DEUQUA EXCURSIONS

Edited by Daniela Sauer

From the northern ice shield to the Alpine glaciations

A Quaternary field trip through Germany

GEOZON

From the northern ice shield
to the Alpine glaciations

Preface

Daniela Sauer

The 10-day field trip described in this excursion guide was organized by a group of members of DEUQUA (Deutsche Quartärvereinigung = German Quaternary Union), coordinated by DEUQUA president Margot Böse. The tour was offered as a pre-congress field trip of the INQUA Congress in Bern, Switzerland, 21– 27 July 2011. Finally, the excursion got cancelled because not enough participants had registered. Apparently, many people were interested in the excursion but did not book it because of the high costs related to the 10-day trip. Because of the general interest, we decided nevertheless to finish the excursion guide.

The route of the field trip follows a section through Germany from North to South, from the area of the Northern glaciation, to the Alpine glacial advances. It includes several places of historical importance, where milestones in Quaternary research have been achieved in the past, as well as new interesting sites where results of recent research is presented.

The field trip starts at Greifswald in the very North-East of Germany. The first day is devoted to the Pleistocene and Holocene Evolution of coastal NE Germany. The Baltic coast with its characteristic cliffs provides excellent exposures showing the Late Pleistocene and Holocene stratigraphy and glaciotectonics. The most spectacular cliffs that are located on the island of Rügen, the largest island of Germany (926 km^2) are shown.

In the morning of the second day, the Geopark "Mecklenburg Ice Age Landscape" in NE Germany will be visited. It comprises a glacial landscape that is representative for the lowlands of central Europe. The close relationship between the geological heritage and the development of the cultural landscape are demonstrated. During the Weichselian glaciation the region was covered by ice at least in three phases (Brandenburg, Pomeranian,

Mecklenburg Phase). Each ice advance is recognizable by distinctive formations, especially end moraines and tills.

From the afternoon of day 2 until the morning of day 4 of the excursion, the young moraine landscape around Berlin will be explored. The Pomeranian ice marginal position (IMP), showing the most prominent ice marginal features in NE Germany, will be visited. Another highlight will be a complete record of the Eemian interglacial that has been preserved in lake sediments and is fully exposed at present. The five sites shown in this area altogether comprise an age range from the Saalian (penultimate glacial period; MIS 6) to the late Weichselian (last glacial period).

Day 5 is dedicated to Quaternary geology and prehistorical findings in an area South of Halle (West of Leipzig). Here, deposits of the Elsterian (third last glacial) and Saalian (penultimate glacial) will be shown.

The main topic of days 6 and 7 is the Quaternary valley and slope development in the headwaters of the Main River in Upper Franconia. Evidence of several changes in the courses of the rivers will be demonstrated.

Day 8 will deal with Pleistocene to rather recent landslides at the Swabian Jurassic Escarpment South of Reutlingen. Based on the observations at the visited sites the risk of landslides in the area will be discussed.

In the morning of day 9 we will arrive in the area characterized by moraine ridges and river terraces of the penultimate Alpine glaciation (Rissian; corresponding to Saalian in northern Germany). A historical highlight will be the Rissian *locus typicus* near Biberach a. d. Riss. The excursion will continue southwards, approaching the Last Glacial (Würmian) terminal moraine and following it to the West, studying Last Glacial till, glacio-fluvial and laminated limnic sediments along the way. We will stay overnight at Lake Constance.

The last day of the excursion will deal with the Pleistocene history of the Danube and Rhine river systems. We will see dry valleys illustrating the river history. Highlights will be a walk into the Wutach Canyon. After a short boat trip across the Rhine River looking at the famous Rhine water fall, a 2 hour bus trip will take the group to Bern.

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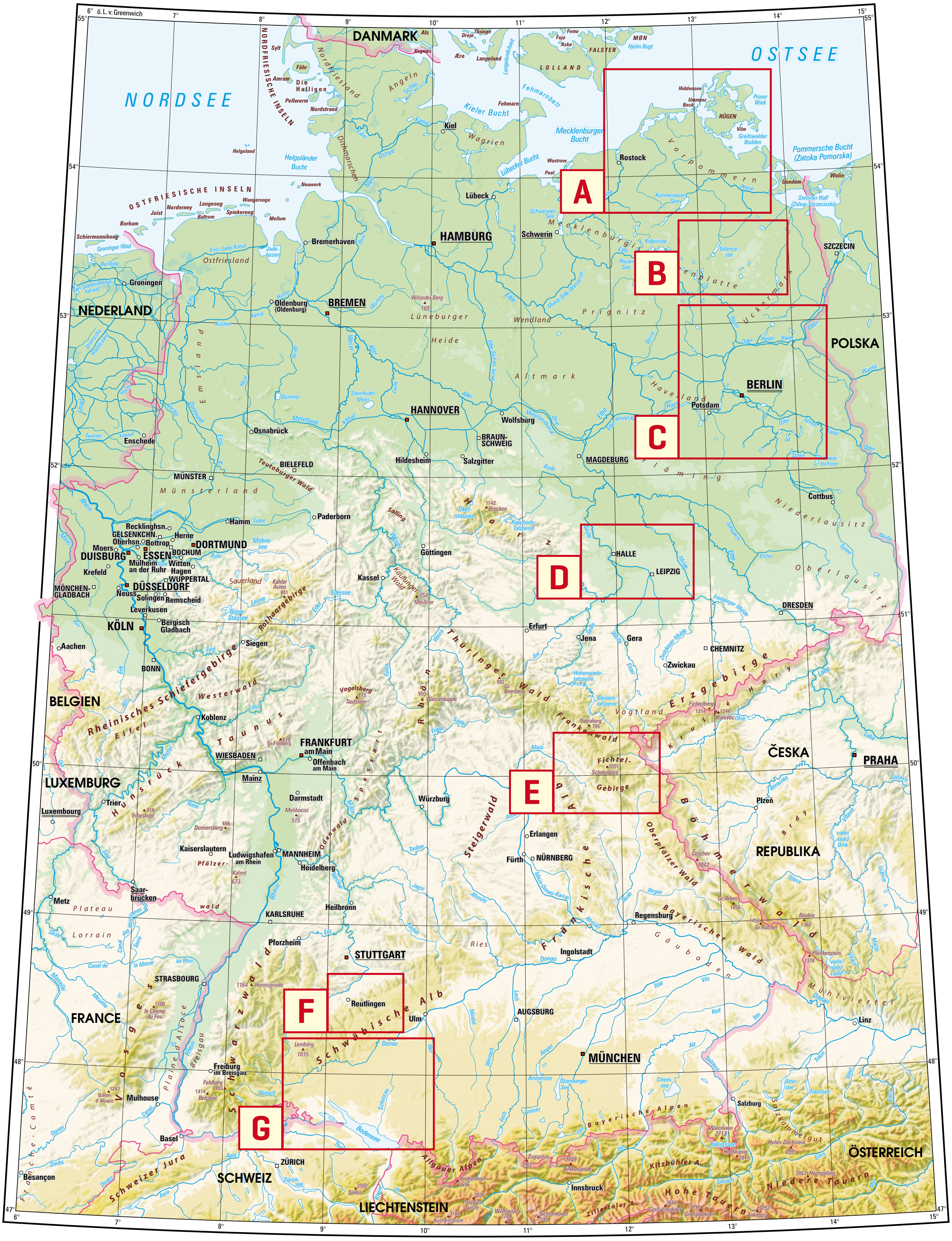
Orohydrographische Karte 1 : 2 500 000



Staatsgrenze der Bundesrepublik
Staatsgrenze im Ausland

BERLIN Bundeshauptstadt, Hauptstadt anderer Staaten
STUTTGART Landeshauptstadt
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KÖLN Stadt über 1 Mio. Einwohner
BREMEN Stadt über 500 000 Einwohner
DRESDEN Stadt über 250 000 Einwohner
Würzburg Stadt über 100 000 Einwohner

Vogtland Landschaften
Schwarzwald Gebirge
OSTFRIESISCHE INSELN Inselgruppe
Norderney Insel

See
Fluss
2962 ▲ Zugspitze Wichtiger Berg mit Höhenzahl

0 km 20 km 40 km 60 km 80 km 100 km

Lamberts winkeltreue Kegelabbildung mit zwei längentreuen Bezugsbreitenkreisen 48°40' und 52°40'
Ellipsoid: Geodätisches Referenzsystem 1980 (GRS 80)

Exkursion A: Reinhard Lampe - **Exkursion B**: Andreas Buddenbohm and Klaus Granitzki - **Exkursion C**: Christopher Lüthgens and Margot Böse - **Exkursion D**: Stefan Wansa and Frank W. Junge - **Exkursion E**: Ludwig Zöller, Ulrich Hambach, Thomas Kolb and Olivier Moine - **Exkursion F**: Birgit Terhorst - **Exkursion G**: Daniela Sauer and Karl Stahr

A

Pleistocene and Holocene evolution of coastal NE Germany (Isle of Rügen)

Reinhard Lampe

Itinerary:

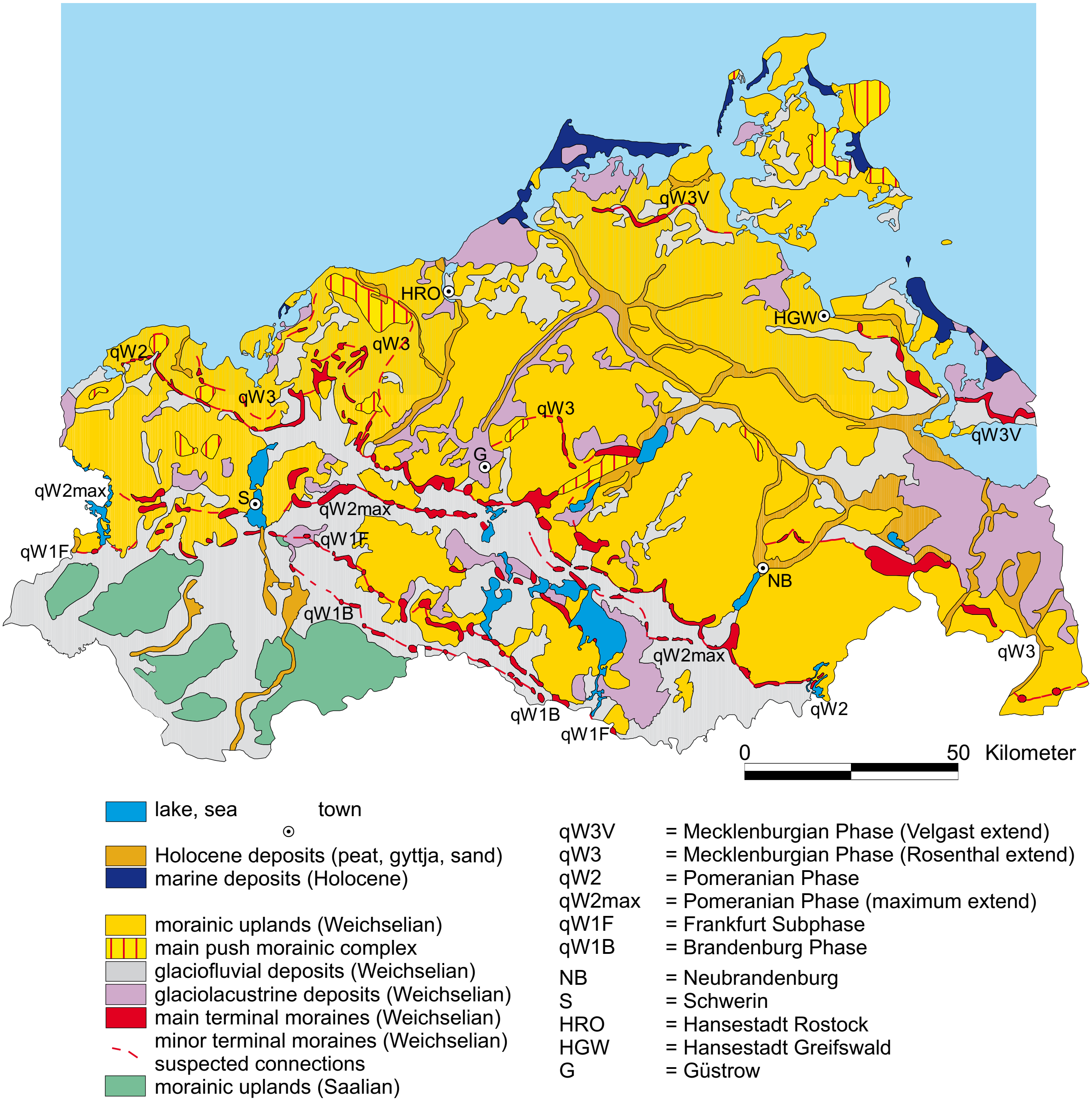

Fig. 1: Quaternary deposits and evolutionary phases in Mecklenburg-Vorpommern (ÜKQ 500).

Abb. 1: Quartäre Ablagerungen und Entwicklungsphasen in Mecklenburg-Vorpommern (ÜKQ 500)

Introduction

In coastal NE-Germany and its hinterland surface sediments and landforms predominate which were built during the Weichselian glaciation (Fig. 1). Three main ice advances from Scandinavia via the Baltic depression to the South led to the deposition of till layers which are separated from each other by sandy sediments mainly. The ice advances and their corresponding terminal and ground moraine deposits are called the Frankfurt-Brandenburgian Phase (qW1), the Pomeranian Phase (qW2), and the Mecklenburgian Phase (qW3), which subsequently covered older sediments of Elsterian (?) and Saalian ages. However, in a vertical profile of Pleistocene sediments – for instance at a cliff - the deposits are conventionally numbered from bottom to top using the letter M for the tills and the letter I for the intercalated sediments regardless of the real stratigraphic position of the sediments. Therefore, a M1-till may belong to a Saalian phase in one cliff section but to the Pomeranian Phase in another section.

Pleistocene outcrops are very rare in the NE German Lowlands. Here, stratigraphic informations were gathered mainly from boreholes and open pit mines. In contrast, the Baltic coast with its characteristic cliffs provides excellent and unique insights into the layering and the Late Pleistocene and Holocene stratigraphy and facilitates glaciotectonic studies. The most spectacular cliffs are located on the island Rügen, which will be visited during the field trip (Fig. 2).

Rügen is the largest island of Germany (area 926 km²) and shows many geological features. Numerous stratigraphical, sedimentological, structural, palaeontological and geoecological studies have been carried out during the 20th century and clarified the main geological problems. Especially the famous chalk cliffs of the Jasmund Peninsula attract visitors from all over the world. In the year 2006 the chalk coast of Jasmund has been approved as a „National Geosite“ of Germany.

Geologically, the northern and the eastern parts of Rügen Island are most important. The peninsulas of Wittow and Jasmund are formed of elevated chalk deposits (Cretaceous, Lower Maastrichtian) with overlying or interbedded Quaternary deposits of different glaciations (Saalian, Weichselian). They represent type localities for prograding glacier deformation structures. At **stop 1** an overview about the Quaternary morphogenesis of Northern Rügen is presented.

In the course of the excursion, field **stops 2** and **5** show special exposures giving insight into the lithofacies, stratigraphy and glaciotectonically controlled architecture of the Pleistocene and Upper Cretaceous chalk deposits. Both represent typical imbricational structures mainly caused by repeated glacier advances. These generally complex geological structures together with exogenic processes (related to i.e. rain- and meltwater runoff) and geotechnical problems due to modern development generate gravitationally-driven hazardous mass movements (landslides) along the cliff coasts. An exceptional cliff failure took place in 2005 at the coast of Lohme (North Jasmund) where c. 100 000 m³ Pleistocene sediments tumbled down to the beach (s**top 4**).

Weichselian Late Glacial deposits mirror the processes of permafrost breakup, revegetation, relief adjustment and groundwater table rise. As an example, at **stop 3** lake sediments will be presented which accumulated during the Bölling to Younger Dryas period in a now dry depression. Between 9 and 5 ka ago the landscape evolution was governed by rapid marine inundation due to the onset of the Littorina (Flandrian) transgression. The development of beach ridge plains and lagoons located behind - discussed at the Schmale Heide flint pebble fields (**stop 6)** – is the result of the adjustment of the coast to the higher water table after the end of the rapid rise. About 1 ka ago the sea started to rise again but was interrupted by a fall/stagnation due to the Little Ice Age. Sedimentological features related to this water table variation are presented at the Karrendorf-Kooser Wiesen salt marsh (**stop** 7).

En-route: Strelasund Bridge – Geology of the Strelasund area (after Krienke 2010)

The Strelasund sound separates the island Rügen from the West Pomeranian mainland. Its development was probably supported by a NE-SW striking fault system in the pre-Pleistocene basement. The weakened ground was repeatedly used by Pleistocene melt waters and thereby deeply eroded. Moreover, an additional influence by narrow ice lobes and melting dead-ice has been discussed.

The cross section which is based on the building ground investigations for the new Strelasund Bridge (4.1 km long, pylon height 128 m, finished in 2007) comprises the entire Quaternary sediment sequence (Fig. 3): in two boreholes the base of the Quaternary (chalk facies of Campanian) was reached in -33.5 m and -55.6 m relative to mean sea level (msl). This depth corresponds with the chalk surface on Rügen (c. -30 m msl) and around Stralsund (c. -55 m msl). Towards the top a partly decametre thick diamict layer follows, which is stratigraphically related to the Saalian glaciation and the Brandenburg-Frankfurt Phase of the Weichselian glaciation (qW1). Above this layer, glacilacustrine/-fluvial deposits (silt to gravel) follow, within which the qW2-till of the Pomeranian Phase is intercalated. Holocene brackish-marine mud completes the sequence in the present subaqueous parts of the cross section.

Sediments, which according to their structure and lithology can be related to a fluvial channel, were found only in the NE part of the section. Here, gravel and sand, assumed to have accumulated subsequent to the qW2-advance, rest directly on the Cretaceous chalk. The lack of till is due to its post-depositional erosion by meltwater.

Stop 1: Lookout from Temple Hill near Bobbin - Quater nary geology and morphogenesis of North Rügen

According to the classification of glacitectonic phenomena the Jasmund push complex is a large-scale composite-ridge. The complex with a maximum elevation of 161 m comprises two systems of subparallel ridge-runnel structures, which contain important fractions of highly deformed pre-Quaternary rocks, in this case Upper Maastrichtian pelagic, fossil rich chalk. The chalk slabs elevate into the highest parts of the push complex while in the vicinity the surface of the chalk is restricted to about -40 m msl. Endogenic, isostatic and/or gravitational causes were repeatedly discussed to explain this exceptional elevation. However, the origination

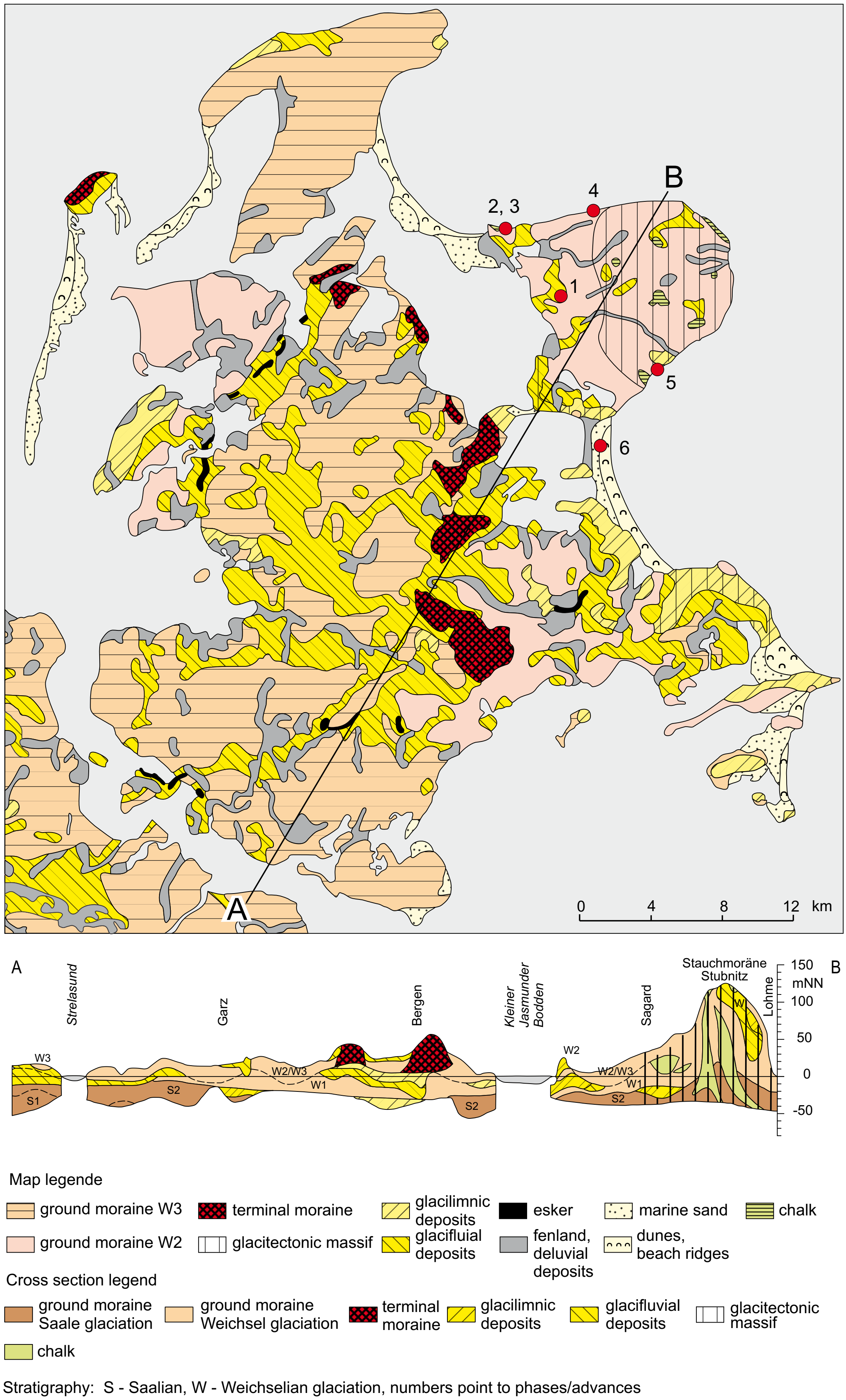

Fig. 2: Surface geology of the Isle of Rügen including section A – B. Along this section elevation increases from SW to NE as a result of glaciodynamic-tectonic processes (acc. to Ükq 200, 1995/Geological Survey of Mecklenburg-Vorpommern). Red dots mark excursion stops 1 to 6, stop 7 is located on the mainland and not shown.

Abb. 2: Oberflächengeologie der Insel Rügen. Der Profilschnit A – B zeigt den von SW nach NE gerichteten morphologischen Geländeanstieg als Resultat glaziodynamisch-tektonischer Prozesse (nach ÜKQ 200, 1995; Geologischer Dienst des Landes Mecklenburg-Vorpommern). Die roten Punkte markieren die Exkursionspunkte 1 – 6, Punkt 7 liegt auf dem südlich anschließenden Festland und ist nicht dargestellt.

of the push complex including the uplift of the chalk slabs can be explained entirely on the base of glacigenic causes, which is particularly backed by the undeformed base level of the Upper Cretaceous sediments. The idea of an endogenic-tectonic cause of the stratigraphic differences between dislocated chalk units is only one interpretation among others. They can easily be explained with differential erosion of the chalk´s surface prior to the M1-ice advance.

The complex developed by proglacial push-up of ridges and subsequent lateral compression between two ice lobes and thus thrusting and folding in an E-W striking N-wing and a NE-SW striking S-wing. Subsequently, the ice sheet overrode the push complex at least in large parts, thereby further deforming the subglacial sediments, and deposited the M3-cover till (qW3). Locally, fluvial erosion, solifluidal dislocation and accumulation of clastic sediments in isolated basins occurred syngenetically (I2-sediments).

After the ice recession the complex was exposed to a periglacial milieu. Solifluction and abluation caused relief adjustment and levelling. Locally, however, internal structures and thus the relief were accentuated due to erosion of the unconsolidated moraines between the more resistant chalk slabs which today pierce monadnock-like through the M3-till layer. Wide-spanning valleys developed which ingested the solifluidal sediments in which subarctic mollusc assemblages were found. In closed basins limnic-telmatic sediments started to accumulate already in the late Weichselian interstadials (Meiendorf, Bölling, Alleröd). Usually, they contain the Laacher See tephra (12830 cal BP) and - rarely evident - some Icelandic tephras as important stratigraphic marker beds.

The subsequent landscape evolution is closely related to the development of the Baltic Sea resp. its precursors. Waterbodies related to the Baltic Ice Lake which existed during the Younger Dryas reached a level of about -10 to -15 m msl leading to accumulation of limnic sand layers in deeper depressions. During the early Holocene (Yoldia Sea, Ancylus Lake) the area belonged to the mainland. The Littorina transgression which started about 8900 cal BP reached the area off Rügen at c. 8300 cal BP at a level of -10 m. A water level of about -1 m msl at 6800 cal BP is evident. Due to the rapid sea-level rise the accommodation space below the sea level grew faster than it was filled with sediment eroded from nearby cliffs. Only after 5800 cal BP when the sea level rise ceased accumulation became the predominant process. Coastal barrier growth started and until 4000 cal BP beach ridge planes evolved and prograded rapidly. Due to a subsequent long lasting stagnation of the sea level the underwater profile of the coastal sediment wedge became equilibrated to the wave forces and a perfect swash aligned shoreline evolved. About 1000 to 1200 years ago the sea level started to rise again and related adjustment processes such as increased erosion along the cliffs, but sediment starvation and impending barrier breaching along the dune coast are evident.

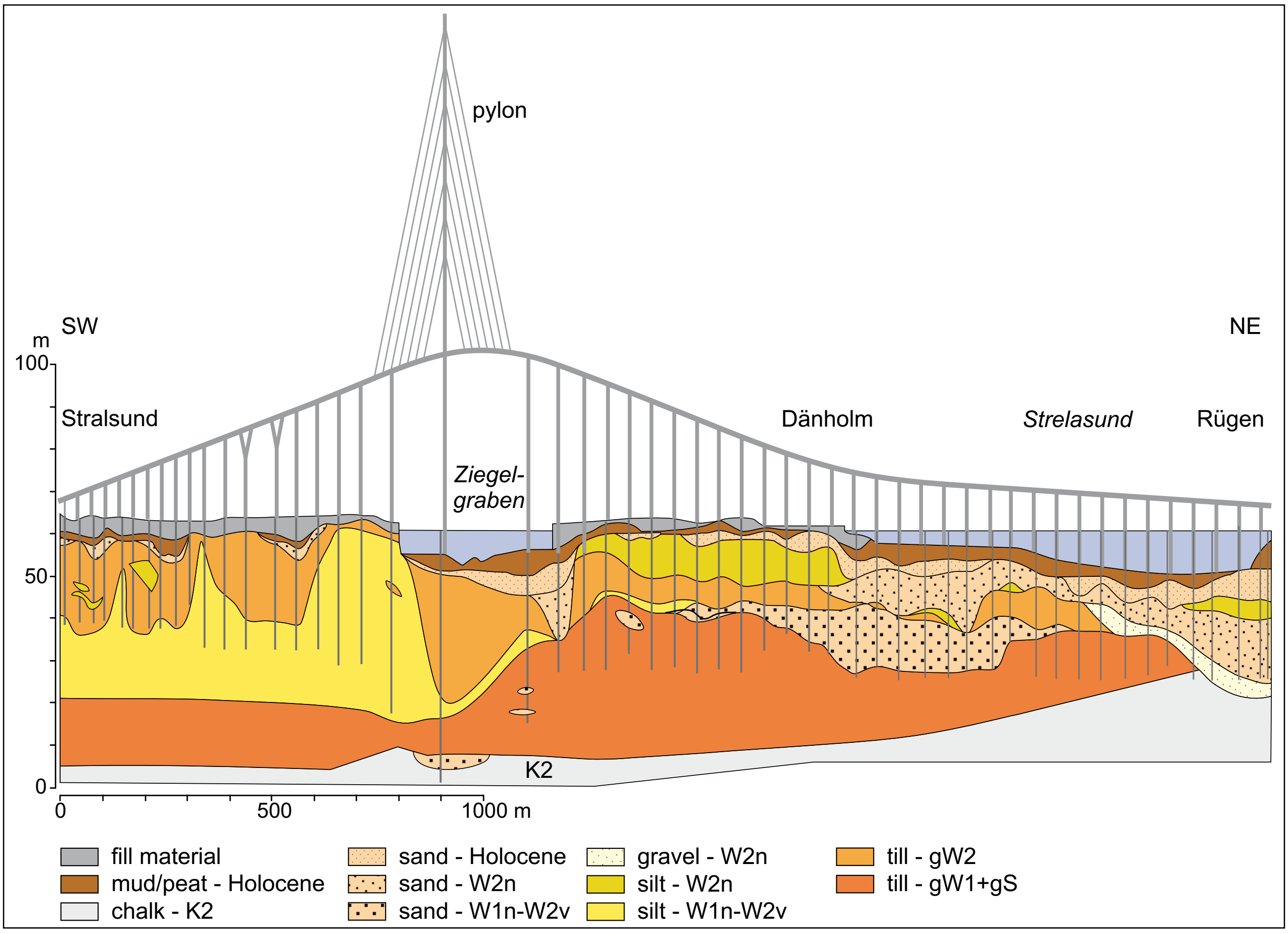

Fig. 3: Geological cross section (SW-NE) of the Strelasund (Krienke in Niedermeyer et al. 2010).

Abb. 3: Geologischer Schnitt (SW-NE) des Strelasunds (Krienke in Niedermeyer et al. 2010).

Tab. 1: Lateglacial and Holocene development stages of the coastal landscape of Mecklenburg-Vorpommern and the southern Baltic Sea.

Tab. 1: Spätglaziale und holozäne Entwicklungsphasen der Küstenlandschaft Mecklenburg-Vorpommerns und der südlichen Ostsee.

ka cal BP	Main periods	Climate periods	Pollen zones	Archaeological periods	Baltic Sea stages	Evolutionary stages in the south Baltic Sea basin (Pomeranian Bay), A - phases of sea level rise, L - Littorina stages (Kliewe & Janke 1982)	Main coastal processes	Salinity in Pomeranian Bay (Kleines Haff)	Baltic Basin water table
0.5	Late Holocene	Subatlantic: Latest	Xc	Modern Times	Mya Sea	A IV - recent transgression minor regression/stagnation during LIA	anthropogenic encroachments on coastal dynamics; white and gray dunes	decreasing to 7-8 PSU, (c. 2 PSU)	
		Late	Xb	Middle Ages					
1.0					(Lymnaea Sea)	A III - Late Subatlantic transgression			
1.5		Middle	Xa	Slawonic Period			accelerated coastal adjustment, first yellow dunes		c. -0,5 m
2.0				Migration Period Roman Iron Age					
2.5		Early	IX	Iron Age (La Téne)					
3.0	Middle Holocene						phase of predominant coastal adjustment, minor sea level variations between -1 m to -0.5 m NHN		
3.5				Bronze Age		Postlittorina phase (L III)			c. -1,0 m
4.0									
4.5		Subboreal	VIII						
5.0				Neolithic	Littorina Sea				
5.5				Linear Pottery Funnel Beaker Culture			brown dunes develop	high: 10 PSU, (≤ 5 PSU)	
6.0									
6.5			VII	Late Ertebølle-Culture (Lietzow-C.)		A II - Littorina main phase (L II), phase of decreasing rise rate	decelerating sea level rise rate to <10 cm/100 a. Onset of coastal adjustment, origination of first spits and barriers, oldest brown dunes		c. -2,0 m
7.0				Early Ertebølle-C.					
7.5		Atlantic						highest: c. 12 PSU (≤ 6 PSU)	c. -4 m
8.0				Mesolithic: Trapez-Mesolithic					
8.5			VI		Mastogloia Sea	A I - Initiale Littorina transgression (L I); transgression, fenlands, rising lake levels	rapid sea level rise, archipelago development, marine abrasion remains still low	moderate: <6 PSU	c. -10 m
9.0									
9.5	Early Holocene	Boreal	V						c. -20 m
10.0				Duwensee-Group		descending groundwater table, extensive desiccation of lakes and mires soil development,	terrestrial evolution, lakes are widespreads above +20 m NHN		
10.5					Ancylus Lake				
11.0		Preboreal	IV			below -20 to -40 m NHN Yoldia Sea and Ancylus Lake			
11.5		Rammelbeek Friesland			Yoldia Sea				c. -40 m
12.0	Lateglacial			Palaeolithic			Lateglacial lakes, which were drained and desiccate later on		c. -15...-10 m
12.5		Younger Dryas	III		Baltic Ice Lake				c. -40 m
13.0		Allerød	II	Ahrensburg Culture		Laacher-See-Tephra	thawing dead ice, origination of lake depressions, incising rivers		c. -20...-15 m

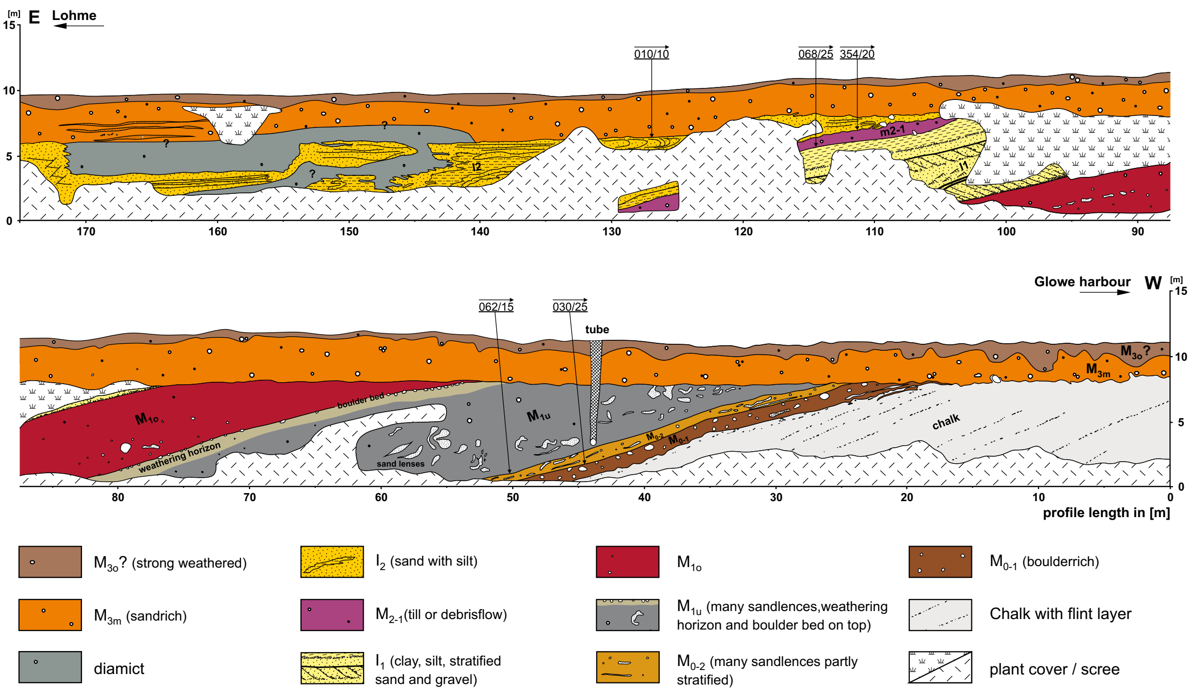

Fig. 4: Cliff section Glowe (re-mapped by Kenzler 2009/2010, Niedermeyer et al. 2010).

Abb. 4: Kliffabschnitt Glowe (Aufnahme Kenzler 2009/2010, Niedermeyer et al. 2010).

Stop 2: Pleistocene outcrop near Glowe (NW-Jasmund) – Facies and lithostratigraphy of tills (M-units) and intercalated sediments (I-successions)

The active cliff of the Glowe chalk anticline represents the most complete Quaternary profile of the southern Baltic region. The c. 300 m long and 16 m high outcrop shows Saalian (Penultimate Glacial) and Weichselian (Last Glacial) sediments. In detail the sequence comprises (from bottom to top, according to Panzig 1997, 2010):

- M0-1-till, which is the oldest moraine to be found on Rügen. The till is c. 2 m thick, green-gray, compact and firm, with a "normal" gravel spectrum, i. e. neither Central Swedish, nor East Baltic components predominate.

- M0-2-till, c. 0.5 m thick, pale gray, firm, rich in gravel and boulders. High amounts of sandstone and quartzite point to a northern provenance.

- M1u/o-till, c. 8 m thick, dark green-gray with a change to red-brown in the upper third. Because the content of Palaeozoic limestone fragments rises abruptly, a lower and an upper till can be distinguished.

- I1-intercalated sediments, at least 4.5 m thick. Generally, the I1-sequence on Rügen starts with a distinct boulder pavement, which may contain *Anodonta* sp. The Cyprina-clay as well as a periglacially deformed horizon often found in I1-sediments is not evident in the Glowe outcrop. Sand and silt predominate, from which two TL data (RÜ7 TL 55+/-9 ka, RÜ8 TL 19+/-3 ka) point to an early to middle Pleistocene age. In the upper part glaciolacustrine clay resp. silt (containing the ostracod *Lymnocythere [Leucocythere]*) has accumulated, which gradually passes into the overlying M2-1-till. Obviously, the M2-1 ice eroded parts of the glaciolimnic clay and incorporated it in its ground moraine.

- M2-1-till, c. 3-4 m thick, with a boulder pavement on the top due to abluation processes. The till is gray-blue, massive, with a high content of Palaeozoic shales.

- I2-intercalated sediments, the thickness is not known, because the base is located below beach level. About 6 m crop out, showing sand, silt and diamictic layers with numerous folds and faults.

- M2-2-till, brown-grey, which is divided by a thin sand/gravel horizon, above which the gravel composition changes in favour of cretaceous components. The thickness amounts to c. 3-4 m.

- I3-intercalated sediments. The usual thickness of this layer in the Glowe outcrop is only 0.2 m.

- M3u-till, bluish-gray, chalk rich, appears only in the eastern part of the outcrop and thickens there to c. 5 m. Due to internal structures the sediment was probably post-genetically mobilised by mass movement processes from the eastern flank of the Glowe anticline.

- M3m-till. With a distinct glaciotectonic unconformity at the base, the c. 1.5 m thick till covers the entire sequence including the chalk anticline. The uppermost part of the sediment profile is strongly weathered, the existence of a M3o is therefore questionable.

Further, it must be considered, that the M2-diamict layers associated with the I2-sediments have been probably dislocated from the top region of the chalk anticline and redeposited and are therefore no tills *sensu stricto*. The stratigraphic attribution of the lithostratigraphic units is shown in Tab. 2.

Stop 3: Cliff near Glowe – A Weichselian Late Glacial – Early Holocene lake profile (after Lampe et al. 2010)

Since about 1990 the sediments of a now dry lake appear in the elongated depression east of the Glowe chalk anticline due to coastal retreat (Fig. 5). The NE-SW stretching basin can be traced about 250 m into the hinterland. The landward dip of the strata, the observed enlargement of the outcrop at the cliff and the also observed decline of the thickness of the colluvium at the top of the sequence suggest that the outcrop will further grow in the future.

Above a Weichselian till the sediment sequence starts with an organic horizon a few centimetres thick, containing wood (11842 ± 39 BP) and mosses (Fig. 6). The layer is overlain by a calcareous organo-mud. Both sediments are restricted to the channel-like depression in the central part of the outcrop and disappear laterally. Layer deformations are conspicuous and are related to cryoturbation or gravitational sliding. Towards the top, horizontally stratified gyttja and calcareous mud layers, rich in molluscs, follow. Scattered wood pieces are noticeable, some with beaver bite traces. A radiocarbon dating provided 11413 ± 38 BP. The lake sequence terminates with a siliciclastic section, with gravel and diamictic intercalations in the marginal parts. A 1 m thick wood rich peat follows in which numerous tree trunks persisted. Radiocarbon data from the lowest and the highest level yields ages of 9444 ± 38 BP and 3016 ± 38 BP, respectively.

According to the course of the three main constituents organic, carbonatic and siliciclastic substance eight sediment sections can be distinguished (Fig. 6), which can be related

Tab. 2: Lithostratigraphical units of the cliff section Glowe and corresponding chronostratigraphy (Niedermeyer et al. 2010).

Tab. 2: Lithostratigraphische Einheiten des Kliffabschnitts Glowe und entsprechende Chronostratigraphie (Niedermeyer et al. 2010).

Lithostratigraphic units on Rügen	Chronostratigraphy Mecklenburg-Vorpommern
M3m	qW3 (Mecklenburgian Phase)
M3u (partly with relocated M3u)	qW2 (Pomeranian Phase)
I2 (with relocated M2-1)	gf/gl qW1n-qW2v
M2-1	qW1 (Brandenburgian Phase)
I1	gf/gl qW1v
M0-2, M1u/o	qS (Saalian complex)
M0-1	qE (Elsterian) ?

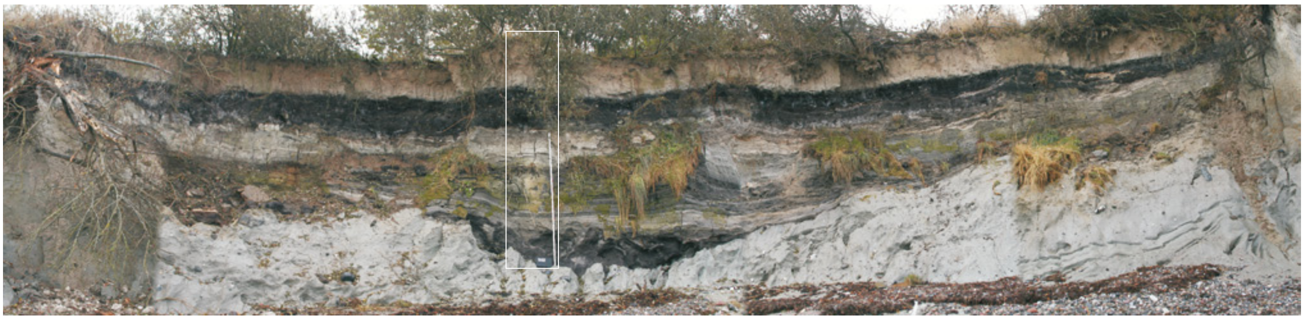

Fig. 5: Outcrop of Late Glacial/Early Holocene lake sediments at the cliff east of the Glowe chalk anticline. The box marks the section shown in Fig. 6. Level rod (3 m) for scale.

Abb. 5: Aufschluss spätglazial/holozäner See-Sedimente am Kliff östlich der Kreide-Antiklinale von Glowe. Der Kasten markiert den in Abb. 6 gezeigten Ausschnitt. Die Länge der Nivellierlatte beträgt 3 m.

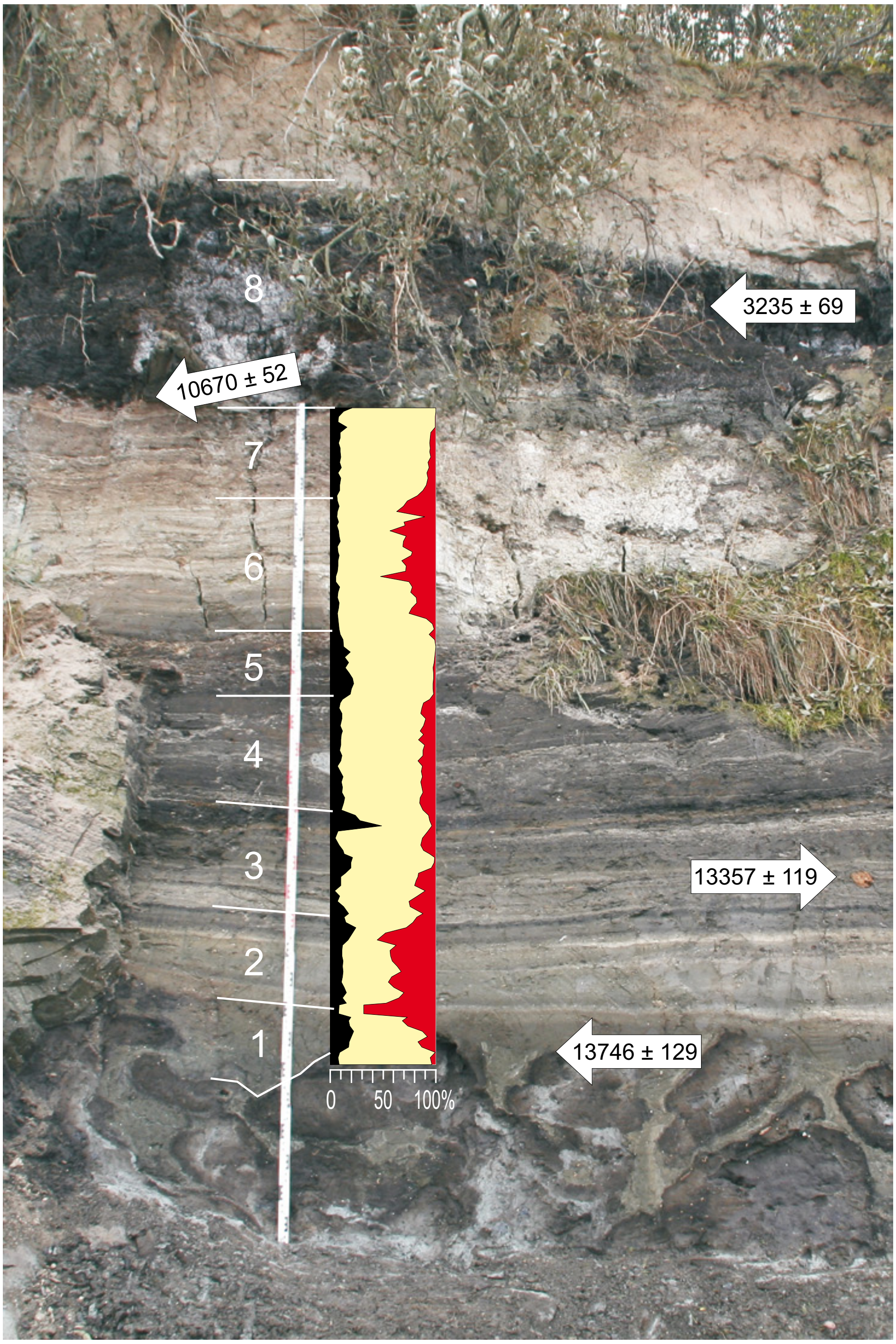

Fig. 6: Lake sediment outcrop at the Glowe cliff, October 2009. Sediment zones are depicted according to the distribution of organic (black), siliciclastic (yellow) and calcareous substance (analyses: Nestler 2010). The overlying peat and the colluvium were sedimentologically not investigated. The arrows point to four sampled wood pieces and show their calibrated ages (cal BP) (Lampe et al. 2010).

