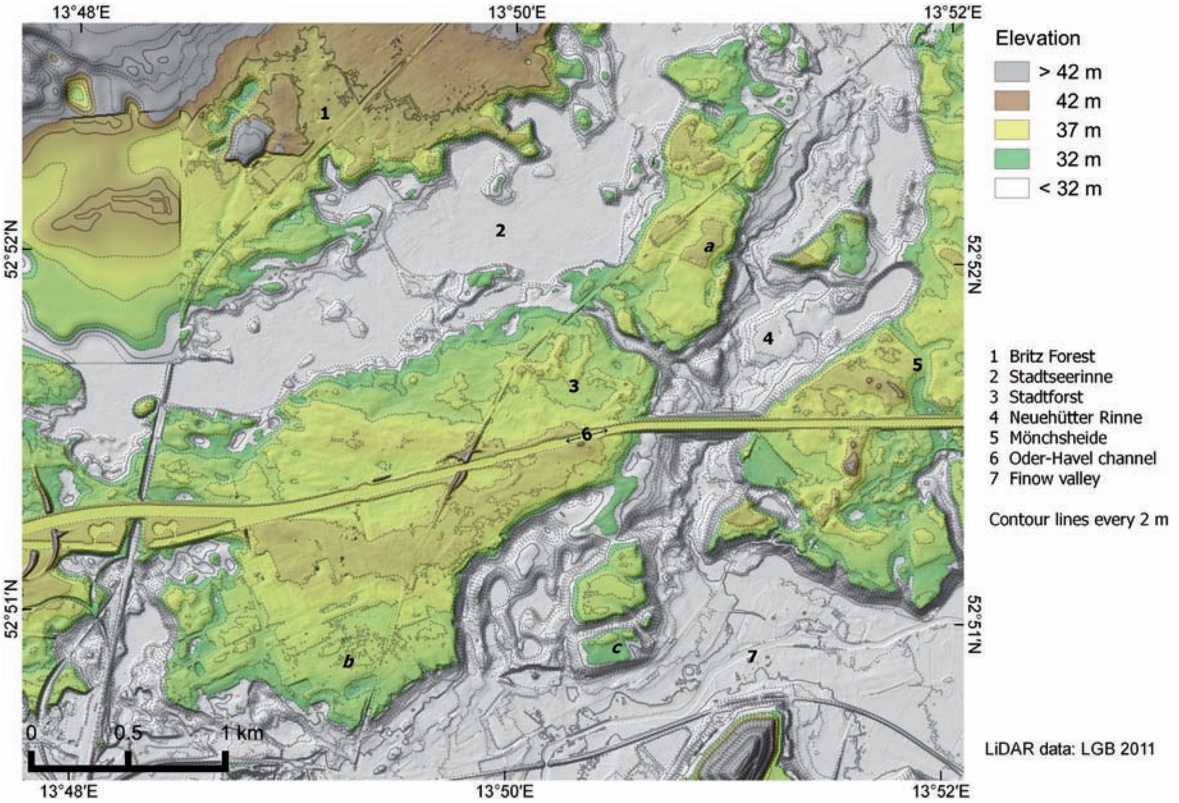

Fig. 8: The Stadtforst area with morphology similar to that of the Mönchsheide. It is more heavily transformed by human activities such as the Oder-Havel-channel (6) and the outskirts of Eberswalde (around b).

Fig. 8: Der Stadtforst hat eine der Mönchsheide ähnelnde Oberflächenstruktur. Sie ist jedoch stark verändert durch menschlische Eingriffe, wie den Oder-Havel-Kanal (6) und die Außenbezirke von Eberswalde (bei b).

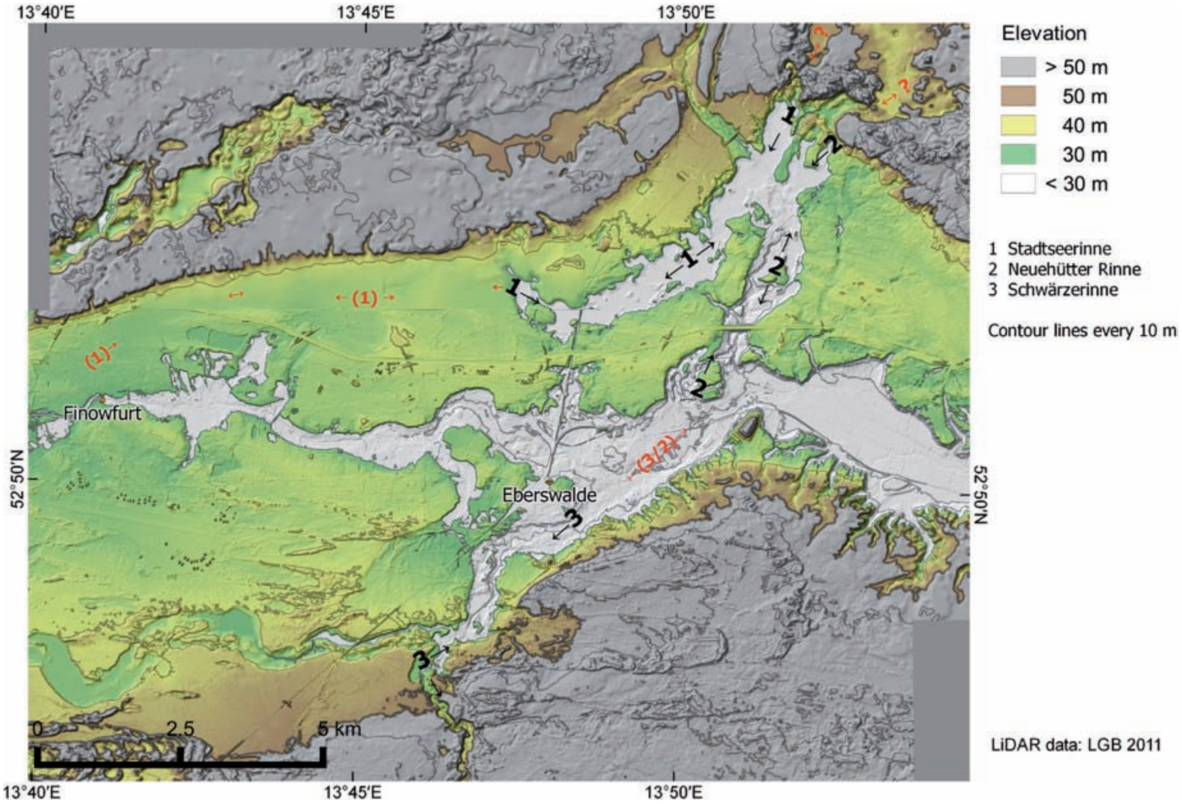

Fig. 9: Pre-Pomeranian channels of subglacial origin in the foreland of the end moraine of the Pomeranian phase and their interpreted connection to the south across the IMV.

Fig. 9: Vor-pommernzeitliche subglazial angelegte Rinnen im Vorland der Pommerschen Eisrandlage und die vermutliche Verbindung nach Süden quer durch das Urstromtal.

4.8 The terraces of the IMV

The "main terraces" of the IMV represent a vague description of fluvial terraces at about 37.5 m a.s.l.; they have never been clearly defined. Liedtke (1956/57) classified the southern part of the Mönchsheide as "main terraces", whereas this separation is justified by the artificial Oder-Havel channel. Marcinek & Brose (1987) placed these "main terraces" at 36–37 m a.s.l. and considered them as representing the discharge level related to the Angermünde subphase.

All areas from 32–40 m a.s.l. that have not been described as sandurs are attributed to "the main terrace". Areas at lower levels are seen either as dead ice topography or Holocene fluvial formations. Most of these areas, especially the Mönchsheide south of the Oder-Havel channel, have been transformed by the construction of the channel. A geomorphological interpretation of this area is therefore almost impossible.

South of the Finow valley, a spur at Eichwerder has the same elevation as the "the main terraces".

4.9 Laminated silts

In the area of Macherslust, outcrops of laminated silty deposits, as well as clay deposits, have repeatedly been described and were also exploited by mining (Berendt 1896, Berendt & Schröder 1899, Beschoren 1934, Liedtke 1956/57). They are located at the margins of the IMV and in the Neuehütter Rinne, but not in the Stadtseerinne.

Most of the sites (Fig. 2) are now inaccessible, but the remnant outcrop at Macherslust, east of Eberswalde, has been repeatedly studied over the last decades (Schirrmeister 2004, Lüthgens et al. 2011, Pisarska-Jamroży 2013). These glaciolacustrine laminated deposits include sliding and deformation structures and are located on the northern fringe of the Holocene Finow valley to the Stadtforst. The sediments have been dated by OSL to 14 ± 1 ka (Lüthgens et al. 2011), and by Infrared Stimulated Luminescence (IRSL) to 17 ± 4.4 ka (data from M. Krbetschek, Freiberg, published in: Schirrmeister 2004). Pisarska-Jamroży (2013) also presented two OSL ages of 14.6 ± 6.5 ka and 12.18 ± 4.5 ka from these deposits. These results show a high uncertainty, and the information about the applied methodology is sparse. Pisarska-Jamroży (2013) attributes the sedimentation to a hyperconcentrated meltwater flow of the Angermünde subphase. At any case, the statement by Schlaak (in: Gärtner et al. 1995:249) that laminated clays in the Eberswalde IMV belong in general to the Saalian glaciation, cannot be sustained at least in the case of the Macherslust outcrop and at the Kienwerder site in Eberswalde.

5 Interpretation of the landforms

The revised interpretation of the landforms is given according to their relative ages. The geomorphological results are bracketed by the existing geochronological data of the Pomeranian phase and the silty limnic sediments in the IMV terrace. The IMV itself is considered to be at least partly a pre-existing landform which was already occupied during the downwasting of the Brandenburg phase. It cannot be excluded that there was already a Saalian valley system as clays west of Eberswalde suggest even a pre-Weichselian depression that has been re-occupied by Weichselian meltwaters (Chrobok 1987).

The Britz Forest is the highest terrace remnant in the study area of the IMV. These deposits were sourced from northeasterly direction and their surface gradient was directed to the southwest. The surface of this area is very flat and shows no fluvial pattern at its surface, probably resulting from a relatively long and intense periglacial transformation smoothening the surface by gelifluction. Therefore the formation is considered to be older than the other accumulation landforms in the IMV, and is attributed to the down wasting of the Brandenburg phase. This interpretation is not in accordance with the interpretation of Liedtke (1956/57) who has seen the Britz forest as part of the youngest meltwater stream from the Angermünde subphase. He reconstructed a meltwater stream through the Chorin gap from northeasterly directions to the main terrace of the IMV.

The Mönchsheide, repeatedly classified as a sandur in front of the end moraine of Pomeranian phase (Liedtke 1956/57), shows a former fluvial surface with channels and bars. It was formed by a braided river in a bend with water flowing from easterly to westerly direction. Such braided rivers (Paola 2006), found in periglacial areas and typical for the IMVs in northern Germany, suggesting a high sediment supply. At an elevation of about 38–38.5 m a.s.l. the Mönchsheide forms a continuous braided river valley bed, roughly corresponding to the "main terrace" altitude, but about 2 m higher than the actual IMV terraces. The DEM-based surface contradicts the interpretation of being part of a sandur deposited from meltwaters from the Pomeranian end moraine. Furthermore, the area of Mönchsheide shows no indication of being a sandur related to the Parstein or Angermünde subphase. Its gradient neither slopes from the end moraines nor from the Chorin gap.

This fluvial pattern of the Mönchsheide is also found in the Stadtforst. Eichwerder at the southern fringe of the IMV is of similar altitude, but owing to the artificial constructions of Eberswalde, the surface is poorly preserved. Therefore it is suggested that during an early stage of the Pomeranian phase, water was flowing from an easterly direction through the IMV, incising older deposits and undercutting the Britz Forest. It is not clear whether this fluvial system also cut into the Amtsweg Sandur deposits, forming the upper step at 60 m. This part of the IMV must have been connected to a meltwater and fluvial system to the east and was a passage to the west.

