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

Hein, M.

CHAPTER II: LUMINESCENCE CHRONOLOGY OF THE KEY-MIDDLE PALEOLITHIC SITE OF KHOTYLEVO I (WESTERN RUSSIA) – IMPLICATIONS FOR THE TIMING OF OCCUPATION, SITE FORMATION AND LANDSCAPE EVOLUTION

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

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ABSTRACT

Here we present the luminescence chronology for the Middle Paleolithic open-air site of Khotylevo I, area I-6-2, in Western Russia. Even with a sizable number of such sites available on the Russian Plain, to our knowledge, no successful corresponding luminescence dating has been published before. Coupled with extensive sedimentological logs and grain-size analysis, our data is further used to infer the palaeoenvironmental conditions on site as well as the landscape-forming processes of the wider region. As the site is contained within the sediments of the 2nd fluvial terrace, our high-resolution chronostratigraphy is a valuable contribution to the understanding of this widespread phenomenon and Late Pleistocene geo-climatic events on the Russian Plain. For the formation of the 2nd terrace, a full incision/aggradation cycle was detected with a duration from MIS 5c/5b to MIS 3. Our results indicate that late Middle Paleolithic human occupation took place during the more ameliorate Early Weichselian phase of MIS 5a. Furthermore, the dates for Khotylevo I-6-2 prove the onset of the late Middle Paleolithic *Keilmessergruppen* occurred as early as MIS 5a. The archeological comparison with other numerically dated Late Middle Paleolithic assemblages across the northern central European Plain suggests a complex picture of population dynamics between MIS 5a and MIS 3.

1. Introduction

The last interglacial-glacial cycle on the European Plain has been an eventful period with respect to climatic shifts and (partially) climate-driven landscape evolution, including vegetation cover, sedimentation processes and hydrological regimes (Caspers and Freund, 2001; Christiansen, 1998; Helmens, 2014; Vandenberghe, 2015; Velichko et al., 2011). This complex of interdepending factors, in turn, was the canvas for the occupation of the Middle Paleolithic foragers, i.e. Neanderthals. Many studies have addressed their respective adaptabilities to this constantly changing environment (Gaudzinski-Windheuser et al., 2014; Gribchenko and Kurenkova, 1999; Locht et al., 2016a; Richter, 2006; Roebroeks et al., 2011; Skrzypek et al., 2011; Toepfer, 1970; Velichko, 1999, 1988). Such investigations are necessarily based on material objects, mainly lithics and skeletal remains, whether hominin or faunal, and very rarely, organic artefacts, like wooden tools or birch tar adhesives (Gaudzinski, 1999; Hublin, 1984; Kozowyk et al., 2017; Thieme and Veil, 1985; Weiss et al., 2018). But equally important is the up-scaled view of the geographic and temporal distribution of various sites in order to try and understand occupational and migrational patterns – keeping in mind the huge bias that the established sites presumably represent a diminishingly small part of the whole record (Hublin and Roebroeks, 2009; Richter, 2016). The spatial and temporal distribution of late Neanderthal sites can help to understand human behavior within, and adaptations to, changing environmental and climatic conditions. By attributing those patterns and specific assemblages to climatic shifts, climate-driven landscape and faunal properties, it might prove possible to depict adaptive and/or evasive or simply coping-strategies of the Neanderthals. On the European Plain, where cave sites are less abundant, open-air sites assume an important role in deciphering those adaptive patterns (Weiss, 2019). The entirety of these sites can arguably be regarded as a representation of the environmental demands and habitual realities of the

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populations.

Necessary prerequisites for elucidating Neanderthal adaptabilities to changing environments (apart from the analyses of the finds on open-air sites) are (1) a reliable dating of those sites and (2) a way to regionally or better locally reconstruct the diachronic former states of environment, climate and landscape. Wherever bone material or other organic remains are available, ^{14}C dating is the first, obvious and right choice for chronological control, as its precision and reproducibility is unrivalled by most other methods (Wood, 2015). However, the better part of the Neanderthal overall existence has been spent well outside the range of radiocarbon, and even within the range, at its far end (ca. 50 kyrs.), the method is known to still hold some challenges (Briant and Bateman, 2009; Pigati et al., 2007).

Thus, studying suitable sediment sequences at open-air sites is an elegant way to fulfill both the dating and the paleoenvironmental requirements. Luminescence dating has been successfully applied to Lower and Middle Paleolithic sites contained within or surrounded by aeolian, fluvial and colluvial sediments (Lauer et al., 2020; Lauer and Weiss, 2018; Mercier et al., 2003; Richter and Krbetschek, 2014; Skrzypek et al., 2011; Strahl et al., 2010; Weiss, 2015; Weiss et al., 2018; Winsemann et al., 2015; Wiśniewski et al., 2019). Even though the uncertainties might sometimes impede an attribution to distinct climatic periods, the benefits of this method clearly lie in its ability to chronologically resolve records older than 50.000 years. When accompanied by thorough sedimentological logging, it can potentially account for a conceivable reworking of the find layers by cryogenic processes and periglacial mass wasting (Bateman and Van Huissteden, 1999; Döhler et al., 2018; Harrison et al., 2010; Wenban-Smith et al., 2010). Moreover, the characteristics of the sediments on site and the processes responsible for their deposition can, in many cases, be traced back to climatic and environmental driving factors that would have affected the Neanderthals' habitats accordingly.

To our knowledge though, even with a high number of Late Middle Paleolithic (LMP, Marine Isotope Stages 5d to 3) open-air sites available (Hoffecker, 1987; Matyukhin and Sapelko, 2009; Otcherednoi et al., 2014a; Velichko, 1988) on the Russian Plain, no unambiguous luminescence chronology has been presented (but see Hoffecker et al., 2019). Hence, in terms of temporal classification this area remains an "unproven domain" with enormous potential to substantially complement the precognition of Neanderthal spatial behavior from Western and Central Europe (Higham et al., 2014; Locht et al., 2016a; Richter, 2016). Many of the Russian LMP sites are associated with either loess-like sediments or the deposits of the 2nd fluvial terrace (Velichko, 1988). Both of which phenomena have been extensively investigated throughout the 20th century resulting in elaborate respective stratigraphies (Matoshko et al., 2004; Panin et al., 2017; Velichko et al., 2011, 2006). Due to the relatively homogeneous nature of this machrochoric physical region (in terms of tectonics and geology) the loess and fluvial stratigraphies can seemingly be correlated over vast distances (ibid.). This allows for an easy-to-use temporal and paleoenvironmental classification of LPM open-air sites on a large proportion of the Russian Plain, while still considering potential differences in local and regional paleosol characteristics (Otcherednoi et al., 2018).

Within the time-frame of the LMP, the chronological frameworks of both the loess and the fluvial sequences to this day remain rather fragile, because they are supported by merely a handful of luminescence dates on the entire Russian Plain, represented by the works of Little et al. (2002) and Panin et al. (2017). Simple extrapolations to specific on-site environments are consequently not yet advisable. For that reason, the comparison with hemispherical climatic cycles as well as the identification of occupational patterns and any other form of Neanderthal adaptations is somewhat restrained, unless a high-resolution luminescence chronology is established directly on site.

In this study the LMP open-air site of Khotylevo I, area I-6-2, has been chosen for its geographic position and its suitable sediment archive. As one of the northernmost undisputed LMP assemblages on the European Plain (Nielsen et al., 2015) it provides valuable insights into the extension of the Neanderthal habitat. The site preserves ~12 m of well-stratified fluvial and loess-like sediments, giving it the potential to act as a hinge between the archeological and lithostratigraphical records on the Russian Plain. The objectives of this study are to establish a robust luminescence-based chronology for the sedimentary sequence exposed at Khotylevo I-6-2 and to clarify site formation by applying sedimentological logging and granulometric analyses. In doing so we intend to (i) obtain new results for the chronology of the late Middle Paleolithic of the north central and northeastern European Plain, (ii) reconstruct Pleistocene changes in palaeoenvironment to potentially better understand the connectivity between climatic shifts and Neanderthal appearance or disappearance, and (iii) give insight on the relation of fluvial archives to better known Loess-Paleosol-Cryogenic formations. The data presented here will chronologically constrain the occupation and sedimentary units at Khotylevo I, supplementing our knowledge of the late Pleistocene stratigraphy. Analysing geological and archeological deposits in conjunction should prove to be mutually beneficial for the chronological framework of both branches of quaternary science.

2. Geological and geomorphic setting

The Middle Paleolithic site of Khotylevo I (53.3° N, 34.1° E) in Western Russia is situated near the eponymous village, ca. 20 km from Bryansk upstream the River Desna (Fig. 1). Geologically the region is characterized by sedimentary rocks from the Upper Cretaceous, where unconsolidated Cennomanian sands and marls as well as flint-bearing chalks from the Turonian predominate (Sytchkin, 1998). During the course of the Pleistocene the area witnessed a succession of alternating glacial and periglacial periods. The Desna basin was last covered by ice sheets during the Dniepr Middle Pleistocene glaciation in MIS 8 when the layout of the River Desna was set as a glacial drainage channel (Gozhik et al., 2014a; Velichko et al., 2011). Fluvioglacial deposits of this era are found in the undulating watershed surfaces outside the river valley and consist of coarse-grained sands interlayered with bands, and clasts stemming from bedrock material (Gavrilov et al., 2015). These sediments represent the parent material for the Salyn soil formation of the Eemian (Mikulino) Interglacial (Otcherednoi and Voskresenskaya, 2009). In contrast, during the Weichselian (Valdai) glaciation between MIS 5d and 2, the region was subject to periglacial conditions interchanging with interstadials (MIS 5a, 5c and MIS 3). Several fluvial aggradation and incision phases occurred, forming the 1st and 2nd fluvial terrace, while loess accumulated in the coldest and most arid stages (especially MIS 4 and 2) (Little et al., 2002; Velichko et al., 2006). The latter cold phases were accompanied by the formation of pronounced, permafrost-induced cryogenic horizons. In contrast, pedogenic processes occurred mainly during the interstadial periods leading to intensive paleosols being frequently preserved in loess and fluvial terrace suites (Panin et al., 2018; Sycheva and Khokhlova, 2016; Velichko, 1990; Velichko et al., 2017). For many of the Weichselian processes and deposits the region constitutes the type area on the East European Plain.

The site itself is located on the raised right bank of the asymmetric Desna valley and is part of the sediment sequence that forms the 2nd fluvial terrace. Said terrace has been recognized in many fluvial catchments in Russia and the Ukraine as a morphological feature some 16–25 m above the current river courses (Grischenko, 1976; Matoshko et al., 2004). Whether it can also be regarded as a coherent and correlatable chronostratigraphical phenomenon is difficult to assess, largely due to a shortage of numerical dates. According to Velichko (1988) it accumulated in the Early Weichselian, a notion recently supported by Panin et al. (2017). The 2nd terrace of the Desna valley has been dissected by scores of ravines, dividing the riverbank into repeating promontory-ravine successions. The trench Khotylevo I-6-2 sits directly alongside one of those ravines' outlet into the recent floodplain (Fig. 1). For the archaeologically relevant layers at the bottom, it contains a succession of slope deposits, fluvial sediments and paleosols. These are

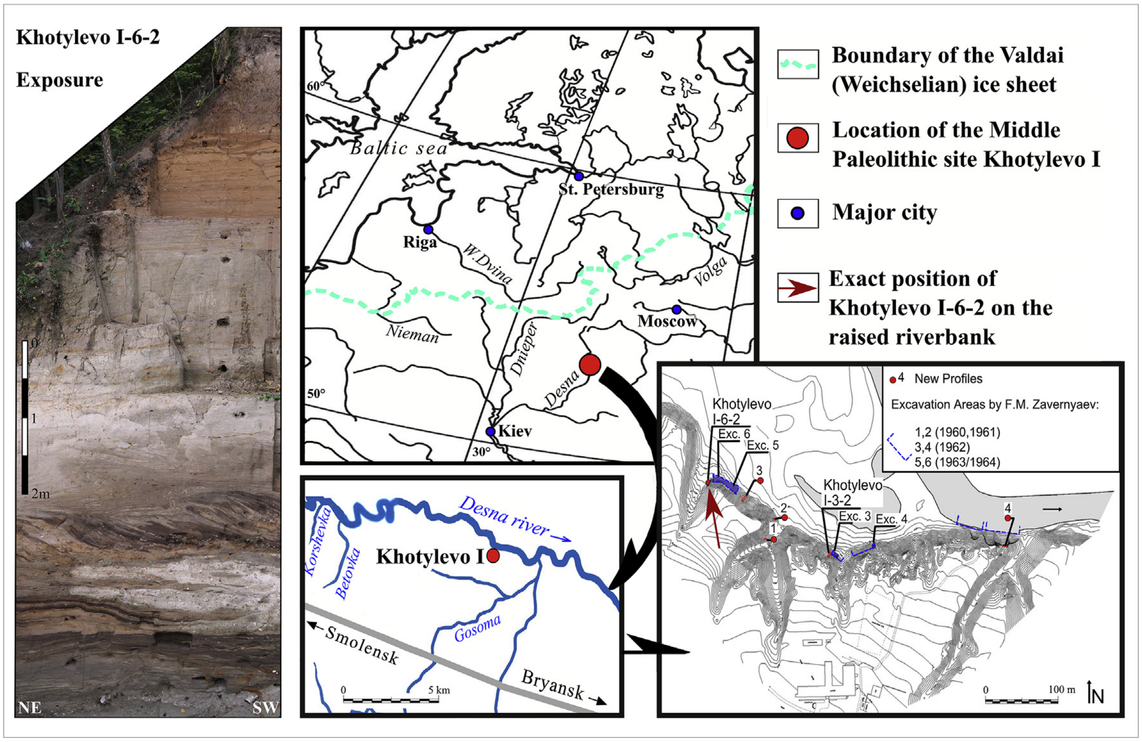

Fig. 1. Location of the site Khotylevo I, area I-6-2 with respect to the LGM ice sheet border, the other Khotylevo I trenches and the position within the river valley (adapted from Otcherednoi et al., 2014).

overlain by different alluvial sediments and topped by a cover loess. A detailed description of the exposure is given in section 4.1 of this article.

