Quaternary Stratigraphy, Paleoenvironments and

Geoarchaeology in central Germany

August 25 – 29, 2025

Michaelstein Abbey, Saxony-Anhalt, Germany

Excursion Guide

Edited by Henrik Rother & Andreas Börner

(with contributions from C. Brandes, H. Helbig, J. Keßels, F. Lehmkuhl, J. Lang, K. Schuberth and S. Wansa)

Sachsen-Anhalt

Reference

Quaternary Stratigraphy, Paleoenvironments and Geoarchaeology in central Germany. Excursion guide of the INQUA Peribaltic Working Group international field symposium, August 25-29, 2025. Edited by Rother, H., Börner, A., Halle (Saale) 2025.

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Cover Photo

Michaelstein Abbey (Kloster Michaelstein), the venue of the Peribaltic 2025 Field Symposium, is a former Cistercian monastery founded in the 12. century near the town of Blankenburg in the Harz Mountains of Saxony-Anhalt, Germany.

INQUA Sachsen-Anhalt Mecklenburg Vorpommern

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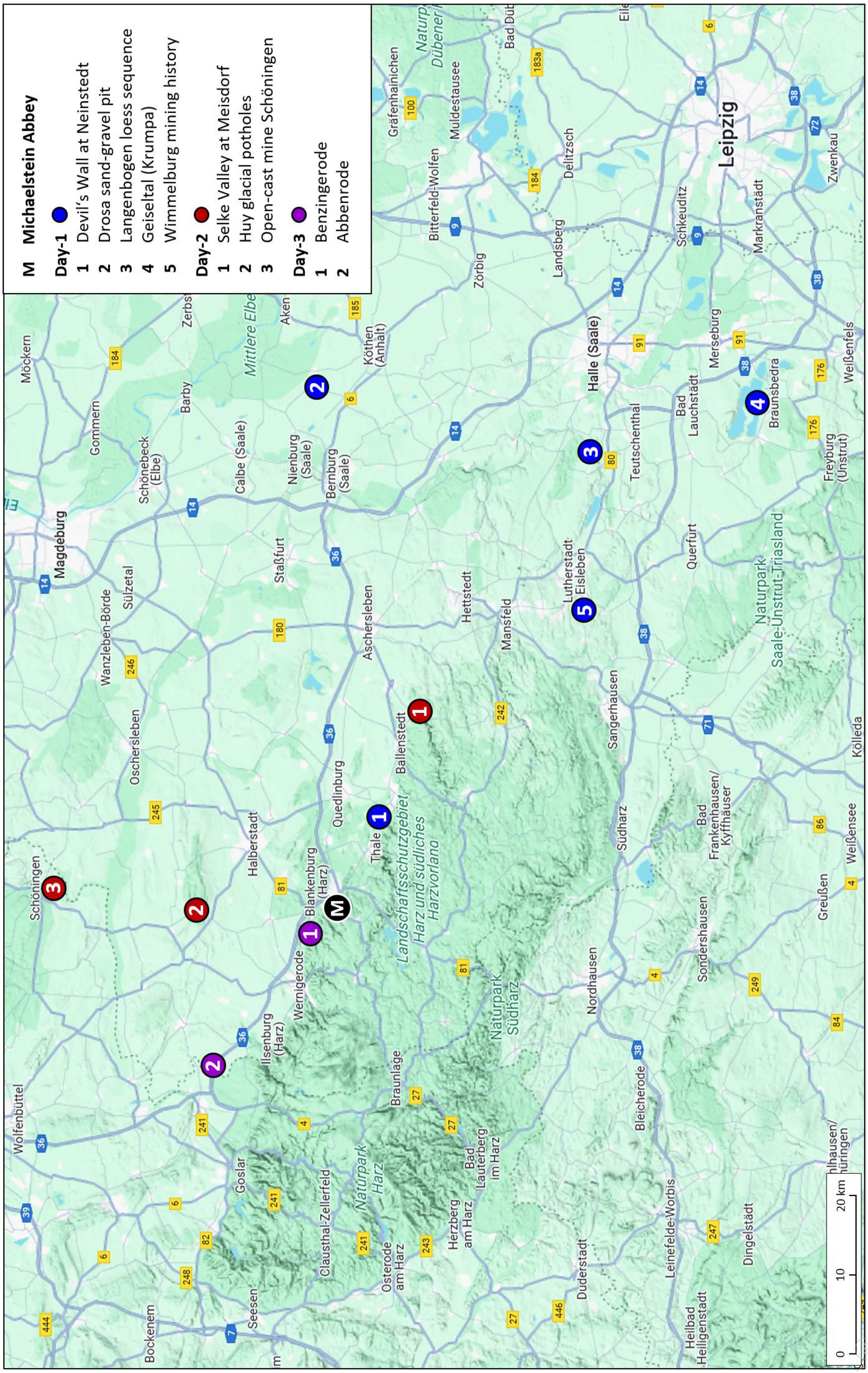

Introduction to excursion area

Overview Harz and its northern and eastern foreland

The excursion area covers the northern and eastern Harz foreland and small parts of the Harz itself. Forming a prominent NW-SE striking (95 x 35 km) topographic high, the Harz reaches a maximum altitude of 1,141 m a.s.l. (Brocken). The mountains constitute a deeply eroded block of uplifted Variscan basement of predominantly low-grade metamorphic Devonian and Lower Carboniferous clastic strata and several granite intrusions that were emplaced during the early Permian (Fig. 1). Structurally, the Harz represents a south-tilting block, bound to the north by a major reverse fault, the so-called Harz Northern Boundary Fault (‘*Harznordrandstörung’*) which separates the Harz from the adjacent Subhercynian Cretaceous Basin (SCB). Beginning in the late Cretaceous compressional stresses led to the inverse reactivation of older extensional faults and the uplift of Variscan basement such as the Harz block, accompanied by the thrusting of these blocks over their Mesozoic foreland basins (VOIGT et al. 2006).

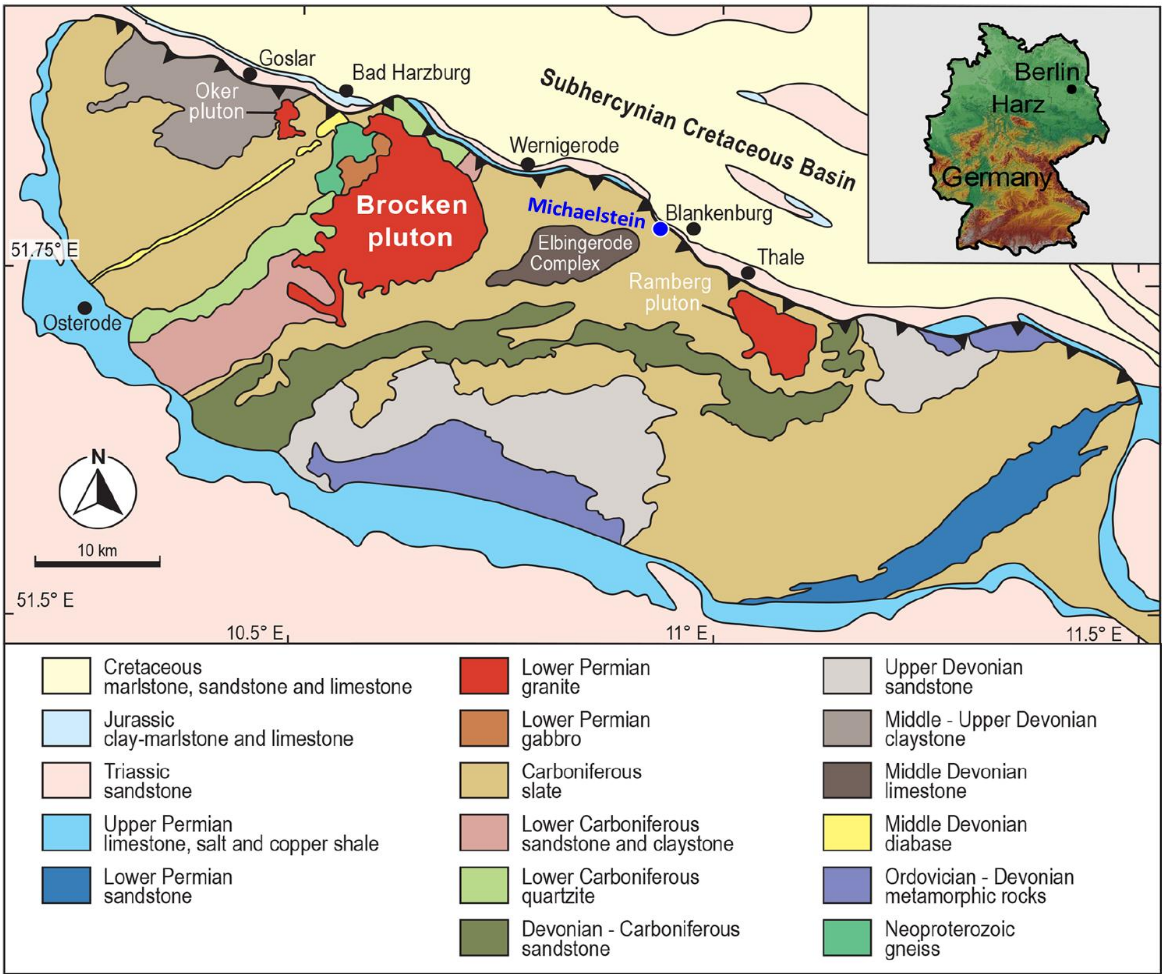

Fig. 1: Geological overview map of the Harz Mountains, the Harz Northern Boundary Fault (black line with triangles), and the adjacent Subhercynian Basin in central Germany (redrawn map from HINZE et al. 1998).

The Subhercynian Cretaceous Basin (SCB) itself represents a narrow structure bordered to the south by the Paleozoic Harz block and to the northeast by several halotectonic anticlines including the *Huy* which expose Triassic rocks at the surface (Fig.2). The main portion of the sedimentary fill of the SCB consists of up to c. 2.500 m syntectonic deposits that have played a key role for reconstructing the regional tectonic history of Northern Germany (e.g. EYNATTEN et al. 2008). During the Neogene the Harz block was heavily eroded forming a peneplain across the Paleozoic basement and extending into the foreland. This was followed by a renewed phase of tectonic activity during the Miocene/Pliocene periods generating the modern Harz topography (THIEM 1974).

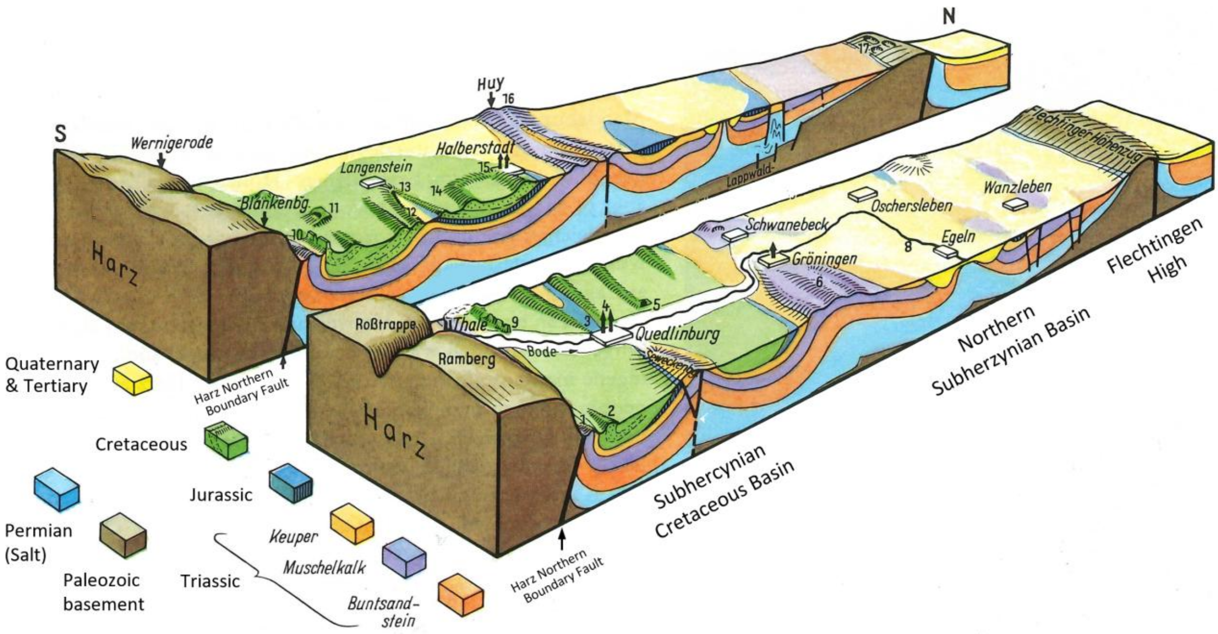

Fig. 2: Schematic model of the Harz and its northern foreland (modified from WAGENBRETH & STEINER 1989).

Quaternary Geology

Within the larger context the Harz region marks the geographic transition between areas that were directly influenced by the former northern glaciations and the periglacial zone of Central Europe during the Quaternary. The excursion area features an extensive array of frequently loess covered Quaternary sediments, the oldest of which comprise isolated remnants of preglacial Middle Pleistocene fluvial deposits that characteristically lack any clast lithologies of Scandinavian or north-German provenance. During the mid-Pleistocene Elsterian and Saalian glaciations (see chrono- and climate stratigraphic table, pg. 42) the Fennoscandian ice sheet glaciated the entire region and advanced across the lower portions of the eastern Harz mountains itself (EISSMANN 2002). Of these glaciations, the Elsterian stage represents the most extensive regional glaciation with a maximum ice position located far south of the Harz within the Thuringian Basin and at the foot of the Erzgebirge (Ore Mountains, Fig. 3). During each of the Middle Pleistocene glaciations the regional drainage system was completely rearranged, as rivers that previously drained northward to the Baltic and North Sea were dammed and re-routed. Thus, the stratigraphic sequence of each major advance cycle begins with varved clays deposited in ice dammed lakes, followed by tills and different types of meltwater sediments (LITT & WANSA 2008).

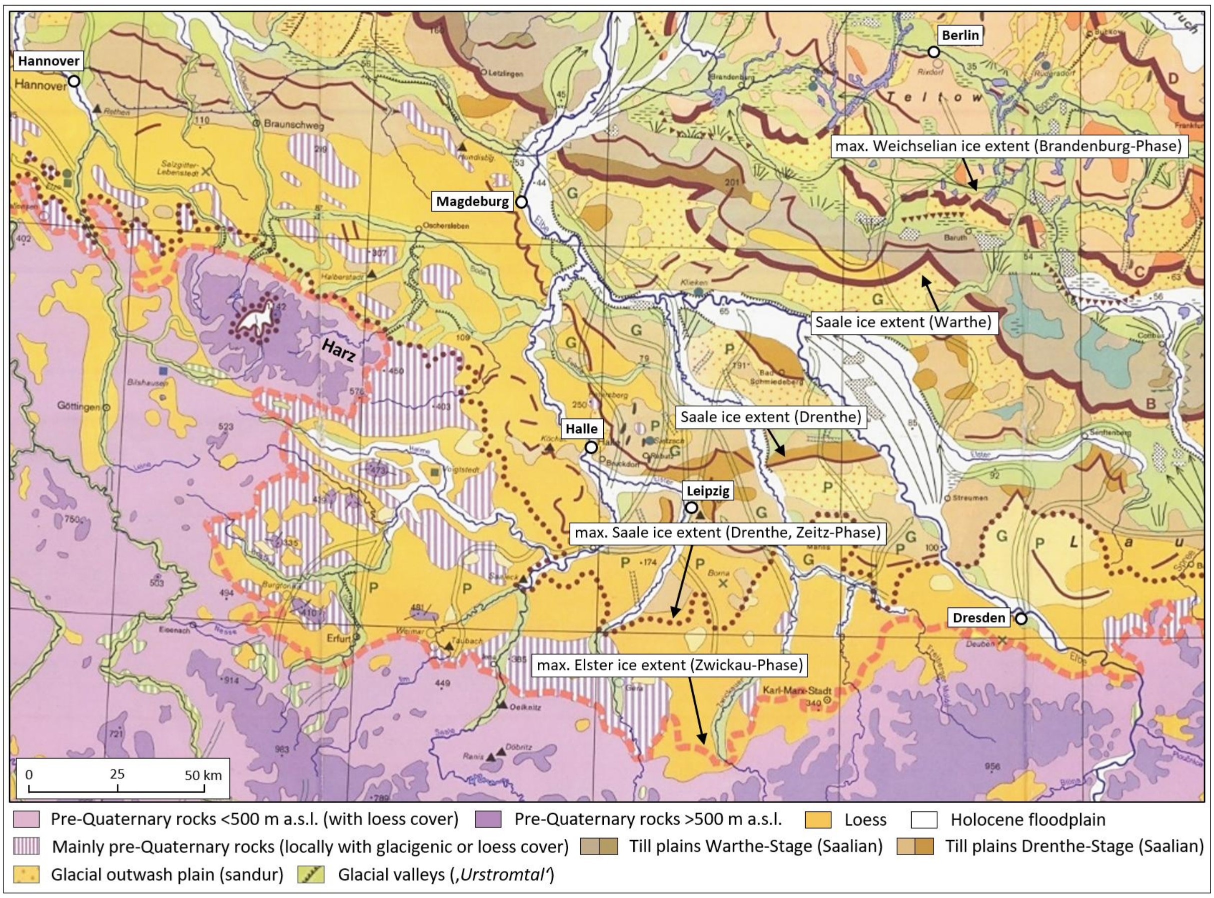

Fig. 3: Simplified geological map of eastern central Germany showing the principal distribution of Quaternary sediments and main ice limits during the Elsterian, Saalian and Weichselian glaciations (after LIEDTKE 1981).

