Beyond the trenches: a landscape-oriented chronostratigraphic approach to MIS 5 Middle Paleolithic open-air sites on the European Plain : case studies from Lichtenberg and Khotylevo I

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CHAPTER V: CONCLUSION

5.1 Outline of the thesis chapters II to IV

Chapter II: Luminescence chronology of the key-Middle Paleolithic site Khotylevo I (Western Russia) - Implications for the timing of occupation, site formation and landscape evolution

The Russian Plain has a rich record of open-air sites that are ascribed to the Middle Palaeolithic based on the type of lithic artifacts. Many of these sites are contained within the deposits of the 2nd fluvial terrace, which accompanies numerous Russian and Ukrainian rivers ca. 16-25 m above the current stream. The understanding of both, the Middle Palaeolithic occupations and the late Pleistocene fluvial history suffers from insufficient chronological information. For the 2nd terrace, only a handful of OSL dates exists while no open-air Neanderthal site on the Russian Plain had been dated so far. Therefore, establishing a chronology for either of these two components would be mutually beneficial for both areas of interest. The site of Khotylevo I, W-Russia (53.3° N, 34.1° E), is located at the base of the 2nd fluvial terrace fill at the River Desna. It was first discovered and excavated in the 1960s by F.M. Zavernyaev, who established several sections alongside the river (Zavernyaev, 1978). Khotylevo I attracted interest and attention in the archaeological community for its sheer size, northerly location, and its large and representative lithic artifact assemblage, associated with the Keilmessergruppen. Previous excavations in Khotylevo I were supported by stratigraphical and geological investigations by A.A. Velichko, which led to the temporal ascription of the site to the Early Valdai (Weichselian) period (Velichko, 1988). Renewed (geo)archaeological excavations were started by A.K. Otcherednoi in 2006, *inter alia* intended to refine the temporal resolution of the site (Otcherednoi and Voskresenskaya, 2009). This resulted in a revised chronology for the occupation. Newly-obtained results from radiocarbon dating and magnetostratigraphy suggested an MIS 3 age of the archaeological remains (Otcherednoi et al., 2014), which contradicts the previous stratigraphic assumption for MIS 5 made by Velichko. For that reason and for the lack of a chronostratigraphic framework for the 2nd fluvial terrace, which could potentially elucidate the "true" age of the occupation, a luminescence-based chronology became desirable. Thus, the present author and two colleagues (M. Weiß and T. Lauer) visited

Khotylevo I, section I-6-2 for the first time in 2017. The present author conducted a meticulous stratigraphic description of the whole profile and collected 17 samples for luminescence dating throughout the archaeological and the entire overlying sequence. Stratigraphic context was provided by several natural and artificial sediment exposures in the vicinity. Furthermore, on the luminescence sample material, grain sizes were determined using a laser diffractometer. Pollen samples, collected from the humic archaeological layers proved to be sterile, however.

Because of the high-resolution luminescence sampling design and the supporting stratigraphic and sedimentological information, we detected a full cycle of fluvial incision and aggradation within the 2nd fluvial terrace fills. Incision took place around the MIS 5c/5b transition in this part of the valley, evidenced by non-existent warm-stage deposits from MIS 5c and 5e. Instead, a huge hiatus to Cretaceous sediments follows below. After the incision, fluvial aggradation began slowly, so that in the distal areas of the floodplain, slope deposition and phases of humic soil formation dominated. This was the setting for the Neanderthal occupation, dated to MIS 5a. Contemporary humus accumulation implies high bioproductivity and thus a warmer interval. Availability and quality of raw material for lithic production was exceptional. It could be procured as tabular flints from slope sediments and outcrops of the primary Cretaceous deposits. Main fluvial aggradation started in MIS 4 and accelerated toward the MIS 4/3 transition. Firstly, laminated fluvio-lacustrine sediments were deposited, that are rich in reworked loess, as evidenced by their noticeable peaks or shoulders within the coarse-silt fraction of the grain size distributions (cf. Vandenberghe et al., 2018). Their deposition broadly coincides with major loess sedimentation in the region, for which Khotylevo is even the type locality (*Khotylevo loess*). Thereafter, about 3 meters of horizontally-bedded fine sands quickly aggraded around latest MIS 4. Finally, throughout MIS 3, fine-grained overbank deposition dominated, forming the uppermost part of the terrace fill. The age of an MIS 3 palaeosol (humic Fluvisol) which developed on top of these overbank fines could not be further constrained, as it is disconformably overlain by loess of the last glacial maximum. Hence, the incision/aggradation cycle of the 2nd fluvial terrace lasted from MIS 5c/b to (Mid-) MIS 3. While the posterior incision into this terrace fill could not be accounted for, it is known to have occurred between 45 and 35 ka (Panin et al., 2017).

With this first unambiguous luminescence-based chronostratigraphy for a Middle Palaeolithic site on the Russian Plain, we can add a valuable data point for the understanding of Neanderthal population dynamics in Northern and Eastern Europe. The numerical dates as well as the stratigraphic framework without contradiction support an MIS 5a age of the occupation in Khotylevo I-6-2. This provides evidence for the early presence of the Keilmessergruppen, prior to the onset of the Weichselian Pleniglacial. Our chronology further highlights the worth of the initial stratigraphic considerations by A.A. Velichko, ascribing the occupation to the early glacial.

Chapter III: Eemian landscape response to climatic shifts and evidence for northerly Neanderthal occupation at a palaeolake margin in Northern Germany