During the formation of the Pomeranian end moraine the extent of fluvioglacial deposition was much more restricted than proposed by Liedtke (1956/57) and Börner (2007).

The Ragöse Sandur, as well as the Amtsweg Sandur, were formed as small fans along the end moraine by local, small meltwater outlets. On the Amtsweg Sandur this happened during two phases, the upper step likely being formed by a mudflow-type event. A second generation of fan deposits with steep frontal steps but without erosional forms at the distal parts was formed afterwards, but according to the geochronological data of the Klosterbrücke Sandur also belongs to the Pomeranian phase.

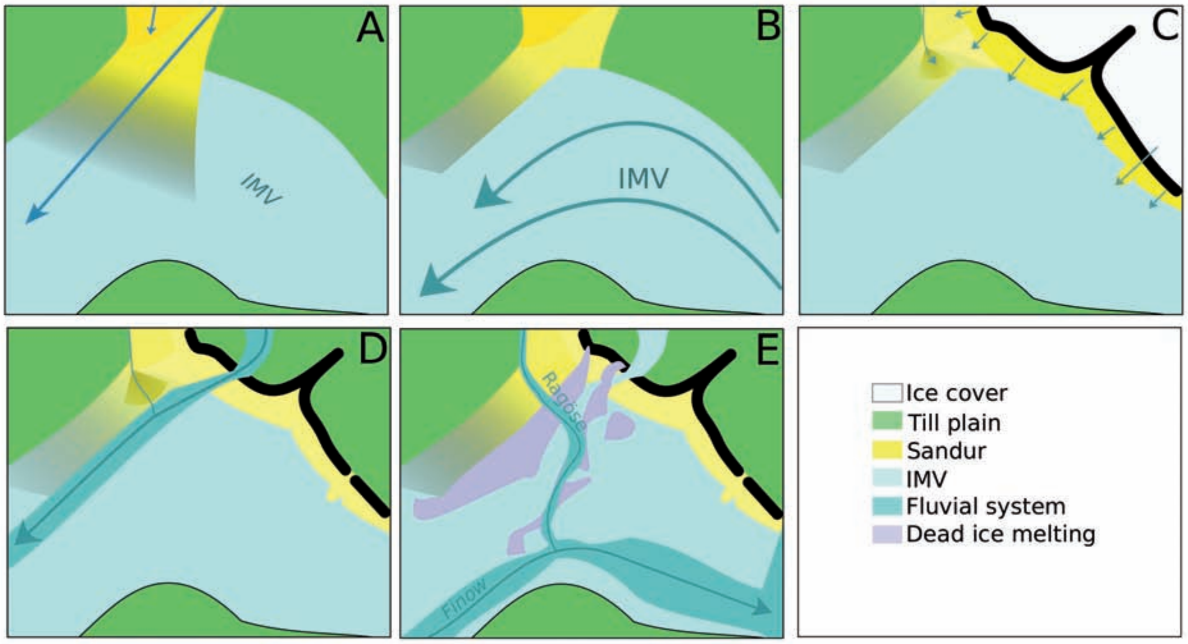

Fig. 10: Model of the formation of the landscape elements

A: An early stage of the IMV during the down melting following the Brandenburg ice advance. Deposition of the glaciofluvial deposits in the Britz Forest.

B: Fluvial to glaciofluvial discharge from east to west, incision into the eastern side of the Britz Forest, formation of the Mönchsheide and Stadtforst sediment structures.

C: Formation of the Pomeranian end moraine and the meltwater fans of the Amtsweg Sandur and the Ragöse Sandur; deposition of the alluvial fan on the Britz Forest sequence.

D: Meltwater flow from the northern Parstein and Angermünde subphases through the gap at Chorin Monastery.

E: Late-Glacial dead-ice melting inducing the appearance of the Stadtseerinne and the Neuehütter Rinne, as well as the initiation of the Late Glacial to Holocene fluvial system.

Fig. 10: Modell der Genese der Reliefformen

A: Ein Vorläufer des Urstromtales während des Abschmelzens des Eises des Brandenburger Stadiums. Glazifluviale Ablagerung des Sedimentkörpers des Britzer Forsts.

B: Fluvialer und glazifluvialer Abfluss von Ost nach West. Unterschneidung der Ostflanke des Britzer Forsts und Anlage der Oberflächenstrukturen der Mönchsheide und des Stadtforsts.

C: Bildung der Pommerschen Endmoräne und der Schmelzwasserkegel des Amtswegsanders und des Ragöse Sanders; Ausbildung des Schwemmfächers auf dem Britzer Forst.

D: Schmelzwasserabfluss der nördlich gelegenen Parsteiner und Angermünder Staffeln durch den Durchbruch beim Kloster Chorin.

E: Spätglaziales Toteistauen und Erscheinen von Stadtseerinne und Neuehütter Rinne sowie die Anlage des spätglazialen bis holozänen Flußsystems.

As a main result from this study, we propose that it is highly likely that no major meltwater stream reached this area. The main water stream from the Althüttendorf glacier mouth continued to the southwest along the Werbellin lake depression. The area of the Ragöse Sandur received some fluvioglacial deposits from the end moraine forming small fans, and the water was collected in a small stream, a predecessor of the Ragöse, which formed a flat fan on the Britzer Forst (Fig. 7D). At the same time the upper part of the Amtsweg Sandur was deposited.

The Klosterbrücke fan can partly be seen as a continuation of the Amtsweg Sandur, but it drained a far greater catchment area. Whereas for the Amtsweg Sandur possible sedimentation sources do not extend further than the terminal moraine itself, the Klosterbrücke fan must have had a connection to the end moraine's hinterland. Either it was an outburst from a meltwater pocket in the ice, or a small lake was dammed between the ice and the end moraine. The overflow can still be seen in the small, abruptly terminating valley (Fig. 6 A). The timing is provided by the dating results available for the Klosterbrücke fan, approximately dating to the Pomeranian phase, but later activity is well within the error margin of the dating.

No major meltwater activity is seen in the IMV at that time and therefore a rerouting of IMV waters (as discussed, for example, in Liedtke 1956/57, Kozarski 1966) is likely.

The glaciofluvial gap at the Chorin Monastery is related to the younger retreat subphases, such as the Parstein or Angermünde subphases, when the meltwaters eroded into the sediments of the Mönchsheide-Stadtforst. The continuation cannot be traced further because the area has been strongly remodelled by the melting of dead-ice and fluvial processes of the Finow.

According to this interpretation, the formation of the Neuehütter Rinne and the Stadtseerinne are attributed to a pre-Pomeranian ice advance as subglacial meltwater channels, which were filled with dead ice. The present day irregular geomorphological forms cannot be attributed to a proglacial meltwater stream of the Pomeranian phase or the subsequent subphases. Thus, they did not exist as landforms neither during the formation of the fluvial pattern with the east-west trending bars on the Mönchsheide and the northern Stadtforst, nor during the formation of the Pomeranian end moraine. The channels were inexistent probably until the substantial dead-ice melting phase. This process also induces the incision of the Ragöse-Limnitz valley down to the level of the Stadtseerinne.

The dated clays and silts of Macherslust occur in the depressions of the Neuehütter Rinne. The data obtained imply late deposition during the downmelting of dead ice, predominantly during the Weichselian Late-Glacial Bølling-Allerød interval. They are too young to follow the interpretation of Pisarska-Jamroży (2013). She attributed them to meltwater streams of the Pomeranian phase, but according to the OSL data of the landscape stabilisation during and after the melting of dead ice (Hardt 2017: 110), the surface deglaciation happened significantly earlier and the relief was only later on influenced by periglacial processes and the melting of buried dead ice.

6 Conclusions

- The Mönchsheide, as well as the Stadtforst, are not part of a sandur related to the Pomeranian end moraine position north of the area as postulated by Liedtke (1956/57), but are part of a fluvial or glaciofluvial system that flowed from east to west. It can be argued that the Mönchsheide, the Stadtforst and the remnants at Eichwerder all form parts of the same fluvial system.

- The Britz Forest is not directly linked to the glaciofluvial gap at the Chorin monastery but is considered to be older, representing only a remnant of a pre-Pomeranian meltwater deposit.

- The Neuhütter Rinne and the Stadtseerinne are also pre-Pomeranian by formation, but reappear as landforms only after the downmelting of buried dead ice.

- The main Pomeranian end moraine, deposited during the LGM at 20 ka in MIS 2 (Cohen et al. 2011), supplied little meltwater in the research area and only small fans accumulated at its margin. The meltwater from the glacier mouth at Althüttendorf did not pass through this area, and small local fans formed the Ragöse Sandur.

- The lacustrine deposits at Macherslust and Eichwerder predate the final Late-Glacial dead-ice melting as the banded silts show deformations, but are too young to be linked to the meltwater flow of the Parsteiner and Angermünder subphases. The final melting of dead ice not only led to the reappearance of the Neuehütter Rinne and Stadtseerinne as morphological features, but also terminates the paraglacial reorganisation of the landscape including the infill of small depressions with meltwater and sediments reworked by periglacial processes.

Acknowledgements

We thank Dr.Jacob Hardt for inspiring and helpful discussions, and Prof. Phil Gibbard. We appreciate the substantial comments of Ass. Prof. Dr. Christopher Lüthgens and an anonymous reviewer.

References

Berendt, G. (1888): Die südliche baltische Endmoräne in der Gegend von Joachimsthal. – Jahrbuch der Königlich-Preußischen Geologischen Landesanstalt und Bergakademie zu Berlin, 1887, 301–310.

Berendt, G. & Schröder, H. (1899): Hohenfinow, Gradabteilung 45 Nr. 10. Geologische Karte von Preußen und benachbarten Bundesstaaten 1:25000; Berlin.

Beschoren, B. (1934): Über jungdiluviale Staubeckentone zwischen Havel und Oder. – In: Jahrbuch der Preußischen Geologischen Landesanstalt 55, 395–428.

Börner, A. (2007): Das Eberswalder Urstromtal: Untersuchungen zur pleistozänen Landschaftsgenese zwischen Niederem Oderbruch und Werbellinseerinne (Nordost-Brandenburg). – Schriftenreihe für Geowissenschaften 17; Ostklüne.

Brose, F. (1978): Weichselglaziale Rückzugsstaffeln im Hinterland der Eisrandlage des Pommerschen Stadiums südlich von Angermünde. – Wissenschaftliche Zeitschrift der Ernst-Moritz-Arndt-Universität Greifswald, Math.-Nat. Reihe, 27 1/2, 17–19.

Brose, F. (1995): Erscheinungen des weichselzeitlichen Eisrückzuges in Ostbrandenburg. – In: Brandenburger Geowissenschaftliche Beiträge 2(1), S. 3–11.

Brose, F., Piotrowski, A. & Schroeder, J. (2003): Entwicklung des Oderbruchs: Neue Daten zur Sedimentfüllung der Oderbruchdepression. – In: Schroeder, J. & Brose, F. (eds.): Oderbruch—Märkische Schweiz–Östlicher Barnim. – Führer zur Geologie von Berlin und Brandenburg 9, 57—65.

Chrobok, S. M. (1987): Der Gas- und Karbonatgehalt des Gletschereises und seine Bedeutung für die glazilimnische Sedimentation. – Wissenschaftliche Zeitschrift der Ernst-Moritz-Arndt-Universität Greifswald, Math.-Nat. Reihe 36, 41–43.

Cohen, K.M., Gibbard, P. (2011): Global chronostratigraphical correlation table for the last 2.7 million years. Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy), Cambridge, England.