Across the excursion area preglacial fluvial units, Elsterian glacial sediments as well as Holsteinian interglacial deposits were usually eroded during later stages and are only preserved locally in depressions that formed due to subrosion or salt movement. The subsequent Lower Saalian Complex is further subdivided into alternating interstadial, stadial and at least two additional fully developed interglacial stages (WANSA et al. 2019, see table pg. 42). Predominantly within the colder stages of this period extensive fluvial gravel accumulations were built. The most significant of these aggradational pulses formed the so called *Hauptterrasse* (*Main Terrace*, part of the Middle-Terrace Formation), constituting gravel bodies averaging 8 – 15 m in thickness, that are widely distributed across the northern and eastern Harz forelands (e.g. EISSMANN 1994). These gravels are also of archeological significance as they contain an important inventory of Paleolithic stone artefacts (BERNHARDT et al. 1997; LAUER & WEISS 2018).

During the Upper Saalian Complex the continental ice sheet re-advanced into central Germany glaciating the Subherzynian Basin and reaching the Harz and beyond during the Drenthe Stage (older Saalian glaciation). In contrast to the Elsterian glaciation, where the eastern Harz was ice overridden up to an altitude of c. 450 m a.s.l., the Drenthe ice only reached altitudes of c. 200 m a.s.l. there (LITT & WANSA 2008). Drenthe Till and associated meltwater deposits are commonly found across the excursion area. During the younger Saalian (Warthe) and the Weichselian cold stage, glaciers did not reach the area anymore and periglacial conditions prevailed. Weichselian deposits (aeolian loess and reworked loess, mass flow deposits) are widespread on higher lying surfaces, with fluvial accumulation forming the Weichselian lower Terrace system (*Niederterrasse*).

A key feature of the regional Quaternary succession is the repeated interfingering of northern-derived glacial facies with southern-derived fluvial facies, interbedded with periglacial sediments, primarily solifluction and loess deposits. The resulting stratigraphy is further complicated by repeated phases of fluvial aggradation (during the pre-Elsterian,

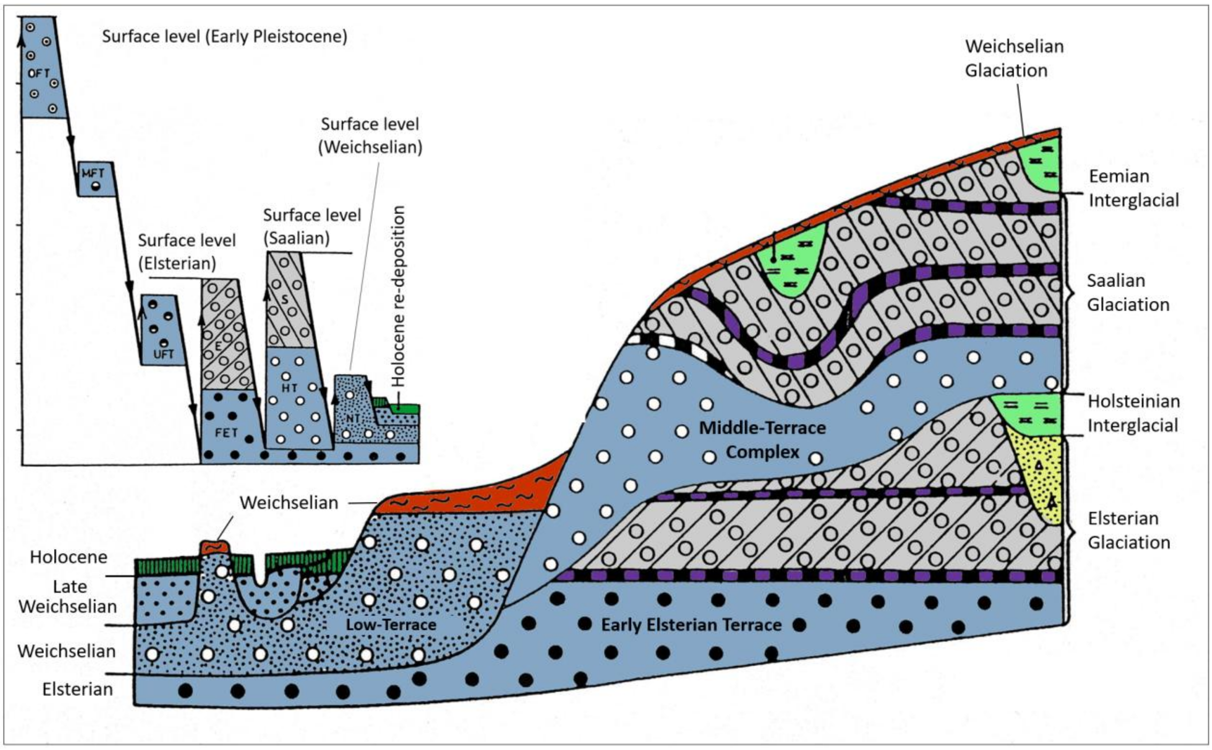

Fig. 4: Conceptual model of accumulation and erosion with its resulting lithofacies architecture of the Quaternary in central Germany (modified after EISSMANN 1994). Different aggradational gravel bodies are traditionally referred to as 'terraces', not to be understood in a morphological sense. Across the region the gravels of the Main-Terrace Complex separate the Elsterian and Saalian glacial sequences, and serve as a lithostratigraphic marker horizon of regional significance.

Elsterian, Saalian and Weichselian stages) and multiple phases of interstadial/interglacial erosion. The resulting regional Quaternary sequence forms a complex depositional stack associated with different surface levels (Fig. 4). Including the older pre-glacial fluvial deposits, three sets of terrace systems can be differentiated in the northern Harz foreland based on their relative position above the modern floodplain and their petrographic clast composition. Of these, the highest and oldest terraces level is found 35 - 70 m above the modern river representing pre-Elsterian fluvial aggradation. A second flight of terraces, the abovementioned *Hauptterrasse*, is located 15 - 20 m above the modern drainage. Finally, a lower terraces system, associated with accumulation during the Weichselian cold stage, is found c. 1 m above the modern river level (WEYMANN et al. 2005).

Day 1 / Stop 1: Devil's Wall (*Teufelsmauer*) at Neinstedt / Weddersleben
(Coordinates: 51°45'27"N, 11°04'59"E)

Over a distance of approximately 20 km at the northern Harz margin the so-called Devil's wall exposes tectonically rotated and nearly vertically-standing Upper Cretaceous sandstone beds (70-80° NE). The location offers a good introductory overview across the excursion area and its key structural units chiefly including the Harz Mountains to the south and the Subhercynian Cretaceous basin (SCB) to the north. The Paleozoic rocks of the Harz block are locally separated from the Mesozoic sedimentary sequences of the SCB by the Harz Northern Boundary Fault (*Harznordrandstörung, HNBF*). The crest segment at Stop 1 (*Königsstein*) is formed by the Heidelberg-Sandstone deposited during the Upper Santonian period. Percolating silica-rich fluids led to localized silicification and lithological hardening of some beds. Rotational steepening and up-bending of the Mesozoic strata in the SCB was caused by Late Cretaceous regional-scale compression leading to crustal shortening, uplift and thrusting of the Harz Mountains over the SCB foreland strata (Fig. 5). Movement occurred along the HNBF, located approximately 2.5 km SSW of Stop 1, a fault system originally generated during the Variscan orogeny and reactivated during Late Cretaceous intraplate thrusting. Based on the sedimentary record and its relationship to various unconformities the deformation took place during the Santonian to Campanian periods (i.e. 86 - 71 Ma, VOIGT et al. 2004).

Overturning of all marginal strata in the SCB, including the Cretaceous units containing the silicified Devil's wall beds, explains the visible vertical attitude of the exposed bedding. Subsequent differential erosion preferentially stripped away surrounding weaker cemented strata sculpturing out the well-lithified sandstone of the Devil's wall hogback. At Stop 1 the Devil's wall reaches its highest point (332 m a.s.l.), c. 50 m above the nearby Bode River.

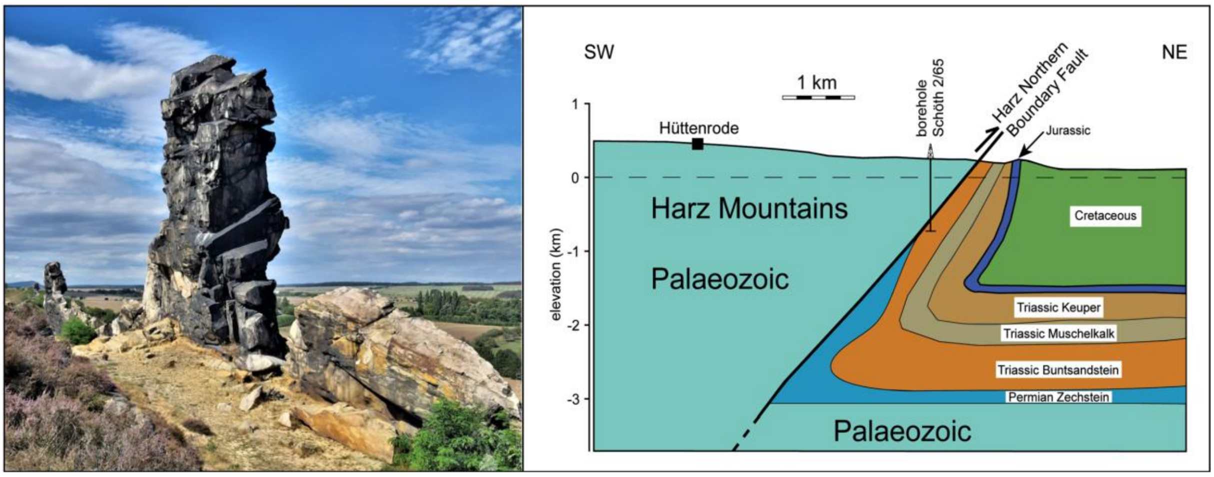

Fig. 5: The Devil's Wall (left) and a simplified cross-section of the northern boundary of the Harz Mountains (right) (Diagram: FRANZKE et al. 2004; TANNER & KRAWCZYK 2017).

Day 1 / Stop 2: The mid-Pleistocene depositional sequence of the sand-gravel-pit Drosa
(Coordinates: 51°48’24”N, 11°54’47”E)

Located on an interfluve c. 25 m above the Saale River to the west and the Elbe River to the east, the pit at Drosa displays a depositional sequence from the Elsterian to the Saalian glaciation. The local Quaternary reaches a depositional thickness of c. 15 m and is underlain by Middle Oligocene clastic sediments. The basal unit of the exposed profile at Drosa is formed by 3-5 m of light-colored, well-stratified glaciofluvial fine to medium sand with occasional thin pebble beds. Bedding indicates deposition from the NE. Above an erosional contact and a gravel lag deposit with ventifacts follows a 3-5 m thick package of horizontally to cross-bedded coarse-grained gravels with occasional sandy to silty interbeds (Fig. 6). This unit represents the ‘Main Terrace’ deposit of the so-called Middle-Terrace Formation, the latter representing

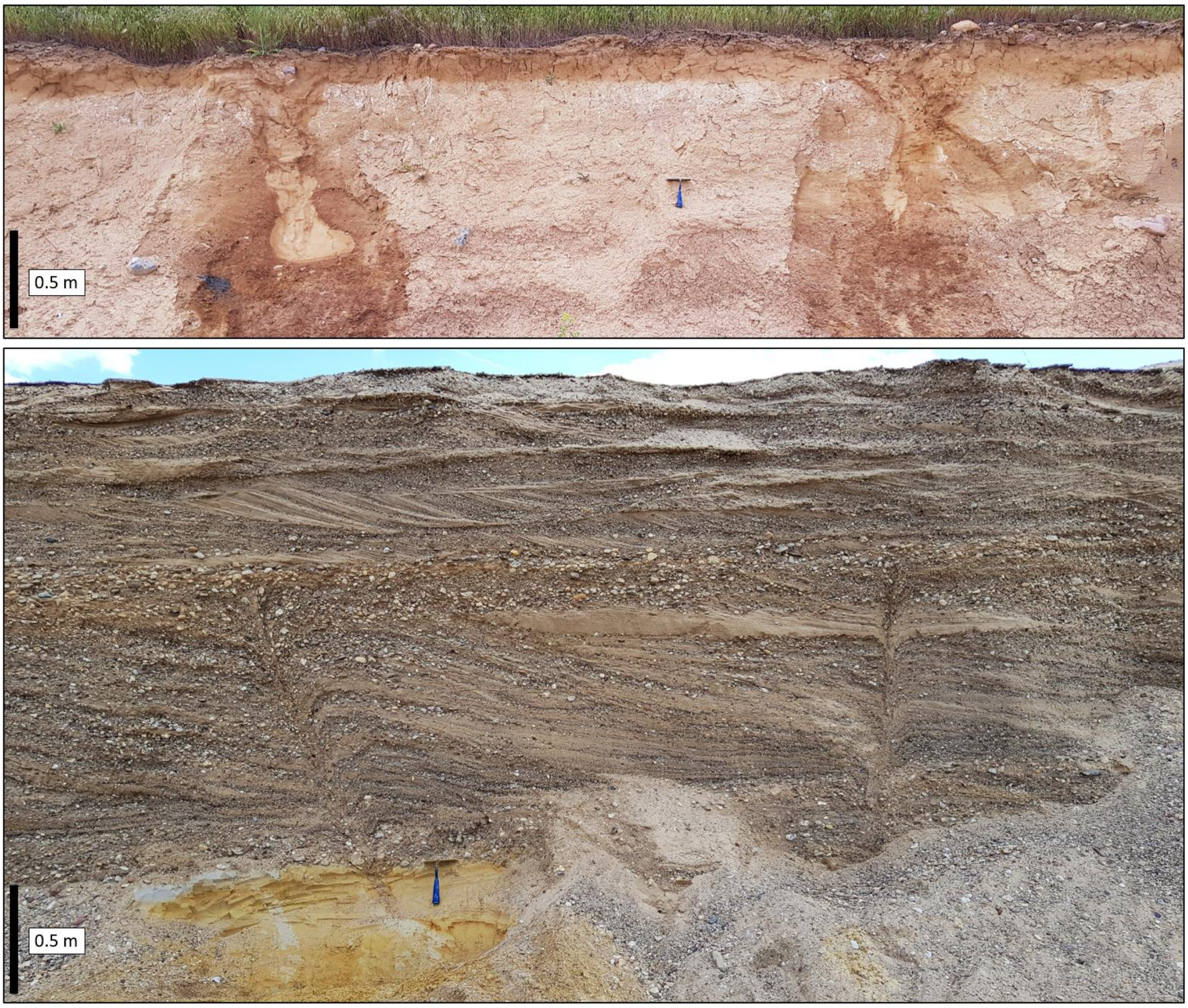

Fig. 6: ‘Main Terrace’ (*Hauptterrasse*) gravels (lower image) at Drosa, showing the typical differentiation into several subunits. Periglacial deformation structures including intraformational fossil ice wedge casts are common. The Main Terrace gravels, in turn, are overlain by a Saalian (penultimate) glaciation till (Drenthe stage, MIS 6) locally showing pocket-shaped cryogenic deformation structures (upper image). Sandy material obtained for OSL dating from the pocket infill of these features by R. Sokolowski (2019) returned MIS-2 (Weichselian) ages.

different gravel bodies preserved at varying elevations, all of which are associated with fluvial aggradation during the Saalian Complex (MIS 10 to Mis 6). Gravel lithologies within this unit comprise 90 % regionally sourced Paleozoic and Mesozoic rocks from the Saale and Mulde River catchments (i.e. greywacke, quartzite, rhyolite, clay slate, radiolarites, limestone, sandstone, residual quartz) and only about 5-10 % clasts of Scandinavian provenance (due to the reworking of older Elsterian deposits).