The Eemian Interglacial is generally considered a period of stable landscapes with prevailing pedogenesis and negligible sediment (re)deposition. However, there are hardly any systematic geomorphological studies addressing this issue. Most of the palaeoenvironmental information about the terrestrial interstadial comes from small-scale palaeolake basins, formed after the Saalian ice decay in association with the glacial deposits. Owing to their small diameters and relative shallowness, these landforms are of limited value for geomorphological research. Moreover, also data on past vegetation and palaeoclimate, retrieved from such archives could be called into question because local hydrographic conditions and the general shortage of accommodation space might bias or mislead the interpretations. On the doorstep of the Middle Palaeolithic site of Lichtenberg, N-Germany, previous geological investigations yielded evidence for an Eemian to Early Weichselian palaeolake of presumably larger extent (Veil et al., 1994). Building on this, a GIS-based geomorphological survey and seismic profiling were conducted, both revealing the suitability of the study area to decipher Eemian landscape dynamics. A subsequent expansive sediment coring campaign resulted in a borehole transect (n = 20) that exposed a complex infill sequence of a palaeolake basin. It comprises up to 15 m thick colluvial, lacustrine and organogenic deposits, likely formed between the late Saalian and the Middle Weichselian. For this study, we focused on the lower (i.e. Eemian) part of these infill deposits and applied palynological analysis on bulk samples (n = 25), dispersed across the transect, and luminescence dating on two samples in one core (PD.030). Regrettably, datable and well-bleached clastic sediments were scarce within the deeper segments of the transect. But since the subdivision of the Eemian is hinged on pollen zones anyway, numerical dates were not of primary importance for the actual research question. Our results further the understanding of interactions between sedimentation, hydrology and vegetation density in the Eemian Interglacial, since we obtained information on sediment dynamics and relative lake levels alike: Two pronounced phases of geomorphic activity have occurred at the beginning and toward the end of the Eemian in times of reduced vegetation cover, with a prolonged period of landscape stability in between. The intense incision of the first active phase can be restricted to the Saalian/Eemian transition and is likely linked to fluvial downcutting in the neighboring Elbe River valley. It formed a side valley, which hosted an elongated lake in due course. At first, clastic sedimentation was high but it decreased gradually towards the Mid-Eemian, parallel to the establishment of dense forests. From then on, stabilized slopes and temperate climate promoted soil formation in the exterior of the basin and also hindered surface flow into the lake. In combination with the higher evapotranspiration rates of the forests, this lack of influx led to a progressively sinking water table until the end of the Eemian. It also led to the total absence of clastic sedimentation within the lake basin for a period of ca. 6,000 years in the Mid-Eemian. Instead, organogenic deposits and lake marls can be found, the latter indicative of intense soil formation and decalcification of the Saalian sediments in the exterior. This must have led to subterranean carbonate influx and its precipitation at the lake bottom. At an early stage of this stability phase, we discovered a few diagnostic Middle Palaeolithic artifacts in repeated corings. They indicate a Neanderthal occupation on a semi-terrestrial (half-bog) soil at the lakeshore during Mid-Eemian pollen zone E IVb/V. In later phases of the Eemian, the lake had been reduced to a swampy depression, without drying out completely, and acidic forest peat covered the bottom of the basin. Geomorphic activity soon resumed with an incision into the basin infill deposits, implying renewed fluvial downcutting in the adjacent Elbe River valley, which also affected this distal side valley. The subsequent rise of the water table refilled the lake nearly to its initial extent and was associated with increasing clastic sedimentation, coinciding with sparser forest cover. This late Eemian geomorphic activity phase lasted well into the following first Early Weichselian stadial (Herning Stadial).

Our highly-resolved spatio-temporal data can substantially contribute to the comprehension of climate-induced geomorphic processes throughout the Eemian and the earliest Weichselian. It elucidates Eemian landscape dynamics on the European Plain between the loess belt to the south and coastal areas to the north. Neanderthal presence in the fully-forested optimum of the interglacial makes Lichtenberg the northernmost Eemian Middle Palaeolithic site in Europe, closely ahead of Lehringen (Thieme and Veil, 1985). At the time of writing the article of Chapter 3, the present author had no knowledge of Eemian artifact finds in a sandpit near the neighboring Woltersdorf (Breest, 1992, see 1.3.3), which outranks Lichtenberg by about 3 km in terms of northernness.

Chapter IV: Neanderthal presence in changing environments from MIS 5 to early MIS 4 at the northern limit of their habitat in Central Europe – Integrating archeological, (chrono)stratigraphic and paleoenvironmental results at the site of Lichtenberg

The site of Lichtenberg, N-Germany, has been discovered by K. Breest in 1987, whereupon several years of excavation have been carried out by S. Veil (Breest and Leunig, 1989; Veil et al., 1994). Similar to the case of Khotylevo I, the northerly location of Lichtenberg (52°55′ N) and the impressive artifact assemblage (ca. 4,000 pieces) led to special recognition of this site within the Palaeolithic scientific community (Jöris, 2006). And equally similar to the case of Khotylevo I, the Lichtenberg assemblage is attributed to the Keilmessergruppen of Central and eastern Central Europe. The occupation deposit had been dated with thermoluminescence to a mean age of 57 ± 6 ka, with the individual dates ranging from 66 ± 14.6 ka to 52 ± 6.8 ka (Veil et al., 1994). Based on this mean age, Lichtenberg is mainly considered an early MIS 3 site, however, this view is not uncontested. In particular, Jöris (2004) holds the opinion that the occupation must have occurred before the first glacial maximum (~MIS 4). This is justified by the fact, that the integrity of the find layers is disturbed by post-depositional cryoturbation, likely to have happened in MIS 4. In agreement with this alternative view, the present author and colleague M. Weiß located the previous excavation area and revisited the site in 2017, 2019 and 2020 in order to re-date the sequence. Targeted excavations took place in the latter two years. Cryoturbation disturbances of the find layer have largely been avoided by excavating at the southern fringe of the former area. It was known from the accompanying coring campaign (Chapter 3), that sediment overburden thickens toward the adjacent palaeolake basin, rendering post-depositional distortion of the find-bearing sediments by cryoturbation less likely. That way, the find layer could mostly be identified in original stratification and three luminescence samples yielded absolutely consistent ages with a range from 70.8 ± 8.0 ka to 71.6 ± 7.0 ka and a mean age of 71.3 ± 7.3 ka. In a sediment core, retrieved directly next to the excavation, a humic sand with pollen preservation was detected a few centimeters underneath the deposit of the find layer and could be correlated with Greenland Interstadial GI-19 (ca. 71 ka) (Rasmussen et al., 2014). This is the first evidence of this minor interstadial at the transition from the Weichselian Early- to Pleniglacial on the European Plain. Not only does its presence firmly support the numerical dates obtained by luminescence, but it also proves that Neanderthals could cope with severely cold environments because the vegetation of GI-19 was characterized by an open tundra steppe. The occupation of the previously known site Lichtenberg I (Li-I) could therefore only have taken place in Greenland Stadial GS-19, whereas the former age of 57 ± 6 ka likely corresponds to the timing of cryoturbation.

During the coring campaign, another unknown occupation has been discovered in a stratigraphic position between Li-I and the Eemian artifacts (reported in Chapter 3). It was partly excavated and has been named Li-II. Its assemblage differs from Li-I in terms of smaller tool size, lower raw material quality, and a higher typological tool diversity. The artifacts are contained within shoreline deposits of the palaeolake, which clearly can be related to the late Brörup Interstadial in the palynological analysis. Two luminescence samples returned nearly congruent ages of 90.5 ± 8.7 ka (range from 89.5 ± 8.2 to 91.5 ± 9.1). Therefore, in unison of these two methods the occupation is correlated with the forested interval of GI-22 and late MIS 5c. By extension, it could be shown for the first time in the type area that the terminations of the terrestrial Brörup Interstadial and MIS 5c coincide.