Abb. 6: Aufschluss von See-Sedimenten am Kliff von Glowe, Oktober 2009. Dargestellt sind die Sedimentabschnitte entsprechend der Verteilung von organischer (schwarz), siliziklastischer (gelb) und karbonatischer (rot) Substanz (Analysen: Nestler 2010). Der überlagernde Torf und das Kolluvium wurden nicht untersucht. Die Pfeile weisen auf vier beprobte Hölzer und geben deren kalibriertes Alter (cal BP) an (Lampe et al. 2010).

to water level variations and land surface stability in the adjacent terrestrial environment. The first section (SA-1), directly deposited upon the till, is characterized by *Pinus*- and *Salix*-pollen and by vast abundance of redeposited pollen probably of the Eemian period. Even the major part of the *Pinus* pollen is assumed to be redeposited. Diatoms or aquatic plants were not found. The following sequence up to the peat layer accumulated in a shallow lake in the period from Alleröd until the onset of the Holocene. All sediment samples contained remains of subaquatic plants and crustaceae, diatoms and *Pediastrum*. Also, fish remains were detected. The basin silted up for the first time in SA-5 at the end of the Alleröd. After a subsequent water table rise in SA-6 (with the beginning Younger Dryas) it fell nearly dry again in SA-7, favoured by increased input of siliciclastics. According to palynological evidence the younger Preboreal, the Boreal and the early Atlantic are missing, indicating that the lake fell dry at the end of the Younger Dryas or the onset of the early Preboreal. The peat growth in SA-8 points to repeated water logging of the site in the later Early Atlantic. From the upper third of the peat layer archaeological findings were reported, e. g. several silex artefacts, a core axe of probably Bronze age and bones from wild boars and a human being. The undisturbed growth of the peat ends at the latest in pollen zone IX, the uppermost two decimetres of the peat are disturbed for unknown reason. The peat is covered by a colluvium of unknown age, its thickness getting thinner with ongoing coastal retreat.

Stop 4: Coastal cliff in Lohme – Potential of geohazards (after Niedermeyer et al. 2010)

Facies variability and complex layering structures of the Pleistocene sediments on Rügen (and especially within the glaciotectonic complex of the Jasmund Peninsula) cause risks of cliff failures and land slides. These events triggered by exogenic processes hold hazard potential and may lead to consequences regarding planning, infrastructure and development.

Slope collapses/slides occur mostly after periods characterized by higher precipitation/melt water production and/or repeated frost action and, therefore, most frequently during fall and spring seasons. While collapses are restricted to steeper slopes (e. g. the chalk cliffs) slides may occur at slopes dipping flatter than the sediment´s angle of repose. Such slides move across a lower layer, the lithology of which is different from that of the sliding mass, e. g. in grain size distribution, compaction, grain contact, mineral assemblage etc. These primary properties result in specific soil mechanic properties such as water permeability, shear strength and internal friction which in turn may become critical favouring the lower layer acting as a glide plane under exceptional circumstances. The sliding mass may get down as a uniform gliding mass or as a cluster of smaller masses, thereby in permanent contact to the glide plane which mostly shows a listric shape. Internal deformations are limited because the shear stress is concentrated to the base, i. e. to the contact with the glide plane.

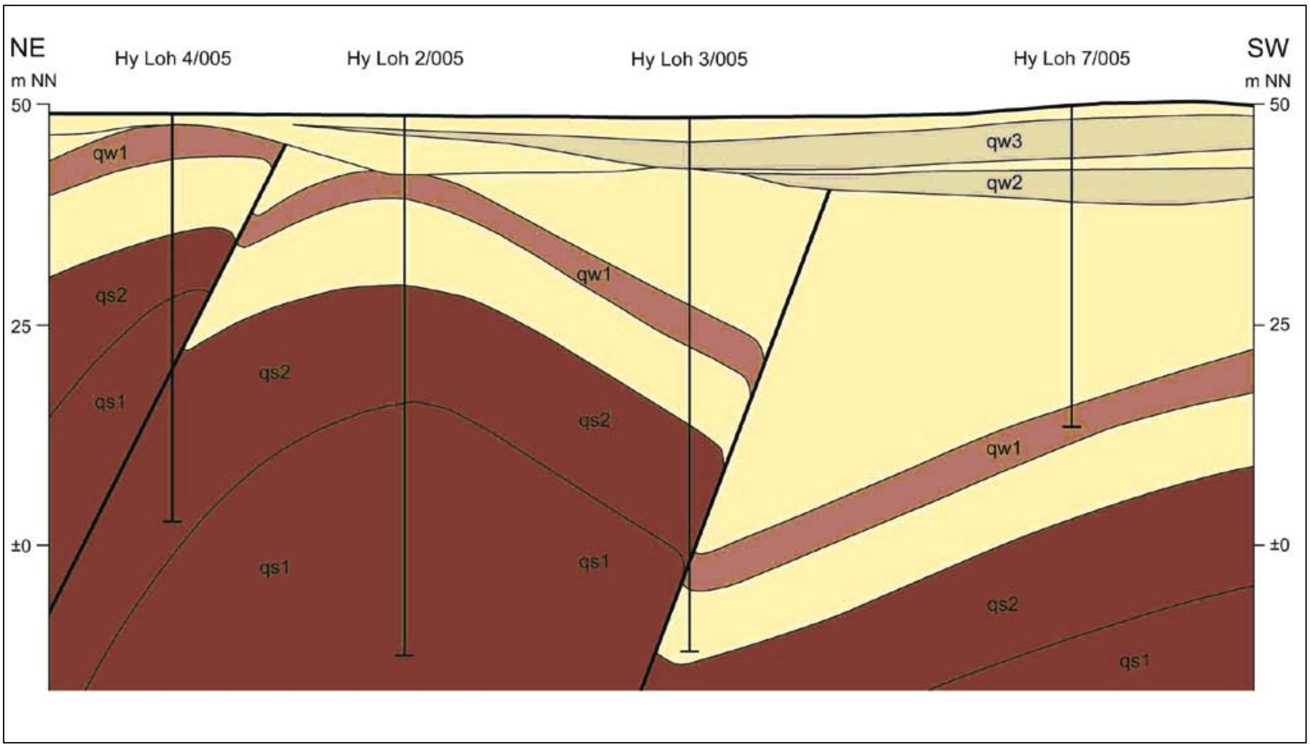

Fig. 7: Facies architecture of Saalian and Weichselian till units including chronostratigraphy (M, brown) as well intercalated glaciolimnic/-fluvial deposits (I-successions, yellow) at the Lohme cliff section (Müller & Obst 2006, Niedermeyer et al. 2010).

Abb. 7: Abfolge und Lagerung saale- und weichselzeitlicher Tills und deren chronostratigraphische Stellung (M, braun) sowie glazilimnisch/-fluviatile Zwischensedimente (I-Folgen, gelb) am Kliff von Lohme (Müller & Obst 2006, Niedermeyer et al. 2010).

Landslides are common on Jasmund as can be observed in the relief along the Jasmund cliff coast. Many traces (listric outbursts) of small and medium scale slides can be seen, but some great deeply seated slides are also evident. Local names such as "Hell´s Ground", "Hell" or "Devil´s Ground" point to large-scale sliding events, some of which are already depicted on the Swedish Cadastre Map from 1692–1709. Parts of the sliding mass remained until today and in the upper part of the ravine numerous springs are located.

One of the most spectacular slides of the past decades occurred March 19th 2005 in the Lohme village, where 100 000 m³ suddenly moved from the seemingly inactive cliff down to the beach, thereby partly spilling the harbour. According to the geological cross section of the Lohme cliff the sliding mass was built by the topmost M3-till and the I2 intercalated sediments below which moved down across the underlying M2-till, which dips towards SE and act as an aquitard (Fig. 7).

The slide event caused the temporary closure of endangered buildings in the vicinity of the breakout. Their further usage will be possible only after geotechnical restoration (i. e. slope drainage and stabilization).

Stop 4: Pleistocene outcrops north of Saßnitz – facies, bedding and stratigraphy of Pleistocene strip 4 (after Ludwig et al. 2010)

The cliff at stop 4 shows the glaciotectonic structure of a synecline with the horizontally M3-cover complex above a distinct unconformity, which also overrode the neighbouring chalk complexes. The cross section shows the typical synecline/anticline construction of the Jasmund push complex. The traction synecline of strip 4 builds one of the main structural elements. Together with the chalk the Pleistocene M1- to I2-strata have been folded glaciogenically. While the footwall limb of the synecline shows the structure in its original sequence and in about the primary thickness, the hangingwall limb was heavily thinned out by traction and overthrusting. In the core of the complex the strata, especially those of the I2 laminated clay, were compressed to nearly vertical position. At many locations a boulder pavement can be observed at the base of the M1-till, the boulders of which are pressed into the chalk´s surface. Their polished and striated surfaces are overlain by M1-till. The M3-ice has truncated the uppermost part of the synecline (development of the unconformity) and its M3-till covers the remaining structure.

The steep relief of the Jasmund push complex favoured lateglacial dislocation and redeposition processes which moved morainic materials from the ridges into nearby depressions. The distinction of these diamictic slide and flow materials from the sandy M3-moraine is very difficult and resulted in stratigraphic misinterpretations. Sometimes a M4-till has been postulated for this reason, which is not evident on central Jasmund. In some cases the misinterpretation became evident due to findings of loess snails. The last weak M4-ice advance did not cover central Jasmund, but flowed around. Probably its further advance was stopped by vast dead ice complexes which covered the lower lying areas around Rügen. Therefore, the accumulations of the M4-ice occur not widespread.

On Northeast Rügen, gravel and boulder layers which were interpreted as ablation moraines by Ludwig (1954/55) cover

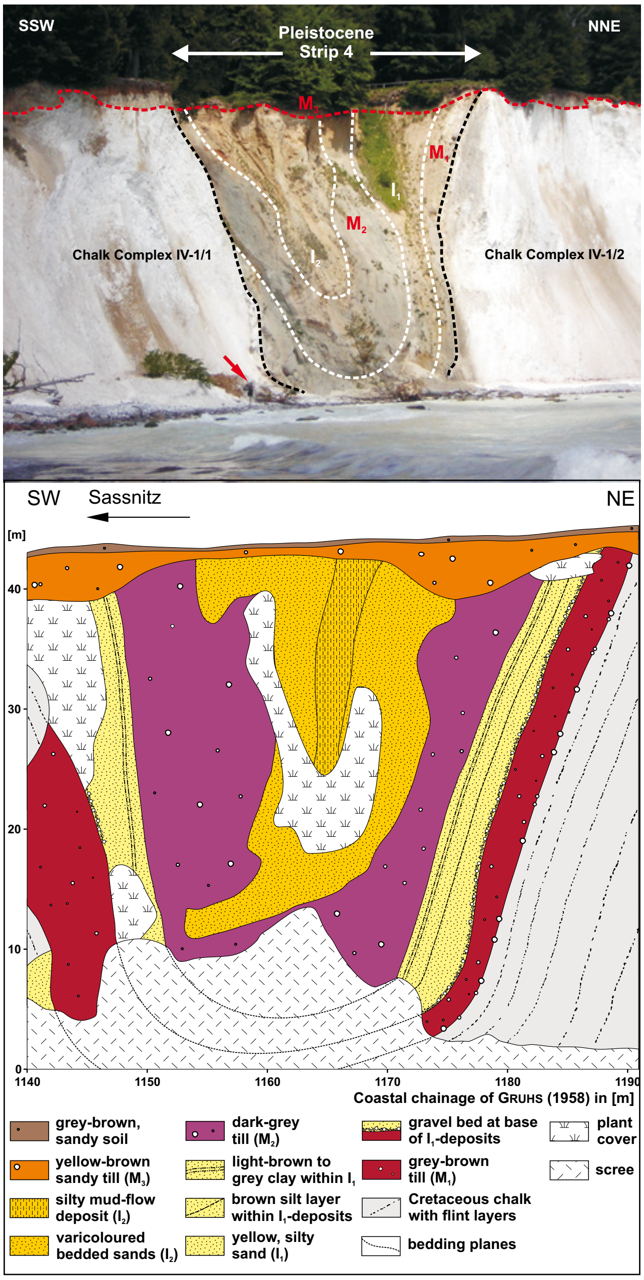

Fig. 8, left: Pleistocene strip 4 showing the synclinal facies architecture of M1-, M2-till units as well as I1-, I2-intercalations overlain discordantly by the M3-unit (Kenzler 2010); right: cliff section (Kahlke 1982, redrawn by Kenzler 2010, Niedermeyer et al. 2010).

Abb. 8, links: Pleistozänstreifen 4 mit synklinal lagernden M1-, M2-Tills und I1-, I2-Folgen, diskordant überlagert vom M3-Deckkomplex (Kenzler 2010); rechts: Kliffabschnitt nach Kahlke (1982), umgezeichnet von Kenzler 2010 (Niedermeyer et al. 2010).

the M1- and M2-tills. Partly, the gravel was spilled by meltwater and redeposited in shallow depressions on the surface of melting dead-ice where temporary shallow meltwater lakes occurred. In these environments cold-resistant faunal assemblages developed, as the shell remnants of freshwater molluscs such as *Anodonta cygnaea* MÜLL. in the boulder horizon at the top of the M1-till at the cliffs of Jasmund and Arkona shows. Both the lag boulder horizons at the top and the polished boulders at the base of the till (the striated facets indicate the top side), provide criteria to estimate the spatial position of the till layers often overfaulted.

North of Saßnitz the thickness of the Pleistocene sediments increases by some metres. While on the Wittow peninsula a marine layer is intercalated in the I1-strata, this layer is missing here. However, a clay slap with marine microfauna similar to that of Wittow is incorporated into the M2-till (strip 5) and shows that already the M2-ice has exarated the subsoil in the eastern vicinity. On Wittow such finds in the M2-till are evident, too. Both, the absence of the marine strata in the I1-sediments of Jasmund and the low thickness of the M1- to M2-sequence in the open pit mines near Saßnitz and near Dwasiden indicate a higher position of the relief around Jasmund, which was not drawned by the sea, in which the Cyprina-clay accumulated.

Some ice-wedge pseudomorphoses, reaching from the I1-sediments down to the underlying M1-till point to a still cold climate during the accumulation of the I1-sands as the cryoturbation structures are found in the I1-sediments at Dwasiden and in the occassionally laminated Lymnocythere-clay. At Arkona, the I1-sequence is thicker and the Limnocythere-clay rests above the marine Cyprina-clay and closely below the M2-till. According to radiocarbon data the Cyprina-clay represents a warmer period prior to the maximal extent of the Weichselian ice sheet. The I2-sediments rarely contain fossils but locally they comprise some laminated clay. Signs of significant warming are missing. It can be assumed that the accumulation of these sediments took only a short time.

With the ongoing growth of the Jasmund push complex in its distal area the resistence against the further compression increased. The chalk and Pleistocene sediments were turned aside thereby getting plastically deformed or faulted. This happened in positions of strongest resistence against the pushing ice. There, in the area proximal to the ice-margin, the strongest ice pressure developed. With increasing compression the built folds and slaps were pushed into increasingly steeper inclination and the most proximal folds could even be slightly inclined against the steep ice-front. In strip 4 such a structure crops out acute-angled.

From strip 4 until the Königsstuhl structures like this can be repeatedly observed and, together with more or less steep dipping slaps, they are predominant elements within the push complex. As a single element they can be characterized as thrusted drag folds.

The structural pattern observed along the coastal cliff indicates rather a compression around a higher elevated landform (lesser thickness of the Pleistocene sediment sequence, missing marine inundation during the I1 period) than a "Kerbstauchung" (indent compression) in the sense of Gripp (1947). Especially at the stoss side in the East of the elevation glacigenic slap- and fold-like constriction structures are to be expected, as they crop out at the cliff. To some extent they trace the course of the eastern lobe. The elevated relief in the area of Jasmund which existed already before the M3-ice arrived was the prerequisite for the glacigenic push process (beside favouring ground mechanical properties).

Due to its growth the push complex became temporarily an ice-dividing, circumflowed nunatak. Later, the growing ice mass moved across the compressed complex and truncated and eroded the uppermost parts of the structure. During this process the less compressed flanks in the south and in the north were more heavily eroded and became dissected in slabs which were moved to the west. For this and other reasons (slab movement, roll out of chalk, covering of the glaciotectonic structure with the debris left by the overriding M3-ice) the pattern of outcropping chalk hardly allow for any conclusions about the inner structure of the push complex.

According to the investigations on the Danish island Moen the multiphase deformation pattern of the push complex Jasmund coincides with the model of a glacigenic imbrication fan later overthrusted by the ice.

Stop 6: Prorer Wiek, Jasmund Lagoon and the barrier Schmale Heide (after Lampe & Janke 2010)

The **Prora Bay** is one of the two great embayments in the northeastern and eastern side of Rügen. Exaration by repeated glaciations (Pleistocene base at c. -100 m), thawing dead-ice and erosion by meltwater formed the surface of its basement and the depressions of the present lagoon in its

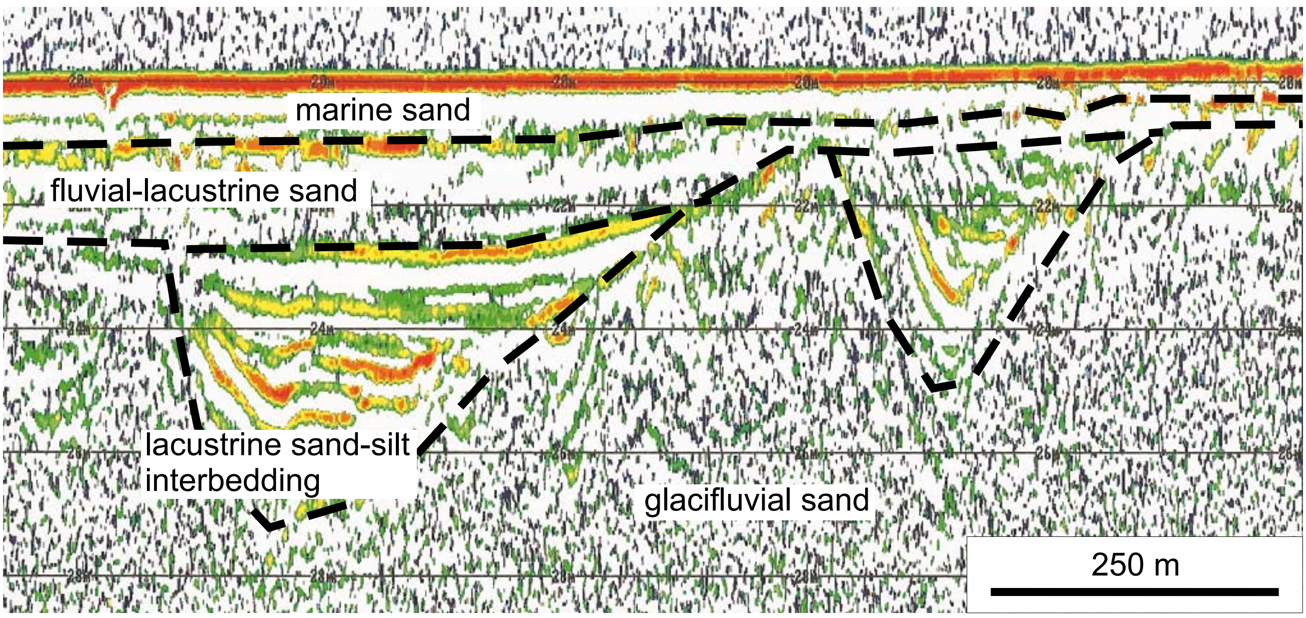

Fig. 9: Sediments and bedding structures in the NE section of Prorer Wiek, sediment echosounder record (Lampe et al. 2010).

Abb. 9: Sedimente und Lagerungsstrukturen im NE-Bereich der Prorer Wiek, Sedimentecholotaufzeichnung (Lampe et al. 2010).

Fig. 10: Schmale Heide and NPA Feuersteinfelder (Flint fields), in the background Prora and Binz (Photo: R. Lampe 2007).

Abb. 10: Schmale Heide und NSG Feuersteinfelder, im Hintergrund Prora und Binz (Foto: R. Lampe 2007).

distal vicinity. Shortly after the ice melted the depressions hosted a system of meltwater basins which then largely desiccated due to further ice retreat. In the subsurface of the Prora Bay numerous meltwater basins were found, in which fossil bearing interbedded fine sand and silt accumulated (Fig. 9). Radiocarbon data from *Pisidium* shells indicate ages between 13000 and 11000 BP (= 16000 to 12600 cal BP) and point to relations to the Baltic Ice Lake. The Yoldia Sea (-40 m) did not reach the coast of Rügen. Also the Ancylus Lake did not exceed a level of -20 m and transgressed only over the former Oder valley east of Rügen. During the Littorina transgression the bay was rapidly inundated. Today, the thickness of the sandy marine sediments farther offshore amounts to only some decimetres while the thickness of the marine mud can reach several metres.

The development of the coastal waters is exemplified by means of a sediment core from the **Kleiner Jasmunder Bodden** lagoon. In the depression, sedimentation started already in the Meiendorf interstadial during which peat accumulated upon sandy sediment. Two thin peat layers were found in a tilted position (c. 35°) and point to thawing of buried dead-ice and ongoing deepening of the depression. During the subsequent period of the lateglacial silt accumulated. From the Preboreal and the Early Boreal no sediment is found, probably the depression desiccated. In the Late Boreal and Early Atlantic lake-marl and calcareous gyttja accumulated and point to a rising water table. About 7800 BP the transition to brackish-marine conditions started. Since the onset of pollen zone VII black organic mud accumulated, comprising many marine shell remains at the base. The highest salinity phase is designated by the predominant occurrence of the diatom *Paralia sulcata.* The transitions between the pollen zones VII/VIII, Xa/Xb and Xb/Xc are conspicuous. The latter marks the German colonization (c. 1250 AD) and coincides with the isolation of the lagoon from the sea. The resulting salinity decrease continues until today and is superposed by heavy eutrophication since the onset of the 20th century.

The **Schmale Heide** is one of the largest barriers of Rügen. A distinctive feature is the high abundance of flint pebbles in its northern section, where 15-17 beach ridges in a 2.5 km long and 0.3 km wide area dominate the landscape (Fig. 10). Only few boreholes give information about the construction of the barrier. The till surface is located unusually deep at -26 m. Above the till, calcareous sand follows containing freshwater diatoms and molluscs from -12 m upwards. A 20 cm thick Early Atlantic peat is covered again by freshwater sand which changes into marine at about -10 m. Flint pebbles occur at -4 m. The sequence is completed on the lagoonward side by aeolian sand sheets and peat and on the seaward side by aeolian sand forming several dune generations.

Only few data on the chronology of the development of the barrier are available (Fig. 11). The Early Atlantic peat is dated to 8310 ± 55 cal BP. The lowermost *Cardium* shells found in boreholes in the Großer and Kleiner Jasmunder Bodden provide age data of 7680 ± 35 cal BP and 7400 ± 50 cal BP, respectively. In a water pipeline ditch at the northern edge of the beach ridge area, two peat layers were detected resting on marine sand but below the beach ridges. The top layers of the peat strata yield ages of 4800 ± 100 (lower peat) and 4380 ± 55 cal BP (upper peat).

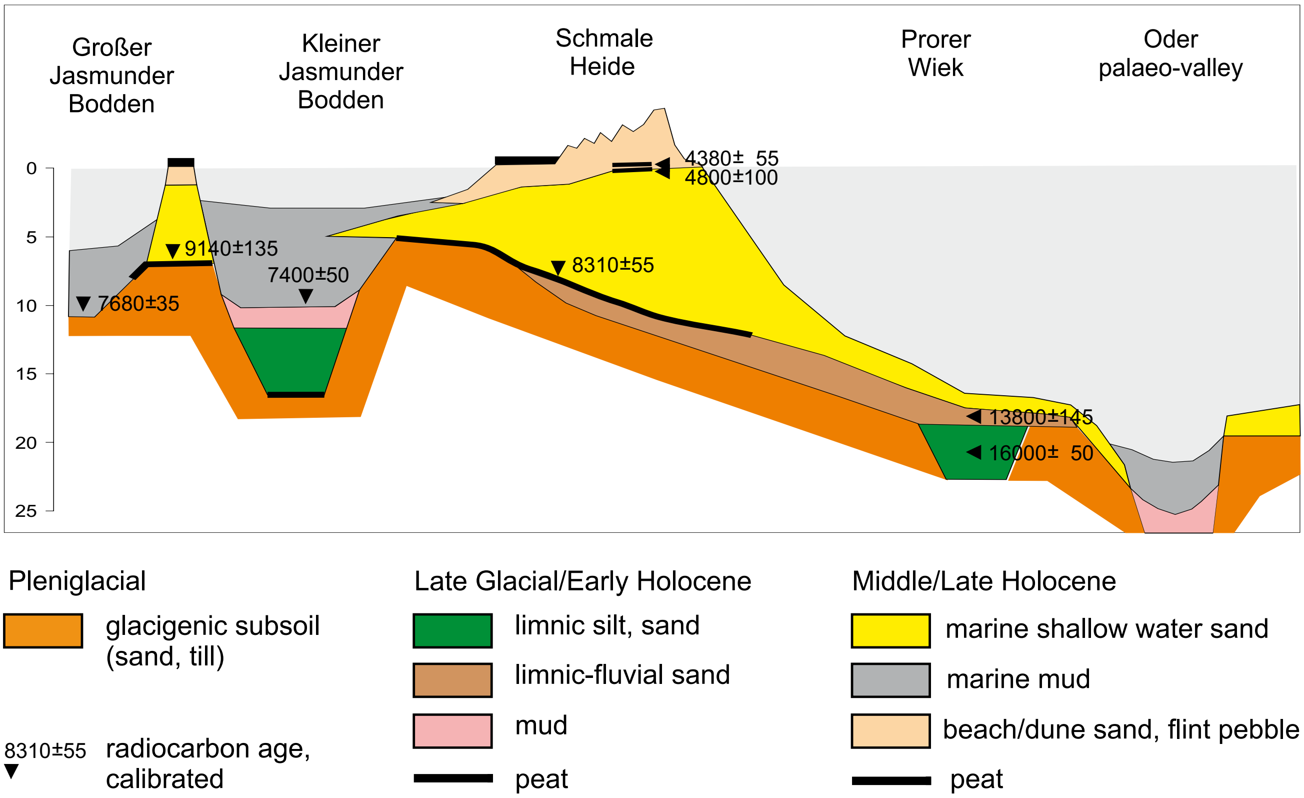

Fig. 11: Geological cross section from Großer Jasmunder Bodden to Prorer Wiek and calibrated radiocarbon ages (cal BP) (Lampe et al. 2010).

Abb. 11: Geologischer Schnitt vom Großen Jasmunder Bodden zur Prorer Wiek mit kalibrierten Radiokarbonaltern (cal BP) (Lampe et al. 2010).

Stop 7: Karrendorf-Kooser Wiesen – Salt marshes and coastal fenlands as archives of sea-level development (after Lampe & Janke 2010)

The Karrendorf-Kooser Wiesen salt marsh is typical for the Holocene fenlands located at the sheltered inner coastal waters along the southern Baltic coast. Peat accumulation started in the Early Atlantic in a still fresh environment. Due to the rising sea-level (Littorina transgression) brackish conditions exerted and since then the level of the Baltic Sea controlled peat growth. About 1200 years ago the sea level was located c. -0.7 m NHN and started to rise again (Late Subatlantic Transgression) after a 4000 years long period of stagnation. The former fenlands were flooded and mud accumulated. During the cold period of the Little Ice Age the sea level fell or came at least to a halt and the coastal fenlands desiccated. The decomposed peat formed a black, pitchy layer which is to observe as a widespread phenomenon in coastal fens (Fig. 12). After the end of the Little Ice Age, mud and peat accumulation started again due to the sea-level rise, but became also influenced by artificial drainage and agricultural use.

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Notes

A

Geopark Mecklenburg Ice Age Landscape – Weichselian glaciation and geotourism

Andreas Buddenbohm, Klaus Granitzki

Itinerary:

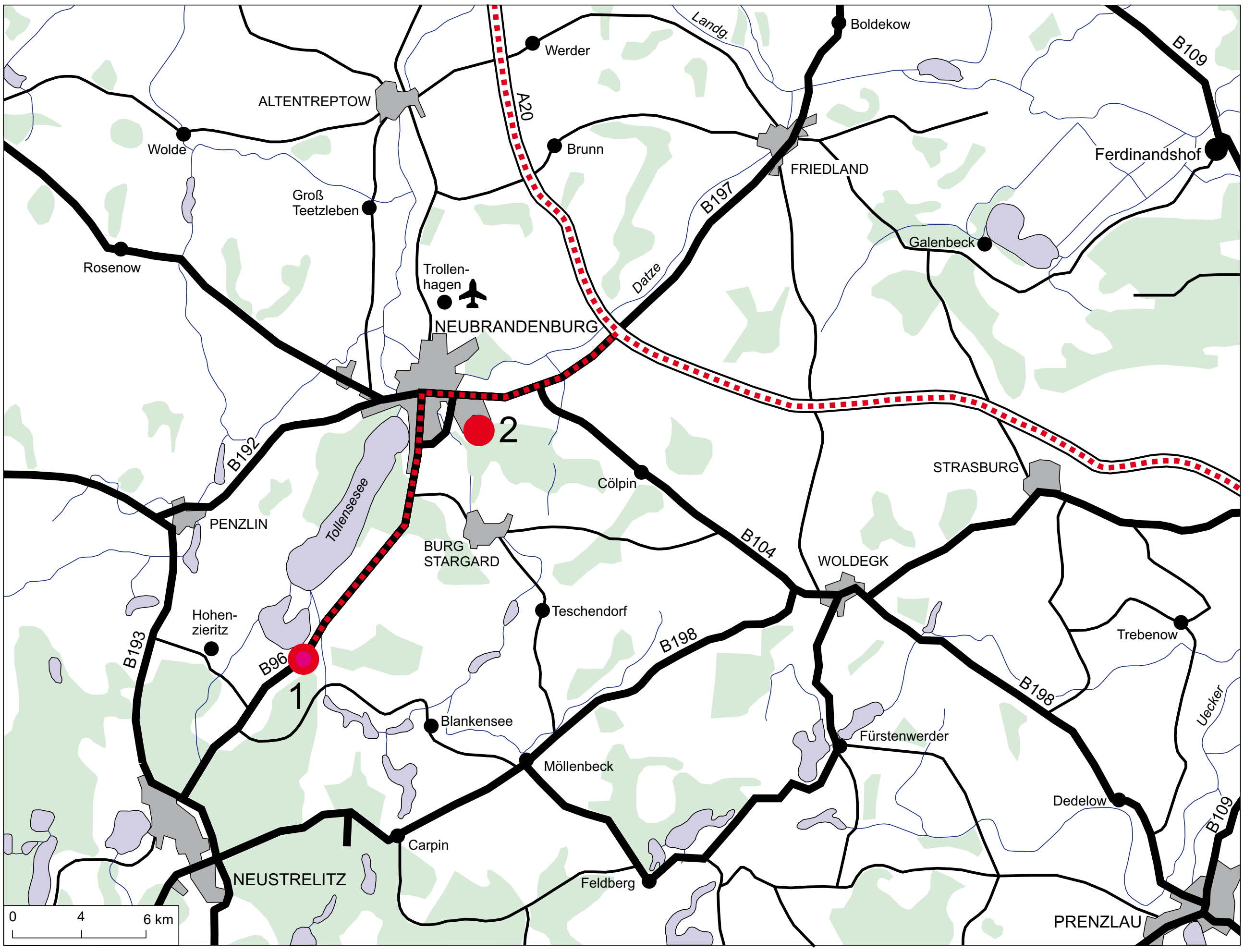

Fig. 1: Itinerary Geopark Mecklenburg Ice Age Landscape : 1 – Gravel Pit Neubrandenburg-Hinterste Mühle, 2 – Usadel, Paterenenberg.

Abb. 1: Geopark Mecklenburgische Eiszeitlandschaft: 1 – Kiestagebau Neubrandenburg-Hinterste Mühle, 2 – Usadel, Paterenenberg.

Introduction

Geopark Mecklenburg Ice Age Landscape in the North-East of Germany outlines a region, which is representative for a glacial landscape in the lowlands of central Europe. In the Geopark the close relationship between the geological heritage and the development of the cultural landscape are demonstrated, making the Ice Age a resource of regional identity. During the Weichselian glaciation the region was covered by ice at least in three phases (Brandenburg, Pomeranian, Mecklenburg Phase). Each ice advance is recognizable by its distinctive formations, especially its end morains and tills. Older glacial formations have been proven underneath the Weichselian records.

Early Pleistocene sediments are absent in the Geopark Mecklenburg Ice Age landscape. The glacial deposits are assigned to three glacial (Elsterian, Saalian, Weichselian glaciation) and two interglacial periods (Holstein complex, Eemian). The Quaternary sequence starts with sediments of Elsterian age, characterized by a mostly thin ground moraine. Particularly striking are deep subglacial channels in the whole of northern Germany including the

Particularly striking are the deep subglacial channels (buried valleys), which are known from the whole of northern Germany including the North Sea. The Möllenhagen channel west of Neubrandenburg is such a structure as well as the Tollense channel (Stop 1). It is characteristic for these channels that they were completely filled by sediments of Elsterian age, but certainly at the end of the Holstein-complex.

The Saalian ice moved over a largely balanced relief. Sediment records concentrate on the Upper Saalian with two major ice advances. The several tens of metres thick till of the Drenthe-moraine (Saalian 1) contains numerous rafts of preglacial sediments. Sometimes they are of economic interest, such as the Miocene quartzsands near Neubrandenburg and the Friedland Eocene clay. The till is followed by mainly fine-grained glaciolimnic sediments of sometimes considerable thickness. Compared to the thick Drenthe till the relatively thin an incomplete Warthe-moraine (Saalian 2) represents a less dynamic ice advance.

Late Saalian sand and silt are widespread and can reach dozens of metres thickness, this way creating exploitable deposits. A profile at gravel pit Neubrandenburg-Hinterste Mühle opened an undisturbed sequence, ranging from Late Saalian to Early Weichselian including a complete sequence of limnic Eemian (stop 2). Further evidence of Eemian interglacial is limited to drillings.

The Weichselian glaciation was of major importance for today's surface of the Geopark. Only little is known about Early Weichselian sedimentation in south-eastern Mecklenburg-Vorpommern, and there is also no equivalent to the oldest Weichselian moraine (Weichselian 0 = Warnow-Advance), proven at the Baltic coast.

There are two end moraines known from Brandenburg Phase (Weichselian 1). Both Brandenburg end moraine (W1B) and Frankfurt end moraine (W1F) run a few kilometres South of the border of the Geopark. South-West of Lake Müritz the corresponding ground moraine represents the oldest quaternary formations at the Geoparks's surface. Between Malchow and the west bank of Lake Müritz Poppentiner end moraine indicates an oscillation in the meltdown of the Brandenburg ice. It contains a number of rafts of Turone chalk (Malchow Chalk District), which were sheared off from uprising salt structure Malchin and transported about 30 km by the ice.

From Pomeranian Phase (Weichselian 2) also two end moraines are found. The first end moraine (W2u) is only locally developed and demonstrates the maximum ice advance. More important and moreover the most remarkable morphological element of the glacial inventory of the whole Geopark is the Pomeranian main end moraine (W2o). It crosses the region from South-East to North-West and displays an ice margin, that was divided into individual lobes. The compact and complete ridge of the endmoraine is a result of a stationary ice margin, temporarily balanced out between advance and meltdown. Large proglacial outwash plains reach more than 15 kilometres into the foreland, where older ice was buried and melting afterwards, creating depressions that today forms the numerous lakes of Mecklenburg Lake District.

Pomeranian main end moraine mainly shows typical picture of undisturbed sedimentation with low ice pressure dynamics. Exemplary boulder deposits occur at Feldberg, Kratzeburg, Kargow, Blücherhof and Langhagen. Their economic exploitation ist not longer permitted as boulder deposits belong to legally protected geotopes in Mecklenburg-Western Pomerania.

North of the Pomeranian main end moraine the wide and even plains of the corresponding ground moraine extend, containing typical records of glacial meltdown like meltwater channels (lake channels and brooks), eskers, Sölle (small, water-filled holes) and erratic boulders (Findlinge). The largest boulder on the mainland of Mecklenburg-Western Pomerania is the Big Stone (Großer Stein) near Altentreptow (about 133 m³, 350 t).

The last ice advance, that reached the Geopark, was the maximum advance of Mecklenburg Phase (Weichselian 3). The extension of the ice was recognized by the specific clast composition of its till. However, end moraine ridges or corresponding outwash areas are rarely found. They concentrate on two impressive push moraine complexes near Strasburg (Rosenthaler Stauchendmoräne) and Malchin (Retzow-Gülitzer Höhen).

The outer North-East of the Geopark is dominated by glaciolimnic sediments of the Late-Glacial ice-damned lake Haffstausee. It collected the meltwater until the progressing meltdown of the Mecklenburg ice allowed drainage to the western Baltic Sea.

Stop 1: Usadel near Neustrelitz, Mecklenburg-Western Pomerania (Germany)
Paterenenberg Hill near Usadel
Tollense Basin – A subglacial tunnel valley

The view from Paterenenberg near Usadel extends over the shallow lake Lieps (2–4 m water depth, water level +14.7 m asl), the southern end of Lake Tollense and the intervening peninsula Nonnenhof, overgrown with alder forests. The viewpoint is situated some 300 m North of the northern foothills of Pomeranian main endmoraine (Weichselian 2), showing a morphologically very distinct morain forking (Usadeler Endmoränengabel) between the Tollense-Lobe and Strelitz-Lobe.

Both Lake Tollense and Lieps are situated in the so-called

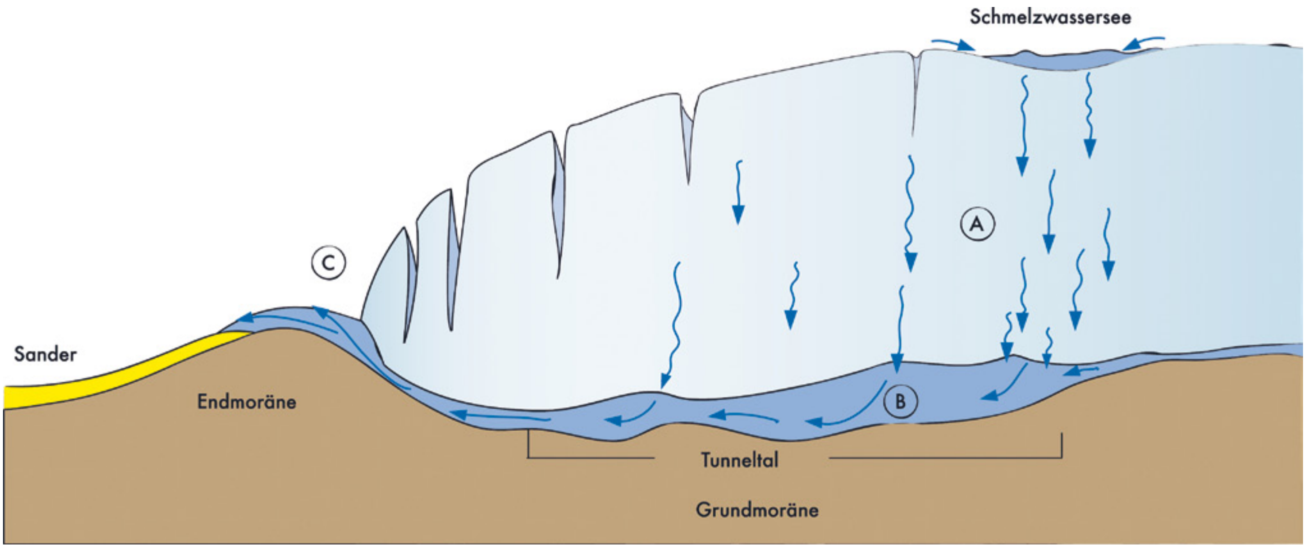

Fig. 2: The figure shows the ways of melt water inside the glacial ice shield. High hydrostatic pressure resulted in intensive erosion of the subsurface and pressed the melt water out of the glacier snout. (Information Panel at thematic bicycle route Eiszeitroute, reproduction with permission of the Regional Planning Association of Mecklenburg Lake District)

Abb. 2: Die Abbildung soll die Wege des Schmelzwassers durch das von Spalten durchzogene Inlandeis veranschaulichen. Unter dem Eis steht das Schmelzwasser unter großem Druck, wodurch es den Untergrund ausspült und in Richtung Eisrand gepresst wird. (Darstellung für die Geoinformationstafeln an der Eiszeitroute, Abbildung mit Genehmigung des Regionalen Planungsverbandes Mecklenburgische Seenplatte)

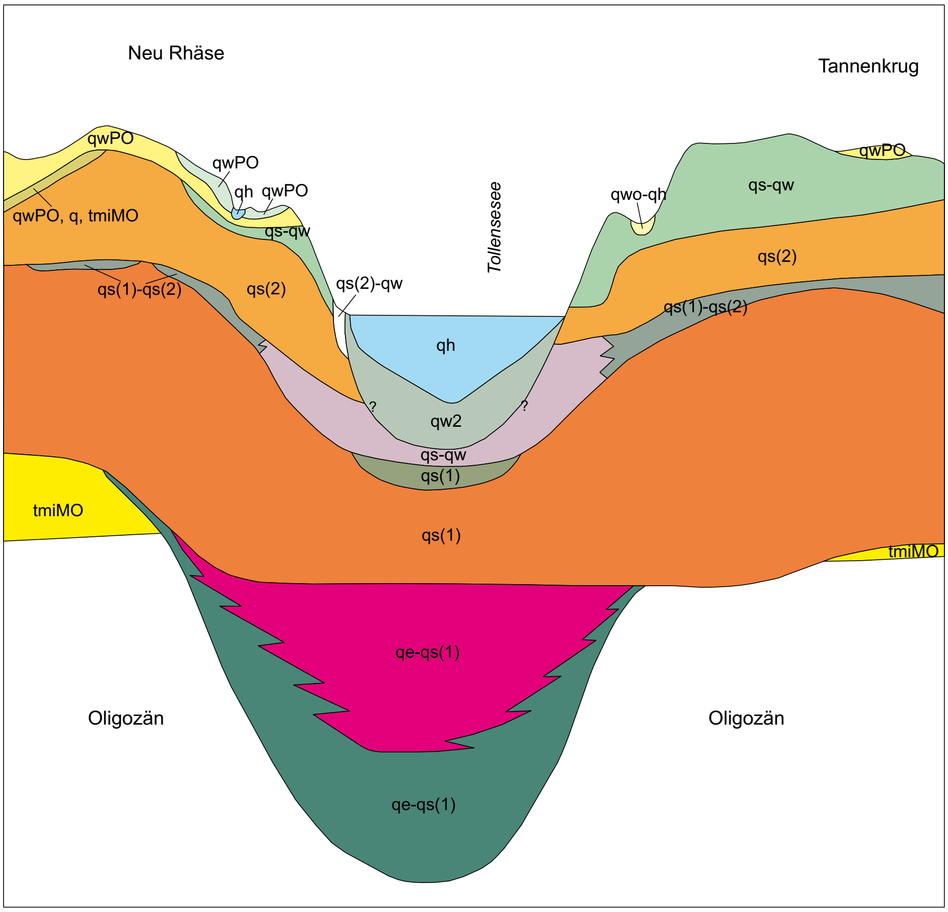

Fig. 3: Geological cross-section trough Tollense-channel near Usadel (Source: LUNG M-V, Geological Survey)

Abb. 3: Geologischer Schnitt durch die Tollense-Rinne bei Usadel. (Quelle: LUNG MV, Geologischer Dienst)

Caption: *Stratigraphy:* tmiMO – Mölliner Schichten (Tertiary, Miocene); qe – Elsterian glaciation; qs – Saalian glaciation; qs(1) – First Saalian ice advance (Drenthe, S1); qs(2) – Second Saalian ice advance (Warthe, S2); qw – Weichselian glaciation; qw2 – Pomeranian advance (W2u); qwPO – Pomeranian main advance (W2o); qwo – Late Weichselian; qh – Holocene. *Petrography:* yellow – quartz sand (Tertiary); brown/light brown/yellow brown – till (ground moraine); purple/light purple – silt (glacio-limnic); green/light green/white green – sand; gravel (glacio-fluviatile)

Legende: *Stratigraphie:* tmiMO – Mölliner Schichten (Tertiär, Miozän); qe – Elster-Glazial; qs – Saale-Glazial; qs(1) – Jüngerer Saale-Vorstoß (Drenthe, S1); qs(2) – Älterer Saale-Vorstoß (Warthe, S2); qw –Weichsel-Glazial; qw2 – Pommerscher Vorstoß (W2u); qwPO – Pommerscher Hauptvorstoß (W2o);qwo – Weichselspätglazial; qh – Holozän. *Petrographie:* gelb – Quarzsand (Tertiär); braun/hellbraun/gelbbraun – Geschiebemergel (Grundmoräne); violett/hellviolett – Beckenschluff (glazilimnisch); grün /hellgrün/weißgrün – Sand; Kiessand (glazifluviatil)

Tollense Basin. This large, about 15 km long and only about 2 km wide channel-like depression is the dominant morphological element of the picturesque area between Neubrandenburg and Neustrelitz.