Dörschner, N. (2008): Zur Zeitstellung weichselzeitlicher proglazialer Schmelzwasserablagerungen am Rande der morphostratigraphischen Pommerschen Eisrandlage. – Bachelor-Arbeit, Freie Universität Berlin, Institut für Geographische Wissenschaften.

Gärtner, P., Behrendt, L., Bussemer, S., Marcinek, J., Markuse, G. & Schlaak, N. (1995): Quartärmorphologisches Nord-Südprofil durch Brandenburg. – Berichte zur deutschen Landeskunde 69 (2), 229–262.

Hardt, J. (2017): Weichselian phases and ice dynamics of the Scandinavian Ice Sheet in northeast Germany. – Dissertation am Fachbereich Geowissenschaften, Freie Universität Berlin; http://www.diss.fu-berlin.de/diss/receive/FUDISS_thesis_000000104286.

Hardt, J. & Böse, M. (2016): The timing of the Weichselian Pomeranian ice marginal position south of the Baltic Sea: A critical review of morphological and geochronological results, Quaternary International (2016), http://dx.doi.org/10.1016/j.quaint.2016.07.044.

Hardt, J., Hebenstreit, R., Lüthgens, C. & Böse, M. (2015): High-resolution mapping of ice-marginal landforms in the Barnim region, northeast Germany. – Geomorphology 250, 1, 41–52.

Heine, K., Reuther, A., Thieke, H. Schulz, R., Schlaak, N.& Kubik, P (2009): Timing of Weichselian ice marginal positions in Brandenburg (northeastern Germany) using cosmogenic in situ ^{10}Be. – Zeitschrift für Geomorphologie 53 (4), 433–454.

Kozarski, S. (1966): Die glazialen Abflußverhältnisse im westlichen Teil des Notéc-Warta Urstromtales. – Wissenschaftliche Zeitschrift der Ernst-Moritz-Arndt-Universität Greifswald, Math.-Nat. Reihe 15(1), 63–72.

Liedtke, H. (1956/57): Beiträge zur geomorphologischen Entwicklung des Thorn-Eberswalder Urstromtales zwischen Oder und Havel. – Wissenschaftliche Zeitschrift der Humboldt-Universität Berlin, Math.-nat. Reihe 6, 3–49.

Liedtke, H. (2001): Das nordöstliche Brandenburg während der Weichseleiszeit. – In: Bussemer, S. (ed.): Das Erbe der Eiszeit. Festschrift zum 70. Geburtstag von Joachim Marcinek, 119–133; Langenweißbach.

Lippstreu, L. mit Beiträgen von Brose, F. & Marcinek, J. (1995): Brandenburg. – In: Benda, L.: Das Quartär Deutschlands. Stuttgart.

Lüthgens, C. (2011): The age of Weichselian main ice marginal positions in north-eastern Germany inferred from Optically Stimulated Luminescence (OSL) dating. Dissertation am Fachbereich Geowissenschaften, Freie Universität Berlin. http://www.diss.fu-berlin.de/diss/receive/FUDISS_thesis_000000022882

Lüthgens, C., Böse, M. & Preusser, F. (2011): Age of the Pomeranian ice-marginal position in northeastern Germany determined by Optically Stimulated Luminescence (OSL) dating of glaciofluvial sediments. – Boreas 40 (4), 598–615.

Marcinek, J. & Brose, F. (1987): Neuere Ergebnisse zur Urstromtalforschung und Entwicklung des Gewässernetzes im mitteleuropäischen Einflußbereich des nordischen Inlandeises. – Petermanns Geographische Mitteilungen 131(2), 113–124.

Paola, C. (2006): Braided river. – In: Goudie, A. S.: Encyclopedia of Geomorphology, Vol. 1: 98–101. Taylor and Francis, London & New York.

Penck, A. & Brückner, E. (1901–1909): Die Alpen im Eiszeitalter; 3 Bde.

Pisarska-Jamroży, M. (2013): Varves and megavarves in the Eberswalde Valley (NE Germany) – A key for the interpretation of glaciolimnic processes. – Sedimentary Geology 291, 84–96.

Pisarska-Jamroży, M. (2015): Factors controlling sedimentation in the Toruń-Eberswalde ice-marginal valley during the Pomeranian phase of Weichselian glaciation: an overview. – Geologos 21: 1–29. doi: 10.1515/logos–2015-0001

Rinterknecht, V., Braucher, R., Böse, M., Bourlès, D. & Mercier, J.-L. (2010): Late Quaternary ice sheet extents in northeastern Germany inferred from surface exposure dating. – Quaternary Science Reviews 30, 89—95

Scamoni, A. (1975): Die Wälder um Chorin. Vegetation und Grundlagen für die Erschließung und Pflege eines Landschaftsschutzgebietes. – Naturschutzarbeit in Berlin und Brandenburg, Beiheft 4; Potsdam, Frankfurt an der Oder.

Schirrmeister, L. (2004): Macherslust: Glazilakustrische Ablagerungen. – In: Schroeder, J. H. (ed.): Nordwestlicher Barnim – Eberswalder Urstromtal. – Führer zur Geologie von Berlin und Brandenburg 5, 236–245; Berlin.

Symbolschlüssel Geologie (2015): Digitale Fassung des Symbolteils. LBEG Hannover. www.lbeg.niedersachsen.de/download/74117/Symbolschluessel_Geologie.pdf (9.6.2016)

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / er 1–5 / DOI 10.3285/eg.66.1.er1
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

EXPRESS REPORT

Age of the Most Extensive Glaciation of Northern Switzerland: Evidence from the scientific drilling at Möhliner Feld

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Keywords: *Alps, Quaternary, Pleistocene, glaciation, chronology, loess*

1 Introduction

Möhliner Feld is a key area in the Swiss Pleistocene stratigraphy of the Northern Alpine Foreland. It is located at the River Rhine, about 20 km east of the city of Basel, and its topography sticks out from the Low Terrace surrounding on the northern flank (Fig. 1). Already Gutzwiler (1894) describes till outcropping in the still open gravel pit 'Bünten' and interprets a shallow ridge on Möhliner Feld as a terminal moraine formed by an alpine glacier advancing from the East. Penck & Brückner (1901–1909) follow this conclusion and describe another, slightly more exterior, terminal moraine. This ridge is interpreted to result from a glacier tongue within the Rhine Valley and is assigned to the Rissian glaciation, the penultimate glaciation in the classical Alpine stratigraphy. The Rissian is usually correlated to Marine Isotope Stage (MIS) 6, i.e. an age of 180–140 ka.

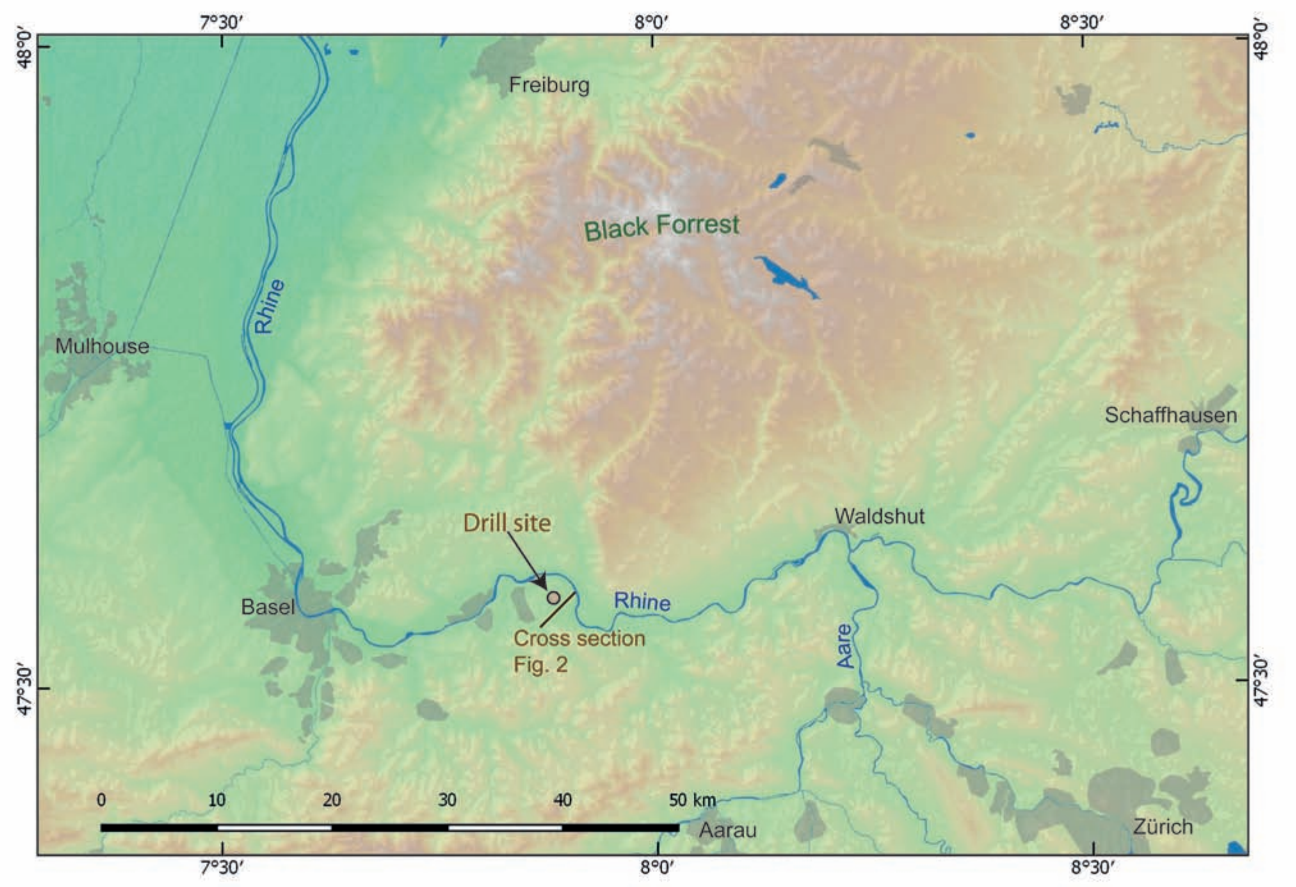

Fig. 1: Overview map of the study area with location of the drill site. / Abb. 1: Übersichtskarte des Untersuchungsgebietes mit Lage der Bohrstelle.

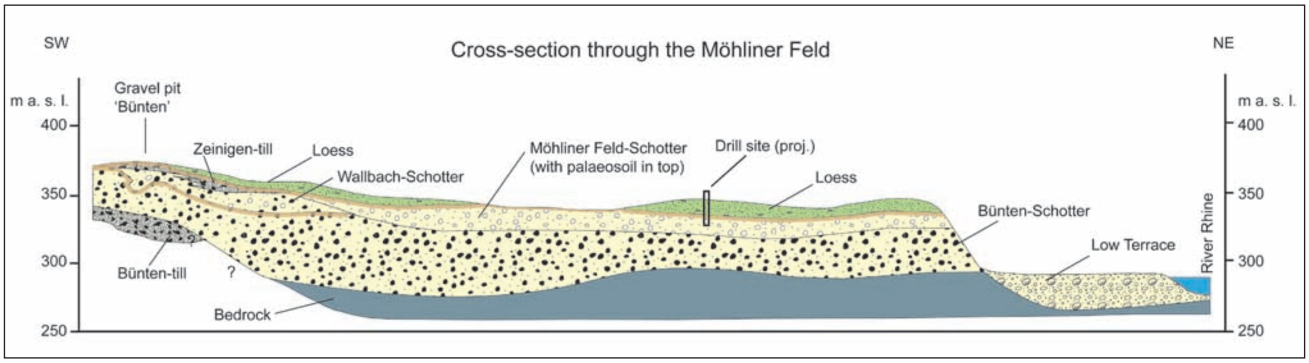

Fig. 2: Cross section through Möhliner Feld with the geological setting elaborated by Graf (2009).