This chronostratigraphic framework allows for the inspection of palaeoenvironments and palaeoclimates in their possible effect on migration and tool production. Neanderthals seem to have been well-adapted to interglacial (Eemian) and forested interstadial (Brörup) conditions but similarly coped with cold environments at the transition of the Early- and Pleniglacial at exactly the same location. Differences between the tools of Li-I and Li-II are partly explainable by the availability of raw material, only provided by Saalian glacial sediments in the region. In relatively stable landscapes during the Eemian and the Brörup, dense forest covers concealed surface objects and also impeded sediment erosion. By contrast, unstable landscapes at the brink of the Pleniglacial promoted the exposure and redeposition of Saalian deposits and the contained flint nodules. Our data set adds a whole new occupation (Li-II) to the spacious map of Early Weichselian sites and provides further evidence, that the Keilmessergruppen had already settled the European Plain prior to the first glacial maximum (Li-I) (cf. Chapter 2).

5.2 Discussion

5.2.1 Evaluation of the chronological and biostratigraphic data

A chronostratigraphic resolution at the level of Marine Isotope Stages (Lisiecki and Stern, 2016) is arguably often insufficient to relate Middle Palaeolithic occupations to distinct climatic and environmental phases and to compare spatially-detached occupations. Rather, in order to unlock a higher synthetic-interpretative potential of the various findings made in the course of excavations, a correlation with Greenland Interstadials and Stadials (Rasmussen et al., 2014) is desirable. In case of the occupations in Lichtenberg, the opportunity arose to succeed in this attempt, despite a challenging depositional setting at the immediate sites. Beneficial factors were the good pollen preservation in certain strata and the remarkably well-resolved sediment basin which is adjacent to and partly overlapping with the position of the sites (see Chapter 3). For a better transparency, the high temporal resolution presented for the Lichtenberg find layers Li-I and Li-II in Chapter 4 shall be critically reviewed in terms of the methodological precision and the applied approach.

Chronostratigraphy

Since the advent of the SAR protocol (Murray and Roberts, 1998; Murray and Wintle, 2000) and the later introduction of novel procedures for feldspar measurements (Buylaert et al., 2012; Thiel et al., 2011), luminescence ages for Pleistocene sediments have become significantly more reliable, reproducible, and less prone to be affected by anomalous fading. But still, internal measurement errors, disparate luminescence characteristics, and uncertainties in water content estimation and dose rate determinations regularly add up to overall error ranges of about +/- 10 %, but at least 5 % of the obtained ages, even in well-bleached and favorable deposits (Mahan et al., 2022). In these latter settings, the choice of statistical model for equivalent dose (D_e) estimation arguably does not have a decisive influence on the resulting ages (cf. Galbraith and Roberts, 2012). However, in less advantageous depositional environments, characterized by insufficient and partial bleaching, the accurate (1) selection of the sampling position and (2) D_e-estimation is of the utmost importance in the present author's opinion to produce robust ages (cf. Mahan et al., 2022). Possibly, misjudgments in these aspects can cause deviations from the "true" depositional age of much higher magnitude than the errors and uncertainties mentioned above. Therefore, these two factors and how they were handled for the research in Lichtenberg will be explained in more detail here:

(1) Periglacial hillslope deposits are among the most challenging sediments for luminescence dating due to unclear exposure to light prior to burial and possible post-depositional mixing (Bateman, 2019). Thus, only limited research has been done on these features (Bateman, 2008; Christiansen, 1998; Hülle et al., 2009), and an independent age or biostratigraphic control is to be recommended. In archaeological sequences, cryoturbated sediments are generally best avoided for luminescence dating, as they are likely to produce inconsistent ages that fall somewhere between the deposition and involution events. From the previous excavation in Lichtenberg it was known, that the find layer was (i) intensively disturbed by cryoturbation, and that it (ii) dipped steeper than the terrain surface in a north-south section through the excavation (Veil et al., 1994), implying increasing accommodation space due south. The latter could be con-

firmed during our sediment coring campaign as reported in Chapter 3. This necessarily results in a thickening sediment overburden of this find layer so that (possibly multi-phased) cryoturbation would be less likely to have affected this layer in the respective permafrost phases. For that very reason, we established our re-excavation (Trench 1) at the southern margin of the former investigation area and exceeded the depth of the previous excavation by about 1 m. In effect, we were able to detect the find layer in original stratification and could sample it in a non-cryoturbated position. The present author argues that the avoidance of this major sampling error has led to more consistent ages, as is illustrated by the comparison of the newly-obtained and previous dates (section 5.1 in Chapter 4).

(2) For the research presented here, each luminescence sample was subdivided into 24 subsamples/replicates (aliquots) on which the measurements were carried out. Deliberately, a very small aliquot size was chosen (0.5 mm diameter) corresponding to a number of ~ 10 to 20 individual grains per aliquot. As a result, the statistical variation is higher when compared to measurements using bigger aliquot sizes of 1, 2 or 5 mm (Duller, 2008). However, it has been shown in detail, that these 'ultra small' aliquots substantially help identify different age components in poorly-bleached sediments and especially periglacial environments (e.g. Bateman, 2019; Olley et al., 1999; Tooth et al., 2007). That way, individual modes that would otherwise fall prey to averaging effects in bigger aliquots can better be detected within the age frequency distribution. Therefore, an advantage of this higher spread and resolution in the data is a likely better-informed D_e-estimation to use for age calculations. For identifying the appropriate D_e-estimates that correspond with the targeted bleaching event, a number of statistical models are available e.g., the *Central Age Model* (CAM) and the *Minimum Age Model* (MAM) (Galbraith et al., 1999). The choice of model is a scientific decision made by the researchers and specific to each individual sample. It is mainly governed by the sedimentary context and stratigraphic considerations (Galbraith et al., 2005; Galbraith and Roberts, 2012; Mahan et al., 2022). Previous attempts to formalize a universal protocol for the choice of age model based on statistic criteria (e.g. Bailey and Arnold, 2006; Rowan et al., 2012) have been discarded within the luminescence dating commu-

nity more recently (e.g. Mahan et al., 2022). In well-bleached deposits, resulting in almost normal D_e-distributions, the CAM is usually thought to be the best means of estimating the equivalent dose (Galbraith and Roberts, 2012; Mahan et al., 2022). By contrast, heterogeneous or poor bleaching can lead to skewed, non-normal or multi-modal D_e-distributions that may be better accounted for when applying the MAM (Bateman, 2019; Galbraith et al., 1999). The MAM assumes a sub-population of well-bleached grains and thus targets the lower values within the D_e-frequency distribution. Notes on the correct application of the MAM can be found in Chamberlain et al. (2018) and Galbraith and Roberts (2012).

