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ABSTRACT

The goal of this paper is to refine the relative and absolute chronology of Epigravettian culture (26.5–15.0 ka) in eastern Central Europe (ECE) and clarify its relation to the Last Glacial Maximum (LGM) and subsequent climatic changes. Epigravettian sites were sorted into three chronological clusters: initial LGM (ILGM) (26.5–24.0 ka), local LGM (LLGM) (24.0–20.0 ka), and post-LGM (PLGM) (20.0–14.7 ka). We obtained new radiocarbon dates from previously dated and undated sites, then analysed the lithic tool typology and faunal data to seek correlations between age and archaeological features.

The lithic typology study did not find differences between ILGM and LLGM sites, but the tool type variance between LLGM and PLGM was significant, applicable for relative chronology. ILGM and LLGM lithic assemblages were characterized by domestic tool dominance and the frequent use of flake tools. PLGM assemblages were correlated with armature dominance and blade/let tools. Among the armatures, backed point variants characterized the PLGM sites compared to the ILGM and LLGM. The sole ILGM lithic armature was the retouched blade/let point. The LLGM also possessed this type and often included backed blade/lets.

ILGM faunal data, although few, implied the hunting of mammoth and reindeer. The LLGM data represented recurring hunting of reindeer and horse, and PLGM data indicated the hunting of horse, reindeer, and mammoth.

Our results suggested that the territory of Poland was deserted by humans in the LLGM. Moravia and Lower Austria was inhabited until the first half of the LLGM, while the Carpathian Basin was all along the ILGM. The preference for the Carpathian Basin could have been the milder climate, the abundance of fauna, and permanent access to tree vegetation. After the LGM the glacial flora and fauna gradually disappeared, leading to a reduced human presence in southern ECE. Thus, the disappearance of the Epigravettian culture and Pleistocene hunter-gatherer occupations are linked to the amelioration of climate that resulted in the disappearance of the Pleistocene environment.

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1. Introduction

The term Epigravettian was first coined in the 1960s for the Franco–Cantabrian Late Upper Palaeolithic (LUP) to chronologically frame various post-Gravettian archaeological cultures (Laplace, 1964a), which date to the Last Glacial Maximum (LGM), post-LGM (PLGM), and Late Glacial (LG). Shortly, it became an independent archaeological culture especially applied to the Italian LUP (Broglio, 1969; Bartolomei et al., 1971).

In eastern Central Europe (ECE) in the 1960s, the Epigravettian was also a cultural term applied to PLGM microlithic lithic assemblages lacking Magdalenian features (Bárta, 1967). As the number of non-Magdalenian PLGM sites was mere, the term Epigravettian briefly disappeared until Kozłowski (1986) re-introduced in the same cultural and chronological meaning. Meanwhile, LGM sites of the Carpathian Basin, were classified Ságvárian, a culture named after the site Ságvár in western Hungary (Kozłowski, 1979). Then, except in Hungary, the Epigravettian became widely used to classify LGM sites (Montet-White, 1990; Svoboda, 1991; Bánesz et al., 1992; Kozłowski and Kozłowski, 1996).

To replace the term Epigravettian of the LGM, the Kašovian (Svoboda and Novák, 2004) and Grubgrabian (Terberger, 2013) were suggested. None of these took roots in LUP taxonomy, but recent archaeological dialogues still make references to three LGM cultures in ECE: (1) the Epiaurignacian with Sagaidak–Muralovka-type microliths (EASMM) (Demidenko et al., 2019), (2) the Epigravettian that embraces most of the sites, (3) and the Ságvárian or Pebble Gravettian in the Carpathian Basin (Kozłowski, 1979; Dobosi, 2000a, 2009). The PLGM up to date includes the younger phase of the Epigravettian and the Middle and Late Magdalenian.

Comparative lithic tool studies on LUP sites of Hungary found no compelling reason to distinguish cultures into more divisions beyond Epigravettian in the LGM age. Retention of the term Epigravettian was suggested as appropriate for lithic assemblages postdating the Gravettian and lacking characters of both Gravettian and Magdalenian (Lengyel, 2016, 2018). This definition of Epigravettian has an Early phase in the LGM and a Late phase in the PLGM. The split taxonomy seemed reasonable as it had been used previously (Kozłowski and Kozłowski, 1996; Anghelinu et al., 2012). This comparative study also assumed that archaeological data processing by a uniform methodology may result in a coherent cultural division for the LUP in ECE.

The lithic features that divided the Epigravettian into two phases were also recognized outside Hungary in contemporaneous sites on the basis of published data (Lengyel, 2018). The similarities were explained by a paleo-ethnological approach, which supposed that the formation of synchronous and analogous archaeological records from ECE's ~ 200,000 km^2 most likely were the products of the same hunter-gatherer culture. Thus, variability of the contemporaneous archaeological record could be explained by differences in site functions and human activities directly responsible for creating the artifacts. Although the lithic raw material circulation of the Hungarian sites greatly supported the idea that ECE was one foraging area (Lengyel, 2018), the weakness of the proposal still was that the comparison of lithic features from all over ECE was based on published data which had been obtained through diverse research methods.

In order to acquire a body or more compatible data about whether or not the Epigravettian phases have a uniform eastern Central European archaeological appearance, we studied lithic and faunal assemblages and AMS radiocarbon dated prominent LGM and PLGM sites of Austria, Czechia, Hungary, Poland, and Slovakia. Our research results thus are able to refine absolute chronology and to establish relative chronology, which when placed in prehistoric and paleo-environmental contexts can add fresh knowledge to the domain of human population dynamics in MIS2 period of ECE.

2. Materials and methods

The studied sites are listed in Table 1. Table 1 also shows the type of study we performed. The key criteria of a site to be included in this study were to have identified faunal material and absolute chronological data. When possible, we aimed at obtaining radiocarbon data. We preferred including sites that have no contradictory dating results.