The depositional architecture of the Main Terrace indicates several cycles of accumulation, with intermediate breaks in sedimentation during which a rich inventory of periglacial and cryogenic deformation structures developed (Fig. 6). The fluvial aggradation of the Main Terrace occurred by northward-flowing rivers throughout the Lower and Upper Saalian Complex, with most of the depositional volume aggraded during the Delitzsch Phase, prior to the first Saalian ice sheet reaching central Germany (see chrono- and climate stratigraphic table, pg. 42). At Drosa, the Main Terrace is overlain by a c. 3 m thick light-brown, highly consolidated massive diamicton with a silty to sandy matrix containing erratics that reach up to 40 cm in diameter. The unit represents a penultimate glaciation till, associated with the Drenthe stage (Zeitz-Phase) of the Saalian glaciation. Clast lithologies within the till are characterized by a high proportion of nordic crystalline rocks and Paleozoic limestone as well as regionally sourced residual quartz clasts, incorporated by the glacier as it advanced over pre-existing gravel surfaces into central Germany. In the southern portion of the Drosa pit the till forms the present land surface, while further to the north the till is overlain by a further unit of glaciofluvial gravels reaching up to several meters in thickness (Drenthe stage).

Day 1 / Stop 3: Loess-paleosol sequence at Langenbogen ('Hammerlöcher') (H. Helbig, LAGB) (Coordinates: 51°29'14"N, 11°46'22"E)

Weichselian loess and loess derivates are widely distributed across the northern and eastern Harz foreland, forming a c. 50 km wide closed loess belt, extending in more separated patches further to the east into the Leipzig Bay and Lausitz area. Loess thicknesses rarely exceed 2.5 m, only in some settings greater thicknesses of up to 10 m can be reached (e.g. in subrosion depressions). One such setting occurs near the village of Langenbogen, located approximately 20 km west of Halle (Saale) at the southern limits of the Polleben loess plateau and within the larger structural Mansfeld basin. Below Quaternary cover deposits, the near-surface geology of the basin comprises Middle Triassic (*Muschelkalk)* carbonate rocks within the central portion of the basin, but to a larger extent Lower Triassic (*Buntsandstein*) as is the case at the Langenbogen site where clastic rocks of the Detfurth-Formation directly underly the local Quaternary sequence.

Climatically, the eastern Harz foreland is part of the so-called Central German Dry Region in the rain shadow of the Harz Mountains where mean annual precipitation is generally below 500 mm and can even drop to under 400 mm in drier years. Seasonally, precipitation minima are recorded during the winter months, while the local maxima occur during the summer where they are associated with heavy rain events and thunderstorms. The local substrate (loess) and the regional climatic conditions supported the development of widespread chernozems, which in slope positions and when eroded form loess pararendzinas.

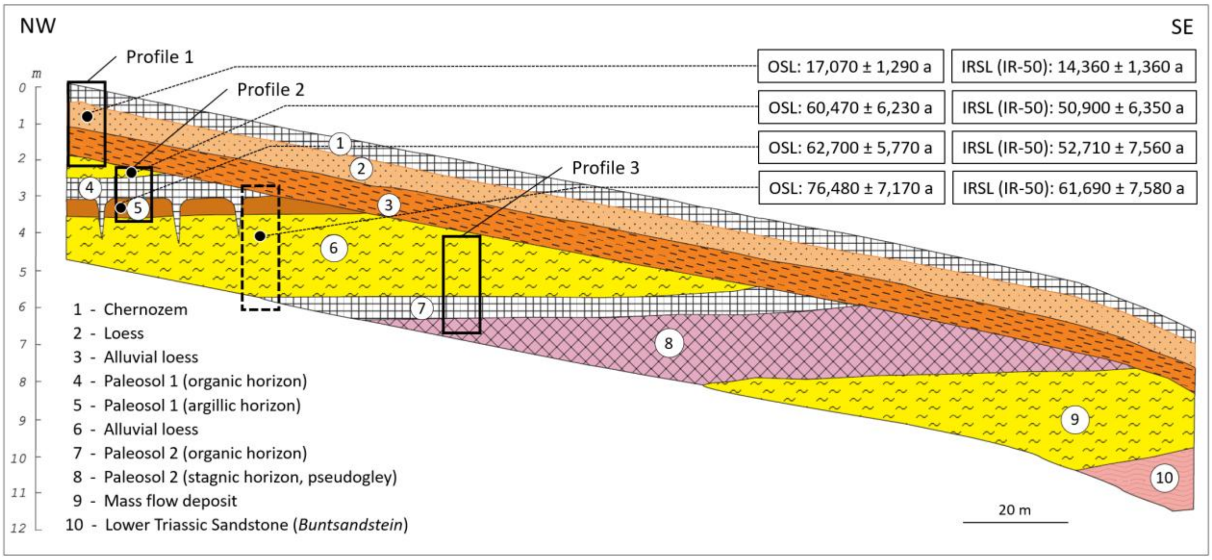

Fig. 7: Schematic cross section through the loess-paleosol sequence at Langenbogen. Profiles 1-3 will be presented during the stop. Note that both paleosol surfaces tilt c. 1-2° to the NW against the modern relief which tilts c. 10° towards SE. Luminescence ages from AUGUST (2011), IRSL feldspar ages (IR-50) are not fading corrected (modified from KUNERT & ALTERMANN 1965).

Generally, the chernozems are considered to be relict soils which formed during drier periods of the Holocene.

The local loess sequence at Langenbogen is exposed within a gully system, up to 20 m deep, that formed due to erosion at the southern edge of the Polleben loess plateau, which in this area descends from altitudes of around 150 m a.s.l. to approximately 85 m a.s.l. in the nearby Salza River valley. The highest point of the loess plateau lies at 226 m a.s.l. roughly 12 km to the NW of Langenbogen. Historic maps show that the gullies were used for centuries as local pathways for horse drawn carriages onto the plateau, locally enhancing surface and subsurface erosion of the loess (HARDENBICKER & HECHT 2000). The profiles at stop 3 are located in a side gully of only 6 m depth and oriented towards N-NW (locally referred to as '*Höhnstedter Path'*). The section features a 10 m thick sequence of Quaternary deposits (Fig. 7) comprising loess, alluvial loess and mass flow deposits over Mesozoic strata (*Buntsandstein, Detfurth Formation*). Within the sequence two buried paleosols were discovered and first described by KUNERT & ALTERMANN (1965).

Below a thin colluvial cover (profile 1) follows a chernozem developed in calcareous Weichselian loess (OSL: 17,070 ± 1,290 a; all ages cited from AUGUST 2011). This is underlain by several meters of redeposited loess (alluvial loess) and a c. 50 cm thick layer of a dark brown loamy mass flow deposit containing gravel and sand (profile 2). A luminescence age obtained from the lower portion of the alluvial loess and just above the mass flow deposits indicates formation during the mid-Weichselian period at around 60,470 ± 6,230 a. In profile 2, this unit

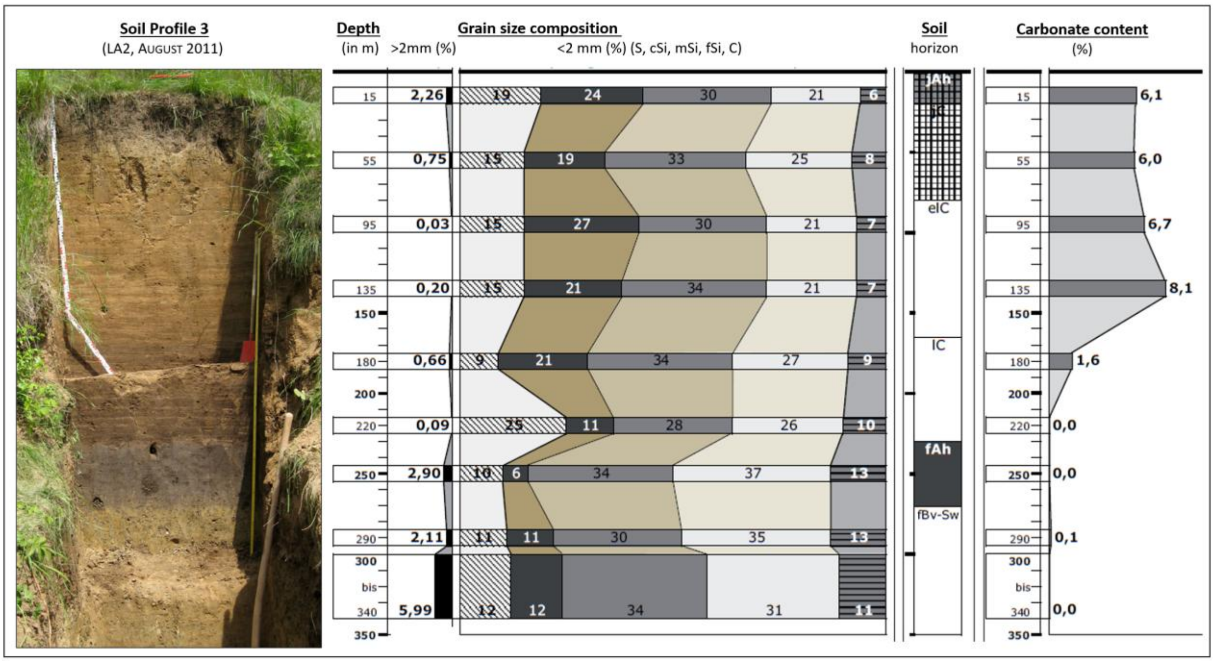

Fig. 8: Data from profile 3 (location shown in Fig. 7) from the loess-paleosol sequence at Langenbogen showing Paleosol-Complex-2 (*Drawing* modified from AUGUST 2011).

is underlain by a c. 45 cm thick loamy paleosol, comprising a buried dark chernozem-like organic horizon followed by a clay-enriched argillic horizon, interpreted as a remnant of a former Luvisol (*Parabraunerde*; KUNERT & ALTERMANN 1965). The stratigraphic and pedogenic characteristics indicate a correlation to the regionally known Naumburg Soil Complex with a tentatively assigned Eemian (argillic horizon) to Early Weichselian (humic horizon) soil formation age. However, this contrasts with the available OSL and IRSL chronology at Langenbogen (AUGUST 2011), which indicate mid-Weichselian ages below and above paleosol 1. In profile 3 and below further mass flow deposits and well stratified silts with dispersed fine gravel and organic layers, follows a second paleosol complex, comprising an organic horizon and a greyish stagnic horizon (Fig. 8). This paleosol has been termed the Langenbogen Paleosol Complex. Based on the Eemian ages previously assigned to the paleosol 1 complex above, the Langenbogen Paleosol Complex was formerly believed to represent soil formation during an Upper Saalian Drenthe-Warthe (MIS 6) interstadial (KUNERT & ALTERMANN 1965).

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Day 1 / Stop 4: Geiseltal lignite (a) and late glacial Laacher See Tephra (b) at Krumpa
(Coordinates: 4a: 51°18’02”N, 11°50’58”E; 4b: 51°18’03”N, 11°50’54”E)

The stop offers two outcrop sections (4a, 4b) near the village of Krumpa at the southern scarp of a former open-cast lignite (brown coal) mine. Before mining commenced, the Geisel River, a tributary to the Saale River, flowed across this area through a wide valley. The Geisel Valley (*Geiseltal*) was a highly productive coal mining area with industrial-scale mining for over 100 years, completely transforming the natural landscape until operations ceased in 1993. Since then, the area has been rehabilitated and flooded, creating Germany's largest man-made lake (*Geiseltalsee, 18.4 km^2, max. depth 78 m*). The Geiseltal lignite formed c. 46 mya ago comprising five brown coal layers with intercalated clastic beds, locally combining to an extraordinary lignite thickness of up to 120 m (KRUTZSCH 1976). Yielding a wealth of excellently preserved reptilian, amphibian, mammalian and other fossils, the Geiseltal *Fossillagerstätte* represents one of the most important biostratigraphic (vertebrate) section for the terrestrial/palustral Middle Eocene in Europe. The remarkable thickness of the Geiseltal lignite beds results primarily from local synsedimentary subsidence due to the subrosion of subsurface Upper Permian (*Zechstein*) and Lower Triassic (*Rötsalinar*, Upper *Buntsandstein* evaporites and lateral underground salt movement (THOMAE & SCHROETER 1996, Fig. 9).

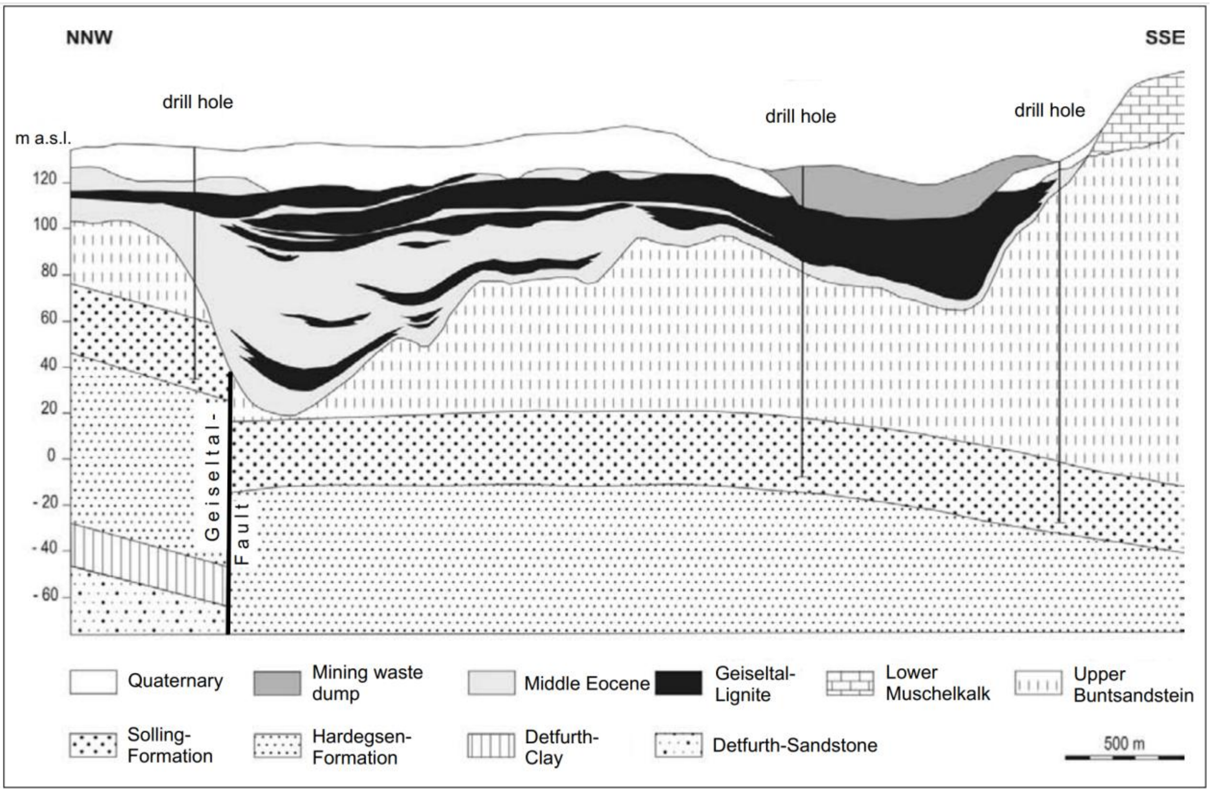

Fig. 9: Geological cross section of the western Geiseltal area (disused open-cast mine at Mücheln) showing the local succession of Eocene lignite overlying formations of the Upper, Middle and Lower Buntsandstein (Lower Triassic). Source: IHU GmbH Nordhausen.