3. Materials and methods

3.1. Archeological finds

The site was found in 1958 by an archaeologist of the Bryansk Regional Museum, F.M. Zavernyaev, who started excavations in 1960 in areas where surface finds were previously collected. His team excavated six large trenches and several test pits along the right bank of the Desna over five years (Zavernyaev, 1978, see Fig. 1). The finds from Khotylevo I were associated with alluvial sediments. New work at the upstream sectors of the site began in 2010 and cultural remains were found in buried soils. The excavation area "Khotylevo I-6-2" is the focus of the present study.

The trench is characterized by three main find layers (Otcherednoi et al., 2014b, 2014a; Otcherednoi and Voskresenskaya, 2009; Weiss, 2019; Weiss et al., 2017): 'Cultural Layer 1' (CL1), 'Cultural Layer 2' (CL2) and 'Cultural Layer 4' (CL4) (Fig. 2). 'Cultural Layer 3' (CL3) revealed only a low number of finds (Table 1) and is not described in detail here. All occupations of Khotylevo I-6-2 can be attributed to the equivalent late Middle Paleolithic Micoquian (Bosinski, 1968, 1967), *Keilmessergruppen* (Mania, 1990; Veil et al., 1994), or the 'Mousterian with Micoquian Option' (Richter, 2016, 2012, 2002, 2001, 2000, 1997) of central and eastern Europe (for a discussion of the terms in relation to research history see Frick, 2020). Whereas the former terms put their emphasis on the presence of specific bifacial tools, the latter interprets Mousterian (without bifacial tools) and Micoquian (with bifacial tools) assemblages as related technocomplexes and continuous components of a single archeological entity (compare "Mousterian with bifaces", as termed by Gladilin, 1985). The terms will be used synonymously throughout the text. All find layers of Khtoylevo I-6-2 are characterized by Levallois and prepared core blank production (Table 1; Fig. 2: 1–3 & 6). The latter refers to cores with striking platform and core surface preparation, but these do not fall into one Levallois scheme *sensu stricto*. In CL1 and CL4 also bifacial tools occur, like typical bifacial backed knives or *Keilmesser* (Fig. 2: 5 & 10) in CL4, a characteristic tool type for the late Middle Paleolithic *Keilmessergruppen* or Micoquian of central and eastern Europe. Additionally, unifacial *Keilmesser* which are part of some *Keilmessergruppen* assemblages (Weiss et al., 2018) occur as well (Fig. 2: 4 & 9) in Khotylevo I-6-2, restricting this tool concept not only to bifacial tools. Although no bifacial tools could be recovered from CL2, ten flakes resulting from bifacial production could be identified (Otcherednoi et al., 2014a; Otcherednoy and Voskresenskaya, 2019; Vishnyatsky et al., 2015; Weiss, 2019; Weiss et al., 2017) and evidence their on-site manufacture. The late Middle Paleolithic character of the stone artefacts is reinforced by the fact that the analysis of the Khotylevo I-6-2 assemblages revealed strong relationships to other late Middle Paleolithic open-air assemblages between MIS 5a and MIS 3 from the European Plain (Ocherednoy, 2010; Weiss et al., 2017), namely Pouch (Weiss, 2015) and Königsaue (Mania, 2002; Mania and Toepfer, 1973), both Saxony-Anhalt/Germany, and Wrocław-Hallera Av. (Wiśniewski et al., 2013), southwestern Poland. The occurrence of high-quality flint slabs from the Cretaceous sediments directly at the site, together with the rather low frequency of tools in all layers (Table 1), as well as the potential manufacture and export of bifacial tools (CL2) point to a workshop character of the site.

3.2. Luminescence dating

3.2.1. Sampling and sample preparation

Eighteen samples were collected for luminescence dating by hammering stainless steel tubes horizontally into the freshly cleaned profile walls. For sampling positions and stratigraphy, the reader is referred to Fig. 4 and section 4.1. In order to prevent using sediment grains that might have been exposed to sunlight during sampling, the outer 2 cm were removed from both ends of the tube. These subsamples were used to estimate the burial water content. Sample preparation and equivalent dose-estimation (D_e) was conducted at the luminescence-dating laboratory of the Department of Human Evolution, Max Planck

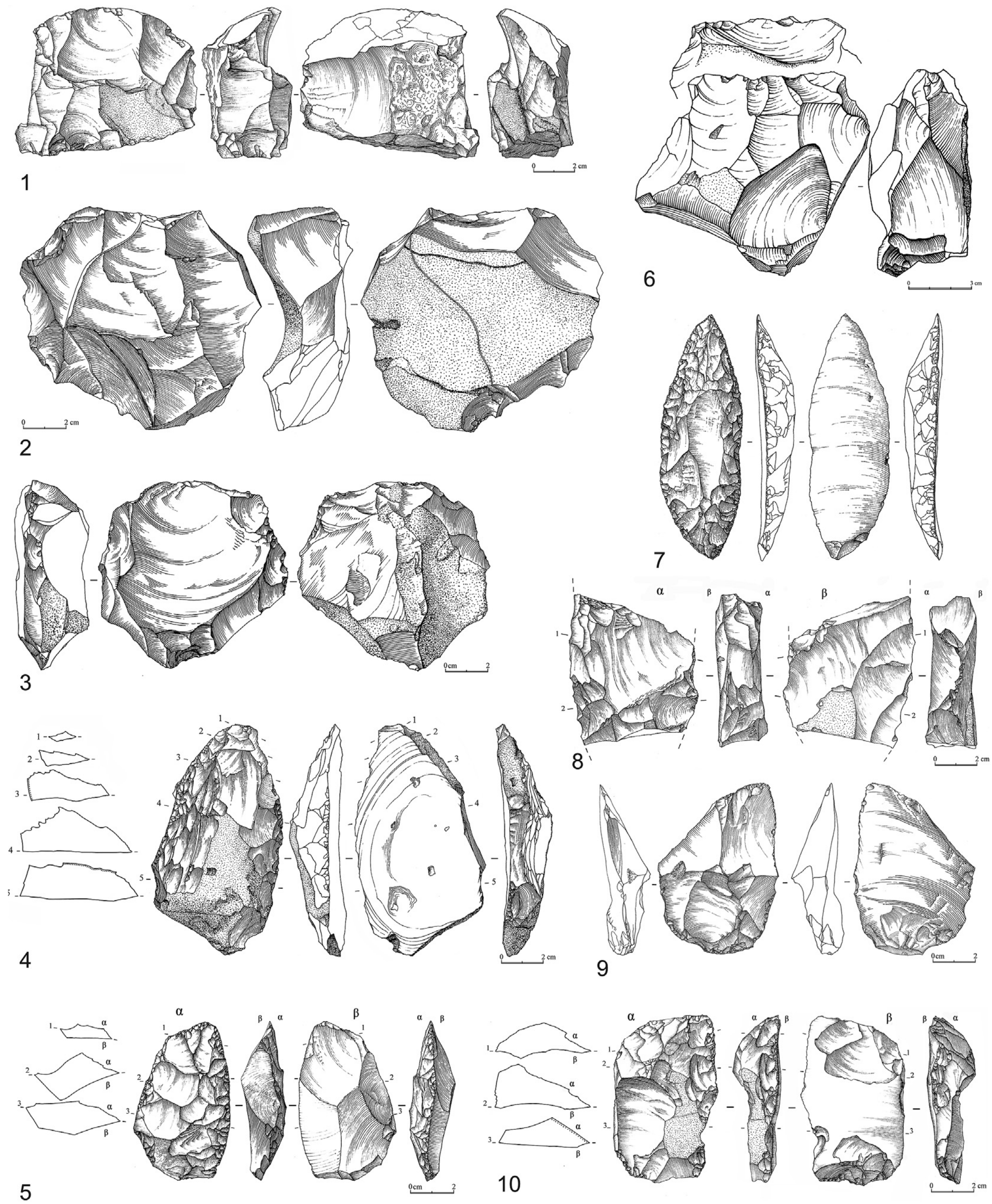

Fig. 2. Examples for artefacts from Cultural Horizon 1, 2 & 4. CL1: 1, 4, 6–8; CL2: 2; CL4: 3, 5, 9–10. 1–2: prepared cores; 3: Levallois-core (preferential), 4: unifacially surface shaped backed knife (Keilmesser-concept); 5, 10: bifacial backed knives (Keilmesser); 6: Levallois-core (preferential); 7: unifacially surface shaped point; 8: fragment of a bifacial tool; 9: retouched backed flake or simple backed knife (Keilmesser-concept). Drawings: A. Otcherednoy.

Table 1
Summary of the artefacts discovered at Khotylevo I-6-2. The result for the 2017 season of CL4 is displayed separately, as it provided the largest quantity of artefacts but is not yet fully analyzed. *Plane and prepared cores only. **Levallois centripetal only.

Cultural Layers	Cores (n*/L**)	flakes	chips	Unifacial tools	Bifacial tools	∑
1	22/0	207	371	11	4	973
2	7/0	1074	1884	7	0	3033
3	3/0	120	191	1	0	326
4	37/3	831	2132	30	4	3388
4 (2017 season)	2446		7514	2	1	9963

Institute for Evolutionary Anthropology, Leipzig. Preparation under subdued red light comprised drying at 50 °C, sieving to obtain the desired grain-size (180–250 µm, and 4–11 µm for sample 1702), and a chemical treatment to remove carbonates and organic matter, utilizing HCl (10%) and H_2O_2 (30%) respectively. Heavy liquid separation (lithium heterotungstate) was used to separate quartz and K-feldspar from the remaining mineral matrix at densities of 2.62–2.68 g/cm3 and <2.58 g/cm3, respectively (cf. Aitken, 1998). The extracted quartz was subsequently etched with concentrated HF (40%) for 60 min to remove the naturally α-irradiated outer rind and potential feldspar contaminations (Wintle, 1997). The etched samples were re-sieved to recover the desired grain-size fraction. Laboratory measurements were made using multiple-grain aliquots by mounting grains onto stainless steel discs (24–48 aliquots) using silicone spray and a mask of 0.5 mm; each aliquot comprised 5–10 grains (Duller, 2008). Luminescence sensitivity was tested beforehand with higher but successively decreasing aliquot sizes to ensure sufficient photon counts. Lacking adequate coarse-grained material for sample L-EVA 1702, the polymineral 4–11 μm fraction was prepared and mounted on aluminum discs (16 aliquots).

3.2.2. Dose rate determination

Additional sediment samples were collected alongside the OSL-samples for dose rate determination using high-resolution germanium gamma spectrometry. Analyses of the specific activities of the radioelements ^{238}U, ^{232}Th, ^{4}K and their daughter isotopes were undertaken at VKTA laboratory in Dresden (Table 2, and supplementary information). In-situ gamma spectrometry was measured using a calibrated $LaBr_3$-detector (Inspector 1000) for three samples (L-EVA 1712, 1714 and 1716) to improve dose rate determinations in thin archeological layers. The saturated water content was used to approximate dose rate attenuation by moisture (Table 2). The contribution of cosmic radiation to the total dose rate was calculated based on Prescott and Hutton (1994). The internal beta dose-rate contribution for the K-feldspar samples assumed an effective potassium content of 12.5 ± 0.5% (Huntley and Baril, 1997). Radioactivity conversion factors were applied following Guérin et al. (2011). For the K-feldspar samples an a-value of 0.11 ± 0.02 was used to allow for the comparison of lower luminescence-efficient alpha particles with beta and gamma radiation (Kreutzer et al., 2014).