Two major model concepts on its genesis have been developed. Janke (1966) compared the morphogenesis of the Tollense Basin with formations of mountain glaciers. He assumed a more than 20 km long and narrow glacier tongue, that moved southwards again after the "retreat" of the Pomeranian ice shield, in this way exarating the Tollense Basin. Schulz (1998) also described the Tollense Basin to be a typical glacier tongue basin, surrounded by horseshoe-like push moraine ridges in the south. Most popular in literature is the schematic block model of its formation by Wagenbreth & Steiner (1982).

As a result of a profound geological surface mapping Eiermann (1967), who did not completely reject the existence and effects of small glacier tongues, clearly pointed to the role of subglacial erosion in the formation of the basin, that he called a tunnel valley (Tunneltal). Rühberg (1998) contradicted the genesis as glacier tongue basin with the following facts:

- In contrast to mountain glaciers, the ground is missing a steady drop, which could cause the formation of individual glaciers tongues of the required dimension. In contrast, the bottom in the Tollense channel rises to the south.
- There is no diamicton at the floor of the valley, which would give evidence of an ice advance.
- The edges of the valley show undisturbed sediments, which cannot be interpreted as lateral moraines.

Rühberg (1998), evaluating lots of drillings, further demonstrated, that a first subglacial channel occured during the Elsterian Glaciation, reaching down to about 160 m below todays sea level. Although this channel was largely filled up with glacio-fluvial and glacio-limnic sediments, it repeatedly influenced subsequent ice advances and their meltwater outflows. Thus, the younger formation of the sub-glacial tunnel valley of Lake Tollense took place during the advance and meltdown of the Pomeranian Phase (Weichselian 2). Large amounts of sub-glacial meltwater gathered and were pressed to the ice edge, rinsing out basin-like depressions into the ground. The sediment load was deposited in marginal columns (esker Hellberge) or - mainly - in front of the ice.

Kanter (2000) again summarized all recent geological findings and underlined the decisive differences between the dynamics of alpine glaciers and inland ice. Today the origin of the Tollense Basin as tunnel valley is generally accepted.

During the Middle Ages a major Slavic settlement chamber existed at Lake Lieps and the southern end of Lake Tollense, which was proved by archaeological excavations. It has been assumed that this could be the place of Rethra, the central sanctuary of the slavic Lutizen league and the social centre of the Slavonian Tribes living in North-East Germany during the 11th and 12th century. First mentioned by medieval German chronicler Thietmar of Merseburg, its location has never been described exactly. Especially the excavations on the small islands on Lake Lieps and Fisher's Island on Lake Tollense verified extensive settlement remains from that period, but still not the final evidence for this place to be Rethra (Schmidt 1992, Szczesiak 2005). The decline of the

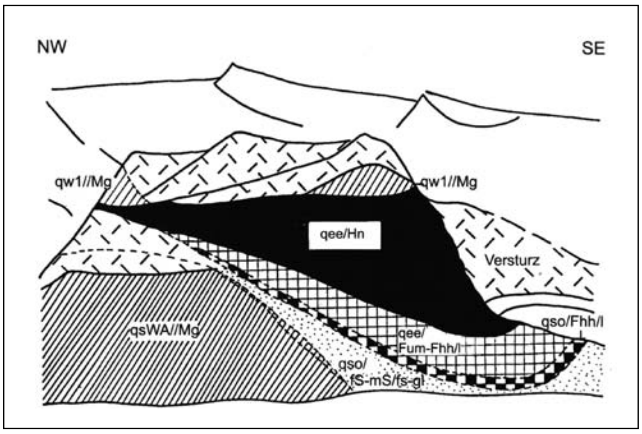

Fig. 4: Generalized geological cross section trough Eem outcrop Hinterste Mühle (at Profile 1) qw1//Mg = till, Brandenburg Stage, Weichselian-1; qee/Hn = limnic peat, Eemian; qee/Fum - Fhh/l = limnic silty mud and peat clay, Eemian; qso/Fhh/l = peat clay, Late Saalian; qso/fS – mS/gf-gl = glacio-fluviatile - glacio-limnic fine- and medium-grained sand, Late Saalian; qsWA//Mg = till, Warthe-Stage, Saalian-2 (Strahl 2000)

Abb. 4: Generalisierter geologischer Schnitt durch den Eem-Aufschluss Hinterste Mühle (am Pollenprofil 1) – qw1//Mg = Geschiebemergel, Brandenburger Stadium, Weichsel 1; qee/Hn = limnischer Torf, Eem; qee/Fum-Fhh/l = limnische Schluffmudde und Torfmudde, Eem; qso/Fhh/l = Torfmudde, Saalespätglazial; qso/fS – mS/gf-gl = glazifluviatile-glazilimnische Fein- und Mittelsande, Saalespätglazial; qsWA//Mg = Geschiebemergel, Warthe-Stadium, Saale-2 (Strahl 2000)

settlement chamber was probably related to the lake level rise, caused in 1270 by the mill dam at the town of Neubrandenburg.

Stop 2: Neubrandenburg, Mecklenburg-Western Pomerania (Germany) Gravel pit Neubrandenburg-Hinterste Mühle A complete sequence of limnic Eemian

Gravel pit „Hinterste Mühle" in Neubrandenburg is the oldest still active opencast of Mecklenburg-Western Pomerania. Its exploitation started in 1876, after the outcrop had been opened in the course of the newly built railway. The glaciofluvial sediments represent the filling of a sub-glacial meltwater channel, formed and filled up in several phases since Saalian glaciation. Sediments start with glacio-fluvially reworked Miocene quartzsands with typical organic content (fine coal particles), followed by a more than 60 metres thick sequence of gravel and sand. Main sedimentation occurred during the Saalian-2 and Weichselian glaciations.

In 1994 the gravel pit gained special attention for the occurence of a complete profile of limnic Eemian, that is sandwiched between ground moraine sediments. Sedimentation was probably supported by the gradual melting of buried Saalian dead ice, creating a small limnic basin. The sequence, that has been researched especially by detailed pollenanalytical investigations, starts with Late Saalian glacio-fluvial to glacio-lacustrine sands covering the Drenthe ground moraine. They represent Saalian A to C after Menke & Tynni (1984). During Saalian A a limited number of open land species (esp. Poaceae) reflects a rupiculous plant coverage with first occurence of Betula and Juniperus. A remarkable participation of Tertiary sporomorphs points on intensive lateral mass input into the depression, that decreases gradually during Saalian B. This period is especially characterized

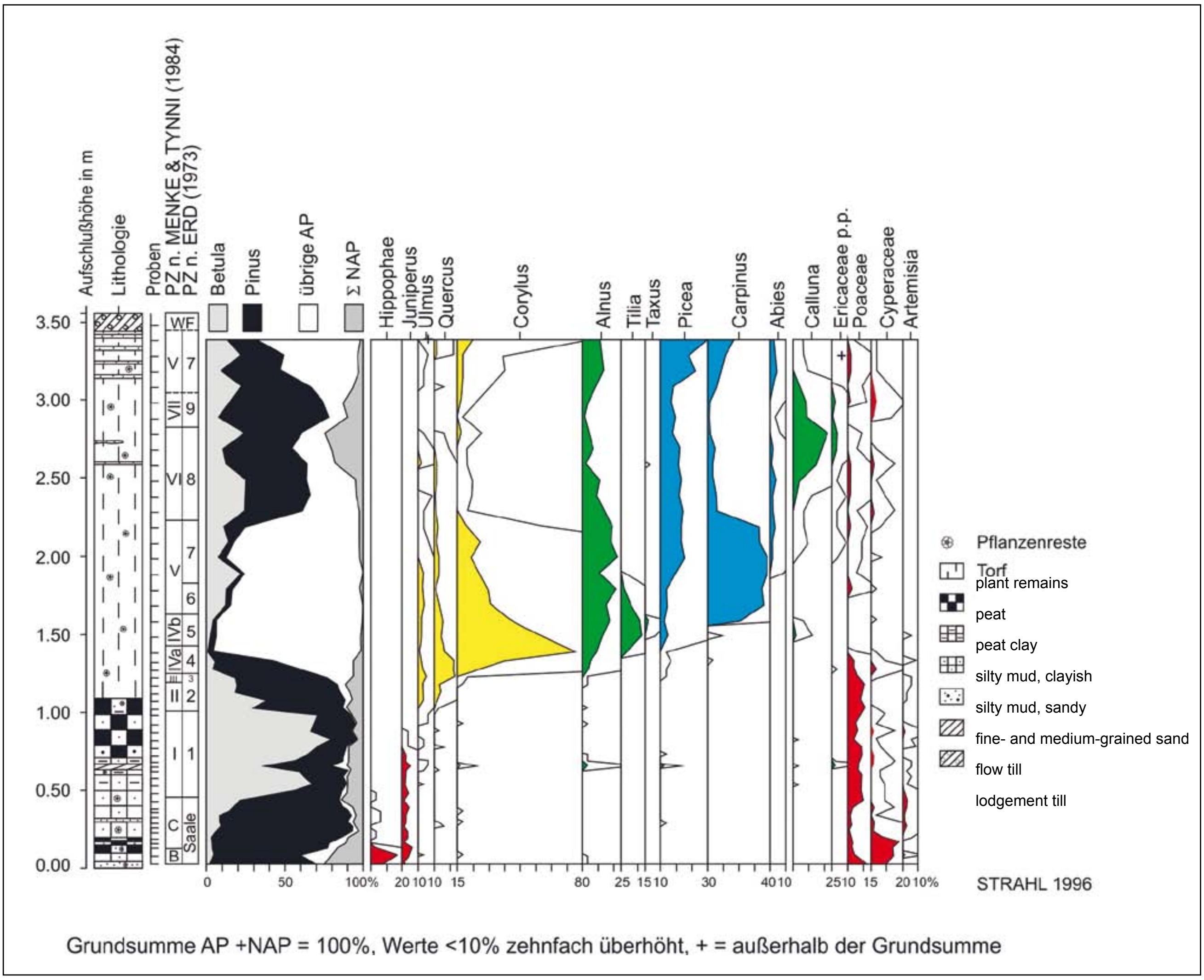

Fig. 5: Pollen diagram Hinterste Mühle, Profile 1 (selected taxa) – (Strahl 2000)

Abb. 5: Pollendiagramm Hinterste Mühle, Profil 1 (ausgewählte Taxa) – (Strahl 2000)

by a Hippophaë maximum. In Saalian C first organic mud sediments were deposited in the edge area of the depression, whereas in the central parts limnic sedimentation continued until the Eemian interglacial. It started with a strong spreading of Betula (PZ I after Menke &Tynni 1984), followed by predominance of Pinus (PZ II), at the time the peat accumulation started. The pollen diagram further demonstrates a complete and typical Eemian sequence (PZ I to PZ VII after Menke &Tynni 1984). A thin layer of fine-coarsed sediments with reworked Eemian content is interpreted as Early Weichselian. They prove the temporary occurence of thermophilous species as well as episodic limnic conditions after the Eemian. The whole sequence was finally cut by the advancing ice of the Brandenburg Phase (Weichselian 1, 22.000–20.000 bp), leaving a cover of till (ground moraine), that prevented further erosion.

The site is the only outcrop of limnic Eemian in North-East Germany. Most of the complex was extracted by the further exploitation of the gravel pit. The remaining parts are still visible in the southern slopes of the pit. In 2001, the outcrop has been declared as a natural monument because of its outstanding scientific importance, initiated by the Geoscientific Association Neubrandenburg.

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B

Exkursion C

Ice marginal positions of the Last Glacial Maximum (LGM) in north-eastern Germany

Christopher Lüthgens, Margot Böse

Itinerary:

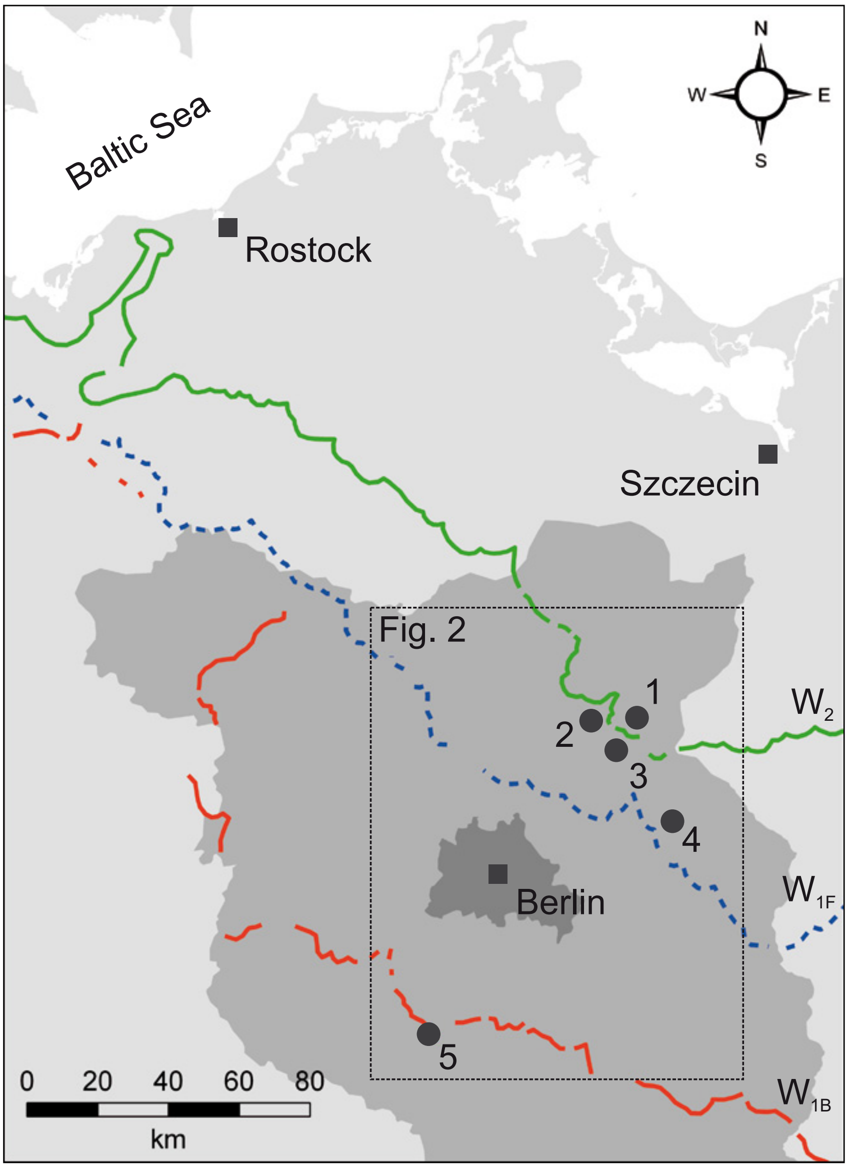

Fig. 1: Overview map of north-eastern Germany and neighbouring areas (light grey), with administrative areas of Brandenburg (grey) and Berlin (dark grey); main ice marginal positions (IMPs, based on Liedtke 1981) indicated by coloured lines: red – Brandenburg IMP (W_{1B}), dashed blue – recessional Frankfurt IMP (W_{1F}), green – Pomeranian IMP (W_2); Field trip sites: 1 – Kleiner Rummelsberg, 2 – Althüttendorf gravel pit, 3 – Macherslust clay pit, 4 – geotope of Vevais, 5 – Luckenwalde gravel pit "Weinberge"; dashed rectangle indicates area depicted in figure 2; modified from Lüthgens & Böse (2011).

Abb. 1: Übersichtskarte von Nord-Ost-Deutschland and benachbarten Gebieten (hellgrau), Verwaltungsbereiche von Brandenburg (grau) und Berlin (dunkelgrau); Haupteisrandlagen (nach Liedtke 1981): rote Linie – Brandenburger Eisrandlage (W_{1B}), gestrichelte blaue Linie – Frankfurter Rückzugsstaffel (W_{1F}), grüne Linie – Pommersche Eisrandlage (W_2); Exkursionspunkte: 1 – Kleiner Rummelsberg, 2 – Kiesgrube Althüttendorf, 3 – Tongrube Macherslust, 4 – Geotop von Vevais, 5 – Kiesgrube Luckenwalde "Weinberge"; das gestrichelte Rechteck entspricht dem Bildausschnitt von Abbildung 2; verändert nach Lüthgens & Böse (2011).

Abstract: During this part of the excursion, the geomorphology, sedimentology and geochronology of the young morainic landscape around Berlin is introduced. The first stop illustrates the glacial geomorphology of the Pomeranian ice marginal position (IMP), which shows the most prominent ice marginal features in NE Germany. The gravel pit "Althüttendorf" (second stop) is one of the key sites were the ice advance to the Pomeranian IMP was recently dated by means of optically stimulated luminescence (OSL) dating of glaciofluvial sediments. Within the "Macherslust" clay pit (third stop) the melting of buried dead ice is documented by fissures within laminated glaciolacustrine sediments within the Toruń-Eberswalde ice marginal valley (IMV). At the geotope of Vevais (fourth stop) a complete record of the Eemian interglacial (Marine Isotope Stage (MIS) 5e) has been preserved within lake sediments and is nowadays fully exposed. Finally, the last stop in the Luckenwalde area illustrates how the Saalian heritage was preserved within the young morainic landscape of the Weichselian glaciation. The five exemplary sites to be visited therefore comprise an age range from the Saalian glaciation (MIS 6) to the late Weichselian glaciation (MIS 2).

Eisrandlagen des Last Glacial Maximums (LGM) in Nord-Ost-Deutschland

Kurzfassung: Während dieses Exkursionsabschnittes werden die Geomorphologie, Sedimentologie und Geochronologie der Jungmoränenlandschaft der Umgebung Berlins vorgestellt. Der erste Halt veranschaulicht die Glazialmorphologie der Pommerschen Eisrandlage, die die am deutlichsten ausgeprägten Eisrandformen in NO-Deutschland aufweist. Bei der Kiesgrube „Althüttendorf" (zweiter Halt) handelt es sich um eine der Schlüsselpositionen, an denen kürzlich das Alter des Eisvorstoßes zur Pommerschen Eisrandlage mit Hilfe optisch stimulierter Lumineszenz (OSL) Datierungen an glazifluviatilen Sedimenten bestimmt wurde. In der Tongrube von Macherslust (dritter Halt) ist das Austauen von begrabenem Toteis in Form von Brüchen in laminierten glazilakustrinen Sedimenten im Bereich des Toruń-Eberswalder Urstromtales dokumentiert. Im Bereich des Geotops von Vevais (vierter Halt) ist eine vollständige Abfolge von Seesedimenten aus dem Eem Interglazial (MIS 5e) erhalten und heute vollständig zugänglich. Der letzte Halt bei Luckenwalde verdeutlicht wie im Bereich der Jungmoränenlandschaft der Weichsel-Vereisung das saalezeitliche Erbe konserviert wurde. Insgesamt umfassen diese fünf exemplarischen Exkursionspunkte ein Zeitfenster von der Saale-Vereisung (MIS 6) bis ins Spätglazial der Weichsel-Eiszeit (MIS 2).

Keywords: *Weichselian glaciation, Brandenburg ice marginal position, Pomeranian ice marginal position, Eeemian lake sediments, glacial geomorphology, geochronology*

Introduction

In general, three main Weichselian ice marginal positions (IMPs) can be differentiated in north-eastern Germany (Fig. 1): The Brandenburg IMP, representing the southernmost ice advance in the research area (W_{1B}), the Frankfurt IMP (W_{1F}), and the Pomeranian IMP (W_2). This pattern of ice marginal positions and the herein included relative chronology (younger from south to north) was named and thereby established by Woldstedt (1925) already, shortly after the introduction of the concept of polyglaciation in northern Germany (Lüthgens & Böse, 2010). Although specific ice marginal valleys (IMVs, "Urstromtäler") have frequently been assigned to the main IMPs (Glogów-Baruth IMV & Brandenburg IMP, Warszawa-Berlin IMV & Frankfurt IMP, Toruń-Eberswalde IMV & Pomeranian IMP, Fig. 2), the drainage of meltwater has been shown to be highly complex (Juschus 2001). Meltwater was still flowing through the complex channel system even after the ice margin of the Scandinavian Ice Sheet (SIS) had retreated north of the Pomeranian IMP.

Because the ice marginal features related to the Brandenburg phase and the Frankfurt phase are relatively weakly developed, both IMPs have mainly been reconstructed along ridges of outwash plains (sandar). Terminal moraines or even push-moraines only rarely occur. In addition, the Weichselian morphology has in many places been shown to be inherited from the relief already formed throughout the penultimate Saalian glaciation (Böse 2005, Brose 1995). The area between the Brandenburg IMP and the Pomeranian IMP (which includes the Frankfurt IMP) is dominated by glaciofluvial deposits and landforms as well as dead ice topography (Lüthgens & Böse 2011). The Frankfurt IMP is not considered to represent an independent ice advance, but is interpreted as a halt in the course of the down-melting of the SIS from the Brandenburg IMP (Lippstreu 1995, Böse 2005, Litt et al. 2007). The Pomeranian IMP in contrast is represented by the most prominent terminal moraines in north-eastern Germany. It is assumed to have been formed throughout a strong re-advance of the SIS originating from the Baltic Sea basin (Lippstreu 1995, Böse 2005).

Tab. 1: Coordinates of field trip stops

Tab. 1: Koordinaten der Exkursionspunkte

Stop no.	Name	UTM* coordinates	Altitude a.s.l. (m)
1	Kleiner Rummelsberg	33N 431620 5863330	82
2	Althüttendorf gravel pit	33N 424230 5868770	70
4	Macherslust clay pit	33N 421750 5855960	60
5	Vevais geotope	33N 441650 5838630	30
3	Luckenwalde gravel pit	33N 372880 5772410	72

* Universal Transverse Mercator (UTM) projection, zone 33N (also see Fig. 2).

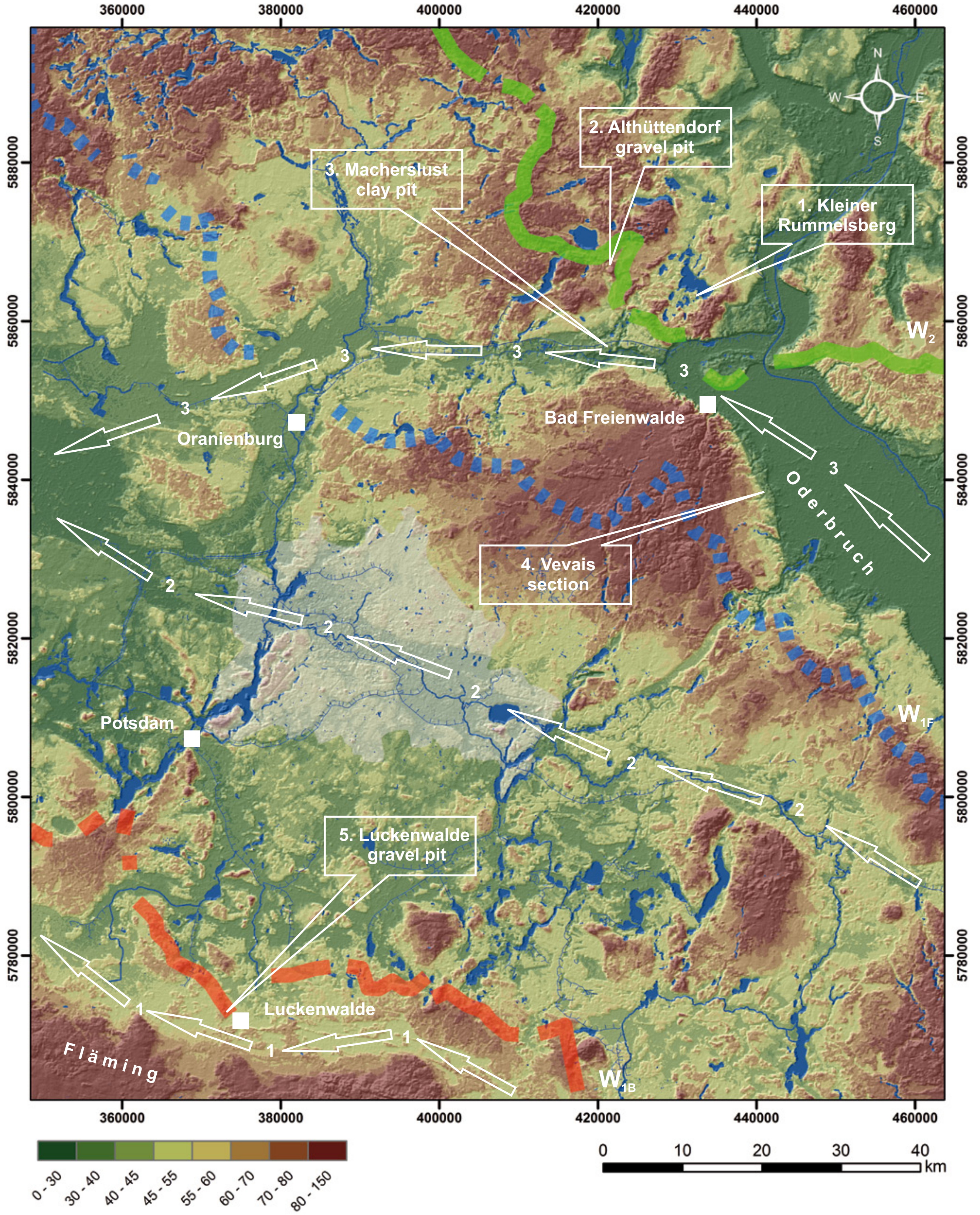

Fig. 2: Location of the field trip sites within the area surrounding Berlin (indicated by greyish shaded area); main IMPs: red – W_{1B}, dashed blue – W_{1F}, green – W_2 (based on Liedtke 1981); general direction of meltwater flow within the main ice marginal valleys (IMVs) indicated by white arrows: 1 – Głogów-Baruth IMV, 2 – Warszawa-Berlin IMV, 3 – Toruń-Eberswalde IMV; map based on a digital elevation model (DEM) derived from hole-filled seamless SRTM-3 data (processed by Jarvis et al. 2006); modified from Lüthgens & Böse (2011).

Abb. 2: Exkursionspunkte im Umland Berlins (grau hinterlegter Bereich); Haupteisrandlagen: rot – W_{1B}, blau gestrichelt – W_{1F}, grün – W_2 (nach Liedtke 1981); Hauptabflussrichtung der Schmelzwässer in den Urstromtälern angedeutet durch weiße Pfeile: 1 – Głogów-Baruther Urstromtal, 2 – Warszawa-Berliner Urstromtal, 3 – Toruń-Eberswalder Urstromtal; Karte basiert auf einem digitalen Höhenmodell abgeleitet aus SRTM-3 Daten (prozessiert von Jarvis et al. 2006); verändert nach Lüthgens & Böse (2011).

Fig. 3: View to the SW from the top of the "Kleiner Rummelsberg": Pomeranian terminal moraines (background), landforms interpreted as recessional terminal moraines (middle), lake "Wesensee" (foreground).

Abb. 3: Blick vom „Kleinen Rummelsberg" nach SW: Pommersche Endmoräne (Hintergrund), Geländeformen, die als Endmoränen eines Rückzugshaltes gedeutet werden (Mitte), Wesensee (Vordergrund).

Throughout this part of the fieldtrip (afternoon of day 2 to morning of day 4), the individual sights will give an overview about the geomorphology, sedimentology and chronology of the Weichselian ice advances in the area surrounding Berlin (Fig. 2, see Table 1 for coordinates).

Stop 1 Geomorphology of the glacial landscape around the "Kleiner Rummelsberg"

The view from the top of the 82 m high hill "Kleiner Rummelsberg" (Fig. 2) gives an overview of the typical geomorphology in the area attributed to the Pomeranian IMP. To the west, south and east the view is framed by the terminal moraine of the "Parsteiner Bogen" which is part of the Pomeranian IMP (Fig. 3). Within the glacially shaped Parstein basin, which is nowadays dominated by lakes (the biggest being lake "Parstein" to the north), insular hills like the "Kleiner Rummelsberg" itself occur (Fig. 3). The hills have been interpreted to represent local, recessional IMPs formed in the course of the ice retreat from the Pomeranian IMP (Brose 1978). However, some of the hills (including the "Kleiner Rummelsberg") have a drumlin-like shape. Because of that, it has also been discussed whether they may represent older landforms, which were overridden by the glaciers of the SIS during the ice advance to the Pomeranian IMP.

Stop 2 Althüttendorf – outwash plain of the Pomeranian IMP

The gravel pit "Althüttendorf" is situated east of the village of the same name. Access to the pit has to be permitted by the company's administration, otherwise, entering the pit is strictly forbidden. Within the gravel pit the glaciofluvial sediments of the "Althüttendorf" sandur are excavated. The outwash plain is framed by the terminal moraines of the "Joachimsthaler Bogen", where meltwater formed an outwash cone in an interlobate position (Fig. 2). In general, the sandur sediments are characterised by a high percentage (20–25%) of coarse material (>2mm) (Hultzsch 1994). The sediments are exposed in two approximately 1 km long pit walls (up to a depth of ~15 m). The major part of the sediment section consists of a succession of glaciofluvial sands and gravels (Lüthgens, Böse & Preusser 2011). Especially in the SE section of the pit, the glaciofluvial sediments are disrupted by a massive diamicton rich in boulders which itself is overlain by a matrix supported diamicton containing only moderate proportions of clasts (Fig. 4). Similar sediment successions have also been observed near Chelm, Pomeranian IMP, in Western Poland (Pizarska-Jamroży 2006) and are interpreted as debris flow deposits. Short phases of debris flow activity (years to decades), are assumed to be caused by gravitational destabilisation of sediment accumulated on the ice-front surface during phases of re-advances. In depressions within the unsettled relief formed by the mass movements, the debris flow sediments are overlain by laminated silts which show strong cryoturbation structures (Fig. 4). According to Lüthgens, Böse & Preusser (2011) these have been deposited within small lakes which developed in depressions of the unsettled relief formed by the debris flow events. In some places the glaciolacustrine fines are again overlain by a diamiction of varying thickness which is interpreted as periglacial cover sediment.

Lüthgens, Böse & Preusser (2011) dated the deposition of the glaciofluvial sediments of the "Althüttendorf" outwash plain using single grain quartz optically stimulated luminescence (OSL) to 20.1±1.6 ka (mean age based on results for four samples which agreed within error). They interpret this age to represent the initial sandur formation in front of the active ice margin of the Pomeranian phase. It is in excellent agreement with a single grain quartz OSL age

Fig. 4: Topmost layers overlying glaciofluvial deposits exposed in the "Althüttendorf" gravel pit: A - massive diamicton rich in boulders, B - matrix supported diamicton containing only moderate proportions of clasts, C - laminated silts. Cryoturbation structures are clearly visible along the sedimentary contact of units B and C. The topmost ~1.5 m of sediment is missing because of excavation activities.

Abb. 4: Oberste Schichten über den glazifluviatilen Ablagerungen in der Kiesgrube Althüttendorf: A – massiver Diamikt, reich an Blöcken, B – matrixgestützter Diamikt mit einem moderaten Anteil an Klasten, C – laminierte Schluffe. Kryoturbationserscheinungen sind am Kontakt zwischen Schicht B und C deutlich erkennbar. Die obersten 1,5 m an Sediment fehlen aufgrund von Aushubarbeiten.

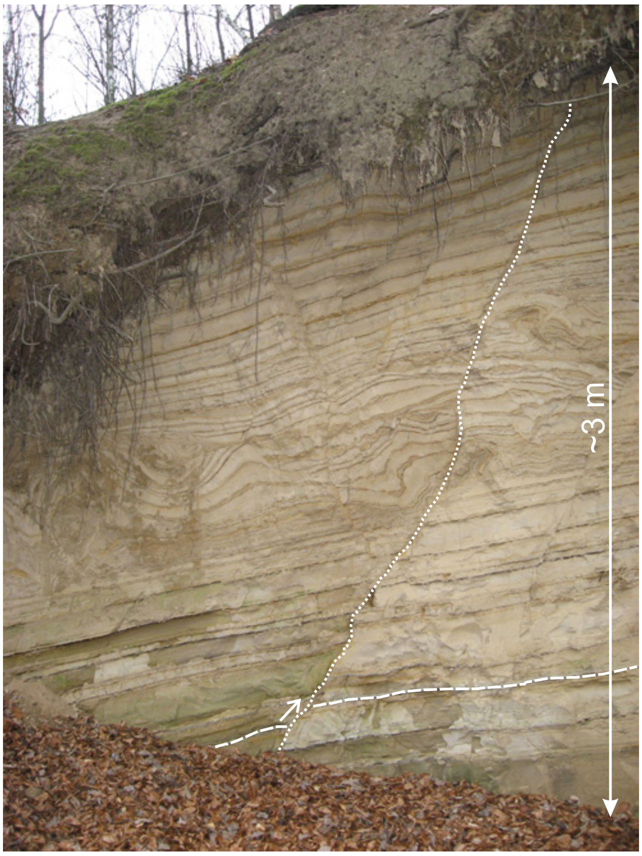

Fig. 5: Glaciolacustrine silt and clay of the Macherslust section: Disturbed layers in the centre of the picture caused by a subaquatic slide. A fissure (dotted line) caused by melting of buried dead ice in the ground; exemplary offset for one layer indicated by dashed line and small arrow.

Abb. 5: Glazilakustriner Schluff und Ton im Aufschluss von Macherslust: Die Störung der Lagen in der Bildmitte wurde durch eine subaquatische Rutschung verursacht. Ein Riss, der durch Austauen von begrabenem Toteis im Untergrund entstanden ist, wird durch eine gepunktete Linie markiert. Exemplarisch wurde der Versatz einer Schicht an einer Stelle durch eine gestrichelte Line und einen kleinen Pfeil markiert.

of 19.4±2.4 ka (mean age based on results for three samples which agreed within error) from a sandur approximately 10 km SE of the "Althüttendorf" site, which represents the final accumulation of glaciofluvial sediments on the outwash plains associated with the Pomeranian IMP (Lüthgens, Böse & Preusser 2011).

Stop 3 Macherslust – glaciolacustrine silt and clay in the Eberswalde IMV

The outcrop of Macherslust (NE of Eberswalde) is preserved within an abandoned clay pit in the Toruń-Eberswalde ice marginal valley (Fig. 2). The exposure comprises 4–5 m of laminated silt (1–25 cm thick layers) and clay (2–10 mm layers). According to Schirrmeister (2004) the general dip of the layers towards WNW at an angle of ~10° was caused by the melting of buried dead ice in the ground. Part of the section shows folding and intense deformation of the layers caused by a subaquatic slide which occurred when the sediment was still unconsolidated (Schirrmeister 2004; Fig. 5). Intercalated sand layers indicate that the glaciolacustrine conditions were repeatedly interrupted by phases of streaming water conditions. However, these glaciofluvial sediments consist of well sorted fine sand and do not contain coarser material. According to Schirrmeister (2004), this indicates a distant ice margin as the source of the meltwaters. From a geomorphological point of view the lake basin is interpreted to have formed in a depression in a meltwater channel which was most likely caused by the melting of buried dead ice (Marcinek & Schulz 1995). According to Schirrmeister (2004), the laminated sediments do not reflect annual layers. Lüthgens, Böse & Preusser (2011) dated the deposition of an exposed sand layer to 14.7±1.0 ka by means of single grain quartz OSL and interpret this age to represent the meltout of buried dead ice in the area.

Stop 4 Vevais – a Saalian-Eemian-Weichselian sediment succession

Near the village of Vevais, a sediment succession of glaciofluvial to fluvial sands at the base and the top of the section encompassing a ~3.5 m thick sequence of lake marls is accessible adjacent to a railroad track (Fig. 6). The sediments were exposed for the first time during the construction work for a railway line in the early 20th century. Although the first description of the succession and the bedding conditions dates back to 1912, the lake sediments were first classified as being of Eemian origin by Brose in 1971 (Brose et al. 2006). Detailed palynological analyses revealed an almost complete record of the Eemian (MIS 5e) to be preserved within the lake marls (Brose et al. 2006). However, owing to a lack of pollen in the sand layers, the exact timing of their deposition remained unclear. Lüthgens et al. (2010a) dated these sediments using OSL of small aliquots of quartz and feldspar and confirmed the results of Brose et al. (2006). They dated the onset of the Eemian at the site to 126 ±16 ka, and the termination and beginning transition from the Eemian to the Weichselian to 109 ±8 ka. A sample from the glaciofluvial sands at the base of the section yielded an age of 194 ±15 ka, which is interpreted as a maximum age by the authors. However, the age is consistent with the age control from the pollen record and is additionally supported by the findings of Brose et al. (2006), who assume a Saalian age of the sediment based on stratigraphical and geochemical findings (Lüthgens et al. 2010a). For the sandy glaciofluvial sediments on top of the section Lüthgens et al. (2010a) report a minimum age of ~10 ka. A more precise age could not be determined within that study due to methodological drawbacks.

Stop 5 Luckenwalde – sandur sediments of the Brandenburg IMP

The Luckenwalde area is located about 70 km south of Berlin (Fig. 2). The Luckenwalde terminal moraine stretches from Luckenwalde in a north-north-westerly direction to the village of Frankenfelde, the highest parts reaching ~75 m asl. With the Glogów-Baruth IMV (Fig. 2) roughly marking the southernmost extent of the Weichselian glaciation in north-eastern Germany, the Luckenwalde terminal moraine and the related outwash plain had been attributed to the Brandenburg IMP by different authors throughout the research history of the area (e.g. Behrmann 1949/50, Marcinek 1961). However, Franz (1961) proposed a pre-Weichselian origin of the landform. The general stratigraphy of the sediments exposed in the gravel pit Luckenwalde "Weinberge" (a permission is needed to enter the pit, otherwise access is strictly forbidden) can be described as follows (according to Lüthgens et al. 2010a, also see Fig. 7): At the base of the pit, ~3 m

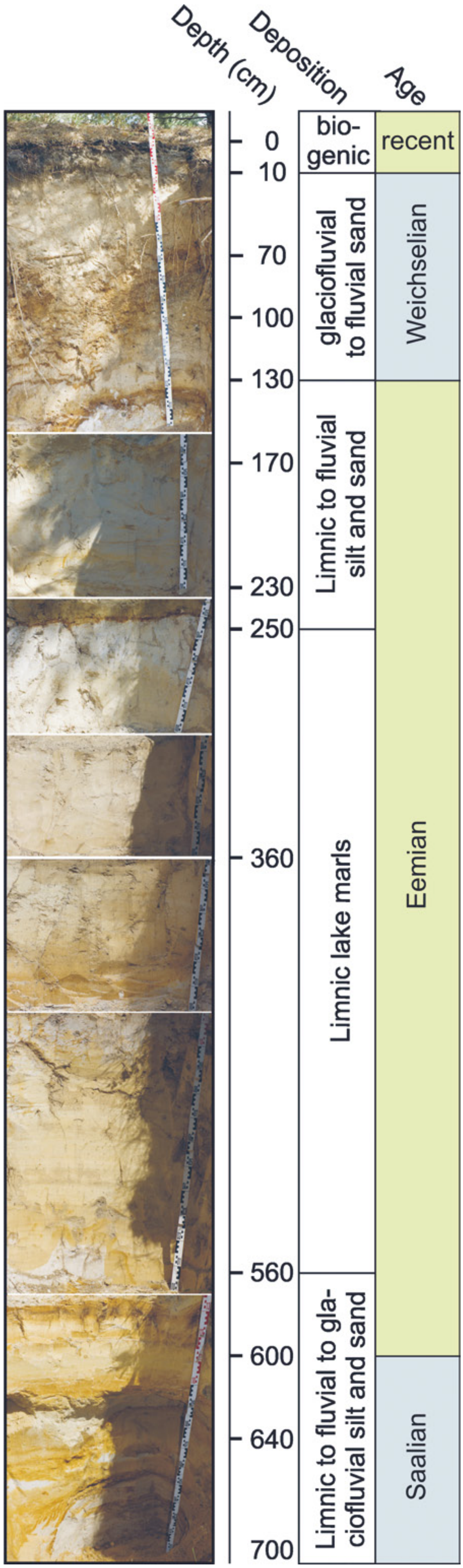

Fig. 6: Sediment section of Vevais: Gaps in the compilation of photographs indicated by white lines, depth given in cm below surface, depositional environment, simplified facies and age range (green colour indicates interglacial conditions, blue colour indicates cold stage conditions); modified from Lüthgens et al. (2010).

Abb. 6: Sedimentabfolge von Vevais: Lücken in der Fotocollage durch weiße Linien angezeigt, Tiefe angegeben in cm unter Geländeoberfläche, Ablagerungsmilieu, vereinfachte Fazies und Altersbereich (grüne Farbe repräsentiert interglaziale Bedingungen, blaue Farbe repräsentiert kaltzeitliche Bedingungen); verändert nach Lüthgens et al. (2010).

Fig. 7: Glaciofluvial sediments of the Luckenwalde outwash plain and stone layer (dashed line and enlarged detail) covered by periglacial sediments. Top ~0.5 m of sediment missing owing to excavation activities.

Abb. 7: Glazifluviatile Sedimente des Luckenwalder Sanders und Steinlage (gestrichelte Linie und Ausschnittsvergrößerung) bedeckt von periglaziären Sedimenten. Die obersten 0,5 m an Sediment fehlen aufgrund von Aushubarbeiten.

of glaciofluvial sands characterised by cryoturbation structures are exposed. These are overlain by a ~0.5 m thick basal till. The major part of the section comprises ~12 m of glaciofluvial layered sands with intercalated gravel layers. The glaciofluvial sediments are overlain by a stone layer which is rich in ventifacts. This stone layer itself is overlain by a ~0.5 m thick layer of sandy, periglacial cover sediments. Based on results from quartz OSL dating which yielded consistent ages of around 130–150 ka for seven samples, Lüthgens et al. (2010a) attribute the bulk sedimentation to the Saalian glaciation (MIS 6). However, samples from sandur sediments taken further north (Luckenwalde outwash plain near Frankenfelde) showed Weichselian ages and the authors therefore conclude that the SIS also reached the Luckenwalde area during the Weichselian glaciation. They propose that a considerable number of landforms attributed to the Weichselian glaciation may actually be of Saalian age, only partly overridden during the Weichselian glaciation (Lüthgens et al. 2010a).

Concluding remarks

Additional studies have shown that the ice advance to the Brandenburg IMP happened some time between 34–24 ka (Lüthgens et al. 2010b, Lüthgens 2011). However, more dating efforts are needed in order to further specify the age and to clarify whether this ice advance may be correlated with ice advances in late MIS 3 as known from Denmark (Houmark-Nielsen 2010). Results from OSL dating of glaciofluvial sediments from the Pomeranian IMP have shown that this ice advance represents the LGM (defined as the global maximum ice volume inferred from the marine isotope record at ~20 ka, Bard 1999) in NE Germany. Based on a review of the results from recent geochronometrical studies, Lüthgens & Böse (2011) propose a new chronology for the Weichselian ice advances. Apart from the studies based on results from OSL dating they also include the results of surface exposure dating (SED) of glacigenic boulders from the studies of Heine et al. (2009) and Rinterknecht et al. (2010). Lüthgens & Böse (2011) conclude that the ice advance to the Brandenburg IMP happened sometime between 34–24 ka as implied by accumulation of glaciofluvial sediments on outwash plains dated by means of OSL (Lüthgens, Böse & Krbetschek 2010, Lüthgens et al. 2010b, Lüthgens 2011). Results from SED (Heine et al. 2009) provide a minimum age of >23 ka for the deglaciation north of the Brandenburg IMP. Owing to a lack of geochronometrical data, it remains unclear how far the ice front had retreated at that time and whether that retreat can be correlated with the Frankfurt IMP. Based on results from OSL dating of sandur sediments (Lüthgens, Böse, & Preusser 2011) the SIS advanced to the Pomeranian IMP at ~20 ka. Results from SED indicate initial deglaciation north of the Pomeranian IMP at least up to the Gerswalde IMP prior to 17 ka (Heine et al. 2009, Rinterknecht et al. 2010).