In addition, the coal beds at Geiseltal and at several other mining pits across the region are noted for displaying impressive large-scale deformation structures where the lignite forms ascending diapirs which often reach over 10 m in height (Fig. 10). These features are interpreted to have been generated by hydroplastic ductile deformation in response to sediment and/or glacier loading of water saturated and lower density lignite beds over decaying permafrost (EISSMANN 1981). Based on their stratigraphic context and discordant relationships to overlying units the age of the coal-diapirism can be constrained to several phases associated with permafrost degradation during successive mid- to late Pleistocene glaciations (EISSMANN 1987).

Fig. 10: Lignite diapir in the former open-cast pit Neumark-Nord (Geiseltal). Source: M. THOMAE, 1986.

The outcrop at stop 4a is unique, as it represents the only remaining modern day site with exposed Geiseltal lignite from the highest Middle Eocene. At this site, the upper and lower lignite seams are merged into a single unit, while in a northerly direction the beds separated into four main coal seams. The exposed brown coal at the Krumpa section represents the top of a deformed coal diapir. It is directly overlain by fluvial sand and gray-white gravels deposited by the Geisel River and forming the Weichselian low-terrace (*Niederterrasse*). The hiatus between both units amounts to a gap of c. 41 mya years. The Weichselian fluvial unit is locally deformed by cryoturbation. Above the Weichselian sediments rest overbank fines locally developing into lake silts followed by late glacial lacustrine deposits and Holocene organic-rich floodplain sediments of the postglacial Geisel River.

A second outcrop (Stop 4b), located approximately 70 m to the west of stop 4a, exposes within a lateral trough which formed at the margin of the coal diapir, a thick late glacial and Holocene sequence, comprising late glacial basin silts, organic lake muds and peat, partially deformed by cryoturbation and covered by Holocene lacustrine deposits. In 1986, a 2 - 5 cm thick layer of the Lake Laach Tephra (*Laacher See Tephra*, LST) was discovered within this section, attributed to a well dated eruption at 13,006 ± 9 a BP (REINIG et al. 2021) in the Eifel region, some 340 km to the WSW of Krumpa. Combined investigations using stable isotopes, pollen and mollusc shells allowed the detailed reconstruction of a complete climatic record covering the regional Late Glacial / Holocene transition (BÖTTGER et al. 1998).

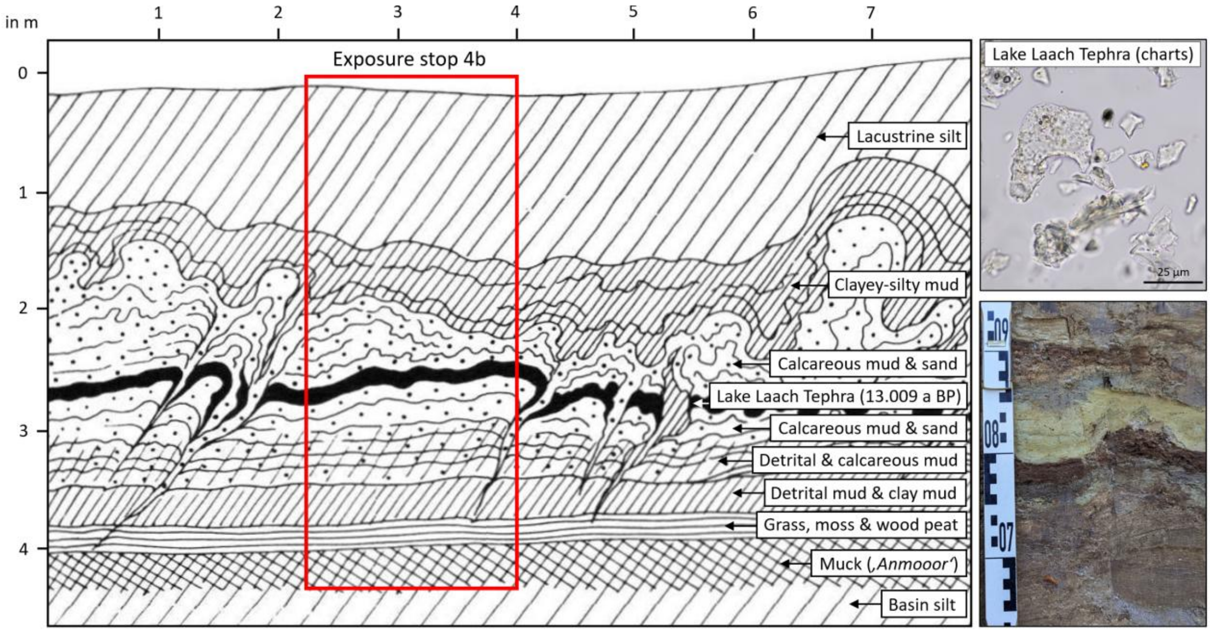

Fig. 11: Exposure 4b at Krumpa showing late glacial and Holocene deposits at Krumpa / Geiseltal. Microscopic glass charts (top right) are from a brown-yellowish bed of Lake Laach Tephra (bottom right), which formed at 13,006 ± 9 a BP (REINIG et al. 2021) following a Plinian eruption in the East Eifel volcanic field. (Excavated: 03.2025 / Drawing: modified from MANIA 1995).

Day 1 / Stop 5: Copper Shale mining history at Wimmelburg (K. Schuberth, LAGB)
(Coordinates: 51°31'00"N, 11°29'58"E)

The south-eastern Harz foreland was shaped by mining over a period of about 800 years, with its center in the area around Mansfeld and Eisleben. The main target of this century long mining history was a copper shale (*Kupferschiefer*), a clay marlstone approx. 40 cm thick and found at the base of the Upper Permian (*Zechstein, Werra Formation*). This marine sludge formation acted as a barrier for rising metal-rich deep waters. Mineralization took place in several phases up to the Triassic period. The copper content within the shale bed is between 2 to 3 %. Numerous other metals also occur within the copper shale and were extracted, including silver, lead and zinc. The deposit is associated with the geological structure of the Mansfeld Basin, a 30 x 20 km Triassic depression (*Mansfelder Mulde,* Fig. 12, Strobel et al. 2008). It forms a down-dropped block between the Harz Mountains in the west and the Halle Volcanic Complex to the east, originating during the Upper Cretaceous to Tertiary period (Saxonian fault tectonics). The copper shale deposit crops out in an elliptical shape at the edges of the Mansfeld Basin. Here the initial mining, after its documented discovery in 1199, began in small open-cast pits with mining and metallurgy technology developing rapidly thereafter.

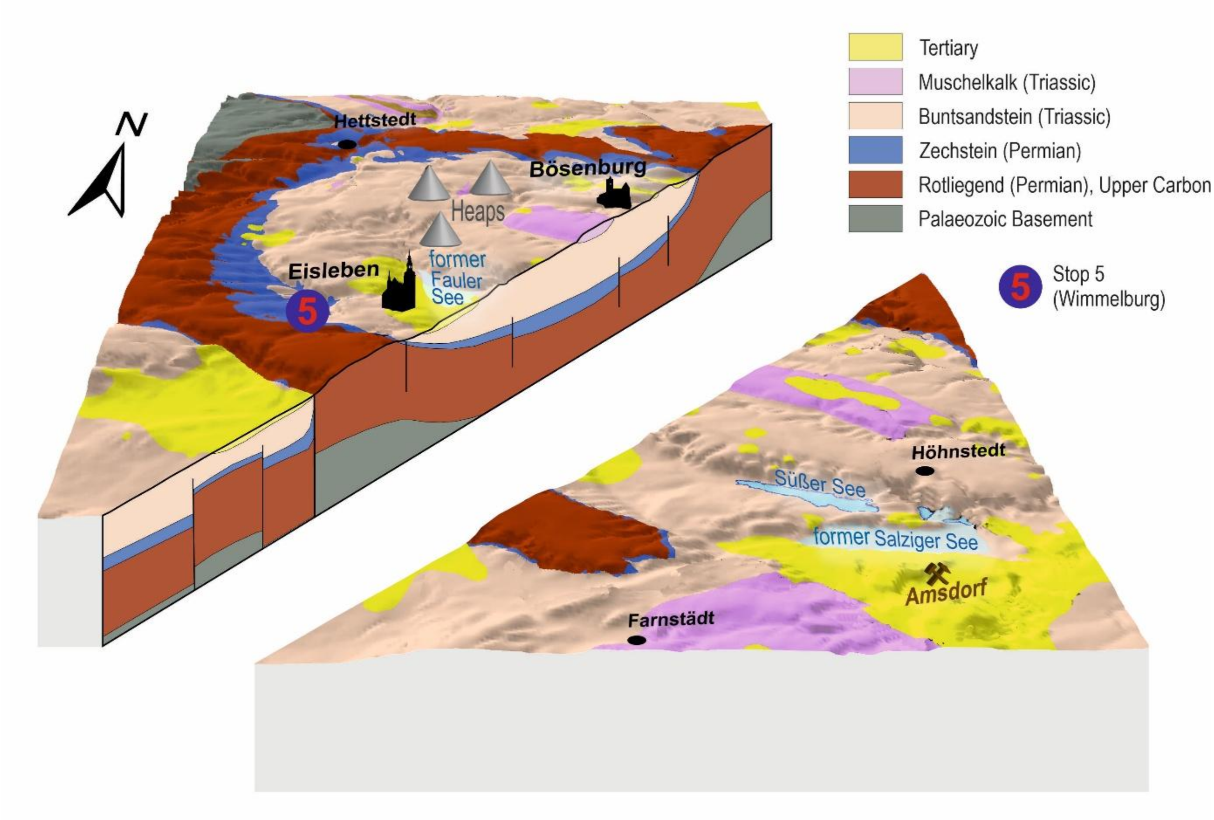

Fig. 12: Schematic Model (30 km x 30 km) of the Mansfeld Basin, without Quaternary (Graphic: Rappsilber).

Over the centuries, mining then shifted from the basin's edges to the deeper parts of the basin. The excursion stop is located in a medieval mining area (Fig. 13, 14). Typical mining depths at that time were about 10 m, with tunnel lengths of around 7 m, and shaft distances of c. 15 m ('*Duckelbau*'). The problem of supplying fresh air (ventilation) had a limiting effect to mine depths and extent. Initially, the overburden was stockpiled in a ring around the shaft. The mining depths and heap sizes continued to increase towards the center of the basin. The central and deepest parts of the basin could only be mined with the development of modern technology from around 1900 onwards. At Bösenburg, the copper shale lies at a depth of 995 m. Remnants of this mining period are three cone-shaped heaps (Fig. 12), visible from afar, and belonging to shafts operating in the surrounding area. This period also brought a sophisticated mine drainage system to the Mansfeld Basin, which was only discontinued in 1970. Flooding of the Mansfeld underground mine field was completed by 1981. The main drainage of the highest parts of the Mansfeld mine system is still operational to this day via a free fall through the '*Schlüsselstollen'*. After 31 km, the mine drainage flows over the Schlenze into the Saale River near Friedeburg.

In total, the Mansfeld mining district yielded c. 80 million tons of ore, from which c. 2 million tons of copper and 11,000 tons of silver were extracted. From 1970 onwards, mining only took place in the Sangerhausen Basin to the west. However, in 1991, after the reunification of Germany, this fundamental economic sector in the region also came to a complete standstill. Metallurgical processing was also closely linked to mining in the region. In the early days of mining, the copper shale was processed in proximity to the shafts. At about 1500, however, there were already more than 40 smelting plants in the area. In one of them, to the west of Wimmelburg, the father of the reformer Martin Luther also worked as a master smelter. From the 19th century onwards, the smelting industry became increasingly centralized. It left behind extensive slag heaps and large areas of industrial wasteland (including the Karl Liebknecht smelting plant, formerly the Krug smelting plant, east of Wimmelburg).

An extensive karst landscape has formed on the south-western edge of the Mansfeld Basin (KUPETZ et al. 2021). This is not 'bare' karst, but 'green' karst, as the leachable rocks (Upper Permian sulphates and chlorides) are mostly covered by thin, non-karstifiable sediments and vegetation. Numerous caves have formed underground, which are locally referred to as the '*Mansfelder Schlotten*' (Mansfeld karst caves). Water-filled cavities represented a serious danger as they could flood the mine. Air-filled cavities, on the other hand, were used to store overburden, which therefore did not have to be brought to the surface. The largest cave system are the '*Wimmelburger Schlotten*' (Wimmelburg karst caves), which extend under the village of Wimmelburg over an area of 600 m x 300 m, with

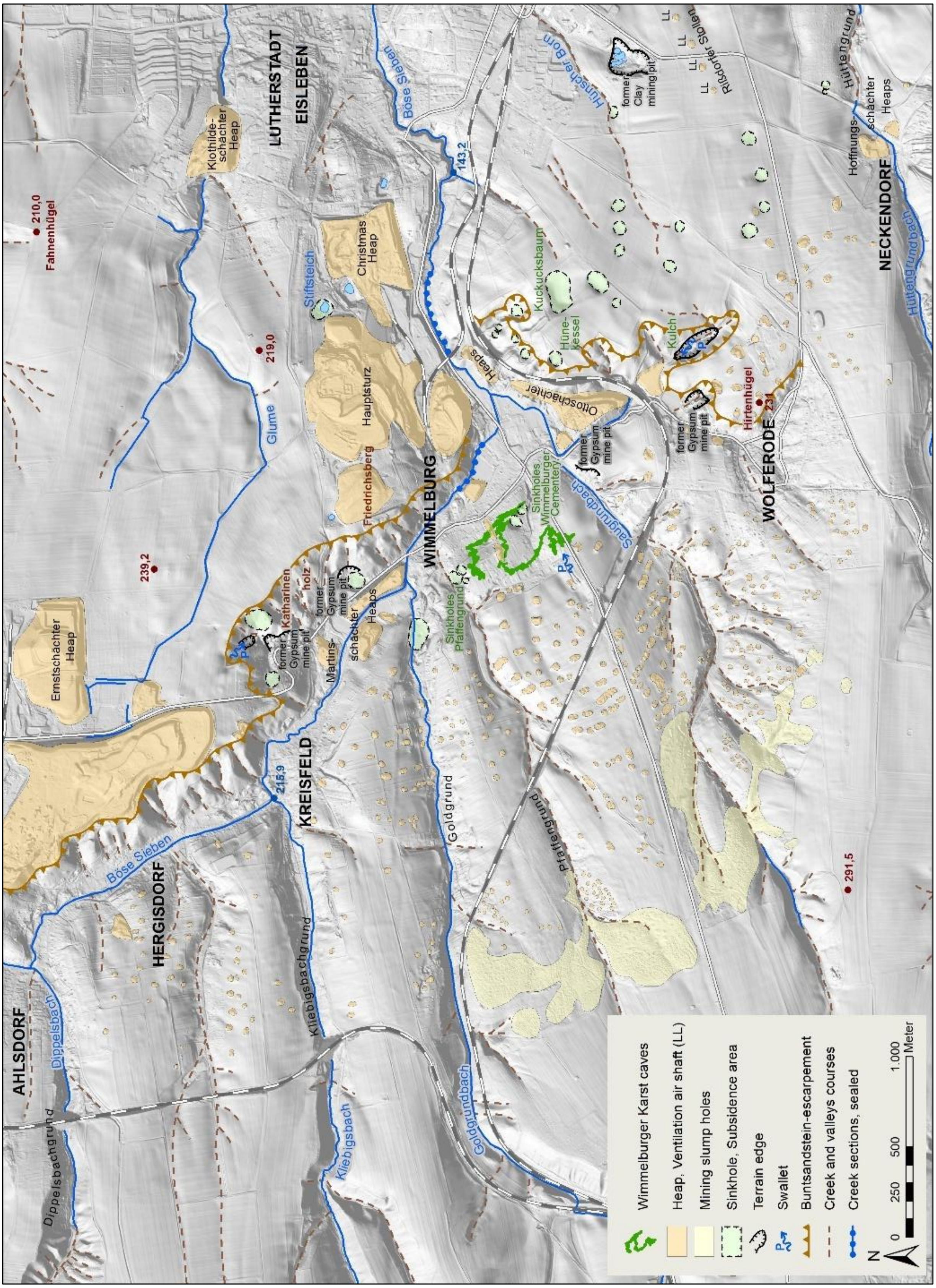

Fig. 13: Relief forms in the copper shale mining area near Wimmelburg (Digital Terrain Model: Landesamt für Landesvermessung und Geoinformation Sachsen-Anhalt, 2009; Graphic: RAPPSILBER).

individual caves reaching heights of up to 15 m. At the surface large sinkholes with diameters of up to 70 m and depths of up to 20 m formed already in historical times (e. g. '*Hünekessel*', Fig. 13). In other places uvalas formed, while stream sinkholes and ponors also characterize the landscape. Sections of the '*Böse Sieben*' stream were sealed with concrete half shells to minimize the infiltration of water into the subsoil (Fig. 13). The installed drainage system of the copper shale mining industry led to major changes in the natural hydrological regime of ground- and surface waters throughout the wider area. The regional groundwater level was lowered by more than 100 m and the former '*Salzige See*' (east of Eisleben) was drained. There was an increased influx of fresh water, leaching increased, cavities enlarged and sinkhole activity intensified. This led to the formation of large depressions in the Eisleben area in 1973/74. Parts of the urban area and several industrial plants had to be demolished. South-east of Wimmelburg, near Neckendorf, a main road had to be temporarily closed in 1987 due to sinkhole formation and was later abandoned altogether. At present, subsidence west of Eisleben has made it necessary to close roads and re-route an existing water pipeline. The effects of historic copper shale mining on the environment will continue to affect the people in this region for centuries to come.