3.2.3. Equivalent dose estimation and testing

Equivalent doses were estimated using a Risø TL-DA-20 reader equipped with IR light-emitting diodes transmitting at 870 nm wavelength for K-feldspar measurements and blue light-emitting diodes (470 nm) for quartz. The emitted luminescence signal was detected through a D-410 filter and a Hoya U-340 filter, respectively. Artificial irradiation was delivered by a calibrated $^{90}Sr/^{90}Y$ beta source with a dose-rate of ~0.23 Gy/s. First test-measurements on quartz using samples L-EVA 1702, 1704, 1706, 1707, 1709, 1710 and 1711 (from the upper part of the sequence) showed the natural quartz luminescence signal close to, or in saturation for the majority of the samples. The only sample that showed a natural quartz signal below $2D_0$ was sample L-Eva 1702. Thus, further measurements were undertaken solely on K-feldspars as they typically saturate at much higher doses (e.g. Buylaert et al., 2012). To avoid the issue of anomalous fading and the potentially problematic correction involved (Huntley and Lamothe, 2001; Wintle, 1973), we used the $pIRIR_{290}$ approach as suggested by Thiel et al. (2011) and summarized in Table 3. Generally, stimulating and measuring feldspars at elevated temperatures after depleting the IR_{50} signal has been shown to produce robust luminescence ages (Thomsen et al., 2008). Six samples were bleached in the solar simulator for 3 h and used for dose recovery tests with different protocols. Comparison of the residual-subtracted measured-to-given dose ratios from the different signals ($pIRIR_{225}$, $pIRIR_{290}$ and $pIRIR_{290}$ with a hotbleach), showed the most reliable results from the latter protocol (Fig. 3, see supplementary information for discrete residual doses). Thus, a 325 °C hotbleach was included at the end of each measurement cycle (Table 3, step 9). The dose response curve was built using four to five regenerative dose points following the measurement of the natural IR-signal (L_x) and fit with an exponential function. Recycling ratios were calculated by re-measuring the first low-dose point after the highest regenerative dose point and all aliquots deviating >10% were rejected. In addition, only aliquots with recuperation below 5% of the natural signal were included. To examine the stability of the $pIRIR_{290}$ signal anomalous fading was measured in 6 samples (3 aliquots each) following the procedure of Huntley and Lamothe (2001), but including a 325 °C hotbleach. All g-values obtained using the $pIRIR_{290}$ signal were substantially lower than the values from the corresponding IR_{50} signal (Fig. 3). With the exception of samples L-EVA 1715 and 1717 all $pIRIR_{290}$ fading rates are <2.0%/decade, whereas the mean of all obtained g-values is 1.6 ± 0.1%/decade, attesting to the stability of the $pIRIR_{290}$ signal.

Table 3
Measurement steps for the $pIRIR_{290}$-approach.

Step	Treatment	Description
1	Dose	
2	Preheat (320 °C for 60s)	
3	IRSL, 100 s at 50 °C	Remove unstable signal
4	IRSL, 200 s at 290 °C	L_x
5	Test dose	
6	Cutheat (320 °C for 60s)	
7	IRSL, 100 s at 50 °C	Remove unstable signal
8	IRSL, 200 s at 290 °C	T_x
9	IRSL, 100 s at 325 °C	Hot bleach
10	Return to step 1	

3.3. Grain size analysis

A portion of the material collected for luminescence dating was used for grain-size determination. Analyses were conducted at the Leibnitz Institute for Applied Geophysics, Geochronology Section using a

Table 2
Results of high resolution gamma-ray spectrometry and saturation water contents used for correction. The gamma dose rate contribution for samples L-Eva 1712, 1714 and 1716 were obtained by in-situ gamma spectrometry using a calibrated $LaBr_3$ detector. The alpha, beta and gamma dose rates for each sample are presented in the supplementary information.

Lab.-ID	U (ppm)	Th (ppm)	K (%)	Cosmic Dose (Gy/ka)	DR_{total} (Gy/ka)	H_2O (%)
1702	2.1 ± 0.4	9.6 ± 0.7	1.80 ± 0.15	0.20 ± 0.02	3.49 ± 0.22	21.5 ± 5
1703	2.1 ± 0.3	8.9 ± 0.6	1.45 ± 0.12	0.19 ± 0.02	2.81 ± 0.15	21.4 ± 5
1704	2.3 ± 0.4	7.8 ± 0.5	1.51 ± 0.12	0.18 ± 0.02	3.02 ± 0.16	12.2 ± 5
1705	1.8 ± 0.3	7.8 ± 0.5	1.10 ± 0.07	0.17 ± 0.02	2.54 ± 0.14	12.9 ± 5
1706	1.4 ± 0.2	5.7 ± 0.4	1.15 ± 0.07	0.16 ± 0.02	2.35 ± 0.14	13.3 ± 5
1707	2.0 ± 0.3	7.9 ± 0.5	1.52 ± 0.12	0.16 ± 0.02	2.84 ± 0.15	17.2 ± 5
1708	2.6 ± 0.5	9.5 ± 0.6	1.88 ± 0.14	0.15 ± 0.01	3.27 ± 0.16	19.9 ± 5
1709	1.9 ± 0.3	8.8 ± 0.6	1.73 ± 0.11	0.14 ± 0.01	3.06 ± 0.15	16.2 ± 5
1710	1.9 ± 0.5	6.6 ± 0.4	1.37 ± 0.11	0.14 ± 0.01	2.67 ± 0.16	13.5 ± 5
1711	1.6 ± 0.3	6.0 ± 0.4	1.34 ± 0.11	0.14 ± 0.01	2.56 ± 0.15	12.4 ± 5
1712	1.0 ± 0.2	4.1 ± 0.3	0.88 ± 0.07	0.13 ± 0.01	2.05 ± 0.14	12.0 ± 5
1713	1.18 ± 0.2	4.1 ± 0.3	1.10 ± 0.07	0.13 ± 0.01	2.18 ± 0.14	9.5 ± 5
1714	1.09 ± 0.2	4.9 ± 0.3	1.05 ± 0.09	0.13 ± 0.01	2.20 ± 0.15	12.1 ± 5
1715	1.43 ± 0.27	3.6 ± 0.3	1.06 ± 0.09	0.13 ± 0.01	2.15 ± 0.15	10.2 ± 5
1716	1.4 ± 0.3	5.9 ± 0.4	1.16 ± 0.07	0.12 ± 0.01	2.37 ± 0.14	12.9 ± 5
1717	0.9 ± 0.3	3.3 ± 0.3	0.83 ± 0.09	0.12 ± 0.01	1.80 ± 0.15	11.0 ± 5
1718	1.1 ± 0.3	4.7 ± 0.3	1.07 ± 0.08	0.12 ± 0.01	2.13 ± 0.14	12.6 ± 5
1719	1.5 ± 0.4	4.8 ± 0.3	0.92 ± 0.07	0.12 ± 0.01	2.08 ± 0.15	12.7 ± 5

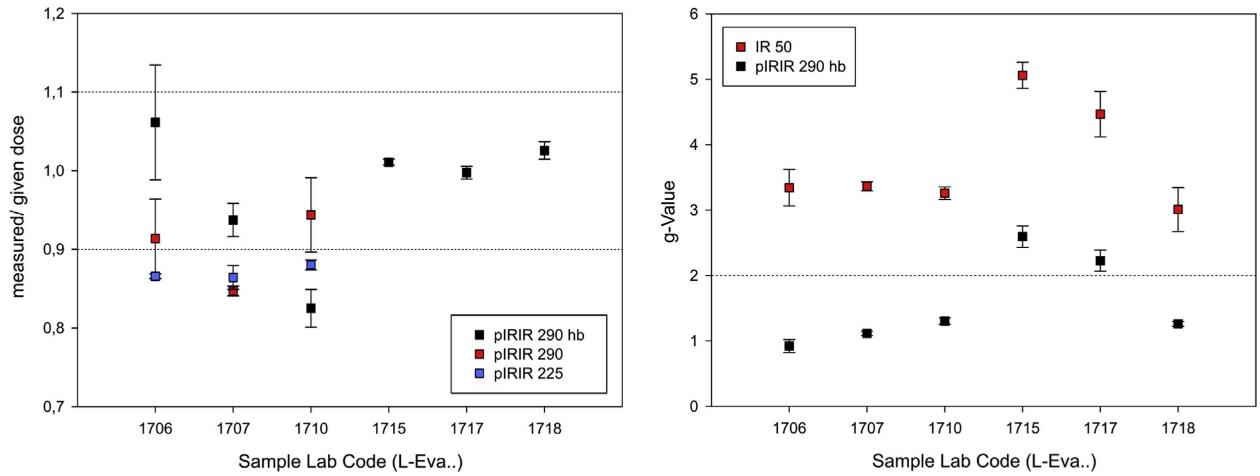

Fig. 3. Left - Comparison of dose recovery tests for the pIRIR225 and pIRIR290 (with and without a hot bleach, hb) protocols; the residual signal was subtracted from the measured dose. Right – Comparison of fading rates (g-values in %/decade) for the IR50 vs. pIRIR290 signals.

Beckman-Coulter LS 13320 PIDS laser diffractometer detecting a spectrum from 0.4 to 2000 μm. The measurement protocol was described by Machalett et al. (2008). For sample preparation, instead of ultrasonic treatment we dispersed with 1% ammonium hydroxide (NH_4OH) in overhead rotators for at least 12 h. We abstained from removing organic matter and carbonates, because organic matter apparently has a negligible effect on grain-size distribution (Beuselinck et al., 1998; Machalett et al., 2008) and because field tests implied no significant carbonate contents in our sediments. All samples underwent a fivefold measurement, averaging the results to receive the final grain-size cluster on condition that standard deviation of all grain-size spectra remained below 5%. Sample L-EVA 1709 did not satisfy this criterion and was therefore excluded from all further interpretations.

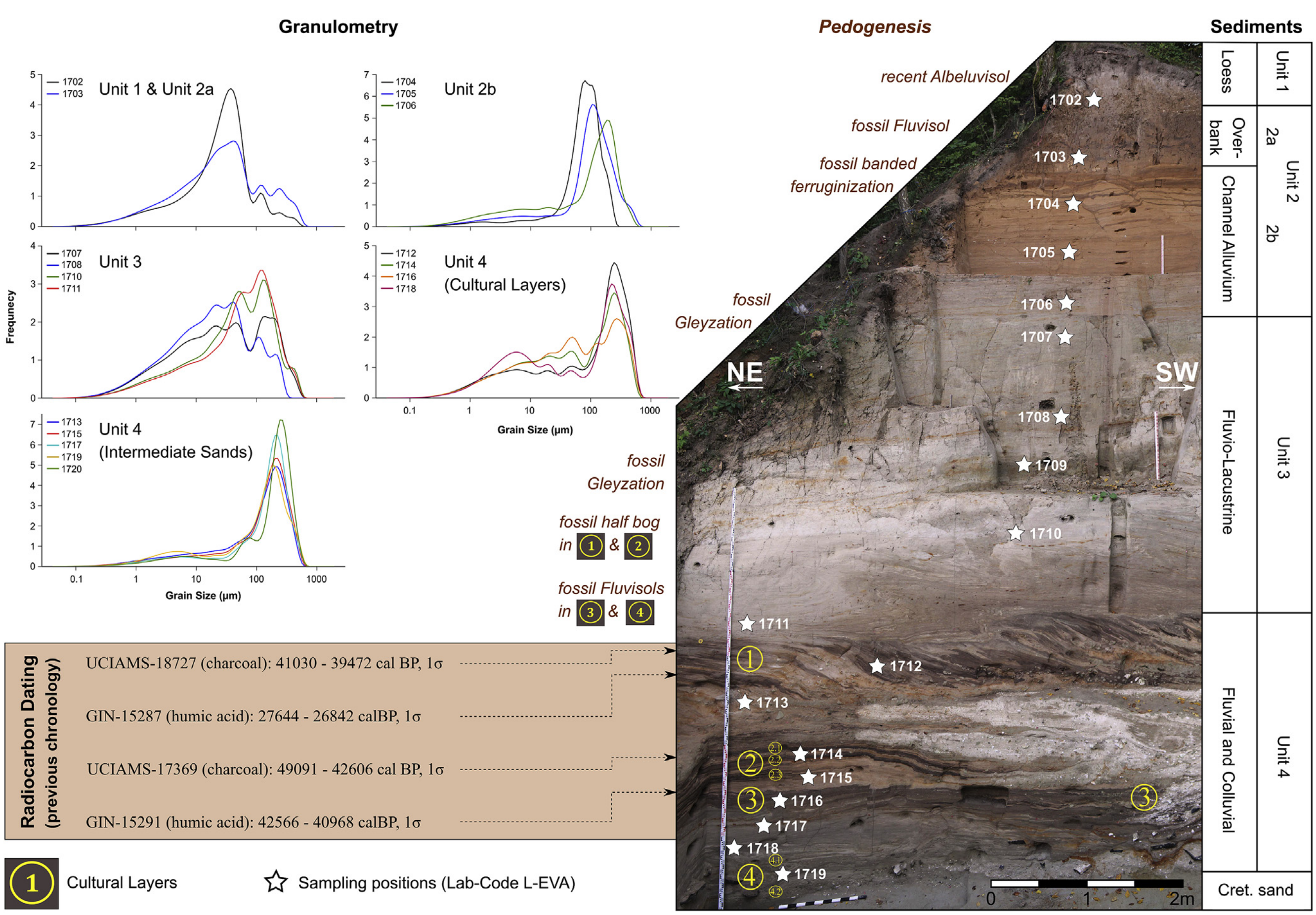

Fig. 4. Overview of the sampling positions, stratigraphy, grain-size distributions and existing ^{14}C chronology following Otcherednoi et al. (2014b); Otcherednoy and Voskresenskaya (2019) and Vishnyatsky et al. (2015).