2.1. Chronology

2.1.1. LGM and PLGM

LGM is generally understood as a period when global sea levels were the lowest during the last glacial period MIS2 between 26.5 and 19.0 ka (ka = calibrated kilo annum BP) (Clark et al., 2009). This period overlaps the GS–3, GI–2, and GS–2 stadial/interstadial sequence of Greenland ice-core records (Rasmussen et al., 2014).

Most terrestrial ice sheets developed maxima by 26.5 ka and the earliest retreat started at 20.0 ka (Clark et al., 2009). The Eurasian Ice Sheet (EIS) (Grosswald, 1980), built up from the British–Irish, Fennoscandian, and Barents–Kara ice sheets, reached its southernmost eastern Central European limit ~ N51°47′ by 24.0 ka in western Poland (Marks, 2012; Hughes et al., 2016; Patton et al., 2017) (Fig. 1). EIS retained this position until 20.7 ± 0.8 ka (Tylmann et al., 2019), and by 20.0 ka EIS retreated ~ 70 km in western Poland (Fig. 1). Synchronously, EIS also moved ~ 70 km southward in eastern Poland reaching its maximum extent by 20.0 ka at ~ N53°19'. The ultimate retreat of the southernmost position of EIS in eastern Poland started earliest at 20.0 ka (Marks, 2012; Hughes et al., 2016; Tylmann et al., 2019).

Based on these episodes, we established three phases to periodise the archaeological sites. The period between the global start of the LGM and the maximum local extent of EIS, 26.5–24.0 ka, is called here initial LGM (ILGM). The period when EIS retained its maximum extent in ECE between 24.0 and 20.0 ka we designate local LGM (LLGM). ILGM and LLGM compose together the LGM. The end of the LLGM at 20.0 ka is the start of PLGM. The end of the PLGM is the start of GI–1 dated to 14.7 ka. GI–1 (Bølling–Allerød) and the subsequent GS–1 (Younger Dryas) stadial between 14.7 and 11.7 ka compose the LG period.

2.1.2. Archaeological classification

We regard the Epigravettian as an archaeological culture that incorporates lithic assemblages having neither Gravettian nor Magdalenian characters in the LGM and PLGM of ECE. Our approach infers that lithic tool similarities among sites are consequences of analogous subsistence strategies using the same techniques (Lengyel, 2018). The Epigravettian, according to the known lithic tool features, has been divided into an early (LGM) and a late (PLGM) phase (Lengyel and Wilczyński, 2018). Previous studies found close lithic typological similarities among contemporaneous sites, resulting in the suggestion to abandon other cultural terms and retain only Early and Late Epigravettian (Lengyel, 2016, 2018). A common feature of the two Epigravettian phases is the lack of Gravettian type armature (e.g., Gravette point, Vachons point, fléchette, and Late Gravettian Rectangle) (Lengyel and Wilczyński, 2018).

The Early Epigravettian was characterized by a low frequency of armature tools (i.e., tools supposed to be related with hunting), such as backed blade/lets, backed truncated blade/lets, and retouched blade/let points, and an abundance of domestic tool types (i.e. tools used for general tasks), such as end-scrapers, burin, or edge-retouched tools. The tools were frequently made of flakes.

Table 1
List of the studied sites. Indicated are the origins of the data used in our chronological, typological, and faunal analysis.

Site/assemblage by excavation year	Data used in our analyses	Origin of data	^{14}C sample in this paper
Brno–Štýřice III/1972, 2014	Lithic	This paper	
	^{14}C	Verpoorte (2004); Nerudová and Neruda, 2014a	
	Fauna	Roblíčková et al. (2015)	
Budapest–Csillaghegy/1967	Lithic	This paper	
	^{14}C	This paper; Sümegi et al. (1998)	(1) A mammoth tooth of the archaeological layer. (2) A horse tooth found by the land owner in a ditch.
	Fauna	This paper	
Deszczowa Cave layer VIII–VIIIa/ 1989–1997	^{14}C	This paper	A reindeer tooth.
Esztergom–Gyurgyalag/1984	Lithic	Lengyel (2018)	
	^{14}C	This paper; Hertelendi (1991)	Two mammoth bones of the archaeological layer.
	Fauna	This paper	
Kammern–Grubgraben/1986 –1990	Lithic	This paper	
	^{14}C	This paper; Haesaerts et al. (2016); Händel et al. (2021)	Two reindeer mandibles of each archaeological layer (AL1–4) and an ibex mandible of AL 3.
	Fauna	West (1997)	
Kašov I upper layer (UL)/1972	Lithic	This paper	
	^{14}C	Bánesz et al. (1992)	
	Fauna	This paper	
Langmannersdorf/1329 A-B, 1907, 1919,1920	Lithic	This paper	
	^{14}C	This paper; Verpoorte (2004)	A mammoth bone of the archaeological layer of area A.
	Fauna	Salcher-Jedrasiak (2012)	
Madaras/1966–1974	Lithic	This paper	
	^{14}C	This paper; Dobosi (1989); Sümegi et al. (2020)	Two horse teeth of the archaeological layer.
	Fauna	This paper	
Moravany–Žakovska/1990–1992	Lithic	This paper	
	^{14}C	This paper; Hromada et al. (1995); Verpoorte (2004)	(1) A horse tooth of the upper archaeological layer. (2) A reindeer tooth of the lower layer.
	Fauna	Hromada et al., 1995	
Mohelno–Plevovce–KSA-B/2013	Lithic	This paper	
	^{14}C	Škrdla et al. (2016); Demidenko et al. (2019)	
	Fauna	Škrdla et al. (2016)	
Nadap/1986	Lithic	Lengyel (2018)	
	^{14}C	This paper; Verpoorte (2004)	A horse tooth of the archaeological layer.
	Fauna	This paper	
Piekary IIa layer 5/1969	^{14}C	This paper	A reindeer phalange, insecurely associated with the archaeological layer.
Pilismarót-Bitóc I/1989–1990	^{14}C	This paper	Two reindeer teeth of the main archaeological layer.
Ságvár/1957–1959	Lithic	Lengyel (2018)	
	^{14}C	Vogel and Waterbolk (1964)	
Ságvár/1936	^{14}C	This paper	Three reindeer teeth, a reindeer tibia, and a horse tooth of the archaeological layer.
Ságvár/1935–1937	Fauna	Péan (2001)	
Sowin 7 lower layer (LL)/2002, 2012	Lithic	This paper	
	OSL	Wiśniewski et al. (2017)	
	Fauna	not available	
Stránská skála IV/1985–1987	Lithic	Svoboda et al. (2020)	
	^{14}C	This paper; Svoboda et al. (2020); Stevens et al. (2021)	Two horse teeth of the archaeological layer.
	Fauna	Boriová et al. (2020)	
Targowisko 10/2005	Lithic	This paper	
	^{14}C	Wilczyński (2009)	
	Fauna	This paper	
Trenčianske Bohuslavice layer A2 –1/2017	Lithic	Wilczyński et al. (2020)	
	^{14}C	Wilczyński et al. (2020)	
	Fauna	not available	
Zöld Cave layer 3/2018	Lithic	Béres et al. (2021)	
	^{14}C	This paper; Béres et al. (2021)	A reindeer tooth and a horse tooth.
	Fauna	Béres et al. (2021)	