Abb. 2: Profil durch das Möhliner Feld mit dem geologischen Rahmen wie von Graf (2009) ausgeabreitet.

A schematic log of the gravel pit 'Bünten' by Dick et al. (1996) shows till containing Alpine material 30 m below surface (not accessible today). This till is overlain by two glaciofluvial aggradations separated by a palaeosol, topped by weathered till ca. 5 m below surface and covered by loess (Fig. 2). This weathered till does not show any Alpine material, but consists completely of crystalline components from the Black Forest, north of Möhliner Feld. This evidence indicates two ice advances reached Möhliner Feld, the first from the Alps, the second from the Black Forest, separated by soil development during interglacial or interstadial conditions. Graf (2009) compiles borehole data from the Möhliner Feld, partly directly located on top of the ridges, but in none of the drillings glacigenic material was identified (Fig. 2). The ridges rather contain up to 10 m thick silty material, which is interpreted as loess. The underlying gravel, mainly composed of Black Forest material, is noticeably weathered in the uppermost 2–3 m, implying a substantial time-lag between its deposition and accumulation of the loess. The abundant loess cover of Möhliner Feld is possibly explained by a special phenomenon in the area, the 'Möhlin Jet'. The Möhlin Jet is a wind of southern direction that develops mainly in winter when cold air in the Swiss Lowlands overflows the eastern Jura Mountains and dries while falling down into the Rhine valley. In the area of Möhliner Feld the wind speed reaches typically 5 to 10 $m\ s^{-1}$ and this phenomenon is likely to have occurred also during Pleistocene glaciations. Together with the geological evidence this leads to the hypothesis that the ridges of the Möhliner Feld may rather represent aeolian dunes than glacial features.

Möhliner Feld is considered as marking the Most Extensive Glaciation (MEG) of the Swiss Northern Alpine Foreland. In fact, although the morphology is not glacial, the lowermost till in the gravel pit Bünten is evidence for the presence of Alpine glaciers in an area well beyond the boundaries of the last glacial maximum. The timing of this MEG, however, remains speculative. Schlüchter (2004) states that the MEG ice advance stratigraphically postdates the Early Pleistocene 'Deckenschotter' (gravel sheet) aggradations and pre-dates the loess cover of the Möhliner Feld. At the Thalgut site close to the Alpine border, till overlying bedrock and lacustrine sediments are interpreted based on magnetostratigraphy being located just above the Brunhes/Matuyama boundary. Schlüchter (2004) therefore concludes that the MEG 'occurred close to, but clearly after this last magnetostratigraphical reversal'. However, it is not stated where the magnetostratigraphic reversal has been identified and how the findings from Thalgut indicate an extent of the corresponding glaciation at Möhliner Feld.

This report focuses on a drill core penetrating the loess cover of the glacial deposits on Möhliner Feld, with the aim to constrain the age of the loess deposition by luminescence dating and by this better establish the minimum age for the glacial deposits.

2 Methods

A rotary core drilling (diameter = 203 mm) was lowered on the 'crest' of the inner ridge (Fig. 2, coordinates 47° 34' 5.00" N, 7° 52' 53.60" E). It reached a depth of 12.3 m. The core was placed in core boxes and logged on site simul-

Table 1: Results of high-resolution gamma-spectrometry, resulting dose rates and ages. Weff: effective water content for dose-rate calculation, DR Q: dose-rate of quartz, DR PM: dose rate of polyminerals.

Sample	Depth (m)	K (%)	Th (ppm)	U (ppm)	W_{eff} (%)	DR Q ($Gy\ ka^{-1}$)	DR PM ($Gy\ ka^{-1}$)	OSL (ka)	IR50 (ka)
Möh 1	1.3	1.59±0.03	11.71±0.22	3.38±0.08	25±5	3.08±0.26	3.34±0.27	19.5±1.8	19.1±1.6
Möh 2	3.0	1.25±0.02	9.86±0.32	3.00±0.06	24±5	2.58±0.23	2.81±0.23	34.6±3.1	31.3±2.7
Möh 3	3.8	1.23±0.02	9.93±2.57	2.96±0.04	22±5	2.58±0.23	2.82±0.23	33.2±3.2	32.3±3.1
Möh 4	5.0	1.24±0.02	10.38±0.29	3.02±0.04	21±5	2.65±0.33	2.89±0.24	33.5±4.3	34.1±3.2
Möh 5	5.7	1.53±0.03	12.79±0.30	3.56±0.09	21±5	3.20±0.28	3.48±0.29	31.0±3.4	43.0±3.6
Möh 6	6.8	1.35±0.03	10.54±0.30	2.80±0.03	17±5	2.78±0.24	3.02±0.25	68.1±6.9	58.1±5.9

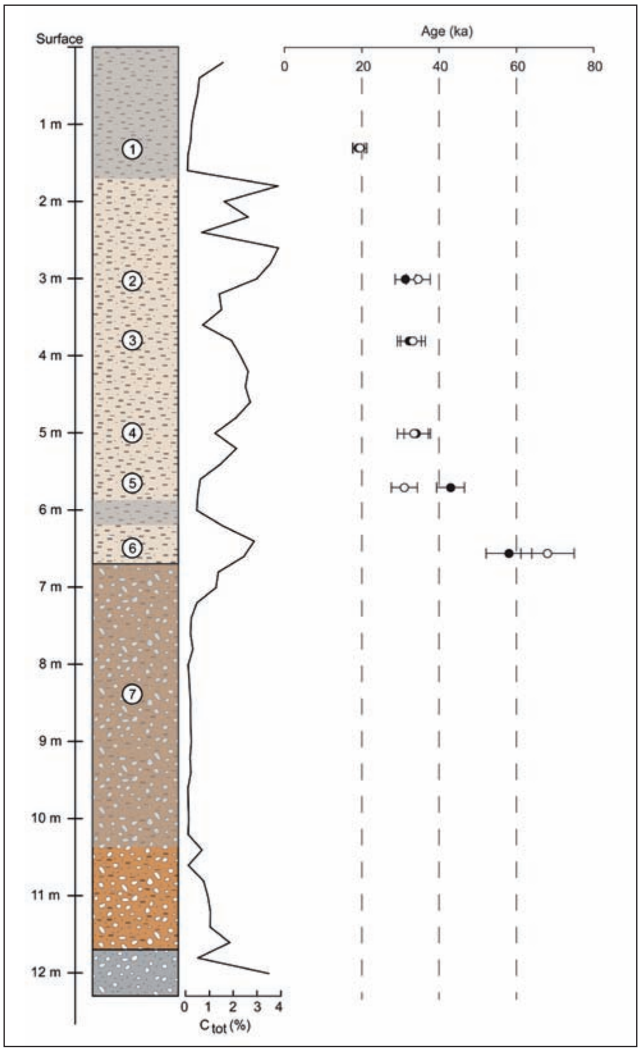

Fig. 3: Drilling profile with carbon content as well as OSL (open symbol) and IRSL ages (closed symbols).

Abb. 3: Bohrprofil mit Kohlenstoffgehalt sowie OSL- (offene Symbole) und IRSL-Altern (ausgefüllte Symbole).

taneously to the drilling progress. Seven samples were taken for luminescence dating, concentrated on the upper part of the core (Fig. 3, Table 1). It was assured that the samples were taken as compact cylinders of ca. 20 cm length in order to have enough non bleached material for luminescence dating. Additionally, along the whole core every 20 cm ca. 400 g of material were taken for other laboratory tests, i.e. granulometry using a Malvern Hydro 2000S Mastersizer, and total carbon (C_{total}) measurements using a Bruker G4 Icarus CS TF element analyser.

All luminescence sample preparation was performed under subdued red light and the light-exposed outer rim was amply removed with a knife, and only the innermost part (ca. 5×5×5 cm) was used for dating. Water content was assessed by drying the samples in an oven at 50° C until constant mass was reached. Samples were decarbonatised using HCl (32%) and subsequently organic components were removed with H_2O_2 (30%). Samples Möh 1, 2, 3, 4 and 5 showed mediocre, Möh 6 and 7 a strong exothermal reaction to H_2O_2. The latter two beakers were placed in water to discharge heat. However, sample Möh 7 developed such a high temperature that is was decided to discard this sample, because an effect on the luminescence signal could not be excluded. The remaining samples were washed with deionised water and stored in a $C_2Na_2O_4$-solution to prevent coagulation of particles. The grain size fraction 4-11 µm was separated using the Atterberg settling technique following Stoke's law (cf. Frechen et al. 1996). Half of the fraction 4–11 µm was left in H_2SiF_6 (34%) for ten days in order to dissolve feldspar grains and obtain a purified quartz separate. Subsequently, the quartz fraction was treated with HCl (32%) and washed with deionised water. Aliquots for luminescence measurements were prepared by settling ca. 2 mg of sample material dispersed in 1 ml of acetone onto stainless steel discs until all acetone evaporated.

The outer part of the sediment cylinders was used for determination of the external dose rate. It was dried, disaggregated in a mortar and bulk samples of ca. 450 g were filled into Marinelli beakers. After a storage time of minimum 30 days to allow for Rn-equilibrium to establish, the dose-rate relevant elements (U, K, Th) were measured using high-resolution γ-spectrometry (Table 1). There is no indication for a disequilibrium in the Uranium decay chain when comparing the activities of ^{238}U and ^{226}Ra (Preusser & Degering 2007). Potassium content of the polymineral samples was set to 12.5 ± 1.0% following the estimates of Huntley & Baril (1997). An a-value (efficiency of alpha particles in causing radiation damage) of 0.05 ± 0.01 was used for the polymineral fraction (Preusser 1999) and 0.03 ± 0.01 for the quartz fraction (Mauz et al. 2006). Dose rates, including the cosmogenic contribution, were calcu-

Table 2: Luminescence protocols used for the dating of loess samples. OSL was applied to quartz, IR50 was applied to polyminerals. OSL: stimulation with blue LEDs, IRSL: stimulation with IR LEDs. 1: Omitted in 1st cycle to measure Ln, 2: only applied in last cycle.

Observed	**OSL**	**IR50**
	[1]Dose	[1]Dose
	Preheat at 230 °C for 10 s	Preheat at 250 °C for 60 s
	[2]IRSL at 50°C for 60 s	
Ln/Lx	OSL at 125°C for 60 s	IRSL at 50°C for 300 s
	Test dose	Test dose
	Preheat at 230 °C for 10 s	Preheat at 250 °C for 60 s
Tn/Tx	OSL at 125°C for 100 s	IRSL at 50°C for 300 s

lated using the ADELE software. Water content was set stable over time to the measured value with an uncertainty of 5% of dry mass.

Luminescence measurements were made on automated Risø TL/OSL DA-20 readers equipped with 9235QA photomultiplier tubes. Palaeodoses were determined using modified single-aliquot regenerative-dose (SAR) protocols (Table 2). Feldspar contamination of the quartz fraction was monitored using the IR-depletion ratio but no contamination was detected in any of the samples. Dose response curves were fitted using a single saturating exponential function for both quartz and feldspar, none of which was close to saturation. A measurement error of 1.5% was included in the D_e determination and the error on curve fitting is included. For age calculation the Central Age Model (CAM) was used.

Feldspar is known to lose some of its signal with time, referred to as 'anomalous fading' that can be estimated in the laboratory and a correction has been suggested (Huntley & Lamothe 2001). However, the correction is only valid for doses within the linear part of the dose response curve, whereas the samples of this study are beyond that range. Furthermore fading tests have been questioned, as they apparently show laboratory artefacts rather than the fading observed in nature (Lowick et al. 2012). Nevertheless, fading tests were performed on two samples revealing fading rates of g = 1.9 ± 0.2% (Möh 2) and 3.1 ± 0.5% per decade (Möh 6). Considering the above-mentioned limitations of the fading tests and correction, however, no correction for fading was carried out.