4. Results

4.1. Site stratigraphy based on field investigations and grain-sizes

Khotylevo I-6-2 is an artificial exposure for archeological purposes. Cut into the steep river bank of the 2nd fluvial terrace, it lies directly at the conjunction with a smaller ravine ceasing at this spot and aligning with the modern floodplain. It comprises ~12 mof alluvial, colluvial and aeolian sediments, resting against the primary slope of the valley which formed earlier in the Pleistocene (Otcherednoy and Voskresenskaya, 2019). The profile was first described by E.V. Voskresenskaya (Voskresenskaya and Ocherednoy, 2010; Voskresenskaya et al., 2011; Voskresenskaya and Ocherednoy, 2012; Otcherednoi et al., 2014a). Based on field work between 2017 and 2019, the section was divided into four broad sedimentary units described from top to bottom in the following paragraphs. The results of the grain-size analysis were utilized to support attribution of the deposits to specific processes (Fig. 4).

4.1.1. Unit 1

Unit 1 consists of fine-grained loess or loess-like deposits, indicated by grain size distribution with a coherent sorting and a pronounced maximum in the coarse silt fraction (L-EVA 1702). The loess has been subjected to pedogenesis after deposition and all primary carbonates have been leached from the substrate, leading to the formation of a rather acidic Albeluvisol according to WRB (2015).

4.1.2. Unit 2a

Unit 2a is a partially laminated sandy-silty deposit (facies code *Fl* to *Fsm*, after Miall (2006)), with a distinct upper boundary and is also devoid of carbonates. Grain sizes infer the relatedness to loess, while at the same time indicating a polygenetic sedimentary process with the additional contribution of fine and middle sands (L-EVA 1703). This unit is best described as overbank fines, assuming the reworking of loess at the time of deposition. Discontinuous humic lenses with a strong blackish color and containing abundant fragments of charcoal occur in this layer, presumably derived from burning events. These overbank fines are capped by a humus-enriched soil of ca. 30 cm thickness (Fluvisol, according to WRB (2015)). A very sharp and likely erosional contact at 190 cm delimits this unit at the bottom.

Overbank sediments are deposited during or after river flooding in shallow water. Longer periods between flooding events may lead to multiphased soil formation of varying degrees within the overbank fines (Fluvisols). The deposition of fine grains is due to preferential sorting and the source material, which is often loess. As is the case in Khotylevo I-6-2, typically comparable Pleistocene overbank deposits are overlain by a younger loess in many European fluvial catchments (cf. Vandenberghe, 2015).

4.1.3. Unit 2b

This unit of ~3 m thickness consists of well-sorted light yellow to light orange fine sands. It is characterized by cm-scale horizontal beds, with individual beds sometimes showing slightly oblique lamination, and is completely devoid of gravels. Very seldom pebble-sized items occur, which are allothonous clasts of the Cretaceous marls and chalks. An overall dip in any direction could not be observed. Downthrows, interpreted as unloading cracks, cut through the sequence with a displacement figure in the dm range. In the topmost 150 cm of this unit secondary ferruginious layers – Ortsands, partially consolidated as Ortstein – occur (cf. Panin et al., 2017). Their thickness gradually decreases downwards from 20 cm at the Unit 2b/2a boundary to a few mm within a meter further down. The lowermost 100 cm of the Unit possess gleyic features, in this respect pre-announcing similar conditions in Unit 3. Grain sizes of the three samples (L-EVA 1704 to 1706) display a fining-upwards trend, with a relative continuation to the top in the form of the hanging overbank fines of Unit 2a.

For this unit we allocated the facies code *Sh* (horizontally laminated sandy fluvial sediments), as proposed by Miall (1977). However, assigning it to a specific element of the alluvial architecture proved challenging, and was not conclusive (cf. Ashworth et al., 2011; Brierley, 1989). In most periglacial rivers crudely-bedded or massive gravel layers are common (Van Huissteden et al., 2013). Horizontal lamination of sands rarely occurs and if so, the units usually have a small extent, both in the lateral and in the vertical direction (Hickin, 1993; Lynds and Hajek, 2006; Miall, 2006). This particular facies (*Sh*) is elsewhere often interpreted as a product of transitional to rapid flow regimes. High-energy, possibly shallow discharge events are held accountable. Even ephemeral, flashy sheetflood events of the "Bijou Creek-type" can lead to these plane-laminated sands (Miall, 2006). In contrast, very low flow velocities and shallow water may also result in horizontal lamination characterized by fine grading (Miall, 1977). This coincides with Vandenberghe's view (2015), whereupon the *Sh*-facies is deposited under predominantly quiet conditions towards the edges of an active channel belt.

However, in the Desna-Dniepr system horizontally laminated fine sands are very common in the alluvial suites of the 2nd terrace, whereas the coarse fraction is usually less than 1% (Matoshko et al., 2004; Panin et al., 2017). This could be explained by the low dip angle and the restricted availability of crystalline bedrock in this part of the East-European Plain, where thick Mesozoic sedimentary rocks predominate. Based on the above considerations, in conjunction with the absence of a coarse fraction in the modern channel bottom of the River Desna, we tentatively interpret Unit 2b as channel alluvium, that may have been deposited in the marginal zone of the active river.

4.1.4. Unit 3

This fine-grained, loamy unit displays definite features of gleyzation throughout, in the form of reduction and lepidocrocite precipitation. Cautiously, said features can be interpreted as synsedimentary (Miall, 2006). The unit is divided into two sub-units with slightly differing depositional environments. The upper ca. 200 cm (L-EVA 1707, 1708) comprise a very dense and massive loam with a noticeable clay content, a slightly raised content of organic carbon and only rare lenses of coarser sands (facies code *Fsm*, after Miall (2006, 1977)). In contrast, the lower part of the unit (L-EVA 1709 to 1711) exhibits lamination of lighter fine-sands and greyish silts with a lower clay content (facies code *Fl*). Presumably the increments represent individual flooding events. Toward the base of Unit 3, these lamellae are distorted by cryoturbation and solifluction.

Grain-size distributions reveal a polymodal distribution, with one peak in clay and silt and another peak in the fine-sand fraction, which supports the subdivision of this unit. While the upper, massive part is informed by a broader clay and silt peak, the lower part is biased toward the fine-sand fraction. As indicted by the grain-sizes, fluvial reworking of more or less contemporaneous loess deposits contributed to the sediment composition of the entire unit. This argument is further supported by the chronological position of the unit close to the time of main loess delivery (see sections 4.2. and 5.2.2).

In general, fine-grained clastics are derived from suspension load and as such cannot be deposited within active river channels. Hence, they represent low-energy (i.e often distal) environments in floodplains, ponds or abandoned channels. In major suspension-load streams the thickness of those units can stretch up to several meters (Miall, 2006). Unit 3 was most likely deposited in the rear part of the Desna alluvium (cf. Velichko, 1988), whereas an abandoned channel fill is ruled out for the lack of peat layers, plant remains and severely clayey segments (Rust, 1972). Following Miall (1977) these sediments of Unit 3 are explained as fluvio-lacustrine or backswamp deposits (cf. Hickin, 1993). Indeed, the lower part could also be interpreted as waning flood deposits due to the lamination. It is however noteworthy, that small desiccation/frost cracks in Unit 3 only appear on the very top, indicating that up to this point in time there were no significant drying-out phases during deposition. Since the continuous gleyzation supports this argument, we refute an interpretation as overbank fines in favor of fluvio-lacustrine backswamp deposition throughout the entire Unit 3. In this milieu the binding effect of vegetation may lead to the formation of small mud laminae. Each increment represents the suspended load of one flood cycle (Rust, 1972; Miall, 2006). In the massive upper part of the Unit, the lamination may never have formed or been destroyed post-depositionally. Until further sites along the river Desna are investigated, an *anastomosing* river-type, formed by an excess of fluvially reworked loess cannot be ruled out for the formation of Unit 3. In anastomosing channels high suspension loads favor an aggradational regime and a constraint in lateral expansion (Hugget, 2011). Similar gleyic fine-grained deposits are well known to exist both in the distal part and as stable elongate islands between braided channels in anastomosed systems (Smith and Smith, 1980).

4.1.5. Unit 4

With regard to depositional regime, Unit 4 is quite diverse and additionally contains four archeological find layers (CL1 – CL4, Figs. 4 and 5). CL1 and 2 are similarly composed of thin beds of greyish-brown loams, rich in humus (L-EVA 1712 and 1714). The individual beds are interfingered with equally thin strata of fine ferruginous sands and fragments of marls and chalk. The same interbeds are found *between* CL1 and CL2. All the archeological finds are restricted to the humic beds. We argue that these humic beds are semi-terrestrial half-bog soils at the edge of the floodplain, whereas the fine-sands represent dislocated glacio-fluvial deposits being washed down the slope of the ravine. Those original deposits from the Saalian glaciation occur in abundance in the plateau positions outside the river valley (Gavrilov et al., 2015). The ravine seems to act as a conveyor of these locally-sourced sediments into the valley, as these deposits are only subordinately found at other Khotylevo I sections further afield from ravine influence (for locations see Fig. 1). CL2 comprise three sublayers interbedded with and underlain by the same dislocated glacio-fluvial ferruginous sands. In CL3 (L-EVA 1716 and 1717) there is a distinct change to gleyic, subhorizontally layered fine sands (facies codes Sh to Sm after Miall (1978)). Furthermore, the top of CL3 (L-EVA 1716) is enriched in organic carbon und thus likely represents another short-termed Fluvisol formation. CL4 (L-EVA 1718 & 1719) is influenced by fluvial and solifluction deposits, bearing slope-adjusted tabular flints with diameters of up to 40 cm. These presumably constitute the source of raw material for stone artefact production at the site. Again, the top of this layer (L-EVA 1718) is enriched in humic material from Fluvisol formation.

The sediments of Unit 4 described above, with alternating fluvial/alluvial and slope deposits, have not all been preserved in their primary stratification. Rather, they have been partially compromised by the intrusion of an extensive lobe of Cretaceous chalks and marls, displaced either shortly after sedimentation as debris flow or solifluction bed, or post-sedimentarily as an oversaturated injection. Neither interpretation is favored at the moment as both seem to be equally reasonable explanations for the encountered sediment characteristics of Unit 4. This lobe is associated with and has been moving down the tributary ravine. It thins out within the section thereby indicating that, at the time of formation, it already reached flood plain level and did not have sufficient relief energy left for further transport. At any rate, the lobe in question causes a considerable distortion of CL1 to CL3, whereas CL4 seems to remain rather unaffected (Fig. 5):

(1) CL1 is reversely dipped at an angle of 45° directly above the bulk of the lobe, but rapidly levels out as the lobe is thinning out in the NE part. Additionally, it is mixed with the underlying and interfingering glaciofluvial sands and clast of chalk and marl.
(2) CL2 and 3 feature small-scale thrust faults (Fig. 5) directly underneath the lobe, probably caused by differential settlement due to its mass. Furthermore, in the southern part of the section these layers have been cut and partially reworked by the Cretaceous sediments' displacement

Below CL4 there is a sharp erosional contact and a hiatus to the underlying Cennomanian glauconite sands, containing phosphorite nodules in large quantities.

