

A radical reassessment of the stratigraphy, palaeoenvironmental processes and dating of the Middle Pleistocene deposits at Schöningen, northern Germany

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ABSTRACT

Open-cast lignite mining east of the town of Schöningen revealed in the North Pit and the South Pit a unique sequence of late Middle Pleistocene deposits. In the North Pit, we recognised a series of alluvial fan deposits, overlying Elsterian glacial sediments, and originating from the Muschelkalk massif of the Elm during the Elsterian late-glacial. Channels and basins eroded into the alluvial fans filled with Holsteinian Interglacial sediments. At the end of later cold stages, periglacial meltwater from these channels temporarily avulsed, eroding two deep, major north-south-oriented channels: the Reinsdorf Interglacial Channel (Channel II) and the Schöningen Interglacial Channel (Channel III), which developed into lakes along the valley floor. The Reinsdorf Channel consists of a sequence of narrow, superimposed subchannels, again eroded by floodwaters, primarily containing beds of silt, detrital mud, and peat deposits, which represent five, sometimes six, sedimentary cycles that can be traced along the entire length of Channel II.

The combined stratigraphical data from the North and South Pits reveal three successive interglacials, each with a distinct vegetation succession. These are located between the Elsterian glacial deposits at the base of the Schöningen sequence and the Saalian till found higher up; the Holsteinian Interglacial, the Reinsdorf Interglacial, and the Schöningen Interglacial, which correspond with Marine Isotope Stage/Substage (MIS) 11c, MIS 9e, and MIS 7e, respectively. The mammalian biostratigraphical data support the MIS 9 age of the Reinsdorf Interglacial deposits and indicate an age of ca. 300 ka for the Schöningen wooden spears.

1. Introduction

Schöningen is known worldwide for the spectacular Palaeolithic spear finds discovered in a Middle Pleistocene lake shore sediment sequence in 1995. Already since the late 1980's, before the cultural heritage of *Homo heidelbergensis* was discovered, the Quaternary sequences had been recorded and examined as part of an archaeological prospection project by the state of Lower Saxony, as new exposures within the former open-cast mine became available (Thieme and Maier, 1995) (Fig. 1A, B and C).

Since then, and up to the present day, the stratigraphy, age and palaeobotany of the Quaternary deposits overlying the Eocene lignite,

which have been uncovered in the very extensive open-cast lignite mines near Schöningen in northern Germany, have been discussed in a series of scientific papers, monographs and books, in particular the Middle Pleistocene layers. In these documents, very profound differences of interpretation were expressed. Following a conference in Hannover in October 2009, a monograph dedicated to the site was published - *Die chronologische Einordnung der Paläolithischen Fundstellen von Schöningen* (The chronological setting of the Palaeolithic sites of Schöningen) (Behre (ed.), 2012). The papers in this volume, with a few exceptions, promoted the view that only one Middle Pleistocene interglacial cycle (possibly two) is present at Schöningen, and this was assigned to the Holsteinian interglacial. Furthermore, most papers assumed and accepted that the

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Holsteinian interglacial relates to Marine Isotope Stage (MIS) 9 and that the preceding Elsterian glacial Stage consequently relates to MIS 10, a conclusion at odds with the accepted stratigraphy in other parts of northern Europe. A second monograph – *Die Geologie der Paläolithischen Fundstellen von Schöningen*, published in 2015 (Terberger and Winghart (eds.), 2015) contains the dissenting interpretation of Mania and further contributions. A further contribution to this debate has been that of Lang and Winsemann (2012), and Lang et al. (2012, 2015a, 2015b), who interpreted the development of the site in terms of other Holsteinian sites in northern Germany, namely an Elsterian tunnel valley, partially filled with glacial till and sands, followed by the development of an extensive Holsteinian lake. More recently, two papers (Van Beirendonck and Verbruggen, 2025; Hutson et al., 2025) have argued that the

Reinsdorf Interglacial deposits at Schöningen should be correlated with MIS 7, challenging the generally accepted view that these deposits date to MIS 9.

After reviewing all the evidence, including a number of earlier dissertations on the earlier phases of the excavation, and the evidence and conclusions of scientists from a variety of fields, which, in our opinion, were never properly synthesised but often developed in isolation by different specialists, we present here a new framework for the depositional environments and ages of the main parts of the Schöningen sequence, and correlations with German and other European sites (Fig. 1A).

Following the history of research at the Schöningen locality and the regional setting, we present details of the North Pit and the South Pit,

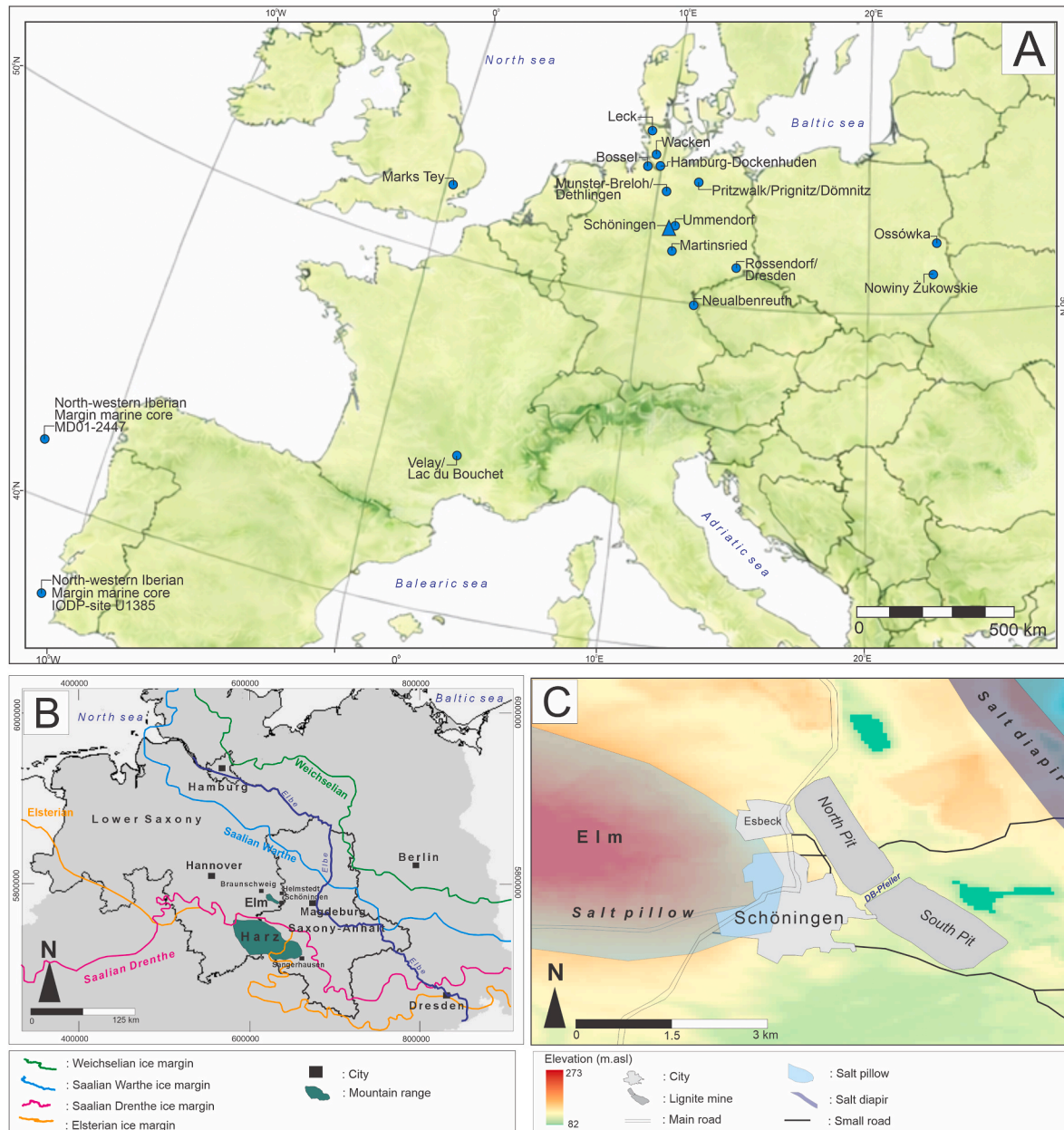


Fig. 1. Map of the study region showing (A) locations in western, southwestern and central Europe with Middle Pleistocene sequences referred to in the study. The location of Schöningen north of the Harz Mountains in northern Germany and maximum extent of ice sheets (coloured lines: Elsterian = E; Saalian Drenthe Stage = SD; Saalian Warthe Stage = SW; Weichselian = W), modified from Urban et al. (2023) are presented in (B). (C) shows the North and the South Pit, the DB-Pfeiler of the former Schöningen open-cast lignite mine east of the town of Schöningen and southeast of the village of Esbeck, which lie on the western slope of the Elm low mountain range. Elevation was taken from Shuttle Radar Topography Mission (SRTM) of Schöningen (downloaded from <https://earthexplorer.usgs.gov/>; Coordinate system: WGS 84). Salt pillow and diapir (Brandes et al., 2012) were downloaded from <https://nibis.lbeg.de/>.

then combine the data and arrange them in a stratigraphical order consistent with data from other localities. This results in a stratigraphical model that we wish to propose. In the discussion, we compare our model with a limited number of publications that provide statements about the age of the Schöninggen deposits.

2. History of research

In 1978, the Braunschweigische Kohlen-Bergwerke AG opened an opencast lignite mine, the Tagebau Esbeck, here referred to as the North Pit, to the east of the town of Schöninggen and the village of Esbeck

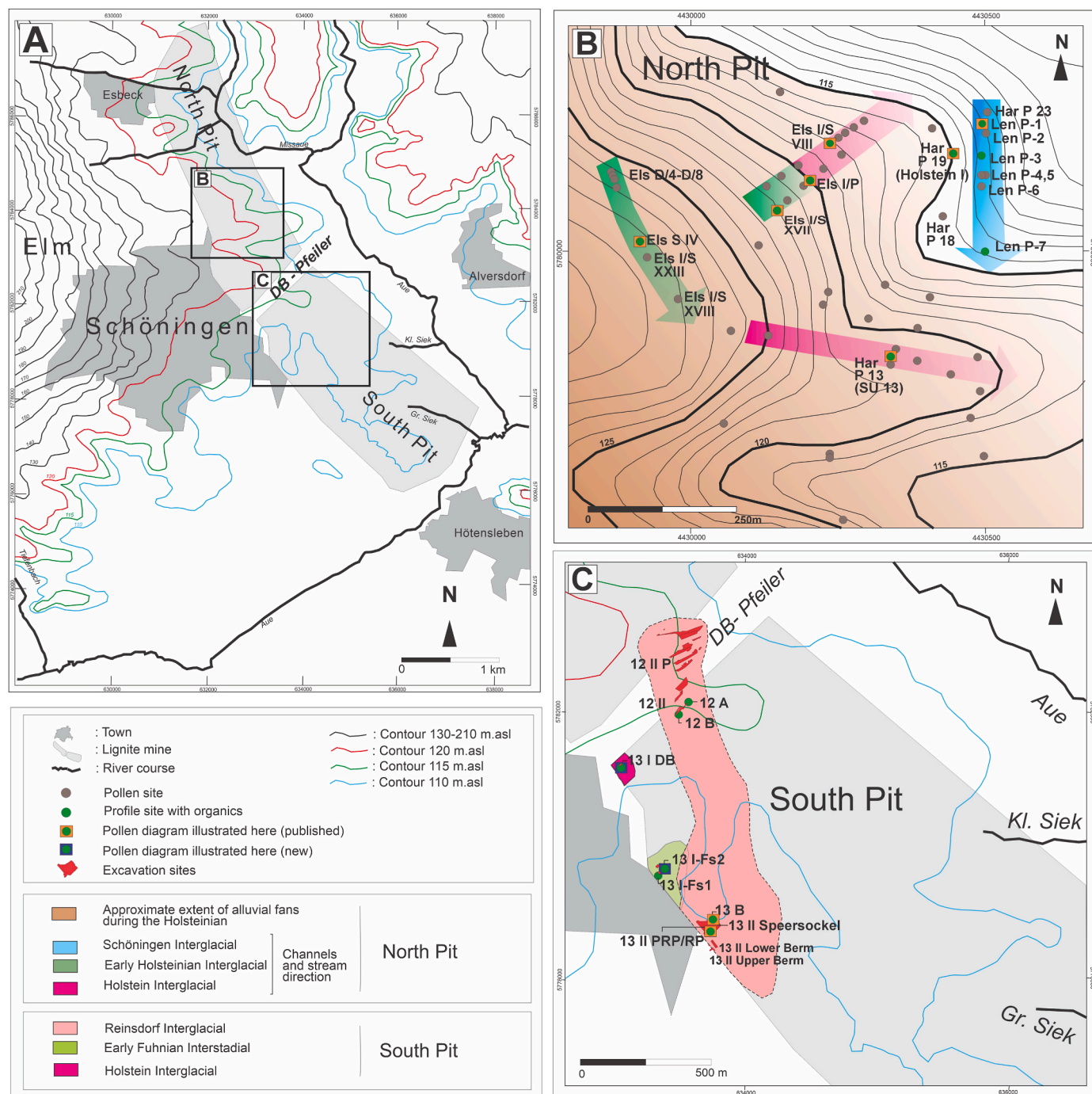


Fig. 2. shows the area under closer investigation. A relief map between the Elm and the Helmstedter Sattel (according to Mania and Altermann, 2015: Fig. 4) is presented in (A). (B) shows a map of alluvial fans with proposed major channels derived from the profile records of Elsner (1987), Hartmann (1988) and Lenhard (1989) of the North Pit. Note the contours relate to the early 20th century, before excavation of the North Pit. The channels were deeply buried and were active over 400ka ago, when the fans were recently formed and continued to expand subsequently. Like deltas, the fans were traversed by many minor channels, marked by a scatter of further residual organic deposits. In (C), important Palaeolithic excavation sites such as 12 II, 12 P, 12 A and 12 B at the DB-Pfeiler, respectively close to it and site 13 I and 13 II at the 'Speersockel' area and biostratigraphically described profile locations are shown. The brown dots in (B) and (C) are profile sites mentioned in context, the green dots mark pollen sites of already published pollen diagrams, which we refer to. The green dots framed by orange squares mark pollen sites previously published, of which we present redrawn and partly refined pollen diagrams here. Two new, previously unpublished pollen diagrams of sites 13 I DB and of the oldest Palaeolithic site 13 I-Fs. 2 of the South Pit are marked as green dots in a blue square. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(Figs. 1C and 2A). This eventually covered an area 0.6–0.8 km by 2.5 km to the north of the then existing railway line from Schöningen to Helmstedt and Magdeburg via Offleben. From 1979 to 1991, in advance of the constantly expanding development of the pit, the Niedersächsisches Landesamt für Denkmalpflege Hannover (NLD) instituted rescue excavations, under the direction of Hartmut Thieme, of a series of Neolithic to Mediaeval archaeological sites on the surface of the landscape (Thieme and Maier, 1995; Thieme, 2007). In 1982, Brigitte Urban joined this project to provide biostratigraphical, sedimentological and pedological analyses.

In the mid-1980s, attention shifted to the underlying succession of older Quaternary deposits that overlaid the Eocene strata, where both Elsterian and Saalian glacial deposits, as well as horizons of organic deposits, were intermittently exposed. As will be discussed in detail later, these deposits were then studied by Urban and in a series of dissertations written by four diploma students from the Geological Institute of the University of Hannover.

In 1992, the excavation of the South Pit, Tagebau Schöningen, began, and in the same year, the first Palaeolithic artefacts were discovered by Hartmut Thieme and Dietrich Mania in the Middle Pleistocene deposits lying between the Elsterian and Saalian glacial sequences (Figs. 1C and 2A). These artefacts came initially from the area Schöningen 12.1 (Schöningen 12 B), from Reinsdorf Interglacial deposits, as defined by Urban (1995), and in the same year from Schöningen 13 I, which we now consider to be of post-Holsteinian age dating to a succeeding interstadial of the early Fuhnian (Thieme, 1995a, 1995b; Thieme and Maier, 1995; Supplementary Information). Later, artefacts were also found in various horizons within the younger Reinsdorf sequences at the site Schö 13 II (Thieme, 1997; Urban, 1995).

In 1992, Dietrich Mania and Thijs van Kolfschoten joined the research team. Mania collected and studied the molluscs and the stratigraphy of the exposed sequences to provide palaeoecological and (bio) stratigraphical analyses. In addition, Mania conducted rigorous and invaluable work documenting sections that were temporarily exposed as the giant excavating machines cut into the underlying lignite deposits throughout the South Pit, erasing all the Quaternary record in their path. Thijs van Kolfschoten was invited to collect and investigate the vertebrate remains from the exposed deposits to provide biostratigraphical and palaeoenvironmental information, as well as data on hominin subsistence and behaviour.

Excavations at the site were originally conducted by a team from the NLD, directed by Hartmut Thieme. In 2008, directorship passed to Nick Conard of the University of Tübingen, with Jordi Serangeli, also from Tübingen, taking on the role of excavation leader.

The palaeobotanical studies, along with the accompanying sedimentological and pedological studies, continued to fall under the aegis of Brigitte Urban, who also initiated the first geochronological investigations in the North pit (Heijnis, 1992; Heijnis and Urban, 1995). Particularly since 2006, several other specialists have contributed to the study of the Quaternary deposits at Schöningen (see e.g. Behre (ed.), 2012; Terberger and Winghart (eds.), 2015; Conard et al (eds.), 2015). Plant macrofossils were studied by Jechorek (2000), Czaja (2012) and Bigga (2018).

A major event in October 1994 was the discovery of a wooden throwing stick, followed in time by the recovery of five complete long wooden spears and fragments of three others within layer 13 II-4 Bed 4, familiarly referred to as the 'Spear Horizon' and also the recognition of a butchery site with abundant remains of large mammals, particularly horses, in association with flint artefacts (Thieme, 1997). These discoveries transformed the public's view of the site. The goodwill of the Braunschweigische Kohlen-Bergwerke AG, and notably its then Director, Klaus-Christian Cornelius from Schöningen, contributed to the preservation of this area, the "Spear Socket" located on the south-west side of the pit, for ongoing scientific investigation.

A further significant contribution to the investigation and conservation of the Schöningen site, its history, and artefacts was the opening

of the Paläon in 2012, which is both a museum and research centre dedicated to the site.

3. The regional setting

The town of Schöningen lies close to the southern margin of the North German Plain and to the north of the Harz Mountains and about 30 km to the south-east of the city of Braunschweig (Fig. 1A and B). Geologically, it sits on the southeastern edge of the Elm, a Muschelkalk massif, consisting of Triassic limestone. Immediately to the east lies a major north-west to south-east, fault-bounded basin, the Helmstedter Mulde, separating the Elm to the west (322 m NN at its highest point) from the Jurassic rocks of the Lappwald (194 m NN). In this basin, during the Eocene, over 360 m of marginal marine and terrestrial sediments were deposited, including thick lignite beds. The basin is divided longitudinally by a major upwelling salt diapir, the Helmstedt-Stassfurt Salzmauer. The area under consideration here, immediately to the east of Schöningen and the village of Esbeck, 2 km to the north, is essentially part of the western side of the basin, flanked by the Elm and the Salzmauer (Fig. 1C). As described later, this basin, creating a valley and containing the Eocene sediments, was invaded and eroded by the Elsterian ice sheet. The Quaternary infill of that valley, which we refer to as the Schöningen Valley, overlying the Eocene sediments, ranges through the products of two major glacial advances and intervening temperate intervals to Holocene deposits from a minor stream, the Missaue, which now drains the valley.

The North and South Pits were separated by a large embankment (the "Deutsche Bahnpfiler", DB-Pfeiler), a strip of land that carried both the railway and a road. From 2008 onwards, the embankment was gradually cut back, accompanied by archaeological excavations (12 II Plateau (P)), until it was finally removed entirely, just before mining operations ended in 2016 (Fig. 2A and C).

4. The stratigraphy of the North Pit (Baufeld Esbeck)

The North Pit, or Baufeld Esbeck, occupies the area to the northeast of Schöningen and east of the village of Esbeck (Fig. 2A and B). Its north-south length is about 4 km, and its width ranges from 800 m to 1 km. Excavation of the Eocene lignite here to a considerable depth was most active during the 1980s. Examining the topographic map of the area before the excavation of the North Pit reveals two important features. First, the original topography was highly irregular, varying in height from 105 to over 128 m, with a series of well-defined lobes or spurs of land descending into the valley from the massif of the Elm on the west side (Fig. 2B). The origin of these lobes is particularly significant. Second, the excavation of the pit required diverting the small stream, the Missaue, which flowed along the valley floor, and eliminating two tributary watercourses draining from the Elm to the north and south of the village of Esbeck.

4.1. The general pattern of the Quaternary sequences of the North Pit

Knowledge of the stratigraphy of the Quaternary deposits exposed in the North Pit comes almost exclusively from the very detailed dissertations of Elsner (1987), Hartmann (1988), Lenhard (1989) and Tschee (1991). Hitherto, their work has largely been published as stratigraphic cross-sections (initially in: Urban et al., 1988, 1991a, 1991b; subsequently by: Thieme, 2007; Mania, 2009; Meyer, 2012), particularly in connection with organic horizons where pollen analyses were carried out. However, as noted when published, these cross-sections are highly schematised and simplified and therefore difficult to interpret. Therefore, it has been necessary to go back to the dissertations themselves to understand the true nature of deposition and the relationships among different horizons.

4.1.1. Glacial deposits

The basal Quaternary deposits in the North Pit and the South Pit relate to the Elsterian Glacial Stage. According to [Elsner \(1987\)](#), the earliest deposits are glacial meltwater sands, which are gravelly below but fining upwards, often horizontally bedded and up to 15 m thick. [Elsner \(1987\)](#) noted that the surface of the Tertiary (Eocene) deposits beneath the sands was strongly affected by permafrost, thereby negating the tunnel valley hypothesis proposed by [Lang and Winsemann \(2012\)](#) and [Lang et al. \(2012, 2015a\)](#). Nowhere did Elsner record the succeeding till, which is locally 10–13 m or more thick, resting directly on the Tertiary deposits; instead, he observed it overlying the sands in 'relatively undisturbed superposition' over several hundred meters, suggesting 'a picture of a calmly flowing ice stream.' In contrast, [Lenhard \(1989\)](#) noted that the till in the southern part of the North Pit cut down into the Eocene lignite deposits, which showed both glaciotectionic disturbance and diapiric intrusion into the overlying sediments. Above this lower till, further meltwater deposits were recorded, then a thinner upper till of about 2 m, followed by varved clays and more meltwater sands.

[Elsner \(1987\)](#) suggested that the melting of the Elsterian ice sheet left behind a swampy landscape affected by periglacial processes, in which the melting of ice blocks within the till formed basins that were infilled with up to several metres of inorganic silt deposits. In Elsner's schematic profile, these were capped by what he believed to be a bed of redeposited loess (Schwemmlöss) ([Urban et al., 1988](#)) (SI Table 1).

Long after all overlying Quaternary deposits had been quarried away across most of the North Pit, the Elsterian glacial sequence remained exposed in the south-west corner, adjacent to the DB-Pfeiler ([Fig. 2C](#)). Here, till and glaciofluvial deposits had not been dug away because, significantly, the western slopes of the pit were quite unstable in this area as a result of serious water pressure from the Elm. In this area, [Lang and Winsemann \(2012\)](#) showed that the glacial sands were deposited, as might be expected, by meltwater flowing from the north.

4.1.2. Deposits overlying the basal glacial sequence

The deposits overlying the glacial sequence, approximately 1 km or further north ([Fig. 2B](#)), in the North Pit, as described successively by [Elsner \(1987\)](#), [Hartmann \(1988\)](#), and [Lenhard \(1989\)](#), are of the most interest and significance. Here, their dissertations recorded a variety of sediment types - silts and sands interpreted as glaciolacustrine or niveo-fluvial, coarser-grained, less well-sorted solifluction deposits, loess, and also beds of organic silt along with small channels where peat, organic muds, and tufaceous sediment occurred, which Urban was able, in part, to study through pollen analysis ([Urban et al., 1988, 1991a, 1991b](#)). All of these can be seen in the schematic cross-sections drawn up by Elsner ([Fig. 3](#) in [Urban et al., 1988](#)), Lenhard ([Fig. 2](#) in [Urban et al., 1991a](#)) and Hartmann ([Fig. 2](#) in [Meyer, 2012](#)) (SI Table 1). Because these cross-sections have been compiled from many smaller measured sections, they change direction, reflecting how the pit was excavated from north to south ([Fig. 1](#) in [Meyer, 2012](#)). They, therefore, reflect an observer looking southwards, but also sometimes to the east and west. This means that they are very difficult, if not misleading, to interpret.

4.1.3. Change in the direction of the sediment supply

It is immediately apparent that those parts of the cross-section that run approximately north-east to south-west and roughly parallel to the escarpment of the Elm show little dip, whereas those running obliquely or even at right angles to the Elm show either a gentle or much more pronounced dip away from that massif. Therefore, unlike the underlying glacial deposits, which were emplaced from the north, deposition appears to have come from the direction of the Elm, although dips and strikes vary. The assumption that there is a change in the direction of the sediment supply is supported by the fact that the coarser fraction within the sediments overlying the glacial sequence, particularly the solifluction deposits, consisted of well-rounded pebbles from the Keuper and Muschelkalk, and only rarely included non-local erratic material. Elsner's diagram indicates that, even before his investigation of the North Pit, nearly an additional 10 m of sediment, overlying those he described, had already been removed ([Elsner, 1987](#)). Thus, the original sequence of

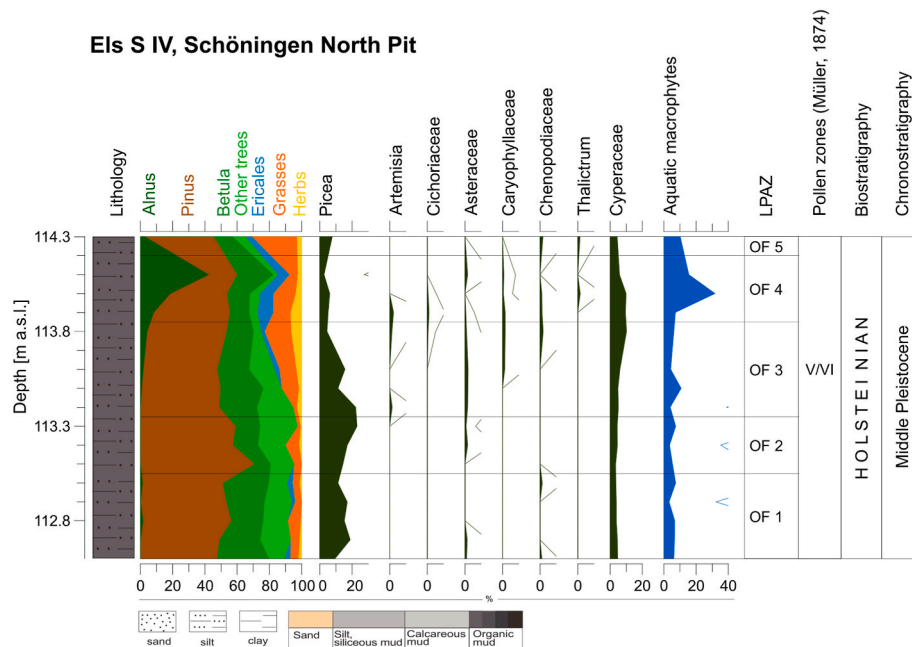


Fig. 3. Simplified pollen diagram of profile Els S IV (10°58'28.813" E 52°08'58.144" N), from the early Holstein Interglacial of the North Pit (formerly Offleben I Interstadial) ([Fig. 2B](#)), data and zonation (Local Pollen Assemblage Zones, LPAZ) according to [Urban et al. \(1988\)](#). Pollen zones (PZ) of the Holstein Interglacial according to [Müller \(1974\)](#). * All pollen diagrams were created in the same way. The pollen sum, which forms the basis for the percentage calculation of all taxa, includes trees and shrubs as well as terrestrial herbaceous taxa, including Poaceae and Ericales. Aquatic and cryptogamic taxa were excluded from the pollen sum. The pollen diagram was created using C2 software version 1.5 ([Juggins, 2007](#)). Pollen zone = PZ; Local Pollen Assemblage Zone = LPAZ; Local Pollen Assemblage Subzone = LPASZ.