3 Results

Dating results are given in Table 1. The age of sample Möh 1 (OSL: 19.5 ± 1.8 ka, IR50: 19.1 ± 1.6 ka) is distinctively younger than samples Möh 2, 3, and 4, which have indistinguishable OSL and IR50 ages of ca. 33 ± 3 ka. The consistency of OSL and IRSL ages implies that fading does not significantly affect these samples. Sample Möh 5 is more difficult to interpret, as the IR50 age is significantly older than the OSL age, which again is indistinguishable from the samples overlying Möh 5. Sample Möh 6 is significantly older than the other samples, with an age difference between OSL (68.1 ± 6.9 ka) and IR50 (58.1 ± 5.9 ka). The fact that IR50 yields a younger age than OSL could indicate signal loss (fading) in the polymineral fraction, but it is inexplicable why this is not observed for any of the other samples. In this case favour should be given to the OSL. There is a substantial time lag between the samples Möh 2-5 and Möh 6 indicating a stop in loess accumulation. The decalcified layer between 5.9 and 6.2 m lies just between the two samples Möh 5 and Möh 6 (Fig. 3). Decalcification probably happened accordingly in the time window missing in the loess accumulation record.

4 Discussion and conclusions

The drill core penetrating the 'Rissian Moraine' of Möhliner Feld did not reveal glacigenic material. While the origin of the morphology of these shallow ridges is not completely solved, interpreting theses as aeolian dunes appears likely (cf. Pye 1995). First loess accumulation occurred during MIS 4, a period when glaciers likely advanced into the Western and Central Swiss Alpine Foreland (Preusser et al. 2007). A hiatus after ca. 60 ka is identified by luminescence dating and supported by a decalcified layer in the core. The stop in loess accumulation is interpreted to be caused by warmer climate, when vegetation cover stabilised dust in the source area. Decalcification likely represents initial soil formation. Interstadial conditions at the time of the hiatus at Möhliner Feld are also identified at other sites in Switzerland and in loess records of Central Europe (cf. Preusser 2004). Main loess accumulation at Möhliner Feld took place around 33 ka in latest MIS 3. This seems to slightly antedate the end of soil formation in the interstadial complexes found in the Swiss Lowlands and in loess records. The uppermost age estimate of ca. 19 ka indicates loess deposition also shortly after the last glacier advance into the foreland.

Considering the age of the MEG, the luminescence ages presented here clearly show that the loess cover was deposited during the Late Pleistocene. This implies a minimum age of MIS 6 for the underlying till originating from the Black Forest (i.e. the Wehra Glacier). In contrast to the assumptions of Schreiner (1995), ice from the Black Forest may have crossed the Rhine Valley during the Rissian. The lower, alpine till at Bünten (MEG), separated by a palaeosol from the upper till (Fig. 2), hence likely pre-dates MIS 6, but there appears no evidence to support an early Middle Pleistocene age, as suggested by Schlüchter (2004).

Acknowledgements

Thomas Kim is thanked for allowing the drilling on his property. Thomas Zimmermann, Gemeindeschreiber, Gemeinde Wallbach showed great interest and organised press releases on the drilling. Michael Schnellmann, National Cooperative for the Disposal of Radioactive Waste (Nagra), is thanked for providing finances covering the drilling costs. Christian Schlüchter provided help and discussion on the interpretation of the drill core. High-resolution γ-spectrometry was carried out by Sönke Szidat, Department of Chemistry and Biochemistry, University of Bern. C_{total} measurements were done by Julijana Krbanjevic. Dorian Gaar was funded through Swiss National Science Foundation (SNF) projects 200021_126784 and 200020_144456.

References

Dick, K., Graf, H. R., Müller, B. U., Hartmann, P. & Schlüchter, C. (1996): Das nordalpine Wasserschloss und seine eiszeitgeologische Umgebung. – Eclogae Geologicae Helvetiae, 89: 635–645.

Frechen, M., Schweitzer, U. & Zander. A. (1996): Improvements in smaple preparation for the fine grain technique. – Ancient TL, 14: 15–17.

Graf, H. R. (2009): Stratigraphie von Mittel- und Spätpleistozän in der Nordschweiz. – 198 pp.; Wabern (Landesgeologie).

Huntley, D. J. & Baril, M. R. (1997): The K content of the K-feldspars beeing measured in optical dating or in thermoluminescence dating. – Ancient TL, 15: 11–14.

Huntley, D. J. & Lamothe, M. (2001): Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating. – Canadian Journal of Earth Sciences, 38: 1093–1106.

Kulig, G., 2005, Erstellung einer Auswertesoftware zur Altersbes-timmung mittels Lumineszenzverfahren unter spezieller Berücksichtigung des

Einflusses radioaktiver Ungleichgewichte in der ^{238}U-Zerfallsreihe. – Technische Bergakademie Freiberg, unpublished BSc thesis.

Lowick, S. E., Trauerstein, M. & Preusser, F. (2012): Testing the application of post IR-IRSL dating to fine grain waterlain sediments. – Quaternary Geochronology, 8: 33–40.

Mauz, B., Packman, S. & Lang, A. (2006): The alpha effectiveness in silt-sized quartz: New data obtained by single and multiple aliquot protocols. – Ancient TL, 24: 47–52.

Penck, A. & Brückner, E. (1901–1909): Die Alpen im Eiszeitalter. – 1157 pp.; Leipzig (Tauchnitz).

Preusser, F. (1999): Luminescence dating of fluvial sediments and overbank deposits from Gossau, Switzerland: fine grain dating. – Quaternary Science Reviews, 18: 217–222.

Preusser, F. (2004): Towards a chronology of the Late Pleistocene in the northern Alpine Foreland. – Boreas, 33: 195–210.

Preusser, F., Blei, A., Graf, H. & Schlüchter, C. (2007): Luminescence dating of Würmian (Weichselian) proglacial sediments from Switzerland: methodological aspects and stratigraphical conclusions. – Boreas, 36: 130–142.

Preusser, F. & Degering, D. (2007): Luminescence dating of the Niederweningen mammoth site, Switzerland. – Quaternary International, 164–65: 106–112.

Pye, K. (1995): The nature, origin and accumulation of loess. – Quaternary Science Reviews, 14: 653–667.

Schlüchter, C. (2004): The Swiss glacial record – A schematic summary. – In: Ehlers, J. & Gibbard, P. L. (eds.): Developments in Quaternary Sciences: 413–418; Amsterdam (Elsevier).

Schreiner, A. (1995): Zur Quartärgeologie des unteren Wehratales und zur Frage der Vergletscherung des Dinkelberges in der Rißeiszeit. – Eiszeitalter und Gegenwart, 45: 62–74.

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / th 1–2 / DOI 10.3285/eg.66.1.th1
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

THESIS ABSTRACT

Luminescence Dating of Middle Pleistocene Glaciofluvial Sediments of the Austrian Northern Alpine Foreland

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Dissertation: http://permalink.obvsg.at/bok/AC10778641 (not provided online)

In the beginning of the 20th century, Albrecht Penck und Eduard Brückner (1909) developed the concept of four large scale Quaternary alpine glaciations extending into the alpine foreland. Since then, the Northern Alpine Foreland (NAF) has played a major role in the investigation of glacial and furthermore paleo-climatic events. However, a numerical chronology has not been established yet. This study focuses on applying luminescence dating to the glaciofluvial deposits attributed to the penultimate glaciation (Riß glaciation, correlated to marine isotope stage 6) when vast areas of the inner Alps were completely glaciated (Figure 1). In the easternmost part of the Alps, the glaciers did not reach the foreland, but formed valley glaciers confined by the mountainous terrain.

Samples for luminescence dating purposes were taken from glaciofluvial sediments mainly deposited in the form of river terraces in the alpine foreland. Samples were collected from 6 river basins for analysis within this PhD thesis (rivers from East to West: Ybbs, Enns, Steyr, Krems,Traun, and Salzach).

On the one hand, this study explored the luminescence properties of quartz and feldspar regarding their potential as robust dosimeters for dating glaciofluvial sediments of the penultimate glaciation in the Austrian NAF (Bickel et al. 2015a, Bickel 2016). On the other hand, the main goal was the construction of a reliable and robust chronology of the deposits.

A highly dynamic depositional environment, such as a glacier-fed river system, implies the possibility of incomplete resetting of the luminescence signal – in particular when transport distances are short. In an environment like this, quartz is the mineral of choice over feldspar, especially if dose rates are low and theoretically allow gaining quartz ages beyond 150 ka.

However, detailed analyses of the quartz OSL signal characteristics had revealed the presence of a thermally unstable medium component in some samples. Because of the lack of independent age control in the expected age range, it remained unclear whether this medium component may result in significant age underestimation for the affected samples (Bickel 2016). Therefore, the luminescence properties of coarse grain potassium-rich feldspar (100–200 µm) were analyzed as well and revealed a general suitability for luminescence dating purposes. To obtain a robust dataset and reliable age estimates for the samples, three luminescence signals were investigated for each sample: blue stimulated quartz OSL, infrared stimulated feldspar luminescence at 50°C (IRSL) and at an elevated temperature of 225°C (pIRIR). By comparing the results gained from all three analytical approaches, it was possible to discern between samples that were well bleached prior to deposition and samples for which the luminescence signals were not properly reset (Bickel 2015a,b).

Using this comparative dating approach, it was possible to establish a reliable chronology for the glaciofluvial deposits attributed to the penultimate glaciation in the NAF. For the first time, it was possible to establish a methodologically and stratigraphically coherent age determination of the formation of terrace sediments during the penultimate glaciation in the Austrian NAF. Additionally, in comparison with previous studies from other alpine regions it was possible to show, that the transition between glacial and interglacial conditions happened relatively fast in late MIS6/starting MIS5 (Bickel et al. 2015b). Even though the dating results allow to discern between glacial and interglacial periods, a finer resolution on a stadial/interstadial level cannot be obtained solely using the current state-of-the art methods of luminescence dating as applied in this study.