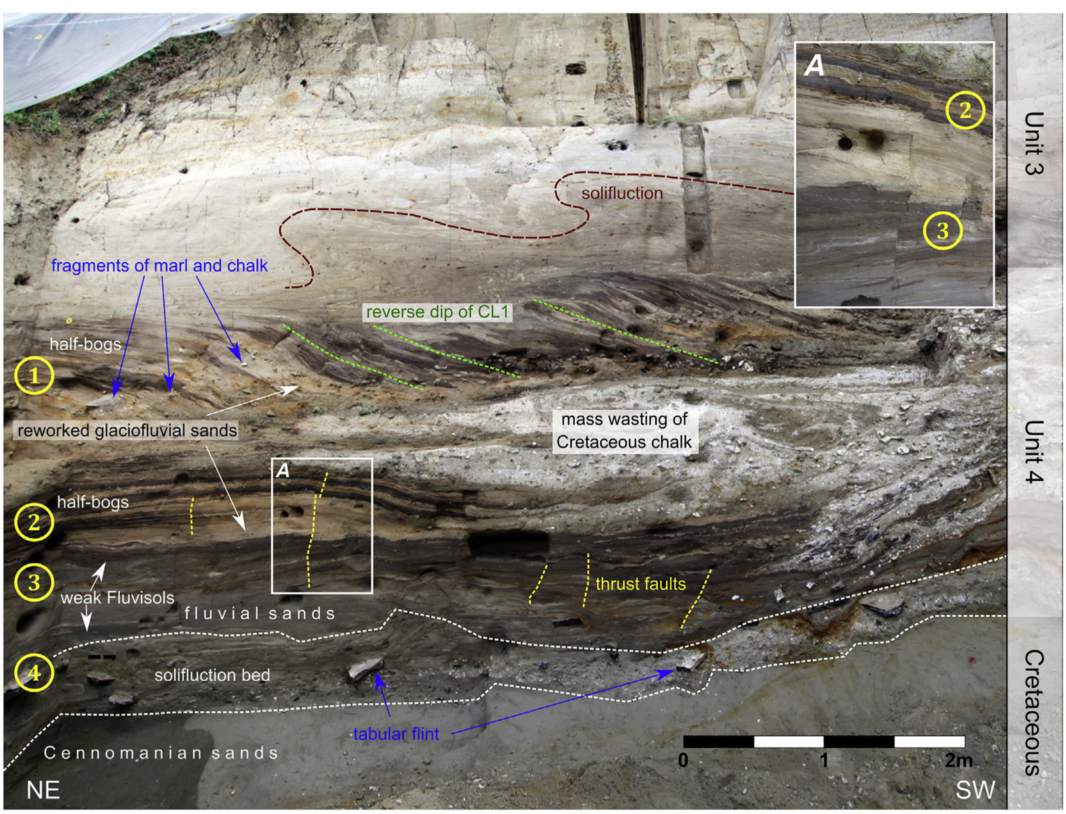

Fig. 5. Close-up view of the stratigraphy and noteworthy features of Unit 4. Details are given in section 4.1. Yellow numbering: Cultural Layers.

4.2. Luminescence dating

The obtained luminescence age-estimates of the exposed sedimentary units range from 21.1 ± 1.6 ka to 130.2 ± 11.1 ka (Table 4). Unit 4 is dated to between 77.6 ± 5.6 ka and 130.2 ± 11.1 ka, Unit 3 between 57.3 ± 4.4 ka and 69.0 ± 4.8 ka, Unit 2b is generally overestimated with an age range of 65.9 ± 6.4 ka to 76.1 ± 4.8 ka. Unit 2a yields an age of 54.1 ± 3.4 ka for the overbank deposit and the loess of Unit 1 is dated to 21.1 ± 1.6 ka. The non-fading corrected results of the feldspar $pIRIR_{290}$ dating are shown in Table 4 alongside the weighted-mean D_e-estimates. The listed one sigma standard errors do not include any systematic uncertainties, as those are not easily quantified and would have applied for all samples similarly, anyway. Using the weighted mean was deemed suitable because of the low scatter in De-distributions as revealed by the low overdispersion (OD) values (Table 4, Fig. 6). The reliability of these ages is discussed below in section 5.1.

5. Discussion

5.1. Luminescence ages and their robustness

5.1.1. De-distributions

Overdispersion (OD) is below 20% for most of the samples, especially in the fluvial and aeolian deposits of Unit 1 to 3 (Table 4). Furthermore, the mean OD value for the entire sample set is 19.7 ± 0.7%, therefore insufficient bleaching is most likely not a serious issue (Duller, 2008). For three samples (L-EVA 1712, 1713 and 1718), OD-values are nearing or exceed 30%. Such high OD-values could result from incomplete bleaching before burial, mixing of grains after burial or small-scale differences in dose rates of same-aged grains (Jacobs and Roberts, 2007). For L-EVA 1712 and 1713 all three potential factors seem to play a role. (1) Representing reworked Saalian glaciofluvial sediments, the aliquots of L-EVA 1713 must be considered incompletely bleached as is also confirmed by the overestimated feldspar age. (2) Since CL1, where sample L-EVA 1712 was collected, is to some extent mixed with these glaciofluvial sands by the intrusion of Cretaceous sediments, the possible effect of partial bleaching on OD-values would have been imprinted upon L-EVA 1712, as well. Additionally, mixing of slope and fluvial deposits might have increased the OD. But the latter influences cannot, in fact, explain the OD spread in those two samples, as L-EVA 1715 has likewise been taken from reworked glaciofluvial sediments and much lower OD-values were obtained (20.6 ± 0.6%). For this reason, we argue (3) that small-scale differences in beta dose-rate are to be held accountable for the higher values in L-EVA 1712 and 1713 compared to 1715. The aforementioned intrusion of Cretaceous sediments into the reworked glaciofluvial sands led to an admixture of little clasts of marls and chalk which are lacking in the otherwise similar reworked glaciofluvial sands around L-EVA 1715. The same seems to be true for L-EVA 1718, where the higher OD-values cannot easily be explained by insufficient bleaching or post-depositional mixing. Rather, here too, uncertainties in beta dose-rate might arise from the interspersed tabular flints within the sediment.

5.1.2. G-values

The g-values obtained using the $pIRIR_{290}$ signal (Fig. 3, Table 4) were generally low, apart from the samples L-EVA 1715 and 1717, whose values exceed 2%/decade. This can either be attributed to a laboratory artefact or different provenances for the respective feldspars, that may be more susceptible to fading, despite using a feldspar emission known to be characterized by a high signal stability (Buylaert et al., 2012). Fading in these two samples (L-EVA 1715 and 1717) is supported by exceptionally high g-values for the corresponding IR_{50} measurements (Fig. 3). If these two samples are in fact prone to slight fading, their dates should be considered as minimum ages. For the overall chronological framework however, this is not a prominent issue. L-EVA 1715 stems from a proximal source, the poorly bleached reworked glaciofluvial sand, that is deemed overestimated (discussed below). And L-EVA 1717, deriving from a fluvial sand with a more distant source, is sufficiently supported by the two samples L-EVA 1718 and 1716 (immediately above and below) that show very consistent age estimates of 77.7 ± 6.4 and 77.6 ± 5.6 ka, respectively.

5.1.3. Age-depth model and reasons for age overestimations

Fig. 7 shows the $pIRIR_{290}$-ages plotted against the sampling depth. For context and orientation, a sketch of the stratigraphy is displayed and the Marine Isotope Stage-boundaries (MIS) alongside the NGRIP-record are appended. The ages are generally consistent with stratigraphic considerations. The cultural layers have fairly homogeneous ages between 77.6 ± 5.6 ka and 87.7 ± 9.0 ka. These ages fall within MIS 5a but cannot be distinguished temporally based on our chronology. For five samples an age inversion has occurred. Aforementioned processes, resulting in a high OD value might be responsible for the overestimation of sample L-EVA 1713, whereas in L-EVA 1715, and L-EVA 1704 to 1706 other factors must (additionally) be held accountable, chief among which is the uncertainty inherent in the determination of the water content. Overestimation of the burial water content would result in overestimated ages for samples L-EVA 1704 to 1706, and 1715 as well as possibly L-EVA 1713 (e.g. Nelson and Rittenour, 2015). However, this alone does not justify the entire chronological deviation as assuming a non-realistic water content of 0% still produces unsatisfactory results in terms of

Table 4
Summary of the k-feldspar $pIRIR_{290}$ dating results. The De-estimations are based on the weighted mean. OD: Overdispersion; No. al: Number of accepted aliquots for De-estimation; DR ratio: measured-to-given dose ratio from dose-recovery test.

Unit	Lab.-ID (L-EVA)	De (Gy), 1σ	Age (ka), 1σ	OD %	No. al	G-value (%/decade)	DR ratio $pIRIR_{290\ hb}$
1	1702	73.6 ± 3.3	21.1 ± 1.6	15.8 ± 0.7	16		
2a	1703	152.0 ± 5.2	54.1 ± 3.4	14.7 ± 0.5	21		
2b	1704	199.0 ± 6.3	65.9 ± 6.4	16.2 ± 0.5	26		
2b	1705	193.2 ± 5.4	76.1 ± 4.8	12.7 ± 0.4	24		
2b	1706	161.5 ± 5.9	68.8 ± 4.8	15.4 ± 0.5	24	0.9 ± 0.1	1.06 ± 0.07
3	1707	162.7 ± 8.8	57.3 ± 4.4	20.4 ± 0.8	19	1.1 ± 0.0	0.94 ± 0.02
3	1708	187.9 ± 5.6	57.4 ± 3.4	15.8 ± 0.5	23		
3	1709	179.9 ± 5.8	58.8 ± 3.5	14.8 ± 0.5	24		
3	1710	171.5 ± 6.6	64.3 ± 4.6	21.1 ± 0.7	22	1.3 ± 0.1	0.83 ± 0.02
3	1711	176.8 ± 6.2	69.0 ± 4.8	15.8 ± 0.5	24		
4 – CL1	1712	175.0 ± 10.7	85.4 ± 7.9	33.9 ± 1.2	20		
4	1713	254.9 ± 18.0	117.0 ± 11.3	27.9 ± 0.8	24		
4 – CL2	1714	180.1 ± 9.9	81.7 ± 7.1	21.7 ± 0.7	22		
4	1715	279.6 ± 13.9	130.2 ± 11.1	20.6 ± 0.6	24	2.6 ± 0.2	1.01 ± 0.00
4 – CL3	1716	183.6 ± 7.1	77.6 ± 5.6	17.4 ± 0.6	22		
4	1717	157.8 ± 9.8	87.7 ± 9.0	18.8 ± 0.6	23	2.2 ± 0.2	1.00 ± 0.01
4 – CL4	1718	165.2 ± 7.8	77.7 ± 6.4	29.7 ± 0.5	41	1.3 ± 0.0	1.03 ± 0.01
4 – CL4	1719	176.2 ± 9.6	84.8 ± 7.5	22.7 ± 0.7	24		

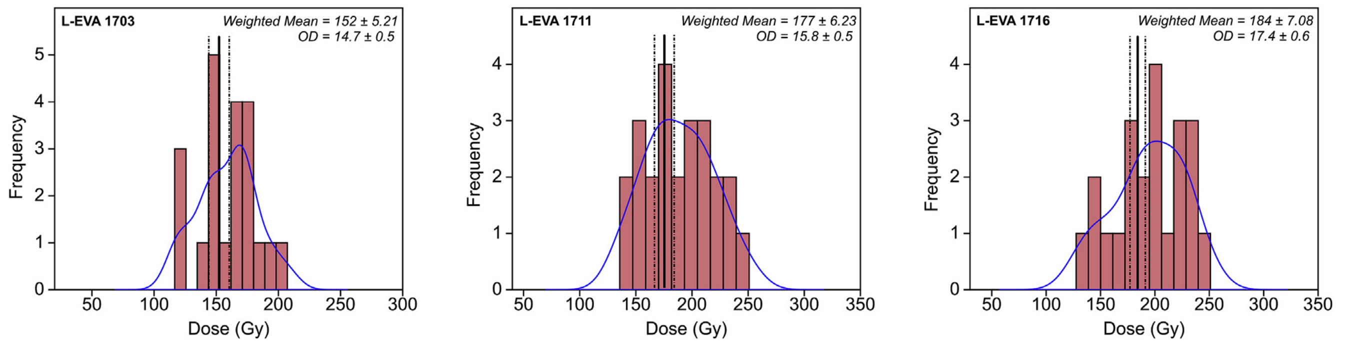

Fig. 6. De-distributions for three representative samples (black lines: weighted mean De-values with their 1σ standard error used for age calculation). Distributions for all samples can be found in the supplementary information.