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C

Excursion D

Quaternary geology and prehistory in the type region of the Elsterian cold stage and of the Saalian cold stage in the Halle (Saale) area

Stefan Wansa, Frank W. Junge

Itinerary:

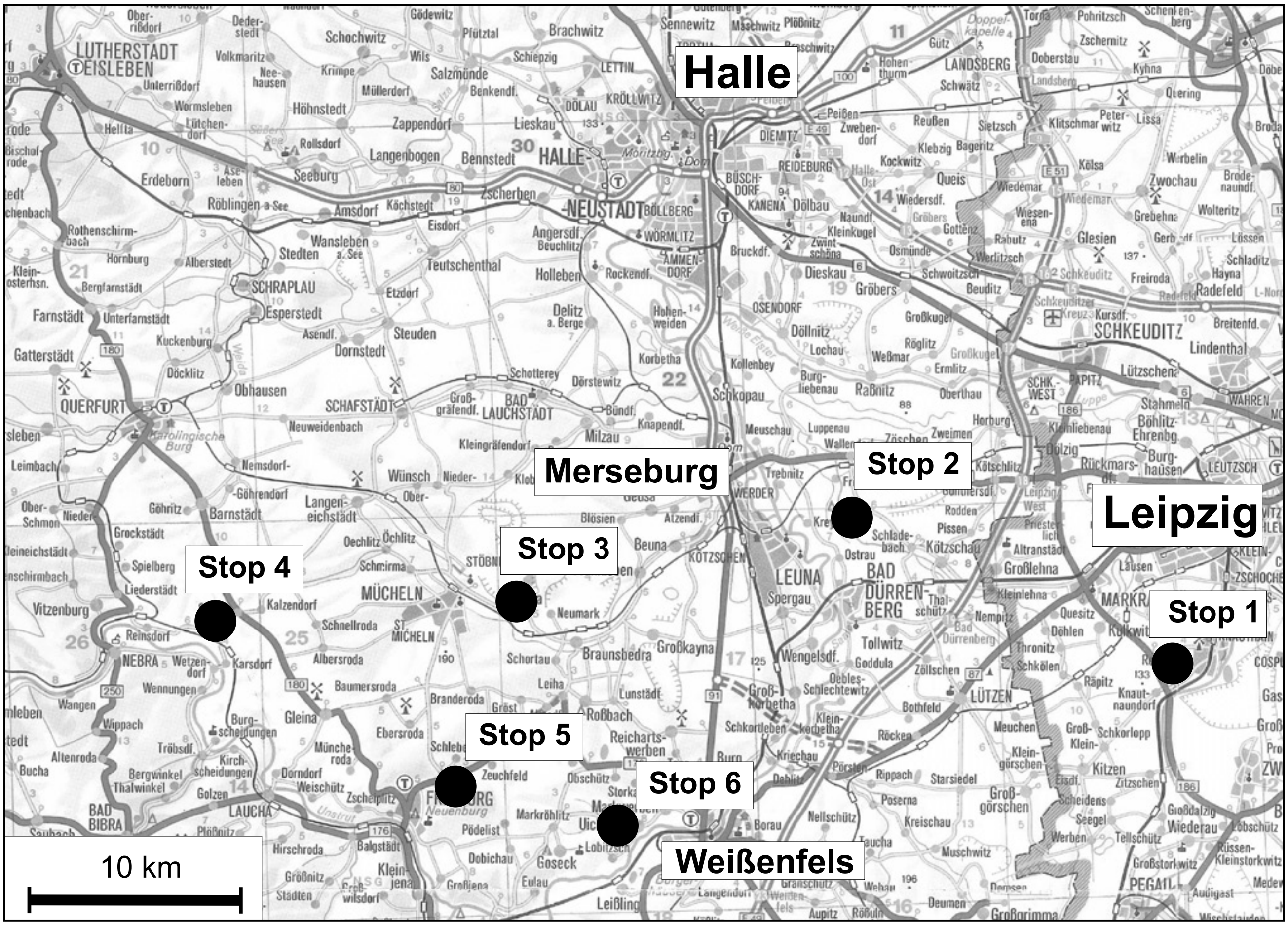

Fig. 1: Excursion map.

Abb. 1: Übersichtskarte des Exkursionsgebiets.

Introduction

Today's field trip takes us about 35 km south of Halle (Fig. 1). It starts in the Leipzig lowland bay and continues in the southwestern Harz foreland, on the Merseburg Buntsandstein plateau (Buntsandstein = Lower Triassic sedimentary rock, in this case sandstone) and the Querfurt Muschelkalk plateau (Muschelkalk = Middle Triassic limestone). The mostly flat or gently undulating plateau relief is subdivided by single narrow valleys and delimited by a steep escarpment in the Lower Muschelkalk.

The field trip area is characterised by an extensive cover of Quaternary sediments that vary greatly in composition and thickness. Apart from locally preserved older deposits, the complex stratigraphic sequence begins with formations of the third last glacial period, i. e. the Elsterian cold stage during which continental ice sheets twice overrode the entire region. This period is documented by widespread meltwater sediments and till as well as local evidence of two cycles of glacial sedimentation (Schulz 1962, Eissmann 1975).

In the Saale/Unstrut area, isolated gravel occurrences, forming the higher middle terrace level, have been assigned to the late Elsterian to early Saalian (penultimate glacial) stages. The Main Saale and Unstrut terrace gravels (lower middle terrace), containing *Corbicula fluminalis* in their lower part, belong to the penultimate interglacial period, *i.e.* the Holsteinian warm stage and the lower part of the Saalian Complex. In the Geisel valley Unstrut gravels merge with Geisel gravels to form the Körbisdorf terrace. During the Drenthe stage of the Saalian Complex, the continental ice sheet reached its maximum Saalian extent. The Halle-Leipzig area was overridden by two – in places three – ice advances (Eissmann 1975, Knoth 1995, Litt & Wansa 2008). The maximum extent of the Saale continental ice sheet (Zeitz phase) reached to the west of the Saale River, probably along the line Lodersleben – Schmon – Steigra – Freyburg (Unstrut) and is marked by the Zeuchfeld sandur and other features. Between the beginning of the ice advance and its maximum extent, there was a period when the ice melted by only a few kilometres. A subsequent short re-advance formed the Langeneichstädt endmoraine, extending northwestward from the Geisel valley via Langeneichstädt (Meng & Wansa 2008). After abandoning this marginal position, the ice margin retreated to the Petersberg – Landsberg – Delitzsch area, probably leaving behind large masses of dead ice (Schulz 1962). Subsequently, the ice advanced again as far as to the Geisel valley (Leipzig phase); however, the margin cannot be satisfactorily reconstructed because of severe erosion of the deposits.

The Eemian warm stage is represented by lake deposits and peats in peripheral sinks of lignite diapirs in the Geisel valley (Neumark-Nord) (Litt 1994, Strahl et al. 2010, cf. Mania et al. 2010). Periglacial conditions prevailed during the Weichselian cold stage. Weichselian deposits (aeolian loess, reworked loess and flow material) are widespread on the plateaus and the valley sides. Fluvial deposits are limited to the Saale, Unstrut and Geisel valleys. Late Glacial sections of more than local significance are exposed in the western Geisel valley near Mücheln and Krumpa (Mania et al. 1993).

During the Holocene, human impact on the natural environment has increased, especially since the Neolithic. Extensive forest clearances due to the growing importance of mixed farming have aggravated soil erosion, triggering and controlling the formation of floodplain deposits.

Stop 1: Rehbach gravel pit

West of the abandoned lignite opencast mine at Zwenkau (Bellmann et al. 1994), Rehbach gravel pit exhibits the standard Central German sequence of the Elsterian and Saalian glaciations with their interlocking glacial and periglacial sediments.

The basal, 3–8 m deep, early Elsterian terrace lacks any nordic material but contains rocks from both the Vogtland catchment of the Weiße Elster (quartz, siliceous shale) and the catchment of the Saale River (volcanic rocks of the Thuringian Forest and Harz mountains, Muschelkalk), which at that time flowed via Leipzig (Leipzig branch of the Saale). Over a great distance the terrace is divided by a layer of silt and fine sand (Knautnaundorf horizon) with signs of frequent cryogenic impact (drop soil, convoluted soil features). Within the horizontally layered gravels, four levels containing ice wedge casts are indicate that the gravel was deposited under largely glacial conditions (Bellmann et al. 1994). In the overlying layers the gravels merge continuously into a littoral sand body ("Schlepp") and finally into an Elsterian ice-dammed lake sediment: the Dehlitz-Leipzig varved clay (Junge 1998). In general, only the lower part of the overlying First Elsterian till has been preserved. It is a compact grey boulder clay whose shear joints are filled with varved clay. Upper Elsterian till and younger ice retreat sediments have mostly undergone erosion or are only recognisable in the outcrop as a boulder pavement consisting of nordic rocks mainly (Fig. 2).

The Early Saalian Main terrace is composed of continuous, horizontally bedded, coarse-sandy, fine to coarse gravelly material containing quartz, graywacke and siliceous shale from the Vogtland-east Thuringian catchment of the Weiße Elster as well as Scandinavian material (e.g., flint). The upper part of the gravels is characterised by abundant permafrost indicators (e.g., ice wedge casts with depths of 3–5 m) and contains a widespread cryoturbated silty horizon (Markkleeberg cryoturbation horizon). The early Saalian terraces are well known for their Middle Palaeolithic artefacts (e.g., Levalloisian artefacts of the "Markkleeberg Culture"). By 1995, about 1850 stone artefacts had been found in the basal part of the Weiße Elster Main terrace (nearby site Eythra; e.g., Eissmann et al. 1991). They were mainly made of flint, occasionally of Tertiary quartzite, fine-grained quartz, siliceous shale or rhyolitic tuff. In contrast to the Markkleeberg site, Eythra had a much higher share of tools (such as numerous scrapers and scraper-like artefacts) that are interpreted as remains of early human sites.

The Main terrace is overlain concordantly by the Böhlen varved clay, which is only a few cm thick and has evolved from a sandy facies. It is overlain by the Saale (penultimate glacial) till, which is up to 2 m thick in the pit area and has been partly decalcified and coloured reddish-brown by weathering processes during the Eemian warm stage. This till is covered by a dense stone layer including ventifacts and a 1 m-thick sequence of Weichselian loess with intercalated loamy zones forming the end of the Quaternary sequence.

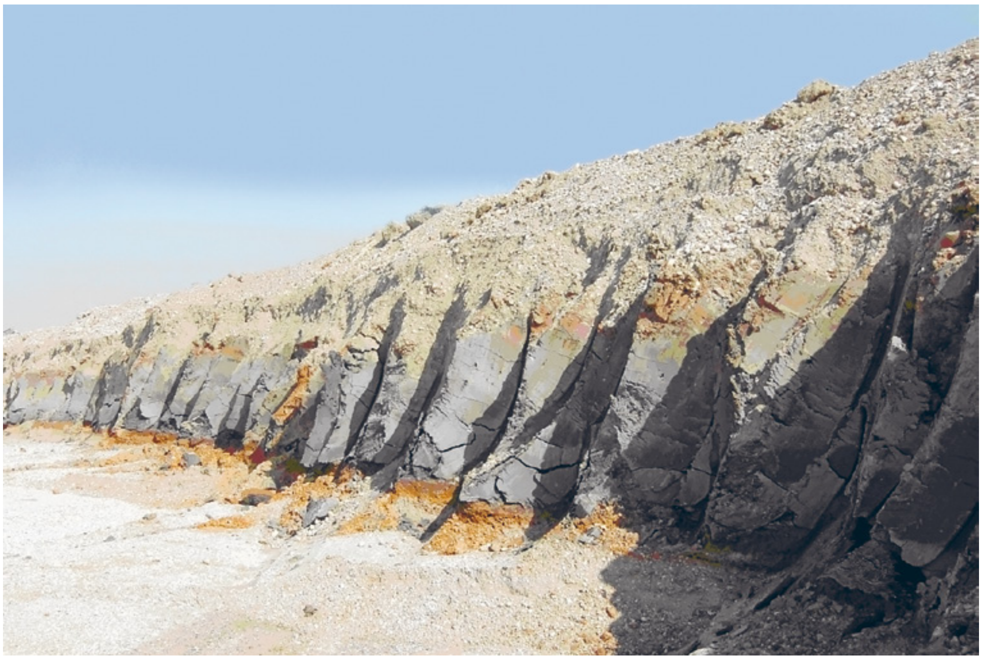

Fig. 2: Transition from Early Elsterian river gravels of the Weiße Elster and Saale to the overlying proglacial sediments of the Dehlitz-Leipzig varved clay and the overlying First Elsterian till. This sequence is overlaid by the Early Saalian river gravels of the Weiße Elster (Main terrace with Markkleeberg cryoturbation horizon on top). Rehbach gravel pit 2008. Photo: F. W. Junge.

Abb.2: Abfolge mit der Frühelsterterrasse der Weißen Elster und Saale, Dehlitz-Leipziger Bänderton, Erster (Unterer) Elster-Grundmoräne und frühsaalezeitlichen Schottern der Weißen Elster (Hauptterrasse mit Markleeberger Kryoturbationshorizont im Hangenden). Kiesgrube Rehbach 2008. Foto: F. W. Junge.

Stop 2: Wallendorf/Schladebach gravel-sand pits near Merseburg

East of the present-day Saale floodplain near Merseburg, Elsterian deposits are largely cut off and replaced by Late Elsterian to Early Saalian gravel deposits, which were built up by the merged rivers Saale, Ilm and Unstrut and are mined at many gravel pits between Wallendorf and Schladebach. The 5–12 m thick deposits, known as "Wallendorf gravels," lie on top of an erosion unconformity that separates the Upper and Lower Elsterian tills; over large areas, they directly overlie the Lower Elsterian till and Dehlitz-Leipzig varved clay (Fig. 3). Blocks of Scandinavian till and moraine in the lower part of the gravel deposits are interpreted as erosion remnants and outwash remains of the Upper Elsterian till. In comparison to the Early Saalian Main terrace West of Merseburg the Wallendorf gravels lie 5–10 m higher, which accounts for their possibly older age (Ruske 1964, Eissmann 1975). This assumption is backed by decalcification (probably during the Holsteinian interglacial period) that is frequently observed in the Wallendorf gravels. Ice wedge casts occur in many places in the upper part of the gravels, pointing to glacial conditions and permafrost. Molluscs found at the base provide evidence of cool temperate climate; those found in upper horizons point to a cold-stage steppe environment. The gravels are covered by Saalian till.

The Wallendorf gravels are well known because of their abundant silex artefacts (Simon 1964, Weber et al. 1996, Bernhardt et al. 1997) (Fig. 4), with their typologically characteristic, simple stone-working technology of percussion-flaking (Clactonian techniques). These artefacts represent the oldest evidence of humans in the Central German region; they are probably derived from the Late Elsterian to very Early Saalian right-hand slope of the Saale valley. They are very different from the Levalloisian-type artefacts found in the early Saalian Main terrace gravels (at Markkleeberg, for instance) and thus document a change in stone-working techniques and hence a substantial advance in human cultural evolution during the period between the two great ice advances of the Elsterian and Saalian glaciations (transition from the Lower to the Middle Palaeolithic).

Stop 3a: Geiseltal (Geisel valley), view point at Krumpa

The name "Geiseltal" is associated with an abandoned lignite mine, about 100 km² in size, in the southeastern Harz foreland west of Merseburg; it has attracted worldwide attention because of its abundant well-preserved Middle Eocene fossils (Krumbiegel et al. 1983, Haubold 1989). Before mining activities completely changed the landscape, the Geisel River, a tributary of the Saale River, had created a wide, flat valley between the Merseburg Buntsandstein plateau and the Querfurt plateau.

The first documented mention of lignite mining in Geiseltal dates to 1698. In the second half of the 19th century, substantial lignite mining activity took place above and below ground, leading to industrial-scale mining in large opencast pits in the early 20th century. When the mines closed on 30 June 1993, about 1.4 billion tons of lignite had been mined, and the deposits were practically exhausted. The lignite layer was up to 120 m thick; the 1:1 ratio of lignite:overburden was very favourable. The main customers were eight coal briquette manufacturers in Geiseltal and the chemical industry in the neighbourhood. Sixteen towns and villages in the region fell victim to coal mining; between 1929 and 1968, some 12 500 people were relocated. The landscape was completely transformed by slag tips and by pits excavated down to 35 m below sea level.

Clean-up measures for the 48 km² area of abandoned mines aim to create a complex of post-mining lakes to be used for a combination of water tourism and environmental projects. The focus is on Geiseltal lake, which has been flooded with Saale water since 30 June 2003 at an average flooding rate of about 70 million m³/a (about 2.22 m³/s). The lake has attained its final water level of +98 m asl. It is the sixteenth largest lake in Germany, with an area of 18.4 km²,

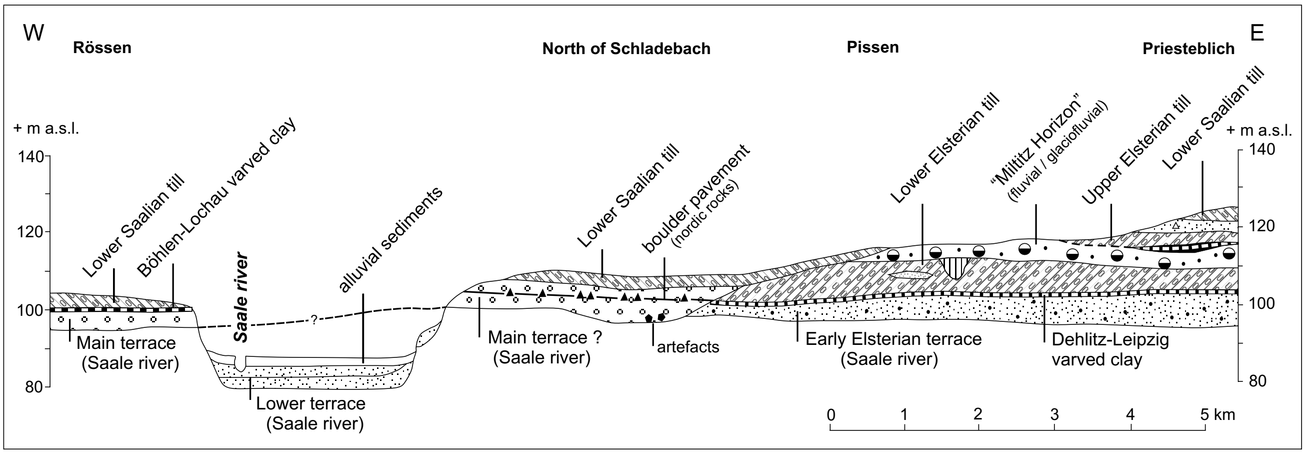

Fig. 3: Geological section across the area to the west and east of the Saale near Merseburg with exposed Wallendorf gravels (Main terrace ? in centre of section; after Eissmann 1975).

Abb. 3: Geologischer Schnitt durch das Gebiet westlich und östlich der Saale bei Merseburg mit den Wallendorfer Schottern in der Mitte des Schnitts (Main terrace?; nach Eißmann 1975).

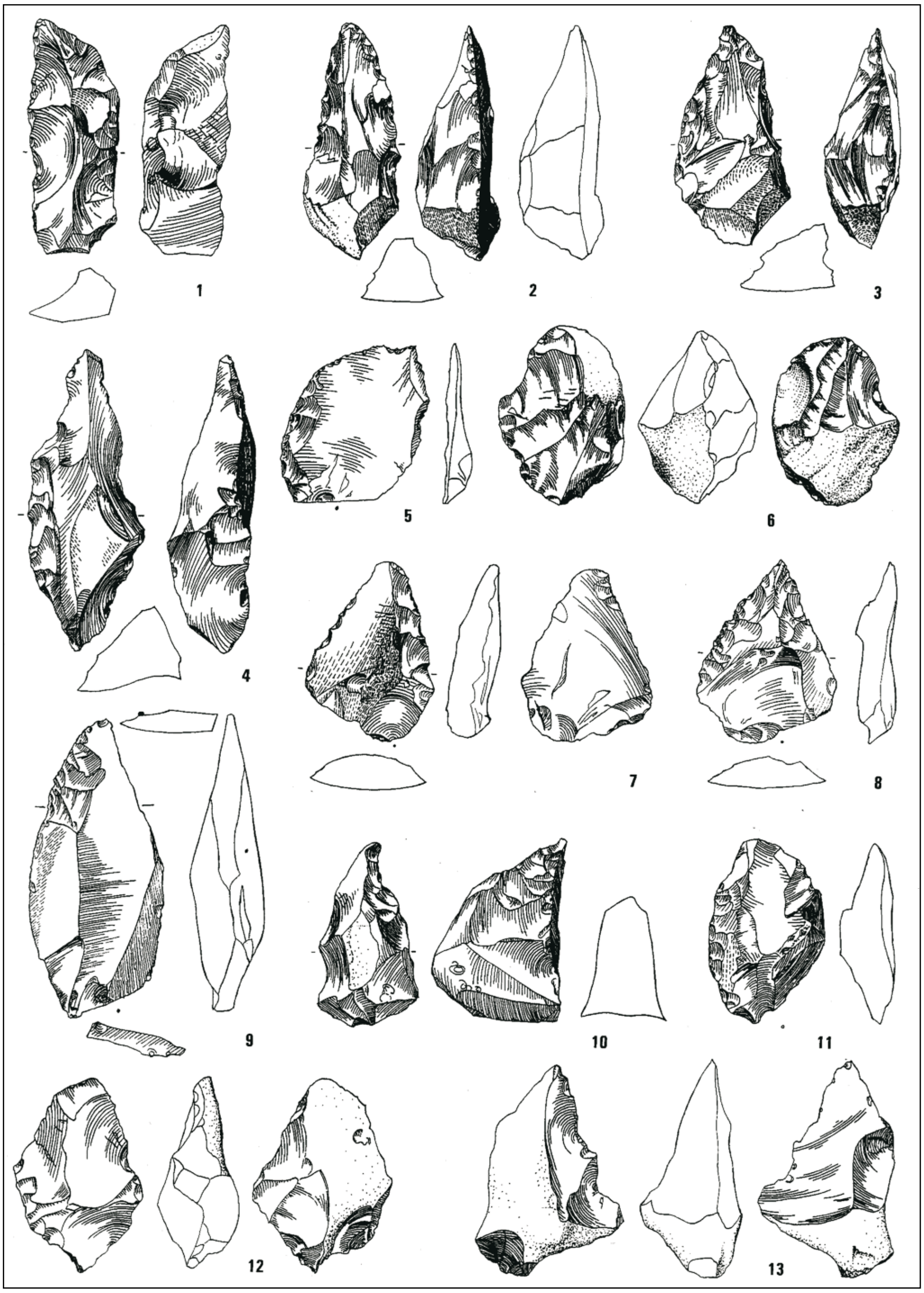

Fig. 4: Clactonoid silex artefacts from Wallendorf (from Bernhardt et al. 1997).

Abb. 4: Clactonoide Silexartefakte von Wallendorf (aus Bernhardt u. a. 1997).

a water volume of more than 400 million m³ and a maximum depth of 78 m. It is Germany's largest man-made lake. The Geiseltal lake complex also includes the two lakes Großkaynaer See (2.6 km², already used for water sports) and Runstedter See (2.3 km²). Further tourist attractions are the lookout on top of the Klobikau mining waste tip (218 m asl) and additional view points, the "Nordic Plateau" erratics garden near Mücheln, the "Geological Window" near Krumpa, the machinery building at Braunsbedra and 41 km-long track around the lake (www.geiseltalsee.com, www.braunkohlenstrasse.de).

Origin and geological structure (text after Thomae 2006)

Eocene subsidence was a result of subrosion of subsurface salt beds. Subrosion tended to follow groundwater movements along fault zones. Phases of strong subrosion leading to rapid subsidence alternated with phases of low subsidence rates. A subrosion cycle comprises rapid subsidence with clastic sedimentation, which becomes finer and finer as subrosion weakens and is finally followed by organogenic sedimentation (base for lignite formation). The cycle may contain subcycles represented by intermediate beds within the lignite.

Overall, Geiseltal's structural evolution is presently considered to be a combination of tectonically, halokinetically and subrosively controlled movements during the Upper Cretaceous/Early Tertiary period (Thomae & Schroeter 1996 and others) (cf. Fig. 5).

Stop 3b: Late Glacial section at Krumpa / Geiseltal lignite (text after Thomae 2006)

Laach Lake (Laacher See) tephra section

In 1988, Laach Lake tephra was found on the southern slope of the Südfeld-Weiterführung opencast mine (Fig. 6). Laach Lake is the largest crater lake in the Eifel region. It has a surface area of 3.33 km² and a depth of 51 m, and was formed by a Late Glacial volcanic eruption. Material was ejected 30 km into the air; the wind carried the ash into this area. A 2–5 cm thick layer of Laach Lake tephra has been preserved at the edge of a lignite diapir and constitutes a component of a limnic sediment sequence that supplies a complete climatic record of the Lateglacial/Holocene transition with its cold and warm phases (Boettger et al. 1998). More than 99 % of the tephra consists of minute particles of volcanic glass (Knuth & Thomae 2003). The entire exposure is now a geotope under environmental protection.

Geiseltal lignite

The protected geotope is the only site where the formerly over 100 m thick Geiseltal lignite is still preserved. In this exposure the upper and lower lignite seams are merged, forming a single bed. Northwards the bed separates into four main seams (basal seam, lower seam, intermediate seam, upper seam). The age of the lignite is Middle Eocene, ranging from pollen zone 14/15 to 15 D (Blumenstengel 2001). Coarse, grey-white pebbles from the Weichselian lower terrace directly overlie the lignite, with a distinct temporal hiatus.

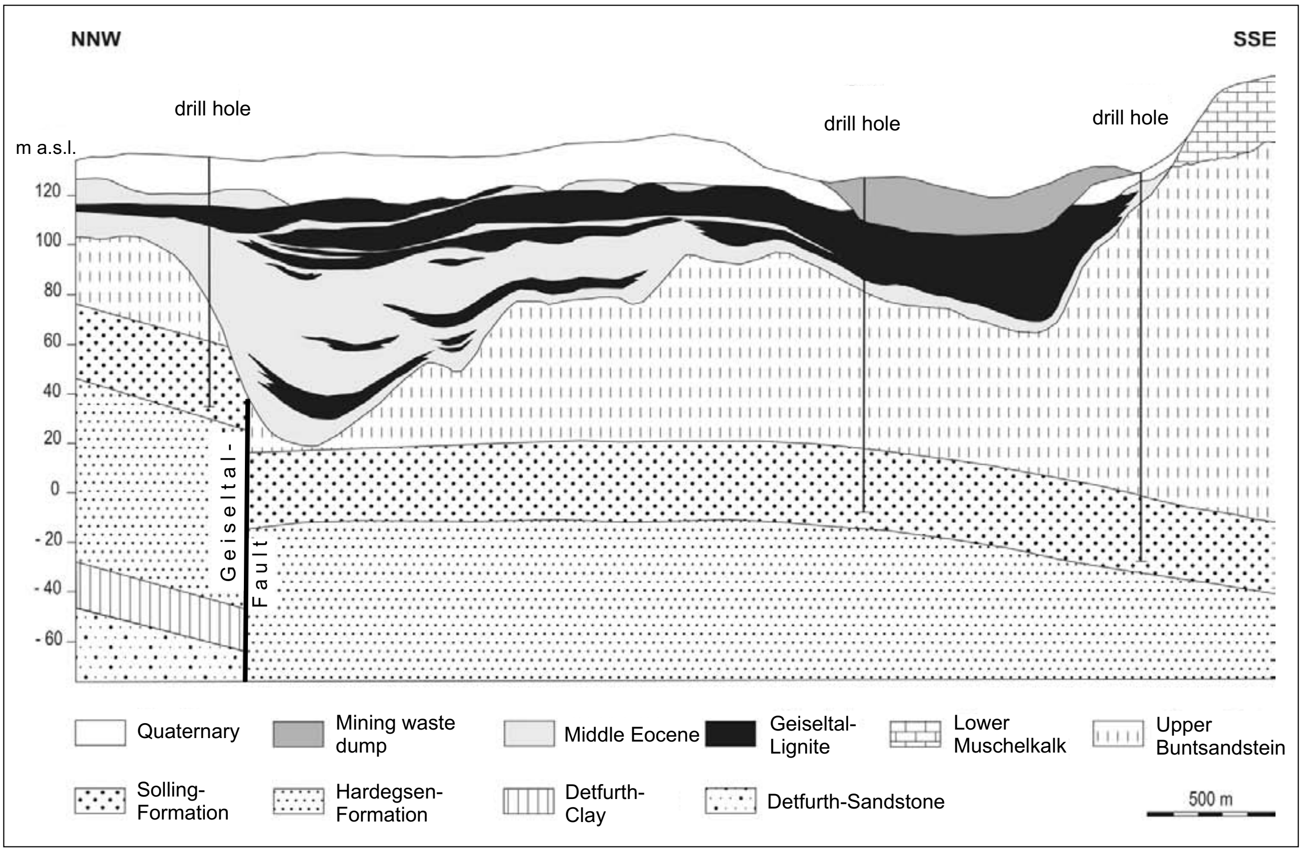

Fig 5: Section across the western Geiseltal (disused opencast mine at Mücheln) (Source: IHU GmbH Nordhausen).

Abb. 5: Schnitt durch das westliche Geiseltal (ehemaliger Tagebau Mücheln) (Bearbeitung: IHU GmbH Nordhausen).

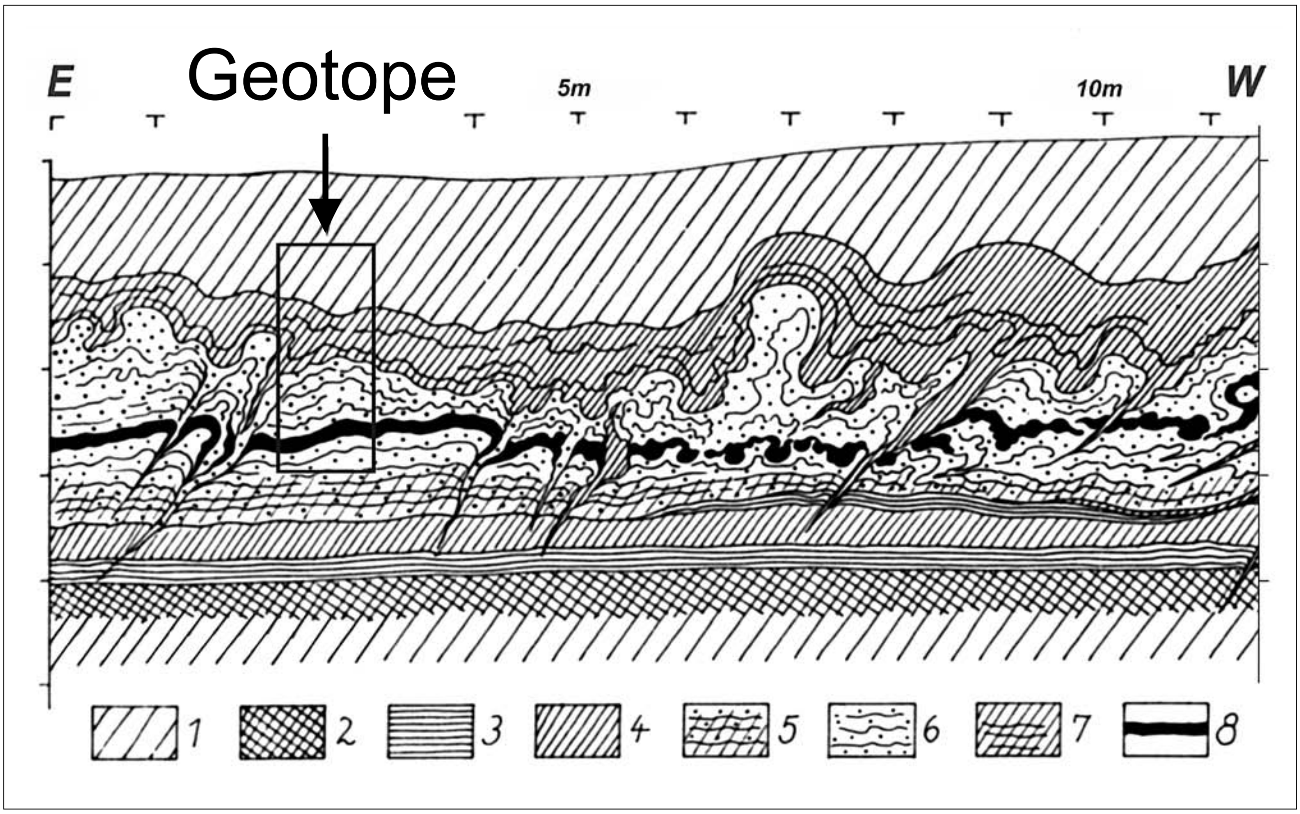

Fig. 6: Late Glacial sedimentary sequence at Krumpa/Geiseltal (after Mania et al. 1993). Legend: 1 – Basin silt; 2 –peaty moulder; 3 - grass, moss and wood peat; 4 – fine detritus mud / clay mud; 5 – alternating layers of fine detritus mud and calcareous mud – Chara sand; 6 – yellowish calcareous mud – Chara sand; 7 – grey-brown clayey silty mud; 8 – Laach Lake tephra.

Abb. 6: Spätglazial von Krumpa/Geiseltal (nach Mania et al. 1993). Legende: 1 - Beckenschluff; 2 - Anmoorboden; 3 - Gras-, Moos- und Holztorf; 4 - Feindetritus-/Tonmudde; 5 - Wechsellagerung Feindetritusmudde und Kalkmudde - Charasand; 6 - gelbliche Kalkmudde - Charasand; 7 - graubraune tonige Schluffmudde; 8 - Laacher-See-Tephra.

Stop 4: Main Unstrut terrace and Karsdorf sands in Karsdorf gravel-sand pit (text after Meng & Wansa 2008)

The approx. 20 m section in the Karsdorf gravel-sand pit on the southwestern slope of the Querfurt Muschelkalk plateau mainly consists of the Main Unstrut terrace and an overlying sequence, previously correlated with the glaciofluvial „Schmon sands“ in the nearby Schmon-Reinsdorf valley in the Northwest (Fig. 7 and 8).

The base of the up to 5 m thick gravel layer of the **Main Unstrut terrace** is at about 115 m asl, i.e., about 3 m above the present Unstrut floodplain. The terrace material consists of fine gravel and sand, in parts displaying distinct cross-bedding patterns. Wüst (1904) already described the frequent occurrence of the river mollusc *Corbicula fluminalis* in a nearby pit of these gravels, which he described as the Karsdorf terrace. Hence, Lehmann (1922) correlated the Karsdorf terrace with the Körbisdorf terrace.

Meng discovered a rich mollusc fauna of approximately 60 species in the Unstrut gravels at Karsdorf (Meng & Wansa 2008). Occurrences in stratified sediments, especially in the south-western part of the pit, showed that *Corbicula fluminalis* was mainly concentrated in the lower and middle sections of the gravel deposits. In a reddish, silty area of the middle section of the gravels, a mass occurrence of the spring snail *Belgrandia germanica*, a warm-stage index species, was noticed. This occurrence included many juvenile shells of *Corbicula fluminalis*, with no signs of shape deformation by transport.

As a whole, the fauna found in the gravels is typical of a continental-type warm stage. In contrast, the mollusc fauna assemblages in the upper gravel sections and at the transition to the overlying sand layers indicate a distinct cooling trend, with typical meadow steppe communities including *Vallonia costata*, *Pupilla muscorum* and *Helicopsis striata*. The data are backed up by mammoth and woolly rhinoceros findings. Cold-stage molluscs such as *Pupilla loessica*, *Columella columella* and *Vallonia tenuilabris* were found in a silt lens in slope detritus at the bottom of the overlying sand layers.

It is important to mention that strongly re-worked and re-deposited remains of the thick-shelled river snail *Theodoxus serratiliniformis* were found in the gravels, because this Middle Pleistocene index species probably represents a phase of the Holsteinian warm stage, whereas *Corbicula fluminalis* probably belongs to a warmer fluctuation in the lower Saalian complex. An additional finding was a shell of *Fagotia acicularis*, revised *Esperiana wuesti* (Meijer 1990), an index species of the Early Pleistocene Fagotia gravels, found in several places in the Unstrut area (Zeissler 1971, Mania 1973). After the occurrence of this snail in the Born valley near Zeuchfeld, this gravel layer containing *Fagotia acicularis* was named the Zeuchfeld terrace (Fritsch 1898, Eissmann 1975). Evidence is thus provided that the Unstrut gravels at Karsdorf include re-deposited material from very

Fig. 7: Karsdorf sands in the gravel-sand pit at Karsdorf, 2009. Photo: S. Wansa.

Abb. 7: Karsdorfer Sande im Kiessandtagebau Karsdorf, 2009. Foto: S. Wansa

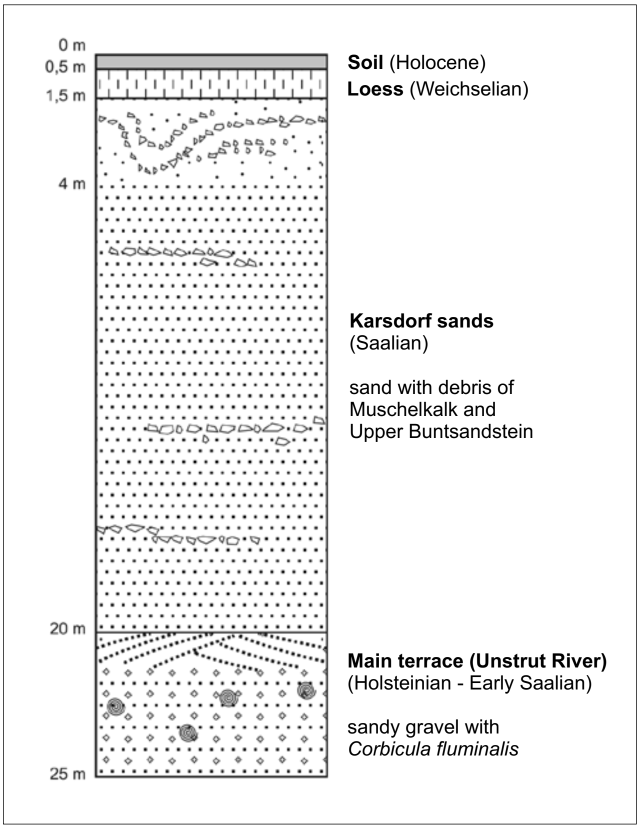

Fig. 8: Schematic section of the gravel-sand pit at Karsdorf (after Meng et al. 2006).

Abb. 8: Schematisches Aufschlussprofil des Kiessandtagebaues Karsdorf (nach Meng et al. 2006).

different gravel levels of the Pleistocene Unstrut River. The composition of the fluvial gravels is typical for the Unstrut River, with high amounts of rock from the Thuringian Forest (porphyry), derived from the Gera/Apfelstädt fluvial system, and of rocks from the Harz Mountains (siliceous shale and greywacke), deposited by the Helme system. The limestone content near Karsdorf is distinctly lower compared to the gravels from the lower reaches of the Unstrut, with their increasingly heavy load of calcareous detritus from the adjacent Muschelkalk slopes.

An indistinct boundary separates the Unstrut gravels from the overlying Karsdorf sands, which have a strong silt component in places, with interspersed layers of fine gravels ("Karsdorf sands" in Fig. 8). They are closely interlocked with debris up to several metres thick, consisting of coarse angular Muschelkalk and Upper Buntsandstein material, documenting accumulation in a cold climate. Up to 3 m wide channels are typical. The landform at the valley edge is recognisable as a delta-like alluvial fan in front of a valley notch in the Muschelkalk escarpment west of Steigra.

Whereas mollusc remains of a meadow steppe fauna occur in the lowest parts of the Karsdorf sands and at the transition to the Unstrut gravels, no faunal remains are known from the middle and lower sections, except for single, strongly reworked fragments of mollusc shells that do not allow for a detailed description.

The Karsdorf sands contain relatively high percentages of Unstrut material (porphyry, siliceous shale, greywacke). In comparison with the Unstrut gravels they have slightly higher proportions of Scandinavian material (crystalline rocks and flint) and contain more carbonates from the adjacent Muschelkalk plateau. It is assumed that the Karsdorf sands represent the interlocking zone between the Unstrut deposits and periglacial, Early Saalian slope sediments, i. e., a marginal facies of the Main Unstrut terrace. Some of the Scandinavian rocks may have been brought in from Elsterian meltwater deposits on the plateau (Wansa & Radzinski 2004). The uppermost parts of the Karsdorf sands, which form the morphologically recognisable alluvial fan, probably developed during Weichselian time; however, no unconformity was observed in the exposure.

Stop 5: Zeuchfeld sandur and Weichselian periglacial features in the gravel-sand pit at Freyburg (text after Meng & Wansa 2008)

The Quaternary section in the Zeuchfeld valley near Freyburg (Unstrut) is composed of an approximately 80 m thick sequence of Middle Pleistocene Unstrut gravels, Saalian ice marginal deposits (basin sediments and valley sandurs) as well as Saalian and Weichselian periglacial deposits with paleosols.

Drillings have shown that the base of the Holsteinian to Early Saalian Main Unstrut terrace lies at about 102 m asl on Lower Muschelkalk. The up to 5 m thick, sandy, partially silty gravel body comprises mainly limestone pebbles, with secondary occurrence of Thuringian porphyry and quartz. The Unstrut gravels in the Geiseltal area consist of 75 % Muschelkalk, 11 % quartz and up to 10 % porphyry from the Thuringian Forest (Lehmann 1922, Laurat et al. 2006).

The river gravels are overlain by glaciolimnic basin sediments, considered to be equivalent to the Böhlen-Lochauer varved clay of the Zeitz phase (Eissmann 1975). According to available core data, the lower, thicker section of these up to 45 m thick sediments is composed of clayey, partly finesandy silt, locally varved at the base. The uppermost max. 10 m consist of quartz-rich, silty fine sand or sandy silt, interlocked with the overlying sand and pebbles of the Zeuchfeld sandur. The up to 30 m thick valley sandur (about two thirds of which were exposed during our 2001–2002 fieldwork) is heterogeneous in composition. Yellowish grey, calcareous medium and fine sand with silt and pebble layers predominates. The middle section of the eastern part of the pit shows a higher proportion of pebbles, which probably represent the greatest proximity to the ice margin (proximal facies). The lateral change in the grain-size composition of the sandur was already described by Ruske (1961): the sandur was deposited in a WSW direction, the end farthest from the ice being almost exclusively composed of medium sand, whereas pebbles predominate near the ice margin.

The composition of the Zeuchfeld sandur is very similar to that of the Main Unstrut terrace. The sandur contains about 70 % Muschelkalk material and many Thuringian rocks, probably partially originating from the widespread Unstrut gravels of the old valley (Ruske 1961). Scandinavian material is only of minor importance in the Zeuchfeld sandur.

Findings of mollusc remains provide additional evidence of the input of Unstrut material. Shell fragments of snails and bivalves are distributed regularly across the sandur section. More complete snail and bivalve remains less abundant. The many fragments are only partly identifiable, for instance if the surface structure is well preserved. About 20 species were identified in the middle part of the sands. Some of these are important species, permitting a detailed biostratigraphic classification of their host sediments. The thick-shelled river snail *Theodoxus serratiliniformis* is relatively frequent. This is an index species for a warm stage, probably the Holsteinian. *Corbicula fluminalis* is a freshwater mollusc characteristic for the Middle Pleistocene "Corbicula gravels" deposited during a warm fluctuation of the early Saalian (Mania & Mai 2001). The peak warm-stage species *Drobacia banaticum* and *Aegopis verticillus* were also identified. Cold-stage species tend to be under-represented, possibly because they generally have small, fragile shells that are less frequently preserved than some more robust shells of warm-stage species. One example of the former is *Vallonia tenuilabris*. Overall, mollusc fauna assemblages represent several phases of the Mid-Pleistocene, all of which were identified in the area of the Main Unstrut terrace or the Körbisdorf terrace (cf. Lehmann 1922, Mania & Mai 2001).

Up to the mid-1980s and especially in the 1950s and 1960s, many vertebrate remains were found in the Zeuchfeld sandur, some of which are shown in the museum at Schloss Neuenburg near Freyburg. They include mammoth *Mammuthus primigenius* (Blumenbach 1799), reindeer *Rangifer tarandus* (Linnaeus 1758), horse *Equus caballus* Linnaeus 1758, woolly rhinoceros *Coelodonta antiquitatis* (Blumenbach 1799), musk ox *Ovibos moschatus* (Zimmermann 1780), saiga antelope *Saiga tatarica* (Linnaeus 1766) and bovid remains. The discovery of the right horn core of a saiga antelope is especially well known (Töpfer 1964). It is one of the oldest findings worldwide (Kahlke 1990, 1992).

The basin sediments and the sandur were formed by stagnating ice or its meltwater during the Saalian maximum stage (Zeitz phase or first Saalian ice advance in Central Germany, Eissmann 1975, 1997). At that time, the Holsteinian to early Saalian Unstrut valley was infilled. The valley sandur measures about 3 km from West to East and about 1.5 km from North to South (Ruske 1961). However, glaciofluvial sand and pebbles overlying the Unstrut gravels may be traced as far as the Geiseltal margin (Steinmüller 1980), so it may be assumed that the valley still acted as a meltwater channel during the first melting phase of the maximum stage and/or during the Langeneichstädt ice marginal position.

The periglacial sediments covering the sandur are up to more than 10 m thick and consist of a sequence of debris flow material and loess including various paleosols (Meng 2002, 2003, Fig. 9).