The Late Epigravettian was characterized by an abundance of armatures, types usually absent in the Early Epigravettian, such as backed points and curved backed points. The tools were dominantly made of blade/lets.

2.2. Radiocarbon dating

We aimed at obtaining new radiocarbon dates for each site we studied. As a direct association between the artifacts and the dated material is crucial, our sampling targeted the hunted faunal assemblages and avoided botanical remains. The reason for selecting faunal elements was that the co-occurrence of lithic artifacts and herbivore mammals remains at open-air UP sites has been seen as unambiguously associated with human activity. Therefore, it follows that the remains of herbivore mammals in open-air archaeological assemblages expectedly date to the same time as the

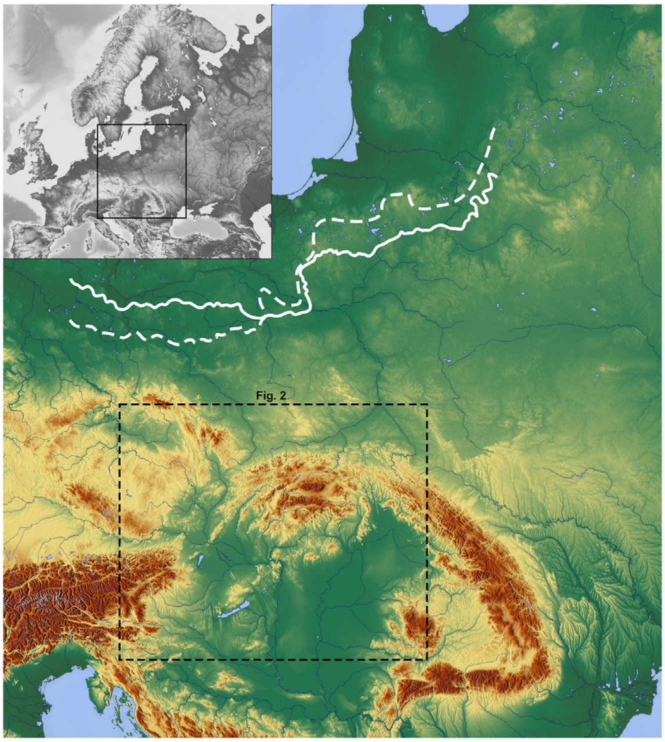

Fig. 1. The extension of EIS in ECE during the LGM (after Marks, 2012); white dashed line: EIS limit at 24.0 ka; white solid line: EIS limit at 20.0 ka. Black dashed line rectangle marks the location of Fig. 2.

production and use of closely associated lithic artifacts. In contrast, herbivore mammals remains in cave sites could have accumulated from both cultural and non-cultural (natural) processes since caves were often occupied by both humans and carnivores (Wojtal, 2007). In caves, only human related modifications to animal bones can prove their association with a human activity (Lyman, 1994).

Among the studied sites, Brno–Štýřice III faunal material was not available for dating; Kašov I upper layer (UL) and Targowisko 10 yielded scanty faunal assemblage inappropriate for dating; and Sowin 7 lower layer (LL) and Trenčianske Bohuslavice layer A2–1 did not preserve fauna. The chronological positions of these sites were estimated from published radiocarbon or OSL dating.

For the present study accelerator mass spectrometry (AMS) radiocarbon dating was done at Poznan Radiocarbon Laboratory, Poland, and at the Hertelendi Laboratory of Environmental Studies in Debrecen (HEKAL), Hungary. Methods of chemical pretreatments of both laboratories are similar, including ultrafiltration (Czernik and Goslar, 2001; Piotrowska and Goslar, 2002; Goslar et al., 2004; Goslar, 2015; Major et al., 2019).

Radiocarbon dates were calibrated with OxCal 4.4 against the IntCal 20 curve (Reimer et al., 2020). Each date mentioned in the text was calibrated with 95.4% probability (2 σ).

In justifying the age of a human occupation, we preferred AMS results versus dates obtained by standard radiometric dating (RD). This choice was based upon that (1) AMS provides higher precision (Hedges, 1987; Linick et al., 1989); and that (2) sample pretreatment techniques constantly improved especially related with AMS in the past 30 years (Major et al., 2019). Also, when interpreting radiocarbon dates, we gave less confidence to burnt bone as those regularly yield younger results (Olsen et al., 2008).

2.3. Lithic tool typology

The lithic analysis referred to in this paper was previously published (Lengyel, 2016, 2018). Differentiated were the blanks of the tools, which could be either a blade/let (blade and bladelet unseparated), a flake, a core, or any piece of knapping waste. The tool types were sorted into two major classes: (1) domestic tools, such as end-scraper, burin, edge-retouched tool (notched and denticulated tools included), perforator, truncation, splintered tool, combined tool, and (2) the collective group of armatures.