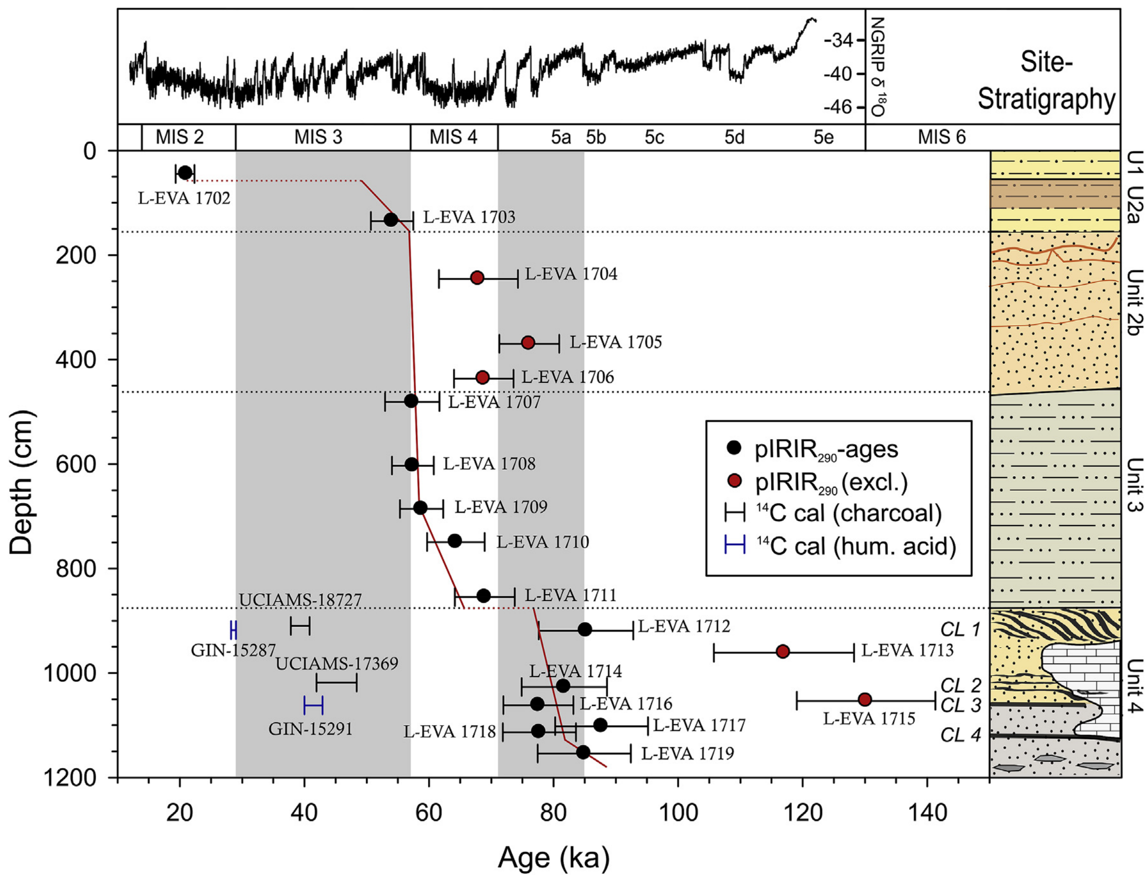

Fig. 7. Age-depth plot of all measured luminescence samples, including the former ^{14}C chronology. The NGRIP-data has been taken from North Greenland Ice Core Project members (2004), the Marine Isotope boundaries from Lisiecki and Raymo (2005). CL1 to CL4: Cultural Layers.

alignment with the rest of the sequence. Hence, we conclude that a combination of overestimated water content and poor bleaching, which is not noticeably accounted for in the OD values, is the reason for the obtained age inversions (cf. Buylaert et al., 2009). Partial bleaching in turn could have been caused by such factors as reworking of much older material, transport distance and the mode of sediment transport. For samples L-EVA 1713 and 1715, slope sediments reworked from Saalian fluvioglacial deposits on the adjacent plateau, short transport distance conceivably hampered solar resetting. The older the original depositional ages before reworking, the more likely the luminescence signal is only partially reset during re-sedimentation. Samples L-EVA 1704 to 1706 were collected from a fluvial sediment that possibly derived from a more distal source. Mesozoic sandstones as well as (fluvio-)glacial deposits surely contributed to the sediment load. Thus sediment origin (and inconsistent former ages and bleaching) might have played a role as well as the transportation and sedimentation process itself. It has been shown, for instance, that turbid water flow reduces the intensity of light and can lead to less complete bleaching, despite considerable transport distances (Rittenour, 2008; Wallinga, 2002). This scenario of a high-energy flow regime was previously discussed (section 4.1) for the formation of this respective sediment facies.

Excluding these five overestimated samples, a regression line was drawn in Fig. 7 through all 13 accepted ages, taking sedimentary properties into consideration and representing our most coherent proposal regarding the chronological succession of sediment delivery. The significance of this age regression for landscape-forming processes and archeological theory building is discussed in section 5.2.

5.1.4. Comparison with the previous ^{14}C chronology

In previous studies, a chronological framework for the cultural horizons of Khotylevo I-6-2 was reported based on radiocarbon dating of ABA (Acid Base Acid)-pretreated charcoals and humic acids (Otcherednoi et al., 2014b; Otcherednoy and Voskresenskaya, 2019; Vishnyatsky et al., 2015). These dates, calibrated by Weiss (2019) using OxCal 4.2 and the IntCal 13 calibration curve (Reimer et al., 2013) are presented in Figs. 4 and 7. They range from ~27 ka to 50 ka (cal BP), coinciding with MIS 3. Radiocarbon dating of Pleistocene samples is challenging in general, as low levels of modern carbon can lead to serious and systematic age underestimations towards the limit of the method. The impact of these contaminations increases with sample age (Wood, 2015). To account for that in charcoal dating, the Acid Base Oxidation/Stepped Combustion (ABOx-SC) pretreatment was introduced, which disposes of contaminants not removed by the conventional ABA pretreatment (Bird et al., 1999). Consequently, it was suggested that ABA-pretreated charcoal--samples older than 30 ka should be considered with extreme caution (cf. Briant and Bateman, 2009; Pigati et al., 2007).

With regards the humic acids, it has been shown repeatedly, that dating these compounds in buried soils and sediments may result in significant age underestimations and even random inconsistencies, because this method is particularly susceptible to contaminations (Martin and Johnson, 1995; Orlova, L.A.;Panychev, 1993; Wang et al., 1996).

Addressing the discrepancy between the ^{14}C and luminescence chronology at our section, we strongly advocate the latter to find the chronological position of the *Keilmessergruppen* in Khotylevo: Firstly, because of the mentioned methodological aspects of possible radiocarbon rejuvenation in the Weichselian Pleniglacial and early glacial and secondly for the higher number of luminescence samples spread over the whole sequence and being in accordance with stratigraphic considerations (cf. section 5.2). However, with their higher potential precision compared to luminescence dating, further application of conventional ^{14}C methods in different parts of the Khotylevo I complex is still valuable to obtain a chronology from organic remains in the upper part of the sediment suite, that is, primarily for correlation of different sections (Zaretskaya and Otcherednoy, 2019).

5.2. Implications for landscape formation and paleoenvironmental conditions

5.2.1. Timing of geomorphic processes on site

We begin by presenting the succession of geomorphic processes in chronological order, which can be regarded as a short model on the formation of the 2nd fluvial terrace, as both a stratigraphic and a morphological entity. The mainly geomorphological information about the Weichselian terrace staircase on the East European plain has not been revised for several decades (cf. Matoshko, 2004). Despite encouraging progress brought about by recent efforts of Panin et al. (2017), there is still much uncertainty as to the timing of local geo-climatic events and their relation to global climatic variability. Our results suggest a full incision/aggradation cycle being preserved at the Khotylevo I-6-2 exposure (Fig. 8).

Unit 4: At the bottom of Unit 4 there is a long hiatus between the Weichselian sediments and the bedrock of the Cretaceous sand. The widespread MIS 5e or 5c soils and in fact any older quaternary sediments are missing. Stratigraphic evidence from the various other sections of Khotylevo I along the raised bank of the 2nd fluvial terrace (see Fig. 1 for positions), suggests that the absence of these MIS 5e and MIS 5c soils is of wider application and not just a local feature. This, in turn, requires a fluvial incision phase in the Early Weichselian, after the optimum of MIS 5c. As sediment suites of fluvial terraces are believed to correspond largely to climatic oscillations, and river incision and aggradation usually occurs at climatic transitions (Vandenberghe, 2015, 2008), we assert that this particular incision phase occurred at the 5c/5b transition. It is quite remarkable that what is expected to be a relatively minor climatic shift, seemingly induced a deeper fluvial downcutting than previous major shifts (MIS 5e/5d or MIS 6/5e) – at least in the margins of this part of the valley. A complete eradication of all pre-MIS 5b/5c sediments to bedrock level throughout the entire valley is however not to be expected, not least because of existing reports about an Eemian base of the 2nd fluvial terrace in other valleys on the Russian Plain, listed in Panin et al. (2017). Thus, for the prevailing scarcity of numerical dates, further research in the Desna river catchment is needed to corroborate our finding.

The lowermost luminsecence sample in Unit 4, L-EVA 1719, yields a $pIRIR_{290}$ age that falls directly into the MIS 5a/5b boundary in the age-regression (Fig. 7). Given the dating uncertainties, the sediment could have been deposited in either of these two intervals. Since it represents a solifluction layer, permafrost has arguably played a role in its development, although not necessarily. However, the thickness (ca. 30–60 cm), combined with the sandy matrix of the deposit, implies an equal or higher freeze-thaw depth for its formation, and conditions of deep seasonal frost to warm permafrost, comparable to current subpolar mountains or mid-latitude high mountains above the tree line (Matsuoka, 2001). It is less likely that the climate and thin vegetation cover

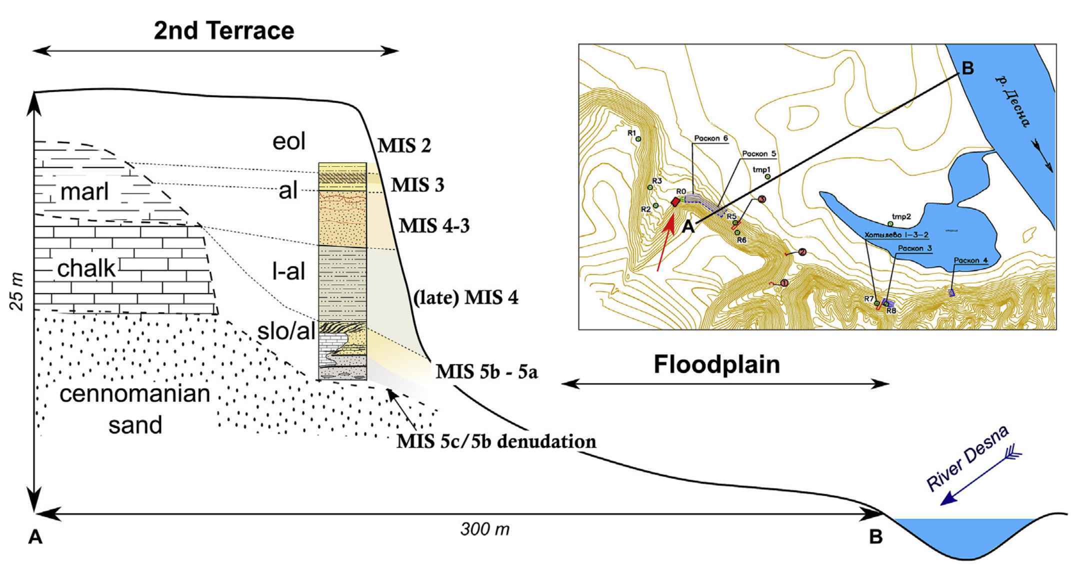

Fig. 8. Virtual cross-section of the 2nd fluvial terrace at Khotylevo I-6-2. The position of the site is shown on the topographic map by the red arrow. Orientation of the cross-section is shown on the map by line segment A-B. slo: slope/colluvial facies; l-al: fluvio-lacustrine; al: channel/overbank alluvium; eol: loess-like sediments.

requirements were met in early to mid-MIS 5a, thus we propose, solifluction occurred in MIS 5b for which matching conditions are assumed (see section 5.2.2 below). Following the age-regression line in Fig. 7, the rest of Unit 4, comprising the beginning of fluvial aggradation alternating with slope deposition and paleosols (=cultural layers), falls comfortably within MIS 5a. This complements the presence of the half-bogs and Fluvisols requiring a rather temperate climate for their formation. Based on luminescence dating however, it is not possible to distinguish the different paleosols, and hence the cultural layers, chronologically. Our interpretation of the interfingering sands of CL1 and CL2 to be local-sourced, reworked glaciofluvial sands from the Saalian glaciation is in compliance with the large age overestimations for the samples L-EVA 1713 and 1715 (117.0 ± 11.3 and 130.2 ± 11.1 ka). As indicated by the chalk-supported displaced mass in Unit 4 and solifluction structures in the lower Unit 3, slope deposition may have continued until mid-MIS 4.