Quaternary sediments abutting the Elm massif was much thicker in places. This can be confirmed by the contours from topographic mapping of the area prior to any commercial excavation (Fig. 2A and B) (Mania, 2009; Fig. 4; Mania and Altermann, 2015; Fig. 4).

Evidence of solifluction and slumping in these upper deposits, previously interpreted as the result of periglacial processes, does not indicate cold-climate freeze-thaw conditions, but rather reflects the typical behaviour of water-saturated sediment on steep slopes. Although Elsner (1987), Hartmann (1988) and Lenhard (1989) interpreted the bulk of these upper deposits to be of glacial origin, the sequences containing organic deposits, often with wood fragments, are clearly related to intervals of milder climate. The sediments appear to relate to alluvial fans laid down largely by powerful active springs emanating from the Muschelkalk high up along the escarpment of the Elm Massif. The radial nature of such fans, which can be deduced from the topographic map, explains the observed variability in dips and strikes (Mania and Altermann, 2015; Fig. 4). The pattern and distribution of these fans are clearly illustrated by the lobes descending into the valley. Sometimes, soliflucted debris or landslips temporarily interrupted other deposition in the channels. The directions of the channels, cut into the fans, also varied as the fans built up; channels could be blocked or abandoned, allowing intermittent ponding, resulting in basins containing finer sediments, including humic silt and even telmatic peat deposits.

4.1.4. Water from the Elm

The bulk of the water that flowed into and then southwards out of the Schöningen valley must have come from the springs and streams associated with these fans, rather than from any Proto-Aue or Missaue stream. Initially, towards the end of the Elsterian glacial stage, there was a great deal of meltwater from decaying ice and permafrost, concentrated on the Elm, but forming powerful torrents that poured down into the Schöningen Valley at a number of sites between Schöningen and Esbeck. The energy of these meltwater torrents was spent in shifting the vast amounts of frost and ice, as well as shattered rock debris, which covered the Elm to form an irregular series of alluvial fans, at least four or five, extending down into and across the Schöningen Valley (Fig. 2B). Most of these lay within the western side of the North Pit. Once the fans had been formed and the available material largely scoured away from the immediate surface of the Elm, the energy of the streams turned from transport to erosive mode and began to cut a network of channels down through the fans, emptying on the valley floor, the water either flowing

down to a stream on the far, east side of the valley or cutting channels along the margins of the alluvial fans. The channels, cut through the fans, could be shallow or deep, narrow or wide, but with irregular floors, where often basins were excavated – a highly unstable environment. It was within these channels that ponds developed during the following interglacial. Some channels were still being cut or enlarged during interglacial periods, presumably due to episodes of heavy rainfall.

4.2. Organic deposits

A relatively small number of sections exposed in the North Pit were investigated palynologically by Urban (Urban et al., 1988, 1991a, 1991b; Urban, 1996), (Fig. 2B). She defined two horizons, Offleben and Esbeck, which she initially regarded as late Elsterian interstadial oscillations, and she identified fully temperate deposits assigned to the Holsteinian (locally Alversdorf) Interglacial. Furthermore, she recognised another bed of interglacial sediments in the North Pit with a distinctly different pollen signal from the Holsteinian, which occupied a north-south-trending marginal channel incised into the valley floor. Urban named this the Schöningen Interglacial (Urban et al., 1991a). In addition, interstadial horizons could sometimes be recognised within deposits overlying interglacial sequences (Fig. 2B). Using the palynological interpretations developed by Urban, the geologists preparing their dissertations generally felt confident in relating and referring the organic horizons within these channel infills to interglacials or interstadials.

4.2.1. Offleben deposits

Elsner (1987) described nine sections (out of more than thirty that he logged) on the western side of the North Pit (Fig. 2B), sequences containing organic deposits, which he, following Urban's palynological studies, assigned to the Offleben Interstadial. These were associated with basins, apparently incised into the adjacent sediments, but, from their distribution, were clearly part of a distinct channel infill. This is marked on Fig. 2B, running at depth between Elsner's profiles D/4-D/8 and Els I/S XVIII. From one such basin, relatively high up on the alluvial slope, Elsner and Urban (Elsner, 1987; Urban et al., 1988) described a basin or channel, cut into coarser-grained sediments of the fan and overlying the Elsterian Schwemmlöss. The basin was infilled with approximately 5 m of silts (Beckenschluff) with a number of dark-brown to black humic horizons. Near the top, a much more organic layer

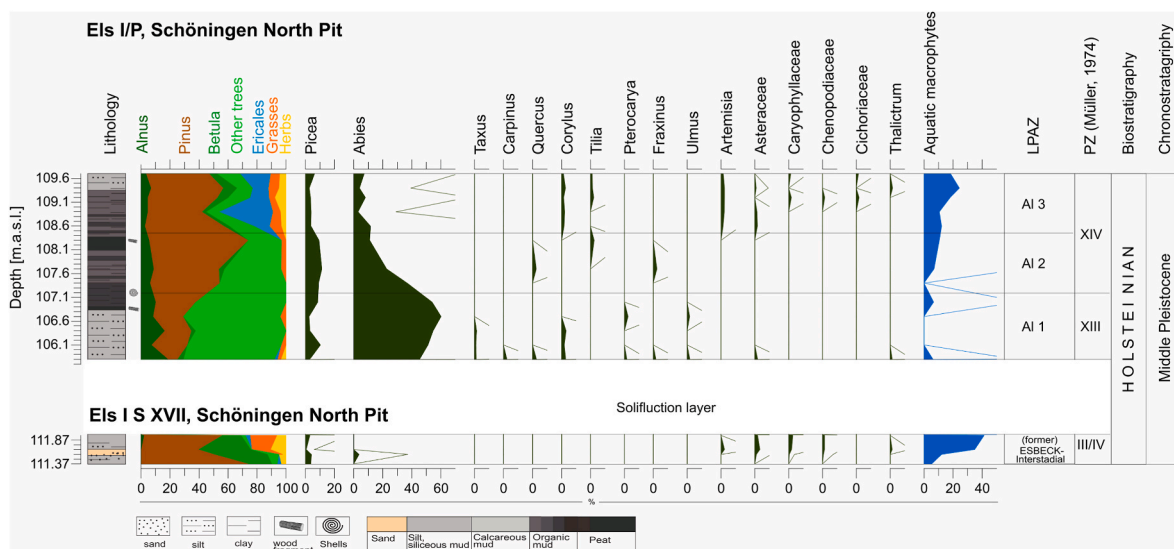


Fig. 4. Combined and simplified pollen diagrams of the Els I/S XVII profile (10°58'40.818" E 52°08'59.898" N) (formerly Esbeck Interstadial) and the Els I/P profile (10°58'43.620" E 52°09'01.540" N) (formerly Alversdorf (=Holstein) Interglacial) from the early and late Holstein Interglacial of the North Pit (Fig. 2B), data and zonation (Local Pollen Assemblage Zones (LPAZ)) according to Urban et al. (1988). Pollen zones (PZ) of the Holstein Interglacial according to Müller (1974).

yielded only sparse residual pollen.

However, from an adjacent section (Profil S IV, [Elsner, 1987](#)) (Els S IV, [Fig. 2B](#)), Urban obtained a pollen diagram from a 1.5 m sequence relating to the lower humic silts ([Fig. 3](#)) showing a dominance of boreal forest trees, *Pinus* (ca. 40–50%), *Picea* (ca. 15–20%), and *Betula* (ca. 10–15%), with indications of a rise of *Alnus* and *Corylus* in the uppermost levels. Herbaceous pollen (NAP) was generally low, with most values below 10%. This horizon was classified by [Urban et al. \(1988\)](#) as the Offleben I Interstadial and assigned initially to the Elsterian late-glacial.

Significantly, sedimentation in this particular section was interrupted by a 1.4 m thick bed of highly mixed sediment (silt, fine and coarse sand, and gravel), which might be interpreted as a solifluction deposit or simply a small landslide into the channel. [Elsner \(1987\)](#) interpreted this layer as evidence of a short interval of climatic deterioration, resulting in (niveo)-fluvial erosion of the slopes above. However, further accumulation of silt within the same basin, up to 3 m, then took place, including two additional 20 cm-thick layers of organic 'peat', which, unfortunately, could not be sampled. In the overlying sediment, well-preserved shells of gastropods and bivalves occurred, as well as plant macrofossil remains, including wood and seeds (none of which appear to have been studied). Two pollen samples from very organic silt layers yielded values for *Pinus* (66%, 53%), *Picea* (23%, 9.9%), and *Betula* (9%, 8.5%), very similar to those of the Offleben I pollen diagram. Urban classified this horizon as the Offleben II Interstadial. This is the only section in which an early Offleben I and a later Offleben II Interstadial have been distinguished ([Urban et al., 1988](#)).

Both Elsner's descriptions and the 3-dimensional plotting of his profiles ([Fig. 2B](#)), show that the Offleben deposits were confined to a single channel trending downslope in a well-defined north-west to south-east direction, which is a distributary channel formed on the surface of one of the alluvial fans. The 'Offleben' deposits appear to have accumulated within this channel over a length of at least 250 m. There is absolutely no possibility that this part of the Schöningen sequence accumulated in a wider lake basin, as they are constrained within a relatively narrow, almost linear depression. Furthermore, there is no evidence that this typical pre-temperate vegetation sequence was

terminated or interrupted by a return to cold-climate conditions, suggesting an interstadial.

4.2.2. Esbeck deposits

On what was an adjacent alluvial fan about 340 m west of the Offleben channel, exhibiting a south-west to north-east trend, Elsner recorded a second cluster of profiles containing humic silt deposits with organic lenses and reworked balls of peat, likely occupying a relatively broad channel ([Fig. 2B](#)). Following Urban's interpretation of the pollen sequence collected from his profile I/S XVII ([Elsner, 1987](#)), and a stratigraphic correlation, that failed to recognise that separate alluvial fans were involved, these organic horizons were assigned to another separate pre-Holstein climatic amelioration, the Esbeck Interstadial ([Urban et al., 1988, Fig. 5](#)). Of the six profiles in which 'Esbeck' sediments were recognised, the base of this unit was only reached in two, where they were overlying silts and sands. In five of the profiles, the unit was overlain by soliflucted material - a poorly stratified mixture of silt, sand and gravel, generally about 1 m or less in thickness, but at one site 3.37 m thick. These solifluction deposits were, in turn, overlain by sediments with organic material ascribed to the Holsteinian Interglacial, which was confirmed by pollen analysis (Els I/S XVII, [Figs. 2B and 4](#)). At one site (profile Els I/P, [Figs. 2B and 4](#)), Esbeck deposits passed directly upwards into Holsteinian sediments without any recorded interruption by soliflucted material.

Once it is recognised that the soliflucted material provides no evidence for renewed cold conditions but is simply the result of steep unstable slope conditions, the hypothesis that these are interstadial deposits rather than representing the transition from the Elsterian late-glacial to the Holsteinian pre-temperate substage has been rejected. The Offleben and Esbeck pollen sequences fit naturally into the well-documented pattern of the pre-temperate substage of the Holsteinian Interglacial itself, with sedimentation in parts of the channels interrupted by solifluction or landslides, involving deformation and shear structures that have been misinterpreted as periglacial. The terms Offleben and Esbeck Interstadial are, therefore, now redundant.

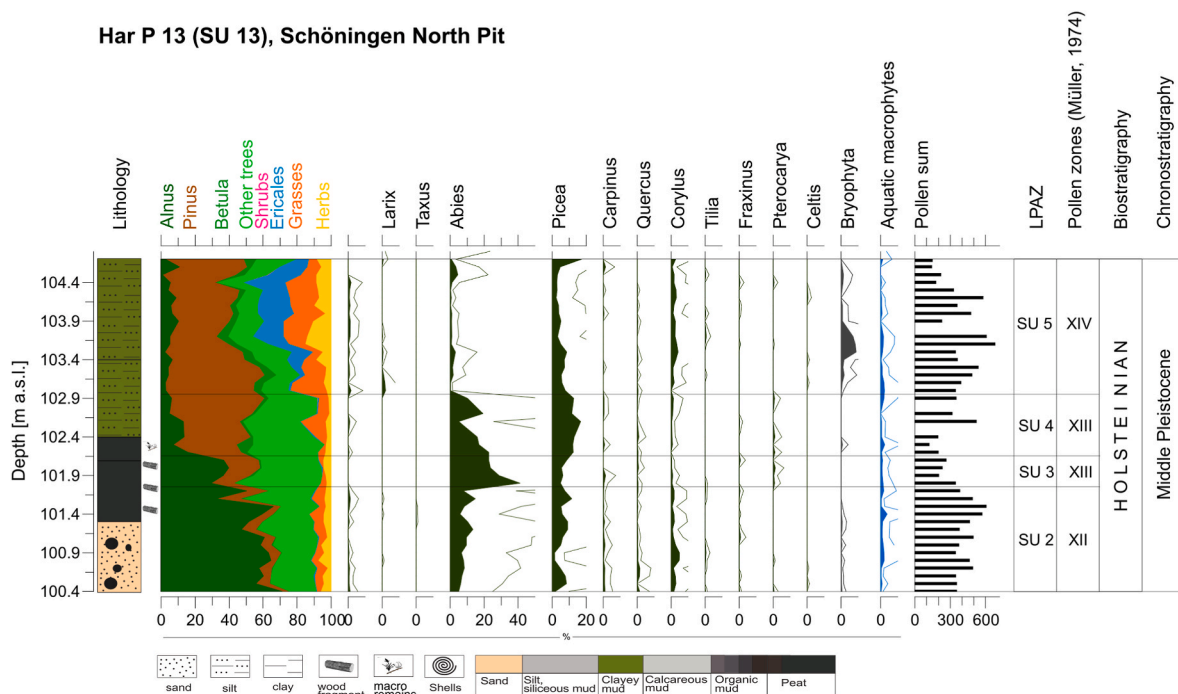


Fig. 5. Simplified and abbreviated pollen diagram of profile SU 13 (Har P 13 (SU 13)) (10°58'51.364" E 52°08'51.804" N) of the North Pit ([Fig. 2B](#)), which covers the Holstein Interglacial period, data and Local Pollen Assemblage Zones (LPZ) according to [Urban et al. \(1991a\)](#). Pollen zones (PZ) of the Holstein Interglacial period according to [Müller \(1974\)](#).

4.2.3. Holsteinian deposits

Of the about 65 profiles recorded from the North Pit by Elsner, Hartmann, and Lenhard, around 32 were considered to contain beds that represented temperate interglacial deposits. The evidence for this was generally a combination of humic silts (some of which might now be classified as clay muds), wood fragments, sometimes very large, and peat beds, either in situ or as eroded lumps. These profiles were scattered at different heights on the fans. However, they were concentrated mainly within two major channel features, each occupying one of the lobes of sediment spreading down from the Elm into the valley (Fig. 2B). Hartmann (1988) described a channel which, from the distribution of the profiles, ran in a north-west to south-east direction. In contrast, the channel recorded by Elsner (1987), following a separate lobe a few hundred metres to the north, was aligned in a south-west to north-east direction (Fig. 2B). Hartmann's channel was, deduced from its direction, possibly connected to the "Offleben channel", much higher up slope. Descriptions by Elsner (1987) and Hartmann (1988) provide insight into the nature of the deposits and the environment of deposition of these channels, while palynological evidence from Urban defines their age.

4.2.3.1. Holsteinian record (Hartmann, 1988). The most detailed description of the Holsteinian deposits is provided by Hartmann (1988). At the site of his profile P 13 (Fig. 2B), which is also the section from which Urban developed a long pollen diagram, SU 13 (Urban et al., 1991a) (Har P 13 (SU 13), Fig. 5), he recorded a channel 10 m in width that was cut down into the underlying strata, probably fluvioglacial sands - these are not part of the channel infill, as implied by Urban et al. (1991a). The bottom 1 m of the infill of this channel consisted of, at the base, well-sorted coarse gravel; however, this was not glacial gravel, as it contained large pieces of wood. It is essentially a 'lag' gravel. Overlying this gravel were beds of black to brown humic silt and sand, which contained abundant plant remains, large wood fragments, reworked blocks of peat, and gravel lenses. In places, cross-bedding and ripple marks were visible. Hartmann did not doubt that these were fluvial deposits. These lower sediments were barely suitable for pollen analysis and yielded only a mixed, clearly reworked assemblage consisting of open-ground taxa indicating a late-glacial origin, alongside a smaller component of tree pollen, mostly *Pinus*, but with a very small contribution from temperate trees (Zone SU 1). Urban suggested an early Holsteinian age for these sediments, largely based on the evidence from the overlying beds.

Above the lower sediments, Hartmann recorded approximately 2.6 m of fluvial sediments with an erosional base characterised by coarse gravel and sand, transitioning into dark organic silts with occasional lenses of sand and fine gravel. This layer contains plant remains and scattered, sometimes large wood fragments, ascending into more peaty sediments that suggest shallow water with minimal flow or even a telmatic environment. It would probably be misleading to describe this as a lacustrine environment. From these sediments, the upper part of the pollen diagram (SU 13, Urban et al., 1991a) (Har P 13 (SU 13), Fig. 2B) indicates a late-temperate interglacial vegetation succession (Fig. 5). In pollen zone SU 2, *Alnus* dominates, probably reflecting local abundance, though *Abies* and *Carpinus* are already present. Other temperate deciduous trees were present but not abundant. Zone SU 3 shows a marked rise in *Abies*, clearly dominating the forest, and in SU 4, this dominance is accompanied by a progressive rise in *Pinus* and *Picea* (Urban et al., 1991a). Small amounts of *Pterocarya* and *Fagus* accompany the dominance of *Abies*, and it is this combination of relatively high pollen values of silver fir and the occurrence of wingnut and beech that are generally held to be highly indicative of the Holsteinian Interglacial and its correlatives in Poland and Britain, the Masovian and the Hoxnian Interglacials (e.g. Srodoń, 1955; Bińka and Nitychoruk, 1995; Hryniewiecka and Winter, 2016; Nitychoruk et al., 2018; Erd, 1970, 1973a, b, 1978, 1994; Turner, 1970; K.-J. Meyer, 1974; Müller, 1974;

Koutsodendris et al., 2010) (Fig. 1A; Table 1). Zone SU5 concludes the Holsteinian record, when *Pinus* becomes dominant in the forests, ericaceous heathland develops, and most other tree species decline or virtually vanish (Fig. 5).

However, a further 8 m of sediment infill the central part of this channel in profile SU13, consisting of silts that are sometimes weakly organic with plant remains, or slightly clayey sand beds and lenses, along with peat horizons. All these indicate shallow water ponded conditions with occasional, more active fluvial input. This pollen diagram from this sequence extending above the Holsteinian (profile SU 13 in: Urban et al., 1991a) suggests a more open vegetation, with expansions of grasses (Poaceae) and sedges (Cyperaceae), as well as herbaceous taxa such as *Artemisia*, Chenopodiaceae, and composites (Asteraceae), and the presence of the dwarf birch *Betula nana*. However, there are at least two intervals when *Pinus* greatly expanded, suggesting occurrences of interstadials - the Missaue and SU A interstadials (Table 1). Nonetheless, given the proximity of interglacial sediments, fluvial inputs that undoubtedly introduced at least a small amount of reworked pollen, fluctuating water levels with possible oxidation, and differential destruction favouring coniferous pollen, this diagram is difficult to interpret in detail in climatic terms. Unfortunately, plant macrofossil samples were not collected.

4.2.3.2. Holsteinian record (Elsner, 1987). There are scattered profiles recorded in the North Pit where organic sediments, probably of Holsteinian age, but possibly younger, occurred. However, just as Hartmann's records indicated a channel associated with a particular lobe of an alluvial fan, so Elsner recorded a series of profiles that suggest a similar channel, defined by nearly 10 profiles, associated with another lobe about 350 m to the north (Fig. 2B). Again, from Elsner's (1987) Profile I/P (Els I/P, Fig. 2B), Urban recorded a late-Holsteinian pollen sequence, covering the late- and post-temperate substages of the interglacial and the characteristic high values of *Abies* pollen combined with the presence of *Pterocarya*. From the adjacent profile I/S VIII (Els I/S VIII, Fig. 2B) she also recorded and defined the overlying Missaue Interstadial, characterised by the expansion of *Pinus*, *Betula* and a little *Picea* (Urban et al., 1988).

What is particularly significant about this channel is that in its higher part, it contains what has been referred to earlier as the Esbeck deposits. These pass upwards into Holsteinian sequences, except that this succession is interrupted by a solifluction deposit. Significantly, though, in Profile I/P (Els I/P, Fig. 2B), Esbeck deposits directly underly the Holsteinian but were not well-enough exposed to be sampled for pollen analysis at that site. This is further evidence that the former Late Elsterian classification of the Offleben and Esbeck sequences has to be reassessed, as they correspond to early phases of the Holstein. The former has always seemed anomalous, because no published Holsteinian or coeval British Hoxnian sites, which record the transition from the preceding glacial stage into the interglacial (e.g. West, 1956; K.-J. Meyer, 1974; Turner, 1970) have detected any trace of a well-defined interstadial between the end of the Elsterian glacial stage and the onset of the Holsteinian. It is clear that throughout the investigation of deposits at Schöningen, there has been an underlying assumption that inorganic clastic sediments, particularly coarse-grained ones, were deposited under cold-climate or even glacial conditions. Consequently, organic deposits, such as small discontinuous beds of humic silts, stratified between inorganic silts or solifluction deposits or in small basins within such deposits, were classified as late-glacial interstadial deposits, representing brief periods of climatic amelioration followed by a return to periglacial or even glacial conditions, even though they already showed a dominance of boreal forest trees, such as *Pinus*, *Picea* and *Betula*. Furthermore, since some solifluction deposits separating Esbeck deposits from the overlying Holsteinian contained a similar erratic content to the underlying Elsterian deposits, Elsner (1987) even considered a renewed glacial advance between the purported

Table 1

Pollen Zones and palynological characteristics of Holsteinian and post-Holsteinian sequences of the North Pit and South Pit including a reclassification of the former Offleben und Esbeck Interstadials (profiles Els S IV, Els I S XVII, Els I/P, Har SU 13 (= P 13), Har P 19 (= Holstein I), 13 I DB), Fig. 1B and C) and correlation to the Holsteinian type profiles of Pritzwalk/Prignitz, Rossendorf/Dresden and Munster-Breloh, Germany and Masovian (=Holsteinian) and post-Masovian (= Fuhnian – Saalian Complex) sequences of southeast or southern Poland.