Fig. 14: View to the northeast into the Wimmelburg Valley (Valley of the '*Böse Sieben*'). The groups of trees in the foreground mark heaps from medieval copper slate mining. The wooded ridge in the background right is the 100-meter-high escarpment of the Buntsandstein. Between them lies the leaching valley of the '*Böse Sieben*' (Photo: SCHUBERTH, January 18, 2016).

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Day 2 / Stop 1: The Anthropogenic Riverscape Transition (HEARTs): Selke River case study
(Coordinates: 51°42'03"N, 11°17'12"E; J. Keßels, F. Lehmkuhl; RWTH Aachen University)

In the frame of a Priority Program of the German Science Foundation (DFG, SPP 2361: '*On the way to the Fluvial Anthroposphere*', Project Number: 509913955) our project HEARTs ('***H**ead-way or **E**scape? The **A**nthropogenic **R**iverscape **T**ransition – How did medieval settlement structures interact with landscape evolution in the Eastern Harz Mountains and its forelands?'*) focuses on the development of floodplain landscapes and fluvial societies in the catchment areas of the Selke River. The aim is to investigate the social, economic, and environmental interactions and consequences of human settlement in riverine areas, based on inter-disciplinary research collaborations that combine geoscientific studies with historical and archaeological expertise (Werther et al., 2021).

The mountainous upper and middle reaches of selected Harz Rivers were once characterised not only by mining and charcoal-burning industries but also by pasture farming and agriculture. These rivers subsequently flow from the Harz Mountains to the adjacent northeastern foreland, an area dominated by agriculture. These riverscapes have been utilised since the Neolithic period and have undergone significant modification through human activities, particularly since the early Middle Ages. Key milestones in the development of the

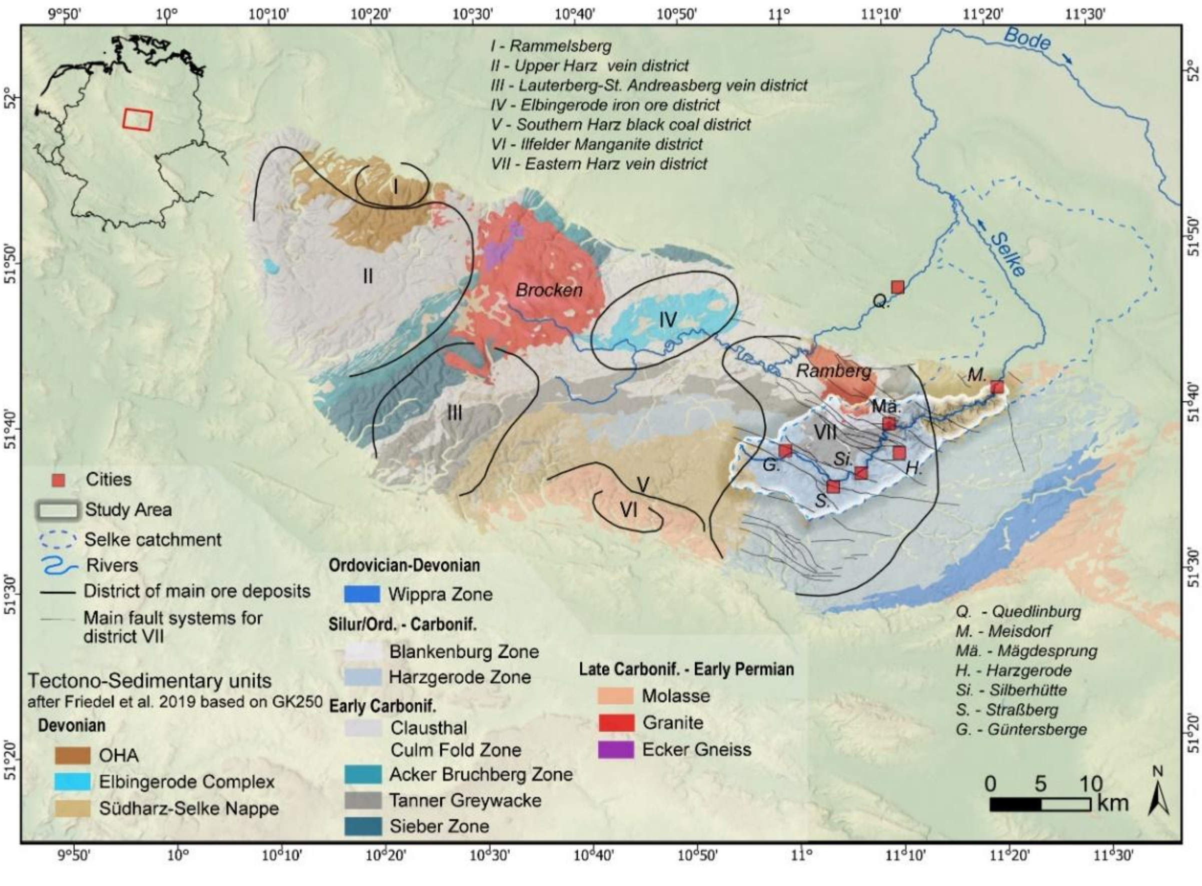

Fig. 15: Geological Map of the Harz Mts. highlighting the Study Area and main ore deposits (Keßels et al. in press).

anthropogenic floodplain habitat include the implementation of hydropower and the first river engineering projects. Recent studies on the chronology and causes of alluvial deposition during the Holocene suggest that the formation of fine-grained overbank deposits, among other factors, is connected to human-induced land cover changes, such as increased soil erosion. However, establishing a direct causal relationship between increased floodplain sedimentation and its causes is complex. Various rivers have experienced periods of enhanced floodplain aggradation, which has been attributed to either climatic factors or human impacts. It is still unclear whether the relocation of production sites (e.g. for smelting or metal processing) and settlements from the small upland streams towards the floodplain landscapes since the 12th and 14th centuries was a consequence or a precondition for these changes (e.g. hydropower, river engineering and the formation of overbank deposits).

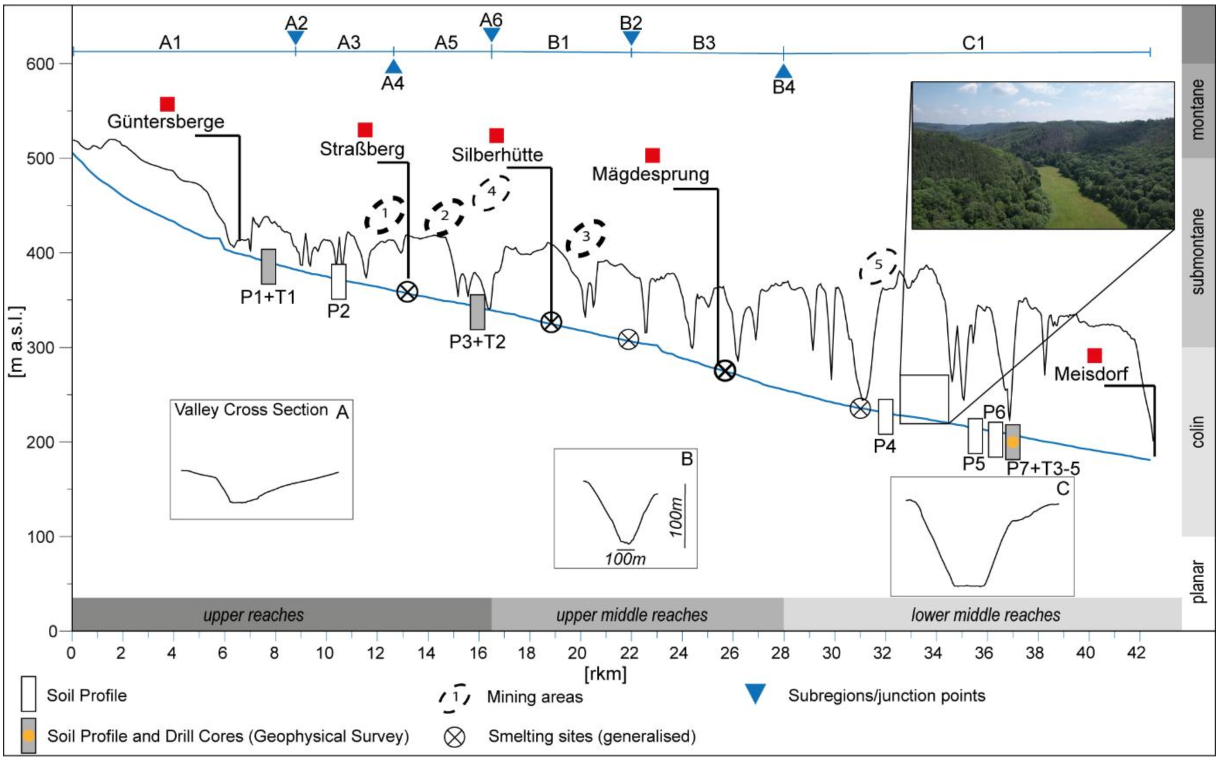

Fig. 16: River profile (blue line) of the Selke River and relief (black line). The rectangles show representative valley cross sections of the upper catchment (A), upper middle catchment (B) and lower middle catchment (C). Drone Image of the Selke River Valley in section C. Drone Image: SWIEDER (LDA).

The study area is a typical example of a European low mountain range landscape that has been altered by human activity. The research project initially focusses on the 180 km² mountainous upper and middle Selke catchment area, upstream of Meisdorf. Sulfidic hydrothermal ore deposits characterise the regions as part of the Eastern Harz vein district. Mining activities in this area date back to the 13th century. However, there are a few historical and archaeological indications suggesting that mining and smelting may have occurred as early as the 9th or 10th century. In this study, we hypothesise that the variability in the concentration of risk elements with sediment depth is a valuable proxy for environmental conditions and anthropogenic impacts. This approach relies on a precise understanding of the type, location, and chronology of settlement structures, mining sites, and smelting sites (see KEßELS et al. in press), as well as the range and distribution of geochemical background values across the catchment area (see KEßELS et al. 2025). Based on these preliminary studies, three key areas have been defined, that (1) represent floodplain characteristics upstream (Fig. 16, P1+T1), in between (Fig. 16, P3+T2) and downstream (Fig. 16, P7+T3-5) of known mining activities and that (2) are not directly influenced by human interactions (on-site), but instead represent natural flow and sedimentation dynamics (off-site) (see Fig. 2).

Figure 17 illustrates the grain size distribution, pH value, Corg, and lead concentrations (raw values) exemplified for the P1, P3 and P7 soil profiles along the Selke River (see Fig. 16). The P1 soil profile is representative for a typical natural Fluvisol (=Vega). The grain size of the overbank deposits shows a distinct peak in the coarse silt fraction and a secondary in the clay fraction. The lead concentration, as an indicator of mining activities, falls within the geochemical background range. Both parameters change significantly further downstream in the P3 soil profile (see Fig. 17). The grain size distribution shows a significant shift towards coarser particles. While various horizons are defined by a maximum grain size in the coarse sand fraction, the clay component is absent. This phenomenon can be attributed to the

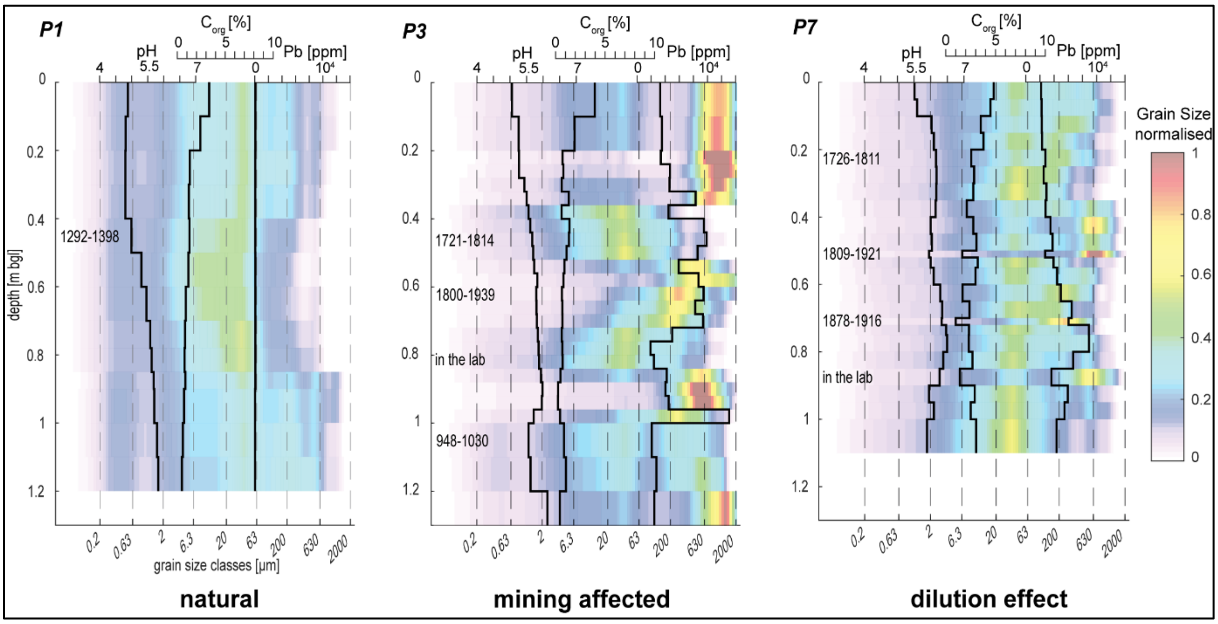

Fig. 17: Visualisation of the Profiles P1, P3 and P7 (see Fig. 2) showing the grain size distribution for <2mm normalised to 0-5 vol.% and depth variability of pH-values, C_{org}. and lead concentrations. The numbers are calibrated radiocarbon ages of charcoal pieces (cal. AD).

presence of smelting works further upstream around Straßberg and the input of *Pochsande* (remains of ore crushing) into the fluvial system. In addition, the lead concentrations show maxima exceeding 10,000 mg/kg. In this regard, P3 reflects the onset of the mining activities in the catchment area. In the downstream direction (P3 to P7), the signal for both parameters is less pronounced. Nevertheless, the high lead concentrations throughout the profile significantly exceed the expected geochemical background values.