Apart from a comprehensive understanding of the depositional environment and the application of suitable statistical models, an adequate visualization of the D_e-distribution is indispensable for the straightforward inspection and interpretation of the measured values (see overview of various plot types in Galbraith and Roberts, 2012). Because of the challenging sedimentary history at the site of Lichtenberg, the present author has chosen Abanico Plots (Dietze et al., 2016; Kreutzer et al., 2020) to display the data presented in Chapter 4. These graphs merge the benefits of a radial plot - a widely-used but not very intuitive technique to illustrate replicate D_e-values - with those of a kernel density estimation (KDE). Thus, they provide a way to explore the distribution in a less biased way than in a histogram (by means of the KDE part), while presenting the individual standard errors for each measured value at the same time in the radial plot part (Dietze et al., 2016).

An example of how Abanico Plots can contribute to a parsimonious D_e-estimation and thereby help justify the choice of age model is given in Figure 4, using luminescence data of the Lichtenberg find layers (Chapter 4). After plotting the data, a particular age model was chosen if it reflected the most informative D_e-population in terms of (i) sediment formation, (ii) data precision (in the radial plot part), and (iii) data representation (in both parts of the plot). For find layer Li-I (stratigraphic layer 7), the interpretation as a shallow lacustrine deposit implies an incomplete and partial bleaching of the feldspar grains, making the MAM the likely adequate option. The two samples taken <10m apart in the very same layer (L-EVA 2014 and 2017) display surprising differences in their distributions, demonstrating the spatially heterogeneous nature of the sedimentation process. L-EVA 2014 shows a unimodal distribution with comparably low variability, whereas the D_e-values in L-EVA 2017 are bimodally distributed and exhibit a much higher variability (Figure 4). However, when applying the MAM, in both cases the final D_e-estimates concur with a distinct mode in the distribution and high data precision. Eventually, for both samples very similar ages were obtained (71.6 ± 7.0 and 70.8 ± 8.0 ka, respectively). This reproducibility suggests a functional analytical chain (cf. Bateman, 2019; Mahan et al., 2022).

Similarly, for find layer Li-II (stratigraphic layer 11a) the D_e-distributions of the two samples L-EVA 2022 and 2024, taken <5 m apart, differ concerning modality and variability (Figure 4). The sediment of this layer was interpreted as a beach sand, and thus, a better bleaching is to be expected, because the grains would have been repeatedly reworked on the beach face by wave action and movement. Therefore, the CAM is likely the best way to approach the D_e-estimation. This holds true for sample L-EVA 2022, where a broad and smooth unimodal curve describes the D_e-distribution of the replicates and the CAM estimate is close to the mode of this distribution. Conversely, the distribution of individual values in sample L-EVA 2024 is discontinuous and can be described as bi- to polymodal. The use of the CAM would likely lead to an age overestimation, because the position of the CAM estimate – indicated as grey bar and line in Figure 4 - does not reflect a distinct population. Therefore, the *Weighted Mean* was chosen for final D_e-estimation, as its result is congruent with the first mode of the distribution and data precision is sufficiently high. Again, very comparable ages for these two samples (91.5 ± 9.1 and 89.5 ± 8.2 ka), despite the application of disparate age models, imply an adequate reproducibility and support this analytical chain.

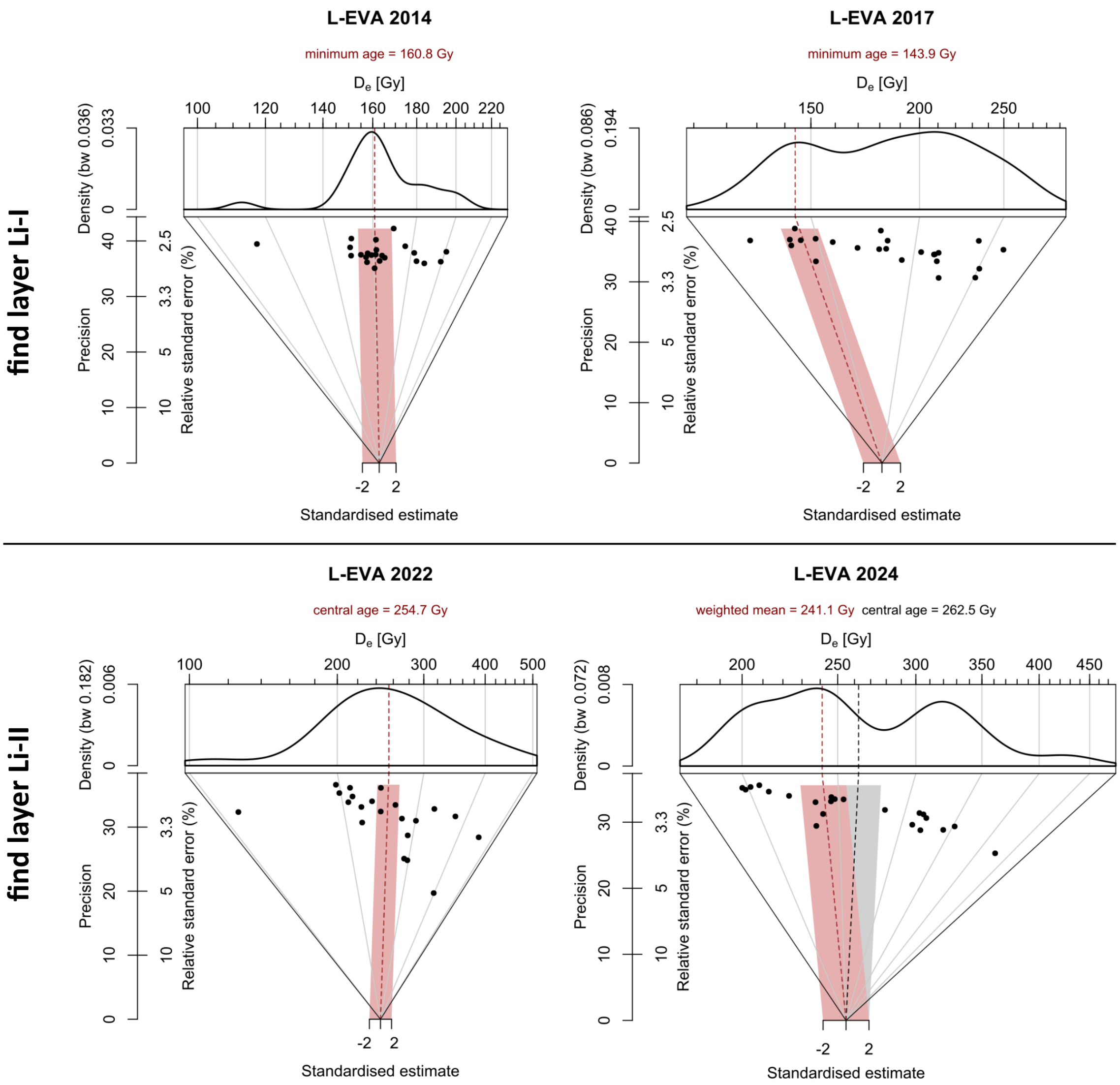

Figure 4: Abanico Plots of the D_e-distributions for the two samples each, taken from the find layers Li-I and Li-II in Lichtenberg. Red bars and red dotted lines indicate the resulting position of the equivalent dose (D_e) estimated with the selected age model. The age models were chosen to correspond with a distinct and sedimentologically most informative mode within the distributions (see text). For both find layers, two different samples returned nearly congruent ages using this approach. For comparison, in the plot of L-EVA 2024 the position of the CAM (not used for age calculation) is additionally displayed with a grey bar and line. The CAM does not represent a population within the data in that case and was therefore discarded in favor of the *Weighted Mean*.