Schöningen North Pit				Schöningen South Pit	Pritzwalk/Prignitz; Rossendorf/Dresden, Germany	Munster-Breloh, Germany	Various locations, Poland	Stratigraphy
Holstein locally Alversdorf incl. former Esbeck Interstadial	Former Offleben Interstadial I, II	Profile SU 13	Profile HO I	Profile 13 I DB				
Urban et al. (1988) this paper	Urban et al. (1988); this paper	Urban et al. (1988), 1991	Urban (1997)	this paper	Erd (1973a); Erd et al. (1987); Strahl (2019, 2023)	Müller (1974)	Bińka and Nitychoruk (1995); Hrynowiecka and Winter (2016); Nitychoruk et al. (2018); Bińka et al. (2023)	
LPAZ/PZ	PZ (Müller, 1974)	LPAZ	LPAZ	PZ (Müller, 1974)	PAZ	PAZ	LPAZ	
		SU 13: Stadial SU A <i>Poaceae</i> , <i>Artemisia</i> , <i>Betula</i>			Fuhne Stadial 3; <i>Poaceae</i> , <i>Artemisia</i> , <i>Betula</i> (cf. <i>nana</i>)			Fuhnian Saalian Complex
		SU 12: Interstadial SU A <i>Pinus</i> , <i>Sphagnum</i>			Fuhne Interstadial B1/B2? <i>Betula</i> , <i>Pinus</i> , <i>Juniperus</i> , <i>Larix</i>		O-7: Interstadial 3	
		SU 11: Buschaus B Stadial <i>Poaceae</i> , <i>Artemisia</i>			Fuhne Stadial B/B1; <i>Poaceae</i> , <i>Artemisia</i> , <i>Betula</i> (cf. <i>nana</i>)		O-6: Stadial 3; <i>Poaceae</i> , <i>Artemisia</i> , (<i>Betula</i> , <i>Pinus</i>)	
		SU 9, SU 10: Missaue Interstadial II; <i>Pinus</i> , <i>Betula</i> , <i>Picea</i>			Pritzwalk Interstadial <i>Betula</i> , <i>Pinus</i> , <i>Juniperus</i> , <i>Larix</i>		O-5: Interstadial 2	
		SU 8: Missaue I/II Stadial <i>Artemisia</i> , <i>Poaceae</i>				XVI-XVIII?	O-4: Stadial 2	
		SU 7: Missaue Interstadial I <i>Pinus</i> , <i>Juniperus</i> , <i>Betula</i>				XVI-XVIII?	O-3: Interstadial 1	
		SU 6: Buschhaus A Stadial <i>Betula</i> , (<i>Pinus</i>), <i>Artemisia</i> , <i>Poaceae</i>			Fuhne Stadial A <i>Betula</i> , <i>Pinus</i> , <i>Salix</i> , <i>Artemisia</i> , <i>NAP</i>	XV?	O-2, Stadial 1	
Al 3 <i>Pinus</i> , <i>Poaceae</i> , Ericaceae		SU 5 <i>Pinus</i> , <i>Poaceae</i> , <i>Ericaceae</i>	HO I 2 <i>Pinus</i> , <i>Picea</i> , <i>Ericaceae</i>	XIV <i>Pinus</i> , <i>Picea</i> , <i>Betula</i> , <i>Alnus</i>	7a, b <i>Pinus</i> , <i>NAP</i> , <i>Larix</i>	XIV <i>Pinus</i> , <i>Betula</i> , <i>Picea</i> , <i>Alnus</i> , <i>Ericaceae</i>	O-1 <i>Pinus</i> , <i>Betula</i> , <i>Larix</i> , <i>Picea</i>	Holsteinian
Al 2 <i>Pinus</i> , <i>Abies</i> , <i>Picea</i> , (Pterocarya)		SU 4 <i>Pinus</i> , <i>Picea</i> , <i>Abies</i> (<i>Pterocarya</i>)	HO I 1 <i>Abies</i> , <i>Alnus</i> , <i>Pinus</i> (<i>Pterocarya</i>)	XIII <i>Abies</i> , <i>Alnus</i> <i>Pinus</i> , <i>Picea</i> (<i>Pterocarya</i> , <i>Fagus</i>), <i>Carpinus</i>	6a, b, c <i>Abies</i> , <i>Carpinus</i> (<i>Picea</i> , <i>Pterocarya</i> , <i>Fagus</i>)	XII <i>Pinus</i> , <i>Abies</i> , <i>Picea</i> , <i>Carpinus</i> (<i>Pterocarya</i> , <i>Celtis</i> , <i>Fagus</i>)	MA VIII + IX MA VII <i>Picea</i> , <i>Pinus</i> , <i>Alnus</i> , <i>Pterocarya</i> , <i>Fagus</i> , <i>Celtis</i>	
Al 1 <i>Abies</i> , <i>Pinus</i> , <i>Alnus</i> , (Pterocarya) Solifluction layer		SU 3 <i>Abies</i> , <i>Alnus</i> , <i>Picea</i> , <i>Pinus</i> (<i>Carpinus</i>)			5a, b <i>Abies</i> , <i>Carpinus</i> , <i>Celtis</i> , <i>Vitis</i> , <i>Buxus</i>	XII A, B <i>Quercus</i> , <i>Abies</i> (<i>Pinus</i> , <i>Alnus</i> , <i>Carpinus</i> , <i>Buxus</i> , <i>Vitis</i>); XII C: <i>Quercus max.</i> , (XI 2nd <i>Betula</i> , <i>Pinus</i>)	MA VI <i>Abies</i> <i>Carpinus</i> , <i>Buxus</i> , <i>Ilex</i> , <i>Pterocarya</i>	
Hiatus		Hiatus			3–4	VII-XI	MA III - V	

(continued on next page)

Table 1 (continued)

Schöningen North Pit				Schöningen South Pit	Pritzwalk/Prignitz; Rossendorf/Dresden, Germany	Münster-Brehloh, Germany	Various locations, Poland	Stratigraphy
Holstein locally Alversdorf incl. former Esbeck Interstadial	Former Offleben Interstadial I, II	Profile SU 13	Profile HO I	Profile 13 I DB				
Urban et al. (1988) this paper	Urban et al. (1988); this paper	Urban et al. (1988), 1991	Urban (1997)	this paper	Erd (1973a); Erd et al. (1987); Strahl (2019, 2023)	Müller (1974)	Bińka and Nitychoruk (1995); Hryniewiecka and Winter (2016); Nitychoruk et al. (2018); Bińka et al. (2023)	
LPAZ/PZ	PZ (Müller, 1974)	LPAZ	LPAZ	PZ (Müller, 1974)	PAZ	PAZ	LPAZ	
	OF 4/OF 5; <i>Pinus</i> , <i>Picea</i> , <i>Alnus</i> , <i>Betula</i>				2 <i>Pinus</i> , <i>Picea</i>	VI <i>Picea-Pinus</i> - <i>Alnus</i> - <i>Betula</i>	MA II + MA III <i>Pinus</i> , <i>Betula</i> , <i>Picea</i> , <i>Alnus</i>	
(Esbeck) <i>Pinus</i> , <i>Betula</i>		SU 1 <i>Pinus</i> , <i>Betula</i>			1 <i>Betula</i> , <i>Pinus</i>	IV <i>Pinus</i> , <i>Betula</i>	MA I <i>Betula</i> , <i>Pinus</i>	

interstadial and the interglacial. However, this material may well have derived from a patch of high-level kame deposits.

4.2.3.3. Channels on the valley floor. The channels descending from the fans, along with other small downslope streams, brought water to the valley floor. Because there was no natural barrier at the southern end of the Schöningen valley and, contrary to the suggestions of Lang et al. (2012), no significant over deepening of that floor, it is considered here that, rather than a single widespread lake, streams flowed across to the lower northeastern side of the valley floor to join and form a Proto-Missaue. However, during extreme flood conditions, they also cut temporary channels, trending down the valley along the foot of the alluvial fans. These channels, though extensive, were soon abandoned and held no flowing water, becoming long, narrow lakes. Evidence for such a channel during Holsteinian times is sparse but can be inferred from a further late-Holsteinian pollen diagram, - "Profil Holstein I" of Hartmann's Profile P 19 (Hartmann, 1988; Urban et al., 1991a; Urban, 1996) and probably also from Hartmann's Profile Har P.18, a little further down valley (Figs. 2B and 6).

Correlation of pollen zones and climate sequences from the Holstein interglacial period and the subsequent early Fuhnian oscillations of the Schöningen profiles described above with those of selected type localities in western and central Germany and Poland reveals clear

palaeoecological similarities over long distances (Table 1). Profile Har P 19, along with profile Har P 18 (Hartmann, 1988), both of which contain interglacial levels, are isolated sections closer to the floor of the valley (Fig. 2B). However, their relationship to the drainage system cannot be verified at the time. The proposal is that, as the fans expanded more slowly in later temperate periods, these marginal channels were either obliterated or buried and replaced by new channels at much the same level, but further toward the centre of the valley, as indicated by the channel next described.

4.2.4. The Schöningen interglacial

Lenhard (1989) recorded a series of seven profiles that followed a well-defined, north-south-trending channel to the east of all profiles containing Holsteinian deposits. Hartmann's Profile P 23 also clearly falls within this channel (Fig. 2B). Pollen diagrams from three of these limnic-telmatic sequences, Lenhard's P-1, P-3, and P-7 (Len P-1 – Len P6, Fig. 2B) (Urban et al., 1991a), yielded a vegetational history convincingly different from that of the Holsteinian; however, only the middle part of this interglacial, which Urban et al. (1991a) named the Schöningen Interglacial, was present. The pollen diagram of the Len P-1 profile (Fig. 7) of a mud-peat sequence overlain by Saalian till, bears a strong similarity to that of the Dömnitz Interglacial described by Erd (1970) from Pritzwalk in the state of Brandenburg, revised and refined

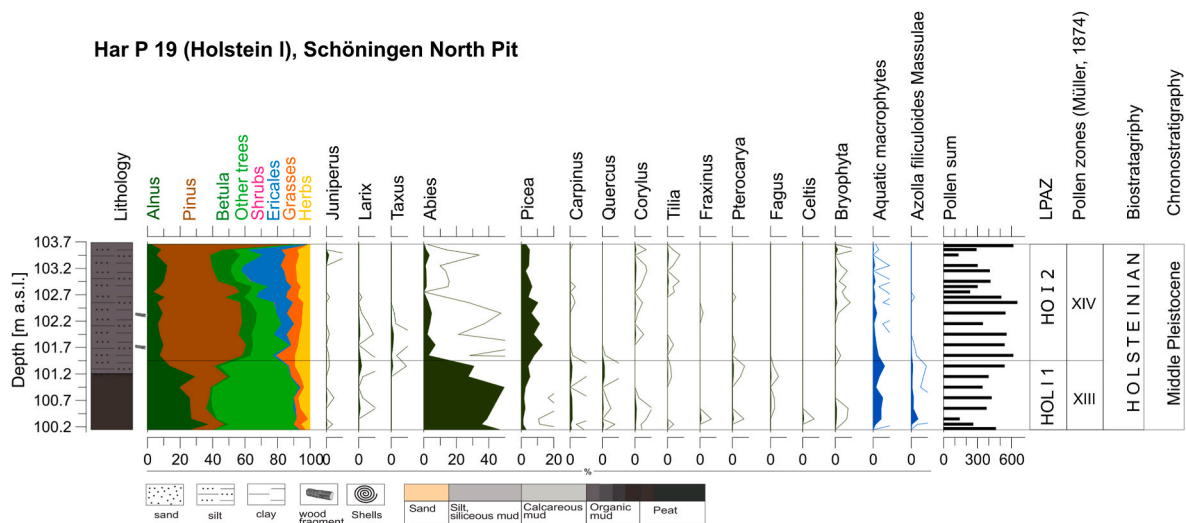


Fig. 6. Simplified pollen diagram of the Holstein Interglacial profile Har P 19 (Holstein I) (P 19 of Hartmann, 1988) (10°58'56.678" E 52°09'03.238" N) of the North Pit (Fig. 2B) data and Local Pollen Assemblage Zones (LPAZ) according to Urban 1996. Pollen zones (PZ) of the Holstein Interglacial according to Müller (1974).

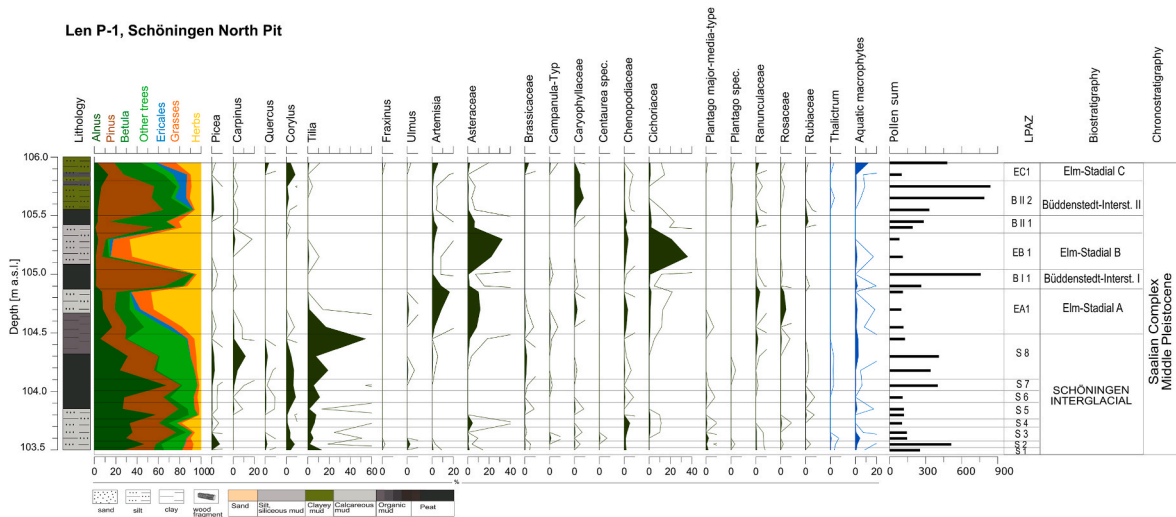


Fig. 7. Simplified pollen diagram from the Schöningen Interglacial, Elm-Stadial A, B and Bündenstedt-Interstadials I and II of profile P1 of Hartmann (1988), Len P-1 (10°58'59.323" E 52°09'04.879" N) of the North Pit (Fig. 2B), data and Local Pollen Assemblage Zones (LPAZ) according to Urban et al. (1991a).

by Strahl (2019, 2023), and from that of Wacken in Schleswig-Holstein (Menke, 1968, 1980, 1984), illustrated in Table 2. Meyer (2012) has insisted that because Hartmann's Profile P 19 and Lenhard's Profile P 4 are at much the same level and only about 60 m apart, they must be part of the same wider lake deposit. However, in the same volume, Bittmann (2012), on palynological grounds, whilst attempting to conflate Urban's Holsteinian and Reinsdorf Interglacials, which will be contested later, concedes that the Schöningen Interglacial must be something different. To counter Meyer's arguments, it must be pointed out that Elsner's records and description have made it quite apparent that the Schöningen Interglacial deposits lie in a clearly defined gravel-based channel cut into older deposits, including a loess deposit, which elsewhere appeared to overlie Holsteinian deposits (SI Table 1).

4.3. Saalian and Eemian deposits

Elsner (1987), Hartmann (1988) and Lenhard (1989) all described sequences of Saalian till and solifluction deposits in the North Pit, which overlie and often erode older deposits. Eemian deposits were recorded from boreholes in the southern part of the North Pit, but in the northern

part, adjacent to Esbeck Urban et al. (1991b) recorded a channel approximately 200 m wide, probably cut by meltwater. After the Drenthe ice sheet melted, it was filled with Eemian organic sediments. The North Pit sequences were capped by Weichselian loess deposits with occasional thin paleosols, and an early channel of the Missaue, extending hundreds of meters, containing Late-glacial and Holocene deposits (Thieme et al., 1987).

4.4. Summary of conclusions from the stratigraphy of the North Pit

The North Pit revealed a sequence of Quaternary deposits, with Elsterian glacial sediments at its base, emplaced from the north. Inter-calated between the Elsterian and Saalian glacial layers are alluvial fan deposits containing or associated with a diverse range of sediment types, including those attributed to two distinct interglacial phases: the Holsteinian and Schöningen Interglacials. The pre-Saalian deposits show the following characteristics:

- Major alluvial fan formation occurred along the western side of the Schöningen valley after deglaciation and climatic amelioration. This

Table 2

Pollen zones, palynological characteristics and correlation of the Dömnitz, Schöningen, and Wacken Interglacials. The Schöningen interglacial data refer to profiles Len P-1, Len P-3 and Len P-7 of the North Pit (Fig. 2B and 7), (Urban et al., 1991a; Urban, 2007). The asteriks (*) indicates the partial mass occurrence of *Azolla filiculoides* massulae.

Dömnitz Interglacial		Schöningen Interglacial		Wacken Interglacial		Stratigraphy
Pritzwalk, Perleberg, Karstädt (Brandenburg, Germany)		Schöningen, North Pit		Wacken (Schleswig-Holstein, Germany)		
Erd (1973a,b); Erd (1978); Strahl (2019, 2023)		Urban et al. (1991a); Urban (2007)		Menke (1968, 1980, 1984)		
Pollen Zones	Main palynological characteristics	Pollen Zones	Main palynological characteristics	Pollen Zones	Main palynological characteristics	
4e	<i>Pinus</i>	Late phases not recorded		Late phases not recorded		Saalian Complex
4d	<i>Pinus-Alnus-Picea-Abies</i>					
4b	<i>Pinus-Alnus-Quercus-Corylus-Carpinus</i> , (*)	S 6 – S 8	<i>Pinus-Alnus-Carpinus-Corylus-Quercus-Picea-(Taxus)</i> , (*)	5	<i>Alnus-Pinus-Carpinus-Corylus-Picea</i> , (*)	
4a	<i>Pinus-Alnus-Quercus-Corylus-Taxus</i> , (*)	S 4 – S 5	<i>Pinus-Alnus-Quercus-Corylus-(Taxus)</i>	4 b	<i>Alnus-Pinus-Corylus-Quercus-Taxus</i> , (*)	
3	<i>Pinus-Alnus-Quercus</i> , (*)	S 1 – S 3	<i>Pinus-Alnus-Quercus (Ulmus, Tilia)</i>	4a	<i>Pinus-Alnus-Quercus (QM)-Corylus</i>	
2	<i>Pinus-Alnus</i> , (*)	Early phases is not recorded				
1c	<i>Pinus</i> , (*)			3	<i>Pinus</i>	
1b	<i>Betula</i> , (*)			2	<i>Betula-Pinus</i>	
1a	NAP <i>Betula-Pinus</i> , (*)			PZ 1 is not recorded		

- was related to wetter climate and the end of permafrost on the Muschelkalk massif.
- There is a clear distinction between fan deposits and glacial sediments, based on dip patterns and lithology. The presence of coarse clastic deposits does NOT imply cold-climate conditions.
 - Water from meltwater streams and springs high up on the valley side not only deposited the alluvial fans, but when the main source of sediment dried up, it changed mode and, cascading down the slope, eroded deep channels within the lobes of the fans. Basins excavated within these channels accumulated organic deposits at different levels in different channels. Unstable slopes also favoured solifluction processes, even during interglacial times.
 - Pollen analytical studies indicate that some of these basins continued to accumulate sediment during much of the Holsteinian Interglacial and subsequent stadial and interstadial intervals. The sequences, initially referred to as separate Offleben and Esbeck Interstadials, should now be regarded as part of pre- and early-temperate phases of the Holsteinian Interglacial, with the sequence of deposits being simply interrupted by solifluction deposits, which do not imply a cold-climate interval.

- At times of intense flooding on the Elm, particularly as permafrost melted after major cold periods, or otherwise after very heavy rainfall or snowmelt, the streams within channels down the alluvial fans, normally flowing across the valley to a precursor of the modern Missau, temporarily avulsed to flow southward, powerfully excavating lengthy channels into the floor of the valley, marginal to the foot of the alluvial fans. As we will see in discussing the South Pit, these channels, or a sequence of partly overlapping subchannels, never contained flowing water, once excavated, but existed over time as a series of long, linear lakes within the Schöningen valley.

5. The stratigraphy of the South Pit (Tagebau Schöningen)

The South Pit (Fig. 1C, 2C and 8) was first opened in 1992 and expanded as lignite extraction proceeded, ultimately covering an area of approximately 2.4 km × 1.2 km. While the North Pit was located adjacent to the eastern flank of the Elm massif, the South Pit lay to the south-east of the Elm and extended diagonally across the original valley floor to the south-east. This implies distinct differences between the Quaternary stratigraphy and palaeoenvironments recorded in the North

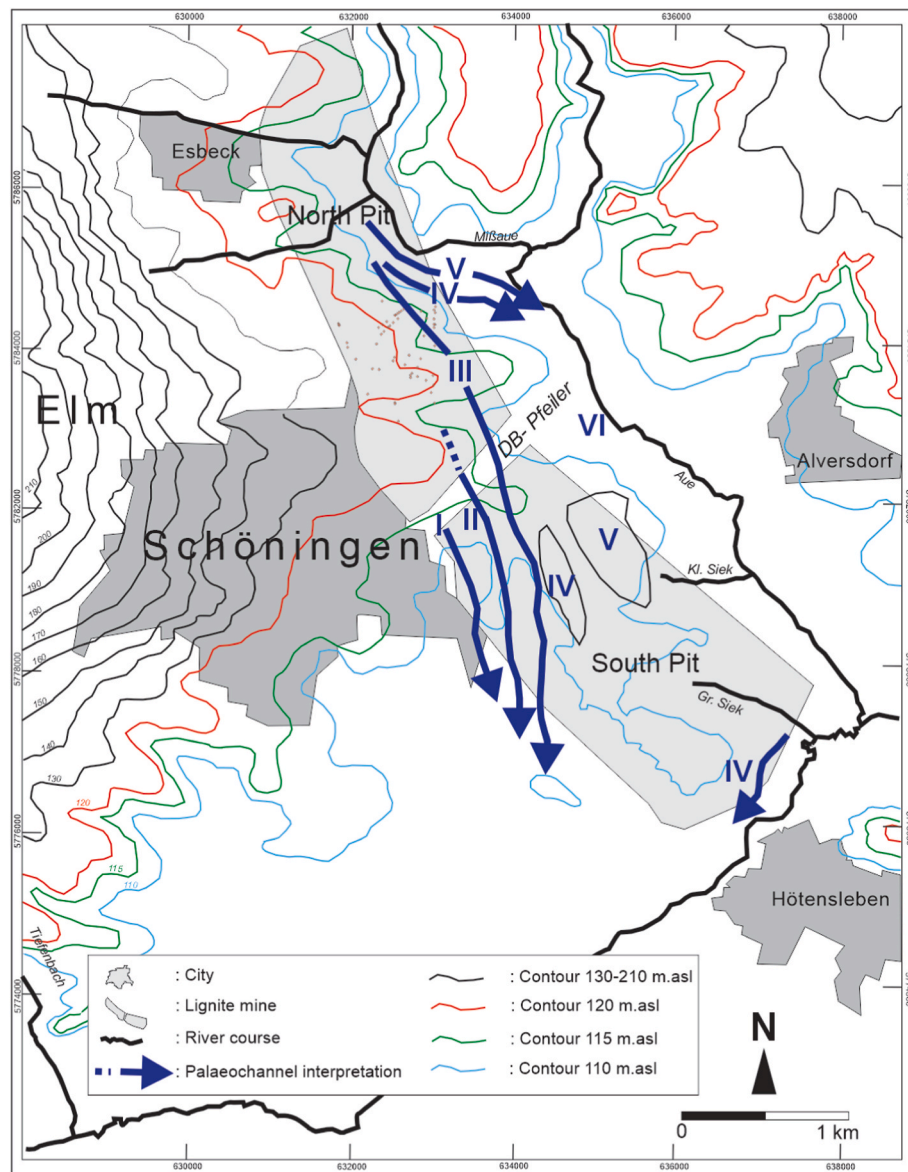


Fig. 8. Map showing the former relief of the area between the Elm and the Helmstedter Sattel, along with the course of the main channels of the North and South Pit (modified according to Mania in: Thieme, 2007; Fig. 4; Mania and Altermann, 2015; Fig. 4).

and South Pits. As in the North Pit, the sequences containing organic sediments (and archaeological material) have been the most extensively studied. Units comprising inorganic sediments are often regarded as glacial outwash or till, associated with either the Elsterian or Saalian glaciations, since ice sheets from both advances clearly overrode the site (Meyer, 2012; Lang and Winsemann, 2012; Lang et al., 2012). However, alluvial sediments carried down from the fans at intervals, solifluction processes, and flood events following high rainfall must also have contributed.

As excavation proceeded between 1992 and 2005, detailed profiles were recorded along the exposed faces by Mania (Mania, 2009; Mania and Altermann, 2015), which were used to reconstruct long sections in various directions across the pit. This has provided an invaluable record of the stratigraphical sequence and spatial disposition of sediment units, information that would have otherwise been entirely lost. Unfortunately, this information has either been overlooked or not fully appreciated by some later workers.

5.1. Channel sequences in the South Pit

Mania proposed (Thieme and Mania, 1993; Mania, 1995, 1998; Thieme, 2007) and described a series of six N-S to NE-SW trending channels, assigned to different ages (Fig. 8). They considered that the infill of channels I–VI was related to major climatic cycles. Of these, channels I–III, which cut into the Elsterian glacial deposits, underlie the Saalian till; channel IV was thought by Mania to represent an intra-Saalian climatic cycle, channel V being of Eemian age, while channel VI is associated with the Holocene and the present Missaue stream. Mania regarded the formation and migration of these channels' positions over time from west to east, due to the underlying salt solution. Some channels could be traced in the southern area of the pit, but others extended or extrapolated into areas of the pits where observations had been sparser or absent.

In different publications, Mania refers to these channels as 'Rinnen' or 'Folgen' and collectively as 'Rinnenfolgen'. Urban (2007) refers to them as Channels or, more generally, sedimentary cycles. For clarity, we generally refer to these units here as Channel I, etc., but simply use 'channels' for smaller-scale geomorphic features.

Within Channel II, the Reinsdorf Channel, there exists a sequence of smaller, yet still extensive, superimposed channels, prominently exposed in the Schöningen 13 II area (the Spear 'Sockel' area) and previously along the DB-Pfeiler section of the Schöningen 12 II area (Fig. 2C). Mania first described these in Thieme et al. (1993) as 'Folgen 1–4' and subsequently referred to as 'Unterfolgen' or 'Kleinfolgen'. Urban (in Thieme, 2007), called these 'Verlandungsfolgen', which Conard et al. (ed.) (2015a,b) adequately translated as 'shallowing cycles'. However, Urban and Bigga (2015) used neutral terms, such as Levels 1–5, leading to subdivisions such as Sublevel and Sub-sublevel. We use Channel for the major features and subchannel for the divisions of Channels, which may refer to these features or their contents.

Mania demonstrated that the three major channels, which he labelled Channels I–III, lie in superposition. Hence, there is no doubt that they belong to separate interglacial intervals (cf. Bittmann, 2012). The oldest of these, which we ascribe to the Holsteinian Interglacial and subsequent interstadial-stadial phases, corresponds to most of those present in the North Pit, based on stratigraphic and palynological grounds. Channel II, referred to as the Reinsdorf Channel, is wider and features a more complex infill and stratigraphy with five separate sub-cycles of erosion and deposition. It was not only exposed in area Schöningen 12 II (Thieme et al., 1992), adjacent to the DB-Pfeiler, but during the development of the South Pit, Mania (Mania, 2009; Mania and Altermann, 2015) was able to plot the course and form of this Channel (Fig. 2C and 8). This showed that it extended diagonally across the pit in a north-to-south direction, intersecting the western margin of the expanding pit in the area now known as the "Speersockel" or Spear Sockel site, Schöningen 13 II (SI Fig. 11.1 and Fig. 2C). Channel III is not

well known, but its course, again exposed diagonally across the pit, parallel to and south-east of the Reinsdorf Channel, was carefully mapped by Mania (Mania, 2009; Mania and Altermann, 2015) and contained a well-developed organic infill. However, the excavation speed and the dangerous access conditions meant that the sediments were sampled only for molluscan analysis (Mania and Altermann, 2015; Mania, 2026), and pollen samples were not taken. It can be assumed that this channel was equivalent to the one containing the Schöningen Interglacial sediments in the North Pit; however, this cannot be confirmed directly.

5.2. Holsteinian and early Fuhnian deposits

Mania (Mania, 2009; Mania and Altermann, 2015) considered that a Holsteinian channel (Channel I) existed in parallel with the later Reinsdorf (Channel II) and Schöningen (Channel III) channels (Fig. 8). However, the sites recorded below are instead connected to channels flowing from the Elm into the Schöningen Valley, as was the case with the much steeper channels documented in the North Pit. This finding is also supported by recent studies of aquatic microflora and fauna and chironomid communities that document Elm-bearing tributaries flowing into the paleolake of channel II (Krahn et al., 2021, 2024; Rigterink et al., 2024). We therefore do not use the term "Channel I".

The Holsteinian and early Fuhnian (Erd, 1970) sediments exposed in the South Pit, which are described palynologically for the first time, were limited to two locations in the northwestern corner of the South Pit, 13 I DB and 13 I, including the archaeological and palaeontological sites 13 I-Fs1 and 13 I-Fs2 (Fig. 2C). (See Supplementary Information (SI), Chapter I for more details of these sites).

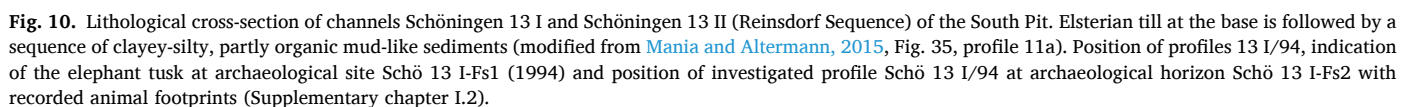
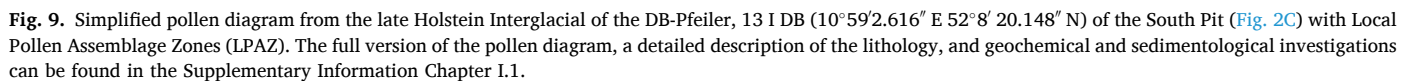
5.2.1. Schöningen 13 I DB

In 2008/2009, an area of approximately 30 m² at site Schöningen 13 I DB—located on the NE/SW slope of the former DB-Pfeiler (Fig. 2C–SI Fig. 11.1, SI I.1.2 A and B)—was examined more closely due to its possible archaeological importance, following the discovery of wooden fragments (Supplementary Information, Chapter I.1). Since there were no stone artefacts or other signs of human presence and the large pieces of wood also turned out to be natural fragments, this site has not been further archaeologically investigated, and the geological and botanical aspects have not been published to date.