The group of armatures were subdivided into backed blade/lets, backed-truncated blade/lets, geometric forms (trapeze, rectangle, trapeze-rectangle), and points. The common feature of the geometric forms is also the backing retouch. A crucial criterion to classify a backed artifact was that the abrupt retouch creating the back had to have been perpendicularly shaped to the ventral face at or near the thickest part of the blank.

The points were subdivided into retouched point, backed point (straight), and curved backed point. These points distinctly differ from the Gravette/microgravette point that has a backed side and the oppositely situated edge has an inverse flat retouch, often proximal, rarely distal, that created an asymmetry for that part of the point. We recorded the length of the tools in millimetres.

Typological data from Esztergom–Gyurgyalag, Nadap, Ságvár, Stránská skála IV, Trenčianske Bohuslavice layer A2–1, and Zöld Cave layer 3 were presented in previous papers listed in Table 1. New typological studies were made on Kammern–Grubgraben, Langmannersdorf, Kašov I UL, Mohelno–Plevovce KSA–B, Madaras, Brno–Štýřice III, Sowin 7 LL, Targowisko 10, and Budapest–Csillaghegy (for further details see Table 1).

2.4. Faunal data

We performed archaeozoology studies on assemblages from Budapest–Csillaghegy, Esztergom–Gyurgyalag, Kašov I UL, Madaras, and Nadap. Another part of the faunal data was collected from publications listed in Table 1. The faunal elements were identified by use of comparative material at the Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, and publications (Schmid, 1972; Pales and Garcia, 1981a, 1981b). We defined the Minimum Number of Individuals (MNI) for large mammal taxa from each human occupation (Klein and Cruz-Uribe, 1984; Lyman, 1994).

2.5. Statistics

We applied non-parametric statistical tests (Leech et al., 2005). Mann-Whitney U test was used to point out differences between means of lengths of the artifacts. The measured length data in millimetres were analysed on an interval scale. Spearman's Rho correlation was used to seek associations among lithic, chronometric, and faunal data. Spearman's Rho correlation involved the percentile ratio of the given archaeological feature in the total assemblage on an ordinal scale.

2.6. The sites (in alphabetical order) (Fig. 2)

2.6.1. Budapest–Csillaghegy

Budapest–Csillaghegy (Gábori-Csánk, 1986) yielded a small archaeological assemblage consisting mostly of knapped lithics. The archaeological layer was situated in loess 1.6 m beneath the top soil. Besides the lithics, the layer included a fragment of a juvenile mammoth molar and a small pit 23 cm wide by 20 cm deep. Horse teeth together with lithics also had been found at the site by the land owner, before the excavation took place.