Units 3 and 2: These units are considered jointly, because other than the temporal setting provided by the age regression, we do not have credible numerical dates for Unit 2b. The main fluvial aggradation phase commenced in late MIS 4 and, with a possible hiatus, resumed in the MIS 4/MIS 3 transition phase or earliest MIS 3. It started out with a low-energy and likely fluvio-lacustrine deposition in Unit 3, before the discharge changed to a high-energy flow regime for Unit 2b, reducing light-intensity during its deposition und thus *inter alia* being responsible for age overestimations. Apart from L-EVA 1710 and 1711, that are gradually older, the larger portion of Units 3 and 2b seem to have been deposited near the MIS 4-MIS 3 transition. Alternatively, considering the desiccation/frost cracks at the boundary between these units, possibly indicating a hiatus of unknown duration, Unit 2b could have formed entirely in early MIS 3. Regardless, the sedimentation rate corresponding with the slope of the regression was potentially high during this transitional period. High vertical accretion rates of the regional rivers of that time have been highlighted by Panin et al. (2017) as well. Unit 2a in turn ties in very well with the ages of Unit 3. It is evident that in the first half of MIS 3 the deposition changed from channel alluvium to overbank fines with a likely hiatus in between, as indicated by the sharp lower boundary of Unit 2a. The potential reasons for that changeover are manifold and cannot be discussed based on our data. After deposition ceased, the overbank deposits remained a stable surface for an unknown time, enabling pedogenesis (Fluvisol formation) and likely spanning several temperature inflections within MIS 3. The timing of the follow-up incision, shaping the now observable landform of the terrace, is not accounted for in our data set, but is expected to have occurred between 45 and 35 ka (Panin et al., 2017; and discussion below).

Unit 1: Ensuing this hiatal phase, directly overlying the Fluvisol is the weathered loess with a typical LGM age of ~21 ka at the height of MIS 2 (L-EVA 1702). This loess was later subjected to decalcification and pedogenesis.

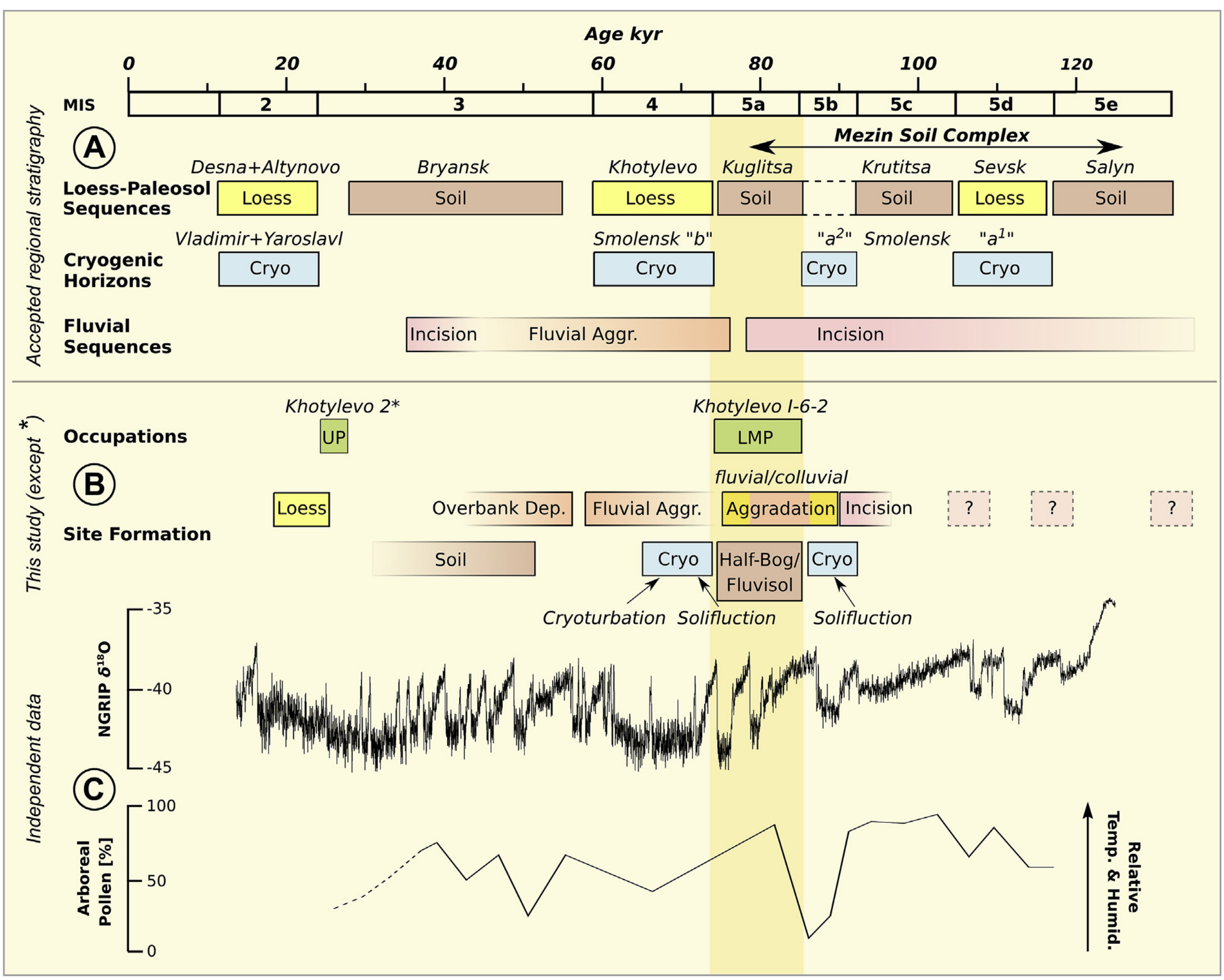

Fig. 9. (A) Accepted chronostratigraphy of the region compiled from Velichko (1990), Velichko et al. (2006, 2011, 2017) and Panin et al. (2017, 2018) compared with (B) findings of this study. Chronology for the occupation at Khotylevo 2 taken from Gavrilov et al. (2015)*. (C) NGRIP-data from North Greenland Ice Core Project members (2004), and Arboreal Pollen taken from Yelovicheva and Sanko (1999).

5.2.2. Comparison with existing chronostratigraphies and palaeoenvironmental records

In Fig. 9, we compare our chronostratigraphic findings with independent paleoclimatic data and the presently accepted stratigraphy within the observed timespan. The figure does not intend to provide detailed correlations but allows for the exploration of general patterns regarding site formation, landscape processes, occupation and climate evolution of the Late Pleistocene. Also, it does not take into account the various diachronic offsets between terrestrial sedimentation and the MIS (e.g. Kukla et al., 2002). Fig. 9A aims to give insight on the relation of fluvial archives to much better-known Loess-Paleosol-Cryogenic formations (LPC) on the Russian Plain. Significantly, the study area is the type region for several of the stratigraphic units of the LPC (Khotylevo Loess, Bryansk Soil, Desna Loess). The concept of the LPC and their relations across the Russian Plain is exceptionally well-established and incorporates regional differences (Panin et al., 2018; Velichko, 1990; Velichko et al., 2017, 2011, 2006). Considering numerical ages however, information for the time outside the radiocarbon range remains very scarce. To our knowledge, the only reliable luminescence-based geochronology has been presented by Little et al. (2002), where the period from the Eemian to the Last Glacial Maximum (LGM) is characterized by six OSL-dates. Beyond that, Gozhik et al. (2014) report a comparison of four different TL and OSL laboratories for the dating of the Maksymivka loess section in the Dniepr Lowland, based on about 20 samples each. However, the different results show very high discrepancies, rendering the overall chronology rather inconclusive. Particularly the quartz grains used for OSL-dating seem to be in saturation early on, leading to profound age underestimations. It is for this general paucity of available data that the alignment of the LPC with the hemispherical climate proxies is in fact not incorrect, but still a broad-brush rendition. This is aggravated by the fact that MIS 5a soils (Kuglitsa) have seldom been recognized in the East European Plain (Velichko et al., 2006), and so have mostly not been considered in correlation with, for example, the MIS or central European pollen zones. Sometimes a previous interstadial (Krutitsa) has been assigned to MIS 5a rather than 5c (Little et al., 2002), with contradictory statements regarding the occurrence and correlation of Kuglitsa found in the same publication (Velichko et al., 2011), adding more vagueness to the discussion.

A similar situation exists regarding the fluvial suite of the 2nd terrace. While it has been identified and elaborately described in several river systems on the East European Plain, 16–25 m above the current streams (e.g. Matoshko, 2004, with a compilation of the mostly Russian-language literature in Panin et al., 2017), until now there was only one luminescence chronology in existence (Panin et al., 2017). Conveniently, this study was conducted at the Seim River, a nearby tributary to the river Desna. It comprises three dates that delimit the formation of the 2nd terrace (included in Fig. 9). They suggest, aggradation started before 77 ka, requiring an earlier incision. Meanwhile, subsequent incision which led to the morphological landform of the 2nd terrace must have taken place between 35 and 45 ka. This is roughly in accordance with the age assumptions found in previous studies that are solely “based on climatic stratigraphy and geomorphological correlation” (ibid.), where a formation time between MIS 5d and MIS 4 is stated.

In Fig. 9B, the chronostratigraphical data acquired in our study has been compiled. Therein we argue that the fluvial incision, preceding the 2nd terrace-formation occurred probably at the MIS 5c/5b transition. While there might have been earlier incision events between this time and late MIS 6, we cannot account for these. Aggradation gathered pace in the MIS 4 and earliest MIS 3, concluded by an overbank deposit and a Fluvisol, that we suspect formed the surface for a considerable period of time. Both of these findings roughly agree with former considerations, but having a higher number of luminescence samples at our disposal, we are able to locate those events more precisely within the temporal framework.

When compared to the LPC, our data reveals striking similarities, as well. A cryogenic horizon in the form of a solifluction bed (L-EVA 1719) is followed by various short-termed soil formations (Fluvisols and half-bogs), coinciding with the cultural layers (cf. NGRIP and arboreal pollen in Fig. 9C). The solifluction bed likely represents Smolensk a^2 cryogenic phase and the soils cover for the Kuglitsa phase. As mentioned, the latter is very sparsely documented in the literature, but when (at least implicitly) recognized, the paleosols are usually developed as a gleyic stratum (Velichko, 1988). The pedogenic features in Unit 4 of Khotylevo I-6-2 seem to be the semi-terrestrial, yet contemporaneous equivalents of these gleys found in loess sequences. Smolensk b cryogenic phase is asserted in our data through the solifluction and cryoturbation phenomena in lower Unit 3. The sediments of the fluvio-lacustrine Unit 3 consist largely of re-deposited loessic silts, implying that later MIS 4 was the main delivery phase for the Khotylevo loess. After all, availability of loess covers in the catchment area is imperative for its re-sedimentation. Bearing in mind the vastly impaired coupling of sediment erosion in catchments and sediment delivery in floodplains (Fryirs, 2013; first suggested by Walling, 1983), our dates for this fluvially reworked loess (MIS 4/MIS 3 transition phase) do not directly elucidate the time of primary loess deposition. Rather there is likely a temporal offset between these two respective processes. Even so, loess admixture into the fluvial suite stopped abruptly for Unit 2b. Whether this is a function of decreased loess-erodibility due to the binding effect of re-establishing vegetation after the glacial maximum, or due to a changing architecture within the fluvial system, remains a subject of future research. The Fluvisol capping the overbank fines of Unit 2a is related to the Bryansk soil in MIS 3. Indications, that MIS 3 accommodates a two-phased paleosol formation (including the ortsands in upper Unit 2b) at the Khotylevo I site will be investigated at a later time. The loess on top of the sequence (L-EVA 1702) falls within the LGM in MIS 2 and is attributed to the Desna loess phase of the western Russian stratigraphy.

5.3. Archeological implications

5.3.1. Synthesis of environmental and climatic conditions during the occupational period

It has been observed repeatedly that higher places alongside the yearly submerged floodplain, especially riverbanks and terraces, were particularly attractive to Paleolithic foragers (Vandenberghe, 2015; Velichko et al., 2009). In accordance, the occupation at Khotylevo I-6-2 has been located directly at the margin of the floodplain, with supposedly a precursor of the recent ravine granting a smooth approach from the higher banks. The solifluction bed, formed shortly before occupation set in, provides an easily-exploitable large-sized and high-quality raw material source for on-site stone tool production, supporting the workshop character of the site. At the onset of Middle Paleolithic land use, periodic to episodic shallow flooding events were likely to happen, as revealed by the fluvial sediments and weak Fluvisols in CL3 and 4. During CL2 and CL1 these events became much more sporadic. However, the half-bogs in the upper part of the archeological sequence attest to a continuously high groundwater table. Even though the paleosols indicate a phase of geomorphic stability controlled by a dense vegetation, the interfingering glaciofluvial sands, coming down the slope of the ravine point to interruptive spells within the MIS 5a, evoked by a sparser plant cover (e.g. Ballantyne, 2018). Since these spells might have been caused by climatically induced patchiness in the vegetation, it is worth considering the respective paleoclimatic proxies for that time. In the NGRIP-record, for the harsh millennial-scale oscillations within MIS 5a, such less densely vegetated spells appear plausible (Fig. 9 C), even though MIS 5a is set apart from the neighboring phases by a generally milder climate (cf. Velichko et al., 2011). A similar observation has been reported by Antoine et al. (2016) for the loess area of Northern France, where the MIS 5a paleosols indicate a pronounced alternation between phases of stabilization (pedogenesis, corresponding with Greenland Interstadials 19–21) and accelerated colluviation in between. According to the closest pollen archives for Khotylevo I in eastern Belarus, vegetation was characterized by a dense *Betula* and *Pinus* forest with the admixture of *Alnus*, *Salix* and even some temperate taxa like *Quercus*, *Tilia*, *Fagus* and *Corylus* at the height of the interstadial (Yelovicheva and Sanko, 1999). Herbs and grasses were reduced to about 10%. This reveals mild, yet relatively strong continental conditions, including low precipitation values, warm growing seasons and low winter temperatures with thin snow cover (Helmens, 2013; Yelovicheva and Sanko, 1999). Although these data suggest a rather dense and therefore erosion-inhibiting plant cover in MIS 5a, we cannot exclude that drier and colder spells might have rendered the vegetation more open, making the system more prone to erosion.