The lacustrine sequence of profile 13 I DB (Fig. 2C–SI Fig. 11.3, I.1.4 and I.1.5), which lies discordantly over Elsterian deposits, was formed in a channel, probably an ox-bow lake, whose extent remains unknown due to the relentless progress of extraction at the mine. Stratigraphically, it covers the late stages of the Holstein Interglacial (Fig. 9). The dominance of *Abies*, the extremely rare occurrence of *Carpinus*, and the presence of *Pterocarya* and *Fagus* suggest a correlation with the Holstein pollen zone (PZ) XIII and the subsequent post-temperate boreal phase with PZ XIV, according to Müller (1974). They thus encompass the widely recognised and characteristic late Holsteinian vegetational phases also known from the North Pit (Figs. 4–6) (Urban et al., 1988, 1991a; Urban, 1997) and indicate a further expansion of Holsteinian occurrences into the South Pit (Table 1 and SI Table 1).

5.2.2. Schöningen 13 I

The site 13 I is situated on the southwestern slope of the South Pit, where a sediment sequence featuring two discrete find horizons, 13 I-Fs1 archaeological and 13 I-Fs2 palaeontological was exposed (Fig. 2C). This sequence is stratigraphically positioned between Elsterian till deposits and Channel II sediments of the Reinsdorf sequence (Fig. 10), since the channel in which it sits, is intersected at its southern margin by Channel II (Mania, 2009; Mania and Altermann, 2015) (Fig. 10). Site 13 I-Fs1 yielded stone artefacts, including numerous fire-cracked flints and vertebrate fossils of large herbivores such as elephants, horses, red deer, and aurochs (Thieme and Maier, 1995; Thieme, 2007; Mania, 2022; Altamura et al., 2023). In contrast, 13 I-Fs2 did not produce stone



The vegetation at site 13 I-Fs1 can best be described as an open steppe forest rich in grasses and herbaceous floral elements with *Pinus*, *Betula*, *Alnus*, a few *Picea* and *Larix* (Altamura et al., 2023). This is confirmed by the results of the molluscan analyses (Mania, 2026). The

The cyclical development of the two sites—from a cold period through a possibly two-part interstadial into a new cold phase—shows

parallels with the vegetation development of the two-part Missaue Interstadial, between the Buschhaus Stadials, or possibly the SU A interstadial from the North Pit, which immediately followed the Holstein (Urban et al., 1988). Based on the palynological findings for the post-Elster and pre-Reinsdorf sequences at the sites 13 I-Fs 1 and 13 I-Fs 2, which show a development from cold climates to cool, temperate boreal forest steppes, an early Fuhnian age can be assumed (Strahl, 2023), (Table 1; SI Fig. I2.3).

5.3. The Reinsdorf sequence (Channel II according to Mania)

Examining the shape and formation of Channel II, it appears in outline to be an almost linear feature, skirting the margin of the alluvial fan that stretches out from the Elm massif to the north-west. In this respect, it resembles the much smaller remnant of the channel containing the Schöningen Interglacial deposits from the North Pit. The Channel was recorded in at least thirteen of Mania's sections (Mania, 2009; Mania and Altermann, 2015), and although some of these traverse the channel diagonally or only record part of it, it is possible to create not only an outline plan of its course but also an estimate of its width and the outline of the subchannels that, in due course, infilled it.

The Reinsdorf Channel consists of a sequence of narrow superimposed subchannels, primarily containing beds of silt, detrital mud, and peat deposits (Fig. 11). At 13 II, these represent five, sometimes six, shallowing cycles (Verlandungszyklen), but of these only four are preserved in area Schö 12 II (Serangeli et al., 2015a). They can be traced along the entire length of the Channel and, as the pollen diagrams from various sites show, they developed contemporaneously along the Channel (see extension of the Reinsdorf paleolake in Fig. 2C). The repetitive nature of the depositional sequences constituting each of these cycles is crucial for understanding the palaeoenvironment of the Schöningen valley during the Reinsdorf Interglacial and the subsequent stadial and interstadial intervals, as well as that of the early hominids occupying the site throughout this period. The origin of these repeated

cycles has been a subject of much debate. Before discussing the details of this sequence, it is best to clarify this matter.

5.3.1. The origin of Channel II and that of the subchannels

Unlike the Holsteinian channels, particularly those described from the North Pit, which relate directly to the alluvial fans, the Reinsdorf Channel sequence was formed along the floor of the Schöningen Valley, essentially at the foot of the alluvial fans bordering the western side of the valley that descended from the Elm. The initial downcutting and excavation of the basal channel, in which the deposits of subchannel II-1 were laid down, occurred at the end of the Fuhne cold stage, when meltwater was released from the Elm following the thawing of permafrost. The original channel was about 100m or slightly wider and may have been slightly widened by later erosion of its banks. It was incised at its centre by as much as 15 m, cutting down into or even through the Elsterian meltwater sands and till (laid down long before) that still covered the floor of the Schöningen Valley. Such a channel must have been carved by a very powerful stream of water, as indicated not only by the depth of incision but also by the coarse lag deposits, including boulders, deposited at the base of the channel. We do not know how far southwards along the valley floor this channel extended. However, after it was incised, the channel ceased to contain water and dried out, as it was altered solely by the temporary avulsion of a stream cascading down one of the alluvial fans. This suggests that the primary drainage of the Schöningen Valley was, as it is today, a stream or river on its north-east side, rather than via the Reinsdorf subchannels.

The stratigraphy of subchannel II-1 is more complex than that of the later ones. This channel appears to have remained dry until the middle of the Reinsdorf Interglacial, when it was even occupied by trees. Widespread, a rather impermeable gleyic soil developed at this time. This, coupled with a flood event or a general rise in water level, significantly converted the partially infilled subchannel I into a long, narrow, shallow marshy lake. With shallowing, wood and fen peat were deposited and then truncated by the formation of subchannel II-2.

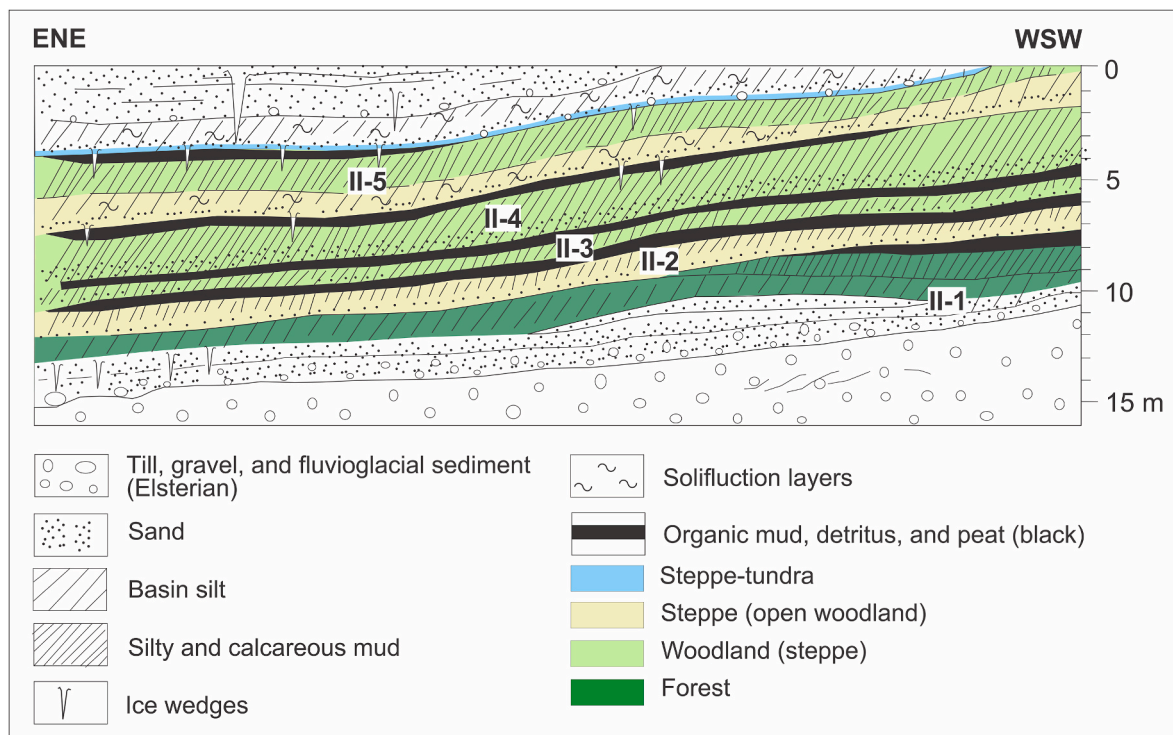


Fig. 11. Schematic representation of the Reinsdorf sediment sequence in the South Pit (Subchannel II-1 to II-5), which lies discordantly above the Elsterian glacial sediments. Legend: 1: till, gravel, and fluviglacial sediments (Elsterian); 2: sand; 3: basin silt; 4: silty and calcareous mud; 5: ice wedges; 6: solifluction layers; 7: organic mud, detritus, and peat (black) (after Urban et al., 2023).

Except where small streams entered this lake, there is no evidence, for instance, from freshwater molluscs, to suggest any significant flow within the lake. It had no exit downstream.

The formation of subchannel II-2, along with the subsequent subchannels II-3 to II-5, is again marked by a powerful flood that erodes the surface of the sediment filling the earlier channel. However, this time, the centre of the new channel was shifted north-eastwards, towards the centre of the valley, a trend that continued with successive subchannels following similar flood events. A gentle regional flow of salt towards the diapir would account for a gradual sinking of the valley floor, which is differentially more pronounced to the north-east, thus deflecting the downcutting of the subchannels. It would also explain the stream or river draining the valley, as it runs along the north-eastern margin rather than along any channel near the alluvial fans on the western side. It is quite clear from the brecciated horizons that separate the successive subchannels that, since the climate was no longer periglacial, the causative factor in creating these channels must be powerful but temporary floodwater events, presumably linked to torrential rainfall over the Elm.

5.3.2. Reinsdorf Subchannel II-1

The stratigraphy of Subchannel 1, Stratum Schö II-1 in excavation records, is documented in Mania's Profiles 1, 2, 4a, 8, 9 and 10 (Mania and Altermann, 2015), (Figs. 2C and 11). Its upper section and part of the lower, remain visible in the walls of the most northerly extant excavation trenches at the Spear Sockel site (13-II), (Speersockel, Fig. 2C). In general, the sequence may be divided into two distinct parts, filling much of Channel I, which was excavated to a depth of 15 m in its deepest parts (Mania and Altermann, 2015: p. 111). The basal lag

deposit consists of about 1 m of gravelly sand and small boulders, resting on the erosion surface. This is followed by about 1 m of grey-brown medium-to-fine sand. The presence of collared lemming, *Dicrostonyx*, fossils indicate cold late-glacial conditions. Cold conditions persisted with 2-4 m of pale grey silt (Beckenschluff), perhaps indicating reworked loess deposits, here containing fragments of coarse plant detritus, but sometimes exhibiting frost cracks and evidence of cryoturbation. In certain areas of the channel, now lost (e.g. Profiles 9, possibly 10), Mania and Altermann (2015) recorded the onset of lacustrine conditions, with calcareous mud passing up into coarse detritus mud or even a thin travertine. These may have been related to the early substages of the Reinsdorf Interglacial, for which we now have no record. Elsewhere, as interglacial conditions began, the channel was not only dry but also supported woodland vegetation, and a dark black-brown soil horizon (Anmoor) developed (not always preserved) with occasional wood fragments. From this horizon, large root casts penetrate down into the underlying sediments. Rising water table resulted in the deposition of coarse detrital mud passing upward into 0.5 m of dark brown peat, rich in wood fragments, particularly *Alnus*, sometimes finely fragmented, with again traces of root penetration into the underlying bed. The top is usually brecciated or eroded during the formation of subchannel II-2.

5.3.2.1. Botanical data of Channel II-1 to II-2. Interglacial deposition begins in the mixed oak forest phase (local pollen assemblage zone, LPAZ R1), characterized by *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, and some *Corylus* (subchannel/level II-1) (Urban, 1995; Urban and Bigga, 2015; Urban et al., 2023) (Figs. 12 and 13). In the younger part of this zone, *Tilia* reaches a characteristic first maximum, accompanied by elevated

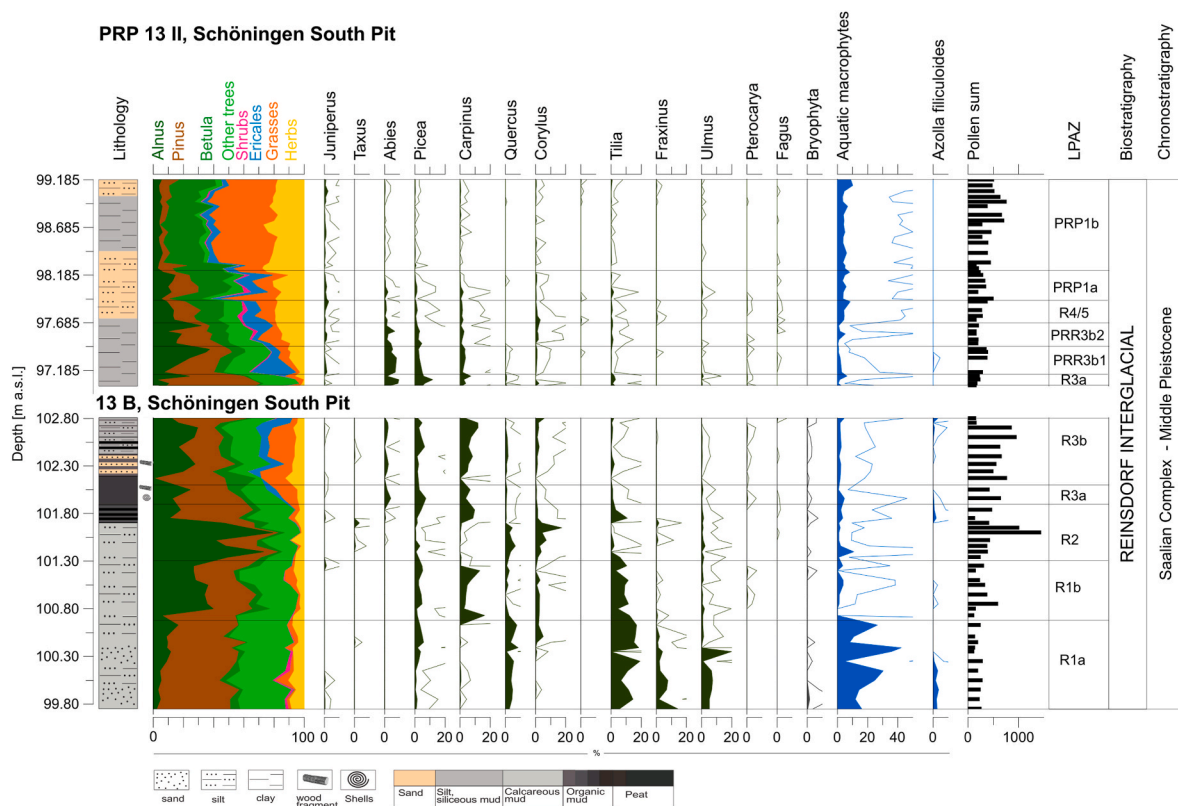


Fig. 12. Abbreviated and simplified composite pollen diagram of the Reinsdorf Interglacial from profiles Schöningen 13 B (10°59'20.67"E 52° 8'2.37"N) (Urban, 1995) and the lower part of the Para-Reference Profile (PRP) 13 II (4430850, 5778188) (Urban et al., 2023), which are located in the area of the excavation site of the Speersockel of the South Pit (cf. Fig. 2C). The pollen zonation of the Reinsdorf Interglacial was carried out according to the initial subdivision of profile 13 B according to Urban (1995), the subdivision of the Reference Profile 13 II (RP) according to Urban and Bigga (2015) and the refined subdivision of the Para-Reference Profile (PRP) 13 II according to Urban et al. (2023). The LPAZ/LPASZ R3a – R3b2 of the 13 B and the PRP pollen diagram are shown overlapping due to the higher resolution of these zones in the PRP.

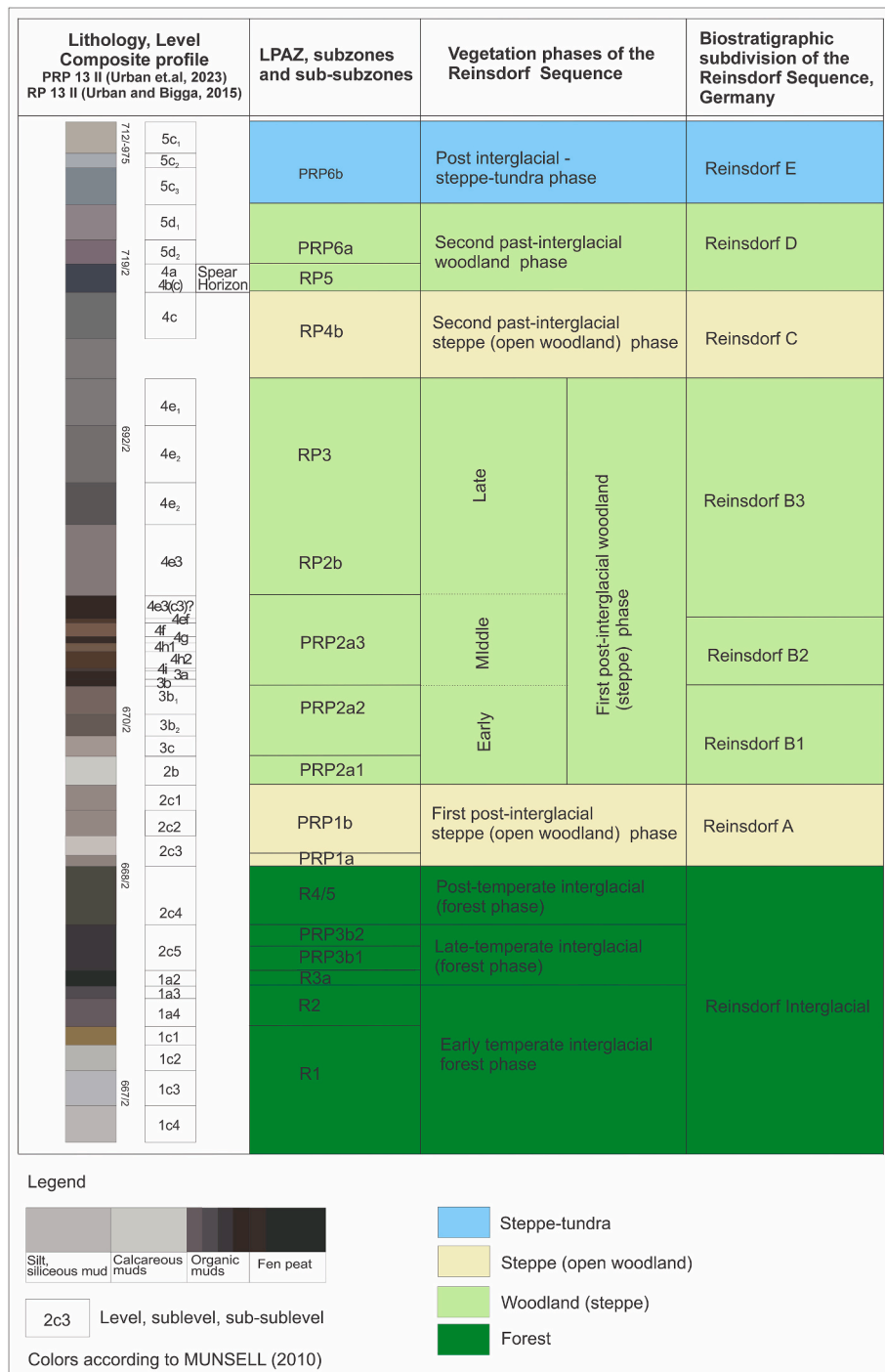


Fig. 13. Description of the sedimentation sequences of Subchannels 13 II-1 to 13 II-5 with level and more defined subdivision, local pollen assemblage zones, vegetation phases, and biostratigraphic division of the Reinsdorf Interglacial and post-interglacial Reinsdorf sequence (after Urban et al., 2023).

Alnus values. In the subsequent LPAZ R2, mixed oak forest elements, such as *Quercus* continue to dominate together with *Corylus* and *Alnus*, with *Taxus* occurring sporadically. From LPAZ R3 onwards, *Carpinus* spreads rapidly for the first time and then exhibits a two-phase expansion pattern. *Picea* accompanies the spread of hornbeam, as does *Abies*, which is, however, of minor importance. This first phase (LPAZ R3a) also includes the second *Tilia* maximum, and *Pinus* values rise slightly, while in the younger part, *Carpinus*, together with *Picea* and *Abies*, characterises the phase of shade-tolerant tree species (LPAZ R3b, sub-channel/level II-2). *Fagus* and *Pterocarya*, as well as massulae of the water fern *Azolla filiculoides* were detected in this section. Other

thermophilous woody plants had already largely declined, and the subsequent LPAZ R4 and R5 (II-2c4) are now characterized by *Pinus*, *Betula*, *Alnus*, and *Larix* and a grass-rich herbal vegetation. Ericaceae were spreading, indicating increased bog formation and the end of the interglacial period.

5.3.2.2. Mammalian data. The fossil mammalian assemblage from Subchannel 13 II-1 is mainly composed of forest-dwelling species, for example *Clethrionomys glareolus*, *Stephanorhinus kirchbergensis*, *Sus scrofa*, *Capreolus capreolus*, semiaquatic species (e.g. *Desmana* sp., *Castor fiber*, *Trogontherium cuvieri*, *Arvicola terrestris cantianus*) and species that

prefer open habitats (e.g. *Microtus arvalis*, *M. agrestis*, *Lasiopodomys gregalis*, *Stephanorhinus hemitoechus*, *Bos/Bison*) (van Kolfshoten, 2014a; van Kolfshoten et al., 2015; Verheijen et al., 2022). The faunal assemblages indicate interglacial/temperate climatic conditions and a partly forested environment, alternated with areas of more open, “steppe” vegetation near a lake or a stream.

5.3.3. Reinsdorf Subchannels II-2 to II-5

The formation of the Reinsdorf Subchannel II-2 was once again caused by a powerful surge of water originating from upstream through a temporary avulsion of one or more streams, flowing from the Elm or into a previously abandoned channel. However, while the base channel was likely carved out by meltwater from melting permafrost, in this and subsequent cases the surge must have resulted from heavy rainfall on the Elm or from melting exceptionally thick snowfall. Nonetheless, these events were rare but catastrophic.

The central axis of Subchannel II-2, along with that of Subchannels II-3 to II-5, was deflected north-eastward towards the opposite side of the Schöningen Valley. Like Mania and Altermann (2015), we attribute this to the gentle subsidence of the valley floor, particularly towards the east, caused by salt solution at depth. Since this presumably occurred almost continuously, its effects would have been felt not only during water surges. It seems plausible that smaller water surges occurred without creating new channels. Evidence of this can be seen perhaps in the erosion of the Anmoor horizon in subchannel II-1, where the transport of fine sediment led to the sealing of the channel floor and the initiation of lacustrine conditions. Similarly, within subchannel II-4, there is a second brecciation horizon that clearly influenced water levels but was insufficiently powerful to alter the channel's course.

Two key factors influenced the lake's water level and sedimentation. Dry steppe conditions observed after the end of the Reinsdorf Interglacial suggest an actual decline in lake levels, while sedimentation rates affect seral succession, which is clearly visible in all subchannel sequences. In subchannel II-1, there is a distinct transition in the profiles published by Mania and Altermann (2015), as well as in the remaining sections, from open-water sediments to coarse detritus mud, then to wood peat. In subchannels II-2, II-3, and II-4, where the upper part of the succession has not eroded away, there is a transition from open-water sediments to fen peat (Fig. 13).

It might seem coincidental that water surges occur at times when the lake has nearly been filled in by sedimentation, as evidence of this appears in almost all of Mania's profiles (Mania, 2009; Mania and Altermann, 2015). However, this may simply reflect a considerable slowdown in sedimentation. Additionally, as recognised by Urban et al. (2023), the impact of global climate change is reflected in the assignment of new biostratigraphical subdivisions to MIS substages (Urban et al., 2023) (Fig. 13). The water surges and the formation of new subchannels occurred quite independently of the vegetation changes on which these biostratigraphical subdivisions are based. The first steppe Reinsdorf A is a forest-free vegetation phase dominated by grass and herbs (II-2c3 - II-2c1), which led to the disappearance of thermophilous woody plants, which did not return to the sites even in the post-interglacial oscillations Reinsdorf B and at the time of human activity in Reinsdorf D of Subchannels II-3 to II-5 (Fig. 13).

5.3.3.1. Faunal data. The Reinsdorf Subchannels II-2 to II-5 deposits have yielded a rich assemblage of mollusc and vertebrate fossils (Mania, 2026; Böhme, 2007, 2015; van Kolfshoten, 2014a; van Kolfshoten et al., 2015). The abundant herbivore remains from the Schöningen levels Schö 12B and 13 II-2–4, including species such as wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*), which suggests temperate climatic conditions and a mosaic landscape at the edge of the palaeo-lake, characterised by a mix of woodlands and open grasslands. The presence of forest-dwelling species such as *Apodemus sylvaticus* in the II-1 assemblage further supports the woodland habitat reconstruction

inferred from palaeobotanical data. The mammalian assemblage from the uppermost post-interglacial, early steppe-tundra phase (level 13 II-5c3) is characterised by the dominant presence of the steppe-dwelling species *Lasiopodomys gregalis*. However, the assemblage lacks indicators of truly cold climatic conditions, such as the arctic lemming *Dicrostonyx torquatus*, a typical inhabitant of tundra environments.

5.3.4. Channel III (Schöningen Interglacial)

Mania (Mania, 2009, 2022; Mania and Altermann, 2015) recognised Channel III, which runs to the north-east of and parallel to Channel II (Fig. 8). His sections reveal it incised up to 12 m into the Elsterian sediments of the valley floor and partly overlying the subchannels of Channel II. This channel formerly extended across almost the entire South Pit, north-east to south-west, but was truncated in the north by Saalian glacial deposits, so it was absent from sections along the DB-Pfeiler (K.D. Meyer personal communication). However, the edge of the channel can still be seen overlying Channel II deposits at the east end of the Spear Sockel. Like older channels, the infill of Channel III generally begins with a coarse-gravel denudation deposit, followed by gravelly sand; however, the widespread deposit overlying this is a pale grey to yellowish clayey silt, perhaps a mixture of redeposited loess and clay particles originating from exposed Elsterian till.