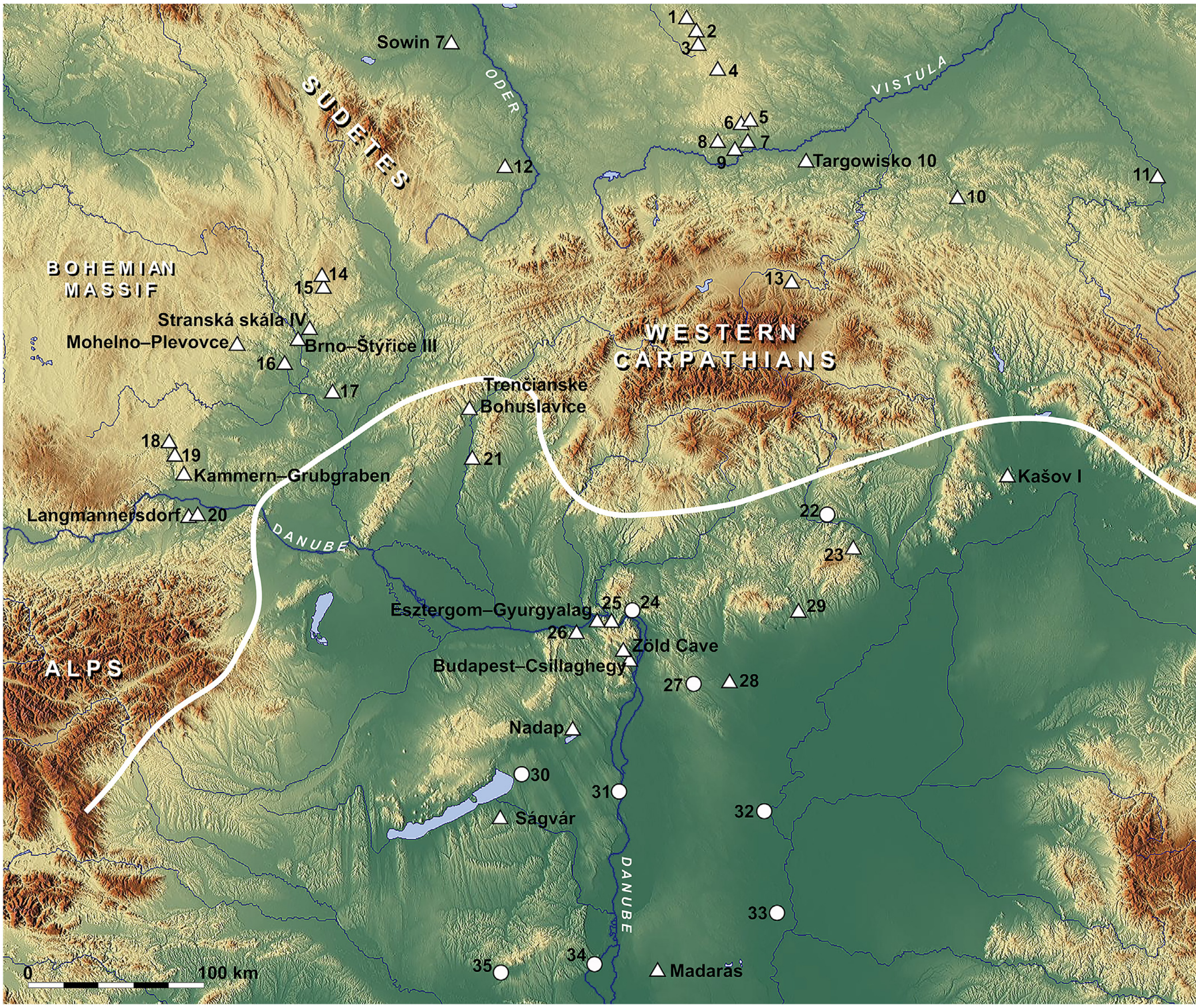

Fig. 2. The location of the sites of this study. Names of studied sites are shown on the figure. Other locations mentioned in the text are marked by numbers. Triangles indicate archaeological sites, circles mark non-archaeological locations.1: Komarowa Cave, 2: Deszczowa Cave, 3: Dziadowa Skała Cave, 4: Biśnik Cave, 5: Maszycka Cave, 6: Mamutowa Cave, 7: Kraków Spadzista, 8: Zawalona Cave, 9: Piekary IIa, 10: Ujazd, 11: Święte 9, 12: Dzierżysław 35, 13: Obłazowa Cave, 14: Kůlna Cave, 15: Balcarka Cave, 16: Bratčice, 17: Velké Pavlovice, 18: Rosenburg, 19: Kamegg, 20: Saladorf, 21: Moravany–Žakovska, 22: Nagymohos, 23: Herman Ottó Cave, 24: Verőce, 25: Pilismarót Site Cluster, 26: Mogyorósbánya and Jankovich Cave, 27: Tápiósüly, 28: Jászfelsőszentgyörgy–Szúnyogos, 29: Feldebrő, 30: Csajág, 31: Dunaújváros, 32: Lakitelek, 33: Fehér Lake, 34: Dunaszekcső, 35: Zók. Solid white line: warm line of continuous permafrost zone during the LGM (after Ruszkiszay–Rüdiger and Kern, 2016).

A bulk sample of mollusc shells from 1.7 to 2.0 m of the stratigraphy (Sümegi et al., 1998) returned an age of < 19.6–18.9 ka (Deb–3160) for the human occupation. The assemblage was classified Epigravettian (Dobosi, 2000a) and lately Late Epigravettian (Lengyel, 2018).

2.6.2. Brno–Štýřice III

Brno–Štýřice III, formerly known as Brno Koněvova or Vídeňska Street, was the first PLGM dated Epigravettian site in Moravia (Nerudová, 2016). The archaeological finds, situated 0.5–0.8 m under the recent surface, were embedded in a humic loess-like sediment ~ 25 cm thick (Nerudová and Neruda, 2014a). The archaeological assemblage included a rich lithic collection (Nerudová, 2016) and fauna consisting mainly of mammoth (Roblíčková et al., 2015).

Two radiocarbon dates obtained on charred bones, 17.9–17.3 ka (GrN–9350) and 18.6–17.9 ka (OxA–28114) (Verpoorte, 2004; Nerudová and Neruda, 2014a) are disregarded in the chronology of the site. Other dates made on mammoth teeth (OxA–26961 and OxA–28298) and a cut-marked reindeer long bone fragment (GrA–20002) (Verpoorte, 2004; Nerudová and Neruda, 2014a) placed the possible time span of the human occupation between 19.1 and 17.4 ka.

2.6.3. Esztergom–Gyurgyalag

The site yielded the richest Epigravettian lithic archaeological record in Hungary (Lengyel, 2018). The cultural layer was claimed to be associated with a humic horizon in loess situated 1.0–1.2 m beneath the actual surface (Dobosi and Kövecses-Varga, 1991). It was dated 20.0–19.0 ka (Deb–1160) on bulk charcoals from a hearth (Hertelendi, 1991). The findings were knapped lithics, a few bones of mammoth, horse, and reindeer, and fossil shell personal ornaments (Dobosi and Kövecses-Varga, 1991; Vörös, 1991). The assemblage was lately classified Late Epigravettian (Lengyel, 2018).

2.6.4. Kammern—Grubgraben

The site yielded a sequence of Epigravettian occupations embedded in loess (Montet-White, 1990; Brandtner, 1996; West, 1997; Neugebauer-Maresch et al., 2016; Haesaerts and Damblon, 2016). The four archaeological layers (AL) represented two distinct human occupations. The upper occupation was in AL1, and the lower consisted of AL2, AL3, and AL4 (AL2—4) (Haesaerts, 1990). AL3 and AL4 were also identified as humic horizons of the embedding loess.

AL1 first was dated to 20.9—19.6 ka (Lv—1825), and AL2—4 to 23.7—21.3 ka (Lv—1660, Lv—1680, and AA—1746) (Haesaerts, 1990; Haesaerts et al., 2016). Haesaerts et al. (2016) concluded that all radiocarbon dates younger than ~ 18,600 uncalibrated BP could be wrong. Disregarding those dates, the chronological difference between AL1 and AL2—4 disappeared (Haesaerts et al., 2016).

The latest AMS dates did not change the age of the human occupations. AL1, including the dates younger than ~ 18,600 uncalibrated BP, was regarded a palimpsest archaeological record due to the divergent age determinations (Händel et al., 2021).

Terberger (2013) proposed to name the LGM sites of ECE after the site Grubgrabian. Then the site was also associated with the EASMM on the basis of Sagaidak—Muralovka-type microliths (SMM) and the lack of backed blade/lets in AL2—4 (Demidenko et al., 2019; Škrdla et al., 2021). The site is also known for its extensive stone structure (Händel et al., 2021), and an abundant fauna of reindeer and horse, which was subject of a study of LGM human hunting strategies (Logan, 1990, 2000; West, 1997).