Biostratigraphy

In suitable deposits, ancient pollen can preserve over long periods of time and are considered a key tool for the biostratigraphic subdivision of the Quaternary in general, but also of the later Pleistocene in particular (Sanchez Goñi, 2022; Stojakowits and Mayr, 2022). When analyzing coherent sedimentary sequences, the established local to supraregional palynostratigraphic frameworks facilitate a mostly unequivocal assignment of local pollen spectra and pollen assemblage zones to distinct biostratigraphic units within the last interglacial-glacial cycle in Northern Germany (Behre and Lade, 1986; Caspers et al., 2002; Caspers and Freund, 2001; Menke and Tynni, 1984). Contrastingly, the sampling design for palynological analysis presented here pursued two slightly deviating approaches.

(1) For the research presented in Chapter 3, we took bulk samples distributed across the entire borehole transect. They were collected from organogenic units at the bottom of the palaeochannel infill and were presumed to have formed during the Eemian. This approach may introduce a certain ambiguity in pollen zone classification, because of quite similar pollen spectra from the early/late Eemian and the Brörup Interstadial, that may be difficult to distinguish in individual samples (Caspers et al., 2002; Caspers and Freund, 2001). This uncertainty could largely be resolved by taking into account (i) local references of coherent Eemian/Early Weichselian sequences from the immediate study site, both unpublished and published (Veil et al., 1994), and (ii) stratigraphic considerations, i.e., the directionality of respective depositional units and their relationship to one another. By using this cost- and time-efficient sampling approach, we gained a much higher spatial coverage of biostratigraphic information, enabling us to focus on the reconstruction of geomorphic dynamics and landscape evolution throughout the Eemian. The plausibility and connectivity of the results seem to confirm that such a design can generally produce a viable outcome, despite some undeniable drawbacks.

(2) For the research presented in Chapter 4, we could make use of a pollen-bearing organogenic deposit in Trench 2, layer 11b, which we sampled as a four-part sequence. Additionally, we took three bulk samples from the find layer Li-II (stratigraphic layer 11a) and the overlying stratigraphic layer 10. The four-part sequence in itself is indicative of the late Brörup Interstadial and the transition to the following Rederstall Stadial. The bulk samples from the find layer Li-II – and thereby the occupation - can clearly be connected with the late Brörup within this sequence. Again, excellent local reference is available through the pollen sequence described in Veil et al. (1994), situated merely 40 m apart. Furthermore, litho- and biostratigraphic control is provided by the findings presented in Chapter 3, where for instance a half-bog soil c. 130 cm directly underneath layer 11 has been described as Eemian formation.

Since there is no pollen preservation in the deposits exposed within Trench 1, we sampled three organogenic beds in the core PD.028 right at the southern margin of the trench. The lowermost bed is a peat and is represented by two pollen samples that place it into the Odderade Interstadial. Stratigraphic considerations derived from the borehole transect in Chapter 3/Figure 4 concur with this interpretation, as the Brörup and the Eemian can be expected to lie much further down the profile. Moreover, the upper boundary of this Odderade peat in PD.028 is at 16 m a.s.l. nearly congruent with the top of the Odderade in core Veil 1 (Veil et al., 1994), positioned ~10 m away in a matching geomorphological position (Chapter 4, Figure 1c).

Considering the described stratigraphic control and the fact that the palynologist who analyzed the reference sequence in Veil et al. (1994), namely B. Urban, was also responsible for the biostratigraphic assignments in Chapter 3 and 4, the present author is confident, that the pollen-based interpretations presented in these chapters are in line with the best scientific practice, despite a comparably low sampling resolution.

Integration of chronological and (bio)stratigraphical data

The combination of the litho-, chrono- and biostratigraphic findings reveals a good accordance of the respective data and thus justifies the attempt to assign certain deposits to climatostratigraphic phases. This shall briefly be exemplified for the find layers Li-II and Li-I in Lichtenberg (Chapter 4) in the following paragraphs.

Li-II - Palynological information places Li-II into the late Brörup Interstadial. Warm-stage conditions are corroborated by:

- the sediment characteristics (e.g. considerable to very high total organic carbon content, charcoal fragments, plant residues in thin sections, no discernible cryogenic features)
- the presence of rich and temperate phytolith assemblages
- archaeological evidence (raw material, size/type/use of tools, traceology)

The mean luminescence age of two very similar dates is 90.5 ± 8.7 ka. This mean age is time-equivalent to the terminal phase of MIS 5c (Lisiecki and Stern, 2016) and to the terminal phase of the warm stage represented in the Greenland ice core record by the

Greenland Interstadials GI-23 and GI-22 (Rasmussen et al., 2014). And it coincides chronologically with the on-site finding of sediment deposition in the late Brörup Interstadial, with the Brörup usually being equated to MIS 5c in Northern Germany and neighboring regions (e.g. Antoine et al., 2016; Boch et al., 2011; Bolland et al., 2021; Litt et al., 2007). Hence, within the nearly identical temporal references of the Marine Isotope Stages and Greenland Interstadials, the late Brörup Interstadial would equal GI-22 and the terminal MIS 5c. Furthermore, within the luminescence dating uncertainty of ± 8.7 ka for Li-II, apart from the late Brörup, no other interstadial termination seems to occur in the North Atlantic records (Chapter 4, Figure 7). This integrative consideration of the available data supports the tentative correlation of find layer Li-II with Greenland Interstadial GI-22 and the termination of MIS 5c.