The sandur is directly overlain by an up to 2 m thick Saalian debris flow with a high proportion of loess containing mollusc fragments (*Succinella oblonga* and *Pupilla loessica*) of a pleniglacial fauna, comparable to a loess fauna. During the Eemian warm stage a Luvisol formed on the debris flow material. The soil is overlain by two colluvial Phaeozem-type soils (1–2 % humus contents) of the early Weichselian cold stage. This complex soil succession from the Eemian to the Early Weichselian has been termed the Naumburg soil complex (Ruske & Wünsche 1961, 1964). The overlying, about 4 m thick Weichselian debris flow material with broad grain-size range similar to a boulder clay, contains additional weak humus accumulation horizons, the correlation of which to the so-called Kösen loamification zone (Ruske & Wünsche

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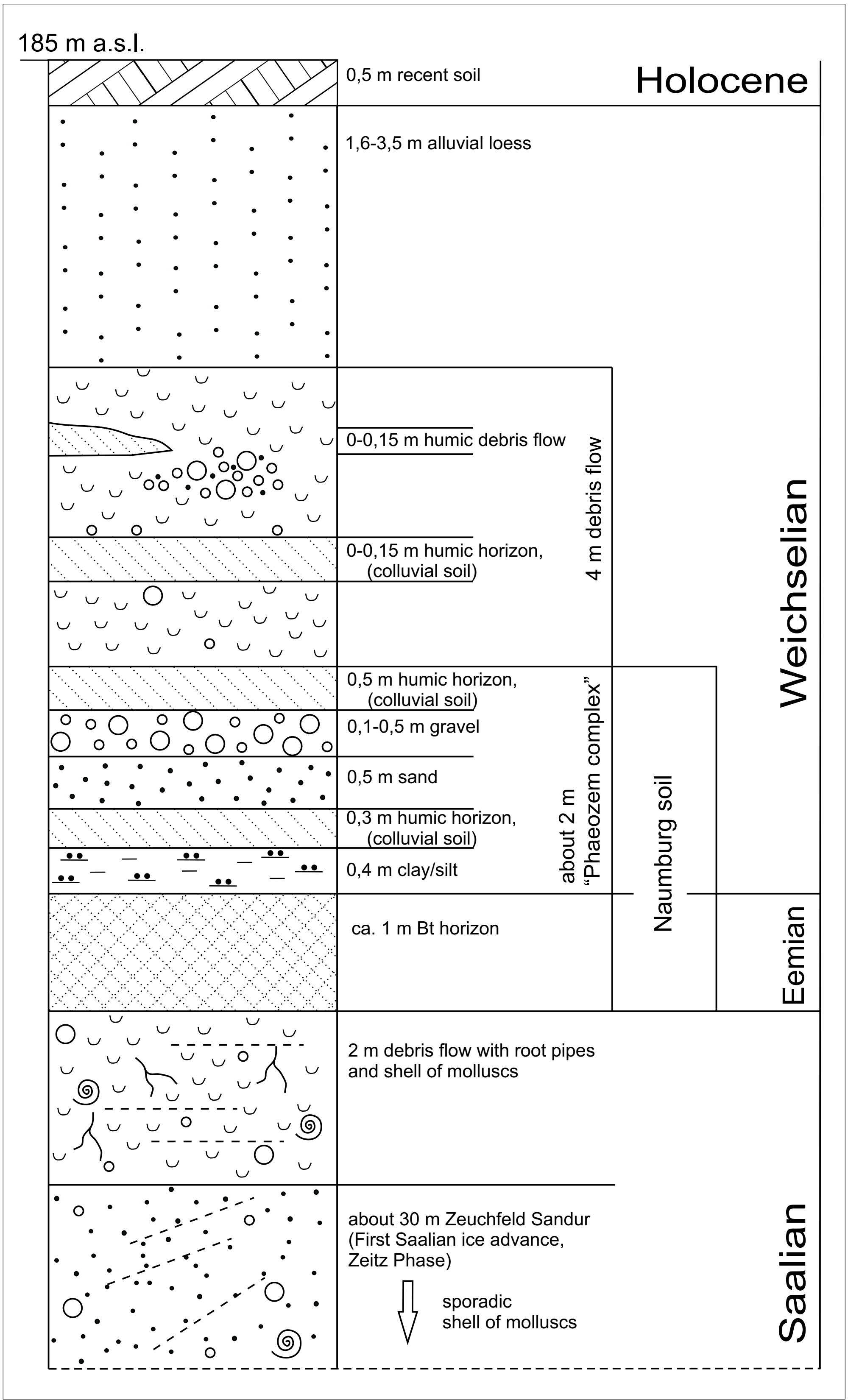

Fig. 9: Section in the eastern part of Freyburg gravel-sand pit (after MENG 2003).

Abb. 9: Aufschlussprofil im Ostteil des Kiessandtagebaues Freyburg (nach MENG 2003).

1961) could not be settled definitively (cf. HAASE et al. 1970). The section ends with Weichselian alluvial loess.
The composition of both debris flow deposits is relatively similar, with high proportions of limestone (Muschelkalk), quartz and porphyry. Limestone is more dominant in the lower debris flow deposit, while the percentage of quartz is somewhat lower. The porphyries largely originate from the Thuringian Forest and suggest an increased redeposition from the Main Unstrut terrace or the Zeuchfeld sandur. Crystalline rock and flint were probably derived primarily from nearby Saalian till. There are various possible sources of the quartz rocks, e.g., the quartz-rich meltwater pebbles of the Langeneichstädt ice-margin position.

Stop 6: Main Saale terrace and alluvial loess at the Markwerben Geotope in the Dechant-Fabig market garden, 06667 Markwerben, Salpeterhütte 9

The about 50 m long and max. 5 m high section is located on the north-western slope of the Saale valley, about 8 to 13 m above the floodplain, at 106–111 m asl. The lower part consists of pale, cross-bedded medium sand, with some areas of coarse sand and fine pebbles. It belongs to the weathering horizon of the Thuringian Chirotherium sandstone of the Solling formation of the Middle Buntsandstein. Above a stratigraphic gap of more than 240 million years follows, with a sharp boundary, the Main Saale terrace, the most distinctive component exposed in the geotope (Fig. 10). Owing to subsequent erosion, the gravel layer is only up to about 2 m thick, but at Weißenfels it reaches a thickness of more than 8 m. The terrace sediments consist of coarse to medium sized pebbles with many boulders and a sandy matrix, including many rock fragments (autochthonous sandstone and Scandinavian crystalline rock) with edges longer than 20 cm, at most 40 cm. The pebbles are often flat shaped and horizontally bedded, sometimes overlapping like roofing tiles. The gravel body is calcareous throughout, and its ochre colour is due to strong iron hydroxide precipitation.

Most of the Main terraces of the Central German rivers were built up in the lower part of the Saalian complex in the Middle Pleistocene. Their composition reflects the Saale catchment at that time: The dominant rock is limestone from the nearby Muschelkalk area, followed by rocks from the Thuringian Slate Mountains (quartzite, greywackes, clay shale, phyllite, siliceous shale). Most of the quartz also originates from here. The porphyries were transported from the Thuringian Forest via the Ilm River. The Scandinavian material is derived from Elsterian meltwater sands and tills.

Tills and meltwater sediments have been found at many locations in the vicinity of the geotope. However, they are absent in the geotope section, so that the terrace is sharply overlain by alluvial loess from the Last Glacial period. The originally wind-transported, slightly sandy silt was subsequently re-deposited by flowing water and exhibits a partly wavy, horizontal bedding marked by a change in material and colour. A conspicuous feature is a large, elongated pebble cluster of re-deposited Main terrace material.

Quaternary fluvial history of the Saale and Unstrut Rivers

The Naumburg–Weißenfels area contains gravel terraces of the Saale River from different sub-stages of the Quaternary (Siegert & Weissermel 1911) (Fig. 11). They occur at different elevations, and their petrographic composition sometimes differs. Here, at the transition from uplands to lowlands, erosion generally outweighed deposition. Hence, the oldest terrace is the highest at 170–180 m asl, and the youngest terrace is only slightly above the floodplain with its base at below 90 m asl. At the geotope, the base of the Main terrace is about 10 m above the floodplain, at 107–108 m asl.

During the Lower Pleistocene the Unstrut River flowed from Freyburg through the Zeuchfeld valley towards Merseburg, accumulating the Zeuchfeld terrace. It contains limnic-fluvial deposits comprising a rich mollusc fauna. More than 70 species also include Pontic-Balkan elements (*Fagotia acicularis, Valvata naticina, Lithoglyphus pyramidatus*) (Fritsch 1898, Ruske & Wünsche 1964, Zeissler 1971). Because of the terrace's position in the Saale-Unstrut system, it should probably be assigned to the Tegelen or the Waal complex.

Whereas generally only remnants of the pre-Elsterian fluvial sediments are preserved, many occurrences of Early and Late Elsterian gravel deposits show that the Saale flowed through the Markröhlitz valley during the Elsterian cold stage. At that time, the Unstrut merged with the Ilm and then discharged into the Saale River near Freyburg (Leh-

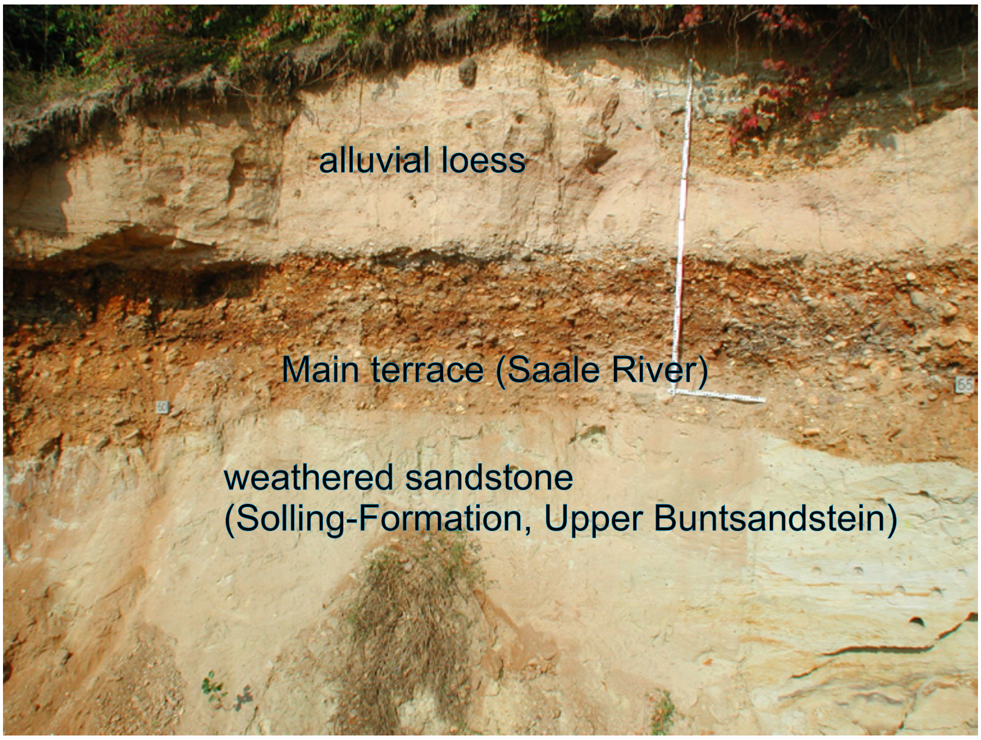

Fig. 10: Markwerben Geotope. Photo: S. Wansa.
Abb. 10: Geotop Markwerben. Foto: S. Wansa.

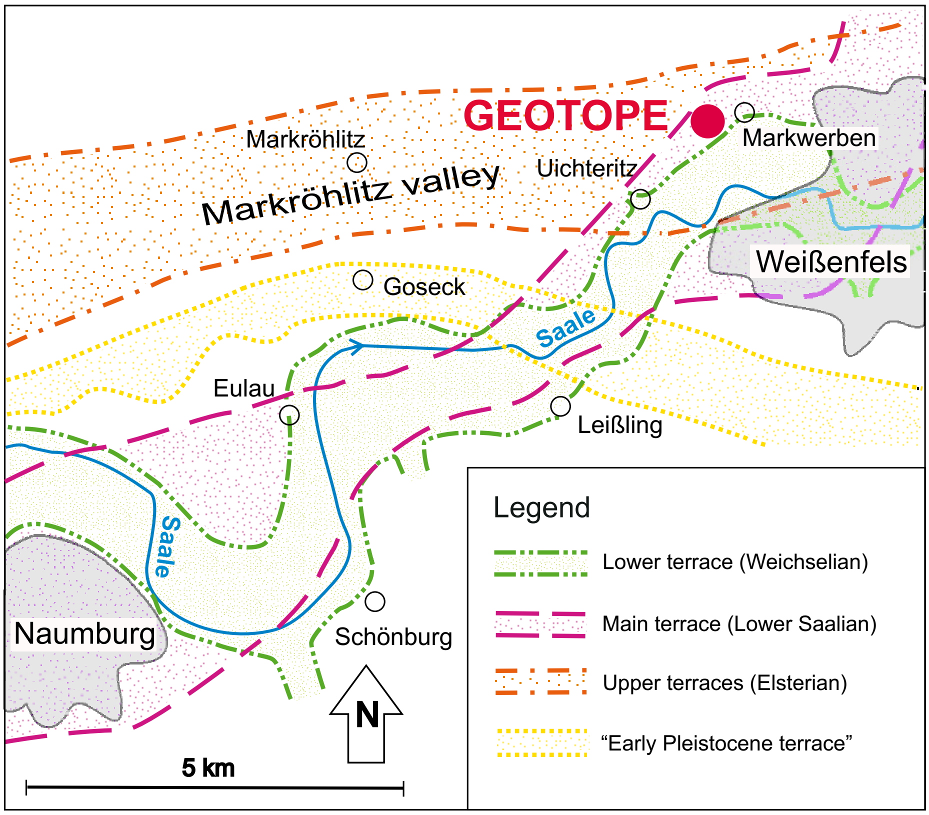

Fig. 11: Pleistocene river history of the Saale and Unstrut in the Freyburg-Naumburg-Weißenfels area (compiled by Meng & Wansa 2005).

Abb. 11: Pleistozäne Flussgeschichte von Saale und Unstrut im Raum Freyburg–Naumburg–Weißenfels (zusammengestellt von Meng & Wansa 2005).

mann 1922, Schulz 1962, Meng & Wansa 2005). The Elsterian glaciation was followed by a re-organisation of the river system. Since the Holsteinian warm stage, the Saale River has been using its present valley, and the Unstrut River has been flowing from Freyburg through the Zeuchfeld valley towards Geiseltal, reaching the Saale River near Merseburg. The extensively preserved Main terrace gravels of the Saale and Unstrut Rivers are evidence of this fluvial history. Large parts of Naumburg and the Weißenfels area North of the Saale River are located on the Main Saale terrace. In Geiseltal the Unstrut and Geisel Rivers deposited Holsteinian to early Saalian Körbisdorf gravels (Lehmann 1922).

After infilling of the valley with sediments related to the Saalian continental ice sheet and subsequent renewed incision, the river system finally attained its present shape. After the Zeuchfeld sandur was deposited during the Zeitz phase of the Saalian glaciation, the Zeuchfeld valley was infilled, preventing the Unstrut River from flowing to Merseburg. The Unstrut River shifted its channel southeastward and since then discharges into the Saale at Naumburg. The lower terraces formed during the Weichselian cold stage and were widely covered by floodplain sediments during the Holocene.

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Excursion E

Quaternary valley and slope development in the headwaters of the River Main, Upper Franconia – puzzling ancient stream courses and sedimentary archives

Ludwig Zöller, Ulrich Hambach, Arno Kleber, Thomas Kolb, Olivier Moine

Itinerary:

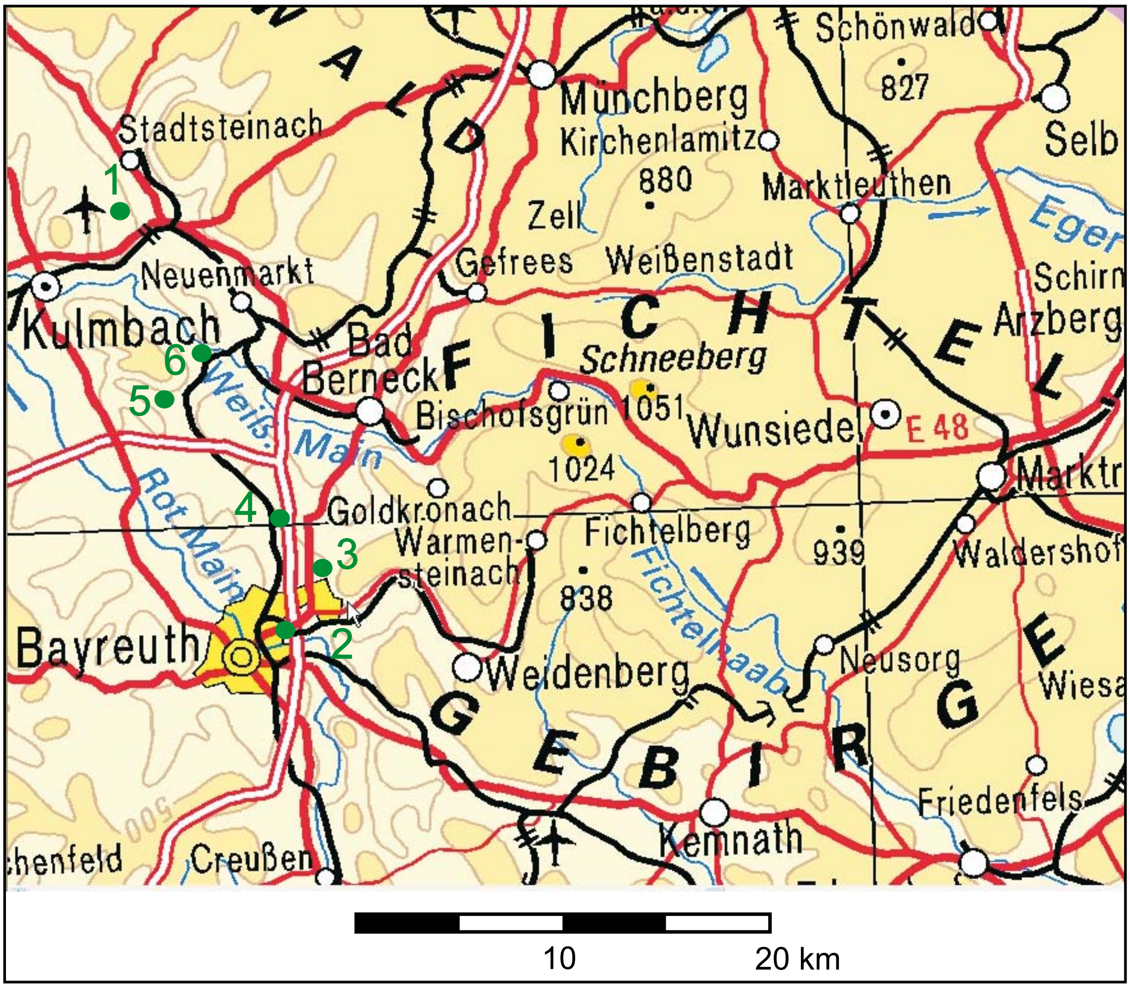


Fig. 1: Excursion route and stops 1–6 (in green) in the Western foreland of the Variscian Massifs "Frankenwald" (northeast of stop 1) and "Fichtelgebirge". Stop 1: "Espich" site northeast of the city of Kulmbach; Stop 2: Small exposure in the T2 terrace at the A9 motorway at the suburb Bayreuth-Laineck; Stop 3: Exposure in the T3 terrace at the village Bindlach, north of Bayreuth; Stop 4: Road-cut at the locality "Eckershof" near the village Crottendorf, north of the village Bindlach; Stop 5: Lindau Moor, east of the village Lindau; Stop 6: Cellar in the "Trebgast Sandstone", Haberstumpf-Brewary at the village Trebgast. Source of cartography: DTK50 © Bayerische Vermessungsverwaltung 2011.

Abb. 1: Exkursionsroute und Haltepunkte 1–6 (grün) im westlichen Vorland der Variszischen Gebirge „Frankenwald" (nordöstlich von Haltepunkt 1) und „Fichtelgebirge". Stop 1: „Espich" nordöstlich von Kulmbach; Stop2: kleiner Aufschluss in der T2-Terrasse an der Autobahn A9 bei Bayreuth-Laineck; Stop 3: Aufschluss in der T3-Terrasse bei Bindlach, nördlich von Bayreuth; Stop 4: Straßenanschnitt an der Lokalität „Eckershof" bei Crottendorf, nördlich von Bindlach; Stop 5. Lindauer Moor, östlich von Lindau; Stop 6: Keller im „Trebgaster Sandstein" Brauerei Haberstumpf in Trebgast. Kartographische Quelle: DTK50 © Bayerische Vermessungsverwaltung 2011.

Introduction

The excursion starts near the village Stadtsteinach in the western foreland of the Variscian "Franconian Forest", then continues near the city of Bayreuth and ends at Trebgast, North of Bayreuth (Figure 1).

Geological setting

The main geological feature of the excursion area is the NW-SE striking "Franconian Lineament", a tectonic fault (indicated as "Bruchschollenland" in Figure 2), separating the Bohemian Massif in the northeast from the Southern German Block covered by thick (>1,000 m) Mesozoic sediments. The main activity phases of the Fanconian Lineament occurred during the Lower Triassic and Upper Cretaceous. The Bohemian Massif was uplifted by several km along overthrust zones and flexures. Crustal stacking, so far known only from subduction or suture zones, is evident along the Franconian Lineament (Coyle et al. 1997, Duyster et al. 1995) in an intra-plate tectonic setting. The Upper Cretaceous to Lower Tertiary tectonic activity also affected a band of several km width in the western foreland of the lineament leading to more or less parallel NW-SE striking, often antithetic block faulting of the Mesozoic rocks and their Variscian basement. Since the Upper Oligocene, intra-plate volcanism occurred along the Eger Rift and the Franconian Lineament (Pöllmann & Peterek 2010, Peterek & Schunk 2008).

Geomorphological setting

The evolution of the River Main since the onset of the Neogene has been most puzzling and has kept busy numerous geologists and geomorphologists. The primal Main river course can be roughly reconstructed between the Franconian Forest, a part of the Variscian orogen in Northern Franconia, and the Molasse Basin in the Northern Alpine Foreland. This river system was initially established on a south-dipping peneplain cutting rocks from Palaeozoic to Upper Cretaceous age. The prominent cuesta of the Upper Jurassic limestone plateau was already present in the South of the "Franconian Alb" before the Miocene "Ries Event" (meteorite impact 14.7±0.1 Ma ago, Di Vincenco & Skála 2009), whereas in the North (Upper Franconia) the peneplain may have persisted to the Pliocene and cuestas were carved out of it by erosion only afterwards. Due to subsidence of the Upper Rhine Graben and the more or less coeval downstream prolongation of the Danube River the present staggered river course of the Main River developed stepwise by headwater erosion and river deflections until the Quaternary (Eberle et al. 2007, Schirmer 2010). The European watershed between the Rhine River (tributary to the North Sea) and the Danube catchments (tributary to the Black Sea) moved eastward and southward, leaving behind a very irregularly organized drainage system and course of the European watershed in Franconia (Büdel 1957). Some former Upper Fanconian river courses proposed in the older literature are summarized by Hüser (1986, see Figure 3). The easternmost branch (primal Naab River) of the depicted river system in Figure 3, originating from the Franconian Forest, was not confirmed in recent studies (see Zöller et al. 2007) as for its part in north-western prolongation of the Heidenaab River. Schirmer (2010) called the south-directed primal Main River course "Moenodanuvius" (Main-Danube River, see Figure 4) and distinguished it from the primal Main River directed towards the Rhine River. He was able to depict several headwaters of the Moenodanuvius River in Upper Franconia based on indicator pebbles and geomorphologic analysis (Figure 4). He dated the termination of the Moenodanuvius River to the end of the Pliocene. At the onset of the Lower Pleistocene, the present-day catchment of the Main River reaching eastward to the Franconian Forest and the adjacent mountains called Fichtelgebirge was more or less

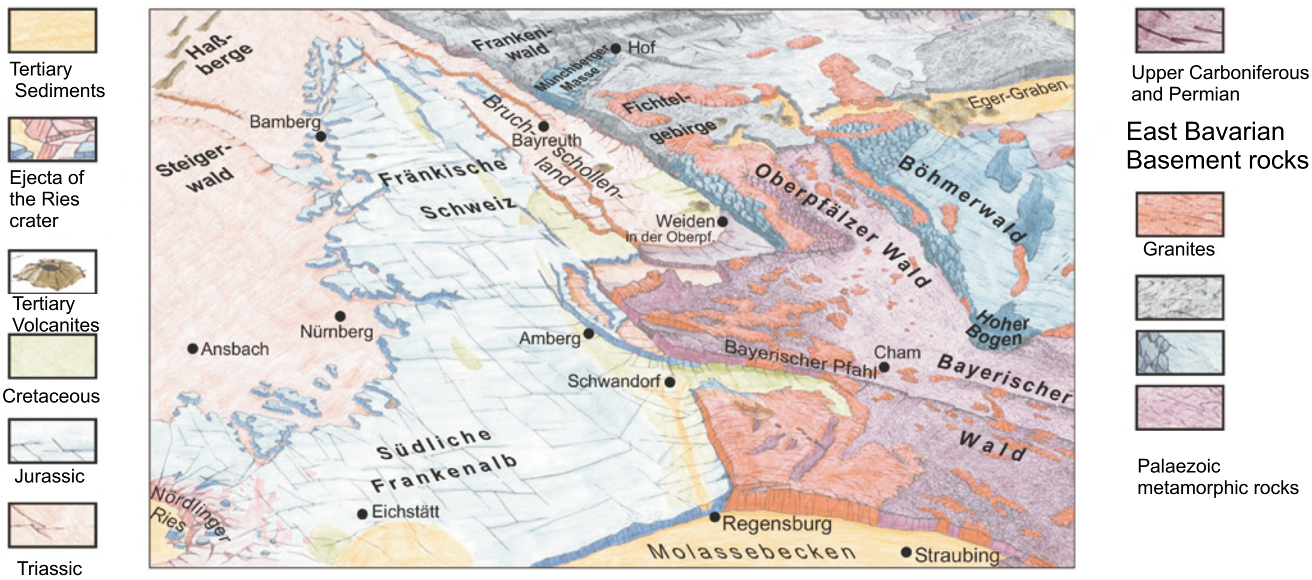


Fig. 2: The Franconian Lineament ("Fränkische Linie") separates the Variscian Western Bohemian Massif in the Northeast from the Mesozoic sedimentary rocks in the Southwest. Along a band parallel to the Franconian Lineament the Mesozoic layers are affected by block faulting and overthrusts ("Bruchschollenland"). The Upper Jurassic plateau ("Fränkische Schweiz") forms a slight syncline and is thus bordered by cuestas towards the West and towards the East (source: www.lfu.bayern.de/veranstaltungen/doc/ausstellung_geologische_wanderung_2.pdf).

Abb. 2: Die „Fränkische Linie" trennt die variszische westliche Böhmische Masse im Nordosten von mesozoischen Sedimentgesteinen im Südwesten. In einem Band parallel zur Fränkischen Linie sind die mesozoischen Gesteine von Störungen und Aufschiebungen verstellt („Bruchschollenland"). Das Plateau des oberen Juras („Fränkische Schweiz") bildet eine leichte Synklinale und wird daher nach Westen wie nach Osten durch Schichtstufen begrenzt. (Quelle: www.lfu.bayern.de/veranstaltungen/doc/ausstellung_geologische_wanderung_2.pdf).

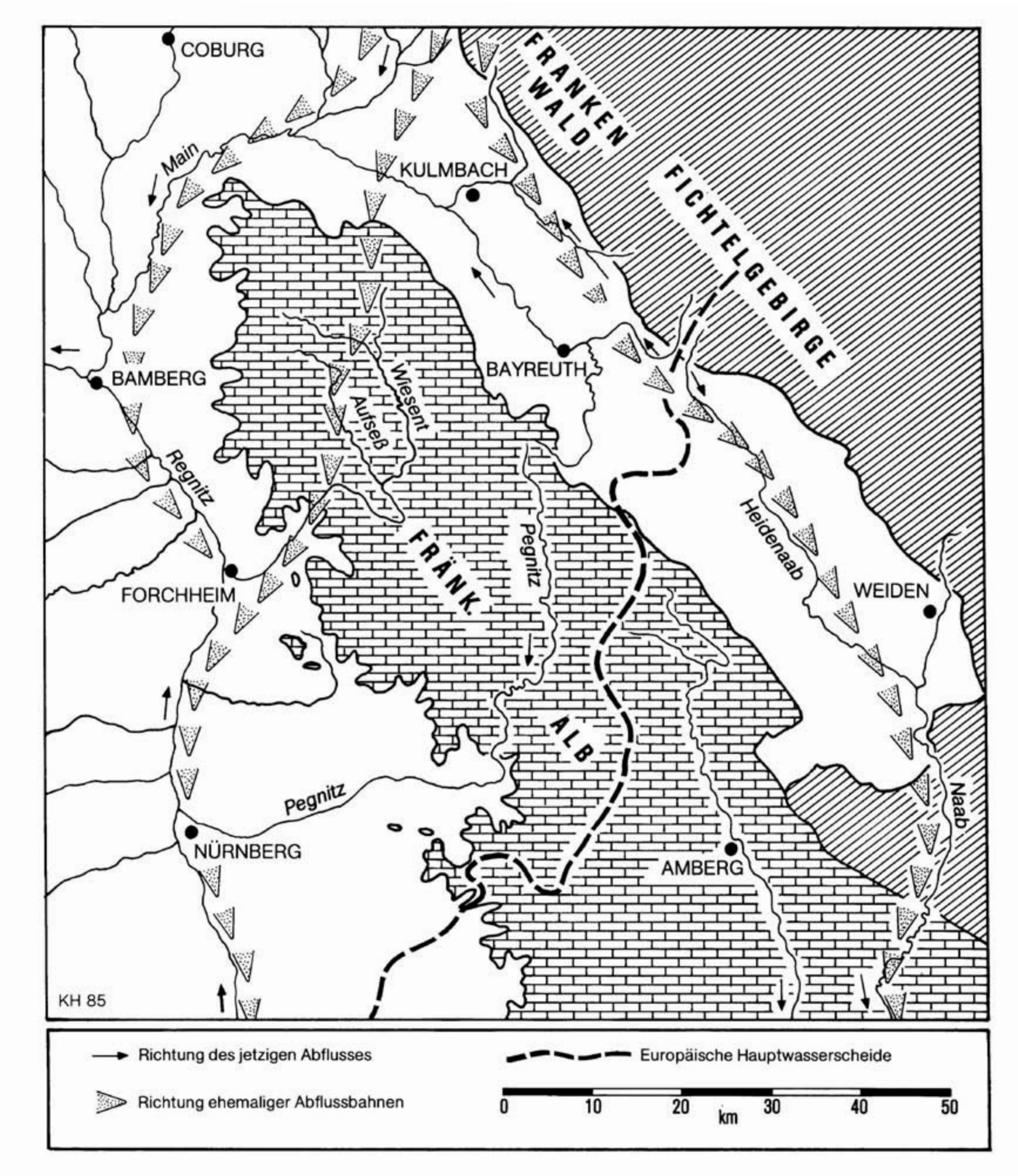


Fig. 3: Supposed Tertiary river courses in north-eastern Bavaria compiled by K. Hüser (1986, from Zöller et al. 2007). Hatched area: Western Bohemian Massif; area with rectangular signature: Upper Jurassic Plateau; broken double line: European watershed; thin arrows: present-day drainage directions; thick arrowheads: directions of former drainage systems.

Abb. 3: Vermutete tertiäre Flussläufe in Nordost-Bayern, zusammengestellt von K. Hüser (1986, aus Zöller et al. 2007). Schraffiert: Westliche Böhmische Masse; Rechtecke: Plateau des Oberen Jura.

achieved. Only the uppermost headwaters of the "Warme Steinach" River originally flowed to the Naab River system and were deflected to the Main River during the Lower Peistocene (Zöller et al. 2007).

The latest river deflections are found in Upper Franconia in the vicinity of the city of Bayreuth. Even after the overall establishment of the Rhine-tributary drainage system of the Main River with its two frontal flows "White Main" (Weißer Main) and "Red Main" (Roter Main, the latter flowing through the city of Bayreuth), river deflections of second order occurred. They affected the Red Main River and its tributary "Warme Steinach" today ending in the Red Main River at an eastern suburb of Bayreuth[1]. As a result of these Middle to Upper Pleistocene deflections, an oversized valley ("Trebgast valley") north of Bayreuth with an extremely flat valley floor divide was left behind which has well preserved Pleistocene fluvial terraces and post-deflective alluvial, biogenic and slope sediments as archives of landscape development. Although the evolution of the Trebgast valley has been disputed among geoscientists for almost 100 years (Reck 1912, Henkel 1919) only recently was finally demonstrated that both rivers, the Red Main and the Steinach, formerly flowed through this valley and were deflected at different times (Kleber & Stingl 2000, Zöller et al. 2007). The timing of the two deflections has, however, so far only been approached by morphostrati-graphic evidence and still lacks numerical dating. The dating of the youngest deflection

[1] Note that another small river called „Steinach", coming from the Franconian Forest flows into the White Main River upstream of the city of Kulmbach, north of Bayreuth. In the following the "Warme Steinach" is labelled Steinach only.

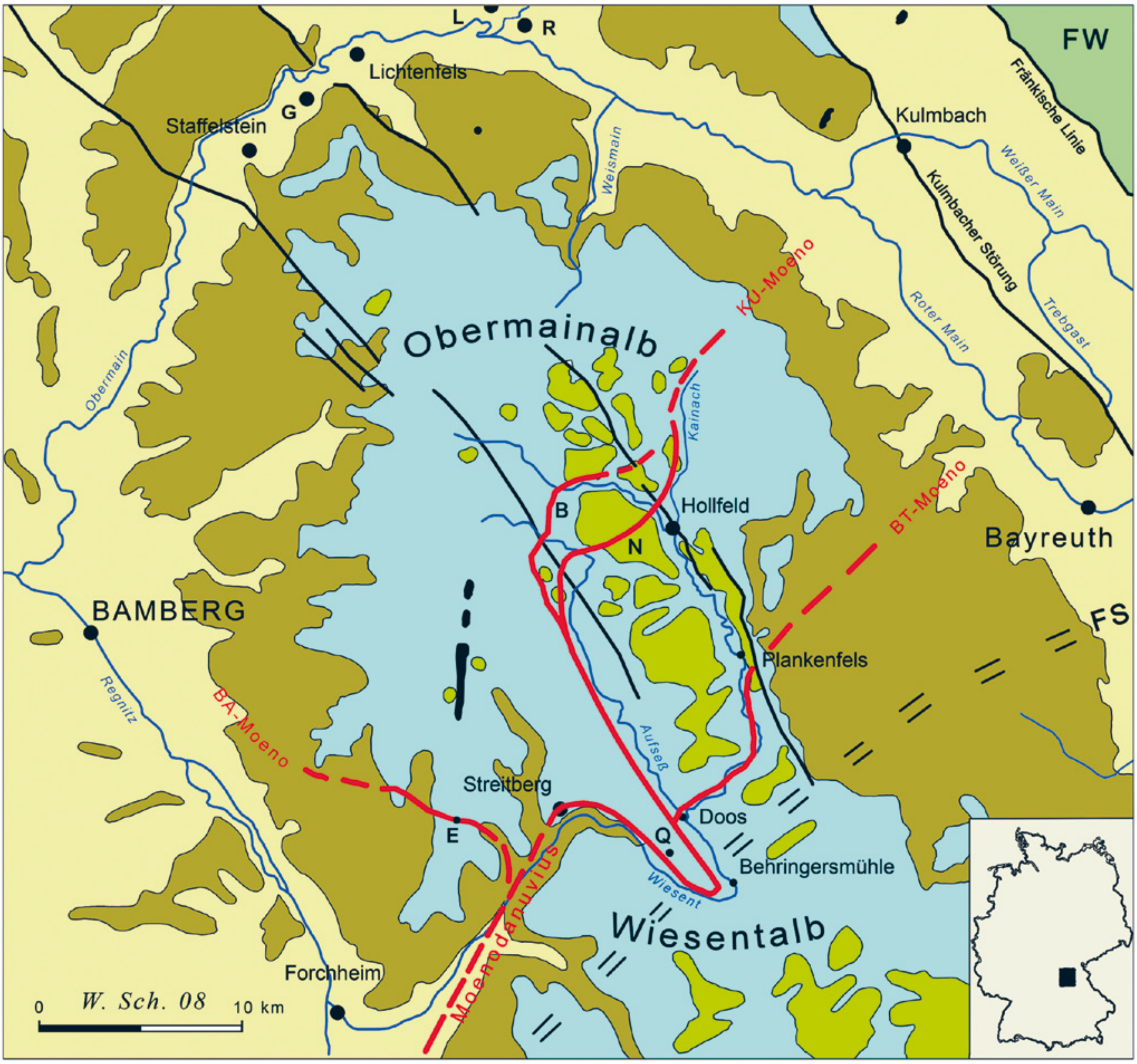


Fig. 4: Headwaters of the "Moenodavius" River in Upper Franconia (from SCHIRMER 2010, with kind permission from the author). Blue: Upper Jurassic Plateau; olive: Middle and Lower Jurassic; dull yellow: Keuper; light green: Upper Cretaceous sandstone; black: Tertiary basalts; FW: Franconian Forest.

Abb. 4: Quellflüsse des "Moenodanuvius"-Flusses in Oberfranken (aus SCHIRMER 2010, mit freundlicher Genehmigung des Autors). Blau: Plateau des Oberen Jura; Oliv: Mittlerer und Unterer Jura; Blassgelb: Keuper; Hellgrün: Oberkreide-Sandstein; Schwarz: Tertiäre Basalte; FW: Frankenwald.

is of particular interest in order to unravel post-deflective sedimentary and environmental archives.

Stop 1: Tertiary gravel of the Espich site northeast of Kulmbach

The site is located on an elongated ridge of Middle Triassic Limestone (Oberer Muschelkalk, mo_2) close to the Franconian Lineament which can be clearly detected by its eye-catching geomorphology. Despite this, there is no clear evidence of neotectonic (Neogene) block faulting at this site. If at all, it cannot exceed ca. 40 m, and the escarpment along the Franconian Lineament is rather explained as a fault line scarp due to erosion of the soft Upper Triassic (Keuper) layers outcropping in the direct foreland of the lineament.

Gravel, clayey sand and clay cover the erosional surface of the mo_2-limestone and dolomite at elevations between 470 m and 510 m a.s.l. The so far explored thickness is minimum 6.5 m (Figure 5). The sediments were studied and sampled in two dredge-holes by DREXLER (1980). 60–70 % of the gravel fraction consists of Palaeozoic (Silurian and Devonian) lydites and radiolarites originating from the nearby Franconian Forest. The clay fraction is dominated by kaolinite (50–55%) and contains in addition illite/vermiculite mixed layer minerals (1–14 Å, 10%), vermiculite (10%) and quartz (5%), pointing to tropoid weathering favouring desilification in a humid and warm environment in the source area of the sediments prior to erosion. Sedimentation occurred, however, under warm and arid climate with discontinuous fluvial transport (DREXLER 1980).

An erosional discordance (etchplain) between the Triassic limestone (mo_2) and the fluvial sediments was ranged as "post-basaltic" by DREXLER (1980). Despite some already published older K/Ar-ages many geologists still believed in

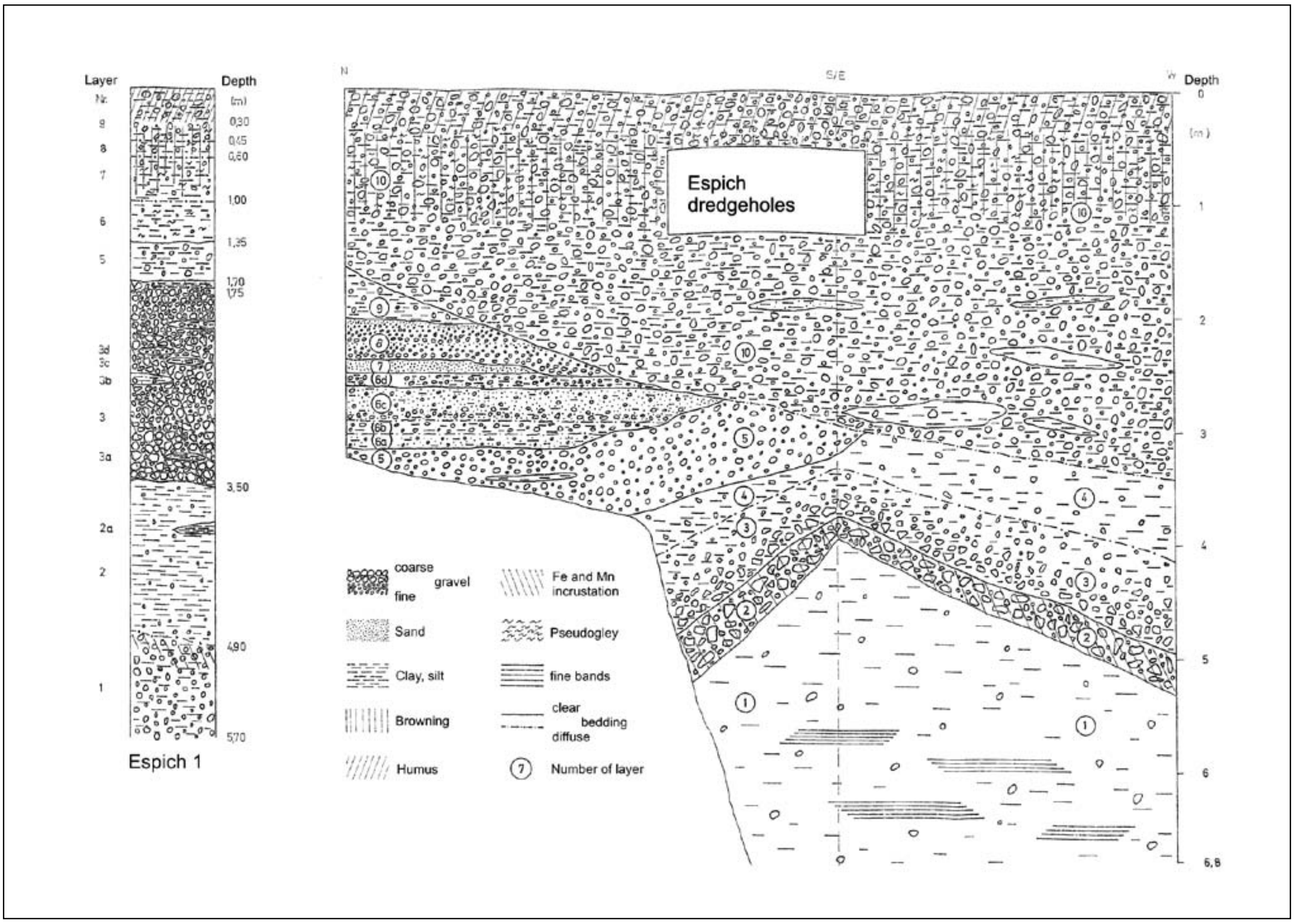


Fig. 5: Stratigraphy of dredgeholes at the Espich site (adopted from Drexler 1980).

Abb. 5: Stratigraphie der Baggerlöcher an der Lokalität „Espich“ (aus Drexler 1980, verändert).

a Lower Pliocene age of the Tertiary volcanism in the Eger rift and its surroundings. Thus, Drexler tentatively dated the fluvial sediments at the Espich site as Upper Pliocene. Since the Upper Oligocene to Lower Miocene age of this basaltic volcanism was confirmed by Ar/Ar datings (Horn & Rohrmüller 2005, see also compilation of numerical ages in Pöllmann & Peterek 2010) there is no more convincing argument for an Upper Pliocene age of the Espich gravel, but a Lower to Middle Miocene age appears reasonable, because lydites from the Franconian Forest are found in deltaic sediments of "Lake Rezat-Altmühl" (SW Franconia) which was dammed by ejecta of the Ries Event. The Moedodanuvius fluvial system existed, thus, already prior to the Ries Event (Schirmer 2010, see Figure 6). The Espich site is a key site to reconstruct the general course of the Moenodanivus River which was completely different from the Quaternary course of the Main River.