A similar effect regarding erodability would have been achieved if the slope (or in fact a precursor of the ravine) was subjected to trampling by ungulates or other forms of game, accessing the valley bottom for drinking water. This would have caused compaction of the sediments and scarring of the vegetation, both triggering linear erosion. While the impact of *grazing* on denudation and subsequent erosion is fairly well studied, the contribution of *trampling* especially executed by wild ungulate herds is still only rather vaguely understood, but thought to be consequential (Heggenes et al., 2018; Moen and Danell, 2003). Previous field campaigns at Khotylevo I uncovered a reasonable number of big mammal bones, among them (odd-toed) ungulates such as horse *(Equus latipes Gromova)*, bison (*Bison priscus Boj.)*, red deer *(Cervalus elaphus)* and reindeer (*Rangifer tarandus* L.*)* (Chubur, 2013). Neither the archeological layers nor the artefacts themselves show clear traces of animal trampling, in the form of distortions or mechanical damages. Although we are unable to definitively substantiate an animal contribution to sediment erosion in MIS 5a at Khotylevo I-6-2, we suggest this phenomenon should be given more attention in future archeological research. Geomorphic positions, preferred as migration routes of big game might have influenced the Neanderthal choice of encampment location.

5.3.2. The age of Khotylevo I-6-2 and its influence on the chronology and population dynamics of the late Middle Paleolithic

Following the chronological and typological classification of the Keilmessergruppen proposed by Jöris (2004), the presence of prepared core blank production methods together with bifacial backed knives with convex cutting edges places the assemblages from Khotylevo I-6-2 into Keilmessergruppen Type A (KMG-A). Jöris (2004) attributes assemblages of this group chronologically to MIS 5a/early MIS 4 and geographically to the northern European lowlands. However, his chronological attribution is only tentative, as the MIS 5a/early MIS 4 ages are constructed based on stratigraphic interpretations of mainly Königsaue (Mania, 2002; Mania and Toepfer, 1973), and Salzgitter-Lebenstedt, Lower Saxony/Germany (Pastoors, 2009, 2001; Tode, 1982). Jöris' (2004) interpretation is in contrast to the radiocarbon ages of these sites (Hedges et al., 1998; Pastoors, 2009, 2001; Picin, 2016), which date the Neanderthal occupations to MIS 3. However, uncertainties regarding their radiocarbon dating at the limit of the ^{14}C time scale, together with the stratigraphic observations allow chronometric ages between MIS 5a and MIS 3 for these sites and the onset of the late Middle Paleolithic Keilmessergruppen. Following the initial KMG-A, KMG-B to KMG-C assemblages with differing technological assemblage characteristics are placed by Jöris between early MIS 4 and MIS 3. In general, his (Jöris, 2012, 2004) model establishes a "long chronology" for the Keilmessergruppen, with a duration from MIS 5a to MIS 3. This is in contrast to Richter (Richter, 2016, 2002), whose model of a "short chronology" places these late Middle Paleolithic groups exclusively into MIS 3. Richter's interpretation is based on the fact that in his view no Keilmessergruppen or MMO assemblage is securely dated older than MIS 3 (Richter, 2016).

With the age of the late Middle Paleolithic human occupation in Khotylevo I-6-2 we now have secure evidence for the presence of the Keilmessergruppen-makers during MIS 5a on the European Plain. Khotylevo I-6-2 adds an important data point to the growing body of radiometrically dated late Middle Paleolithic Keilmessergruppen/MMO/ Micoquian sites on the European Plain from western Russia to northern Germany. The new luminescence ages support the model of a "long chronology" from MIS 5a to MIS 3 sensu Jöris (2004) for this archaeostratigraphic unit. In other words, with the data from Khotylevo I-6-2 we can finally prove the duration of the Keilmessergruppen from MIS 5a to early MIS 3. Together with recently directly dated open-air assemblages, we see late Neanderthal presence on the northern central and eastern European Plain during the following marine isotope stages:

1) MIS 5a: Khotylevo I-6-2, Neumark-Nord 2/0, Saxony-Anhalt/ Germany (Laurat and Brühl, 2006; Richter and Krbetschek, 2014; Strahl et al., 2010), Wrocław-Hallera Av. Lower Layer (Skrzypek et al., 2011; Wiśniewski et al., 2013)
2) MIS 4/3: Pietraszyn 49a, southwestern Poland (Wiśniewski et al., 2019), Lichtenberg, Lower Saxony/Germany (Veil et al., 1994)
3) MIS 3: Wrocław-Hallera Av. Upper Layer (Skrzypek et al., 2011; Wiśniewski et al., 2013), Pouch (Weiss, 2015; Weiss et al., 2018)

With the new data from Khotylevo I-6-2 together with the age of the additional sites mentioned here, we can draw some inferences about late Neanderthal population dynamics on the European Plain. Khotylevo I-6-2 is a striking example of Neanderthals pushing back the northern limit of their habitat up to 53.5° under continental climate conditions during MIS 5a. Interestingly, there is little evidence of doing so even from the more temperate northwestern European climate of the previous Eemian interglacial or the contemporaneous Early Weichselian (Nielsen et al., 2015). Khotylevo I-6-2, together with the other MIS 5a sites from the European Plain also mark a technological change in the Neanderthal material culture. They started to produce bifacial tools more frequently, and the assemblages show an increasing application of prepared core blank production methods. Thus, starting during MIS 5a, late Neanderthal sites are characterized by a technocomplex called the Micoquian of central and eastern Europe or Keilmessergruppen. This is substantially different from the small-tool, rather opportunistic and flake-based tool assemblages of the previous Eemian interglacial (Litt and Weber, 1988; Pop, 2014; Thieme and Veil, 1985; Weber, 1990). In other words, the MIS 5a assemblages document a change in knapping techniques and tool concepts that persisted on the European Plain until the end of the Middle Paleolithic around 40 ka, the disappearance of Neanderthals.

But the fact that Keilmessergruppen-makers or the idea of a certain knife technology "survived" the cold stadial of MIS 4 (71 ka- 57 ka, Lisiecki and Raymo, 2005) on the northern European Plain, sheds new light on late Neanderthal migration patterns and existing hypotheses. The current data implies a void of Neanderthals at the northern part of the European Plain (Bobak et al., 2013), roughly above 50° N during most of the cold stadial MIS 4. Also, as of yet, the Khotylevo I-6-2 sequence yielded no late Middle Paleolithic occupation layer younger than MIS 5a. The MIS 4 cold stadial is interpreted as a bottleneck for Neanderthal populations and local extinctions (Hublin and Roebroeks, 2009; Roebroeks et al., 2011) as well as southward population movements (Jöris, 2004) are discussed. However, the presence of Neanderthals during MIS 4 cannot be excluded, yet. For example, the age of Salzgitter-Lebenstedt is considered to be early MIS 4 based on stratigraphic observations (Jöris, 2004; Pastoors, 2009, 2001). Furthermore, the error ranges of the luminescence ages of some sites, like Wrocław-Hallera Av. (Bobak et al., 2013; Skrzypek et al., 2011; Wiśniewski et al., 2013) or Lichtenberg (Veil et al., 1994) also make human occupation in early and/or late MIS 4 possible. However, the absence of stone artefacts from MIS 4 in northern latitude sites like e.g., Khotylevo I-6-2 in the east or Neumark-Nord 2/0 in the west, but the presence of inventories with bifacial tools further southwest, are in favor of the movement-to-refuge-areas hypothesis. Examples are the occurrences of such assemblages during MIS 4/3 in northern France around 50° N (Locht et al., 2016b). which we interpret as possible evidence for the southward movement of Neanderthal populations from northwestern Europe. For eastern Europe, a population continuity throughout MIS 4 is suggested based on stratigraphic assumptions for regions south of the Russian Plain, specifically the Crimean Peninsula and (*Trans*-) Caucasia

(Velichko, 1988), but has yet to be confirmed by modern dating techniques.

Another argument for Neanderthal groups moving in and out the northern latitudes of the European Plain between MIS 5a and 3 are diachronic assemblage characteristics: contradicting some of Jöris' observations, KMG-A Keilmesser with convex cutting edges exist as well in some assemblages younger than MIS 5a, like in Pietraszyn 49 a (Wiśniewski et al., 2019), Lichtenberg (Veil et al., 1994), and Pouch (Weiss, 2015). Additionally, the latter assemblage shows that the occurrence of these Keilmesser types can be combined, like in KMG-A, with the application of Levallois and prepared core blank production methods. In other words, the MIS 3 site of Pouch shows assemblage characteristics that share similarities with MIS 5a assemblages like Khotylevo I-6-2 and, potentially, Königsaue (Weiss et al., 2017). In contrast, the MIS 3 Keilmessergruppen assemblage of Wrocław-Hallera Av. Upper Layer, with more simple blank production methods, and variable bifacial tools has assemblage characteristics different from Khotylevo I-6-2 or Pouch. The presence of the latter together with KMG-A assemblages on the European Plain during MIS 3 points to a more complex picture of Neanderthal population movements between MIS 5a and MIS 3 – where southwards movements but also local extinctions and re-population of some areas seemed to interfinger with each other.

6. Conclusion

In this study we have placed particular emphasis on the intersection of natural sediment stratigraphy and the archeological find layers at Khotylevo, area I-6-2. To that end we presented a thorough sedimentological log alongside grain-size analyses and $pIRIR_{290}$ luminescence dating. The implications of the results we generated are two-fold as they yield information on both, (1) the region's fluvial and landscape evolution from the Early to the Mid-Weichselian and (2) the timing of Middle Paleolithic occupation on site.

(1) For the high resolution of our sampling scheme we are able to report the best-dated sequence of the widely occurring 2nd river terrace, thereby adding to the understanding of the Late Pleistocene geo-climatic events on the Russian Plain. One full incision/aggradation cycle was detected, with the incision most likely taking place at the MIS 5c/5b boundary and the main aggradation phase happing in the MIS 4/MIS 3 transitional phase. When compared with the stratigraphy of loess-paleosol-cryogenic phases our chronology shows a predominant compliance. That concerns the main phases of soil formation (within the scope of our sequence) in MIS 5a and MIS 3 as well as the periods of loess deposition in MIS 2 and 4. While we can directly confirm the MIS 2 loess (Desna loess) by dating it to ~21 ka, the MIS 4 loess is represented only indirectly as redeposited silt fraction within the late MIS 4 fluvial aggradation sediments. The potential temporal offset between primary loess formation in the area and alluvial re-sedimentation in Unit 3 remains subject to later fluvio-geomorphological investigations. Future studies at the Khotylevo I sites will also address the sparse numerical information on paleoclimate and paleoenvironment in the region. Those will include a more extensive consideration of cryogenic features and paleosols using geochemical, biochemical, biological and magnetic proxies to produce more precise reconstructions of the diachronic local conditions, relevant to both archeology and geosciences.

(2) In this paper we present the first unambiguous luminescence-based chronostratigraphy for a Late Middle Paleolithic open-air site on the Russian plain. By confidently ascribing the occupation to the rather temperate, but continental interstadial MIS 5a we gain a valuable data point for future reconstructions of Neanderthal population dynamics. Even keeping in mind the fragmented character of both preserved sites and the former land use system(s), it is already safe to say that Neanderthals settled not only the southern mountainous areas of the East European Plain. They also penetrated the more northern lowland regions along the river valleys up to at least 53.5° N. Whether that was restricted solely to warmer periods needs further analysis. Furthermore, our sediment descriptions allow for inferences about the paleo-conditions on site (e.g. a solifluction bed being a likely raw material source, and the decreasing flooding risk of this river-side locality) during the time of (repeated) occupation in MIS 5a (section 5.3.1). Additionally, we compare our stratigraphically well-secured chronology to other numerically dated Late Middle Paleolithic assemblages across the northern central European Plain. We provide evidence for an early onset and long-term continuity, but also for complex population dynamics of the *Keilmessergruppen* or Micoquian on the European Plain, stretching from MIS 5a to MIS 3.

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

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