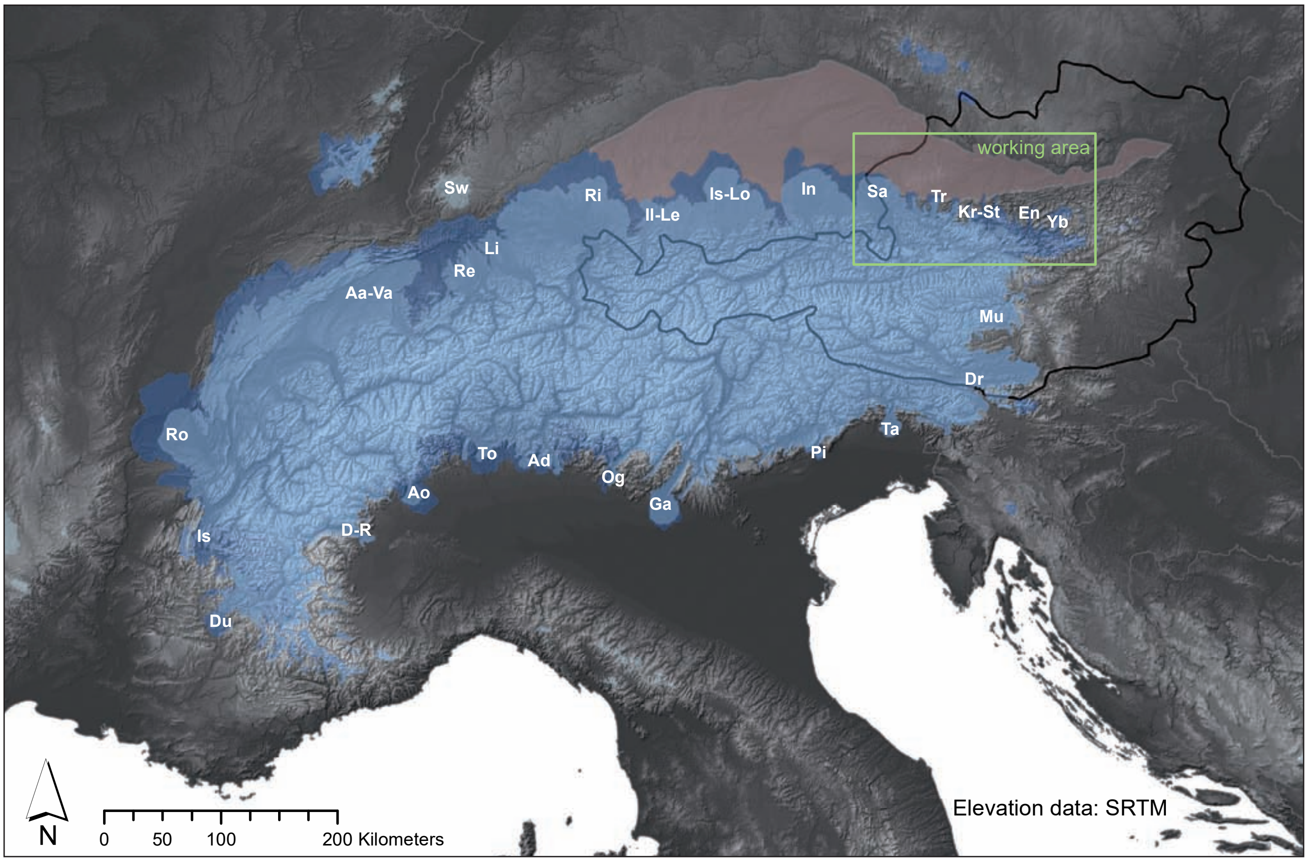

Fig. 1: Ice extent of the last (light blue) and penultimate (dark blue) glaciations of the Alps and surrounding areas. (modified after Ehlers *&* Gibbard *2004,* Kohl *2000). The Northern Alpine Foreland is indicated with a reddish overlay. The working area is framed by a green rectangle. Main glacier systems: Aa-Va…Aare-Valais, Ad…Adda, Ao…Aosta, D-R…Dora Riparia, Dr…Drau, Du…Durance, En…Enns, Ga…Garda, Il-Le…Iller-Lech, In…Inn, Is…Isère, Is-Lo… Isar-Loisach, Kr-St…Teichl-Steyr-Krems, Li…Limmath, Mu…Mur, Og…Oglio, Pi…Piave, Re…Reuss, Ri…Rhine, Ro…Rhône, Sa…Salzach, Sw…Schwarzwald, Ta…Tagliamento, To…Toce, Tr…Traun, Yb…Ybbs.*

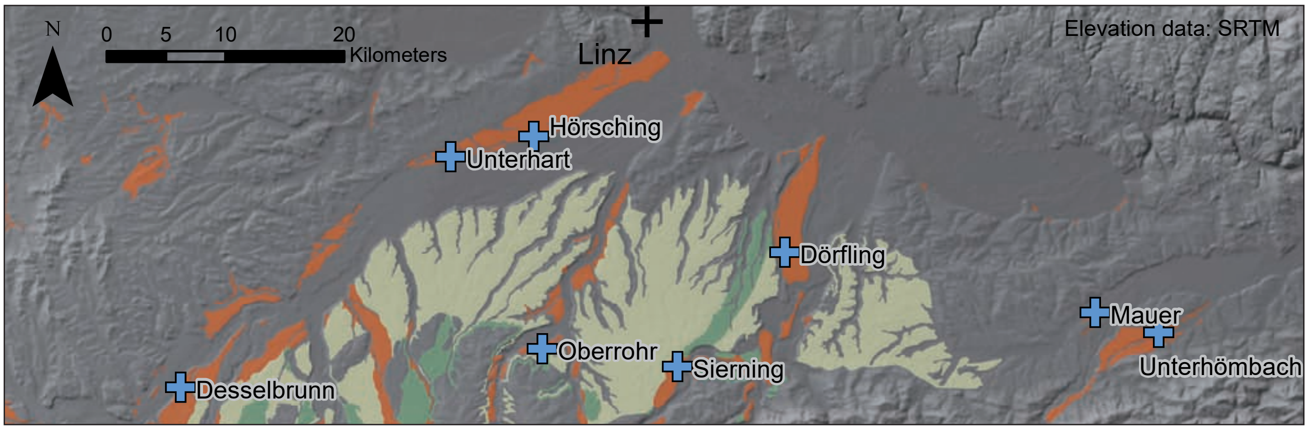

Fig. 2: Overview of the main working area – the „Traun-Enns-Platte" (Traun-Enns-Plateau). Red: High Terrace, green: Younger Cover Gravel, yellow: Older Cover Gravel. Blue crosses represent sampling locations.

References

Bickel, L. (2016): Luminescence dating of Middle Pleistocene glaciofluvial sediments of the Austrian Northern Alpine Foreland. – Phd thesis, BOKU – University of Natural Resources and Life Sciences, Vienna, 166 p., Vienna. http://permalink.obvsg.at/bok/AC10778641

Bickel, L., Lüthgens, C., Lomax, J., & Fiebig, M. (2015a): Luminescence dating of glaciofluvial deposits linked to the penultimate glaciation in the Eastern Alps. – Quaternary International, 357, 110–124. http://doi.org/10.1016/j.quaint.2014.10.013

Bickel, L., Lüthgens, C., Lomax, J., & Fiebig, M. (2015b): The timing of the penultimate glaciation in the northern Alpine Foreland: New insights from luminescence dating. – Proceedings of the Geologists' Association, 126(4–5). http://doi.org/10.1016/j.pgeola.2015.08.002

Ehlers, J. & Gibbard, P. (Eds.) (2004): Quaternary Glaciations-extent and Chronology: Part I: Europe, supplementary data. – Elsevier.

Kohl, H. (2000): Das Eiszeitalter in Oberösterreich. – Schriftenreihe ed. Oberösterreichischer Musealverein, 487 p., Linz.

Penck, A. & Brückner, E. (1909): Die Alpen im Eiszeitalter. – Bd. 1. Die Eiszeiten in den nördlichen Ostalpen. p. 393.

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / th 3–5 / DOI 10.3285/eg.66.1.th2
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

THESIS ABSTRACT

Overdeepened glacial basins as archives for the Quaternary landscape evolution of the Alps

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Dissertation online: doi.org/10.13140/RG.2.2.17415.80802

The Alps and the Alpine foreland have been shaped by repeated glaciations during Quaternary glacial-interglacial cycles. Extent, timing, and impact on landscape evolution of these glaciations remain, however, poorly constrained due to the fragmentary character of proximal terrestrial archives. In this context, the sedimentary infill of subglacially eroded, ‘overdeepened’, basins may serve as important archives to complement the Quaternary stratigraphy over several glacial-interglacial cycles. In this thesis, the infill of deep subglacial basins in the Lower Glatt valley (N Switzerland, Fig. 1) are explored to better constrain the Middle- to Late Pleistocene glaciation history and landscape

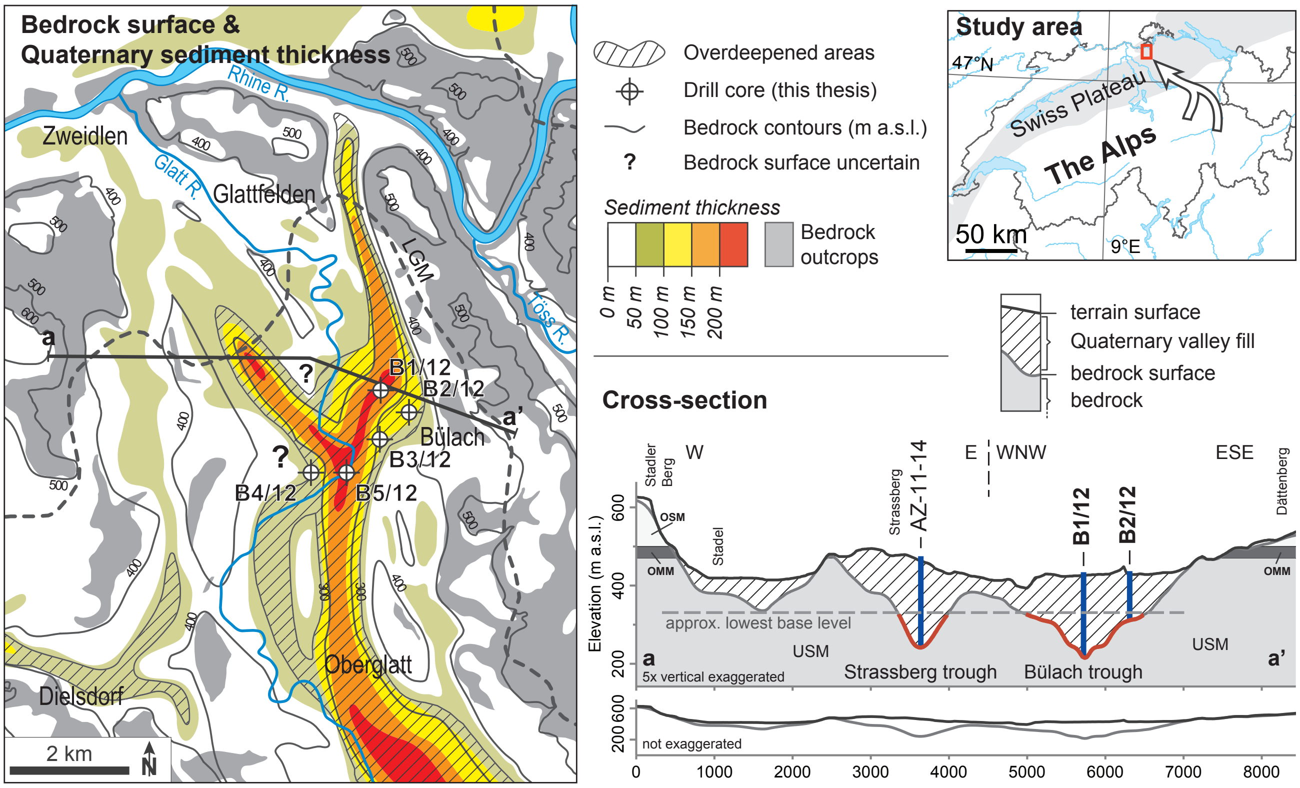

Fig. 1: The bedrock topography in the Lower Glatt Valley (N-Switzerland) is characterized by narrow bedrock depressions forming subparallel to bifurcating troughs attributed primarily to subglacial erosion. These troughs are inset into a broad valley geometry and cut up to ~100 m below lowest fluvial base level. The up to 200-m thick Quaternary sediments infilled into the eastern branch (Bülach Trough) have been recovered in five drill cores (B1-B5/12), which were analysed in detail for this thesis. Bedrock surface map is courtesy of Amt für Abfall, Wasser, Energie und Luft (AWEL), Zürich and Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (Nagra), Wettingen.

evolution. Five drill cores gave direct insight into to the up to ~190 m thick valley fill at the study site and allowed for detailed analysis of sedimentary facies, age, and architecture of the basin fills.

In a first step, the characteristics and origin of the infilled sediments were studied using core descriptions, micro-sedimentology in thin-sections, and compositional analysis of different grain-size fractions. The study by Buechi et al. (2017a) focusses on the sedimentology of coarse-grained diamictons with sorted interbeds, which overlie bedrock in the deepest depressions and mark the onset of deposition in many other glacial bedrock troughs. The macro- and micro-sedimentology suggest that these sediments are emplaced subglacially and reflect deposition, re-working, and deformation in response to repeated coupling and decoupling of the ice–bed-interface promoted by high basal water pressures (Fig. 2, see Buechi et al. 2017a). These results therefore give insights into the subglacial conditions that existed in these otherwise inaccessible bedrock troughs. The overlying valley fill is dominated by submarginal to proglacial glacio-deltaic, glacio-lacustrine, and later lacustrine sediments that document glacier retreat from the basin. Interbedded subglacial tills indicate later glaciations forming nested, or 'inlaid', overdeepened basins with partial preservation of the older valley fill.