Stop 2: Bayreuth-Laineck, deflection of the Warme Steinach River

The stop is situated at the upper edge of the Trebgast valley. Five Quaternary terraces (T1–T5 from younger to older) were mapped in the Trebgast valley and in the valley of the Red Main River (Figure 7). The site with a small outcrop of terrace gravel overlying Upper Triassic (Middle Keuper) sandstone is located on the very broad T2 terrace which bends from the Steinach valley north into the Trebgast valley. A steep ca. 15 m high slope leads down to the Red Main River. The present-day confluence of the Steinach River into the Red Main River is situated a few hundred m upstream. The geomorphologic setting indicates that during sedimentation of the T2 terrace the Steinach River turned north into the present-day Trebgast valley. The T1 is not developed in this part of the Trebgast valley but appears only downstream of the village of Harsdorf (see Figure 13). The extension of the motorway A9 in 2004 and 2005 exposed the T2 terrace in the Trebgast valley over a distance of several hundred meters. Qualitative petrographic gravel analyses of the terrace deposits proved that more than 90% of the gravel (>2cm) originates from metamorphic and plutonic rocks in the catchments of the Steinach River (Table 1 and Figure 8). It must be taken into account that in the upstream catchments of the Red Main River only soft rocks exist, with the exception of Middle Jurassic (Dogger) iron sandstones (limonite crusts), which were not found, however, in the investigated exposure at the motorway (see Table 1 and Figure 8; most of the mentioned 3% of sandstones are different from the Dogger limonite crusts). Even if a few specimen of Middle Jurassic sandstone gravel can be found in the small present-day outcrop very close to the Red Main River, the counting results in Table 1 clearly demonstrate that the T2 in the Trebgast valley was deposited by a primal Steinach River and not by the Red Main River although the Trebgast valley extends in the direction of the upstream Red Main valley. This surprising result leads to the conclusion that at

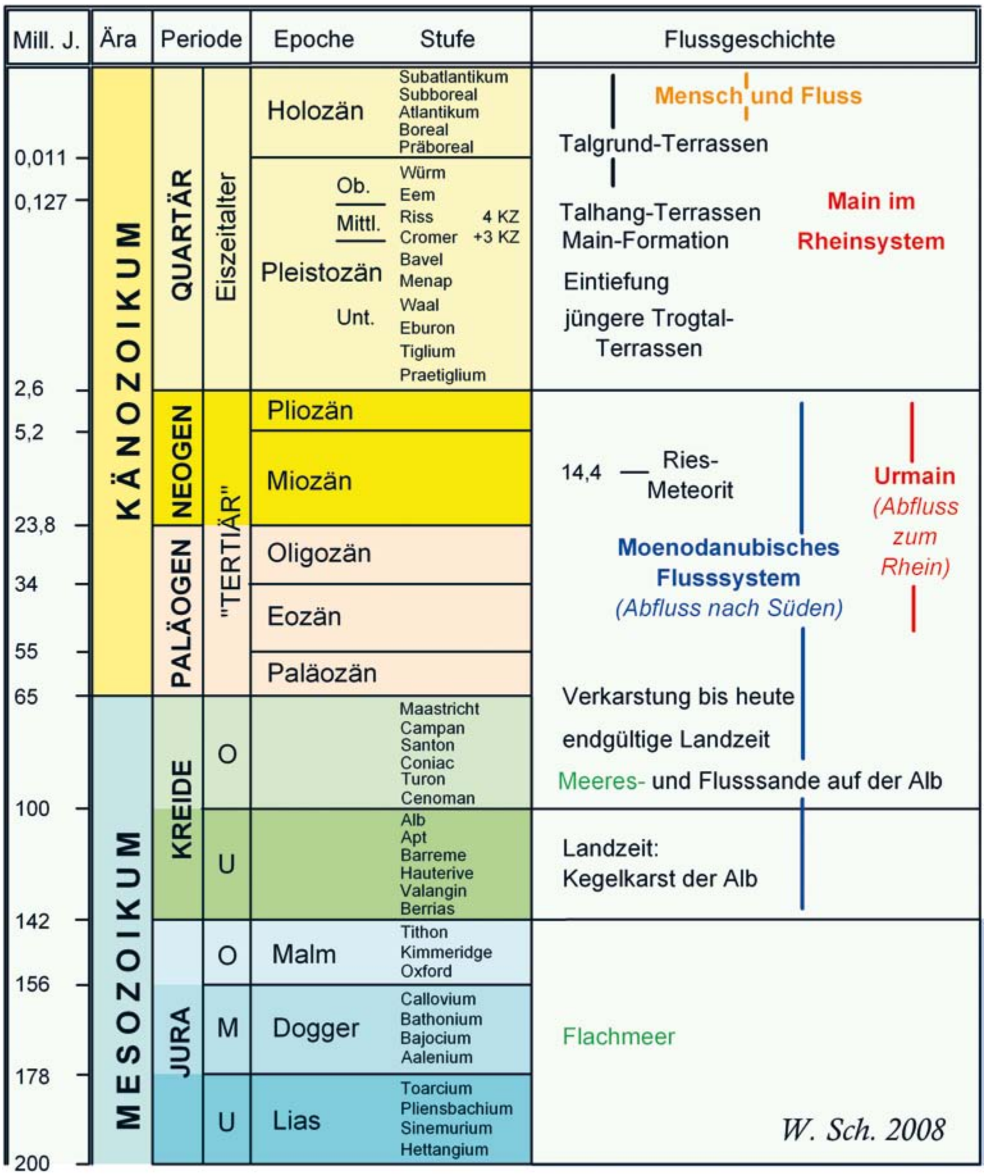


Fig. 6: Timing of the "Moenodavius" River system (denoted in dark blue) according to Schirmer (2010, with kind permission from the author). It may have begun during the Lower Cretaceous when tropical karst with conical forms developed on the Franconian Alb. The southward-draining "Moenodanuvius" system probably persisted during the deposition of Upper Cretaceous marine and fluvial sand and was definitely terminated at the end of the Pliocene (see column "Flussgeschichte" = "river development" at the right-hand side). The Rhine-tributary Main River ("Urmain" in the Figure, denoted in red) developed since the Eocene and incrementally deflected the Moenodanuvius River until the end of the Pliocene. Since then the entire drainage area of the River Main has belonged to the River Rhine system. Since the Middle to Upper Holocene man increasingly influenced the Main River ("Mensch und Fluss", in orange).

Abb. 6: Zeitliche Einordnung des "Moenodanuvius"-Flusssystems (dunkelblau) nach Schirmer (2010, mit freundlicher Genehmigung des Autors). Es kann schon während der Unterkreide begonnen haben, als sich tropischer Kegelkarst auf der Fränkischen Alb entwickelte. Das nach Süden entwässernde „Moenodanuvius"-System existierte vermutlich auch während der Ablagerung der marinen und fluvialen Oberkreide-Sande und wurde definitiv am Ende des Pliozäns außer Funktion gesetzt (siehe Spalte „Flussgeschichte", rechts). Der rhein-tributäre Main („Urmain", rot) entwickelte sich seit dem Eozän und zapfte bis zum Ende des Pliozäns nach und nach das Moenodanuvius-System an. Seitdem gehört das gesamte Main-System zum Rhein-System. Seit dem Mittleren bis Oberen Holozän hat der Mensch zunehmend das Main-System beeinflusst („Mensch und Fluss", orange).

the time of T2 a watershed existed between the two rivers. In fact, a very flat watershed on soft Keuper claystones and sandstones was mapped in a today populated area west of the site. The Red Main valley was 10–15 m deeper at the time of T2 aggradation. By backward erosion from the Red Main valley floor and/or by overflow of the watershed by the alluvial fan of the Steinach River the flat watershed was finally overridden. The former Steinach valley downstream of the deflection point was suddenly bare of a river and is today only drained by a creek named "Trebgast Creek", which enters the abandoned valley floor at the village of Bindlach, ca. 2 km downstream. Subsequently, the Steinach River eroded a 10–15 m deep canyon into the T2 surface. As the valley floor divide of the Trebgast valley lies very close to the de-

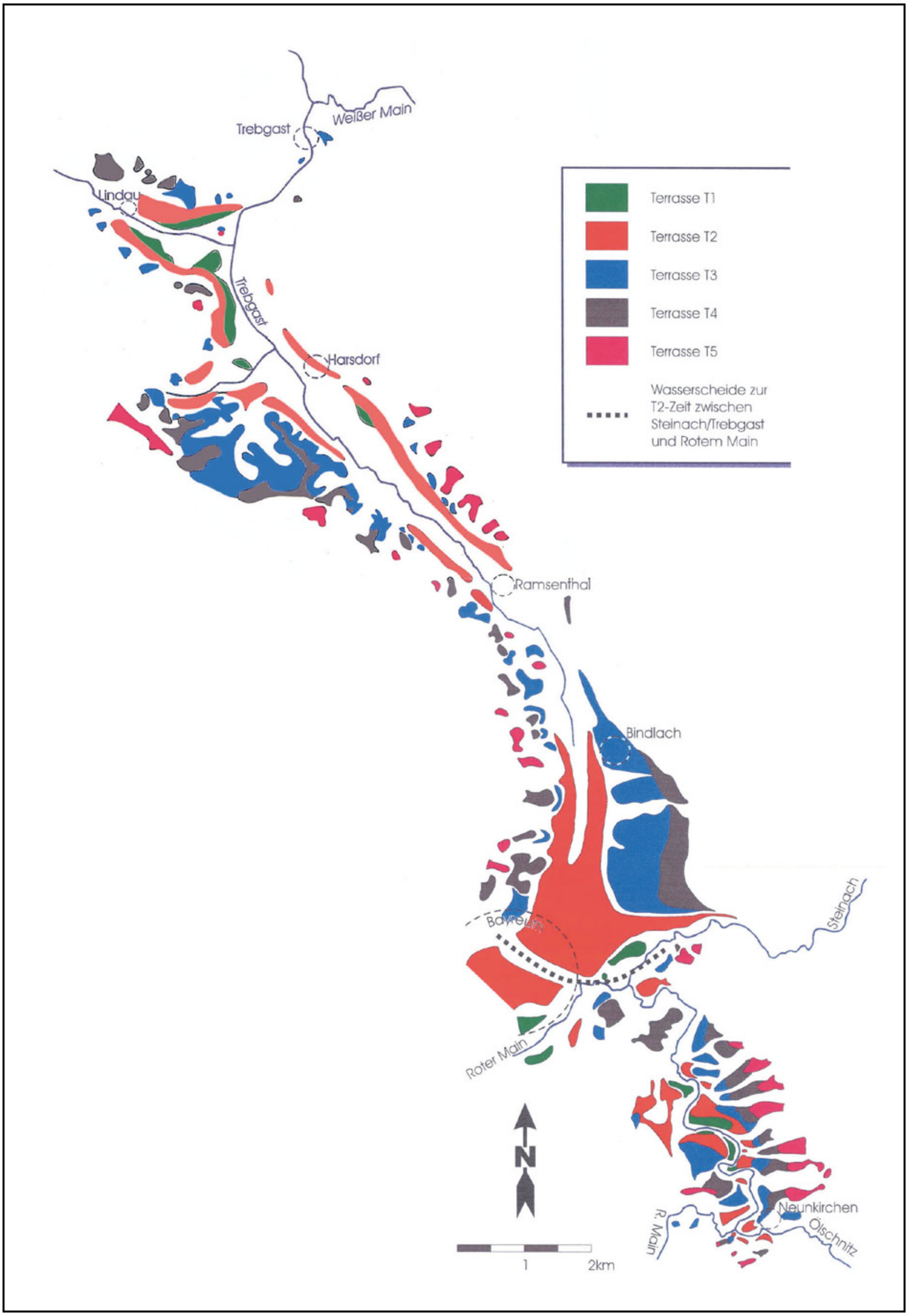


Fig. 7: Quaternary fluvial terraces in the Trebgast valley (compiled after Kleber & Stingl 2000). Roter Main = Red Main River; Weißer Main = White Main River; Terrasse = terrace; bold dotted line = watershed between the Steinach River and the Red Main River during the time of T2 aggradation.

Abb. 7: Quartäre Flussterrassen im Trebgast-Tal (zusammengestellt nach Kleber & Stingl 2000). Fette punktierte Linie = Wasserscheide zwischen der Steinach und dem Roten Main während der T2-Akkumulation.

flection point (ca. 1 km north) and no small creek has so far developed from the divide to the Red Main River, it may be supposed that the deflection occurred during the last glacial. A more detailed discussion about the timing of the deflection will follow later.

Stop 3: Bindlach, former sand and gravel pit

The terraces T2, T3 and T4 are best developed in the gravel fans between the northern margin of the city of Bayreuth and the village of Bindlach, where gravel beds overlie weakly consolidated Lower Triassic sandstone ("Mittlerer Buntsandstein", sm). Large gravel pits were active for many years in the T3 and T4 terraces (Kleber et al. 1988, Veit 1991, Zöller et al. 2007), but at present only the T3 terrace is still exposed.
The layer of coarse fluvial gravel of the T3 is up to 6 m thick and contains boulders of more than 20 cm in diameter. The bedding is principally horizontal with some flat channels filled with sandy gravel and is, thus, indicative of a braided river. The top (uppermost ca. 2 m) of the gravel is strongly weathered and represents remnants of a buried Cambisol or Luvisol. To the North of the former sand and gravel pit an alluvial fan consisting primarily of subangular and slightly altered limestone and dolomite gravel derived from the nearby cuesta of the Middle Triassic limestone (Oberer Muschelkalk, mo) overlies the terrace gravel up to several metres thick. The alluvial fan thins out towards the South. The alluvial fan and the terrace gravel are covered by up to 6 m thick loamy, decalcified loess derivates, alluvial loess with some gravel, and small channel fillings. These cover sediments contain some paleosols of various intensity (Figure 10). The uppermost few dm of the loess derivates are actually revisited as they may represent a (prehistoric) colluvium related to an

Tab. 1: Results of qualitative petrographic gravel analysis of the T2 terrace at Bayreuth-Laineck (from Zöller et al. 2007). The mean values of 7 samples are shaded. The column at the right end gives the mean values in %. Quartz number: percentage of quartz gravel.

Tab. 1: Ergebnisse der qualitativen petrographischen Schotteranalyse der T2-Terrasse bei Bayreuth-Laineck (aus Zöller et al. 2007). Der Durchschnittswerte aus 7 Proben sind schattiert. Die Spalte ganz rechts gibt die Durchschnittswerte in % an. Quartz number (Quarzzahl): Prozentualer Anteil von Quarzgeröllen.

Group	1	2	3	4	5	6	7	Mean	Mean%
Granite	16	20	18	25	40	23	23	24	7
Phyllite	129	54	87	118	97	132	102	103	33
Other metamorphic	26	20	37	37	41	15	93	38	12
Quartz	106	153	121	92	71	68	85	99	32
Quartzite	37	47	82	24	50	58	20	75	14
Sandstone	0	2	0	4	0	4	9	3	1
Others	0	4	0	0	3	0	0	1	0
Sum	314	300	345	300	302	300	332	313	99
Quartz number (%)	33.8	51	35.1	30.7	23.5	22.7	25.6	31.7	

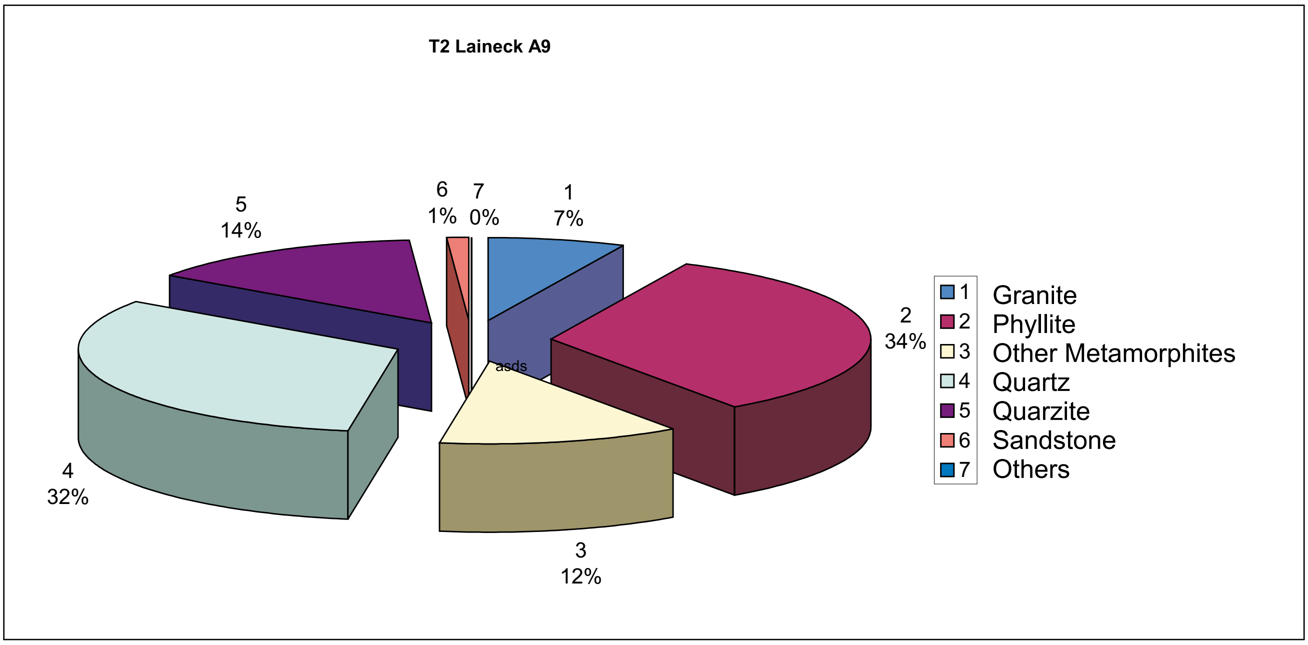


Fig. 8: Graphic illustration of qualitative petrographic gravel analysis of the T2 terrace at Bayreuth-Laineck (after Zöller et al. 2007).

Abb. 8: Graphische Illustration der qualitativen petrographischen Schotteranalyse der T2-Terrasse bei Bayreuth-Laineck (nach Zöller et al. 2007).

Tab. 2: Results of qualitative petrographic gravel analysis of the T3 terrace at the Bindlach site (from Zöller et al. 2007). The mean values of 7 samples are shaded. The column at the right end gives the mean values in %. Quartz number: percentage of quartz gravel.

Tab. 2: Ergebnisse der qualitativen petrographischen Schotteranalyse der T3-Terrasse bei Bindlach (aus Zöller et al. 2007). Der Durchschnittswerte aus 7 Proben sind schattiert. Die Spalte ganz rechts gibt die Durchschnittswerte in % an. Quartz number (Quarzzahl): Prozentualer Anteil von Quarzgeröllen.

Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Mean**	**Mean%**
Granite	9	5	9	20	7	10	34	13	4
Phyllite	130	102	89	140	102	167	91	117	38
Other metamorphic	0	43	65	37	61	0	46	36	12
Quartz	70	89	109	78	76	23	55	71	23
Quartzite	20	18	32	21	38	83	40	36	12
Sandstone	36	29	16	12	0	0	12	15	5
Others	0	6	0	0	0	17	0	3	1
Limestone	42	8	6	5	34	0	8	15	5
Sum	307	300	326	313	318	300	286	307	101
Quartz number [%]	22.8	29.7	33.4	24.9	23.9	7.7	19.2	23.3	

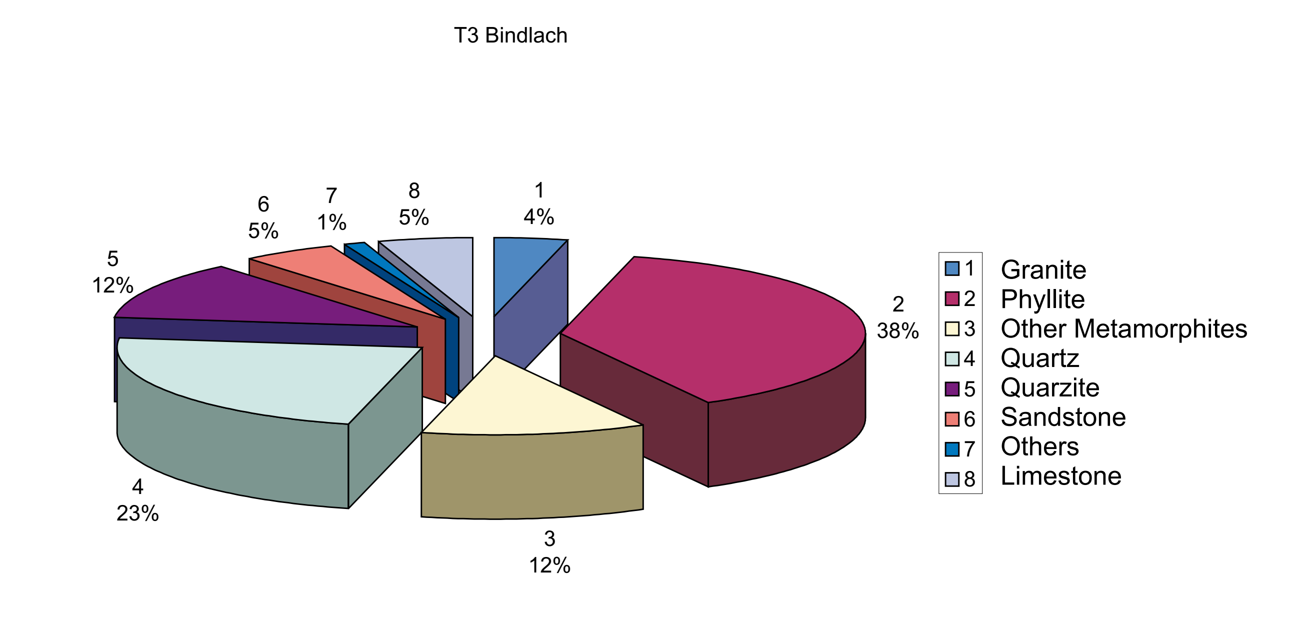


Fig. 9: Graphic illustration of qualitative petrographic gravel analysis of the T3 terrace at the Bindlach site (after Zöller et al. 2007).

Abb. 9: Graphische Illustration der qualitativen petrographischen Schotteranalyse der T3-Terrasse bei Bindlach (nach Zöller et al. 2007).

Tab. 3: Minimum ages of Quaternary fluvial terraces in the Trebgast valley after Veit (1991).

Tabelle 3: Minimalalter der quartären Flussterrassen im Trebgasttal nach Veit (1991).

Terrace	Number of interglacial soils	Age of the terrace
T4	2 + Holocene luvisol	3rd-to-the last glacial
T3	1 + Holocene luvisol	penultimate glacial
T2, T1	Holocene luvisol or cambisol and alluvial soils	Würmian (last glacial)
Floodplain	alluvial soils	Holocene

Iron Age settlement detected in summer 2009 in a rescue excavation on the gentle slope ascending to the T4 level.

The qualitative petrographic gravel analysis of the T3 gravel (Figure 9) yielded results very similar to the mentioned results from the T2 terrace gravel. The limestone content (ca. 5%) is explained by the vicinity of the Muschelkalk (mo)-limestone cuesta. In a nearby exposure of the T3 gravel, a few hundred metres west of the site, no limestone gravel was found. Dogger limonite crusts are almost entirely absent. It must, therefore, be concluded that the T3 gravel in the Trebgast valley was also deposited by the primal Steinach River, and the Red Main River did not run through the Trebgast valley during the T3 aggradation time.

The loess loam-paleosol sequence was used to establish a tentative stratigraphic age of the T3 gravel terrace. Veit (1991) recognized a fossil Btg horizon developed in the lowermost parts of the loess derivates and the underlying gravel. From the former pit in the T4 terrace Veit even reported two buried Btg horizons in the overlying loess derivates. Assigning the buried Btg horizons to interglacial soil formations, Veit concluded the penultimate glacial as the (minimum) age of the T3 gravel and the third last glacial as (minimum) age of the T4 terrace gravel (see Table 3). Ongoing research (luminescence dating, rock magnetism, paleopedology) of the T3 gravel and its cover sediments is expected to give further insights in the chronology of the terrace staircase in the Trebgast valley.

In summer 2010, a 4.6 m thick sequence of cover sediments of the T3 were sampled for sedimentological and rock magnetic investigations as well as for luminescence dating. For rock magnetism sample spacing is maximum 4 cm. In order to characterise the intensity of pedogenesis inside the cover beds Magnetic Volume Susceptibilty, Anhysteretic and Isothermal Remanence were determined providing concentration dependent magnetic parameters (Hambach et al. 2008).

The cover sediments consist of sandy loam mixed with various amounts of pebbles probably derived from terrace bodies in higher topographic positions. The loam developed probably from loess which was decalcified and hill-washed shortly after aeolian deposition. About in the middle of the section, an erosive bed of reworked terrace gravel mixed up with soil material occurs. From about 1.5 m downwards intensity of hydromorphic features increases and is strongest in the lowermost 2 m of the section where Fe-Mn-concretions are frequent.

Magnetic enhancement caused by pedogenesis is present at least in 5 intervals:

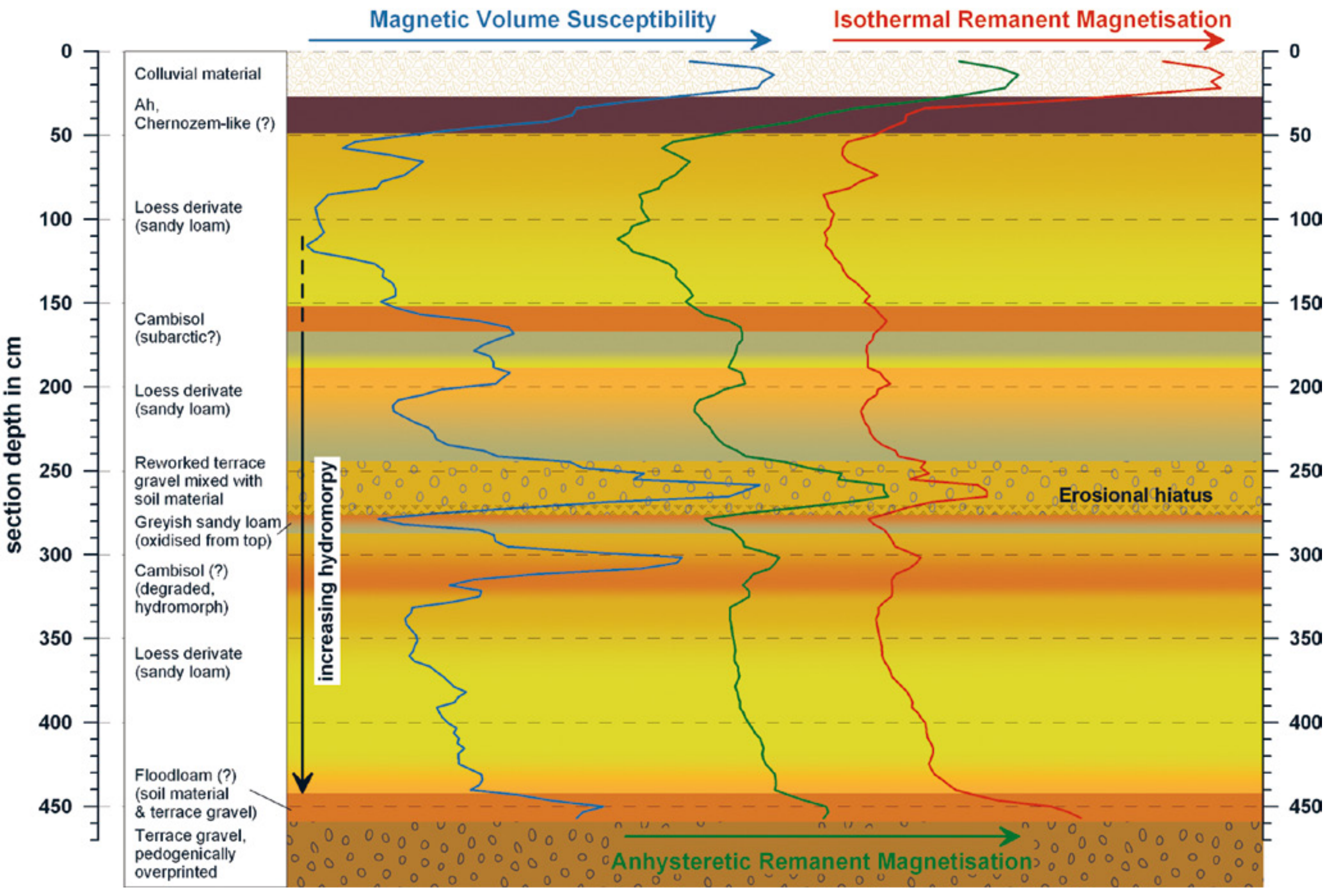


Fig. 10: Stratigraphic plot and selected results of rock magnetic measurements from the cover sediments of the T3 terrace at Bindlach. Magnetic Volume Susceptibilty, Anhysteretic and Isothermal Remanence are displayed as function of stratigraphy. Elevated values are indicative for pedogenesis. Note the extreme values in the colluvium on top of the profile. Data treatment: outlier removal, detrending, normalising and smoothing.

Abb. 10: Stratigraphisches Profil und ausgewählte Ergebnisse gesteinsmagnetischer Messungen der Deckschichten der T3-Terrasse bei Bindlach. Magnetische Volumensuszeptibilität, Anhysteretische und Isothermale Remanenz als Indikatoren für Bodenbildung sind als Funktion der Stratigraphie dargestellt. Bemerkenswert sind die extremen Werte am oberen Ende des Profils. Datenbehandlung: Entfernung von Ausreißern, Trendbereinigung, Normierung und Glättung.

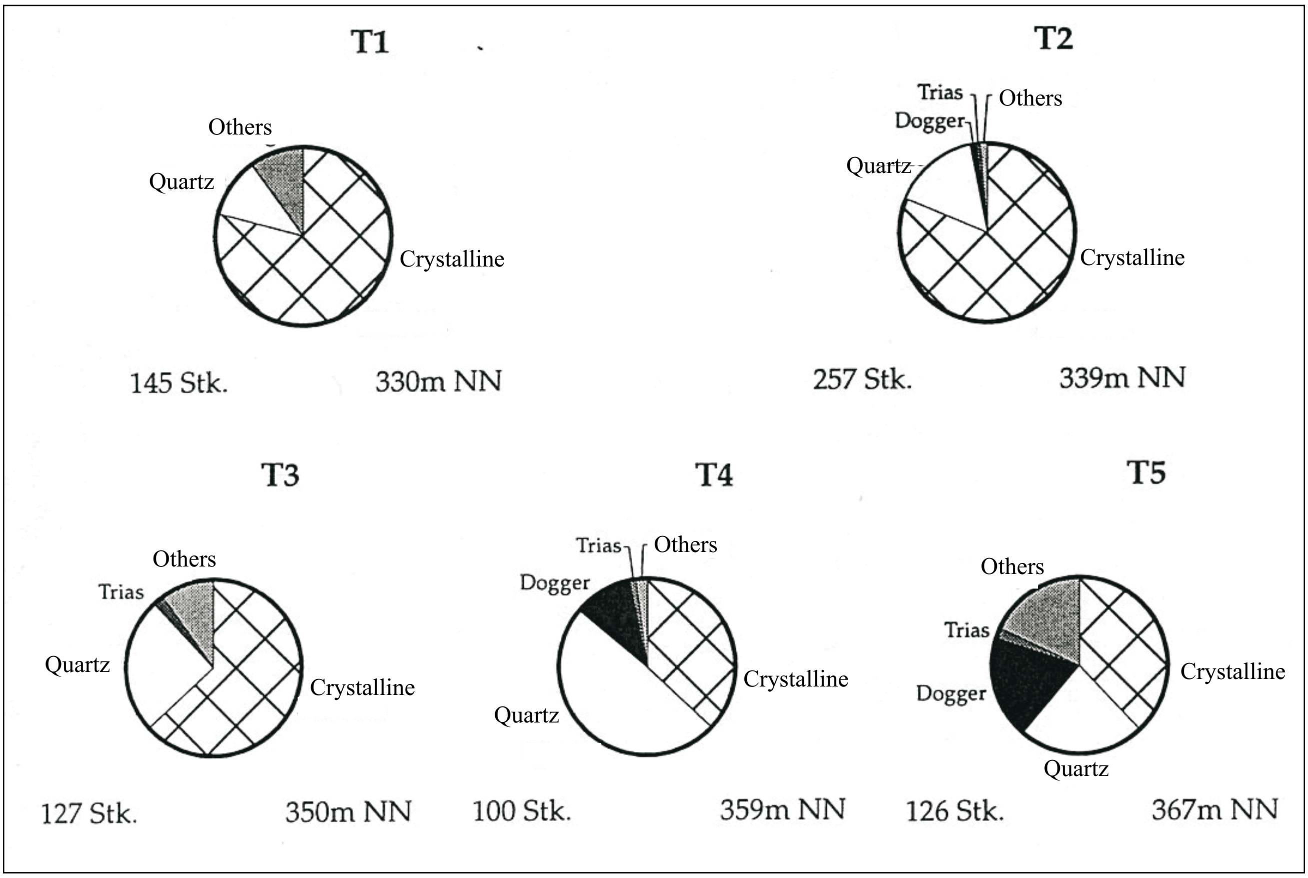


Fig. 11: Gravel composition of Quaternary terraces in the Trebgast valley near the village of Harsdorf (adopted from Kleber & Stingl 2000; Stk = pieces). In contrast to terraces T1 to T3, Terraces T4 and T5 contain high amounts of Dogger limonite crusts (black segment).

Abb. 11: Schotterzusammensetzung quartärer Terrassen im Trebgasttal bei Harsdorf (nach Kleber & Stingl 2000). Im Gegensatz zu den Terrassen von T1 bis T3 enthalten die Terrassen T4 und T5 hohe Anteile an Limonitschwarten aus dem Dogger (schwarzes Segment).

1) in the flood-loam on top of the terrace gravel at 4.5 m depth, 2) at about 3 m depth in the loam (Cambisol, hydromorphically degraded?), 3) in the reworked terrace gravel in the middle of the section, 4) at about 1.5 to 2 m depth in the loam (Cambisol, sub-arctic?) and 5) in a 0.2 m thick Ah-horizon (Chernozem-like?) below the colluvium which covers the sequence. About 1 m of sandy loam near to the top and to the base of the sequence are -beside the hydromorphy-devoid of any pedogenic features and may represent cold phases of loess deposition and reworking. The intermediate interval of the sequence comprises paleosols of various intensity which probably developed under interstadial climatic conditions.

Having in mind these data and considering the interpretations by Veit (1991), the entire sequence may represent the interval from the end of marine isotope stage 5 to the Holocene. However, direct dating by luminescence techniques have to be awaited before any final conclusions can be drawn.

In the higher and older Pleistocene terraces of the Trebgast valley (T4 and T5, tentatively dated to the third last and the fourth last glacial) there exist actually no good exposures. From previous publications (Kleber & Stingl 2000, Zöller et al. 2007) it is well documented, however, that the petrographic spectrum of the T4 and T5 terrace gravels is significantly different from the younger T2 and T3 fluvial terraces. The abundance of crystalline components (metamorphic and plutonic rocks) decreases and there is a considerable amount (up to ca. 25%) of Dogger limonite crusts (Figure 11). Thus, the Red Main River and the Steinach River jointly flowed through the Trebgast valley until the end of the T4 time. It is assumed that this deflection occurred during the T4 accumulation phase of a braided river system by overflow of a flat watershed towards a pre-existing, NW directed valley in the Bayreuth Basin when the heavily loaded Steinach River pushed the Red Main River westward. Consequently, the development of the Trebgast valley presents the unique case of a twofold river deflection at very nearby locations (see Figure 12), favoured by the easy to erode upper Triassic (Middle Keuper; km) layers outcropping around Bayreuth.

A longitudinal section of the Pleistocene terraces in the Trebgast valley (Figure 13) may give some evidence of Quaternary tectonics (uplift in the surroundings of Bindlach), but this may also be an artefact due to imprecise levelling of terrace basements or due to the possible existence of several sub-divisions of the terraces labelled T1 to T5.

Stop 4: Bindlach-Crottendorf (Eckershof), periglacial slope deposits and Holocene sediments covering the T2 terrace

Near the small village of Crottendorf, the valley bottom narrows between outcrops of the more resistant sm_2 sandstone in the West and the mo_2 limestone cuesta in the East

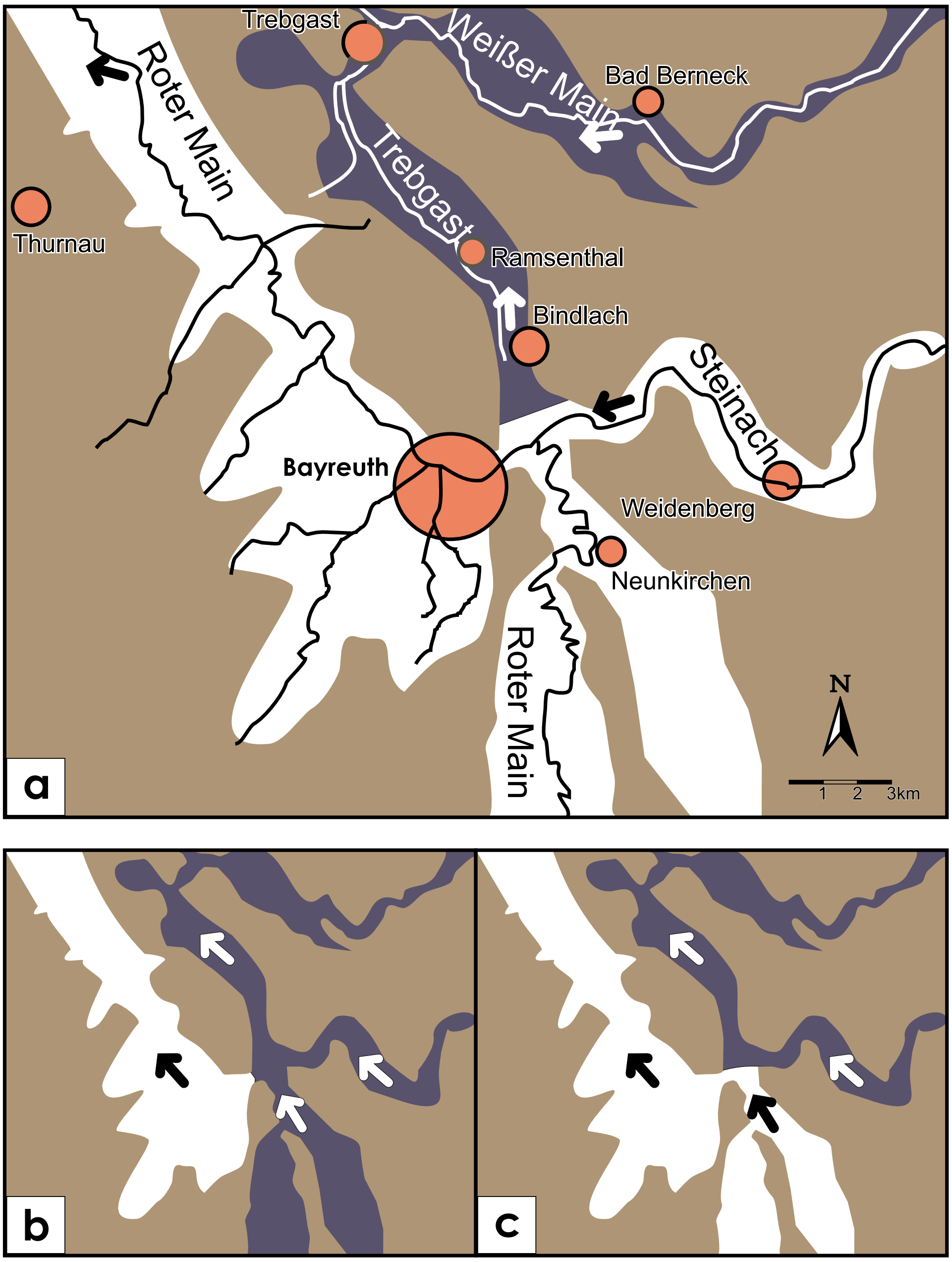


Fig. 12: Twofold river deflection at the confluence of the "Roter Main" (Red Main) and Steinach Rivers near Bayreuth: a) present-day river system, b) Time of T5 and T4 terraces, c) after the formation of T4 terrace (from Kleber & Stingl 2000). "Weißer Main" = White Main River, "Trebgast" = Trebgast Creek.

Abb. 12: Zweifache Flussablenkung am Zusammenfluss von Rotem Main und Steinach bei Bayreuth: a) heutiges Flusssystem, b) Zeit der T5 und der T4-Terrasse, c) nach Ablagerung der T4-Terrasse (aus Kleber & Stingl 2000).

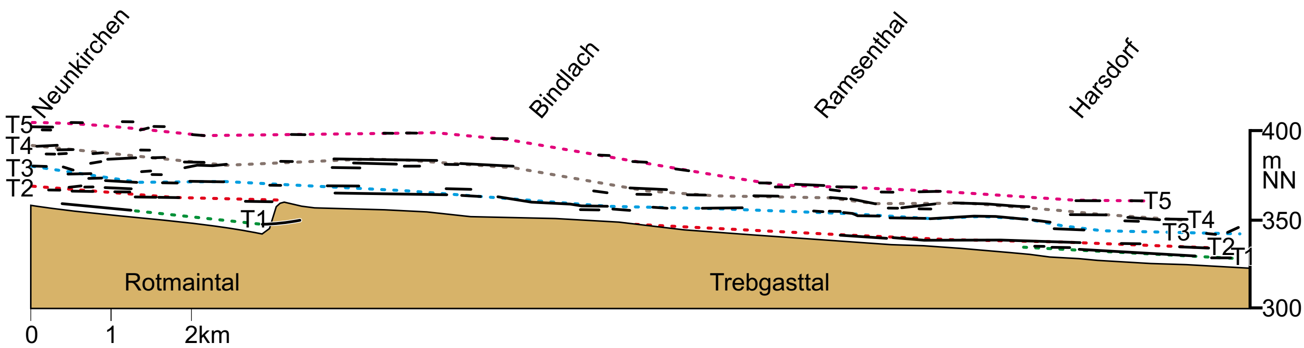


Fig. 13: Longitudinal section of Quaternary terraces in the Trebgast valley (adopted from Kleber & Stingl 2000).

Abb. 13: Längsprofil der quartären Terrassen im Trebgasttal (nach Kleber & Stingl 2000).

Fig. 14: Drill core near Eckershof (extract). 2–2.3 m black Lower or Middle Holocene buried soil overlain by colluvium; 2.3–6.6 m periglacial cover sediment; 6.6–ca. 8.3 m T2 gravel; >8.3 m Lower Triassic sandstone (sm).

Abb. 14: Kernbohrung nahe des Eckershofes (Auszug). 2–2,3 m fossiler schwarzer Boden aus dem unteren oder mittleren Holozän, überlagert von Kolluvium; 2,3–6,6 m periglaziale Deckschichten; 6,6–ca. 8,3 m T2-Kiese; >8,3 m Buntsandstein (sm).

Fig. 15: Gleyed loess lens ("snail loess" between horizontal lines) near Crottendorf, overlying the transitional debris layer.

Abb. 15: Vergleyte Lösslinse ("Schneckenlöss" zwischen den horizontalen Linien) bei Crottendorf über Hangschutt (Übergangs-Fazies).

of the valley (see Figures 19 and 20). During road works in 2009 several some hundred metres long exposures and some up to 6m deep ditches exposed the Pleistocene periglacial slope cover and Holocene colluvial sediments. Several drill cores prove that these sediments overlie the T2 gravel and are, thus, younger than the T2 aggradation by the primal Steinach River (Figure 14). The thickness of the periglacial cover sediments reaches up to 6 m minimum. This unusual thickness casts doubt on the previous age estimate of the Steinach River deflection which was supposed to have occurred before the Bölling Interstadial during the LGM or the early Late glacial (Kleber & Stingl 2000, Zöller et al. 2007). The thickness of the post-deflective periglacial cover sediments can hardly be explained to have accumulated in such short time unless by a landslide, for which no evidence was, however, found so far. The application of the German stratigraphy of Pleistocene periglacial slope cover sediments ("Periglaziäre Lagen" (layers), see AG Boden 2005, pp. 180 ff) appears to be problematic and, thus, a preliminary local stratigraphy was developed which as far as possible refers to the concept of layers:

Upper Layer: facies of the "Hauptlage", loose fitting, loess-bearing, component-supported (but with intercalated lenses of "Basislage" facies), components consisting of mo_2 limestone and dolomite fragments;

Intermediate Layer, facies of the "Mittellage" with loess lenses interbedded with loess-bearing coarse detritus (mo_2 limestone fragments); lense of alluvial loess containing snail shells at its base, "snail loess" (Figure 15);

Transitional debris layer, clayey, loess-free but rather component-supported;

Basal Layer, facies of the "Basislage", clayey, loess-free, par-autochthonous, matrix-supported, deposited in lobes with considerable micro-relief; matrix consisting of marls derived from the Middle Triassic Lower to Middle Muschelkalk (mu to mm).

Up to four stratigraphically distinct loess lenses (Figure 16) were distinguished along the several hundred metres long exposures of which the "snail loess" is the oldest one. Most of them are strongly affected by cryoturbation. The youngest loess lense, situated on top of a small ridge, is about 2 m thick. The mollusc fauna extracted from the oldest loess lense ("snail loess") is – to our knowledge – the first loess fauna described in the region of Upper Franconia.[2]

Material and methods: Molluscs were sieved to > 0.42 mm, sorted and identified from about 30 kg of sediment. Absolute and relative frequencies are presented in Figure 17 as well as population indices and distributions of species and individuals in ecological groups.