The initial results of the floodplain deposits suggest that the overbank deposits are at least biphasic, with the younger deposits reflecting the onset of mining and smelting activities in the study area. Changes in the concentration of risk elements, the presence of slag fragments and their properties characterise anthropogenically affected sediments in particular. The first radiocarbon dates suggest that the earliest anthropogenically affected sediments (i.g. polluted sediments) date back to the 10th or 11th century. In addition, variations in the risk element concentrations within the cross-sections, both vertically and horizontally, indicate intercalation with different phases of erosion and aggradation. Distinct changes in the grain size distribution corroborate this complex floodplain architecture.

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Day 2 / Stop 2: Glacial potholes in Middle Triassic limestone (Huy anticline)
(Coordinates: 51°57’25”N, 10°54’50”E)

Situated at the northern boundary of the Subhercynian Cretaceous Basin (SCB), at a distance of c. 15 km NNE from the Harz Mountain limit, a series of three WNW-ESE oriented anticlines occur, called the *Great Fallstein*, *Huy* and *Hakel*, which rise 120-190 m above the surrounding terrain. The anticlines formed in response to halotectonic upwelling of Upper Permian (*Zechstein*) salt, which was locally mined until 1926 at depths of around 350 m below the *Huy*. Upward salt movement, starting in the Cretaceous, formed an asymmetrical structural dome that was later eroded, exposing mainly Middle Triassic (*Muschelkalk*) limestone at the surface (BACHMANN et al. 2008). In the case of the *Huy* saddle (12 x 3 km), anticlinal crestal structures include localized normal faulting with the formation of a keystone graben, while erosion of the central anticline removed the *Muschelkalk* exposing a narrow zone of the underlying Lower Triassic formations (*Buntsandstein*) at the surface (Fig. 18). The geological conditions within the *Huy* anticline allowed for the mining of salt, sandstone, gypsum and limestone within a small area, but all mining activities ceased here during the first half of the 20. century.

Stop 2 is located in a former opencast pit on the western slope of the Hardelsberg hill, where horizontally bedded Middle Triassic limestone (Lower *Muschelkalk, Upper Wellenkalk*)

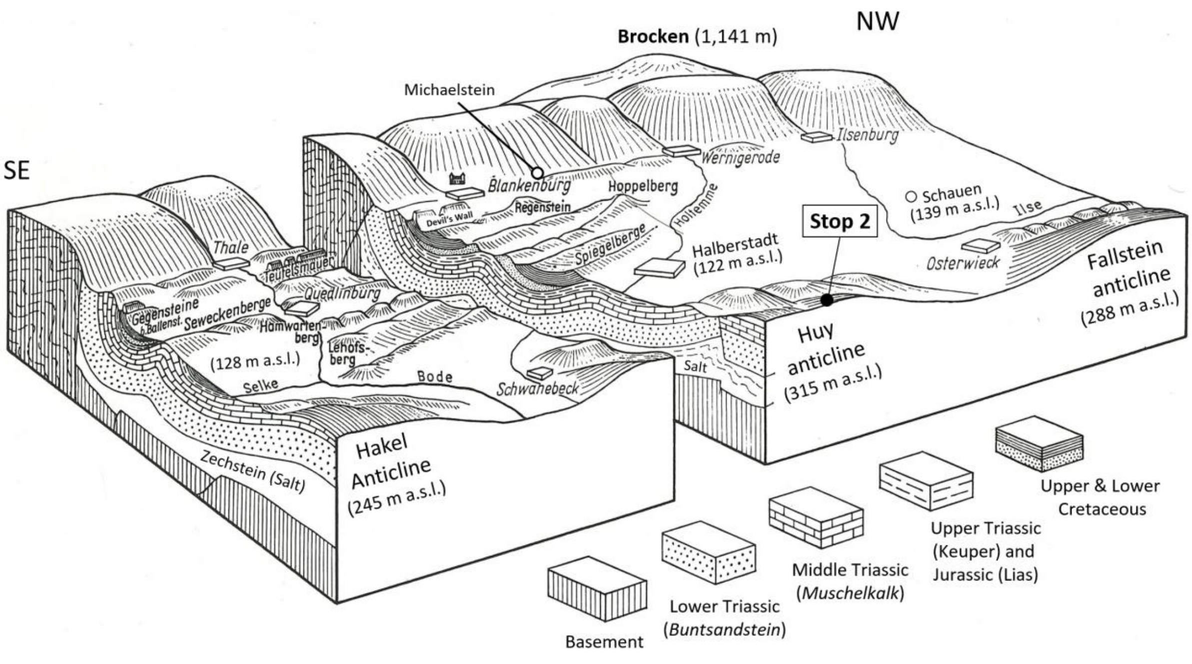

Fig. 18: Geological model of the southern Subherzynian Basin with the salt anticlines of the Hakel, Huy and Fallstein in the foreground. Quaternary deposits not shown. Viewing direction towards the SW, with the Harz Mts. in the background. The rivers in the western part of the basin, such as the Ilse River, are tributaries to the Weser River, while the Holtemme and Bode Rivers in the eastern portion are tributaries to the Saale/Elbe River system (modified from WAGENBRETH & STEINER 1989).

was mined. In 1910, a 18 m deep and 6 m wide erosional channel, infilled with Pleistocene material, cut from the top into the *Muschelkalk* strata, was found during excavation works (HEMPRICH 1913). At the base of the channel, two cylindrical shaped potholes were discovered, with the larger measuring c. 2 m in diameter at a depth of 2.5 m, showing smoothed vertical walls with scour marks (Fig. 19). Both potholes were filled with silt, sand and rounded boulders of up to 30 cm in diameter. The granitic boulders were recognized to be of Scandinavian provenance strongly indicating a glacial origin of the cavities (HEMPRICH 1913). Earlier hypothesis on the subglacial formation of potholes suggested that they result from the erosion of vertically plunging waters at the lower end of moulins, delivering meltwaters from the glacier surface to the glacier bed (e.g. FULLER 1925). However, the probably short-lived nature of the positioning of moulins cast doubt on this explanation, with later studies suggesting turbulent meltwater flow, aided by cavitation erosion, as a more likely mechanism for subglacial pothole formation (BENN & EVANS 2010).

The glacial potholes, situated at a *Huy* altitude of c. 270 m a.s.l., provide clear evidence that the anticline was ice overflown during the Pleistocene, but their formation has variously been ascribed either to the Elsterian or the penultimate glaciation. Importantly, Saalian glacial deposits (Drenthe stage) are present to the N and S of the structure and have been documented on the *Huy* itself at comparable altitudes to that of the potholes, of up to 260 m

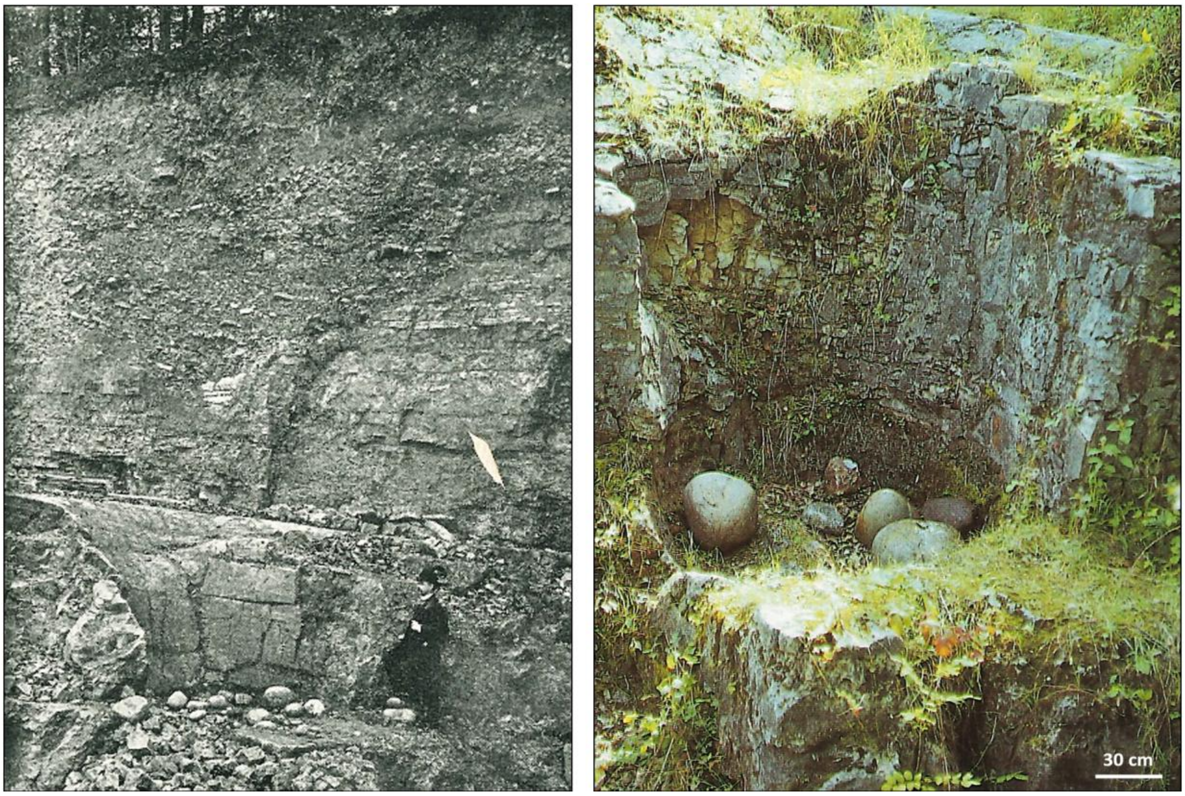

Fig. 19: Glacial potholes in Middle Triassic *Muschelkalk* on the Huy anticline. The image to the left shows the site shortly after discovery in 1910 with an erosional channel visible in the background. The photo to the right shows the larger of the potholes in the 1980s (WAGENBRETH & STEINER 1989).

a.s.l.. Although reliable reconstructions of the thickness of the former Saalian ice sheet in the Subherzynian Basin are lacking, we can derive a reasonable estimate from the altitude of Saalian (Drenthe stage) ice marginal deposits that are perched onto the slopes of the northern Harz Mountains, located some 15 km to the SSW, where these deposits are found at elevations of up to 260 m a.s.l.. Considering a plausible low ice sheet surface slope of ca. 1.5 - 2° for a terminal ice sheet region, based on modern ice sheet analogues (Yi et al., 2005), we obtain a paleo-ice-sheet surface gradient of ca. 30 m km^{-1}. This yields an ice thickness in excess of 450 m at a distance of 15 km from the Drenthe ice margin at the Harz Mountain front. Taking into account the altitude of the Subhercynian Basin itself (i.e. the base level of the ice sheet), we find that the thickness of the Saalian ice sheet, at maximum extent, is highly likely to have exceeded the altitude of the Huy anticline by at least 150 m. Based on this, pothole formation is likely to have occurred during the penultimate glaciation, although a scenario where the potholes formed during the earlier, even more extensive Elsterian glaciation, cannot be entirely discounted.

Day 2 / Stop 3: The Pleistocene succession of Schöningen – an outstanding geological and archaeological archive (Coordinates: 52°08'01"N, 10°59'20"E; Jörg Lang, BGR)

The Schöningen open-cast lignite mine (Fig. 20) is located in the western rim syncline of the Helmstedt-Staßfurt salt wall. The main fill of the rim synclines comprises c. 350 m thick paralic and nearshore marine Palaeogene deposits, overlying Triassic bedrock (LOOK 1984; BRANDES et al. 2012a). Early Eocene lignite seams were exploited in the open-cast mine from 1979 to 2016. Up to 45 m thick Middle Pleistocene to Holocene deposits unconformably overlie the Palaeogene succession. The preservation of such complete successions is rare in the terrestrial record of northern central Europe, where successions are usually incomplete due to erosion during repeated ice advances.

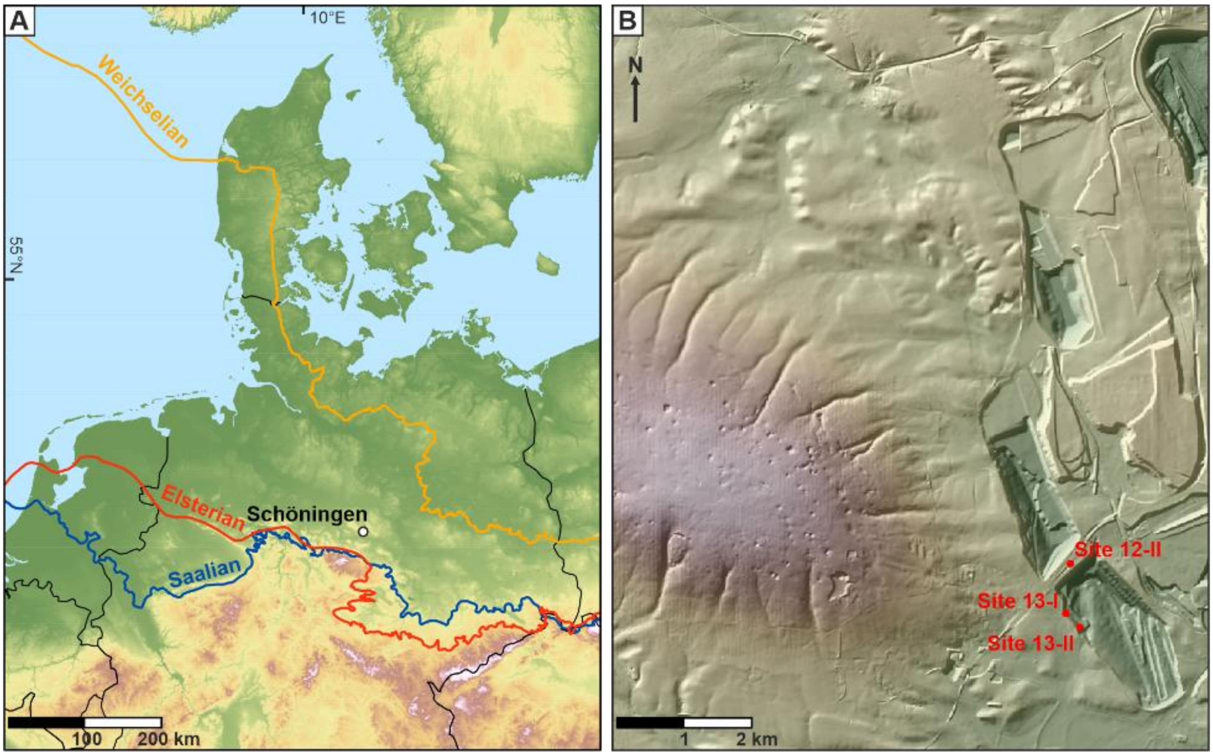

Fig. 20: A) Location of the study area and maximum extent of the Pleistocene ice advances (modified from Ehlers et al. 2011). The digital elevation model (DEM) is based on EU-Copernicus data. **B)** Hill-shaded relief map of the Schöningen open-cast mine, showing the situation before 2009. The main archaeological sites are indicated. DEM based on data provided by LGL Niedersachsen.

The recovery of unique Palaeolithic artefacts from Middle Pleistocene interglacial deposits offers an extraordinary chance for archaeology. The famous Schöningen hunting spears belong to the oldest known wooden tools and represent a technological stage previously not attributed to Lower Palaeolithic humans (THIEME 1997). The Schöningen site is still in the focus of intensive archaeological and palaeoecological research.

The Schöningen area was covered by both the Middle Pleistocene Elsterian and Saalian ice sheets, which reached their maximum extents c. 40 km to the south (Fig. 20A; EHLERS et al. 2011). During the Elsterian glaciation, a NNW-SSE trending tunnel valley (depth c. 45 m, width c. 850 m) was incised in the study area (Figs 21A, 22; LANG et al. 2012). The subglacial origin of the tunnel valley is indicated by its abrupt termination and undulating basal profile. Tunnel-valley incision was probably fostered by the poorly consolidated and erodible Cenozoic infill of the rim syncline in contrast to the surrounding Mesozoic rocks. Elsterian deposits within the structure comprise meltwater deposits and till, which are restricted to the tunnel-valley fill (Figs 21B, 22, 23A, B; LANG et al. 2012).