Only in Mania's Profiles 2 and 3 (Mania and Altermann, 2015) was a thicker sequence visible, with an upper sequence of organic silts containing freshwater molluscs and plant remains, presumably representing a deeper part of the channel and indicating fully temperate interglacial conditions (Mania, 2026). The mollusc fauna is typical of lacustrine deposits, so that, except perhaps for the basal sand, there is no trace of fluvial activity in the channel. We conclude that its formation mechanism was similar to that of Channel II, reflecting melting permafrost at the end of a cold stage, representing MIS 8. It is generally assumed that Channel III is coeval with the channel containing Urban's Schöningen Interglacial deposits in the North Pit (Urban et al., 1991a) (SI Table 1). Regrettably, pollen samples are not available from this channel.

5.4. Summary of important conclusions from the South Pit

Just as in the North Pit, water is the most significant factor in explaining the complex stratigraphy of the South Pit and the processes that shaped it. From the perspective of the Schöningen Valley, it may seem strange that the town of Schöningen, situated high on the Elm, remains so abundantly supplied with water, featuring its fountains and bubbling, rushing streams beside the streets, which eventually disappear into culverts engineered by the mining company. However, this water is heavily laden with calcium and other salts (archaeologists note), necessitating the importation of drinking water from a distance.

We can explain the original excavation of the major Channels II and III in terms of meltwater released by melting permafrost at the end of the preceding glacial/cold stages and flowing down into the Schöningen Valley by now well-established streams, evidence for which was dug away in the North Pit. Examining the pollen diagrams, there is no evidence of climate or vegetational change linked to the events that triggered similar but lesser stratigraphic changes, marking the excavation of Channel II substages. Today, the somewhat diminished drainage of the Schöningen Valley is carried by the heavily altered River Missaue along the northern margin of the valley. We believe that the course was originally determined by salt solution and migration deep underground. With such a significant volume of water coming down from the Elm, we propose that a Proto-Missaue must also have occupied that position during interglacial periods. But the interglacial lakes show no signs of regular flowing water or of involvement in the drainage of the valley. The lesser events that formed subchannels and one or two minor erosional episodes must have been triggered by high precipitation, extreme rainfall, or snowmelt, leading to flooding. The question then arises as to whether these events prompted a temporary avulsion of a stream or streams flowing from the Elm to feed the Proto-Missaue, as

suggested earlier, or if, as another possibility, namely that floodwaters reactivated abandoned channels down the alluvial fans, providing a direct but temporary torrent of water into the valley. At any rate, when these flood events occurred, the facts that the existing Reinsdorf Sub-channel had virtually been infilled, as a result of seral vegetational succession and the gentle, subsidence of the valley floor to the north-east, led to the excavation of a new subchannel that was partly cut into the top of the previous one and partly into the Elsterian deposits that floor the valley. Through this unusual and complex sequence of events, a unique stratigraphical and biological record of the late Middle Pleistocene has been preserved at Schöningen.

6. The stratigraphical setting of the deposits from the north and the South Pit

The Middle Pleistocene deposits at Schöningen are unique in central and western Europe in terms of their formation, preservation, and the timespan they encompass, although there are differences between the North and South Pits.

The preservation of interglacial deposits, particularly organic deposits, primarily depends on the availability of accommodation space. Therefore, the occurrence of Holsteinian interglacial deposits and, to a large extent, Eemian deposits, except where marine transgressions are involved, is linked to the topography of the landscape left by melting ice masses at the end of the Elsterian and Drenthe/Warthe glaciations. For example, deep, abandoned tunnel valleys with uneven floors can create basins where lakes may form, and pollen sequences can be preserved, or on a much smaller scale, where buried ice masses cause collapse upon melting, resulting in dead-ice hollows (kettle holes), which fill with water to become small lakes or ponds. Examples of the former include Hamburg-Dockenhuden, (Linke and Hallik, 1993), Pritzwalk, Brandenburg (Erd, 1970), and Marks Tey, eastern England (Turner, 1970), while examples of the latter include many Eemian sites across northern Germany and Poland (Nitychoruk et al., 2018; Bińka et al., 2023), Hoxne (West, 1956), and other Hoxnian sites in eastern England (Fig. 1A).

Another example of accommodation space is provided by meandering river systems, where abandoned meanders become occupied by cut-off or oxbow lakes. These lakes are particularly significant in southern Britain, where lowland river systems persist outside glacial limits, and they also offer cold-stage environmental evidence. The major difference here is that while the pollen sequences recovered from deglaciated hollows tend to begin with late-glacial assemblages, progressing into pre-temperate and early temperate records—and in rare cases represent complete interglacial cycles—the pollen records from fluvial environments usually document relatively short or interrupted intervals of interglacial time, although the sediments may contain rich aquatic and terrestrial plant macrofossil assemblages. In the Brandenburg/Berlin area, some of the Elsterian tunnel valleys evolved into fluvial channels and indeed became the ancestors of modern rivers. Again, the infill of these channels, primarily sand and gravel, may contain lenses or thicker accumulations of organic deposits with fragmentary sequences of Holsteinian or younger interstadial ages (Strahl, 2023). Less frequent environments where interglacial sequences may be preserved include solution hollows and volcanic maars, as will be mentioned later.

6.1. The late Middle Pleistocene interglacial deposits

6.1.1. The Holsteinian deposits

The correlation of the Holsteinian deposits, that accumulated in hollows within channels running down the faces of the alluvial fans in the North Pit area, with the lacustrine Holsteinian sites scattered across Poland, northern and eastern Germany, and England (locally the Hoxnian Interglacial), e.g. Ossówka (Nitychoruk et al., 2018; Bińka et al., 2023), Dethlingen (Koutsodendris et al., 2010), Munster-Breloh (Müller, 1974), Berlin-Brandenburg (Strahl, 2023), and Marks Tey (Turner,

1970) (Fig. 1A), is based primarily on two different kinds of evidence. The first of these depends on geomorphological and stratigraphical considerations. The alluvial fans descending into the Schöningen Valley are closely associated with the provision of accommodation space for the deposition and preservation of the Holsteinian deposits in the North Pit; however, these fans are formed during late-glacial deglaciation and permafrost melting. Stratigraphically, they also relate to the broader melting of the Elsterian ice sheet, which once filled the Schöningen Valley and covered it with till. Simultaneously, the melting of the Elsterian and Anglian ice sheets created troughs and hollows across the northern European plain, further providing accommodation space for the well-studied Holsteinian lacustrine deposits there, but the environment in which Holsteinian deposits were preserved at Schöningen is quite different (c.f. Lang et al., 2012).

The second line of evidence derives from the pollen diagrams prepared from these sites, the North Pit channels, and Schöningen 13 I DB, as previously argued in sections 4.1.3 and 5.1.1. The high percentage of *Abies* pollen (40%), the relationship between *Abies* and *Carpinus*, and the very late immigration of *Pterocarya* and *Fagus* are all unifying features that confirm these profiles at Schöningen as of Holsteinian age (Table 1).

6.1.2. The Reinsdorf Interglacial

The vegetation sequence of the Reinsdorf Interglacial is distinctive and markedly different from the Holstein and younger periods, such as Dömnitz (Erd, 1973a) or the related Wacken (Menke, 1968) and Schöningen Interglacials (Urban et al., 1991a). In Holsteinian sequences, a hazel maximum occurs before the hornbeam phase (Müller, 1974; Koutsodendris et al., 2012; Strahl, 2023), while in Reinsdorf, there is no pronounced hazel maximum; however, *Corylus* is more frequently present during the mixed-oak forest phase. It differs from the Holsteinian Interglacial in that it includes a spruce-poor hornbeam period followed by a limited spread of fir. In the Holsteinian, spruce spreads before hornbeam and then declines. *Picea* accompanies *Carpinus* rather than *Abies*, whereas, in the late-temperate substage of the Reinsdorf interglacial, fir is only slightly represented (<6%) (Fig. 12) compared to the Holsteinian vegetation pattern, where very high amounts of fir are characteristically recorded (Figs. 5 and 7). The double-peaked *Tilia* maximum and the two-phase *Carpinus* spread are also unknown from the Holstein Interglacial. Comparable vegetation sequences, which also contain *Pterocarya* and *Fagus* since the *Carpinus* expansion, are currently only known from Ummendorf and Martinsried in Germany for the Horstwiesen warm period (Fig. 1A and 12, Table 3), which can be correlated in detail with the pollen zones of the Reinsdorf interglacial period (Strahl, 2019, 2023; Wansa et al., 2019, 2022).

A correlation with the Neualbenreuth sequence (Stebich et al., 2020), which comprises three forest phases, MIS 7e, 7c, and 7a, as proposed by Van Beirendonck and Verbruggen (2025), can be ruled out due to the significantly cooler floral composition and the markedly different dominances and dispersal behaviour of thermophilous taxa compared to the interglacial periods of Reinsdorf and Horstwiesen. For example, *Carpinus* values in forest phases are always well below 10%. Traces of *Fagus* were found throughout the forest and the intervening steppe and woody-steppe phases, suggesting at least partial redistribution. *Pterocarya* does not occur in the forest phases of Neualbenreuth, which adds another criterion for excluding a correlation with Reinsdorf and Horstwiesen in addition to the decisive criteria already listed.

However, there are a small number of special sites in Germany where, similar to Schöningen but under different circumstances, late Middle Pleistocene sequences—including sediments related to MIS 9—have been preserved. For us, the most notable site is Ummendorf, located approximately 14 km east of Schöningen (Fig. 1A). The Ummendorf Basin is a trapezoidal, fault-bounded block, measuring approximately 700 to 1000 m in length and 300 m in width. It is traversed by the southern part of the Aller valley, overlies the crest of the Allertal salt structure, and has experienced discontinuous subsidence since before Elsterian times. Since 1985, four cored boreholes have been

Table 3

Pollen zones and palynological characteristics of the correlated sections of the Reinsdorf (Schöningen South Pit) and Horstwiesen (Ummendorf, Fig. 1A) interglacial and post-interglacial sequences. The pollen zoning of the entire Reinsdorf sequence follows the classification according to Urban (1995) for profiles 13A and 13B, Urban and Bigga (2015) for the Reference profile (RP 13 II) and Urban et al. (2023) for the Para-Reference profile (PRP 13 II), all of which are located in the Speersöckel 13 II excavation area (Fig. 2C and 13). The biostratigraphic classification of the Horstwiesen Interglacial and the correlation of the climatostratigraphic sections of the post-interglacial sequences follow Strahl (2019; Tables 7–1). The asteriks (*) indicates the partial mass occurrence of *Azolla filiculoides* massulae.

Reinsdorf Interglacial and post-interglacial phases		Horstwiesen Interglacial and post-interglacial phases		Stratigraphy	
Schöningen		Ummendorf and Martinsried			
Urban (1995), Urban and Bigga (2015); Urban et al., 2023a		Strahl (2019), 2023; Wansa et al. (2019), 2022			
LPAZ/LPASZ	Biostratigraphic subdivision	LPZ	Biostratigraphic subdivision		
Main palynological characteristics		Main palynological characteristics			
PRP6b NAP, Poaceae	Reinsdorf E early steppe-tundra phase	Later phases not recorded, erosion disconformity		Fuhnian	Saalian Complex
RP5, PRP6a <i>Pinus</i> , <i>Betula</i> , <i>Picea</i> , <i>Larix</i> , <i>Alnus</i>	Reinsdorf D 2nd woodland phase				
RP4: Poaceae, <i>Artemisia</i> , <i>Juniperus</i> , NAP, Ericaceae, (<i>Betula</i> , <i>Pinus</i> , <i>Alnus</i>)	Reinsdorf C	W-S B: Poaceae, <i>Artemisia</i> , <i>Salix</i> , NAP, <i>Hippophae</i> , (<i>Betula</i> , <i>Pinus</i> , <i>Alnus</i>)		Wormsdorf Stadial B	
RP4b: <i>Betula</i> increase, RP4a: Ericaceae, aquatic flora	2nd steppe phase				
RP3, RP2/PRP2: <i>Pinus</i> , <i>Betula</i> , (<i>Picea</i> , <i>Juniperus</i>)	Reinsdorf B1-B3	W-S A/B: <i>Pinus</i> , <i>Betula</i> , <i>Larix</i>		Wormsdorf Interstadial A/B	
RP3, RP2b: <i>Alnus</i> ; PRP2a3: <i>Picea</i> ; PRP2a2: <i>Betula</i> ; PRP2a1: <i>Pinus</i>	1st woodland phase	NAP decrease			
PRB1: Poaceae, <i>Artemisia</i> , NAP, <i>Betula</i> , <i>Juniperus</i>	Reinsdorf A	W-S A: Poaceae, NAP, <i>Artemisia</i> , <i>Betula</i>		Wormsdorf Stadial A	
PRP1b: <i>Juniperus</i> , <i>Larix</i>	1st steppe phase	W-S A2: <i>Artemisia</i>			
PRP1a: <i>Salix</i> increase, (<i>Alnus</i> , <i>Pinus</i>)		W-S A1: Ericaceae (<i>Betula</i> , <i>Pinus</i> , <i>Juniperus</i> , <i>Larix</i> , <i>Alnus</i> , <i>Salix</i>)			
		Hiatus			
R4/5: <i>Pinus</i> , <i>Betula</i> , (<i>Alnus</i> , <i>Larix</i>), Poaceae	Reinsdorf Interglacial	HW 6: <i>Betula</i> , <i>Pinus</i> (NAP)		Horstwiesen Interglacial	Reinsdorf Interglacial
Late R3 (PRP3): <i>Picea</i> , <i>Abies</i> , <i>Pinus</i>		HW 5: <i>Alnus</i> , <i>Abies</i> , <i>Picea</i> , <i>Pinus</i> , (<i>Tilia</i> , <i>Taxus</i>), (*)			
PRP3b2: <i>Pinus</i> , <i>Picea</i> , (<i>Alnus</i> , <i>Tilia</i> , <i>Carpinus</i>), NAP					
PRP3b1: <i>Carpinus</i> , <i>Abies</i> , <i>Pterocarya</i> , <i>Fagus</i> , (*)					
R3a2: <i>Tilia</i> decline, <i>Abies</i> increase		HW 5 c - d: <i>Pterocarya</i> , <i>Buxus</i> , <i>Ilex</i> , <i>Viscum</i> ; HW 5 b/c: <i>Fagus</i> ; HW 5 a: <i>Carpinus</i> , <i>Tilia</i> , <i>Taxus</i>			
Early R3 (PRP3): <i>Alnus</i> , <i>Carpinus</i> , <i>Tilia</i> , <i>Pinus</i> , <i>Corylus</i> , <i>Quercus</i>		HW 4: <i>Alnus</i> , <i>Picea</i> , <i>Carpinus</i> , <i>Tilia</i> , <i>Taxus</i> , <i>Corylus</i> , <i>Quercus</i> , (*)			
R3a1: <i>Carpinus</i> decrease, <i>Pinus</i> max., <i>Picea</i> , <i>Abies</i> ,					
2nd Tilia phase (continues at the base), (*)					
R2: <i>Corylus</i> , <i>Quercus</i> , <i>Alnus</i> , <i>Carpinus</i> , <i>Pinus</i> , <i>Picea</i> (QM, <i>Taxus</i>), (*)		HW 4 c: 2nd <i>Carpinus</i> max., <i>Picea</i> ,			
Top: 2nd <i>Carpinus</i> and 2nd <i>Tilia</i> max.		HW 4 b: <i>Carpinus</i> decline, <i>Picea</i> , <i>Tilia</i> , <i>Corylus</i> and <i>Quercus</i> increase			
Base: <i>Carpinus</i> and <i>Tilia</i> decline, increase in <i>Corylus</i> and <i>Quercus</i>		HW 4 a: 1st <i>Carpinus</i> max., <i>Quercus</i> , <i>Pinus</i>			
R1: QM, <i>Quercus</i> , <i>Ulmus</i> , <i>Tilia</i> , <i>Corylus</i> , <i>Pinus</i> , <i>Picea</i>					
R1b: 1st <i>Carpinus</i> max., (*)					
R1a & R1b: 1st <i>Tilia</i> phase, <i>Fraxinus</i> max.					
Earlier phases not recorded		HW 3: <i>Alnus</i> , <i>Picea</i> , <i>Taxus</i> , <i>Corylus</i> , <i>Quercus</i> (<i>Fraxinus</i>)			
		HW 2: <i>Alnus</i> , <i>Picea</i> , <i>Corylus</i> max., <i>Quercus</i> , <i>Pinus</i> , (*), Hiatus at the basis			
		HW 1: <i>Betula</i> , <i>Hippophae</i> , NAP			

drilled within the basin, along with a series of others along the Aller valley. Pollen diagrams from the earlier boreholes were produced by Erd, though not published (e.g. Erd, 1994). He recognised the potential for three superimposed interglacials, but the closure of the Central Geological Institute in Berlin precluded further work. Investigation resumed in the present century by Stefan Wansa and Jacqueline Strahl, leading to a new borehole in 2012 and a thorough review of the site, that involved various disciplines (Wansa et al., 2019; Strahl, 2019). It is clear from the analysis of various boreholes and seismic investigations that different areas subsided at different times and rates, and that many hiatuses, both small and large, occur in the record of these boreholes. Nevertheless, when considering all the evidence together, it is evident

that three interglacial stages are represented between the Elster and Saalian tills, along with a few interstadials. The oldest of these is clearly Holsteinian, with *Pterocarya* and *Celtis* present, while the youngest can be correlated with the Dömnitz interglacial, described by Erd (1973a) at Prignitz and other sites in Brandenburg (Strahl, 2023), which Urban et al. (1991b) also correlated with the Schöningen Interglacial.

Strahl has named the middle interglacial the Horstwiesen Interglacial (Strahl, 2019; Wansa et al., 2019). She has provided a detailed description of how the vegetational succession of this interglacial differs from that of the Holsteinian Interglacial, particularly concerning the occurrence of *Corylus*, *Picea*, *Carpinus*, and *Abies*. The environment of the Ummendorf Basin differs significantly from that of Schöningen,

featuring a large expanse of marshy land surrounded by dry slopes. However, the key characteristics of the Horstwiesen Interglacial clearly indicate that it correlates with the Reinsdorf Interglacial (Table 3), located only a few kilometres away.

Additionally, another site at Martinsrieth near Sangerhausen has been under investigation, where salt solution at depth has caused subsidence, resulting in the preservation of three late Middle Pleistocene interglacial sequences that can be correlated with those at Ummendorf and Schöningen (Wansa et al., 2022; Strahl, 2023).

6.1.3. The Schöningen interglacial

The youngest of the Late Middle Pleistocene interglacial sequences, the Schöningen Interglacial, was first recognised and defined by Brigitte Urban (Urban et al., 1991a), following the fieldwork of Lenhard (1989) in the North Pit. Lenhard was able to trace a gravel-based channel running north to south for nearly 300 m, farther out into the centre of the Schöningen Valley than the margins of the alluvial fans. The sections logged by Elsner (1987) (Len P-1 - Len P-7, Fig. 2B), were mostly flooded by gravel overlain by silt (Beckenschluff). P 5, more marginal overlay a 2.5 m bed of loess, which could also be traced across the valley. All these sections contained silts sometimes with humic horizons, or in some sections, black or brownish-black silt of varying thickness, or peat, sometimes with wood fragments. Almost every section was different, often with beds of sand or fine gravel interrupting the sequences, making correlation difficult. Urban selected three sections, P1, P3 and P7 for pollen analysis. Often, the pollen was poorly preserved. Only Len P-1 (Fig. 7) produced a clear, if only partial, interglacial succession, covering parts of the early- and late-temperate substages, but P-3 yielded mas-sulae of the water fern *Azolla filiculoides*.

Above the beds that Lenhard attributed to the interglacial were beds of fine, medium or even gravelly sand, of varying thickness, indicating that, unlike Channel II, there were rather regular strong flowing water at times in this channel. But there were predominantly beds of grey, dark grey or even black silt. In the sections Urban et al. (1991a) examined, particularly profile Len P-1, she recognised two interstadials, Büddenstedt 1 and Büddenstedt 2, and also in P-3 and P-7 (referred to by Lenhard as 'Bantega Interstadial' and the interglacial beds as 'Dömnitz') (Fig. 7). Where overlying layers had not been removed, this sequence of deposits was capped by Saalian (Drenthe) sediments and the transfer to colder climate marked by cryoturbation.

In the Schöningen interglacial pollen diagrams from profile Len P-1, and in particular P-3 and P-7, we observe changing lithology and a shortened, interrupted sequence. Consulting the pollen record (Urban et al., 1991a), as at Dömnitz and Wacken (Menke, 1968, 1980, 1984), (Fig. 1A), *Pinus* remained an important element in the forest vegetation throughout the interglacial, in contrast to the Holsteinian and Reinsdorf Interglacials, also *Betula* and *Alnus*, the latter no doubt because of alder carr along the margins of the channel (Fig. 2B and 7; Table 2). The early-temperate substage is very compressed and interrupted below. The forest featured *Quercus*, *Ulmus*, *Corylus*, and *Tilia*, followed by *Picea*. After an expansion of *Corylus* at the expense of the other Quercetum mixtum species, except for *Tilia*, *Carpinus* appears, heralding the late-temperate stage of the interglacial (and confirming that this is a real interglacial and not just an interstadial).

The pollen sample above this yielded very high values of *Tilia* and Polypodiaceae, classic markers for soil development or inwash, and differential destruction of pollen, so that only the most resistant (and easily recognisable) survive (Fig. 7). Stebich et al. (2020) assigned this to a second *Tilia* expansion, a case of not reading the text, but just looking at the diagrams! Above this herbaceous pollen, with a variety of open-ground taxa developed. Clearly, climatic deterioration had begun. Urban recognised two interstadials interrupting the development of open vegetation. The Büddenstedt I Interstadial showed an expansion of *Pinus* to above 80%, but Büddenstedt 2 Interstadial was a longer and more complex event, with an initial expansion of *Pinus*, then of *Betula*, and an unexpected expansion of *Corylus*, which Urban usually

distinguishes from *Myrica*, also the development of heathland with *Calluna* and *Empetrum*, slightly reminiscent of Strahl's Perleberg Interstadial (Strahl, 2023), whilst *Alnus* re-established itself. Tantalisingly, the uppermost sample of this diagram then shows a small expansion of *Quercus*, with traces of other temperate trees, as well as grasses and *Artemisia*. These freshwater pond deposits are then overrun by early glacial sand (SI Table 1).

In the South Pit, we must rely on Mania's survey and his still unpublished study of the Mollusca (Mania and Altermann, 2015; Mania, 2026) to follow his channel. It was recorded in his Profiles 1, 2, 3, 4, 10, 12, 13, 14, 15 and 16. He traced Channel III, running north-south from the north-east to the south-west margins of the South Pit. Incised 12 to 15 m deep, it ran parallel to Channel II, partly overlying it, but partly cutting down into Elsterian sediments or even into the underlying Tertiary sands. Channel III varied in width from about 200 m to over 300 m (Mania and Altermann, 2015: Fig. 58), generally wider than all the subchannels of Channel II (Fig. 8; Mania and Altermann, 2015: Fig. 58). As in the North Pit, it was flooded by a coarse lag gravel, followed by sand passing up into silt deposits that infilled almost the whole length of the channel with occasional sand or gravel incursions. Many of the sections passed up into horizons showing evidence of solifluction, cryoturbation or frost wedges and were overlain by Saalian glacial sediments. Again, as in the North Pit, only in a few places, notably Profiles 2 and 3, were organic lacustrine deposits preserved. From the basal silts of these deposits, Mania was able to retrieve a characteristic late-glacial subarctic to boreal mollusc fauna and from overlying silty and calcareous muds and from about 2 m of organic silts and coarse detritus mud, a species-rich temperate freshwater fauna. This is clearly a major interglacial channel between the periglacial conditions following the Reinsdorf sequence and the onset of the Saalian glacial stage.

6.2. General conclusions

The following conclusions may be drawn about Channel III and its contents, the Schöningen Interglacial and subsequent climatic oscillations.

- 1) There are three temperate interglacial cycles recorded from Schöningen, between the Elsterian and Saalian glacial stages.
- 2) The interglacial sequences in both Channel II and Channel III developed in accommodation space following the very powerful creation of the channels cut into the floor of the Schöningen Valley, due to the melting of permafrost at the end of a major cold stage.
- 3) We are confident that the Schöningen Interglacial channel in the North Pit and Channel III were confluent. Both were overlain by Saalian deposits, including periglacial structures. Both were primarily infilled by basin silts with interruptions by flowing water carrying sand or even gravel, a quite different situation from the subchannels of Channel II. We suspect that much of the silt originated as reworked loess deposits laid down in the valley during earlier cold periods.
- 4) As an incidental, it seems that the absence of Channel II, close to the Schöningen Interglacial channel in the North Pit, means that it was cut by water cascading down an alluvial fan in the south-western part of the North Pit, where there are no stratigraphic records, whereas Channel III began further north.
- 5) Although the pollen record of the Schöningen Interglacial is rather restricted and really has to depend largely on a single diagram Len P-1 (Fig. 2B and 7), it is nevertheless sufficiently distinctive to be clearly separable from that of the Reinsdorf Interglacial (Urban, 1995; see also Bittmann, 2012; contra Meyer, 2012).
- 6) All the stratigraphic evidence, let alone palynological and palaeontological evidence, points to the occurrence of three major climatic cycles represented at Schöningen between the Elsterian and Saalian (s.s.) Stages. The logic of this has to be that deposits related to MIS 11, MIS 9, and MIS 7 are all present there.

6.3. Mammalian biostratigraphical evidence

The rich fossil record from the Reinsdorf sequence provides valuable biostratigraphical information in the debate on the age of the deposits. An important age indicator is the fact that the mammalian fauna from 13 II includes early Middle Pleistocene relicts (*Sorex (Drepanosorex)* sp., *Trogontherium cuvieri*, *Homotherium latidens*), (van Kolfschoten, 2014a; Serangeli et al., 2015b). These species are absent in many late Middle Pleistocene faunas such as Weimar-Ehringsdorf, Ariendorf, Schweinskopf, Maastricht-Belvédère, Cagny l' Epinette (van Kolfschoten, 1990, 2014a) and many more, late Middle Pleistocene, Palaeolithic sites, and these sites are therefore regarded as stratigraphically younger, generally assigned to MIS 7. This assumption is supported by another independent age proxy: the evolutionary stage of the water vole (*Arvicola*) remains, which are abundantly represented in the Reinsdorf Channel faunas and well preserved.

Within the Middle and Late Pleistocene *Arvicola* lineage, notable evolutionary changes in the thickness of the enamel that covers both the concave (leading) and convex (trailing) edges of the molars. To quantitatively assess differences in enamel thickness, Heinrich (1978) proposed calculating the enamel thickness quotient, introducing the *Schmelzband-Differenzierungs-Quotient* (SDQ) values. Higher values

indicate more primitive populations, while lower values suggest more advanced forms.

Establishing the evolutionary stage of fossil *Arvicola* remains has proven to be a powerful proxy for relative dating, particularly in regions where voles are abundant and well-preserved. Its strengths lie in the abundance of vole fossils, the high rate of unidirectional evolution, and the extensive dataset available (Heinrich, 1987; van Kolfschoten, 1990; von Koenigswald and van Kolfschoten, 1996; Parfitt, 1998; van Kolfschoten, 2025; van Kolfschoten et al., 2025).