Interpretation of the malacofauna: In this malacofauna, the strong dominance of Succinella oblonga (65%) associated with Pupilla alpicola (14%) and Trochulus hispidus (15%) reflects a wet and swampy environment covered by short vegetation. The weak proportion of Pupilla muscorum (5%), one of the three most common species in European loess deposits, and the few individuals of Columella columella, Vallonia pulchella and Vertigo pygmaea support this interpretation. However, as the last three species are very scarce and do not request as much humidity as S. oblonga and P. alpicola, their populations were probably living in the surroundings of the sampled location. The outskirts of this gully were probably drier and more convenient for P. muscorum. Columella columella and Pupilla alpicola are also indicators of cold temperatures. Nowadays, C. columella is indeed restricted to high elevations in Scandinavian and European Alpine regions, and P. alpicola to the European alpine region only (Kerney et al., 1983). The single apex of Arianta arbustorum suggests the presence of patches of shrub vegetation nearby. The quasi-absence of slugs, which are generally abundant in loess deposits, may be caused by the very humid conditions. Indeed, it has been observed in loess molluscan records that

[2] A new coring kindly executed by the enterprise "Piewack & Partner" few m downslope encountered 6.5 m of slope detritus (intermediate and basal layer facies) overlying 0.25 m of T2 terrace gravel on top of the sandstone (sm).

Fig. 16: Two loess layers in stratigraphic superposition interbedded with loess-bearing detritus of "Mittellage" facies near Eckertshof.

Abb. 16: Zwei Lösslagen in stratigraphischer Superposition und wechsellagernd mit lösshaltigem Hangschutt der Mittellage-Fazies nahe Eckershof.

the proportion of slugs tends to mimic that of Pupilla muscorum, which is opposite to those of S. oblonga and T. hispidus (Moine et al., 2008).

Interpretation of population and ecological indexes: The different aspect of both species and individual distributions in their respective ecological groups, as well as the very low values of equitability, show the strong disequilibrium of the malacofauna in favour of hygrophilous and palustral species, and the presence of some species characteristic of less humid open environments (Fig. 17). Diversity values are thus relatively low, Shannon's diversity being lower than Simpson's one as it gives more importance to poorly represented species.

However, with nine species this malacofauna is relatively rich compared to Upper Pleniglacial ones from coastal regions along the Channel and the North Sea in France, England and Benelux (Moine, 2008, Moine et al., accepted), which always includes the same six species (P. muscorum, S. oblonga, T. hispidus, C. columella, slugs and Oxyloma elegans), and also compared to the malacofauna from the southward Danube valley between Regensburg and Passau, which only includes S. oblonga, T. hispidus, P. muscorum and P. bigranata (Brunnacker & Brunnacker, 1956). In the latter case, local environmental features (width of the valley, local topography etc.) or a different age may explain these different compositions of their malacofauna assemblages. More well-dated molluscan records are obviously required to answer this question. Besides, we note here that somewhat more than half of the P. muscorum individuals collected in Crottendorf belongs to the „bigranata" morph, which is by some authors recognised as a separate species.

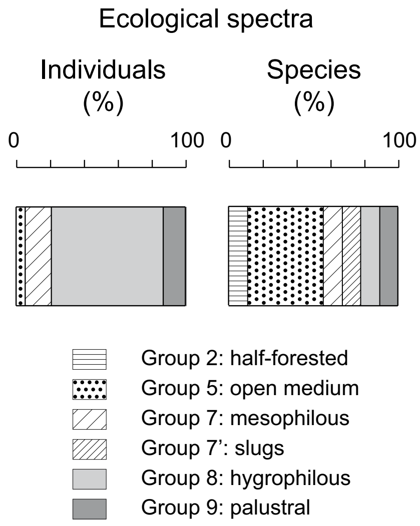
Even divided by three (the taken sample was about three times larger than a normal 10-liter-large loess sample), the total abundance (5534 individuals) would be significantly higher than those of pure loess samples (200–300 individuals at maximum, often less). The total abundance has rather the same order of magnitude as molluscan samples taken from the top of cryoturbated/gelifluction-affected tundra gleys (Moine et al., 2008, accepted). However, the sedimentation rate is probably different as the grain size is rather sandy and thus coarser, and would be akin to, or affected by, flood deposit dynamics. The quasi-absence of earthworm granules indeed indicates an unstable soil surface. Such dynamics could have favoured shell accumulation in this sediment trap. However, the coherent composition of the malacofauna, the good preservation of shells, and the absence of aquatic species, indicate a short calm transport (if any) rather than a long and violent one. Besides, juveniles/adults ratios calculated for the Pupilla genus (5.36), eye-estimated for S. oblonga (~6) and T. hispidus (apparently higher than 6) suggest a favoured reproduction cycle, at least for these three dominant genera. Once more, such dynamics of a mollusc population, accompanied by disequilibrium in favour of hygrophilous/palustral species, has already been characterised at the well-known sites in Nussloch (Rhine valley, Germany) and in Curgies and Bourlon (northern France) at the top of cryoturbated/gelifluctED tundra gleys. It indicates the local occurrence of temperature increases that have been linked with interstadial phases during the Upper Weichselian (Moine et al., 2008; Antoine et al., 2009). However, the composition of the malacofauna cannot help us in assigning an age (Upper, Middle or Lower Weichselian) to this deposit.

First IRSL measurements of the "snail loess" suggest a (minimum) age of ca. 30 ka. This preliminary results need confirmation by IRSL and OSL dating of numerous other samples collected from the loess lenses in the exposures and by AMS ^{14}C dating of snail shells. The preliminary IRSL age of ca. 30 ka, if confirmed by further dating attempts, implies that the age of the T2 gravel underlying the detritus and, thus, the deflection of the primary Steinach River, is even much older (Lower Pleniglacial?) than supposed so far.[3]

The Holocene sequence at the site starts with a clayey black buried soil (see Figure 14), so far detected on the valley bottom and the lowermost parts of the adjacent slope. It is overlain by up to 4 m of colluvial sediments. No archaeological remains were detected so far in the colluvium by bare eyes. Numerous samples for OSL dating were extracted from the colluvial layers, the results of which may shed new light on the settlement history of the Trebgast valley. In a meadow adjacent to the railway track calcareous tuff was found at depths between 40 and 100 cm in the valley bottom.

[3] A recently executed radiocarbon AMS dating from whorls of genus Pupilla (laboratory numbers GifA-11111 and SacA-24633) yielded a conventional age of 26810 ±240 a BP; the calibrated age (Calib 6.1) is 30974-31500 cal BP (2 sigma).

Taxa	Frequencies Absolute	Frequencies Relative
Arianta arbustorum (2)	1	0.02
Columella columella (5)	4	0.07
Pupilla muscorum (5)	298	5.38
Vallonia pulchella (5)	1	0.02
Vertigo pygmaea (5)	3	0.05
Trochulus hispidus (7)	853	15.41
Slugs (7')	2	0.04
Succinella oblonga (7)	3606	65.16
Pupilla alpicola (9)	769	13.90
Total	5534	100



	Diversity	Equitability
Simpson	2.13	0.24
Shannon	1.46	0.46

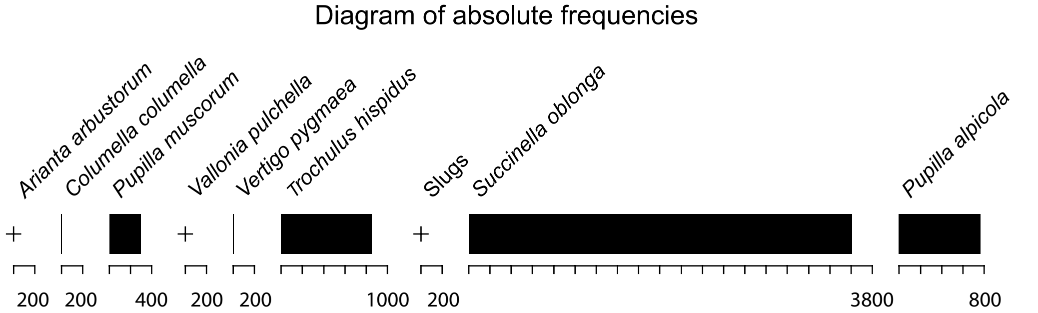


Fig. 17: Malacological results from the gleyed loess lens at the Crottendorf site ("snail loess").

Abb. 17: Malakologische Ergebnisse der vergleyten Lösslinse („Schneckenlöss") bei Crottendorf.

Stop 5: The Lindau Moor, Late Glacial and Holocene archive

The Lindau Moor, situated East of the village of Lindau and West of the present-day Trebgast valley, is a fen with only small parts of a raised bog situated in a morphological depression (Lindau Basin). The width of the depression can be explained by the outcrop of the very easy to erode Lower Triassic sandstone ("Lower Buntsandstein", su) due to a bulge of Upper Permian and Triassic layers. The wide depression is, therefore, the result of relief inversion and not of tectonic subsidence. The geological and tectonic setting of this area with a very diversified relief is illustrated in Figures 18, 19, and 20. Remnants of a Tertiary (Miocene?, cf. stop 1) peneplain at ca. 500 m a.s.l., cutting Triassic layers from the so to the mo, form the framing of the depression (see tectonic setting in Figure 19). A small hill (called "Köstlerberg" or "Kieselberg", 342 m a.s.l.) covered by ca. 2 m thick fluvial gravel (T3 or T4) surmounts the fen by ca. 17 m. In the previous literature (see Zöller et al. 2007 and further references therein) this hill was interpreted as a cut-off meander spur. Kleber & Stingl (2000) mapped the terraces T1 to T4 in the Lindau Basin West of the Köstlerberg (see Figure 7). More recent unpublished investigations by L. Zöller do not confirm, however, that the primal Steinach River ever flowed through the Lindau Basin (see below).

Since 1986, the Lindau Moor is protected FFH (Flora-Fauna Habitat) area to protect it from further peat digging which was active until the 1960s. The unique and endangered fauna includes Drosera rotundifolia, Lysimachia thyrsiflora (glacial relict), Carex diandra, Dactylorhiza incanata, Epipactis palustris and further "Red List" species. Up to 40 different species of butteries were counted (Fröhlich & Gerstberger 1996).

The Lindau Moor is a key site for reconstruction of the Late Glacial and Holocene landscape history. A 158 cm thick pollen profile extracted from a part of the peat not affected by digging was elaborated by Ertl (1987). She distinguished 14 pollen segments which she could correlate with the well-established pollen zones Ib/c to Xa after Firbas. The pol-

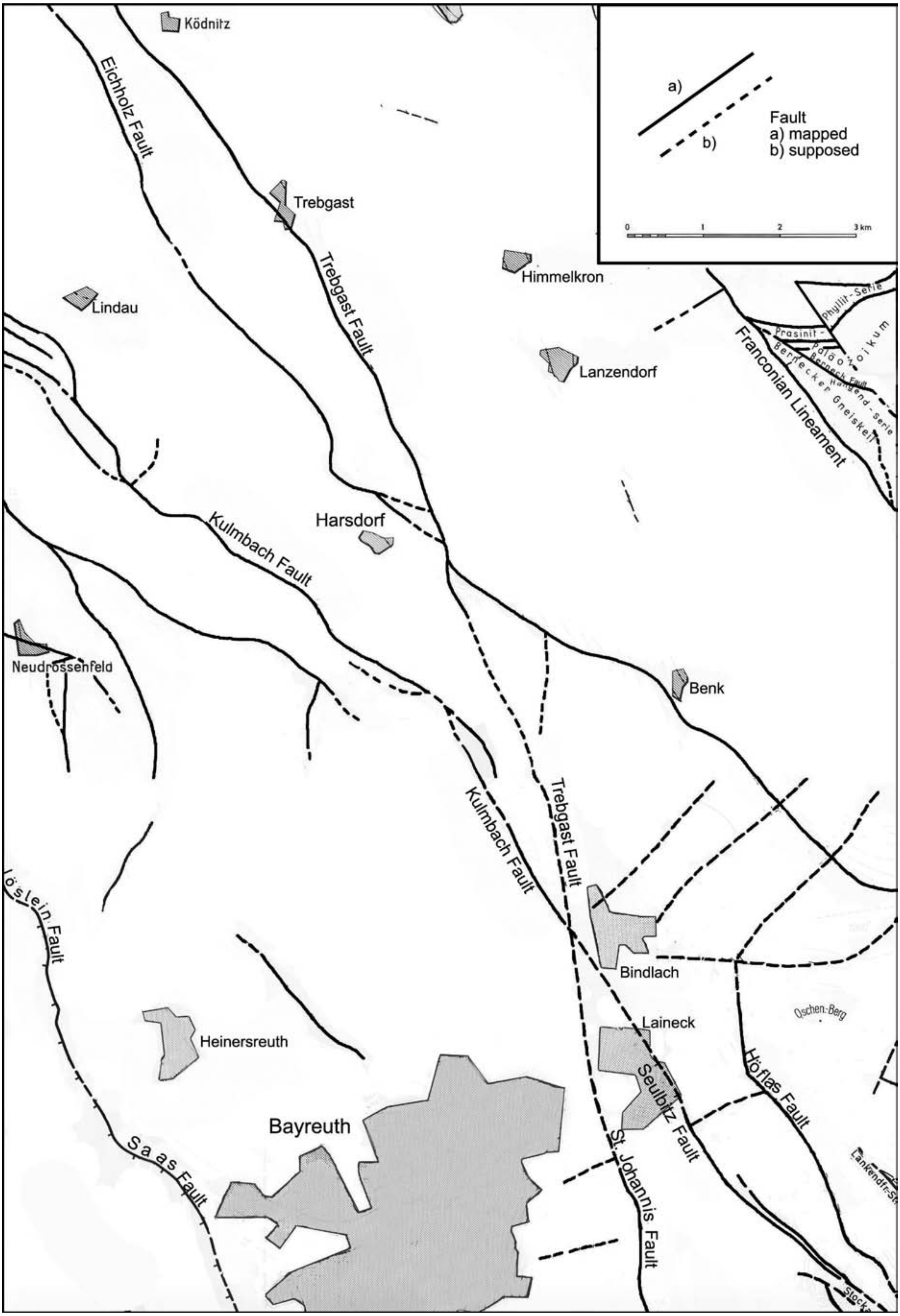


Fig. 18: Tectonic setting of the Trebgast valley and its surroundings.

Abb. 18: Tektonische Karte des Trebgasttales und seiner Umgebung.

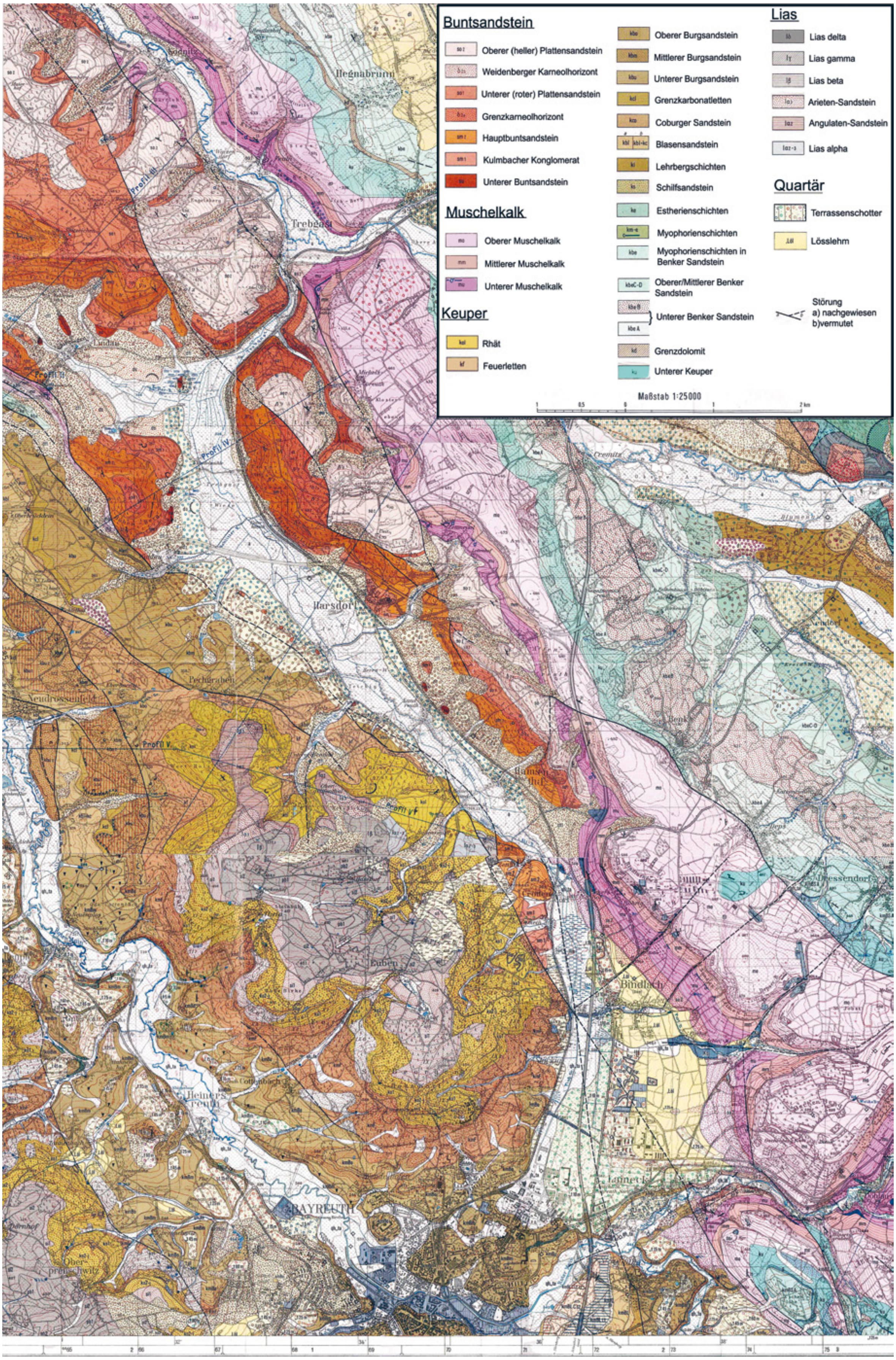


Fig. 19: Geological map of the Trebgast valley and its surroundings (composed and slightly modified from the geological map of Bavaria, 1: 25.000, sheets 6035 (Bayreuth) and 5935 (Marktschorgast)). The stratigraphy in the legend uses local to regional terminology. Stratigraphic series are: Buntsandstein = Lower Triassic; Muschelkalk = Middle Triassic; Keuper = Upper Triassic; Lias = Lower Jurassic; Quartär = Quaternary.

Abb. 19: Geologische Karte des Trebgasttales und seiner Umgebung (zusammengesetzt und bearbeitet nach der Geologischen Karte von Bayern 1:25 000, Blätter 6035 Bayreuth und 5935 Marktschorgast).

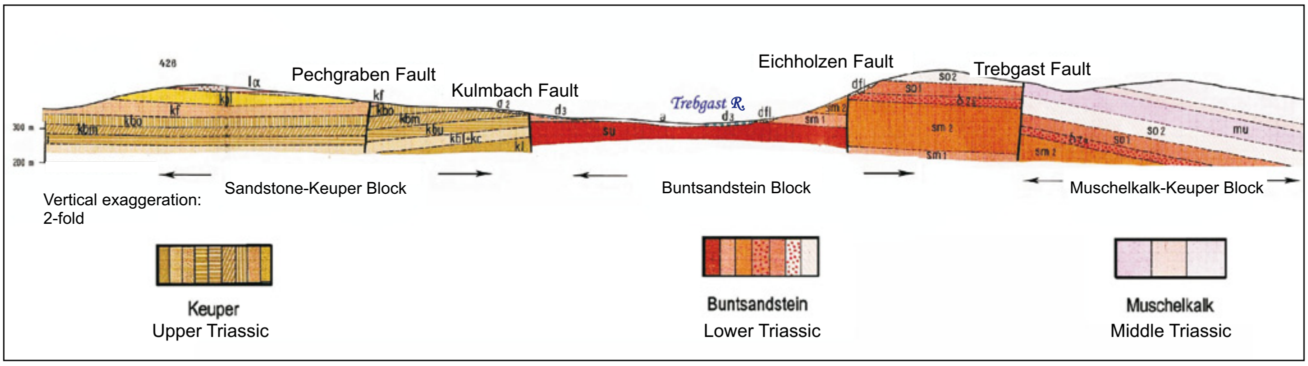


Fig. 20: Geological section (SW-NE) through the Trebgast valley at the village of Harsdorf (modified from the geological map of Bavaria, 1:25.000, sheet 5935 Marktschorgast). Stratigraphic series as in Figure 19; "Störung" = fault.

Abb. 20: Geologischer Schnitt (SW-NE) durch das Trebgasttal bei Harsdorf (nach Geologische Karte von Bayern 1:25 000, Blatt 5935 Marktschorgast). Stratigraphische Einheiten wie in Abb. 19.

len profile spans the time between the Bölling Interstadial (13,000 to 12,000 BP, ca. 15,600 to 13,900 cal BP) and the Subatlaticum (onset at 2,500 BP, ca. 2,800 cal BP) which is also supported by some radiocarbon ages. Pollen from species indicative of intensive forest clearing and agriculture appears in segment 13/14 (corresponding to zone Xa after Firbas).

Zöller et al. (2007) tried to draw geomorphologic conclusions from the palynological dating of the Lindau Moor. Relying on the previous assumption that the Lindau Basin was eroded by the primal Steinach River, they argued that the clay and peat layers could only accumulate after the Steinach River had abandoned the Trebgast valley and slack water conditions followed by fen growth prevailed in the Lindau Basin. With respect to the oldest dated peat clay, the primal Steinach River was deflected before the Bölling interstadial. According to latest investigations, the gravel spectrum of the fluvial terraces in the Lindau Basin is, however, totally different from the gravel spectrum of the primal Steinach River terraces characterized by dominance of metamorphic phyllites and metabasites. These indicative rocks were not at all found among the terrace gravel within the Lindau Basin, which, in contrast, can all be derived from the "Kulmbach conglomerate" (sm1) outcropping on the lower slopes framing the basin. Ventifacts are very frequent among the gravel of the Lindau Basin terraces as well as in the Kulmbach conglomerate deposited under desert environment. As the primal Steinach River apparently did not flow through the Lindau Basin, it is likely that the Kösterberg hill was shaped by a southward deflection of the small creek Köstlerbach today flowing south of the hill. The new findings involve that the formation of the Lindau Moor is completely decoupled from the deflection of the primary Steinach River. A considerably higher age of this deflection as discussed at stop 4 is no longer contradicted by the evolution of the Lindau Basin.

Stop 6: Trebgast radioactivity anomaly and Franconian beer brewing handicraft

The village of Trebgast is known for its former sandstone quarries in the Lower Triassic sm_2 ("Trebgast sandstone"). Around Trebgast the sandstone is characterized by elevated natural radioactivity ("Trebgast radioactivity anomaly" described by Emmert & Weinelt 1962). Parts of the German parliament building ("Reichstag") were constructed from the Trebgast sandstone. The small local brewery ("Haberstumpf Brauerei") is devoted to the traditional Upper Franconian brewing handicraft. In a cellar of the brewery carved into the sm_2 sandstone there is good access to the radioactivity anomaly. Radioactivity measurements in the cellar conducted by the Chair of Geomorphology of the University of Bayreuth proved unusually high concentrations of K (6–7%), whereas U (2.8 to 4.5 ppm) and Th (6 to 24 ppm) concentrations are normal or slightly enhanced with respect to the geochemical average of the upper continental crust. The environmental dose-rate ranges between 2.4 and 3.2 mGy/a. Within the cellar the distribution of radioactivity is not homogenous. From gamma spectrometric measurements executed so far it appears that in general the natural radioactivity is encreased by a factor of ca. 3 with respect to the average of the upper earth's continental crust, but there is some evidence that clayey beds in the sandstone are more active than sandstone beds. A more detailed radiometric mapping of the cellar and nearby exposures may more precisely detect "hot spots" of natural radioactivity. A negative influence on the quality of the beer was not tasted so far, the opposite may rather be the case. Therefore, the excursion day will be terminated with beer tasting and supper in the brewery.

Acknowledgements

The enterprise "Piewack & Partner" (Bayreuth) generously supplied us with stratigraphic plots and photographs of the boreholes near Crottendorf. Prof. Dr. W. Schirmer (Wolkenstein) kindly supplied Figures 4 and 6. Hans and Elfriede Wernlein (Tebgast, owners of the brewery) are acknowledged for continuous access to the cellar to execute radioactivity measurements. Anne Diel (Bayreuth) compiled Figures 7, 18, 19, and 20. Katrin Stumpf (Bayreuth) executed rock magnetic measurements from the cover sediments of the T3 terrace at Bindlach. The Bavarian Bureau of Environment "Bayerisches Landesamt für Umwelt" is acknowledged for the permission to reproduce extracts from two geological maps and the Bavarian Bureau of Topographical Survey and Geo-Information "Landesamt für Vermessung und Geoinformation Bayern" for the permission to reproduce the cartographic background of Figure 1.

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E

Pleistocene landslides and present-day natural hazards at the Swabian Jurassic Escarpment

Birgit Terhorst

F

Itinerary:

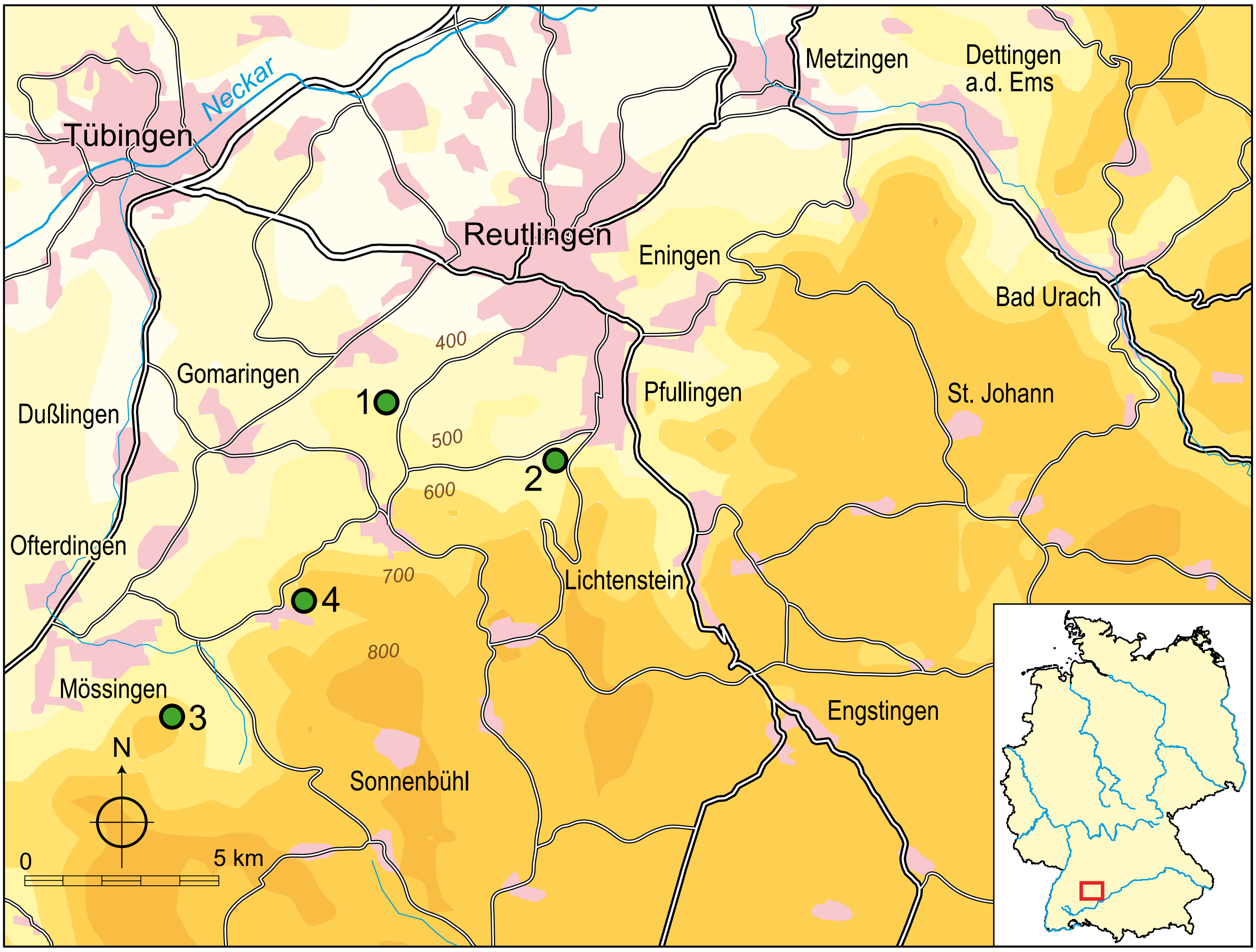

Fig. 1: Study area and excursion stops, 1 = Alteburg, 2 = Scheibenbergle, 3 = Mössingen Landslide, 4 = residential area "Auchtert" in Öschingen.

Abb. 1: Untersuchungsgebiet und Exkursionspunkte, 1 = Alteburg, 2 = Scheibenbergle, 3 = Mössingen Landslide, 4 = residential area "Auchtert" in Öschingen.

Introduction

The excursion area is located at the steep cuesta scarp of the Jurassic escarpment of the Swabian Alb (SW-Germany, Fig. 1), which has been studied for many years (among others, Hölder 1953, Bleich 1960, Bibus 1986, Schädel & Stober 1988). Later, geomorphological research exploring the development, structure, type, age, and causes of past landslides was in the centre of interest (Bibus 1999, Bibus & Terhorst 2001, Terhorst 1997, 2001, 2007). More recently, susceptibility maps were generated by use of statistical methods and GIS (e. g. Kreja &Terhorst 2005, Neuhäuser & Terhorst 2006, Terhorst & Kreja 2009).

In low mountain areas of Central Europe, mass movements of different type, size and age are numerous. The 1st stop at the Altenburg (Fig. 1) provides an overview on the natural settings as well as on causes for basic factors that control landslides in the study area. Current slope instabilities are closely linked to the occurrence of ancient landslides, slide hazards in the temperate zone are gaining increasing scientific and public interest. In SW Germany, mass movements are widespread, and they repeatedly damage and destroy agricultural and forestal areas, roads as well as buildings (3rd and 4th stop). Most slopes of the Swabian Alb cuesta scarp are classified as potential risk areas for mass movements (Durwen et al. 1996, Neuhäuser & Terhorst 2009). In this context, the occurrence of large present-day landslides, e.g. in 1983 at the Hirschkopf near Mössingen (Bibus 1986) (Fig. 1) and in 1972 at the Irrenberg near Thanheim, are essentially relevant for hazard research. For the last 200 years, landslide events of intermediate to large size occurred with an average recurrence rate of about 20 years (Bibus et al. 2001). According to Kallinich (1999) up to 20 % of the slope areas of the W Swabian Alb cuesta scarp shows active movements. Furthermore, approximately 90 % of the recent slope movements are related to older slide masses. For the major part they are of Pleistocene age (Bibus 1999).

Fig. 2: Overview from the Central Jurassic escarpment to the SW part (Stop 1). The wide plains of the plateau form a characteristic landscape element. The slope profiles are concave; Oxford limestone in the upper slopes is related to steep slopes, Oxford marls and Middle Jurassic clays in middle and lower slopes show lower slope inclination (Photo: Birgit Terhorst).

Abb. 2: Landschaftsüberblick von der Mittleren Alb in Richtung SW-Alb (Stop 1). Die weiten Ebenen der Albhochfläche bilden ein charakteristisches Landschaftselement. Die Hangprofile verlaufen konkav, wobei die Oxford-Kalke die steilen oberen Hangbereiche bilden, während Oxford-Mergel und Obere Braunjuratone die flacher einfallenden mittleren und unteren Hänge formen (Foto: Birgit Terhorst).

and in the study area many of them are of Pleistocene age (Terhorst 1997). One example is presented in the 'Scheibenbergle'-landslide area at stop 2.

It has to be considered that on the one hand expansion of urban and industrial areas into landslide prone terrain can influence unstable slope areas negatively (Terlien et al. 1995; Terhorst & Damm 2009). On the other hand, climate change coupled with increasing winter precipitation rates is believed to increase the frequency of landslide processes regionally (cf. Damm 2005).

Therefore, during the last decade, investigations of land-

Study area

The climatic conditions are characterised by a mean annual air temperature of 9°C and an annual precipitation ranging between 800 and 1000 mm. In general, slopes are covered by different varieties of Leptosols and Cambisols (IUSS Working Group WRB 2006).

Over a short distance the escarpment of the Swabian Alb abruptly rises 300 to 400 m above its foreland and consequently is characterised by very steep slopes (Fig. 2).

The geological conditions are determined by interbedding of permeable and impervious bedrock. In general, Oxfordian or Kimmeridgian limestones overlie marls and clays. In the study area, the ductile behaviour of the Callovian clays of the Middle Jurassic and the superposition with expandable Oxfordian marls favour slope instabilities. According to Kallinich (1999) and Kraut (1999) landslides are not present in slopes where Callovian clay dips below the present day surface. This is in complete contrast to Bell (2007), who supposes that geology is not suitable for the assessment of slope stability in the Swabian Alb.

In addition, unfavourable hydrological factors count for the formation of mass movements, such as the drainage of the shallow karst on the Oxfordian marls and the Callovian clays as well as the progressive incision of the Rhenish system related to spring erosion in the slope areas (Terhorst 1997, 1999; Kallinich 1999). Statistical analyses showed that two thirds of all known slides are directly connected with springs, water-logging, channels, etc. at the Swabian Alb (Bibus 1999; Kraut 1999). Triggering factors for landslides are above-average precipitation rates and increased runoff due to intensive snowmelt in winter and spring. Kraut (1999) proved that landslides take place after some months of continuous and above-average rainfall or after extremely high precipitation rates following a dry period in summer. Furthermore, due to the behaviour of the karst aquifer of the limestone plateau, drastic increases in the discharge of springs and thus an enhanced water supply repeatedly affects the slopes.

In the case of the Swabian Alb, a landslide database has been compiled, which consists of more than 600 mass movements. Predominant landforms, which occur in the study area, classified by geological setting and types of mass movements are listed in Table 1.

Earlier studies, which are mainly based on field survey, pedological and sedimentological analyses as well as on dating methods prove that landforms and processes related to mass movements can be divided into two main classes (Terhorst 2001). During the Last Glacial phase, large slump-earth flows (acc. to Varnes 1978, 1984) occurred. In general, recent slopes are characterised by rotational slide blocks of 200-300 m length and 20-50 m width in average. For the major parts, they are situated in the middle slope areas (Fig. 3). The foot of the complex slide is formed by tongue-like dams, related to flow processes there. The average size amounts to 200 m in length and 100 m in width.

The Holocene processes are characterised mainly by flows and translational slides of different sizes (Fig. 3). Investigations by Kraut (1999), Terhorst (1999), and Thein (2000) proved that recent mass movements on the Alb cuesta scarp predominantly occur on middle and lower slopes as well as in the area of spurs. Recently, N and NW exposed slopes are significantly affected by mass movements. According to Bibus and Terhorst (2001) slopes are susceptible to landslides in areas where inclination is > 11°. Nevertheless, slope movements can already occur at inclinations of 5° as well. In general, the probability of landslides rises with increasing inclination.

Tab. 1: Types of mass movements and landforms related to geological units of the Swabian Jurassic escarpment (acc. to Bibus & Terhorst 2001).

Tab. 1: Klassifikation von Massenverlagungen und Oberflächenformen in Abhängigkeit vom geologischen Ausgangsgestein an der Schwäbischen Juraschichtstufe (acc. to Bibus & Terhorst 2001).

Geology	**Dominant types of movement (after Varnes 1978)**	**Dominant relief elements Jurassic cuesta**
Kimmeridge-Limestone (ki2)	Rotational slide, rock fall, debris fall, rock topple, translational slide	Main scarp, rotational block, block field, talus slope, rock fan, translational block
Kimmeridge-Marl (ki1)	Earth flow	Tongue-like dam, dome, undulatory relief, limestone and marl debris accumulation
Oxford-Limestone (ox2)	Rotational slide, slump-earth flow, debris fall, translational debris slide	Main scarp, talus slope, rotational block, tongue-like dam, fissuring, marginal valley-like depression
Oxford-Marl (ox1)	Earth flow, rotational slide, translational slide	Tongue-like dam, dome, undulatory relief, limestone and marl debris accumulation, main scarp, talus slope, rotational block
Middle Jurassic clays	Earth flow, Translational slide	Tongue-like dam, dome, undulatory relief
Middle Jurassic lime- and sandstones	Rotational slide, translational slide, earth flow	Main scarp, breakage, rotational block, undulatory relief

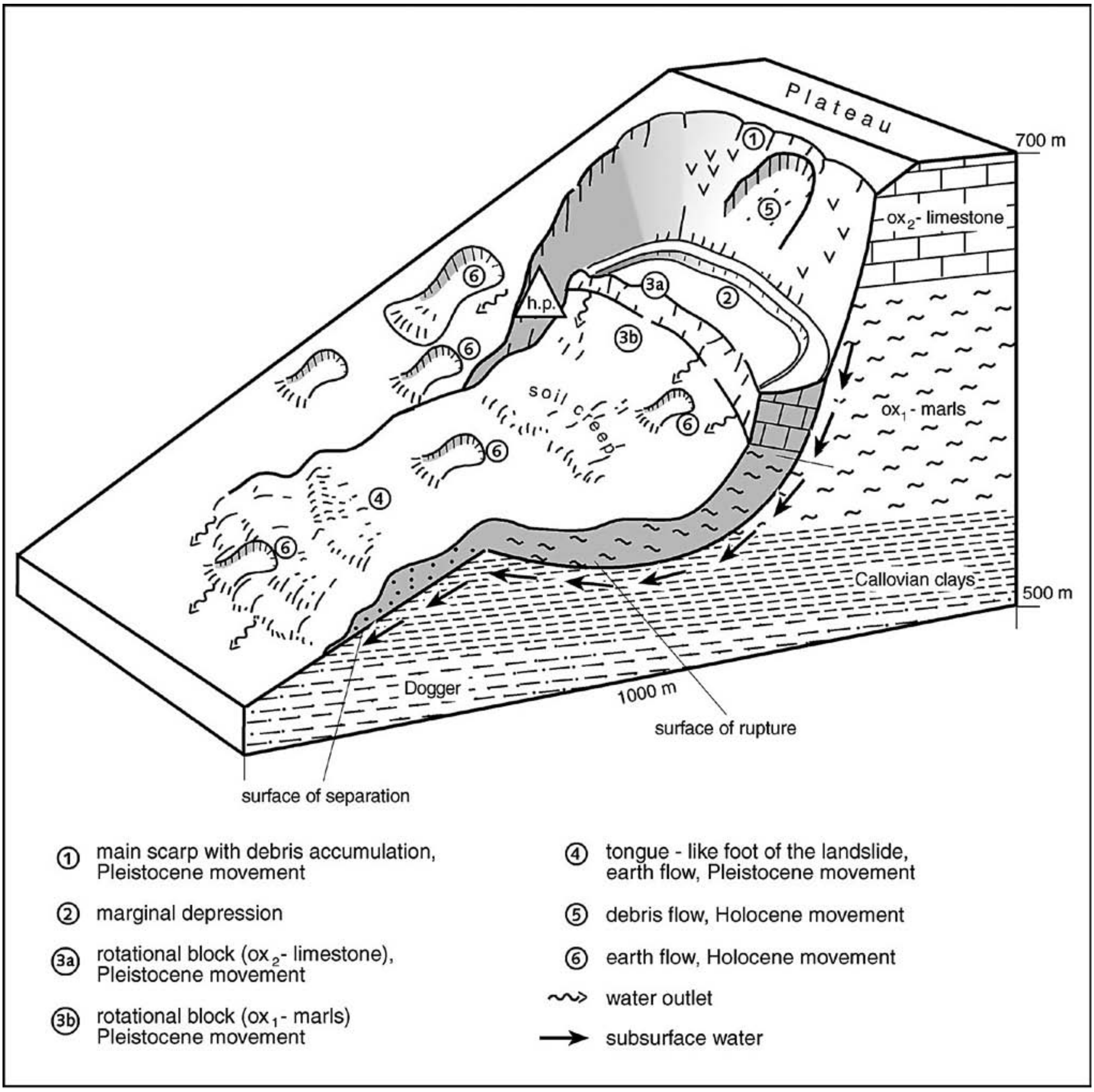

Fig. 3: 3D-model of a characteristic Pleistocene landslide area (Terhorst & Kreja 2009).

Abb. 3: 3D-Modell eines typischen pleistozänen Rutschgebietes (Terhorst & Kreja 2009).

Stop 1: Reutlingen/Alteburg

The Alteburg Hill at 593 m a.s.l. is situated at a distance of approximately 2,200 m from the cuesta scarp of the study area. Thus, the Alteburg constitutes a slide mass characterized by the farthest distance to the present day slopes of the cuesta scarp (Fig. 4). The hill has been interpreted as destroyed outlier (Bleich 1960), as rock fall Hölder (1953) as well as volcanic vent. It is now proved, that it is composed of fall and slide masses. Oxfordian rock material is directly superimposed on Middle Jurassic clays (Bathonian). This means that the Callovian formation is absent and thus, the stratigraphical sequence is not complete.

The Alteburg hill is at its maximum 350 m long and 150 m wide. Measurements, drillings, and exposures proved that an increase in slope inclination from 15° to 17° marks the boundary between the bedrock and the ancient slide mass at approximately 560 m a.s.l. This corresponds to an estimated thickness of the slide mass of 35 m, a value which can be compared to further slide masses in the area of interest. A former exposure exhibited Oxford limestone in horizontal bedding, whereas Oxford marls are nearly absent due to erosion processes. Impressive limestone blocks are situated on the northwestern slope as witnesses of fall processes at a time when the cuesta scarp was close to the Alteburg.

Stop 2: The landslide area Scheibenbergle

The landslide area Scheibenbergle is composed of two different rotational blocks, with one lying on top of the other (Figs. 5 and 6).

Fig. 4: The Alteburg slide mass (Stop 1, Photo: Birgit Terhorst).

Abb. 4: Die Rutschmassen der Alteburg (Stop 1, Foto: Birgit Terhorst).

The cross-section shows that Calci-lithic Leptosols (Fig. 5) are present in the debris cone of the main scar, reflecting unstable geomorphological conditions (Terhorst 2007). Undisturbed soils classified as Vertic Cambisols (Chromic) have developed on the landslide deposits of the middle and lower slope position. The Cambisols (Clayic) are characterised by decalcified and brownish Bw horizons down to a maximum depth of 0.35 cm. The topsoils clearly contain the mineralogical component, which is known as the characteristic spectrum of the Laacher See Tephra (Table 2). These minerals consist of 12.3% brown amphiboles, 5.5 % clinopyroxenes and 5.9 % titanites (Terhorst 2007). Furthermore, the presence of the minerals epidote, garnet, and green amphibole as well as a silt content of 55.2% point to a clear loess component in the topsoil (Table 2 and 3, profile 4; Terhorst 2007). The basal horizon is mainly composed of limestone debris, which is dominated by stable minerals and muscovite. The results give evidence of the presence of the upper periglacial cover bed/upper layer (see Zöller et al., Stop 4, for further explanation) that forms the parent material for Holocene pedogenesis (Terhorst 2007).

In particular the lower rotational block is of special interest. Intensely weathered, reddish-coloured Vertic Cambisols (Chromic) (former and local classification: Terra fusca) are present in limestone debris. The Bw horizon contains 68.2% clay, which is characteristic in the study area (Table 2 and 3: profile 5). In general, modern soils developed in limestone debris contain about 30% clay. Thus, the remarkable clay content of the Vertic Cambisol (Chromic) has to be regarded as a relic feature.

The lower rotational block was covered by limestone debris during or after the sliding event. Inside the debris pure secondary calcite crystals have developed (Fig. 7), which were dated by the U/Th-method. The analyses yielded an age of

Table 2: Heavy mineral composition of selected soils and local volcanic material.

Tabelle 2: Zusammensetzung der Schwerminerale von ausgewählten Böden sowie von lokalem vulkanischen Material.

Mineral group	**Laacher See Tephra**			**Loess minerals**			**Stable Minerals**			**Jurassic**	**Other**
%	Brown Amphi-bole	Clino-pyroxe-ne	Tita-nite	Epido-te	Gar-net	Green Amphi-bole	Zircon	Tou-maline	Rutile	Min.	Min.
Profile 4											
*Bw	12.3	5.5	5.9	6.9	4.5	4.1	8.0	7.2	5.1	40.3	0.2
Profile 5											
*Bw	22.5	3.2	8.6	2.4	3.4	2.4	2.2	6.8	3.4	31.5	11.4
BC	0.0	1.5	0.7	0.0	0.0	0.0	1.5	0.0	1.5	93.3	0
Local volcanic material											
Kugelberg I	0	7.2	0	0.6	4.5	1..2	8.0	0.2	1.0	7.2	82.5
* = Upper Periglacial Cover Bed											

Table 3: Grain size fractions of selected soils.

Tabelle 3: Korngrößenfraktionen von ausgewählten Böden.