In a second step, an absolute chronology of the depositional and erosional periods was developed using luminescence dating of glaciolacustrine silts. Quartz OSL was identified as the luminescence signal of choice as it met all performance criteria and is least affected by incomplete bleaching. The results suggest glaciolacustrine deposition and infilling of the thick sedimentary sequence during different stages of the MIS6 Beringen Glaciation period. However, the resulting burial ages were relatively close to the upper dating limit of the method and the reliability had to be tested extensively in signal stability experiments (Buechi et al. 2017b). The burial ages of the lower glaciolacustrine units partly coincide with the ice-free MIS7 interglacial period. This overlap is interpreted to result from an overestimation of the true burial age

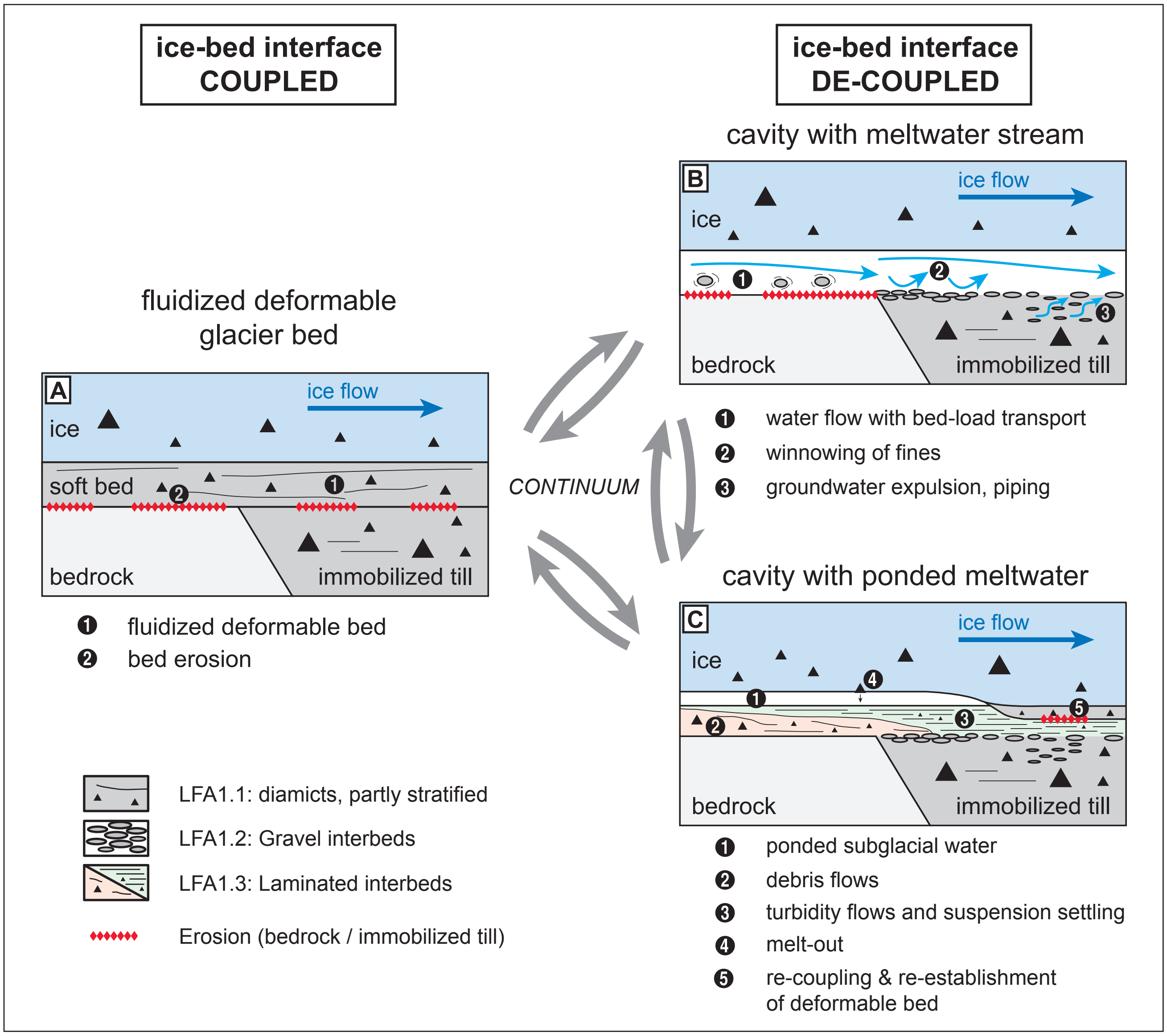

Fig. 2. Schematic diagram showing different states of the ice–bed-interface in the deepest part of the subglacial basin (Buechi et al. 2017a). In this model, the interbedding of subglacial tills with gravels and laminated fines results of repeated switching between a coupled and decoupled ice–bed-interface in space and time.

most likely caused by admixture of unbleached older valley fill material.

This litho- and chronostratigraphic framework was then used to reconstruct the local to regional glaciation history and landscape evolution (Buechi et al. in review). The valley fill is grouped into nine formations, which are related to the Birrfeld Glaciation (~MIS2), the Beringen Glaciation (~MIS6), and up to three earlier Middle Pleistocene glaciations, tentatively correlated to the Hagenholz, Habsburg, and Möhlin Glaciations (Preusser et al. 2011). The complex valley fill and bedrock architecture are therefore interpreted to be result of multiple erosion and infilling cycles and reflect the interplay of subglacial erosion, glacial to lacustrine infilling of overdeepened basins, and fluvial downcutting and aggradation in the non-overdeepened valley fill. Evidence suggests that in the study area deep bedrock incision, and/or partial re-excavation, occurred mainly during the Beringen and Hagenholz Glaciation, while older structures may have existed. Together with the observation of minor, 'inlaid' glacial basins, dynamic changes in the magnitude and focus of subglacial erosion over time are documented. The preservation of sediments in subglacial basins over several glacial-interglacial cycles demonstrates the importance of subglacial basins as archives for glaciation history and landscape evolution of the Alps and glaciated mountain ranges worldwide.

References

Buechi, M. W., Frank, S. M., Graf, H. R., Menzies, J. & Anselmetti, F. S. (2017a): Subglacial emplacement of tills and meltwater deposits at the base of overdeepened bedrock troughs. – Sedimentology 64, 658–685. DOI: 10.1111/sed.12319

Buechi, M. W., Lowick, S. E. & Anselmetti, F. S. (2017b): Luminescence dating of glaciolacustrine silt in overdeepened basin fills beyond the last interglacial. – Quaternary Geochronology 37, 55–67. DOI: 10.1016/j.quageo.2016.09.009

Buechi, M. W., Graf, H. R., Haldimann, P. A., Lowick, S. E., Anselmetti, F. S. (in review): Multiple Quaternary erosion and infill cycles in overdeepened basins of the northern Alpine foreland. – Swiss Journal of Geosciences.

Preusser, F., Graf, H. R., Keller, O., Krayss, E. & Schlüchter, C. (2011): Quaternary glaciation history of northern Switzerland – E&G Quaternary Science Journal 60, 282–305. DOI: 10.3285/eg.60.2-3.06

E&G Quaternary Science Journal
Volume 66 / Number 1 / 2017 / th 6–8 / DOI 10.3285/eg.66.1.th3
www.quaternary-science.net

GEOZON SCIENCE MEDIA
ISSN 0424-7116

THESIS ABSTRACT

Comparison of dating methods for paleoglacial reconstruction in Central Asia

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Dissertation online: http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A955904&dswid=4483

Reconstruction of former extent and timing of Central Asian glaciers can provide valuable information about past atmospheric circulation variations. Further understanding of paleoenvironmental conditions in this area is of particular interest because several studies indicate that periods of extent and retreat of Central Asian glaciers were out of phase with global ice volume records and alpine glaciers from most formerly glaciated areas. However, the robustness of paleoglacial reconstructions largely rests on the accuracy of chronological constraints of glacial landforms, most often moraines. Glacial chronologies derived from moraines and glacio-fluvial deposits are largely based on cosmogenic nuclide exposure (CNE) and optically stimulated luminescence (OSL) dating methods. Large scattering of CNE moraine boulders ages, due to geomorphological processes (e.g. inheritance and post-exposure), often complicates the assignment of a glacial timing associated with moraine formation. Low sensitivity quartz commonly observed in high mountain environment and partially bleached sediments due to short light exposure during glacial or glaciofluvial transport most often hamper the dating of glacio-fluvial deposits using OSL techniques. This thesis focuses on the methodological aspects of directly dating glacial landforms using CNE and OSL techniques, with an emphasis on OSL, in order to improve our understanding of glaciation pattern in Central Asia.

In order to deal with partially bleached sediments, it is essential to measure the luminescence signal at the single grain scale. In line with this need, this thesis contributes to the development of a new Electron Multiplying Charges Coupled Device (EMCCD)-based imaging system for single grain luminescence dating. Such a system would offer a larger flexibility in term of stimulation source, grain fraction and mineral type compared to the current and well-established laser-based single grain attachment scanning system. However, three main issues hamper accurate single grain measurements when using an EMCCD-based imaging system. These issues relate to the sample carrier mo-

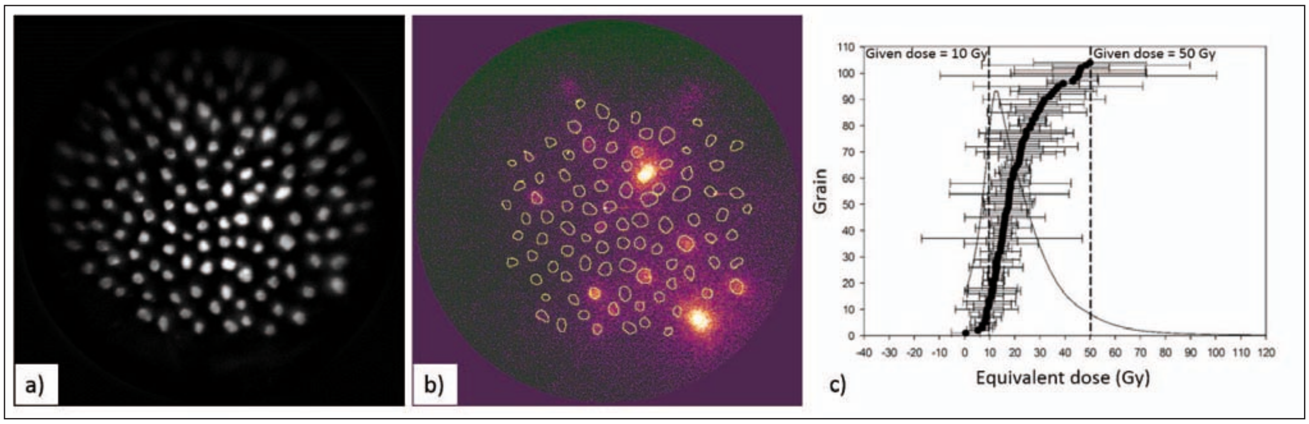
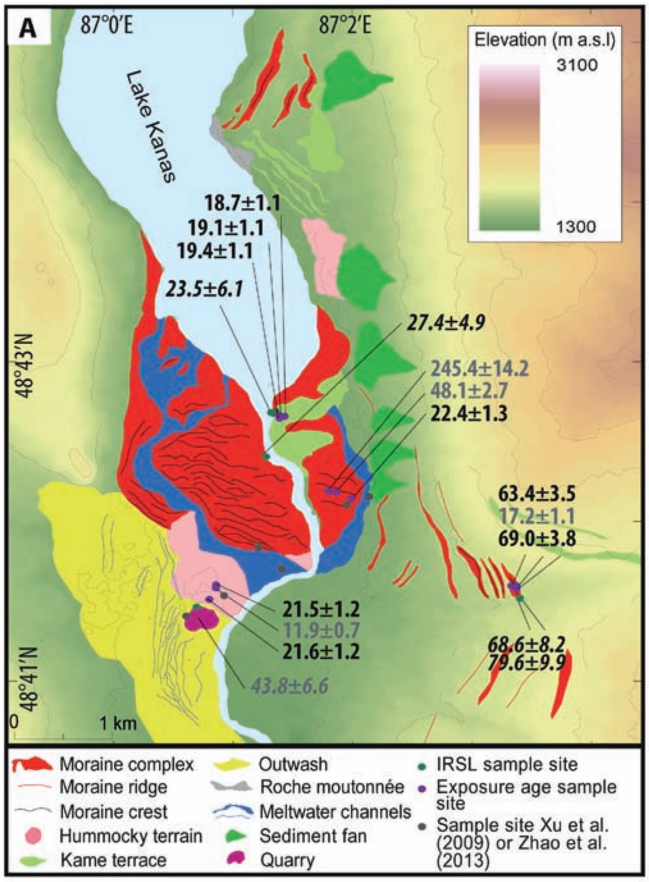