2.6.5. Kašov I UL

The site preserved two archaeological layers. Epigravettian lithic remains overlying Gravettian were excavated between 1960 and 1984 from a reworked loess-like sediment of layer 3 (Bánesz et al., 1992). The site is located near obsidian outcrops in eastern Slovakia, and the abundance of obsidian artifacts signified it as a lithic workshop (Bánesz et al., 1992; Svoboda and Novák, 2004). The archaeological material was found in concentrations within which hearths were located (Bánesz et al., 1992). Kašov I upper archaeological layer (UL) was eponymous for the Kašovian culture that was meant to replace the term Epigravettian for LGM sites (Svoboda and Novák, 2004). No datable fauna was preserved. The sole radiocarbon date, 23.7—21.5 ka (Gd—65699), was made on a bulk charcoal sample probably of a hearth (Bánesz et al., 1992).

2.6.6. Langmannersdorf

The site yielded an archaeological collection spread over several hundreds of square metres (Angeli, 1952—1953). The area where the site is located was divided by strips of agricultural parcels. Out of these, two areas “A” and “B” included extensive archaeological features, such as pits, hearths, and accumulations of mammoth bones, all embedded in loess. As the site was excavated in the early 20th century, no fine stratigraphical observations were made (Salcher-Jedrasiak and Umgeher-Mayer, 2010).

The lithic material earlier was classified as Aurignacian (Hahn, 1977). The first radiocarbon dates on four charred bone fragments from area A and a reindeer bone from area B argued for an age younger than Aurignacian for the human occupation, 25.2—23.0 ka (Verpoorte, 2004). The cultural affiliation thus was re-classified as Epiaurignacian (Salcher-Jedrasiak and Umgeher-Mayer, 2010). Three of these radiocarbon dates were obtained from one sample: GrN—6660 was the residue of GrN—6585, and GrN—6659 was the residue of GrN—6660 (Verpoorte, 2004).

2.6.7. Madaras

The site was excavated between 1966 and 1974 and yielded a single archaeological layer 6.5—7.0 m below modern surface in a 10 m deep quaternary loess—paleosol sequence of MIS3 and MIS2 (Dobosi, 1968; Sümegi et al., 2020). The finds lay in the sandy loess without signs of humic horizons (Dobosi, 1989).

A bulk charcoal sample of a hearth, most of which belonged to *Pinus* spp (Stieber, 1967), was dated to 22.9—20.9 ka (Hv—1619) (Dobosi, 1989). A mollusc shell from 7.0 m depth, unrelated to the archaeological finds but nearly from the same level, was dated to 24.6—23.9 ka (DeA—11860), sandwiched between 23.0—22.6 ka (DeA—11901) from 1.0 m above and 25.9—25.6 ka (DeA-11895) from 2.0 m below (Sümegi et al., 2020).

The archaeological finds consisting of knapped lithics and bones of horse (Dobosi, 1989; Vörös, 1989) were classified Ságvárian or Pebble Gravettian (Dobosi, 2000a), and have been more recently designated as Early Epigravettian (Lengyel, 2018).

There are two other levels in the sequence which yielded few faunal remains: (1) one 1.5—2.0 m below the archaeological layer, and (2) another 0.8—1.8 m above it (Vörös, 1989). The spatial extension of these levels remained unreported. Lithic artifacts were not found here thus the association of these levels with human activity is yet insecure. According to mollusc AMS dates (Sümegi et al., 2020), the age of the upper layer is 23.0—21.4 ka (DeA—11904 and DeA—11901), and that of the lower one is 25.9—25.6 ka (DeA—11895). The upper layer included unidentified bone fragments, and the lower layer yielded mammoth, horse, elk, and bison bones (Vörös, 1989).

2.6.8. Mohelno—Plevovce KSA—B

The site is submerged in a lake of a hydroelectric power station of Mohelno. Two find concentrations were found at the site, KSA—B and AC1—2 (Škrdla et al., 2014, 2015). KSA—B included a stone structure (Škrdla et al., 2016) similar to that of Kammern—Grubgraben (Händel et al., 2021). KSA—B yielded a severely fragmented faunal assemblage consisting of reindeer and horse, charcoals, and a small collection of lithics (Škrdla et al., 2016). The charcoals were of birch and juniper with rare occurrences of willow and species of Vacciniaceae. The first charcoal date of KSA—B revealed a PLGM age, 19.9—19.5 ka (Poz—57861) (Škrdla et al., 2016). Further charcoal samples yielded LLGM age 23.7—22.5 ka (Poz—76195 and Poz—76196) (Demidenko et al., 2019).

The lithic assemblage of KSA—B first was found similar to the Epigravettian, the EASMM, and the Badegoulian (Škrdla et al., 2016). Later, Demidenko et al. (2019) kept only the EASMM association. AC1—2 lithic assemblage, being different from KSA—B, remained undated and archaeologically unclassified (Škrdla et al., 2015).

2.6.9. Nadap

The site was embedded in a sandy slope loess in a stone quarry. Nadap's first chronological estimation was based upon the Upper Pleistocene geochronology of Hungary, which dated the human occupation to between 35.0 and 25.0 ka (Dobosi et al., 1988). The lithic assemblage then was classified Pavlovian (Dobosi, 2000a). In contrast, the biostratigraphy of the site (Vörös, 2000) and an AMS date 15.9—15.4 ka (GrA—16563) of a horse phalange from the cultural layer (Verpoorte, 2004) indicated a PLGM age for the site. The lithic typological features were also found matching Late Epigravettian (Lengyel, 2016).

2.6.10. Ságvár

Ságvár had been known as a two-layered site embedded in loess dated to the LGM (Gábori and Gábori, 1957; Dobosi, 2000a; Lengyel, 2010). Besides the lithic artifacts, it yielded a large faunal assemblage of reindeer and horse (Vörös, 1982). Special site features were huts surrounded by post holes in the upper layer (UL) (Gábori, 1965; Lengyel, 2010).