Samples	**Grain size %**		
	Clay	Silt	Sand
*Profile 4/Bw	41.2	55.2	3.6
*Profile 5/Bw	68.2	28.4	3.4
Profile 5/BC	42.6	33.8	23.7
* = Upper Periglacial Cover Bed			

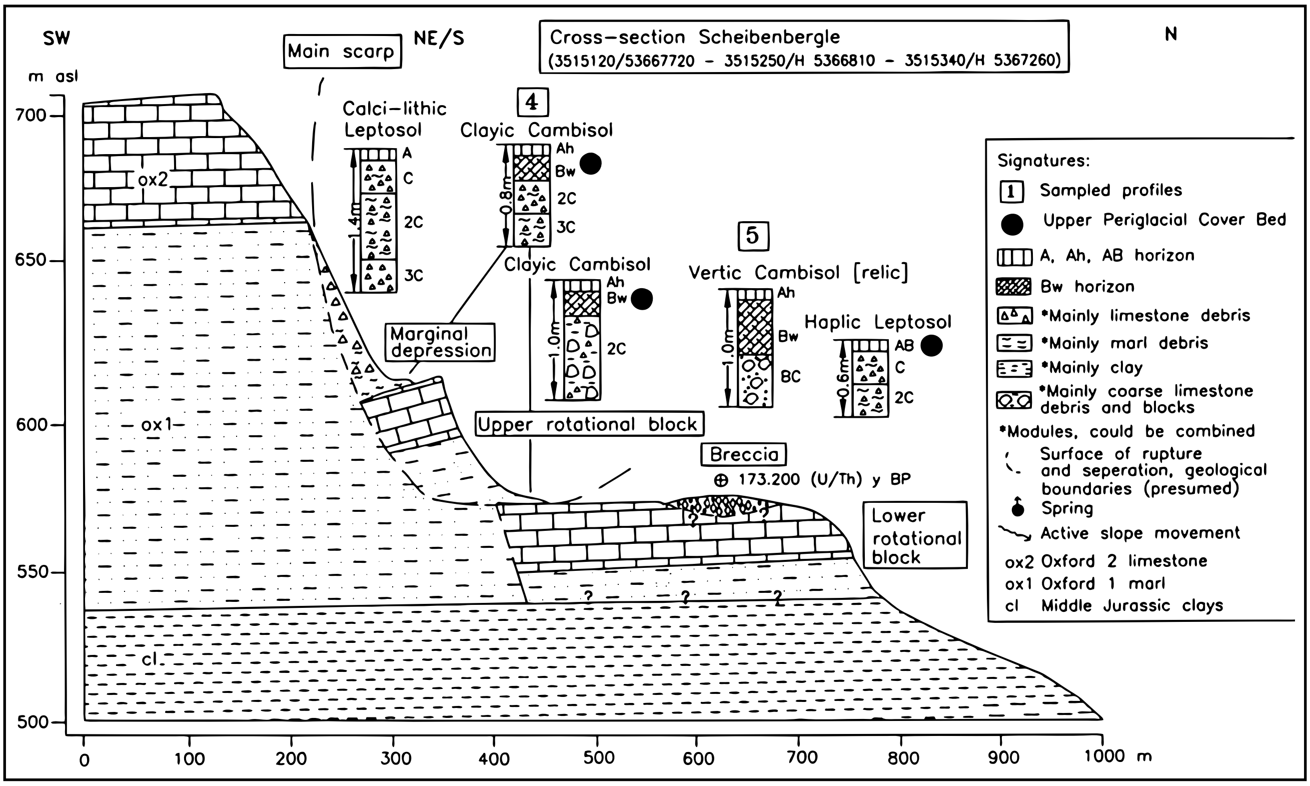

Fig. 5: Cross-section of the Scheibenbergle landslide area (Stop 2) (Terhorst 2007).

Abb. 5: Hangquerschnitt des Rutschgebietes Scheibenbergle (Stop 2) (Terhorst 2007).

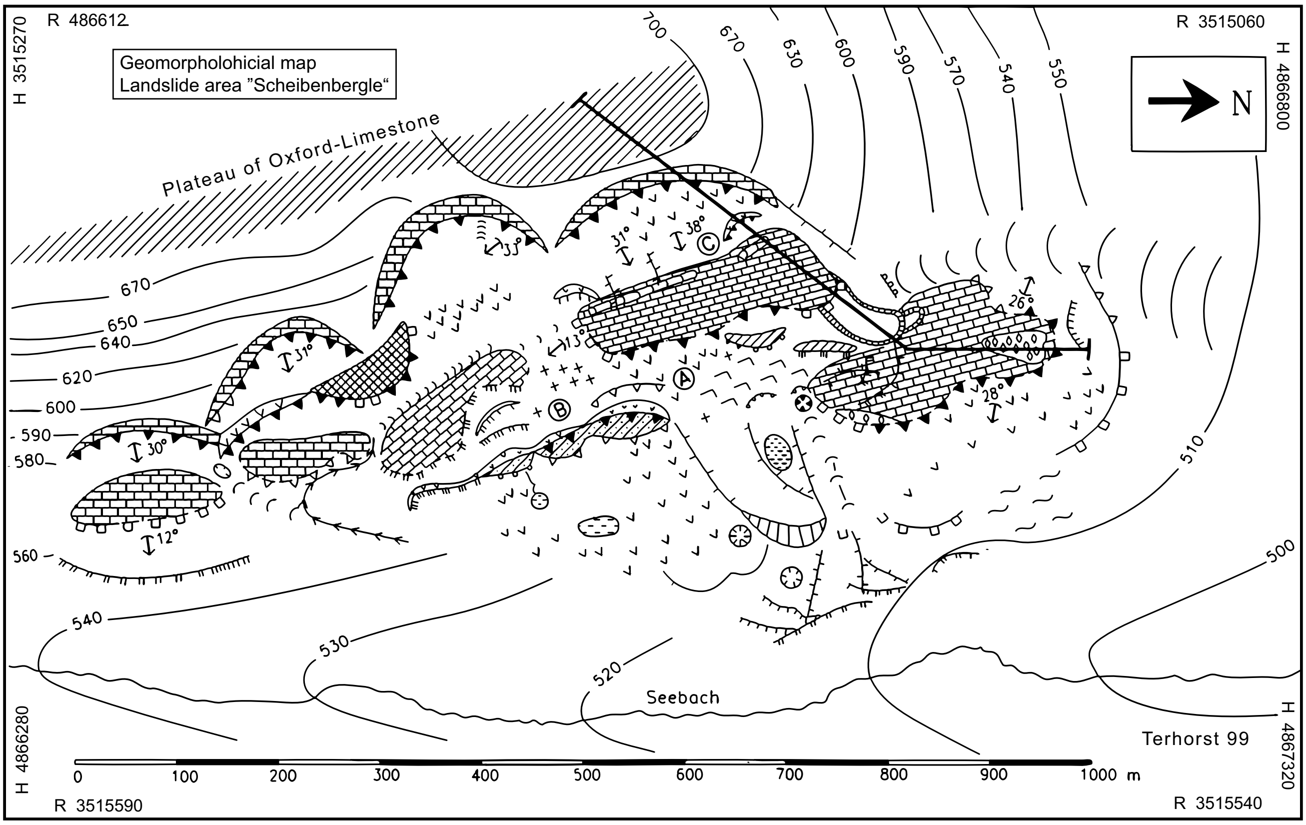

Fig. 6: Geomorphological map of the Scheibenbergle landslide area (Stop 2) (Terhorst 2007).

Fig. 6: Geomorphologische Karte des Rutschgebietes Scheibenbergle (Stop 2) (Terhorst 2007).

Fig. 7: Calcite crystals grown in debris of the Oxford limestone. Debris and calcite crystals overlay a Pleistocene sliding block (Photo: Bodo Damm).

Abb. 7: Im Schutt der Oxford-Kalke gewachsene Kalzitkristalle. Schutt und Kalzitkristalle überlagern eine pleistozäne Gleitscholle (Foto: Bodo Damm).

173,200 yr BP (± 7,600, Lab. no. 1961, Heidelberg Academy of Sciences, Prof. A. Mangini) (Terhorst 2007).

Stop 3: The Mössingen Landslide

About 28 years ago, on the 12th of April, 1983 a landslide event took place at the Hirschkopf Mountain after long lasting rainfall in combination with snow melt. A nearby climate station in Talheim measured precipation of 200mm during the last four weeks prior to the initiation of the landslide. Moreover, three days before the event, 40mm precipitation was documented (Bibus 1986). Combined with the water supply originating from the snow melt, this above-average precipitation triggered the landslide event. The landslide affected an area of 60 ha (Fig. 8). The major parts of the movement took place in a time span of two days.

The geological sequence starts with Oxford limestone of the Upper Jurassic in the upper slope and reaches to the Middle Jurassic limestone in the lower slope. The present-day appearance of the slide area can be subdivided into three main units (Fig. 8). There is an impressive steep scar composed of Oxford limestone and marl. It is characterised by single piles separated from the main wall by vertical fissures. Below the scar, extraordinarily thick debris has accumulated. On the masses of limestone debris, a more or less planar surface is present with partly undisturbed trees. While the upper and lower slope have been totally damaged, the former forest is still present in the middle slope section and was hardly affected by the slide processes. This section corresponds to an ancient slide block, which remained rather stable during the slope movements. The slide block accomplished a secondary movement, despite the complete destruction of the adjacent slope areas. It is remarkable that the vegetation there was completely destroyed.

The third section of the slide area is characterised by flow and debris accumulation (Fig. 8). These deposits have been transported rapidly and finally they dammed up the Buchbach stream.

Former studies of Bibus (1986) show that well developed Holocene soils were present in the study area before the landslide took place. These results indicate that undisturbed an-

Fig. 8: The Mössingen landslide area (Stop 3, Photo: Armin Dieter).

Abb. 8: Der Mössinger 'Bergrutsch' (Stop 3, Photo: Armin Dieter).

Fig. 9: Overview on the residential area Auchtert in Öschingen. The bracket marks the ancient slide mass (Stop 4, Photo: Roger Kreja).

Abb. 9: Überblick über das Wohngebiet Auchtert in Öschingen. Die Klammer zeigt die alte Rutschmasse (Stop 4, Foto: Roger Kreja).

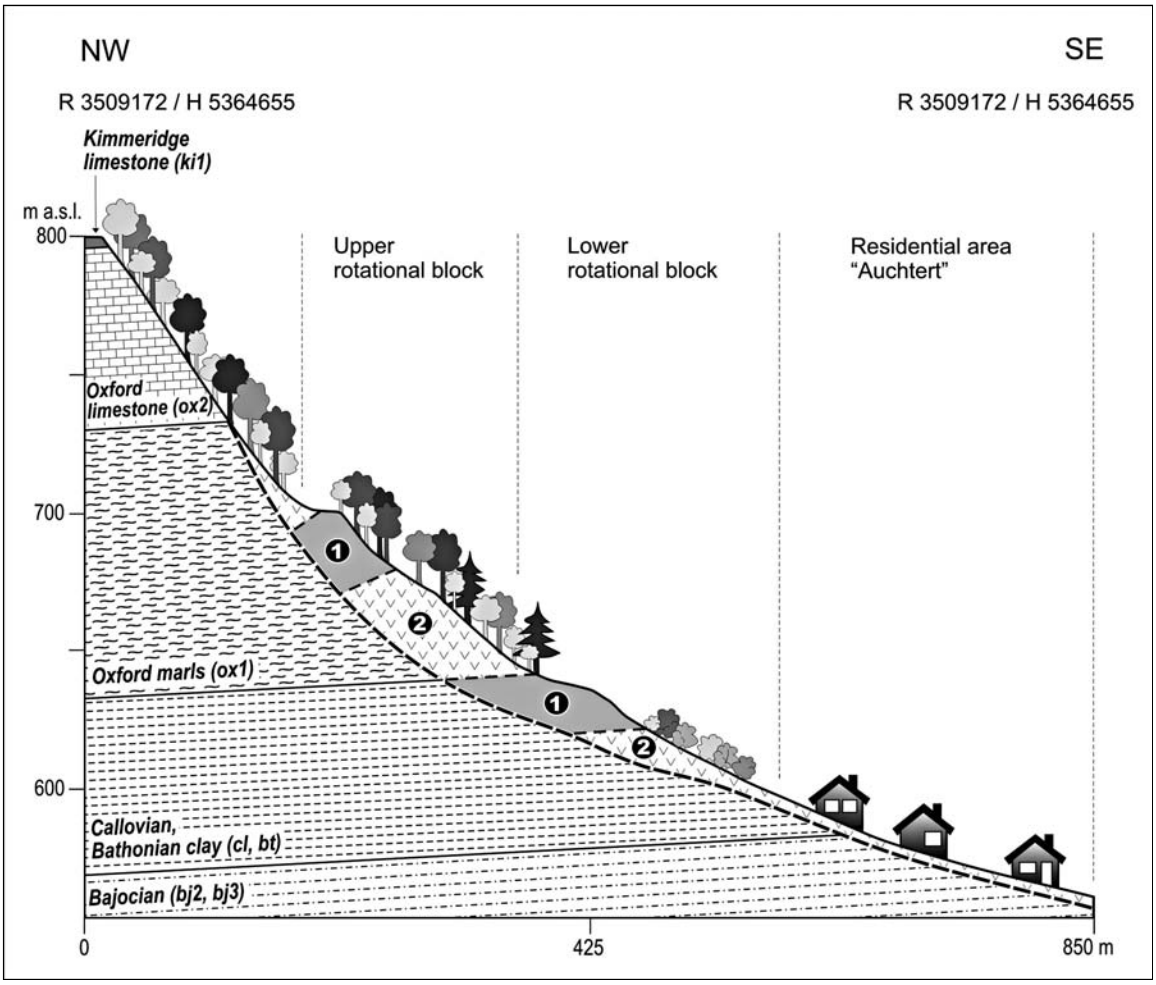

Fig. 10: Cross-section and slide masses of the Auchtert area at the Schönberger Kapf (Stop 4) (Terhorst & Kreja 2009).

Abb. 10: Hangquerschnitt und Rutschmassen des Auchtert-Gebietes am Schönberger Kapf (Stop 4) (Terhorst & Kreja 2009).

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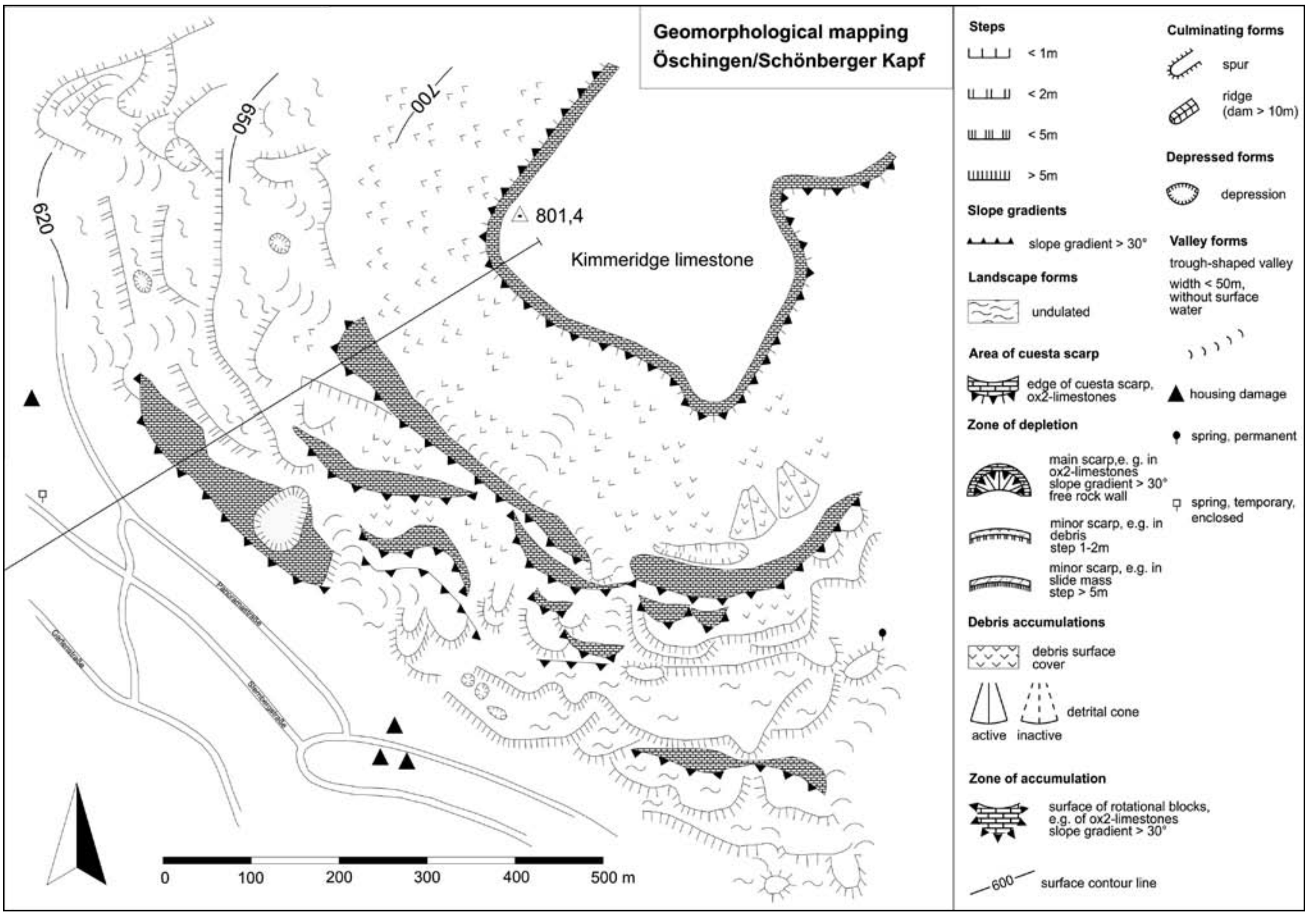

Fig. 11: Geomorphological map of the Auchtert area and the Schönberger Kapf (Stop 4) (Terhorst & Kreja 2009).

Abb. 11: Geomorphologische Karte von Auchtert und Schönberger Kapf (Stop 4) (Terhorst & Kreja 2009).

Fig. 12: Damaged house in the residential area Auchtert (Photo: Birgit Terhorst).

Fig. 12: Beschädigtes Haus im Wohngebiet Auchtert (Foto: Birgit Terhorst).

cient slope areas were locally affected by the landslide event of 1983. Moreover, ^{14}C- datings revealed that minor slope movements took place during the Holocene close to the area of the Mössingen landslide. The datings resulted in 2.285 ± 45 yr and 3.580 ± 90 yr (Bibus 1986).

GIS-based hazard modelling of Thein (2000) suggests that the landslide area is still susceptible to landslides, in particular due to permanent water supply by springs.

Compared to the slope development presented today, it becomes evident that geomorphodynamic processes lead to successive decomposition of ancient slide masses during the Holocene. The reworking and reduction of the slide masses causes instabilities as well as secondary movements, and thus can initiate enormous mass displacements.

Stop 4: Auchtert residential area of Öschingen

The fact that at present slope movements are recognised as natural risks in the study area is due to several damages in local residential areas at the foot of the Swabian Alb cuesta scarp. Especially since the 1970s, building areas have been developed on slopes that are at risk for landslides.

The residential area of Auchtert (stop 4) is situated in the lower slope of the Jurassic escarpment at the Schönberger Kapf near Öschingen / Middle Swabian Alb (Figs. 1 and 9). The settlement area is built in the landslide prone lower slope of the Schönberger Kapf. Damages of houses and infrastructure have occurred repeatedly (Kreja & Terhorst 2005; Terhorst & Kreja 2010). The major part of the Auchtert area is located in expandable Callovian clays and directly related to an ancient slide block of considerable size. Based on mappings (Terhorst 2001; Kallinich 1999), the slide mass can be classified as one of the largest ancient slide masses preserved at the slopes of the Swabian Alb. As a consequence, the near surface underground is made up of diverse and shallow slide masses situated on top of each other (Fig. 10). In the course of earlier geomorphological investigations, the area at the Schönberger Kapf was already mapped and interpreted as an ancient sliding slope (Leser 1982). Geomorphological mapping shows the large rotational block east of the residential area Auchtert. It clearly emerges as a step-like slope section at an altitude of ca. 640 m a.s.l. (Fig. 11) and is ca. 350 m long and 70 m wide (Terhorst & Kreja 2009). It forms an extended planar area with an associated steep slope at its western fringe, which is connected to the residential area (Fig. 9).

According to drillings in the large rotational block by the State Geological Survey of Baden-Württemberg (Geologisches Landesamt 1976), there is a slip plane at a depth of ca. 18 m. Furthermore, geomorphological mapping showed another large rotational block in the upper slope, which is located on top of the lower block (Fig. 11). The lateral NW boundary of this slide complex is connected to a synclinal gully discharge line, which continues into the housing area (Terhorst & Kreja 2009). This gully is responsible for increased water supply and thus for reduced shear strength in this slope section. Currently, there is a terrace house below the described slide complex that is in danger of collapsing (Fig. 12). In close vicinity, slide movements and damages occurred frequently during construction activities. The south eastern area is characterised by several slide masses and close to the cuesta scarp there is another large rotational block. The step-like structures below the block's front indicate a successive displacement of the slide mass and a progressive disintegration process. Steps, depressions, tongue-like dams, debris and wavy surface structures are forming the slope surface indicating former and actual movements in the whole mapping area (Terhorst & Kreja 2009).

The susceptibility map, which is generated by SINMAP (Kreja & Terhorst 2005) shows endangered zones in the residential areas. These zones are classified as highly susceptible in combination with anthropogenic impact and thus reflect the problematic situation here.

Acknowledgement
I would like to thank Daniela Sauer and Bodo Damm for their helpful reviews.

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Pleistocene glaciations in SW Germany and changes of the Danube and Rhine River systems

Daniela Sauer, Karl Stahr

Itinerary:

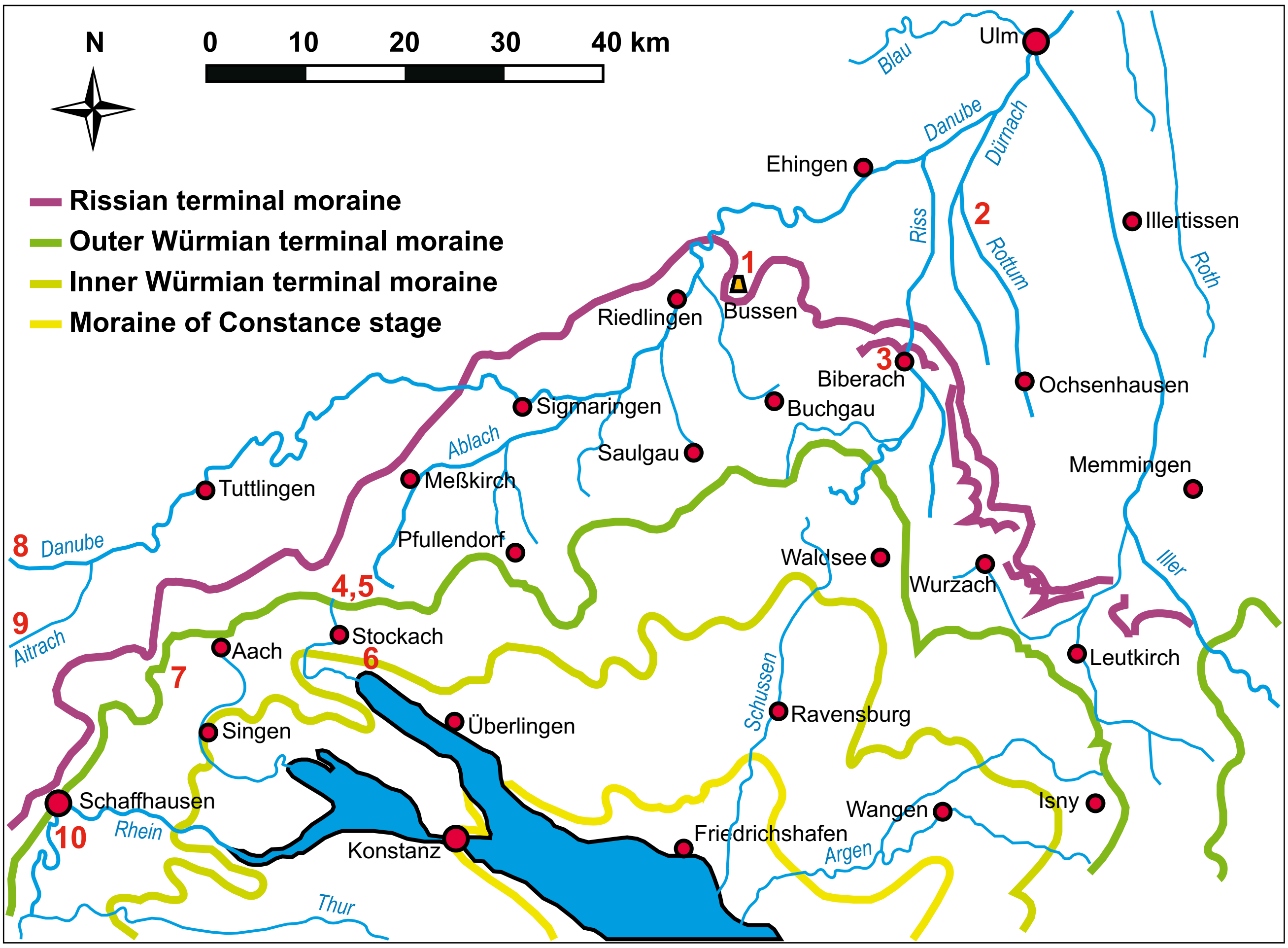

Fig. 1: Excursion area with locations of terminal morains and stops. Based on Schreiner (1997), p. 198, modified.

Abb. 1: Exkursionsgebiet mit Verläufen der Moränenrücken und Exkursionspunkten. Nach Schreiner (1997), S. 198, verändert.

The last two days of the excursion will be dedicated to three major topics forming the structure of this last chapter of the excursion guide. It thus consists of three parts:

- Part A) Penultimate glacial period (Rissian) in the South German Alpine foreland
- Part B) Last Glacial period (Würmian) in the Lake Constance Area, SW Germany
- Part C) Late Pleistocene changes of the Danube and Rhine River systems in SW Germany

The locations of the sites to be shown are indicated in Fig. 1.

Part A Penultimate glacial period (Rissian) in the South German Alpine foreland

Sediments of the Rissian period, i. e. the penultimate glacial period in the forelands of the Alps, will be studied in the eastern Rhine Glacier area, South and Southwest of the city of Ulm. A historical highlight will be the Rissian locus typicus near Biberach.

Sediments of the Rissian glacial period in the eastern Rhine Glacier area include, according to Schreiner (1989, 1997):

Older Rissian:
1) moraines
2) gravel

Middle Rissian (= double ridge Rissian):
1) double ridge terminal moraine, including outer ridge and inner ridge (only in the eastern part of the excursion area, see Fig. 1)
2) glacio-fluvial gravel related to the glacier advance
3) upper high terrace

Younger Rissian:
1) terminal moraines
2) lower high terrace

Older Rissian moraine and gravel deposits are found along the Riss Valley. These deposits are easily recognised in the field due to their stronger degree of weathering compared to the overlying Middle Rissian gravel. Ground moraines occurring in several places north of the Middle Rissian terminal moraine between Meßkirch and Riedlingen (see Fig. 1) are probably of Older Rissian age as well. Older Rissian glacio-fluvial gravel deposits have been preserved in the Dürnach Valley (Fig. 1). In contrast to the Riss Valley, no melt water flow of the Middle Rissian glaciers ran through the Dürnach Valley. Therefore, Older Rissian gravel has been preserved in the Dürnach Valley whereas it has been eroded and replaced by Middle Rissian glacio-fluvial gravel in the Riss Valley.

Middle Rissian (also called double-ridge Rissian) deposits make up the majority of the moraines and glacio-fluvial gravel of the penultimate glacial period in the area that have been preserved. A very characteristic feature of the Middle Rissian is the double-ridge terminal moraine along the eastern boundary of the Middle Rissian Rhine Glacier, between Biberach and Leutkirch (Fig. 1). In this section of the Middle Rissian terminal moraine two moraine ridges, 1-3 km apart from each other, are running NNW-SSE, more or less in parallel, over a distance of approximately 40 km. The two ridges are generally 10-30 m high and represent push moraines, mainly composed of gravel. Weathering on these moraines typically reaches a depth of about 3 m (in the central part of the ridges after Pleistocene or Holocene erosion often only 1–2 m). This moderate weathering depth enables distinction of Rissian deposits from pre-Rissian deposits that are much more intensively and deeply weathered. The limit of weathering is mainly marked by decalcification and clay illuviation.

Stop 1: Mount Bussen – View on the Penultimate Glacial terminal moraine

The terminal moraine of the Penultimate Glacial period can be well observed from the top of Mt. Bussen. The ice advanced from the South, surrounding Mt. Bussen from South, West and East, and depositing its terminal moraine around the mountain from three sides (Fig. 1). Hence, the summit of Mt. Bussen represented a kind of nunatak at that time.

The northern Alps start about 100 km to the South from here. At clear weather conditions the Alps can already bee seen in the distance. The names of the visible peaks are indicated on an explanatory board. Mt. Säntis (above St. Gallen) is the most prominent peak that can be seen.

Stop 2: Gravel quarry at Achstetten near Laupheim

The gravel quarry at Achstetten cuts into glaciofluvial gravel of the Rissian (penultimate glacial) period. Cryoturbation features and fossil ice wedges can be observed within the gravel layers. Soil formation during the last interglacial period has led to a Luvisol that developed in the upper part of the gravel. This soil has in turn been buried by a loess layer during the last glacial period. The Holocene soil – again a Luvisol – has developed in the upper part of the loess layer.

On our way from Achstetten to Biberach we are travelling on the Rissian terrace. On the right hand sight we can look down on the Würmian terrace. Soon after we have passed the road exit to Mietingen, on the left hand side, the outer Middle Rissian terminal moraine is approaching. The inner Middle Rissian moraine follows a few km behind, close to Biberach.

Stop 3: Locus typicus of the Penultimate Glacial period "Rissian" near Biberach

In the former gravel quarry "Scholterhaus" near Biberach we will visit the exposure of Middle Rissian glaciofluvial gravel deposits that reach a maximum thickness of about 60 m in this area. An up to 5 m thick layer of ground moraine is sandwiched between the gravel deposits in this exposure. This alternation of glacio-fluvial and glacial deposits at "Scholterhaus" quarry is historically important because it led Penck and Brückner to the conclusion that several glacier advances must have taken place during the Rissian period.

Part B Last Glacial period (Würmian) in the Lake Constance Area, SW Germany

The excursion will continue from Biberach southwards to Hochdorf where we will have lunch. Afterwards, we will turn West in the direction of Winterstettenstadt. The motorway has already taken us south of the Würmian terminal moraine. We will now cross the Würmian terminal moraine

Tab. 1: Soil properties of Profile Zoznegg at stop 5b.

Tab. 1: Bodeneigenschaften des Profils Zoznegg an Stop 5b.

Horizon	Depth [cm]	Rock fragments [%]	Sand [%]	Silt [%]	Clay [%]	Air capacity [%]	Plant-available field capacity [FC] [%]	Non-plant-available FC [%]
Ah	0–20	0	6.2	65.8	28.0	28	17	22
AB	20–45	0	2.6	63.7	33.9	31	13	18
BEg	45–70	0	2.2	55.0	42.4	17	13	23
Cg	70–100	0	0.2	58.7	41.1	4	6	39

Horizon	Bulk density g cm^{-3}	CaCO3 [%]	pH [CaCl2]	SOM [%]	C/N	Fed [g kg^{-1}]	Feo/Fed	Mnd [g kg^{-1}]
Ah	0.81	0.6	7.01	2.7	10.3	10.10	0.24	1.00
AB	1.09	0.2	7.09	1.1	7.6	9.95	0.17	0.82
BEg	1.23	0.2	6.96	0.1	11.1	11.05	0.13	0.94
Cg	1.36	17.4	7.49	0.3	44.1	6.50	0.09	0.47

Horizon	CECpot mmolc kg^{-1}	Base saturation [%]	Kaolinite [%]	Illite [%]	Mixed layer minerals [%]	Montmor. and Vermic. [%]	Chlorite [%]
Ah	209	100	20	30	25	20	5
AB	206	100	20	30	25	20	5
BEg	211	100	20	30	25	20	5
Cg	145	100	20	35	20	20	5

Fig. 2: Soil developed on Würmian laminated sediments of an ice-scour lake near Zoznegg: Vertic Stagnosol.

Abb. 2: Boden, der sich in würmzeitlichen laminierten Sedimenten eines Eisstausees Nähe Zoznegg entwickelt hat: Vertic Stagnosol.

Fig. 3: View over the area around northern Lake Constance, characterized by hilly relief due to Last Glacial till deposited in the area.

Abb. 3: Blick über die Umgebung des nördlichen Bodensees, aufgrund der würmzeitlich abgelagerten Moränen geprägt durch ein hügeliges Relief (Jungmoränenlandschaft).

again from South to North between Winterstettenstadt and Ingoldingen. Here, we will also have a view on a wide gap in the moraine ridge, indicating the position of a Würmian glacier snout. West of Ingoldingen, situated on a Würmian glacial outwash terrace, we will see the famous baroque basilica of Steinhausen. We will then pass another meltwater mouth between Bad Schussenried and Bad Buchau. We will pass the trail of the "Swabian Railroad" ("Schwäb'sche Eisenbahn") and an important Palaeolithic site at the spring of the Schussen River. We will continue our way on the Würmian terrace, following the outer Würmian terminal moraine to our left-hand side to the West (see Fig. 1 for location of outer Würmian terminal moraine), studying Würmian glacial, glacio-fluvial and laminated limnic sediments along the way.

Stop 4: Mühlingen

Standing on a hill formed of Rissian ground moraine we have a good overview on a dry Rissian ice-scour lake and its surroundings. The Aach River has cut its way through the Rissian till, thus finally draining the ice-scour lake. In the background, the Würmian terminal moraine is visible, covered by forest. A gap in the moraine ridge indicates the location of a glacier snout of the Würmian glacier.

Stop 5a: Zoznegg sand quarry

This quarry exposes sandur deposits distributed in front of the Würmian glacier snout.

Stop 5b: Zoznegg soil profile on glacio-limnic laminated sediments

A permanent soil pit has been established by Hohenheim University on the laminated sediments of the former ice-scour lake. Texture of the sediments is silty-clayey, with silt contents ranging between 59 and 66% and clay contents of 28–42% throughout the soil profile (Table 1). The soil is characterised by a very strong soil structure being granular in the top soil and angular blocky to prismatic in the sub soil (Figure 2). This well-expressed stable soil structure is caused by swell-shrink dynamics due to abundance of expandable clay minerals, including Montmorillonite, Vermiculite and mixed-layer minerals, in total making up about 45% of the clay mineral assemblage in the upper part of the soil. Despite these dynamics rarely large cracks and no slicken sides are observed so that the soil cannot be classified as a Vertisol. Hydromorphic features indicate perched water for some time of the year. Together with the high clay content and strong soil structure described above, the temporally hydromorphic conditions have led to formation of a Vertic Stagnosol. The soil has a dark Ah horizon (colour 10YR4/3) with granular structure, followed by a slightly lighter AB horizon (colour 10YR4/4) with granular to subangular blocky structure. Below, a BEg horizon (colour 2.5Y4/2) is present. Its strong angular blocky to prismatic structure leads to good water permeability. The observed hydromorphic features are caused by the underlying Cg horizon (colour 10Y5/2 and 2.5Y5/6) with weak coarse angular blocky to massive structure.

Fig. 4: Satellite image of Lake Constance with the main lake called "Upper Lake" and the two arms of the lake pointing to the North-West, called "Lake Überlingen" (northern arm) and "Lower Lake" (southern arm). Ludwigshafen (yellow dot), where the excursion group will stay overnight, is located at the shore of Lake Überlingen (source: Wikimedia Commons; http://de.wikipedia.org).

Abb. 4: Der Bodensee im Satellitenbild mit dem Obersee, der den Haupt-Seekörper bildet, und den beiden nach NW weisenden Armen, dem Überlinger See (nördlicher Arm) und dem Untersee (südlicher Arm). Ludwigshafen, der Übernachtungsort der Exkursion, liegt am nördlichen Ufer des Überlinger Sees (Quelle: Wikimedia Commons; http://de.wikimedia.org).

Table 2: Soil properties of the Histosol at stop 7.

Tab. 2: Bodeneigenschaften der Moores an Stop 7.

Horizon	Depth [cm]	Rock fragments [%]	Sand [%]	Silt [%]	Clay [%]	Pore volume [%]	Field capacity (FC) [%]	Bulk density g cm^{-3}
Ah	0–10	1	19.7	41.2	39.1	71	35	0.67
Bw	10–25	5	24.4	43.7	31.9	61	50	0.97
Bg	25–35	5	26.3	39.9	33.8	67	51	0.80
2H1	35–48	0	19.0	41.5	39.5	n. d.	78	0.43

Horizon	CaCO3 [%]	pH (CaCl2)	SOM [%]	C/N	Fed [g kg^{-1}]	Feo [g kg^{-1}]	Feo/Fed	Mno [g kg^{-1}]
Ah	13.4	7.6	14.4	11.7	30.5	7.3	0.24	1.9
Bw	18.3	7.7	7.4	9.2	33.9	8.8	0.26	2.6
Bg	19.1	7.7	7.4	9.3	40.5	11.5	0.28	0.3
2H1	18.6	7.5	67.4	14.5	38.3	10.9	0.28	0.9

Horizon	CECpot mmolc kg^{-1}	Base saturation [%]	Kaolinite [%]	Illite [%]	Mixed layer minerals [%]	Smectite [%]	Chlorite [%]
Ah	593	89	4	7	14	66	4
Bw	534	80	4	6	9	75	5
Bg	520	82	4	7	10	72	6
2H1	752	83	4	6	11	70	7

G

Stop 5c: Zoznegg gravel quarry

In this quarry sandur sediments related to the advancing Würmian glacier are exposed. They are overlain by Würmian till in the uppermost section of the exposure.

Stop 6: Lake Constance

The area around Lake Constance is characterised by the hilly relief formed by the Last Glacial moraine landscape (Figure 3). We will stay overnight at Ludwigshafen, directly at the northern shore of Lake Überlingen, which is the northernmost part of Lake Constance (Figures 4 and 5). Lake Constance is a huge ice-scour lake that obtained its present shape by glacial erosion during several glacial periods. It consists of the main lake called "Obersee" (Upper Lake; area: 412 km2) and two arms pointing to North-West, the northern one called "Überlinger See" (Lake Überlingen, after the town Überlingen; 61 km3), and the southern one called "Untersee" (Lower Lake, area: 63 km2). Lake Constance is located at 395 m a.s.l.; it comprises a volume of 48 km^3 of water, having an average water depth of 90 m and a maximum depth of 254 m.

The central part of the Lake Constance Basin has been carved down to more than 100 m below sea level (Geyer et al., 2003: 142). Its development is assumed to have started during the Cromer Complex period, the period of greatest extension of glaciers in the northern Alpine foreland, which lasted from about 900 to 500 ka BP, thus from the end of the Early Pleistocene to the middle of the Middle Pleistocene. At that time, several deep basins were shaped in the area, including Lake Constance and, to the South-West Lake Greifensee, Zürichsee and Hallwiler See (Geyer et al., 2003: 143). Szenkler & Bock (1999) assume that the origin of theses deep basins is related to deep glacial erosion accompanying the early Cromerian glacial advances. Unusually deep basins were carved particularly along Tertiary tectonic faults. According to Szenkler & Bock (1999) the extremely deep erosion was produced by both sub-glacial melt water under high hydrostatic pressure and glacial erosion. The basins were later repeatedly filled by sediments and eroded again by glaciers advancing in subsequent glacial periods. Today, large proportions of the deep basins are filled by sediments, and only the minor parts form lakes. For instance, the area between the north-western shore of "Untersee" (Lower Lake") and the town of Singen (see Fig. 1) also belongs to the deep basin of Lake Constance but is completely filled by gravel.

Lake Constance represents also an important drinking water reservoir. The lake supplies each year 180 million cubic metres of drinking water for 4.5 million people in South-West Germany and Switzerland.

Stop 7: Fen in Last Glacial dead ice kettle near Weiterdingen

This first stop in the morning of the last excursion day will be at a fen that has developed in a Last Glacial dead ice kettle on Würmian till. The fen has been covered by a 35 cm thick layer of colluvial material. Therein, a Gleysol has developed, comprising three soil horizons: a dark Ah horizon (colour 10YR4/2) with a very loose, spongy soil structure and ex-

Fig. 5: View from Lake Überlingen to the South, over the Upper Lake, in the direction of the Alps, which can be seen on clear days on the other side of the lake.

Abb. 5: Blick vom Überlinger See Richtung Süden, über den Obersee. Bei klarem Wetter sind auf der anderen Seite des Sees in der Ferne die Alpen zu erkennen.

tremely high root density, underlain by a Bw horizon (colour 10YR3/3) with subangular blocky structure and comprising several pieces of bricks. Below, the groundwater-influenced Bl horizon follows (colour 10YR4/6) also characterised by subangular blocky structure and pieces of bricks. Three soil horizons are distinguished within the underlying peat. The uppermost peat horizon, 2H1 (colour 7.5YR2/3) and the second peat horizon, H2 (colour 7.5YR3/3), consist of largely decomposed plant material. The third peat horizon, H3 (colour 7.5YR3/2-2/2), consists of only partly decomposed plant material. Among the peat horizons only the uppermost one has been analysed (Table 2). The onset of sedimentation could be traced back by pollen analysis to the Late Würmian.

Part C Late Pleistocene changes of the Danube and Rhine River systems in SW Germany

The rest of the last excursion day will deal with the Pleistocene history of the Danube and Rhine river systems. We will see dry valleys illustrating the river history. Highlights will be a walk into the Wutach Canyon and a short boat trip across the Rhine River looking at the famous Rhine water fall.

During Miocene, a large Pre-Danube river system developed, running SW-NE, into which all rivers north of the Alps discharged at that time (Geyer et al., 2003) (Figure 6a). The main tributaries of the Pre-Danube were the rivers that are today the Aare (Figure 6c) and Rhone Rivers. Its headwaters are therefore also called Aare-Danube. In addition, an important tributary discharged to the Pre-Danube from the Black Forest in the West: the Feldberg-Danube. During the Upper Pliocene, the source of the Pre-Rhine moved further South until it reached the course of the Aare-Danube, which from then on discharged into the Rhine River system. Also the Wutach River stopped discharging to the Danube River and followed the greater inclination to the Rhine River system (as shown in Figure 6b). Some time later, during Early Pleistocene, the Alpine Rhine (still discharging to the Danube River in Figure 6a) became part of the Rhine River system (Figure 6b). A precursor of Lake Constance probably occurred for the first time when the Rhine glacier of the Günz,

the fourth last glacial period, retreated. It was probably completely filled by sediments in the subsequent interglacial period, and repeatedly carved in by glaciers during the following glacial periods and filled by sediments in the interglacial periods in between. Today's Lake Constance formed during the retreat of the Würmian Rhine glacier. It had its greatest extend about 14 000 years BP. Sediments deposited by the rivers discharging into Lake Constance led to segregation of several lake sections (Upper Lake, Lower Lake, Lake Überlingen; see Figure 4).

Stop 8: **Donaueschingen**

On our way we will have a short stop at Donaueschingen to visit the modern origin of the Danube River at the confluence of the rivers Brigach and Breg, which are draining the central part of the Black Forest.

Stop 10: **Wutach Canyon**

The Rhine River runs along the bottom of the Rhine Graben – thus on a much lower level than the Danube River. Hence, after the Wutach River had been connected to the Rhine River system, it started cutting down through the Midle Triassic limestone, creating the Wutach Canyon (Ricken & Einsele, 1993), a narrow canyon with in places vertical limestone walls (Figure 7). At a first Wutach Canyon stop, gravel of the time when the Wutach was still part of the Danube River system will be visited near the rim of the Wutach Canyon. Afterwards, we will hike down the canyon to get an impression of the enormous forces that became active after the Wutach River started discharging into the Rhine River.

Stop 11: **Rhine River Water Fall**

The last stop of the excursion will be at Neuhausen (Switzerland). From here, we will cross the Rhine River by boat, shortly downstream the Rhine River Water Fall, so that we will get a close view on the largest water fall of Europe (whereas our bus will use the bridge to get on the other side). The Rhine River waterfall is 150 m wide and 23 m high, and 600 000 litres of water pass the waterfall per second.

Until the onset of the penultimate glacial, the Rhine River was flowing from Lake Constance to the West. This former Rhine valley was then successively filled up by Alpine gravel. During the Rissian glacial the Rhine River was thus redirected to the South from Schaffhausen on, as its formerly used valley to the West had been blocked by the gravel. However, soon the new pathway to the South also started filling up with gravel, and during the last glacial period, the Rhine River was again re-directed, following a large bow to the South before reaching its present bed on hard Upper Jurassic limestone just above the waterfall. The water was thus now flowing from the hard limestone to the gravel-filled valley that the Rhine River had used already in the penultimate

Fig. 6: Mayor changes of the Danube and Rhine River systems from 10 million years BP until present. Dark blue: Rhine River system tributaries, light blue: Danube River system tributaries.

Abb. 6: Wesentliche Veränderungen der Flusssysteme der Donau und des Rheins in den letzten 10 Mill. Jahren. Dunkelblau: Rheinzuflüsse, hellblau: Donauzuflüsse.

Fig. 7: Wutach River and steep walls of Middle Triassic limestone making up the Wutach Canyon. Photo: J. Kühnemund, source: www.badische-zeitung.de.

Abb. 7: Die Wutach, umgeben von steilen Wänden aus Muschelkalk, in den sich die Wutachschlucht eingeschnitten hat.

Fig. 8: Rhine River Water Fall – Europe's largest water fall.

Abb. 8: Der Rheinfall – Europas größter Wasserfall.

glacial. The gravel was successively eroded, whereas the hard limestone persisted, leading to the development of the waterfall at about 15 000 years BP.

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