Fig. 1: Single grain measurements using an EMCCD-based imaging system. Light reflected pictures (a) allow delineating the regions of signal integration along the grain borders, which are then used to segment the luminescence images (b). c): Example of single grain equivalent dose distribution obtained from a mixed doses sample (10 and 50 Gy). Cross talk effects hamper the recovery of two dose populations centred on 10 and 50 Gy.



tion over repeated measurements, the absence of an automatic and reproducible method to assign pixels per grain for individual signal integration, and the contamination of individual signals by signal emission from neighbouring grains (cross talk). An automated image processing procedure has been developed to compensate for sample carrier displacement and to attribute pixels cluster for each grain to allow automatic signal integration (Greilich et al. 2015). While laboratory measurements and simulations demonstrate that significant cross talk effects prevent the use of this system to perform routine single grain measurements, preliminary experiments using a basic image processing algorithm suggests good potential for a software correction solution (Gribenski et al. 2015), encouraging further work in this direction.

Palaeoglacial reconstructions studies were conducted in the Altai Mountains in Central Asia (Russia and China; Gribenski et al. 2016, *in review*) to investigate uncertainties related to CNE and OSL dating techniques and their effects on the reliability of glacial chronologies. Resulting chronological data demonstrate the importance of conducting luminescence measurements at the single grain scale for sediments deposited in glacial environments. Measurements carried out with multi-grain aliquots were shown to yield large age overestimates of glacial landform age, due to partial bleaching effects. However, determining accurate glacial landform age from single grain luminescence measurements remains challenging. The ages inferred from

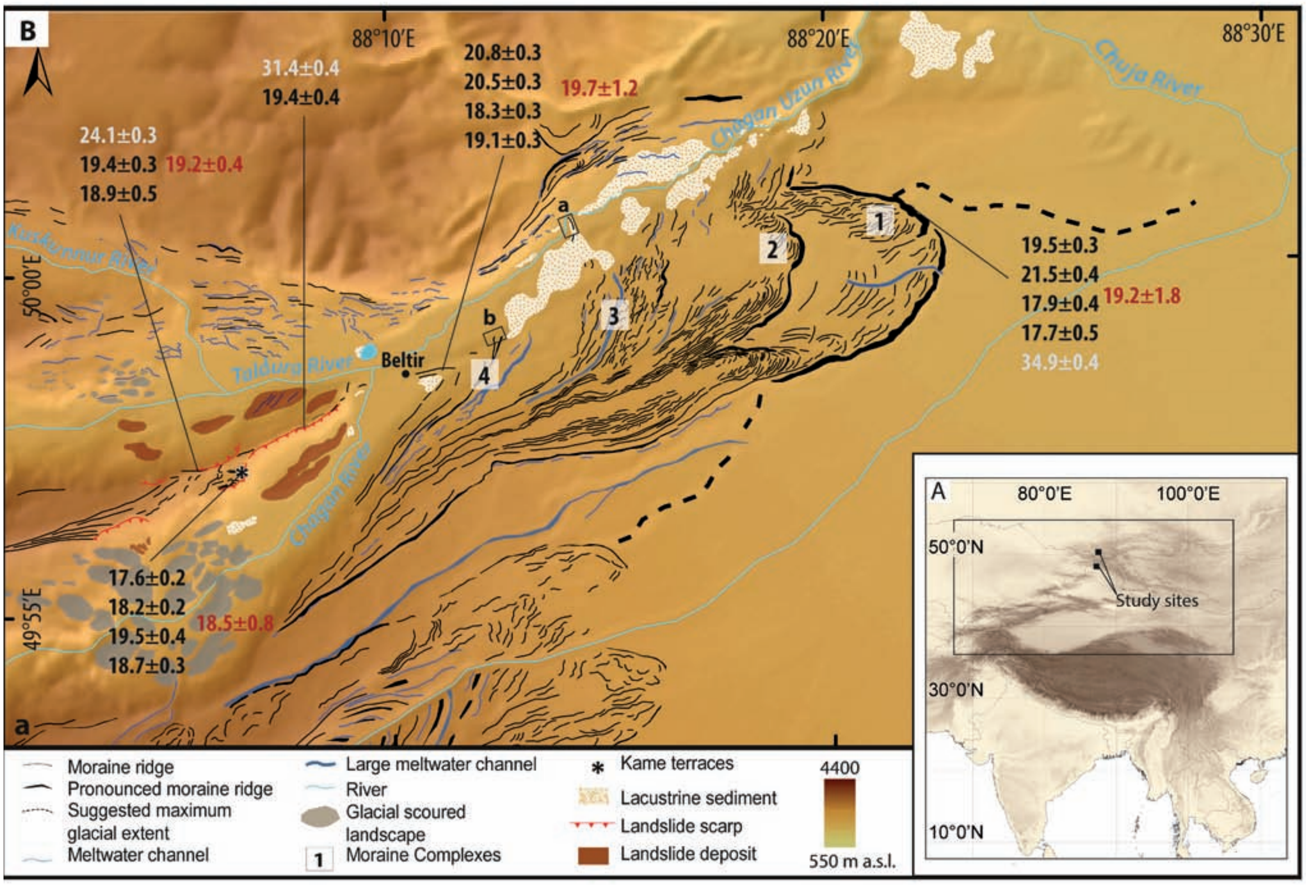


Fig. 2: Geomorphological mapping and cosmogenic as well as OSL (in italic) data obtained from the two palaeoglacial reconstructions conducted in the Chinese (A), and Russian (B) Altai (Central Asia). Ages in grey are discarded for glaciation timing interpretation. Ages in red (in B) represent the average age for each landform sampled.

single grain measurements can vary significantly depending on the statistical sub-sampling technique used for extracting luminescence data associated with well-bleached grains. In addition, fading corrections, associated with the use of the feldspar mineral as a dosimeter, increase the final uncertainty. CNE dates of moraine boulders revealed important inheritance effects, in contrast to previous data-compilation analyses and model-based studies that suggest a pre-dominance of post exposure effects. In general, CNE ages of moraine boulders exhibit significant scattering, however glaciation timing can be extracted from CNE age populations that are composed of a majority of ages concentrated within a few thousand years and a small number of older/younger outliers. Glaciation periods inferred from CNE ages ranging over a few thousand years are considered acceptable, as this time range can reflect still stands oscillations of the ice margin. The presented paleoglacial reconstruction studies show that combining CNE and OSL methods to directly date glacial landforms is a powerful approach for producing reliable glacial chronologies, in particular for pre-LGM glacial deposits for which source of uncertainties are typically larger when dated using a single technique. Consistent CNE and single grain OSL ages strengthens our confidence in the chronologies despite uncertainties related to each dating method individually.

The palaeoglacial reconstructions conducted in the Altai Mountains in this project clearly constrain glacial advances to the MIS 2 and are in line with the glaciation timing indicated by most of the well-constrained glacial chronologies published in Central Asia region. In addition, our study also provides robust evidence for a local maximum extent beyond the MIS 2 glacial extent (Kanas Valley, China; Gribenski et al., *in review*), which occurred somewhere during the MIS 4/late MIS 5 and so predated the global LGM. However, too few palaeoglacial reconstructions have been conducted in the Altai area to attribute a regional character to this pre-LGM glacial event. In general, abundant geomorphological evidence indicates earlier Last Glacial glaciation(s) exceeding the MIS 2 glacial extent in Central Asia. In particular, a period of major glacial advances during MIS 3 in Central Asia has been suggested by several studies, which in addition to be out of phase with global ice volume records, corresponds to a period of relative global warmth. However, detailed analysis of chronological data set associated with major MIS 3 glacial advances in Central Asia indicate that most of the reconstructions are based on few or heavily and evenly scattered CNE ages of moraine boulders, or on OSL or Electron Spin Resonance (ESR) data for which potential partial bleaching of the samples has not been thoroughly investigated. Therefore, at this stage, available chronological data do not present a compelling case for a widespread MIS 3 glaciation in Central Asia. Future detailed geomorphological and chronological studies of former glacial extents in this region are warranted to provide tighter constraints on the pre-LGM glacial activity in Central Asia.

Finally, this thesis highlights the importance of detailed geomorphological and sedimentological investigations to understand former ice dynamics, which is crucial for proper paleoclimate inferences. Indeed, numerous non-climatic factors such as local topography, debris cover, or geological substrate can influence glacier expansion, interfering with the interpretation of climatically induced glacier extent changes. As such, geomorphological and sedimentological data indicate that large outermost moraine belts marking prominent advances of the Chagan Uzun Glacier in the Russian Altai, and dated at ~MIS 2, were formed during fast flowing or surge-like event. Based on these interpretations, it would be inappropriate to reconstruct ELA from the outer moraine belts, as fast flowing/surge-like behaviour reflects a glacier not in equilibrium with climate. Although understanding palaeo ice dynamics might be challenging, detailed geomorphological and sedimentological investigations can help to identify non-climatically driven (or not mainly) paleo glacier expansions, and so prevent inappropriate ELA reconstructions and paleoclimate inferences.

References

Greilich, S., Gribenski, N., Mittelstrass, D., Dornich, K., Huot, S. & Preusser, F. (2015). Single-grain dose-distribution measurements by optically stimulated luminescence using an integrated EMCCD-based system. – Quaternary Geochronology, 29, 70–79. DOI: 10.1016/j.quageo.2015.06.009.

Gribenski, N., Preusser, F., Greilich, S., Huot, S. & Mittelstrass, D. (2015). Investigation of cross talk in single grain luminescence measurements using an EMCCD camera. – Radiation Measurements, 81, 163–170. DOI: 10.1016/j.radmeas.2015.01.017.

Gribenski, N., Jansson, K.N., Lukas, S., Stroeven, A.P., Harbor, J.M., Blomdin, R., Ivanov, M.N., Heyman, J., Petrakov, D.A., Rudoy, A., Clifton, T., Lifton, N.A. & Caffee, M.W (2016). Complex patterns of glacier advances during the Late Glacial in the Chagan Uzun Valley, Russian Altai. – Quaternary Science Reviews, 149, 288–305. DOI: 10.1016/j.quascirev.2016.07.032.

Gribenski, N., Jansson, K.N., Preusser, F., Harbor, J.M., Stroeven, A.P., Trauerstein, M., Blomdin, R., Heyman, J., Caffee, M.W., Lifton, N.A. & Wei, Z. *(In review)*. Major glaciation in Central Asia during MIS 3: reality or dating artefact? – Journal of Quaternary Science.

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Quaternary Science Journal
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