Ságvár was the eponymous site of the Ságvárian culture of the LGM in ECE (Kozłowski, 1979). The name Ságvárian then was replaced with the term Pebble Gravettian, meaning that this type of industry is part of the Gravettian chronology (Dobosi, 2000a). The name Pebble Gravettian, however, was found to be misleading since no Gravettian sites of ECE could be dated to the LGM (Lengyel and Wilczyński, 2018), and all the sites classified Ságvárian or Pebble Gravettian were proposed to be re-classified Early Epigravettian (Lengyel, 2018).

The stratigraphic integrity of the lithic materials of the lower layer (LL) of the 1957–1959 excavation is yet insecure. The finds of the two layers underwent a lithic refitting study that found ~ 40% of all refits included items from both stratigraphic units (Lengyel, 2010). Subsequently, the assemblages of the lower and the upper layers were studied as a single unit (Lengyel, 2016, 2018).

From the 1957–1959 excavation, a bulk charcoal sample from the hut of the UL was dated to 22.0–21.0 ka (GrN–1959), and another sample from the LL to 23.0–22.5 ka (GrN–1783) (Vogel and Waterbolk, 1964). Bulk mollusc and charcoal samples from one of the cultural layer were dated to 22.9–22.1 ka (Deb–8822) and 24.2–23.3 ka (Deb–8821), respectively (Krolopp and Sümegi, 2002). A mollusc sample (*T. hispidus*), from possibly the LL yielded an age 22.4–22.1 ka (DeA–11788) (Molnár et al., 2021).

The UL and LL were interpreted as embryonic soil formations (Gábori and Gábori, 1957), and therefore Gábori-Csánk (1978) identified them as representing interstadials.

2.6.11. Sowin 7 LL

Sowin 7 is the only Epigravettian occupation in Lower Silesia (Wiśniewski et al., 2012, 2021). The finds were located in layer 3 (lower layer = LL) which was composed of sand and silt cemented by a ferruginous substance with periglacial cracks between 0.5 and 0.7 m below the recent surface. Above this, layer 2 was aeolian sand, and layer 1 was the plough zone, together yielding Magdalenian finds from the upper archaeological level. This stratigraphic position is unique in ECE, as there is no other Epigravettian–Magdalenian archaeological sequence. The site did not preserve organic remains, and OSL dating was used to date the sediments. The age of the Epigravettian sediment was 18.0–13.8 ka and that of the Magdalenian was 16.5–12.1 ka.

2.6.12. Stránská skála IV

This site was the only dated LGM human occupation in Moravia until the dating of Mohelno–Plevovce KSA–B (Demidenko et al., 2019). Locus IV marks the Epigravettian occupation of the Stránská skála site cluster. The Epigravettian finds were located in the lowermost part of a Holocene soil B horizon (layer 3) and the uppermost part of the underlying loess layer (layer 4) 0.8–1.0 m below recent surface (Svoboda et al., 2020). Beside knapped lithics and limestone boulders (Svoboda et al., 2020), there was an abundant fauna mainly of horse (Boriová et al., 2020). The site was dated to 24.1–21.1 ka by ten measurements on bones and teeth of horse (Svoboda, 1991; Svoboda et al., 2020; Stevens et al., 2021). Out of the ten, seven AMS dates, yet unpublished in details, were calibrated to 24.1–23.0 ka (Stevens et al., 2021). These overlapped a published AMS date 22.9–22.4 ka (Poz–101463) (Svoboda et al., 2020). The AMS dates were regarded as representing the age of the site (Stevens et al., 2021), which is older than the age counted from the RD dates 22.4–21.1 ka (GrN–14351 and GrN–13954) (Svoboda, 1991).

2.6.13. Targowisko 10

The site yielded a single archaeological layer embedded within a layered sandy loess 1.3 m below ground surface (Wilczyński, 2009). This was the first Epigravettian site unambiguously dated to the PLGM in southeast Poland. The findings were mainly lithics, along with a few animal bones and teeth in a poor state of preservation, and five hearths (I–V). The only wood species identified in a sample was oak, but this does not imply all the charcoals were also oak. A charcoal sample of hearth II was dated to 16.9–16.4 ka (Poz–14693), and four other samples showed an older age, 18.3–17.4 ka (Poz–14691: hearth I, Poz–14692: hearth III, Poz–14694: hearth IV, Poz–14695: hearth V).

2.6.14. Trenčianske Bohuslavice layer A2–1

The site yielded archaeological layers from the Early UP to the LUP (Wilczyński et al., 2020). Layer A2–1 was first recognized in the 1980's, though it was not identified as Epigravettian (Bárta, 1988). The revision of the archaeological and geological sequence in the 2000s produced the first AMS date on charcoal for layer A2–1, 27.0–26.4 ka (GrA–42311) (Vlačiky et al., 2013). The fieldwork in 2017 identified layer A2–1 as Epigravettian. Layer A2–1 did not contain animal bone remains but a *Pinus t. Sylvestris–mugo* charcoal from a hearth was AMS dated to 27.1–26.3 ka (Poz–97252) (Wilczyński et al., 2020).

2.6.15. Zöld Cave layer 3

The Late Epigravettian finds at Zöld Cave were embedded in layer 3, representing the only Palaeolithic layer at the site (Béres et al., 2021). The small lithic assemblage consists exclusively of retouched tools. The fauna is made up of horse and reindeer, bones of which preserved marks of butchering. AMS dates of the bones and one charcoal of *Picea/larix* indicated that layer 3 contained residues of two stratigraphically indistinguishable human occupational events, one dated to 17.0–16.5 ka, and the other to 16.0–15.0 ka.

3. Results

3.1. Radiocarbon chronology (Table 2)

3.1.1. ILGM occupations

The new date of a mammoth bone of Langmannersdorf, 24.6–23.9 ka (Poz–114222), suggested that the previous dates older than 23.9 ka (GrN–6659, GrA–16567, GrN–6660) show the most likely age of the site. The human occupation thus can be dated to 25.2–23.9 ka, which is still at least 1.1 ka younger than the other ILGM site in our analysis, Trenčianske Bohuslavice layer A2–1.