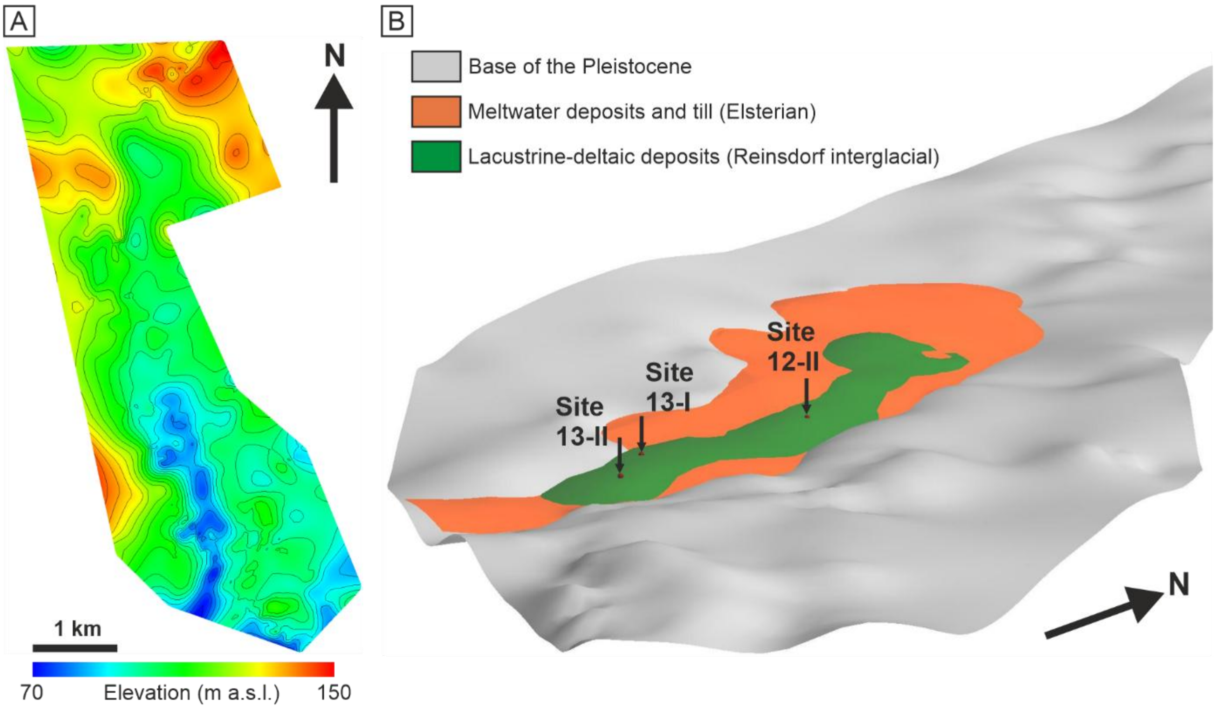

Fig. 21: A) Map of the base Pleistocene in the area of the Schöningen open-cast mine (modified from LANG et al. 2012). The Elsterian tunnel valley, which acted as interglacial depocentre, can be clearly recognised. **B)** Perspective view of the tunnel valley and its main infill extracted from the 3D subsurface model (modified from LANG et al. 2015). The three main archaeological sites are indicated.

After the retreat of the Elsterian ice sheet, the underfilled tunnel valley acted as an interglacial depocentre (Fig. 21B). An interglacial lacustrine succession was deposited in a fine-grained delta that was shed into the lake from the west (Fig. 24C, D). Lacustrine-deltaic deposition was controlled by repeated lake-level fluctuations in the range of 1-6 m, leading to the formation of laterally and vertically stacked delta systems (LANG et al. 2012, 2015). Numerous Palaeolithic artefacts have been recovered from the lacustrine succession. The distribution of the archaeological sites can be explained by the lateral and vertical stacking of the deltaic deposits (LANG et al. 2015). The stratigraphic position of the artefact-bearing strata, including the "spear

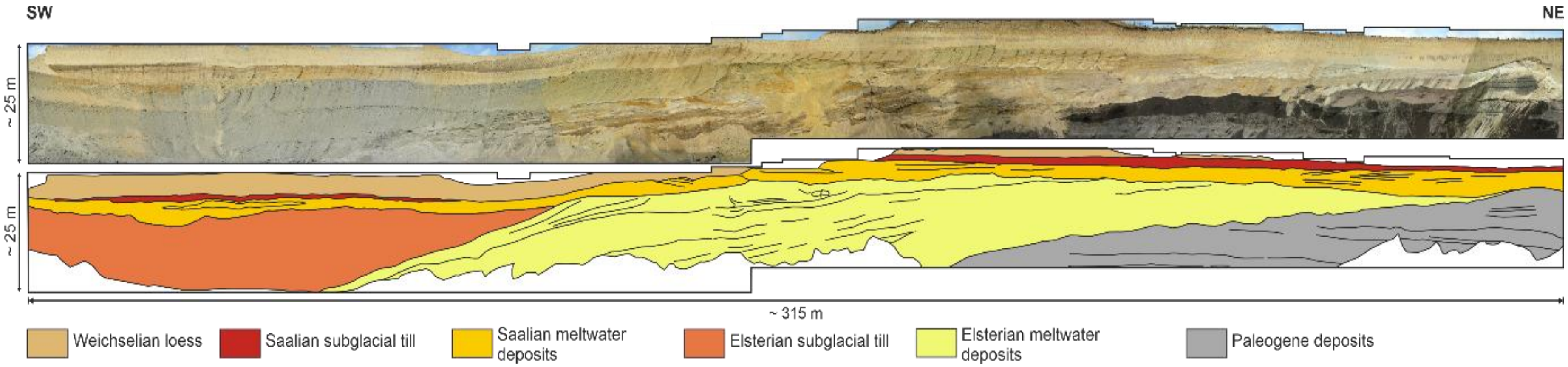

Fig. 22: Photo panel from the open-cast mine, showing the characteristic depositional architecture of the Palaeogene to Pleistocene deposits. Middle Pleistocene interglacial deposits are not exposed in this section.

horizon", is still under discussion. The Reinsdorf interglacial, the part of the lacustrine delta that includes the "spear horizon", was defined based on palynological evidence and is distinct from the Holsteinian interglacial (URBAN 1995, 2007; KRAHN et al. 2024). The Reinsdorf interglacial is commonly correlated with Marine Isotopic Stage (MIS) 9 and is thus younger than the Holsteinian interglacial (MIS 11) (URBAN et al. 2011; TUCCI et al. 2021; KRAHN et al. 2024). However, a re-evaluation of the palynological data (van BEIRENDONCK & VERBRUGGEN 2025) and new numerical dates (HUTSON et al. 2025) suggest a younger age and a correlation with MIS 7.

During the subsequent Saalian glaciation, the remnant tunnel valley was completely infilled and buried by extensive meltwater deposits and till (Fig. 24E, F). Eemian deposits have been mapped in the northern part of the open-cast mine (URBAN 2007). The ice-advances of the Late Pleistocene Weichselian glaciation did not reach the area. During the Weichselian, thick loess deposits covered most of the area.

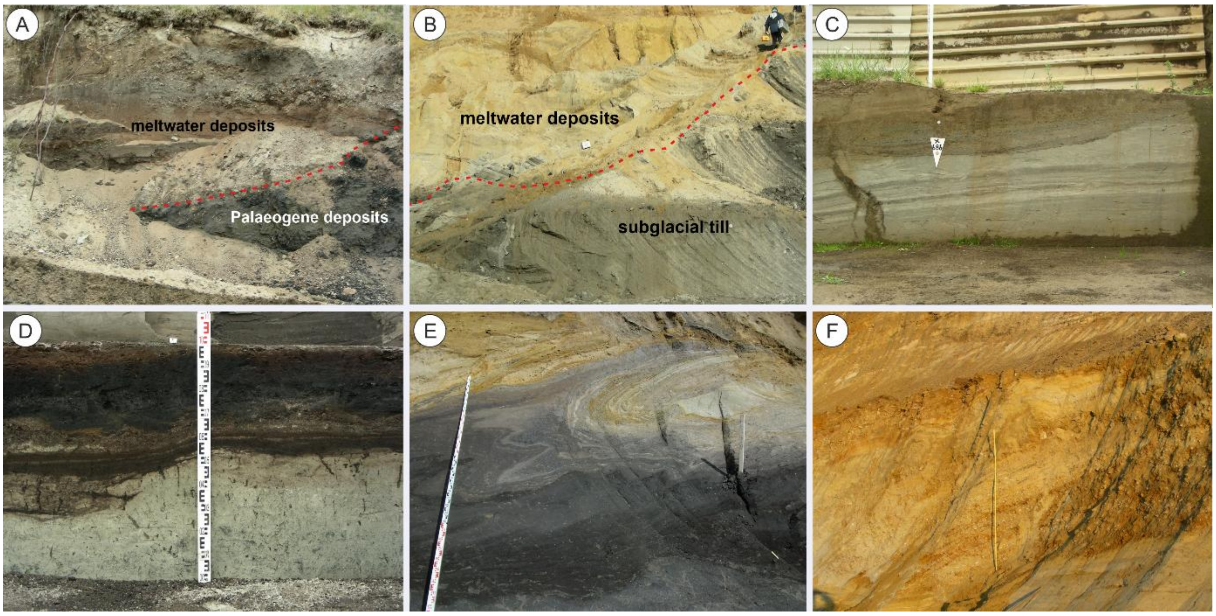

Fig. 23: Outcrop examples of the Middle Pleistocene succession at Schöningen. A) Elsterian meltwater deposits, unconformably overlying Palaeogene marginal marine deposits at the base of the tunnel valley. B) Steep-walled incision into the top of the Elsterian till, indicating a recurring phase of subglacial meltwater incision. C) Laminated silt and fine-grained sand of the interglacial delta front. D) Interglacial lacustrine organic-rich, rooted silt and peat. E) Mud diapir, comprising organic-rich silt, intruding into Saalian meltwater deposits. F) Saalian glacilacustrine shallow-water delta deposits, which prograded into the last remnant of the tunnel valley.

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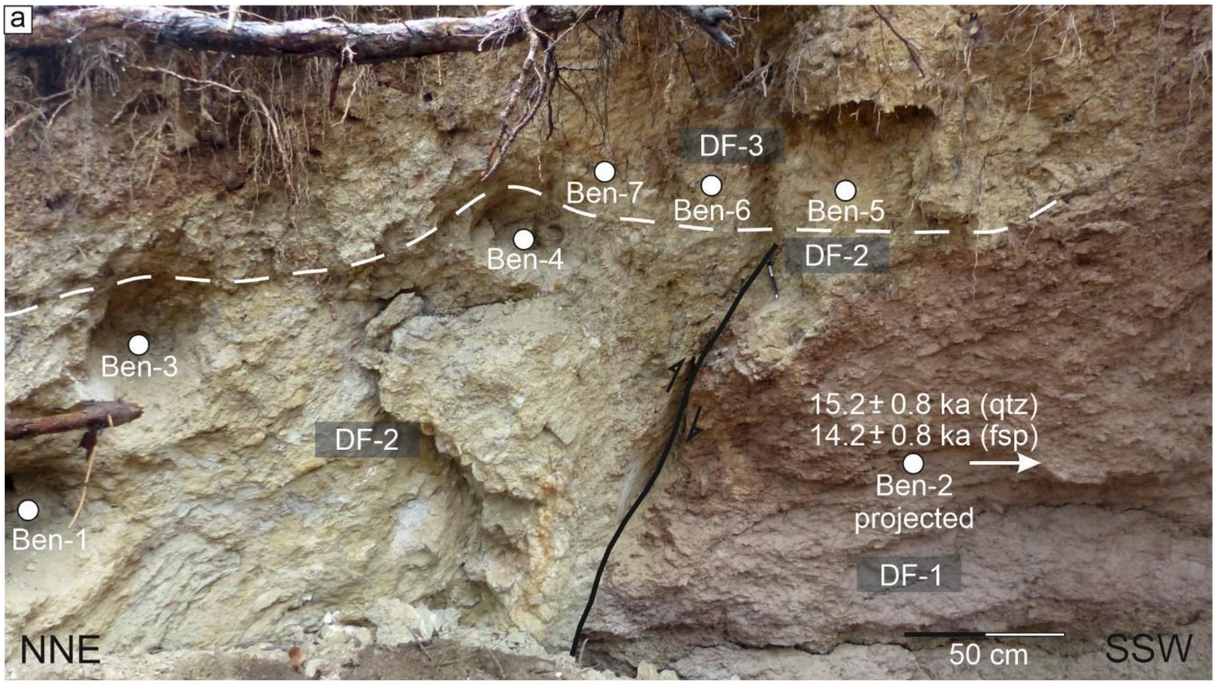
Day 3 / Stop 1: Neotectonic activity at the Harz boundary fault, near Benzingerode
(Coordinates: 51°49'32"N, 10°52'35"E; C. Brandes, Leibniz University Hannover)

Northern Central Europe is a slowly deforming, low-strain intraplate area and commonly regarded as a low-seismicity region. Nevertheless, there is evidence for neotectonic fault activity, as well as for historic and recent earthquakes. In the last decade, paleoseismological and neotectonic studies were executed that extended the record of fault activity further into the past (Hoffmann & Reicherter 2011; Brandes et al. 2011, 2012a; Brandes & Tanner 2012; Brandes & Winsemann 2013; Grube 2019a, b, 2020). Several studies indicate that glacial isostatic adjustment (GIA) related stress field changes are a major trigger for neotectonic activity in northern Central Europe (Brandes et al. 2015; Müller et al. 2020; Müller et al. 2021). Altogether, this changed the view that northern Germany is an area of low seismic hazard. Additional studies on potentially seismically controlled soft-sediment deformation structures were carried out in the Baltic region of northern Germany (e.g., Pisarska-Jamroży et al. 2018, 2022). The current understanding is that the tectonic activity in northern Central Europe is mainly concentrated at major WNW-ESE striking lithospheric structures (Brandes et al. 2015, 2022a) like the Sorgenfrei-Tornquist Zone (Brandes et al. 2018, 2022b), the Thor-Suture (Brandes et al. 2019) and at individual faults like the Osning thrust (Brandes et al. 2012b) and the Harz boundary fault (Müller et al. 2020). At the Thor-Suture, recent deep earthquakes occur (Brandes et al. 2019) and within this region, there is also evidence for neotectonic activity that was found in the Langeland area (Ahlrichs et al. 2023).

One site in northern Germany that provides geological evidence for neotectonic activity is located near Benzingerode at the northern front of the Harz Mountains and lies directly at the Harz boundary fault. The Harz boundary fault is a WNW-ESE trending Late Cretaceous major fault in Central Europe (Kley & Voigt 2008). Together with the Harz Mountains, it forms the southern boundary of the Subhercynian Basin. At the Harz boundary fault, the Harz Mountains were uplifted by several kilometers during the Late Cretaceous. As a result of this uplift and subsequent erosion, deformed Devonian and Carboniferous sedimentary rocks, and Permian granites (Oker, Brocken, and Ramberg Pluton) are exposed at the Earth's surface. The Subhercynian Basin in front of the Harz Mountains is a sub-basin of the Central European Basin System that started as an extensional rift basin in the Permian-Triassic and was later transformed into a type of foreland basin due to the NNE-ward overthrusting of the Harz Mountains onto its foreland during the Late Cretaceous (Brandes et al. 2013). Today the fill of the Subhercynian Basin is characterized by large anticline structures that likely formed due to a combination of early Mesozoic extension and Late Cretaceous contraction (Brandes et al. 2013). The Subhercynian Basin is regarded as a key location for understanding intraplate tectonics in Central Europe. The Harz boundary fault between the Harz Mountains and the Subhercynian Basin can be traced laterally for approximately 100 km.