The Schöningen water voles, among the most well-represented species in the Spear Horizon faunal record, exhibit SDQ-values ranging from 125.4 (the base of the Reinsdorf sequence) to 115.2 (the Schöningen Spear horizon, layer 13 II-4bc and II-4a) (Figs. 13 and 14). This range indicates a Toringian fauna (van Kolfschoten, 2012, 2014a), which is younger than the small mammal assemblages from British MIS 11/Hoxnian (=Holsteinian) sites such as Barnham and Beeches Pit, which exhibit higher SDQ-values (Parfitt, 1998).

Moreover, the rare occurrence of a *Mimomys*-fold in the Schöningen record suggests that water vole populations from Barnham and Beeches Pit, where *Mimomys*-fold frequencies are much higher than in Schöningen, are more primitive and, therefore, stratigraphically older. Conversely, numerous late Middle Pleistocene faunal assemblages, such

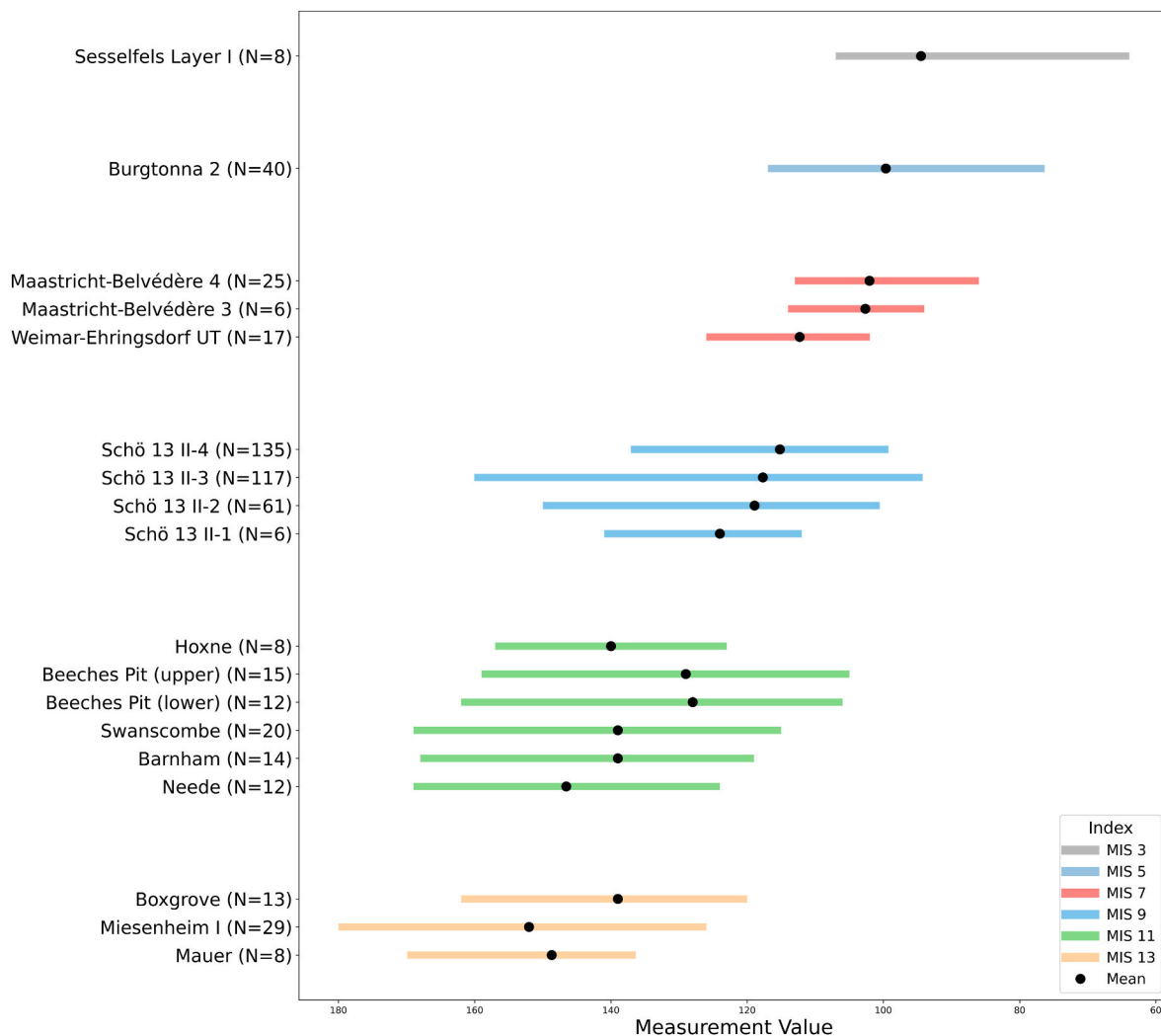


Fig. 14. Temporal changes in the SDQ values of the water vole molars from the MIS 9 Schöningen levels Schö 13 II-1, 13 II-2, 13 II-3 and 13 II-4 compared with the SDQ values of water voles from the German MIS 13 localities Mauer (Maul et al., 2014) and Miesenheim I (van Kolfschoten, 1990), the British MIS 13 site Boxgrove and the MIS 11 localities Barnham, Swanscombe, Beeches Pit (lower level), Beeches Pit (upper level), and Hoxne (Preece et al., 2007), the MIS 11 locality Neede (Netherlands), the MIS 7 localities Weimar-Ehringsdorf UT (Germany) and Maastricht-Belvédère 3 and 4 (Netherlands) (van Kolfschoten, 1990, 2014a), the German MIS 5 locality Burgtonna 2 (Maul et al., 2014) and the German MIS 3 Locality Sesselfels Layer I (van Kolfschoten, 2014b).

as those from German localities like Weimar-Ehringsdorf, Ariendorf, Schweinskopf, and Maastricht-Belvédère (the Netherlands) (van Kolfschoten, 1990), exhibit lower SDQ-values.

6.4. Numerical age determinations

Tucci et al. (2021) provide an overview of the numerical dating results obtained to date for Quaternary deposits in the Schöningen open-cast mine. Here, we will summarize the data with a focus on age determinations in a specific stratigraphic and archaeological context (Fig. 15).

Initial investigations of peat deposits from the Eemian (Channel IV) and Schöningen Interglacial (Channel III) in the North Pit by Heijnis (1992) and Heijnis and Urban (1995) using $^{230}\text{Th}/\text{U}$ yielded ages of 132 ± 17 ka and $180/227$ ka, which supports the classification as MIS 5 and MIS 7, respectively (Fig. 15). The $^{230}\text{Th}/\text{U}$ analyses on peat from the Reinsdorf sequence (channel II, sequence 13 II-3 and 13-4) (Fig. 13), in the South Pit yielded an age of approximately 300 ka (Sierralta and Urban, 2012). However, these were refuted by a more recent study using

thermal ionisation mass spectrometry (TIMS) (Sierralta et al., 2017), which observed open-system behaviour in most samples from the Reinsdorf sequence. Based on thermoluminescence (TL) dating of heated flint from the oldest archaeological horizon 13 I (13 I-Fs 1) (Richter and Thieme, 2012) with a weighted average age of 321 ± 16 ka, Richter and Krubetschek (2015) conclude that the last heating of the flints thus falls within the age range of MIS 10 to 8. From this data, the authors deduce that the Holstein can be assigned to MIS 9 and could also serve as the maximum age estimate for the Schöningen 13 II-4 spear horizon site (Fig. 2C and 13).

However, the very broad dating range of the burnt flint described by the authors also allows us to classify archaeological site 13 I, based on biostratigraphic evidence, as belonging to an early phase of MIS 10 (Table 15; Supplementary Information, Chapter I.2.2.). That said, the correlation between Holstein and MIS 9 must also be rejected. Instead, we assign the Holstein and early Fuhne deposits of the Schöningen sequence to MIS 11 and MIS 11/MIS 10 (Fig. 15), which is also supported by an IR-RF age of 396 ± 31 ka from sediments directly above the Holstein deposits in south-eastern Brandenburg (Strahl, 2023). The very

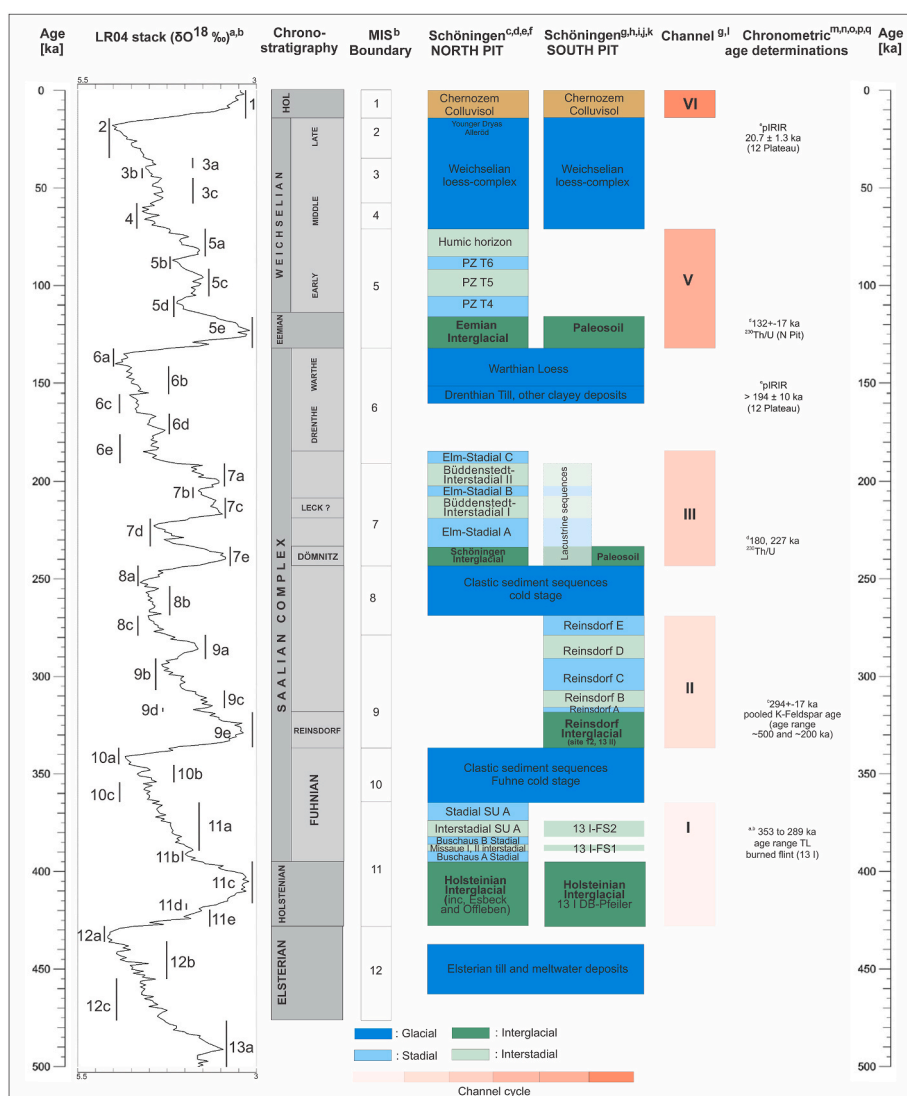


Fig. 15. Stratigraphy, biostratigraphic subdivision, selected chronometric dating results and correlation with the Marine Isotope Stages (MIS) and Substages of the Quaternary sequence of the North and South Pits of the disused former Schöningen lignite mine. Reference is made to a) Rallsback et al. (2015); b) Lisecki et al. (2005); c) Urban et al. (1988); d) Urban et al. (1991a); e) Urban et al. (1991b); f) Urban (2007); g) Mania and Altermann (2015); h) Urban (1995); i) Urban (2007); j) Urban and Bigga (2015); k) Urban et al. (2023); l) Altermann and Mania (2007); m) Richter and Thieme (2012); n) Richter and Krubetschek (2015); o) Tucci et al. (2021); p) Heijnis and Urban (1995); q) Kunz et al. (2017). Channel IV (Mania and Altermann, 2015) was not included in the scheme because its stratigraphic position is unclear.

broad dating range of the burnt flint (Richter and Krbetschek, 2015) does not contradict the biostratigraphic classification of archaeological site 13 I as an early phase of MIS 10 (Table 15; Supplementary Information, Chapter I.2.2.) either.

Recently, IR-RF and post-IRIR dating from subchannel 13 II-2 was used to determine a pooled K-feldspar OSL luminescence age of 294 ± 17 ka for early postglacial Reinsdorf deposits (Fig. 13: layer II-2c1), correlated with MIS 9 (Tucci et al., 2021). The authors state that the dating results must be considered maximum age estimates regarding the methods used. Hutson et al. (2025) noted that these maximum age estimates for this layer span a wide range, from approximately 500 ka to 200 ka (MIS 13 – MIS 7), and would therefore be consistent with an MIS 7 age. We counter this by arguing that, due to the widely scattered age results, an older classification of the Reinsdorf sequence, namely into MIS 9, as postulated by Tucci et al. (2021) and by us here, cannot be refuted.

The numerical data, which represent only a selection of the absolute age data for the Schöningen sites, show that considerable uncertainties remain and that further chronometric investigations using refined methods are necessary.

6.5. Correlation with the Marine Isotope Stages

Lauer and Weiss (2018) convincingly demonstrated that the Elsterian glaciation is linked to MIS 12 of the marine stratigraphic framework, and that the Saalian (Drenthe/Warthe) glaciation corresponds with MIS 6. The combined stratigraphical data from the North and South Pits indicate that, between the Elsterian and the Saalian (Drenthe) glacial deposits, three successive interglacials occur, which are identified as the Holsteinian Interglacial, the Reinsdorf Interglacial, and the Schöningen Interglacial (Urban et al., 1988, 1991a, 2023; Urban, 1995), correlated with Marine Isotope Stages (MIS) 11c, 9e, and 7e, respectively (Fig. 15).

This correlation has been challenged by some German Quaternary scientists (Meyer, 2012; Bittmann, 2012), who insist that the Elsterian should be correlated with MIS 10 and the Holsteinian with MIS 9. This view has even been accepted by the Quaternary Subcommittee of the German Stratigraphic Commission (Bittmann et al., 2018). The critical debate here concerns whether the Reinsdorf Interglacial is distinct from the Holsteinian, which we believe to be the case, based on stratigraphical, palynological, and palaeontological evidence. However, the crux of this issue is not Schöningen but the lack of accommodation space, particularly in Germany, for sediments of MIS 9 age. The Fuhne cold stage, which follows the Holsteinian Interglacial (Erd, 1970; Litt et al., 2007), left no glacial hollows behind, and solifluction has infilled any similar structures. By contrast, in north-west Europe, especially in southern, eastern, and Midland England, as well as in northern France, tectonic uplift has preserved a staircase of terrace deposits along the course of major rivers, providing accommodation space for Middle and Late Pleistocene sedimentation (Bridgland, 1994; van Gijssel, 2006).

MIS 7 was recognised in the ocean record as an unusual stage with three warm substages MIS 7e, MIS 7c and MIS 7a, all a little less developed, maybe shorter than 11c and 5e, separated by two colder intervals MIS 7d and 7b. This sequence was recognised by Reille et al. (2000) from a long core from the volcanic maar lake Lac du Bouchet in the French Massif Central (Fig. 1A). They named the temperate intervals le Bouchet 1, 2 and 3 interstadials. Most recently, a volcanic maar in the Bohemian Massif at Neualbenreuth, north-east Bavaria, Germany, has been investigated by Stebich et al. (2020). These are rare examples where the three optima of MIS 7 may be found without serious interruption in superposition. Elsewhere, largely because of a lack of accommodation space, in most cases only sediments of the first optimum, e.g. the Dömnitz type locality at Prignitz (Erd, 1973a and b; Strahl, 2023) are preserved. Even where accommodation space might have been present, as in Channel III at Schöningen, erosion by an advancing glacial front may sweep the later record away. With programmes of intensive survey and drilling, Strahl (2023, Fig. 6) has been able to

record over 100 sites with Dömnitz or post-Dömnitz sequences in boreholes in four particular areas of Brandenburg. These deposits, in the network of deep glacial valleys occupied by ox-bow lakes, in a predominantly fluvial environment, with sedimentation constantly interrupted by erosion and the changing deposition of sand, clays containing plant fragments, silt, silty and organic muds, and, particularly towards the end of the interglacial, by peat and sands with humic or even peaty lenses. Strahl is cautious about recognising traces of possible succeeding interglacial units, as might be expected from MIS 7. At separate sites she recognises two different interstadials following the Dömnitz Interglacial, the Perleberg and Karstädt Interstadials, but in most areas any subsequent record was swept away by the advance of the Saalian ice.

7. Discussion

Our reassessment of the stratigraphy, palaeoenvironmental processes and dating of the Middle Pleistocene deposits at Schöningen is radical and in conflict with (recently) published hypotheses/views.

7.1. Die chronologische Einordnung der Paläolithischen Fundstellen von Schöningen (The chronological setting of the palaeolithic sites of Schöningen) (Behre (ed.), 2012)

As the title of this volume suggests, its main objective was to reconsider and redefine the stratigraphical position of the entire Pleistocene sequence at Schöningen, in which the horizons containing Palaeolithic artefacts are found. The book provides detailed descriptions of these horizons, along with their fauna, flora, and archaeology.

The papers in this volume, with a few exceptions, support the view that only one interglacial cycle (possibly two) is present at Schöningen, and this has been attributed to the Holsteinian interglacial. Moreover, most papers assume and accept that this interglacial corresponds to Marine Isotope Stage (MIS) 9, with the preceding Elsterian glacial Stage relating to MIS 10. This suggests that the widely accepted stratigraphic view in neighbouring countries, across both western and eastern Europe, as well as by researchers studying the ocean record (Toucanne et al., 2009) and particularly the idea that the Elsterian relates mainly to MIS 12, and the Holsteinian Interglacial to MIS 11c, is incorrect (Behre (ed.), 2012; Bittmann, 2012; Behre and van der Knaap, 2023).

The stratigraphical interpretation, which Behre in his Preface claimed to represent a broad consensus, is profoundly influenced by historical investigations of Holsteinian lacustrine interglacial sites elsewhere in Niedersachsen, in various parts of northern Germany and northern Europe more generally. At most sites, there is a close relationship between the landforms associated with the melting Elsterian ice sheet and the development of tunnel valleys into lacustrine basins that persisted through the Elsterian late-glacial period and into the fully temperate substages of the Holsteinian Interglacial. As described in section 6, many North German Holsteinian sites (e.g. Munster-Breloh: Müller, 1974; Ober-Ohe: Benda and Brandes, 1974; Dethlingen: Koutsodendris et al., 2010), and the type locality Hamburg-Dockenhuden (Jerz and Linke, 1987) developed and were preserved in this way.

The major stratigraphic papers in this volume reinterpret the Middle Pleistocene deposits at Schöningen within this context. Lang and Winsemann (2012) and Lang et al. (2012, 2015b) regard the basin in which the post-Elsterian deposits occur as an Elsterian tunnel valley, primarily because the trough has steep walls and a flat bottom, which they compare to other tunnel valley systems. They conclude that: 'After deglaciation the tunnel valley remained underfilled and acted as a depocentre for interglacial deposition.' However, the criteria on which Lang and Winsemann concluded that the Schöningen sequence formed within an Elsterian tunnel valley are flawed. There is no doubt that as the Elsterian ice front advanced southwards in this region, it encountered the hard massifs of the Elm and the Lappwald. Consequently, ice was funnelled into an already existing intervening valley system, floored by relatively soft Eocene sediments; essentially, the area now known as

the Helmstedt-Staßfurter Braunkohlebecken. Certainly, this ice mass eroded the Eocene lignite, and subglacial meltwater may have played an important role. However, even from the borehole data collected by Lang and Winsemann, there is no evidence that any extensive closed basin was formed, which would have retained a body of water after deglaciation. Not only do the recorded boreholes not extend sufficiently north or south within the valley to demonstrate any barrier that could have retained a lake, but the sediment sequence itself towards the centre of the basin also rules this out. At the centre of the south wall of the DB-Pfeiler, the organic (Reinsdorf) lacustrine deposits exposed at the Schöningen 12 II and adjacent excavation sites (Urban and Sierralta, 2012), (Fig. 2C) rest either on fine-grained glacio-lacustrine deposits (Lang and Winsemann, 2012: Fig. 4) or, in places, almost directly on the Elsterian till. Due to the absence of any clear weathering horizon, Meyer (2012) has claimed that there must have been continuous sedimentation, or at least no stratigraphic break, between the glacial and interglacial sediments. However, it is evident from the repeated pollen profiles produced by Urban (1995, 2007) and Urban and Sierralta (2012), through the Reinsdorf organic sediments, that the deposition of these only commenced well into the temperate substages of the interglacial. Therefore, even if Meyer was correct in assigning the sequence to the Holsteinian Interglacial (which we challenge), using Müller's estimates for the duration of that interglacial (Müller, 1974), there must be a hiatus of up to 10,000 years between glacial and interglacial deposition. We categorically reject suggestions that there might have been some 'damp meadow' scenario, where neither weathering nor deposition occurred! The absence of evidence for subaerial weathering, along with the variable thickness of silts and sands above the till, suggests that erosion has indeed taken place at some point during this interval. It has been argued that there is little evidence for erosion within the Schöningen Middle Pleistocene sequence at this point; however, the organic beds, assigned to the Reinsdorf cycle in its broadest sense, since it covers not just interglacial but also subsequent stadial and interstadial events, have clearly been shown to consist, both at the now lost Schöningen 12 II sites and the still existing Schöningen 13 II area, the Spear Sockel, of a series of discrete sedimentary units, distinctly separated by erosional hiatuses (Mania and Altermann, 2015). This includes the base of the lowest interglacial unit, which can contain clasts of older reworked sediment.

The conclusion from this discussion must be that after the retreat of the ice, the centre of the valley at Schöningen was not a lacustrine basin holding water, but one that at some time or other was more or less open and subject to erosion. Since almost nobody would believe that any ancestor of the Missau stream would be of any size, nor are there surviving deposits of such a stream or river, the question must be, where did the water to effect such erosion come from? At any rate, the concept that this was a lacustrine site, formed in a depression inherited from a tunnel valley, must be dismissed and abandoned.

Meyer's paper (2012) summarises much of the work of his former students within the North Pit and is largely based on his interpretation of that work; in particular, he notes the close proximity of Holsteinian deposits to the Schöningen Interglacial channel of Urban (Urban et al., 1991a) and concludes that they must be of the same age. In discussing the dam or DB-Pfeiler sections (Schöningen 12), he argues for continuous, uninterrupted sedimentation between the Late-Elsterian meltwater sands and the Reinsdorf Interglacial deposits, concluding that these must, therefore, be of Holsteinian age. He notes inconsistencies in Mania's designation and mapping of channels across the South Pit and DB-Pfeiler areas. For his conclusions that the Reinsdorf Interglacial is simply a facies of the Holsteinian and, furthermore, should be assigned to MIS 9, he draws further support from two other papers in this volume. Bittmann (2012) reviews the evidence from Holsteinian and equivalent interglacial deposits across northern Europe. Confusingly, he equates the Hoxnian deposits at Marks Tey in eastern England with the Holsteinian deposits of northern Germany on the basis of the high non-tree pollen phase common to pollen diagrams in both areas, and later

proceeds to suggest a correlation of the type locality at Hoxne, where the high non-tree pollen phase is also represented, with the older Bilshausen Interglacial deposits in Germany. He concludes that, based on the occurrence of very small percentages of pollen from *Pterocarya* and cf. *Celtis* in the Reinsdorf pollen diagrams, the latter must also belong to the Holsteinian, where these taxa are characteristic. Differences in the quantities and timing of key taxa appearances, such as *Abies* and *Carpinus*, between Urban's Holstein and Reinsdorf pollen diagrams from Schöningen are dismissed as being due to local conditions of pollen transport and edaphic factors, despite the sites being merely a few hundred metres apart within the same basin. Secondly, both Bittmann and Meyer are significantly influenced by the dating results of Geyh, concerning one of the Holsteinian type localities at Bossel (Geyh and Müller, 2005), which suggested an age of 312 ± 3 ka, thus placing the interglacial within MIS 9. Despite earlier critical commentary on Geyh's methodology prior to publication, and subsequent remarks in print by referees (Rowe in Preece et al., 2007), these results were again published in Geyh and Müller (2007) and repeated here by Geyh and Krubetschek (2012). However, they were later refuted based on new Th/U dating results by Sierralta et al. (2017) from a Holsteinian Parastratotype in Wedel, Mecklenburg-Vorpommern, and on peat deposits from the Reinsdorf sequence, which indicates that these data, along with those from Bossel (Geyh and Müller, 2007) (Fig. 1A), are unusable due to open system conditions. These methodological clarifications, or rather the ineffectiveness of the Th/U ages for determining the age and correlation of the Holsteinian in northern Germany, have been overlooked by some authors until recently (Schläfli et al., 2023; Behre and van der Knaap, 2023). This dating, based on a single disputed analysis, has been widely accepted within Germany but not elsewhere, causing stratigraphic tables for Germany to be out of synchrony with those from the rest of Europe and with the marine stratigraphy derived from cores in the Bay of Biscay (NE Atlantic), where sedimentological and palynological evidence now fully supports a correlation of the Elsterian glaciation to MIS 12 and the Holsteinian/Hoxnian Interglacial to MIS 11 (Toucanne et al., 2009; Desprat et al., 2009; Desprat and Sanchez-Goni, 2020; Candy et al., 2025).

In summary, the principal contributors of this volume have presented seven arguments that underline their stratigraphic interpretation of the Middle Pleistocene deposits at Schöningen.

- 1) If we accept Geyh's dating of the Holsteinian Interglacial to within MIS 9 (Geyh and Müller, 2007), there would be only room for two interglacial stages between the Elsterian and the Saalian glaciations. There is, however, global evidence that this is not the case and that three interglacials separate the Elsterian and Saalian glaciations.
- 2) According to Litt et al. (2007) and Bittmann (2012), the palynological evidence for the Holstein and Reinsdorf Interglacials can be interpreted as belonging to a single interglacial, demonstrating local differences in vegetation. Meyer dismisses the evidence for an additional Schöningen Interglacial, although Bittmann accepts it. To summarize from Table 3: the fundamental differences between the Holstein and Reinsdorf/Horstwiesen consist of a late maximum of *Corylus* during the mixed oak forest phase, followed by a distinctive two-phase spread of *Carpinus* with low *Picea* occurrences, the maximum and decline of *Carpinus* before the clearly defined spread of *Abies*, an early decline of thermophilic deciduous trees including *Carpinus* and only very low occurrences of *Pterocarya*, *Buxus* and *Fagus* during the late temperate phase as evidenced by the pollen profiles of the Reinsdorf/from Ummendorf, Martinsried (Strahl, 2019; Wansa et al., 2019, 2022) and Schöningen (most recently Urban et al., 2023). And, as already mentioned, the well-developed late Holstein pollen diagram from Schö 13 I DB differs significantly from those from Schö 12 II, which is further out in the valley (Kunz et al., 2017) and is clearly distinguishable stratigraphically.
- 3) The Reinsdorf Interglacial sequence in the Schöningen 12 II exposures rests directly upon either glaciuvial sediments or till, with no

indication of weathering in between. Meyer therefore claims that this serves as evidence for an unbroken sedimentary environment between Elsterian glacial and Holsteinian interglacial deposition. However, Mania's careful mapping shows late glacial and early Reinsdorf sediments within Channel II, but towards the margins, mid-to late-temperate lacustrine sedimentation extending out onto the fresh eroded surface of Elsterian deposits, with a distinct hiatus between.