Li-I – This find layer itself and in fact, the entire excavation of Trench 1 does not yield any pollen-bearing deposits. The basal peat in the sediment core PD.028 at the southern boundary of this trench is assigned to the Odderade Interstadial (section Biostratigraphy above). It is succeeded by two humic deposits separated by niveofluvial sands. The humic deposits display cold-stage pollen spectra and are interpreted as minor interstadial formations occurring after the Odderade. Two climatic oscillations following the Odderade are well documented for many regions in Central and Western Europe and correlated to the Greenland Interstadials GI-20 and -19 (Antoine et al., 2016; Boch et al., 2011; Bolland et al., 2021; Müller and Sánchez Goñi, 2007; Woillard, 1979). The latter are positioned at c. 75 and 71 ka in the Greenland ice core record (Rasmussen et al., 2014). In direct superposition of these two minor interstadials in core PD.028, lies sediment layer 7 that contains the find layer Li-I in Trench 1. The mean age of Li-I with 71.3 ± 7.3 ka, calculated from three nearly congruent individual dates, is in accordance with the classification of the two minor interstadials below as GI-19 and GI-20. According to stratigraphic relationships, the sediment characteristics, the lacking organic compounds and the grass-dominated vegetation as implied from phytolith analysis, Li-I was deposited shortly after GI-19 under stadial conditions. Hence, we assign this find layer to Greenland Stadial GS-19. At both ends of the error range (71.3 ± 7.3 ka) no plausible alternative position seems to exist. At its upper end, an age of 78.6 ka would interfere with the termination of Odderade and the two minor interstadials GI-20 and -19. All of which, Li-I (layer 7) is clearly overlying in core PD.028. At the lower end of the luminescence error range, GS-19 (c. 64 - 70.5 ka) is entirely covered by the 7.3 ka error margin (Chapter 4, Figure 7). An even younger date for Li-I is equally unlikely, as Li-I is overlain by deposits with clear cryogenic features, which can be expected to have formed under stadial conditions in MIS 4. For these reasons, correlating Li-I with GS-19 is the most parsimonious and credible assumption.

Currently, sediment cores Li-BPa, PD.031 and PD.028 (for positions, see Chapter 3, Figure 4) are subjected to detailed and high-resolution analysis using a multi-proxy approach including sedimentology, biostratigraphy, dating and geo-biochemistry. The incoming results so far fully support the preliminary allocations described above.

5.2.2 Stratigraphic implications of the results

Establishing firm and highly-resolved chronostratigraphies was the overall objective of the present thesis. It is a prerequisite for synchronizing behavioral traits with distinct climatic and environmental phases in order to explore possible connections (cf. Pederzani et al., 2021). Encouragingly, this is more and more being achieved for cave and loess sites of the latest Middle Palaeolithic (MP), the Upper Palaeolithic (UP) and the MP/UP transition (Fewlass et al., 2020, 2019; Fuchs et al., 2013; Guérin et al., 2017). It is mainly facilitated by the high precision of radiocarbon dating, often in combination with luminescence-based chronologies and well-stratified sediment sequences. By contrast, numerical dates in general and especially accurate chronostratigraphic data are still sparse for Eemian to early Pleniglacial sites. This is particularly true for open-air sites beyond the loess belt, where mostly shallow slope deposits dominate. Additionally they were often subjected to polycyclic cryoturbation, rendering these deposits challenging for luminescence dating (Bateman, 2008; Fuchs and Lang, 2009; Veit et al., 2017; Waroszewski et al., 2020). While fluvial deposits are much better-suited for luminescence chronologies (Cunningham and Wallinga, 2012), the sequences often lack the required resolution and present artifacts are frequently in secondary (i.e. reworked) positions (Bridgland et al., 2006; Vandenberghe, 2015; Winsemann et al., 2015), which in turn complicates precise chronostratigraphic allocation of the finds.

As expected, our own chronostratigraphic investigations for Khotylevo I and Lichtenberg show varying precision, owing to different site conditions and available auxiliary information (Chapter 1.5). Whereas occupations of Li-I and Li-II in Lichtenberg could be resolved at the scale level of Greenland Stadials and Interstadials, the Eemian occupation was only biostratigraphically assigned to a distinct Eemian pollen zone (E IVb/V). The two respective luminescence dates of the overlying deposits (108.4 ± 17.0 ka and 104.6 ± 10.5 ka) have to be regarded as minimum ages for the Eemian termination. Outside of the radiocarbon range, this exceptional chronostratigraphic resolution and robustness for Li-I and Li-II has otherwise only been achieved for occupations within loess-palaeosol-sequences, so far (Locht et al., 2016). In the former riverine landscape of Khotylevo I, interfingering low-energy deposition of slope and fluvial deposits in the rear part of the floodplain resulted in a well-resolved sediment sequence for the time of occupation. However, such a close-meshed framework as in Lichtenberg could not be fully achieved, and the age estimates, although very consistent, remain on the scale of Marine Isotope Stages. On the one hand, this is due to missing biostratigraphic information for the non-pollen bearing deposits. On the other hand, the setting is even more demanding for luminescence dating, because of mixing with poorly bleached Saalian sediments and the ubiquitous clasts of Cretaceous marl and chalk, leading to small-scale dose rate variations within the sequence (e.g. Jacobs and Roberts, 2007). Still, apart from this relatively lower dating precision, the chronostratigraphy does not lack robustness, as the correlation with regional loess stratigraphy permits a confident and unambiguous assignment of the occupation to MIS 5a. Thus, a firm chronostratigraphic foundation has been established at both sites, allowing for future correlations, archaeological inferences and the purposeful application of additional methods.

At both sites, this framework already led to the discovery of – or helped contextualize – hitherto unknown occupations (research question **RQ 4**): In Lichtenberg, the coring campaign directly resulted in the detections of the Mid-Eemian (PZ E IVb/V) and late Brörup occupations. By reporting the first independent numerical dates for the latest Brörup Interstadial WE IIb (mean of 90.5 ± 8.7 ka) in its type region on the NW European Plain, we advocate the broad coincidence of the Brörup Interstadial and MIS 5c in their terminal phases (research question **RQ 1**). This is fundamental information for several archaeological (and palaeoenvironmental) sites in the wider area, at which the chronologies only rely on biostratigraphical evidence, e.g. the Middle Palaeolithic occupation in Schalkholz, N-Germany (Arnold, 1978; Menke, 1980; Nielsen et al., 2017). Our research approach in Lichtenberg further provided the first evidence of climatic fluctuations at the MIS 5a/4 transition after the Odderade Interstadial (research question **RQ 1**), which had already been demonstrated for southern Germany, Switzerland and France (Boch et al., 2011; Müller and Sánchez Goñi, 2007; Woillard, 1979). They are equally traceable in the North Atlantic palaeoclimate records as high-amplitude oscillations (Lisiecki and Stern, 2016; Rasmussen et al., 2014) and the loess sequences of northern France (Antoine et al., 2016), where they are associated with numerous Middle Palaeolithic sites (Locht et al., 2016). The two detected minor interstadials of that stratigraphic position in Lichtenberg (GI-20 and GI-19, cf. Rasmussen et al., 2014) display pollen spectra similar to the Oerel and Glinde Interstadials, usually correlated with early MIS 3 based on older protocols of radiocarbon dating (Behre and van der Plicht, 1992). If it can be substantiated that the chronology of Oerel and Glinde needs to be revised, and they are in fact attributable to GI-20 and GI-19, this would have far-reaching archaeological implications, as many Neanderthal sites are linked with these presumed MIS 3 interstadials (cf. Jöris, 2004).