Typically, there are no outcrops of the Harz boundary fault, but a recent sinkhole exposes a NNE-ward dipping and WNW–ESE striking planar fault surface that cuts through unconsolidated Lateglacial debris-flow deposits thus pointing to young tectonic activity (FRANZKE et al. 2015; MÜLLER et al. 2020). Based on striations developed on the fault surface



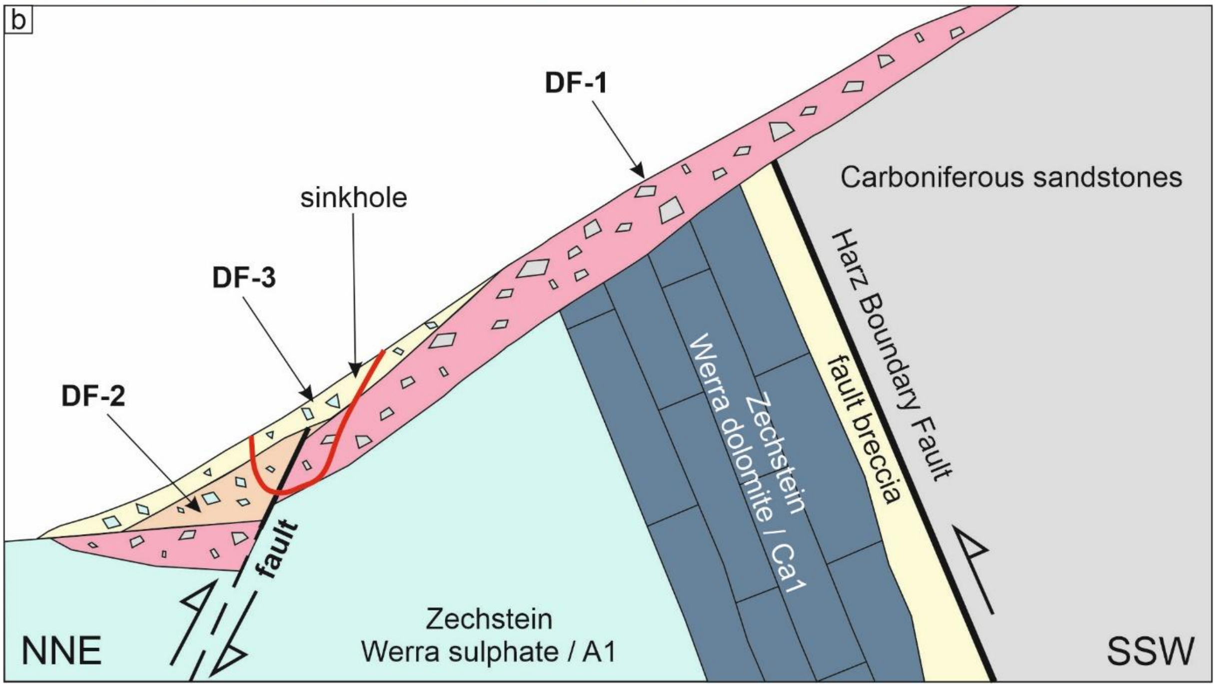


Fig. 24: Neotectonic fault movements at the Harz boundary fault. a) Fault developed in Lateglacial debris-flow deposits and location of OSL samples. b) Schematic profile of the Harz boundary fault zone near Benzingerode with the location of the outcrop, based on FRANZKE et al. (2015) and taken from MÜLLER et al. (2020).

it can be derived that the fault experienced a two-phase evolution with initial normal fault movement and a later reactivation as an oblique fault with reverse and strike-slip components. A shear-wave seismic profile was acquired by the LIAG Institute to analyse the geometry of the fault and show that the Harz boundary fault is steeply dipping and likely has branches. We regard the Harz boundary fault as a kind of splay fault system. Partly, these branches propagate into overlying alluvial-fan deposits that are probably Pleniglacial to Lateglacial in age. The outcrop data in combination with the seismic data give evidence that in the splay fault system, steep back-thrusts are developed. One of these back-thrusts is most likely the NNE-ward dipping fault that is exposed in the sinkhole. The lateral extent of this fault was mapped with electrical resistivity tomography (ERT) profiles acquired by the LIAG Institute. The timing of fault movement was estimated based on optically stimulated luminescence dating of the faulted debris-flow deposits using both, quartz and feldspar minerals. Consistent feldspar and quartz ages indicate a good bleaching of the sediment prior to deposition. Displacement relationships and luminescence ages from the debris-flows (14.2 ± 0.8 ka on polymineral feldspar; 15.2 ± 0.8 ka on quartz) imply that fault movement occurred after ~ 15 ka and supports the idea that the Harz boundary fault system was reactivated during the Lateglacial. Numerical simulations of GIA-related changes in the Coulomb failure stress regime at the Harz boundary fault underpin the assumption that the fault was reactivated during the Lateglacial due to stress changes induced by the decay of the Late Pleistocene (Weichselian) Fennoscandian ice sheet. A recent study by DIERCKS et al. (2021), based on topographic analyses also points to young uplift of the Harz Mountains and is in line with the result from MÜLLER et al. (2020). The movements on the Harz boundary fault are comparable to the Lateglacial activity of the Osning thrust in the Bielefeld area (BRANDES et al. 2012b).

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Day 3 / Stop 2: Push moraine and glaciotectonic deformation at Abbenrode
(Coordinates: 51°56'22"N, 10°37'02"E)

The sand-gravel pit at Abbenrode exposes a glaciotectonized sequence within a Saalian ice marginal setting, located c. 8 - 10 km inside of the maximum Drenthe ice extent. Geomorphologically, the local terminal position forms a subdued c. 700 m long, 15-20 m high, SW-NE oriented broad ridge between the nearby Ecker Valley to the W and the Stimmecke Creek in the E. The gravel pit itself is located less than 100 m from the former border between East and West Germany, allowing for site access and geoscientific logging to start only after 1989 (FELDMANN 1996, 2002; REINECKE 2006). Since then, mining has rapidly expanded the pit thereby changing the exposure situation continuously over the years. At present, the pit exposes a c. 20 m thick Quaternary sequence which is directly underlain by Upper Cretaceous marlstones of the Ilsenburg Formation (currently not exposed).

The Quaternary succession begins with c. 5-6 m of coarse fluvial gravels, the top 2 m of which are exposed at the base of the pit. The gravels are part of the fan shaped Main Terrace

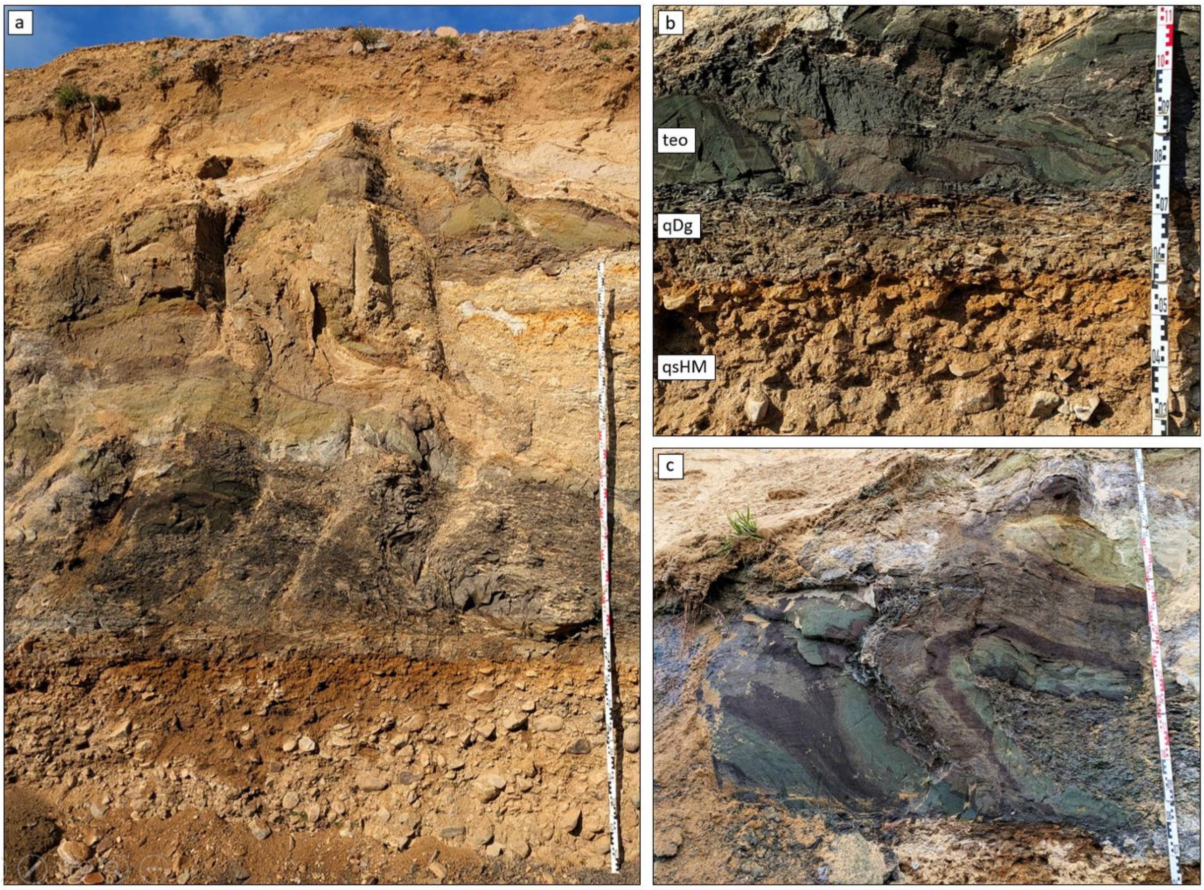

Fig. 25: Lower portion of the glaciotectonic sequence at Abbenrode (25a) exhibiting Main Terrace gravels (qsHM in 25b) overlain by a thin Drenthe glaciotectonite or sheared till (qDg) and blocks of glacially transported dark clay and Eocene glauconite sands (teo) with glaciotectonic deformation as seen in the sheared recumbent fold in Fig. 25c.

deposit accumulated by the Ecker River exiting the Harz and flowing into the northern Harz foreland during the Saalian Complex. Aggradation occurred in several phase probably from varying directions and with intermittent breaks in sedimentation. This interpretation is supported by clast analyses, which petrographically divide the gravel package into a finer grained lower subunit, containing no local Mesozoic limestone, and a coarser upper subunit with a significant content of local limestone (WINTER 1998). Both units are separated by a cryoturbation horizon (FELDMANN 1996).

Directly above the gravel lies a c. 15 cm thick intensely sheared till, locally developing into a 1 - 2 m thick dark gray carbonaceous till. Clast fabric measurements from the till indicate ice movement from the NW to the NE. The profile currently exposed (summer 2025) at the western end of the Abbenrode pit (Fig. 25), shows a series of heavily deformed units above the till, including folded and sheared dark clays and green glauconitic sands. Based on their micropaleontological inventory the glauconite sands suggest an Upper Eocene age (FLECHNER 1997), implying *en-bloc* glacial transport to the site, since the closest known occurrence of Eocene materials lies at a distance of c. 22 km near the village of Jerxheim, indicating glacier flow from the NE to ENE into the area. This would be consistent with clast fabrics measurements from the upper section of the till (FELDMANN 1998). Above this follow a further c. 15 m of weakly carbonaceous, gravely to sandy glaciofluvial meltwater deposits, with intense glaciotectonic deformation including incorporated and sheard clay and glauconite sands. Locally, these sediments are overlain by sandy mass flow deposits in which a Holocene soil developed.

The preliminary genetic model proposed for the sequence involves an initial Saalian (Drenthe) maximum ice advance across the site, depositing the till overlying the Main Terrace gravels and transporting slabs of allochthonous clay and Eocene glauconitic sands to the site. Following the abandonment of the maximum Drenthe ice limit at the Harz Mountain front, the ice retreated northward leaving the site at Abbenrode ice free. Subsequently, a new pulse of glaciofluvial meltwater deposition, still within the Drenthe stage of the Saalian glaciation, draped sand and gravel over till and allochthonous clay and glauconite sands in the basal portion of the section. This was followed by a readvance of the ice sheet, forming the ice marginal push moraine near Abbenrode, leading to glaciotectonic compression with folding and thrusting in an ice proximal proglacial setting.

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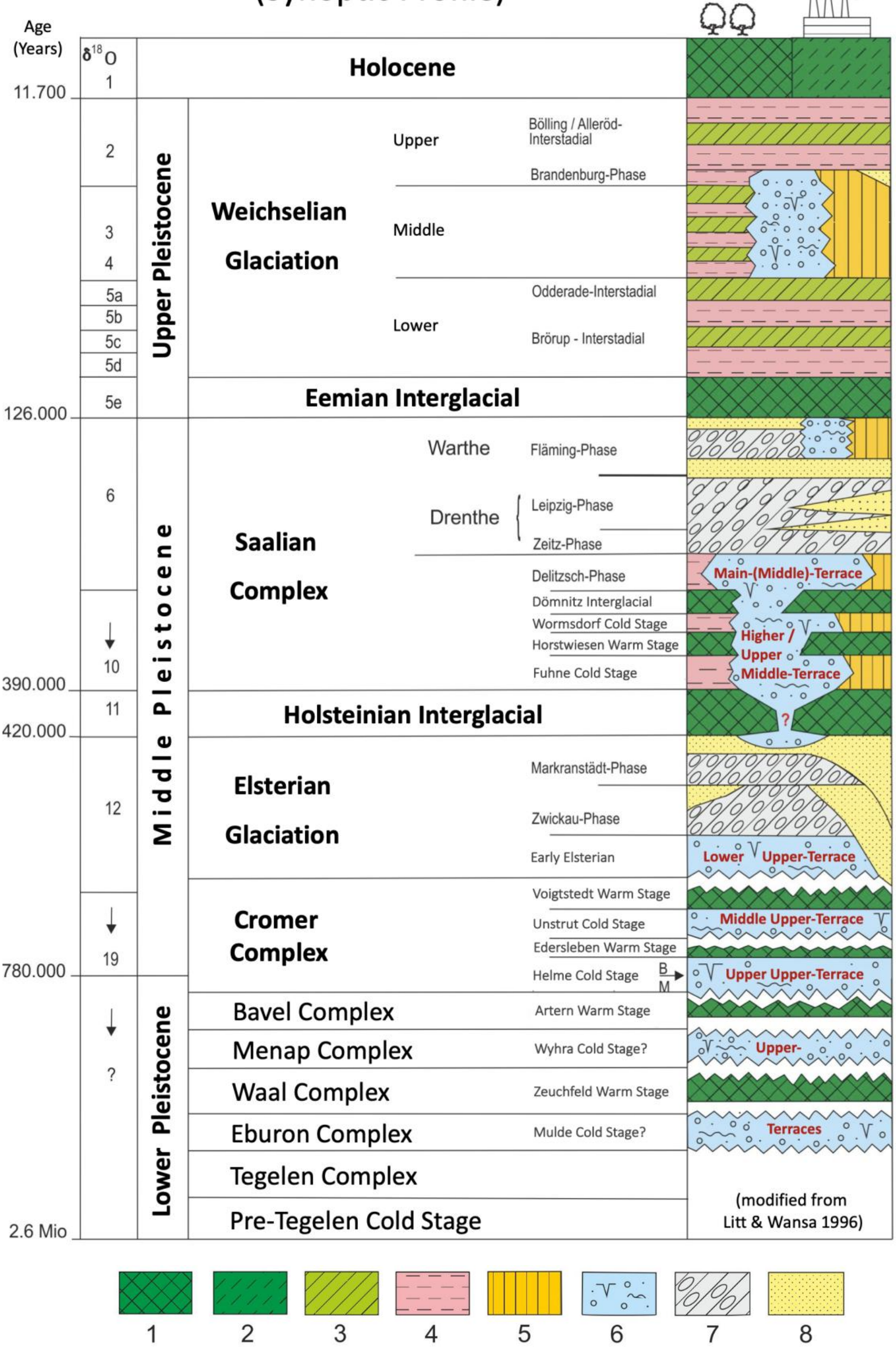
Quaternary of Saxony-Anhalt
(Synoptic Profile)



1 - Interglacial deposits, 2 - Holocene deposits, 3 - Interstadial deposits
4 - Periglacial re-depositions, 5 - Loess and loess derivates, 6 - Fluvial gravel
7 - Till (incl. warved clay), 8 - Glaciofluvial deposits