- 4) It is noted that direct superposition of Reinsdorf above the Holstein Interglacial sediments cannot be demonstrated anywhere. However, Mania's mapping shows that the margins of Channel II overlap the earlier Channel I, containing early Fuhne sites with their archaeological horizons (13-I) (Fig. 10).
- 5) If separate Holstein and Reinsdorf Interglacials were present in the Schöningen basin, corresponding to MIS 11 and MIS 9, there should be a significantly greater amount of sediment to represent the tens of thousands of years that separate them. However, the landscape during the Fuhne cold stage was essentially periglacial with deposition restricted to loessic sediments that are now represented by only thin surviving beds. In the North Pit, younger deposits associated with the alluvial fans were the first, unrecorded, to be quarried away as the pit was cleared for lignite extraction.
- 6) There is an unchallenged conviction that the interglacial deposits at Schöningen can and should be interpreted in the same developmental pattern as other interglacials of Holsteinian age in Niedersachsen; namely, that they were deposited in a lake formed within a residual glacial basin, which originated as a tunnel valley. However, although the vegetational succession from channels in the North Pit is recognizably the same as at other Holsteinian sites, the environment of deposition is clearly different and perhaps unique to Schöningen, as is the deposition of the Reinsdorf sequence in channels on the valley floor.
- 7) Following many years of investigation and numerous proposals that have proved groundless, there was a general consensus among Quaternary geologists in Niedersachsen that only one major interglacial can be demonstrated between the Elsterian and Saalian glacial stages. Evidence from sites such as Wacken (Menke, 1968) and Dömnitz (Erd, 1973a) were often regarded with a degree of ambiguity, and the more recent posthumous publication of Müller's work at Grube Nachtigall (Kleinmann et al., 2011) was also regarded as ambiguous. This background made local Quaternary geologists very reluctant to recognise a further Late Middle Pleistocene interglacial.

7.2. Late Middle Pleistocene palynostratigraphy and landscape evolution in western and central Europe: will the real Holsteinian please Stand up (Van Beirendonck and Verbruggen, 2025)?

Van Beirendonck and Verbruggen (2025) argue that the Alversdorf pollen cluster correlates with the MIS 11 Holsteinian interglacial (cf. Urban et al., 1991b), the Schö 13-I channel infill with MIS 9, the Reinsdorf channel/lake infill with MIS 7e-d, and the Schöningen Channel with MIS 7c-a. How the Reinsdorf Channel sequence might fit into the relatively short MIS 7e and perhaps 7d is, however, ignored. More relevant is the position of the Schöningen Interglacial, presumably relegated to one of the later temperate intervals of MIS 7. Placing the Reinsdorf sequence into MIS 7 would imply that one of the two major downcutting and channel formation events during the late Middle Pleistocene, clearly associated with melting permafrost, occurred during the cool interval, MIS 7d, between the first two temperate intervals. Nowhere is it suggested that this is a major cold interval!

Van Beirendonck and Verbruggen, whose main work involves manipulating pollen data on the computer, actually state: "According to Mania (in: Thieme and Maier, 1995), the Schöningen channel is younger than the Reinsdorf channel because the former cross-cuts the latter, but without any field observations supporting this theoretical cyclical

model"! Although citing Mania and Altermann (2015), they have clearly never read this important but lengthy article, nor appreciated the extensive fieldwork involved.

7.3. Revised age for Schöningen hunting spears indicates intensification of Neanderthal cooperative behavior around 200,000 years ago (Hutson et al., 2025)

The authors provide a revised age for the Schöningen "Spear Horizon" (13 II-4), based on work carried out by a team from the University of York (UK) that determined the new age using amino acid geochronology (AAG) data from fossils directly retrieved from the find-bearing deposits. They measured the D/L values of two *Bithynia* opercula, and the authors regard these data as the primary means of deriving an age estimate. In addition, they calculated the AAG age of 13 ostracod valves and the dentine of 9 horse molars; however, the authors question the fidelity of these age calculations due to concerns about the occurrence of the required closed system.

For intracrystalline protein decomposition in *Bithynia* opercula, the authors assume an effectively closed system of fossil protein. The two *Bithynia* opercula from Schöningen yielded mean D/L values slightly higher than those from the MIS 5e deposits at Neumark-Nord 2 (Germany), indicating that they are older. Conversely, the values are lower, and therefore the deposits are younger, than those of the MIS 11 Holsteinian Paludinenbank deposits in Berlin (Germany) and the MIS 11 fluvial deposits at Bilzingsleben (Germany) (Hutson et al., 2025). The authors conclude: *Considering that these comparator sites have experienced a similar temperature history, an age of MIS 7 is indicated for the Schöningen 13 II-4 Spear Horizon ...* (Hutson et al., 2025). When measured against the British *Bithynia* opercula AAG framework, the Schöningen 13 II-4 opercula dataset falls within the younger range of sites attributed to MIS 7, reflecting regional thermal differences.

However, it is important to note that racemisation rates depend exponentially on temperature (Miller et al., 1999; Wehmiller and Miller, 2000; Nelson et al., 2025a), and low temperatures during cold stages slow or halt intracrystalline protein decomposition (Nelson et al., 2025b). The implication is that, based on AAG data, the end of the one interglacial is hard to distinguish from the beginning of the next warm phase (Miller et al., 1999; Nelson et al., 2025b). In the debate over the age of the Schöningen 13 II-4 horizon, it is important to note that the opercula originate from deposits of post-Reinsdorf Interglacial age.

In addition, it is important to consider the specific burial conditions that characterise the Schöningen deposits. The *Bithynia* opercula were embedded in waterlogged deposits, which accounts for the pristine preservation of the finds (Kuitens et al., 2015). The groundwater partly originated from powerful springs rising from the Muschelkalk high up along the escarpment of the Elm Massif, and the influx of cool spring water might have resulted in lower temperatures than at the comparator sites. A small drop in temperature can significantly decrease the rate of racemisation (Miller et al., 1999; Wehmiller and Miller, 2000). Mitterer (1975) showed that, for example, a drop of 4 °C reduces the racemisation rate by ca. 50%. Lower racemisation rates result in lower AAG values, which indicate a younger stratigraphical age. This could explain the low Schöningen 13 II-4 AAG values.

The local conditions at Schöningen are site-specific and should have been taken into account when interpreting the AAR data. For reliable age determination, it is additionally important to consider independent, biostratigraphically calibrated data, such as those based on the high rate of unidirectional evolution of water voles, which are unaffected by local conditions.

Convinced by the accuracy of the opercula AAG dates, the authors developed a revised Schöningen chronostratigraphic model, entirely discarding previous research. Both Cycles II and III, which predate the MIS 6 Saalian till, are placed in MIS 7 (cf. van Beirendonck and Verbruggen, 2025), with Cycle III also extending into early MIS 6. This interpretation raises serious concerns (see chapter 7.2.). By placing both

Cycles II and III in MIS 7, the authors ignore the occurrence of ice-wedges in the top of Cycle II deposits (Mania and Altermann, 2015) which indicates glacial conditions with temperatures lower than those of MIS7b, the period that separates the two Cycles. In addition, the authors link the Holsteinian (Alversdorf) Interglacial, which they consider to be distinct from and younger than the Holsteinian *sensu stricto*, with MIS 9e, the peak of MIS 9, even though, as noted by the authors, the late Middle Pleistocene is stratigraphically poorly resolved, and a comparison between the Alversdorf sequence and a well-dated MIS 9e pollen sequence is lacking. The authors also propose, without further explanation, a significant stratigraphical hiatus following the deposition of Elsterian sediments. However, in the North Pit, the emplacement of Holsteinian (Alversdorf) interglacial sediments is clearly stratigraphically linked to meltwater channels of late Elsterian age.

Without taking into account the significant palynological and stratigraphic-chronological differences (e.g., low amounts of mixed oak forest trees during the temperate phase, no pronounced *Carpinus* phase, a long-lasting late interglacial boreal coniferous forest phase immediately followed by subarctic conditions (occurrence of *Ephedra*)), the Leck Interglacial (Stephan et al., 2011) is equated by Hutson et al. (2025) with the Dömnitz and Wacken Interglacials, which, however, are equated with the Schöningen Interglacial on a paleobotanical and chronological basis (Urban et al., 1991a; Urban, 2007; Litt et al., 2007; Stephan et al., 2011; Strahl and Wansa, 2019; Tucci et al., 2021; Strahl, 2023) (Table 2). Considering the clear paleoecological differences and according to IR-RF dating, the Wacken Interglacial (=Dömnitz Interglacial = Schöningen Interglacial) is correlated with MIS 7e and the Leck Interglacial with MIS 7c, therefore younger (Krbetschek and Stephan, 2010; Stephan, 2014; Strahl, 2023). Based on these facts, which the authors were apparently unaware of, their subsequent correlation to place the Reinsdorf and Schöningen interglacial-glacial cycles both in MIS 7 with the Reinsdorf interglacial classified as MIS 7e, the interstadial and stadial post-interglacial phases as MIS 7d-7c/b, and the Schöningen interglacial as 7a/6 is untenable. A correlation between the Leck Interglacial and the thermophilous trees lacking cool and dry Reinsdorf Interstadial B1-B3 with MIS 7c as well as a correlation between the stratigraphically older and much warmer Schöningen Interglacial and the cool and rather arid Reinsdorf Interstadial D (13 II-4bc/b, Speerhorizont, Fig. 13) with MIS 7b is completely contradictory.

The essential basis of their revised model is the AAG correlation between layer 13-II-4 and MIS 7c or with MIS 7b, along with their conviction that the shift towards communal hunting strategies, as the authors observe in the Schöningen record, developed within the increasingly complex social environments of Middle Palaeolithic Neanderthals that postdate MIS 9. However, our knowledge of hominin behaviour during MIS 9 is limited by the virtual absence of well-dated MIS 9 Palaeolithic sites. Therefore, we do not regard their assumption that monospecific hunting coalesced into a regular practice during MIS 7 (Hutson et al., 2025) as a convincing basis for rejecting an MIS 9 age for the Schöningen 13II-4 Spear Horizon.

We dismiss the Schöningen chronostratigraphic model proposed by Hutson et al. (2025) given our concerns about the interpretation of the collected AAG data, combined with the limited knowledge of hominin behaviour during MIS 9.

8. Summarizing conclusions

To access the Eocene lignite east of the town of Schöningen, the overlying Quaternary deposits, up to 45 m thick (Lang et al., 2015), were removed across an area of approximately 6 square kilometres, allowing for a detailed study of the sedimentary succession. Middle Pleistocene deposits form the base of the Quaternary deposits. The reassessment of the stratigraphy, palaeoenvironmental processes, and dating of the Middle Pleistocene deposits presented in this paper mainly depends on the work of Elsner (1987), Hartmann (1988), Lenhard (1989), Thieme and Mania (1993), Mania (2009), Mania and Altermann (2015), Lang

and Winsemann (2012), Lang et al. (2012, 2015a), combined with our observations over the past decades. Detailed analyses of the collected data have led to the following summarizing conclusions.

The North Pit, located adjacent to the eastern flank of the Elm massif, revealed a sequence of Quaternary deposits, with Elsterian glacial sediments at its base, emplaced from the north. Intercalated between the Elsterian and Saalian glacial layers are alluvial fan deposits, originating from the Muschelkalk massif of the Elm, containing a diverse range of sediment types, including those attributed to two distinct interglacial phases: the Holsteinian and, farther out in the valley, the Schöningen Interglacials. The South Pit is located to the south-east of the Elm and extends diagonally across the original valley floor to the south-east. This implies distinct differences between the Quaternary stratigraphy and palaeoenvironments recorded in the North and South Pits. The Quaternary geological setting of the northern part of the South Pit was characterised by the occurrence of two major channels: Channel II (with Reinsdorf Interglacial deposits) and Channel III (with Schöningen Interglacial deposits). Exposed at two localities in the South Pit and intercalated between the Elsterian till deposits and the Channel II deposits, are Holsteinian and early Fuhnian deposits (Fig. 9 and Table 1). The Reinsdorf Channel consists of a sequence of narrow superimposed subchannels, primarily containing beds of silt, detrital mud, and peat deposits, which represent five, sometimes six, shallowing cycles that can be traced along the entire length of Channel II. Channel III, which runs north-east of, parallel to, and partially covers the subchannels of Channel II, formerly extended across almost the entire South Pit but was truncated in the north by Saalian glacial deposits.

The most significant factor in explaining the complex stratigraphy in both the North and the South Pit, and the processes involved, is water. Alluvial fans spilling down from the Muschelkalk massif of the Elm form a key element in the Middle Pleistocene stratigraphy and environment in the Schöningen valley. The channels, eroded by powerful but short-lived flood events, cut through the alluvial fans and along the valley floor at the distal margins of the alluvial fans. These processes took place most strongly during the period following the deglaciation of the Elsterian ice, creating ponded basins where Holsteinian interglacial (MIS 11) deposits could accumulate. Similar marginal channels formed, enabling the preservation of organic interglacial and interstadial deposits during the subsequent Reinsdorf and Schöningen/Dömnitz periods (MIS 9 and 7). However, these channels became narrow lakes, and the valley likely drained via a river or stream on its eastern side. During the intervening periglacial stages with no substantial water movement and widespread permafrost, there was little deposition other than thin loess beds, which were often subsequently eroded.

The combined stratigraphical data from the North and South Pits indicate that three successive interglacials occur between the Elsterian and the Saalian (Drenthe 1) glacial deposits, which are identified as the Holsteinian Interglacial, the Reinsdorf Interglacial, and the Schöningen Interglacial. For a summary of events in the Schöningen valley between the Elsterian glacial stage and the Holocene see SI Table 1 in the Supplementary Material. The vegetation sequence of the Reinsdorf Interglacial is distinctive and markedly different from that of the Holsteinian Interglacial and differs from stratigraphically younger warm periods, such as Dömnitz or the related Wacken, and the Schöningen Interglacial. The three successive interglacials are correlated with Marine Isotope Stages 11c, 9e, and 7e, respectively, a correlation supported by mammalian biostratigraphical data (Figs. 14 and 15).

The rich fossil mammalian record from the Reinsdorf sequence reveals a fauna that includes early Middle Pleistocene relicts, which are absent in late Middle Pleistocene faunas assigned to MIS 7. This finding is supported by another, independent age indicator—the evolutionary stage of the water vole (*Arvicola*) remains. *Arvicola* molars are abundantly found in the Reinsdorf Channel faunas and are well preserved. They display an evolutionary stage indicating that the Reinsdorf fossil assemblage postdates the small mammal assemblages from MIS 11 sites (such as Barnham and Beeches Pit) and predates late Middle Pleistocene

faunas from sites attributed to MIS 7, like Weimar-Ehringsdorf and Maastricht-Belvédère (van Kolfschoten, 2014a).

The data summarised and discussed in this paper convincingly indicate that the Holsteinian and the Reinsdorf warm phases should not be classified as a single interglacial (the Holsteinian) as suggested by e.g. Bittmann (2012) and Lang et al. (2015a), but rather that they are two distinct interglacials separated stratigraphically by a significant cold episode. We also reject the proposed correlation between the Reinsdorf Interglacial and MIS 7e, recently published by Van Beirendock and Verbruggen (2025) and by Hutson et al. (2025). Their argumentation is weak and/or incorrect.

The Middle Pleistocene deposits at Schöningen, discussed in this paper, are unique in central and western Europe for their formation, preservation, and the timespan they cover. The Reinsdorf Channel deposits, in particular, have been investigated in great detail, and most of the collected data have been published. The deposits date from a period that is poorly known; therefore, the Schöningen sequence serves as a key reference point for late Middle Pleistocene stratigraphical research.

CRedit authorship contribution statement

Charles Turner: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Brigitte Urban:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Thijs van Kolfschoten:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quaint.2026.110257>.

References

- Altamura, F., Lehmann, J., Rodríguez-Álvarez, B., Urban, B., van Kolfschoten, T., Verheijen, I., Conard, N.J., Serangeli, J., 2023. Fossil footprints at the final lower Palaeolithic site of Schöningen (Germany): a new line of research to reconstruct palaeoenvironments, biological presences and hominin behaviour. *Quat. Sci. Rev.* <https://doi.org/10.1016/j.quascirev.2023.108094>.
- Altermann, G., Mania, D., 2007. Gliederung und Ablauf der Klimazyklen von Schöningen. In: Thieme, H. (Ed.), *Die Schöninger Speere - Mensch und Jagd vor 400 Jahren*. Theiss Verlag, Stuttgart, pp. 58–59.
- Behre, K.-E. (Ed.), 2012. *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen*. Verlag des Römisch-Germanischen, Zentralmuseums, Mainz.
- Behre, K.E., van der Knaap, W.O., 2023. Pleistocene history of vegetation and flora. In: Lang, G., Ammann, B., Behre, K.-E., Tinner, W. (Eds.), *Quaternary Vegetation Dynamics of Europe*. Haupt, Bern, 73–134.
- Benda, L., Brandes, H., 1974. Die Kieselgur-Lagerstätten Niedersachsens I. Verbreitung, Alter und Genese. *Geol. Jahrbuch, Rh.A.* 21, 3–85.
- Bigga, G., 2018. In: *Die Pflanzen von Schöningen. Botanische Makroreste aus den mitteleuropäischen Ablagerungen und das Nutzungspotential einer interglazialen paläoflora*. Forschungen zur Urgeschichte im Tagebau von Schöningen, Band 3. Verlag des Römisch-Germanischen, Zentralmuseums, Mainz, pp. 1–304.
- Bińka, K., Nitychoruk, J., 1995. Mazovian (Holsteinian) lake sediments at Woskrzeniec near Biała Podlaska. *Geol. Q.* 39, 109–120.
- Bińka, K., Szymanek, M., Nitychoruk, J., 2023. Climate and vegetation changes recorded in the post Holsteinian lake deposits at Ossówka (eastern Poland). *Acta Geol. Pol.* 73 (3), 341–354.
- Bittmann, F., 2012. Die Schöninger Pollendiagramme und ihre Stellung im mitteleuropäischen Mittelpleistozän. In: *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Forschungen zur Urgeschichte aus dem Tagebau von Schöningen, Band 1*. Verlag des Römisch-Germanischen, Zentralmuseums, Mainz, pp. 97–112.
- Bittmann, F., Börner, A., Doppler, G., Ellwanger, D., Hoselmann, C., Katzschnmann, L., Sprafke, T., Strahl, J., Wansa, S., Wielandt-Schuster, U., Subkommission Quartär (SKQ) der Deutschen Stratigraphischen Kommission (DSK), 2018. Das Quartär in der Stratigraphischen Tabelle von Deutschland 2016/The Quaternary in the Stratigraphic Table of Germany 2016. *Z. Dt. Ges. Geowiss.* 169, 295–306.
- Böhme, G., 2007. Fisch-, Amphibien- und Reptilien-Reste aus der Schichtenfolge des Reinsdorf-Interglazials von Schöningen. In: Thieme, H. (Ed.), *Die Schöninger Speere; Mensch und Jagd vor 400.000 Jahren*. Theiss Verlag, Stuttgart, pp. 105–111.
- Böhme, G., 2015. *Fische, Amphibien und Reptilien aus dem Mittelpleistozän (Reinsdorf-Interglazial) von Schöningen (II) bei Helmstedt (Niedersachsen)*. In: Terberger, T., Winghart, S. (Eds.), *Die Geologie der paläolithischen Fundstellen von Schöningen. Forschungen zur Urgeschichte im Tagebau von Schöningen, Band 2*. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 203–265.
- Brandes, C., Pollok, L., Schmidt, C., Wilde, V., Winsemann, J., 2012. Basin modelling of a lignite-bearing salt rim syncline: insights into rim syncline evolution and salt diapirism in NW Germany. *Basin Res.* 24, 699–716.
- Bridgland, D.R., 1994. *Quaternary of the Thames*. Springer, Dordrecht.
- Candy, I., Oliveira, D., Parkes, D., Sherriff, J., Thornalley, D., 2025. Marine Isotope Stage 11c in Europe: recent advances in marine–terrestrial correlations and their implications for interglacial stratigraphy—a review. *Boreas*. <https://doi.org/10.1111/bor.12656>. ISSN0300-9483.
- Conard, N.J., Miller, C.E., Serangeli, J., van Kolfschoten, T. (Eds.), 2015a. Excavations at Schöningen: New Insights into Middle Pleistocene Lifeways in Northern Europe. *J. Hum. Evol.* 89.
- Conard, N.J., Serangeli, J., Böhner, U., Starkovich, B.M., Miller, C.E., Urban, B., van Kolfschoten, T., 2015b. Excavations at Schöningen and paradigm shifts in human evolution. *J. Hum. Evol.* 89, 1–17.
- Czaja, A., 2012. Two new floral elements of steppe vegetation from the Pleistocene of Europe. *Feddes Repert.* 123, 233–241.
- Desprat, S., Sanchez-Goni, M.F., 2020. MIS 9 pollen records from sediment core MD03-2697, Northwest Iberian Margin. *PANGAEA*. <https://doi.org/10.1594/PANGAEA.916124>.
- Desprat, S., Sanchez-Goni, M.F., McManus, J., Duprat, J., Cortijo, E., 2009. Millennial-scale climatic variability between 340 000 and 270 000 years ago in SW Europe: evidence from a NW Iberian margin pollen sequence. *Clim. Past* 5, 53–72.
- Elsner, H., 1987. *Das Quartär Im Tagebau Schöningen Der Braunschweigischen Kohlenbergwerke AG, Helmstedt*. Leibniz University, Hannover. Unpublished diploma thesis.
- Erd, K., 1970. Pollen-analytical classification of the Middle Pleistocene in the German Democratic Republic. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 8, 129–145.
- Erd, K., 1973a. Vegetationsentwicklung und Biostratigraphie der Dömnitz-Warmzeit (Fuhne/Saale 1) im Profil von Pritzwalk/Prignitz. *Abh. Zentr. Geol. Inst.* 18, 9–48.
- Erd, K., 1973b. Pollenanalytische Gliederung des Pleistozäns der Deutschen Demokratischen Republik. *Z. Geol. Wiss.* 1, 1087–1103.
- Erd, K., 1978. Pollenstratigraphie im Gebiet der skandinavischen Vereisungen. *Schriftenr. Geol. Wiss.* 9 (S), 99–119.
- Erd, K., 1994. Palynologische Aussagen zum Holstein und Saale-Komplex im Gebiet des Tagebaus Jänschwalde. *Brandenburgische Geowiss* 1 (1), 36–42.
- Erd, K., Plame, H., Präger, J., 1987. Holsteininterglaziale Ablagerungen von Rossendorf bei Dresden. *Z. Geol. Wiss.* 15, 281–295.
- Geyh, M.A., Krbetschek, M.R., 2012. Zum Radiometrischen Alter des Holstein-Interglazials. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen. Forschungen zur Urgeschichte aus dem Tagebau von Schöningen, Band 1*. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 155–170.