In Khotylevo I, thanks to the chronostratigraphic framework, artifact finds within similar sequences and at the same stratigraphic level, can now be easily and reliably assigned to a distinct period in neighboring sections along the riverbank (research question **RQ 1**). Additionally, because all overlying deposits have been included in the framework, a newly-found artifact scatter at a higher level can confidently (but preliminarily) be constrained to the latest MIS 4 already (Otcherednoi et al., in prep.) (research question **RQ 4**). The knowledge on the temporal setting of fluvial aggradation and incision events forming the widespread 2nd fluvial terrace on the Russian Plain, has substantially been improved. With this understanding, also a chronological background for more remote palaeoenvironmental and archaeological findings, and their correlation over large distances is provided (Bridgland et al., 2006; Matoshko et al., 2004; Panin et al., 2017; Vandenberghe, 2015).

In conclusion, an optimistic answer can be given to the research question **RQ 4**, raised in Chapter 1.5: A systematic landscape-oriented and chronostratigraphic approach, even for a few consecutive years, can indeed support the discovery of new Middle Palaeolithic sites, but also the contextualizing of existing ones.

5.2.3 Implications for late Pleistocene Neanderthal population dynamics

The timing and duration of *Keilmessergruppen* assemblages found in Central and Eastern Europe have been widely discussed. Ambiguous and contrasting evidence of stratigraphical considerations and radiocarbon dating existed so far. This made both, the restriction of the *Keilmessergruppen* to the first half of MIS 3 or their earlier emergence in MIS 5a and subsequent persistence until MIS 3 seem possible (Jöris, 2012, 2004; Richter, 2016, 2002). Among such sites with chronologically inconclusive data were Lichtenberg (Veil et al., 1994), Salzgitter-Lebenstedt (Pastoors, 2009; Tode, 1982), Königsaue (Mania, 2002; Mania and Toepfer, 1973) and also Khotylevo I (Otcherednoi et al., 2014; Velichko, 1988; Weiss, 2019). The ages presented in this thesis place the *Keilmesser* occupations of Khotylevo I and Lichtenberg I into MIS 5a and MIS 5a/4, respectively, rather than MIS 3, as previously assumed (research question **RQ 2**). Therefore, these new ages provide substantial evidence for an early appearance, i.e. a "long chronology" of the *Keilmessergruppen*, *sensu* Jöris (2004) (research question **RQ 3**). The emergence coincides with increasingly destabilizing landscapes granting access to larger-sized and high-quality raw material through sediment erosion (Chapter 4). It further coincides with gradual climatic deterioration and the completed dominance of cold-adapted fauna (cf. Chapter 1.3). Hence, it seems likely, that this environmental and climatic constellation has co-determined technological development. A long chronology of the *Keilmessergruppen* from MIS 5a to MIS 3, moreover, implies the survival of the *Keilmesser* concept or its general idea throughout the first glacial maximum (~MIS 4). For the latter period, virtually no unequivocal Neanderthal presence was demonstrated above ca. 50° N, so far (Chapter 1.3.3, cf. Bobak et al., 2013). It could be argued, that such a long-term "collective memory" of tool technology would best be preserved if Neanderthal response to glacial conditions was not local extinction, but rather a southward movement to more habitable refuges (cf. Hublin and Roebroeks, 2009). The appearance of resembling bifacial tool types in northern France (around 50° N) during the MIS 5a/4 transition, and at least their ephemeral re-appearance during GI-18 (ca. 64 ka) in Mid-MIS 4 (Antoine et al., 2014; Guérin et al., 2017; Locht et al., 2016) seem to rather support the migration theorem. In any case, Neanderthal occupation Li-I in Lichtenberg (GS-19) – right *after* a minor interstadial, which was characterized by open tundra-steppe – displays their ability to cope with severely cold environments. Therefore, colonization even throughout MIS 4 should not entirely be precluded (cf. Uthmeier et al., 2011).

But on the other hand, Neanderthals were equally capable to adapt to densely-forested environments. In Lichtenberg, the Eemian and Brörup artifacts are characterized by small, variable and simple tools, made from small-size and low-quality raw material. In these properties they resemble each other and also the assemblages from other occupations in forested MIS 5 environments of the wider area, e.g. Neumark Nord 2/2 (Pop, 2014) and 2/0 (Laurat and Brühl, 2021). Prevailing conditions can be described as temperate with a warm-adapted fauna and (relatively) stable surfaces covered by dense forests and undergrowth, which made raw material procurement difficult (e.g. Locht et al., 2014). Just as discussed above for the *Keilmessergruppen*, palaeoenvironments seem to have co-determined the lithic tool technology. Arguably, its variation in parallel with changing conditions can be regarded as a testimony to Neanderthal adaptive capacities. By contrast, the very low number of existing sites from the Eemian and the Brörup has motivated the theory that dense forests were rather unfavorable for Middle Palaeolithic sustenance (Defleur and Desclaux, 2019; Hublin and Roebroeks, 2009; Richter, 2016; Wenzel, 2007). However, our 'accidental' discovery of an Eemian and a Brörup occupation in Lichtenberg during a single coring campaign suggests that taphonomic and research biases are mainly to be blamed for this shortage instead of forested conditions (cf. Nielsen et al., 2017). Considering the Eemian finds in the nearby Woltersdorf (Breest, 1992), there are now three MIS 5 occupations in forest environments within a radius of 3 km near Lichtenberg.

As Chapter 3 clearly illustrates, a severe erosional phase occurred in the late Eemian and the early Herning Stadial, while other active phases within the Early Weichselian are implicitly linked to all the subsequent climatic transitions, when landscapes needed to readjust toward a new equilibrium (Fränzle, 1988; Lade and Hagedorn, 1982; Schokker et al., 2004). Even though this statement suffers from a low research intensity, the general trend can be transferred to river and loess plains, as well (Antoine et al., 2016; Vandenberghe, 2008). Leaving out these loess landscapes as special aggradation areas, chances are high that erosion toward a cold interval eradicated most of the sediments, soils and archaeological remains, which were formed in the warmer interval before. Only favorable geomorphological situations and landforms reliably preserve Eemian and Early Weichselian natural or archaeological deposits. They comprise especially lake basins but also toe-slopes, dry valleys and distal parts of floodplains. This gives rise to the identification of promising positions with the geomorphological and stratigraphic potential to host unknown sites (cf. Nielsen et al., 2019). But it may also serve as a reminder, that the established occupations of that time could represent a distorted picture which only pretends (i) particularly low population densities (cf. Richter, 2006) and (ii) topographic depressions as the major Neanderthal habitats on the European Plain. While there might eventually be some truth to both assumptions, scientific reasoning demands to only accept the paucity of evidence, if the evidence of paucity is given. In that case, this must involve pursuing predictive modeling approaches for potential archives of Neanderthal occupation, which are firmly based on geomorphological considerations and chronostratigraphic "groundtruthing".