- Geyh, M.A., Müller, H., 2005. Numerical $^{230}\text{Th}/^{232}\text{U}$ dating and a palynological review of the Holsteinian/Hoxnian interglacial. *Quat. Sci. Rev.* 24, 1861–1872.
- Geyh, M.A., Müller, H., 2007. Palynological and geochronological study of the Holsteinian/Hoxnian/Landos interglacial. In: Sirocko, F., Clausen, M., Sánchez Goñi, M.F., Litt, T. (Eds.), *Developments in Quaternary Sciences* 7, 387–396.
- Hartmann, T., 1988. Elster- Bis Saale-zeitliche Sedimente Im Tagebau Schöningen Der Braunschweigischen Kohlen-Bergwerke AG, Helmstedt. Leibniz University, Hannover. Unpublished diploma thesis.
- Heijnis, H., 1992. Uranium/Thorium Dating of Late Pleistocene Peat Deposits in N.W. Europe. PhD Thesis. Rijksuniversiteit Groningen.
- Heijnis, H., Urban, B., 1995. $^{230}\text{Th}/^{234}\text{U}$ dating of the Middle and Late Pleistocene organic deposits from the Schöningen/Helmstedt area, Lower Saxony, Germany. In: *Schriften Der Alfred-Wegener-Stiftung*, 2/95. INQUA, XIV Congress, Berlin, p. 109.
- Heinrich, W.-D., 1978. Zur biometrischen Erfassung eines Evolutionstrends bei *Arvicola* (Rodentia, Mammalia) aus dem Pleistozän Thüringens. *Säugetierkundliche Informationen* 2, 3–21.
- Heinrich, W.-D., 1987. Neue Ergebnisse zur Evolution und Biostratigraphie von *Arvicola* (Rodentia, Mammalia) im Quartär Europas. *Z. Geol. Wiss.* 15, 389–406.
- Hryniewicz, A., Winter, H., 2016. Paleoclimatic changes in the Holsteinian Interglacial (Middle Pleistocene) on the basis of indicator-species method – palynological and macrofossil remains from Nowiny Żukowskie site (SE Poland). *Quat. Int.* 409 (B), 255–269.
- Hutson, J.M., Bittmann, F., Fischer, P., García-Moreno, A., Gaudzinski-Windheuser, S., Nelson, E., Ortiz, J.E., Penkman, K.E.H., Perić, Z.M., Richter, D., Torres, T., Turner, E., Villaluenga, A., White, D., Joris, O., 2025. Revised age for Schöningen hunting spears indicates intensification of Neanderthal cooperative behavior around 200,000 years ago. *Sci. Adv.* 11. <https://doi.org/10.1126/sciadv.adv0752> eadv0752.
- Jechorek, H., 2000. Die fossile Flora des Reinsdorf Interglazials. Paläokarpologische Untersuchungen an mittelpleistozänen Ablagerungen im Braunkohlentagebau Schöningen. *Prähistoria Thuringica* 4, 7–17.
- Jerz, H., Linke, G., 1987. Arbeitsergebnisse der Subkommission für Europäische Quartärstratigraphie: typusregion des Holstein-Interglazials (Berichte der SEQS 8). *Eiszeit. Gegenw.* 37, 145–148.
- Juggins, S., 2007. C2. Version 1.5 User Guide. Software for Ecological and Palaeoecological Data Analysis and Visualisation, Newcastle upon Tyne (User Guide Version 1.5).
- Kleinmann, A., Müller, H., Lepper, J., Waas, D., 2011. Nachtigall: a continental sediment and pollen sequence of the Saalian Complex in NW-Germany and its relationship to the MIS-framework. *Quat. Int.* 241, 97–110.
- Koutsodendris, A., Müller, U.C., Pross, J., Brauer, A., Kotthoff, U., Lotter, A.F., 2010. Vegetation dynamics and climate variability during the Holsteinian interglacial based on a pollen record from Dethlingen (northern Germany). *Quat. Sci. Rev.* 29, 3298–3307.
- Koutsodendris, A., Pross, J., Müller, U.C., Brauer, A., Fletcher, W.J., Kühl, N., Kirilova, E., Verhagen, F.T.M., Lücke, A., Lotter, A.F., Koutsodendris, A., 2012. A short-term climate oscillation during the Holsteinian interglacial (MIS 11c): an analogy to the 8.2 ka climatic event? *Global Planet. Change* 92–93, 224–235.
- Krahn, K.J., Tucci, M., Urban, B., Pilgrim, J., Frenzel, P., Soulié-Märsche, I., Schwalb, A., 2021. Aquatic and terrestrial proxy evidence for Middle Pleistocene palaeolake and lake-shore development at two Lower Palaeolithic sites of Schöningen, Germany. *Boreas* 50, 723–745.
- Krahn, K.J., Urban, B., Pinkerneil, S., Horne, D.J., Tucci, M., Koutsodendris, A., Schwalb, A., 2024. Temperature and palaeolake evolution during a Middle Pleistocene interglacial–glacial transition at the Palaeolithic locality of Schöningen, Germany. *Boreas*. <https://doi.org/10.1111/bor.12670>. ISSN0300-9483.
- Krbetschek, M., Stephan, H.-J., 2010. Dating of sediments (Infrared-Radiofluorescence method IR-RF) at the type locality of the Wacken peat [Kurzfassung und Poster]. DEUQUA 2010, Tagungsunterlagen/Conference Proceedings, pp. 117–118. Greifswald (Inst. f. Geografie u. Geologie, Universität Greifswald).
- Kuitens, M., Plicht, J. van der, Drücker, D., van Kolfschoten, T., Palstra, S.W.L., Bocherens, H., 2015. Carbon and nitrogen stable isotopes of well-preserved Middle Pleistocene bone collagen from Schöningen (Germany) and their palaeoecological implications. *J. Hum. Evol.* 89, 105–113.
- Kunz, A., Urban, B., Tsukamoto, S., 2017. Chronological investigations of Pleistocene interglacial, glacial and Aeolian deposits from Schöningen (Germany) using post-IR IRSF dating and pollen analysis. *Z. Dtsch. Ges. Geowiss.* 168 (1), 81–104.
- Lang, J., Winsemann, J., 2012. The 12II outcrop section at Schöningen: sedimentary facies and depositional architecture. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Forschungen zur Urgeschichte aus dem Tagebau von Schöningen, Band 1. Verlag des Römisch-Germanischen Zentralmuseums, Mainz*, pp. 39–59.
- Lang, J., Winsemann, J., Steinmetz, D., Polom, U., Pollok, U., Böhner, U., Serangeli, J., Brandes, C., Hampel, A., Winghart, S., 2012. The Pleistocene of Schöningen, Germany: a complex tunnel valley fill revealed from 3D subsurface modelling and shear wave seismics. *Quat. Sci. Rev.* 39, 86–105.
- Lang, J., Böhner, U., Polom, U., Serangeli, J., Winsemann, J., 2015a. The Middle Pleistocene tunnel valley at Schöningen as a Palaeolithic archive. *J. Hum. Evol.* 89, 18–26.
- Lang, J., Böhner, U., Brandes, C., Hampel, A., Polom, U., Serangeli, J., Steinmetz, D., Winghart, S., Winsemann, J., 2015b. Die geologische Entwicklung der Randsenke von Schöningen: Implikationen für Landschaftsentwicklung und Archäologie. In: Terberger, T., Winghart, S. (Eds.), *Die Geologie Der Paläolithischen Fundstellen Von Schöningen. Forschungen Zur Urgeschichte Im Tagebau Von Schöningen 2. Verlag des Römisch-Germanischen Zentralmuseums, Mainz*, pp. 191–202.
- Lauer, T., Weiss, M., 2018. Timing of the Saalian and Elsterian glacial cycles and the implications for Middle Pleistocene hominin presence in central Europe. *Sci. Rep.* 8, 5111.
- Lenhard, R., 1989. Schichtlagerung Und Zusammensetzung Elster- Bis Saale-zeitlicher Sedimente Im Baufeld Esbeck, Tagebau Schöningen, Der Braunschweigischen Kohlen-Bergwerke AG, Helmstedt. Leibniz University, Hannover. Unpublished diploma thesis.
- Linke, G., Hallik, R., 1993. Die pollenanalytischen Ergebnisse der Bohrungen Hamburg-Dockenhuden (qho 4), Wedel (qho 2) und Hamburg-Billbrock. *Geol. Jahrb.* A138, 169–184.
- Lisiecki, L.E., Raymo, M.E., E, M., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}\text{O}$ records. *Paleoceanography* 20. <https://doi.org/10.1029/2004PA001071>. PA1003.
- Litt, T., Behre, K.-E., Meyer, K.-D., Stephan, H.-J., Wansa, S., 2007. In: Litt, T. (Ed.), *Quartär. Eiszeitalter und Gegenwart, Quaternary Science Journal*, 56, pp. 7–65 (1/2).
- Mania, D., 1995. Die geologischen Verhältnisse im Gebiet von Schöningen. In: Thieme, H., Maier, R. (Eds.), *Archäologische Ausgrabungen Im Braunkohlentagebau Schöningen, Landkreis Helmstedt. Hahnsche Buchhandlung, Hannover*, pp. 33–43.
- Mania, D., 1998. Zum Ablauf der Klimazyklen seit der Elstervereisung im Elbe-Saalegebiet. *Prähistoria Thuringica* 2, 5–21.
- Mania, D., 2009. Die Stratigraphie Des Mittel- Und Jungquartärs Im Harzvorland Und Saalegebiet, p. 104. *Prähistoria Thuringica, Sonderheft 2009*, Jena.
- Mania, D., 2022. Das Mittel- und Jungpleistozän im Harzvorland und Saalegebiet. Veröffentlichungen des Landesamtes für Archäologie Sachsen-Anhalt 90, 272.
- Mania, D., 2026. Die Molluskenfauna aus dem Mittel- und Jungquartär von Schöningen im Harzvorland. *Forschungen Zur Urgeschichte Im Tagebau Von Schöningen, Verlag des Römisch-Germanischen Zentralmuseums, Mainz*. (in press).
- Mania, D., Altermann, M., 2015. Das Quartär von Schöningen im nördlichen Harzvorland. In: Terberger, T., Winghart, S. (Eds.), *Die Geologie Der Paläolithischen Fundstellen Von Schöningen. Forschungen zur Urgeschichte Im Tagebau von Schöningen, Band 2. Verlag des Römisch-Germanischen Zentralmuseums, Mainz*, pp. 1–190.
- Maul, L.C., Masini, F., Parfitt, S.A., Rekovets, L., Savorelli, A., 2014. Evolutionary trends in arvicolid and the endemic murid *Mikrotia* – new data and a critical overview. *Quat. Sci. Rev.* 96, 240–258. <https://doi.org/10.1016/j.quascirev.2013.09.017>.
- Menke, B., 1968. Beiträge zur Biostratigraphie des Mittelpleistozäns in Norddeutschland. *Meyniana* 18, 35–42.
- Menke, B., 1980. Wacken, Elsterian-glacial, marine Holsteinian – interglacial and wacken-warm-stage. In: Stremme, H.E., Menke, B. (Eds.), *Quartär-Exkursionen/Quaternary Excursions in Schleswig-Holstein*, pp. 19–27.
- Menke, B., 1984. Das Mittelpleistozän im Raum Wacken. In: Degens, E.T., Hillmer, G., Spaeth, C.Hrsg (Eds.), *Exkursionsführer Erdgeschichte Des Nord- Und Ostseeraumes*, pp. 467–481.
- Meyer, K.-D., 2012. Stratigraphie des Saale-Komplexes in Niedersachsen und die Schöninger Profile. In: Behre, K.-E. (Ed.), *The Chronological Setting of the Palaeolithic Sites of Schöningen. Forschungen Zur Urgeschichte Im Tagebau Von Schöningen, Band 1. Verlag des Römisch-Germanischen Zentralmuseums, Mainz*, pp. 61–76.
- Meyer, K.-J., 1974. Pollenanalytische Untersuchungen und Jahresschichtenzählungen an der Holstein-zeitlichen Kieselgu von Hetendorf. *Geologisches Jahrbuch A* 21, 87–105.
- Miller, G.H., Magee, J.W., Johnson, B.J., Fogel, M.L., Spooner, N.A., McCulloch, M.T., Ayliffe, L.K., 1999. Pleistocene extinction of *Genyornis newtoni*: human impact on Australian megafauna. *Science* 283, 205–220.
- Mitterer, R.M., 1975. Ages and diagenetic temperatures of Pleistocene deposits of Florida based on isoleucine epimerization in Mercenaria. *Earth Planet. Sci. Lett.* 28, 275–282.
- Müller, H., 1974. Pollenanalytische Untersuchungen und Jahresschichtenzählungen an der holstein-zeitlichen Kieselgur von Munster-Breloh. *Geologisches Jahrbuch A* 21, 107–140.
- Nelson, E., White, D., Wheeler, L., Wedel, J., Hoselmann, C., Heggemann, H., Rähle, W., Penkman, K., 2025a. An aminostratigraphy of the northern Upper Rhine Graben, Germany. *J. Quat. Sci.* <https://doi.org/10.1002/jqs.70004>.
- Nelson, E., White, D., Wheeler, L., Meng, S., Szymanek, M., Strahl, J., Hein, M., Alexandrowicz, W.P., Urban, B., Greeves, S., Stahlschmidt, M., Kahlke, R.-D., Lauer, T., Tanner, D.C., Penkman, K.E.H., 2025b. Quaternary aminostratigraphies for the eastern North European Plain. [version 1; peer review: 2 approved]. *Open Res Europe* 5, 396. <https://doi.org/10.12688/openreseurope.21815.1>, 2025.
- Nitychoruk, J., Bińka, K., Sienkiewicz, E., Szymanek, M., Chodyka, M., Makos, M., Ruppert, H., Tudryn, A., 2018. A multiproxy record of the Younger Holsteinian Oscillation (YHO) in the Ossówka profile, eastern Poland. *Boreas* 47, 855–868. <https://doi.org/10.1111/bor.12308>. ISSN0300-9483.
- Parfitt, S., 1998. The interglacial mammalian fauna from Barnham. In: Ashton, N., Lewis, S., Parfitt, S.A. (Eds.), *Excavations at the Lower Palaeolithic Site at East Farm, Barnham, Suffolk, 1989e94*, 125. Occasional Paper of the British Museum, pp. 111–147.
- Preece, R.C., Parfitt, S.A., Bridgland, D.R., Lewis, S.G., Rowe, P.J., Atkinson, T.C., Candy, I., Debenham, N.C., Penkman, K.E.H., Rhodes, E.J., Schwenninger, J.-L., Griffiths, H.I., Whittaker, J.E., Gleed-Owen, C., 2007. Terrestrial environments during MIS 11: evidence from the Palaeolithic site at West Stow, Suffolk, UK. *Quat. Sci. Rev.* 26, 1236–1300.
- Railsback, B., Gibbard, P.L., Head, M.J., Voarintsoa, Ny Riavo G., Toucanne, S., 2015. An optimized scheme of lettered marine isotope substages for the last 1.0 million years, and the climatostratigraphic nature of isotope stages and substages. *Quat. Sci. Rev.* 111, 94–106.

- Reille, M., de Beaulieu, J.-L., Svobodova, V., Andrieu-Ponel, V., Goeury, C., 2000. Pollen analytical biostratigraphy of the last five climatic cycles from a long continental sequence from the Velay region (Massif Central, France). *J. Quat. Sci.* 15, 665–685.
- Richter, D., Thieme, H., 2012. One first chronometric date for the Lower Paleolithic occupation at Schöningen 13 I. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Forschungen zur Urgeschichte aus dem Tagebau von Schöningen*, Band 1. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 125–128.
- Richter, D., Krbetschek, M., 2015. The age of the Lower Palaeolithic occupation at Schöningen. *J. Hum. Evol.* 89, 46–56.
- Rigterink, S., Krahn, K.J., Kotrys, B., Urban, B., Heiri, O., Turner, F., Pannes, A., Schwalb, A., 2024. Summer temperatures from the Middle Pleistocene site Schöningen 13 II, northern Germany, determined from subfossil chironomid assemblages. *Boreas*. <https://doi.org/10.1111/bor.12658>. ISSN0300-9483.
- Schläfli, P., Gobet, E., Hogrefe, I., Bittmann, F., Schlunegger, F., Zolitschka, B., Tinner, W., 2023. New vegetation history reconstructions suggest a biostratigraphic assignment of the lowermost Rodderberg interglacial (Germany) to MIS 11. *Quat. Sci. Rev.* 302, 107932.
- Serangeli, J., Böhner, U., vanKolschoten, T., Conard, N.J., 2015a. Overview and new results from large-scale excavations in Schöningen. *J. Hum. Evol.* 89, 27–45.
- Serangeli, J., van Kolschoten, T., Starkovich, B., Verheijen, I., 2015b. The European Saber-toothed cat (*Homotherium latidens*) found in the "Spear Horizon" at Schöningen (Germany). *J. Hum. Evol.* 89, 172–180.
- Sierralta, M., Frechen, M., Urban, B., 2012. 230Th/U dating results from opencast mine Schöningen. 143–154. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Forschungen zur Urgeschichte aus dem Tagebau von Schöningen*, Band 1. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 125–128.
- Sierralta, M., Urban, B., Linke, G., Frechen, M., 2017. Middle Pleistocene interglacial peat deposits from Northern Germany investigated by 230Th/U and palynology: case studies from Wedel and Schöningen. In: *Zeitschrift Der Deutschen Geowissenschaftlichen Gesellschaft ZDGG*, vol. 168, pp. 373–387, 3.
- Środoń, A., 1955. *Pterocarya c. f. fraxinifolia* spach. in the Polish Pleistocene. *Act Societatis Botanicorum Poloniae* 24, 635–637.
- Stebich, M., Höfer, D., Mingram, J., Nowaczyk, N., Rohrmüller, J., Mrlina, J., Kämpf, H., 2020. A contribution towards the palynostratigraphical classification of the Middle Pleistocene in Central Europe: the pollen record of the Neulbenreuth Maar, northeastern Bavaria (Germany). *Quat. Sci. Rev.* 250, 106681.
- Stephan, H.-J., 2014. Climato-stratigraphic subdivision of the Pleistocene in Schleswig-Holstein, Germany and adjoining areas. *E&G Quaternary Science Journal* 63 (1), 3–18. <https://doi.org/10.3285/eg.63.1.01>.
- Stephan, H.-J., Urban, B., Lüttig, G., Menke, B., Sierralta, M., 2011. Palynologische, petrographische und geochronologische Untersuchungen an Ablagerungen der Leck-Warmzeit (spätes Mittelpleistozän) und begleitender Sedimente. *Geol. Jahrb.* 160, 3–80.
- Strahl, J., 2019. Ergebnisse palynologischer Untersuchungen an der Forschungsbohrung Ummendorf 1/2012 und Vergleich mit anderen pollenstratigraphischen Untersuchungen im oberen Allertal. In: Wansa, S., Strahl, J., Rappsilber, I. (Eds.), *Zur Geologie Des Ummendorfer Kessels Im Oberen Allertal*, pp. 41–92. Mitteilungen zu Geologie und Bergwesen von Sachsen-Anhalt, Band 20: Forschungsbohrung Ummendorf 1/2012.
- Strahl, J., 2023. Revision of the palynostratigraphic divisions of the Holsteinian and the Lower Saalian of Berlin and Brandenburg. *Brandenburg. Geowiss. Beitr.* 30, 7–37.
- Strahl, J., Wansa, S., 2019. Stratigraphische Interpretation der Forschungsbohrung Ummendorf 1/2012 im Kontext mit anderen relevanten Profilen in Deutschland. *Mitteilungen zu Geologie und Bergwesen von Sachsen-Anhalt* 20, 117–138. Halle.
- Terberger, T., Winghart, S. (Eds.), 2015. *Die Geologie der paläolithischen Fundstellen von Schöningen, Forschungen zur Urgeschichte im Tagebau von Schöningen*, Band 2. Verlag des Römisch-Germanischen Zentralmuseums, Mainz.
- Thieme, H., 1995a. Die altpaläolithischen Fundplatz Schöninge 13 I (Holstein-Interglazial). In: Thieme, H., Maier, R. (Eds.), *Archäologische Ausgrabungen Im Braunkohlentagebau Schöningen, Landkreis Helmstedt. Verlag Hahnsche Buchhandlung, Hannover*, pp. 57–61.
- Thieme, H., 1995b. Die altpaläolithischen Fundschichten Schöningen 12 (Reinsdorf-Interglazial). In: Thieme, H., Maier, R. (Eds.), *Archäologische Ausgrabungen Im Braunkohlentagebau Schöningen, Landkreis Helmstedt. Verlag Hahnsche Buchhandlung, Hannover*, pp. 62–72.
- Thieme, H., 1997. Lower Paleolithic hunting spears from Germany. *Nature* 385, 807–810.
- Thieme, H. (Ed.), 2007. *Die Schöninger Speere: Mensch Und Jagd Vor 400.000 Jahren*. Theiss Verlag, Stuttgart.
- Thieme, H., Maier, R. (Eds.), 1995. *Archäologische Ausgrabungen Im Braunkohlentagebau Schöningen, Landkreis Helmstedt. Verlag Hahnsche Buchhandlung, Hannover*.
- Thieme, H., Mania, D., 1993. »Schöningen 12« - ein mittelpaleozänes Interglazialvorkommen im Nordharzvorland mit paläolithischen Funden. *Ethnogr. Archaeol. Z.* 34, 610–619.
- Thieme, H., Maier, R., Urban, B., 1987. Archäologische Schwerpunktuntersuchungen im Helmstedter Braunkohlerevier (ASHB). In: *Zum Stand Der Arbeiten 1983–1986. Archäologisches Korrespondenzblatt*, 17, pp. 445–462.
- Thieme, H., Maier, R., Urban, B., 1992. Neue Erkenntnisse zum urgeschichtlichen Siedlungsgeschehen. *Archaeol. Deutschl.* 2, 26–30.
- Thieme, H., Mania, D., Urban, B., van Kolschoten, T., 1993. Schöningen (Nordharzvorland) eine altpaläolithische Fundstelle aus dem mittleren Eiseitalter. *Archaeol. Korresp.* 23, 147–163.
- Toucanne, S., Zaragosi, S., Bourillet, J.F., Cremer, M., Eynaud, F., Van Vliet-Lanoë, B., Penaud, A., Fontanier, C., Turon, J.L., Cortijo, E., Gibbard, P.L., 2009. Timing of massive 'Fleuve Manche' discharges over the last 350kyr: insights into the European ice-sheet oscillations and the European drainage network from MIS 10 to 2. *Quat. Sci. Rev.* 28 (13–14), 1238–1256. <https://doi.org/10.1016/j.quascirev.2009.01.006>. ISSN 0277-3791.
- Tschehe, W., 1991. Die pleistozäne Schichtfolge im Tagebau Schöningen Baufeld Esbeck der Braunschweigischen Kohlen-Bergwerke AG, Helmstedt. Universität Hannover unpublished diploma thesis.
- Tucci, M., Krahn, K.J., Richter, D., van Kolschoten, T., Rodríguez Álvarez, B., Verheijen, I., Serangeli, J., Lehmann, J., Degering, D., Schwalb, A., Urban, B., 2021. Evidence for the age and timing of environmental change associated with a Lower Palaeolithic site within the Middle Pleistocene Reinsdorf sequence of the Schöningen coal mine, Germany. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 569, 110309.
- Turner, C., 1970. The middle Pleistocene deposits at marks Tey, Essex. *Philosophical Transactions of the Royal Society of London, Serie B, Biological Sciences* 257, 373–437.
- Urban, B., 1995. Palynological evidence of younger Middle Pleistocene Interglacials (Holsteinian, Reinsdorf, Schöningen) in the Schöningen open cast lignite mine (eastern Lower Saxony/Germany). *Meded. Rijks Geol. Dienst* 52, 175–186.
- Urban, B., 1996. Mittelpleistozäne Waldzeiten im Tagebau Schöningen: Spektren aus dem Holstein-Interglazial und dem Harbe-Interstadial in: spuren der Jagd - die Jagd nach Spuren. *Tübinger Monographien zur Urgeschichte* 11, 487–495.
- Urban, B., 1997. Grundzüge der eiszeitlichen Klima- und Vegetationsgeschichte in Mitteleuropa. In: Wagner, G.A., Beinhauer, K.W. (Eds.), *Homo Heidelbergensis Von Mauer – Das Auftreten Des Menschen in Mitteleuropa*. Universitätsverlag C. Winter, Heidelberg, pp. 241–265.
- Urban, B., 2007. Interglacial pollen records from Schöningen, north Germany. In: Sirocko, F., Claussen, M., Sanchez Goñi, M.F., Litt, T. (Eds.), *The Climate of past Interglacials*. Elsevier, Amsterdam, pp. 417–444.
- Urban, B., Thieme, H., Elsner, H., 1988. Biostratigraphische, quartärgeologische und urgeschichtliche Befunde aus dem Tagebau "Schöningen". *Landkrs. Helmstedt. Zeitschrift der deutschen geologischen. Gesellschaft* 139, 123–154.
- Urban, B., Elsner, H., Hölzer, A., Mania, D., Albrecht, B., 1991a. Eine eem- und frühweichselzeitliche Abfolge im Tagebau Schöningen, Landkreis Helmstedt. *Eiszeitalt. Ggw.* 41, 85–99.
- Urban, B., Lenhard, R., Mania, D., Albrecht, B., 1991b. Mittelpleistozän im Tagebau Schöningen, Ldkrs. Helmstedt. *Z. Dtsch. Geol. Ges.* 142, 351–372.
- Urban, B., Bigga, G., 2015. Environmental reconstruction and biostratigraphy of late Middle Pleistocene lakeshore deposits at Schöningen. *J. Hum. Evol.* 89, 57–70.
- Urban, B., Sierralta, M., 2012. New palynological evidence and correlation of Early Palaeolithic sites Schöningen 12 B and 13 II, Schöningen open lignite mine. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundplätze von Schöningen, Forschungen zur Urgeschichte aus dem Tagebau von Schöningen*, Band 1. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 77–96.
- Urban, B., Kasper, T., Krahn, K.J., van Kolschoten, T., Rech, B., Holzheu, M., Tucci, M., Schwalb, A., 2023. Landscape dynamics and chronological refinement of the Middle Pleistocene Reinsdorf Sequence of Schöningen, NW Germany. *Quat. Res.* 114, 148–177.
- Van Beirendonck, F., Verbruggen, C., 2025. Late Middle Pleistocene palynostratigraphy and landscape evolution in Western and Central Europe: will the real holsteinian please stand up? *Rev. Palaeobot. Palynol.* 337. <https://doi.org/10.1016/j.revpalbo.2025.105319>.
- van Gijssel, K., 2006. In: A continent-wide framework for local and regional stratigraphies: application of genetic sequence and event stratigraphy to the Middle Pleistocene terrestrial succession of Northwest and Central Europe. Unpubl. Leiden University. <https://hdl.handle.net/1887/4985>.
- van Kolschoten, T., 1990. The evolution of the mammal fauna in the Netherlands and the middle Rhine area (Western Germany) during the late middle Pleistocene. *Meded. Rijks Geol. Dienst* 43–3, 1–69.
- van Kolschoten, T., 2012. The Schöningen mammalian fauna in biostratigraphic perspective. In: *Forschungen zur Urgeschichte aus dem Tagebau von Schöningen*, Band 1. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 113–124.
- van Kolschoten, T., 2014a. The Palaeolithic locality Schöningen (Germany): a review of the mammalian record. *Quat. Int.* 326–327, 469–480.
- van Kolschoten, T., 2014b. The smaller mammals from the Late Pleistocene sequence of the Sesselfelsgrötte (Neuessing, Lower Bavaria). In: Freund, G., Reisch, L. (Eds.), *Sesselfelsgrötte VI. Franz Steiner Verlag, Stuttgart*, pp. 27–119.
- van Kolschoten, T., 2025. The power of the water vole. In: Dusseldorp, G.L., Chu, W., Bakels, C., Soressi, M. (Eds.), *Intent on the Paleolithic. Papers in Honour of Prof. Dr. Wil Roebroeks.. Analecta Praehistorica Leidensia*, 55, pp. 137–146.
- van Kolschoten, T., Buhrs, E., Verheijen, I., 2015. The larger mammal fauna from the Lower Paleolithic Schöningen Spear site and its contribution to hominin subsistence. *J. Hum. Evol.* 89, 138–153.
- van Kolschoten, T., Konidaris, G.E., Doukas, C., Athanassiou, A., Tourloukis, V., Panagoulou, E., Karkanas, P., Harvati, K., 2025. Voles (Rodentia, Mammalia) as a proxy to date the site Kyparissia 4 (Megalopolis Basin, Greece). In: Harvati, K., Ioannidou, M. (Eds.), *Human Evolution at the Crossroads*, 3, pp. 197–206.
- Verheijen, I., Starkovich, B.M., Serangeli, J., Kolschoten, T., van, Conard, N.J., 2022. Early evidence for bear exploitation during MIS 9 from the site of Schöningen 12 (Germany). *J. Hum. Evol.* 177. <https://doi.org/10.1016/j.jhevol.2022.103294>.
- von Koenigswald, W., van Kolschoten, T., 1996. The *Mimomys-Arvicola* boundary and the enamel thickness quotient (SDQ) of *Arvicola* as stratigraphic markers in the Middle Pleistocene. In: Turner, C. (Ed.), *The Early Middle Pleistocene in Europe*, pp. 211–226.

- Wansa, S., Strahl, J., Rappsilber, I., 2019. Fazit der Untersuchungen im Ummendorfer Kessel. In: Wansa, S., Strahl, J., Rappsilber, I. (Eds.), Zur Geologie Des Ummendorfer Kessels Im Oberen Allertal. Mitteilungen Zu Geologie Und Bergwesen Von Sachsen-Anhalt, Band 20 - Forschungsbohrung Ummendorf 1/2012, pp. 201–204.
- Wansa, S., Strahl, J., Meng, S., 2022. Die Forschungsbohrung Martinsrieth – ein neues Profil für das jüngere Mittel- und das Oberpleistozän in der Helme-Niederung bei Sangerhausen (Sachsen-Anhalt). In: Brauer, A., Schwab, M.J. (Eds.), DEUQUA 2022 Conference: Connecting Geoarchives; Abstract Volume, (Scientific-TechnicalReportSTR; 22/02), DEUQUA 2022 – Connecting Geoarchives (Potsdam 2022), p. 143. <https://doi.org/10.48440/GFZ.b103-22024>, 2022.
- Wehmiller, J., Miller, G.H., 2000. Aminostratigraphic dating methods in Quaternary geology. In: Noller, J.S., Sowers, J.M., Lettis, W.R. (Eds.), Quaternary Geochronology: Methods and Applications. American Geophysical Union, Washington D.C, pp. 187–222.
- West, R.G., 1956. The Quaternary deposits at Hoxne, Suffolk. Phil. Trans. Roy. Soc. Lond. B 239, 265–356.