In summary, the presented results and discussions within this thesis document both the potential and the need for integrated archaeological and palaeoenvironmental research, which is jointly coordinated from an early stage of project planning (cf. Garrison, 2016; Goldberg and Macphail, 2006).

5.3 Outlook

The encouraging results and their various implications are merely the basis for ongoing and future studies that the present author and colleagues are conducting in Lichtenberg, Khotylevo and beyond. In fact, too many aspects are worth taking a closer look at to be mentioned here. In the following, the current palaeoenvironmental research, which aims to make use of the outstanding sediment archives of these two sites, will briefly be outlined.

Khotylevo I:

The MIS 5a and MIS 3 palaeosols at this site have only preliminarily been described so far (Chapter 2), which is why current and future research focuses on their characteristics. Especially, the MIS 3 palaeosols differ from the Western and Central European ones in terms of resolution, typology and the higher intensity of soil formation (cf. Meszner and Faust, 2018; Sauer et al., 2016; Terhorst et al., 2015). Therefore, disparate, and possibly more temperate conditions are to be assumed by comparison, which could have repercussions on the MIS 3 population dynamics and the MP-UP transition on the Eastern European Plain (cf. Hoffecker et al., 2019; Sedov et al., 2010). Detailed sedimentological, micromorphological, magnetic and geochemical analyses coupled with luminescence dating will try to shed new light on this.

Most of the large-scale natural and artificial exposures along the Desna riverbank display nearly congruent stratigraphies, so that only select positions have to be luminescence-dated to confirm the newly-established chronology. However, in one section ("*Крючка/Kryutchka*" = "*the hook*") at the current cut bank, higher-energy deposition of seemingly MIS 5 and MIS 4 fluvial sediments took place (cf. Zavernyaev, 1978). Therefore, the chronostratigraphic analysis of the *Крючка* exposure can yield information on fluvial dynamics and on site selection of the Neanderthal occupations, which may well be transferable to other rivers or at least different segments of the catchment (cf. Panin et al., 2017).

Lichtenberg:

Just like for Khoylevo I, the palaeosols in Lichtenberg deserve closer attention. A first fossil soil is directly associated with the occupation of Li-II (ca. 90 ka) and is characterized by the accumulation of organic matter under semi-terrestrial conditions. At the immediate shoreface of the palaeolake, this half-bog soil and parts of the artifact-bearing underlying beach sand have been eroded. For that reason, investigating the soil properties and distribution can be informative of the environmental conditions during occupation, the extent of the site and the archaeostratigraphic integrity. A second incipient palaeosol formation seems to have affected the sediments containing the occupation Li-I (ca. 71 ka). From preliminary descriptions, a non-analog and possibly multi-phased soil development is assumed, resulting in a Podsol-Gley soil type. Its chronostratigraphic position suggests, soil formation likely took place in MIS 4 and/or the MIS 5a to MIS 4 transition (GI-18 and/or GI-19.1 according to Rasmussen et al., 2014). This palaeosol can provide an assessment, whether or not brief spells of habitable conditions existed in the period between 70 ka and 60 ka, which would in principle have allowed the ephemeral use of sites in the region. A similar set of methods as used for the palaeosols in Khotylevo will also be applied to the pedogenic phenomena in Lichtenberg, including sedimentology, micromorphology, geochemistry, magnetic susceptibility, luminescence dating, and also palynological and phytolith analyses.

Three sediment cores (Li-BPa, PD.032 and PD.028, see Fig. 4 of Chapter 3) are being subjected to high-resolution multi-proxy analysis. We make use of a multitude of luminescence samples (n~50), palynology, sedimentology, geochemistry, magnetic susceptibility, malacology as well as the analysis of chironomidae and various biochemical markers. Climatic conditions will be reconstructed from chironomids, biomarkers and pollen, i.e. in three different and parallel ways, which will be compared and jointly interpreted. Integrating all findings, Lichtenberg has the potential to become one of the standard profiles for vegetation, landscape and climate development on the western European Plain from the late Saalian to the Mid-Weichselian. In that capacity, valuable background information is provided for the occupations in Lichtenberg and the wider area. Furthermore, parallel investigations of an infilled late Saalian dead-ice kettle-hole (ca. 2 km away from the site) will help to disentangle the influences of climate and landform geometry of the archive on the reconstruction of former conditions. One of the numerous sub-aspects is the more detailed investigation of the humic sands correlated with GI-20 and GI-19 (Chapter 4). As these late MIS 5a climate variations have been detected for the first time on the European Plain, palynological analysis in 1 cm resolution is being conducted. This will facilitate a climatic reconstruction of these intervals and the inspection of their comparability or even congruence with the presumed MIS 3 interstadials Oerel and Glinde (Jöris, 2004). A last sub-aspect of the core analysis mentioned here is the identification of wildfire cyclicity and its major determinants using micro-charcoal counting, indicator floral taxa and the application of novel pyrogenic biomarkers (de Groot et al., 2013; Dietze et al., 2020; Pop et al., 2016). Once this natural baseline is established, a potential Neanderthal contribution to fire history can be explored for phases in which known occupation and above-expected pyrogenic activity coincide (Dibble et al., 2018; Roebroeks et al., 2015; Scherjon et al., 2015). Due to the investigated three sediment cores from the archaeological sites to the deepest part of the palaeolake basin, the range of a possible human impact could also be accounted for (cf. Bos and Janssen, 1996).

Lastly, because the need for understanding MIS 5 geomorphic dynamics has repeatedly been addressed in the foregoing chapters, research at an additional location is referenced here. In Zeuchfeld, Central Germany, a deep sand pit exposes the infill of a dry valley covering the late Saalian to the Late Weichselian. What makes Zeuchfeld special is that it is not a loess-palaeosol-sequence, but a sequence of alternating and well-preserved *colluvial* deposits and palaeosols. They create a high-resolution record of geomorphic stability and activity phases, which is being deciphered with the palaeopedological methods listed above for Khotylevo I and Lichtenberg I/II. The results, together with all the findings from Lichtenberg, will be used to propose a long-overdue comprehensive model of diachronic landscape dynamics in Central Europe from late MIS 6 to MIS 3/2 (cf. Lade and Hagedorn, 1982).

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