3.1.2. LLGM occupations

Kammern–Grubgraben AL1 was dated on two reindeer mandibles (Poz–105371, Poz–105372) to 22.8–22.2 ka. These overlap three of the four previous dates 22.7–22.0 ka (MAMS–26430, MAMS–32966, and GrN–21902). Lv–1825 calibrated to 20.9–19.6 ka is still considerably younger than the other dates of AL1 (Fig. 3).

AL2 new dates on two reindeer mandibles (Poz–105373, Poz–105374) gave an age 23.1–22.4 ka. These overlap Lv–1822, GrN–21529, and MAMS–40115. Four other dates, MAMS–25868, MAMS–25869, MAMS–30165, and MAMS–40116, however, indicate an age 23.7–23.0 ka that is older than our age estimation. Lv–1821 and Lv–1823, 22.5–20.5 ka, remained the youngest for AL2.

AL3 new dates from two reindeer mandibles (Poz–105375, Poz–105376) and an ibex mandible (Poz–105378) showed divergent ages: 23.7–23.0 ka (Poz–105375), 23.1–22.5 ka (Poz–105376), and 22.5–22.0 ka (Poz–105378). Out of the seven

Table 2
Radiocarbon dates of the studied sites (in alphabetical order) and their calibrated ages (Reimer et al., 2020). B: bone. teeth; Ch: charcoal; MS: mollusc shell; S: soil; SED: sediment; *: date made of the same sample; n. a.: not available; RD: radiometric dating, OSL: optically stimulated luminescence dating; b2k: before 2000. Text in boldface marks the dates obtained in our research.

Site	Lab Code	Date	±	Cal Bp 95.4%		Sample	Method	Reference
Brno–Štýřice III	GrN–9350	14450	90	17923	17352	B	RD	Verpoorte (2004)
"	GrA–20002	14820	120	18588	17801	B	AMS	"
"	OxA–28114	14870	90	18581	17915	B	AMS	Nerudová, 2016
"	OxA–28298	15215	70	18690	18281	B	AMS	"
"	OxA–26961	15625	75	19065	18780	B	AMS	"
Budapest–Csillaghegy	Deb–3160	15940	150	19557	18910	MS	RD	Sümegi et al. (1998)
"	**DeA–19964**	**13460**	**70**	**16451**	**15985**	**B**	**AMS**	**this paper**
"	**Poz–101464**	**15360**	**80**	**18837**	**18311**	**B**	**AMS**	**"**
Esztergom–Gyurgyalag	**DeA–21463**	**15120**	**80**	**18650**	**18249**	**B**	**AMS**	**this paper**
"	**DeA–21462**	**15270**	**80**	**18767**	**18284**	**B**	**AMS**	**"**
"	Deb–1160	16160	200	20031	19005	Ch	RD	Hertelendi (1991)
Kammern–Grubgraben AL1	Lv–1825	16800	280	20925	19578	B	RD	Haesaerts et al. (2016)
"	GrN–21902	18380	130	22535	22032	B	RD	"
"	MAMS–26430	18300	70	22400	22090	B	AMS	Händel et al., 2021
"	MAMS–32966	18590	60	22749	22343	B	AMS	"
"	**Poz–105372**	**18490**	**120**	**22788**	**22153**	**B**	**AMS**	**this paper**
"	**Poz–105371**	**18720**	**130**	**22940**	**22404**	**B**	**AMS**	**"**
Kammern–Grubgraben AL2	Lv–1821	17350	190	21665	20467	B	RD	Haesaerts et al. (2016)
"	Lv–1823	18070	270	22496	21106	B	RD	"
"	Lv–1822	18620	220	22987	22155	B	RD	"
"	GrN–21529	18890	180	23141	22406	B	RD	"
"	MAMS–25869	19330	70	23723	23024	B	AMS	"
"	MAMS–25868	19320	60	23713	23025	B	AMS	"
"	MAMS–30165	19250	70	23688	22971	B	AMS	Händel et al., 2021
"	MAMS–40115	18860	60	22969	22556	B	AMS	"
"	MAMS–40116	19230	60	23667	22961	B	AMS	"
"	**Poz–105374**	**18910**	**140**	**23056**	**22465**	**B**	**AMS**	**this paper**
"	**Poz–105373**	**18810**	**140**	**22983**	**22439**	**B**	**AMS**	**"**
Kammern–Grubgraben AL3	Lv–1810	18030	270	22452	21079	B	RD	Haesaerts et al. (2016)
"	GrN–21530	18920	90	23014	22554	B	RD	"
"	MAMS–25871	19070	70	23136	22887	B	AMS	"
"	MAMS–25870	19170	60	23228	22935	B	AMS	"
"	**Poz–105375**	**19290**	**140**	**23740**	**22962**	**B**	**AMS**	**this paper**
"	**Poz–105376**	**18930**	**140**	**23085**	**22470**	**B**	**AMS**	**"**
"	**Poz–105378**	**18320**	**120**	**22461**	**22029**	**B**	**AMS**	**"**
Kammern–Grubgraben AL3+AL4	Lv–1660	18170	300	22859	21256	B	RD	Haesaerts (1990)
Kammern–Grubgraben AL4	AA–1746	18960	290	23736	22355	B	AMS	"
"	Lv–1680	18400	330	22995	21445	B	RD	"
"	GrN–21893	18820	160	23008	22418	B	RD	Haesaerts et al. (2016)
"	GrN–21790	19270	80	23705	22978	B	RD	"
"	GrN–21531	19380	90	23743	23050	B	RD	"
"	MAMS–25872	19290	70	23707	22997	B	AMS	"
"	MAMS–25873	19210	70	23666	22947	B	AMS	"
"	**Poz–105379**	**18790**	**130**	**22967**	**22441**	**B**	**AMS**	**this paper**
"	**Poz–105380**	**18870**	**140**	**23019**	**22457**	**B**	**AMS**	**"**
Kašov I UL	Gd–6569	18600	390	23712	21480	Ch	RD	Bánesz et al. (1992)
Langmannersdorf	GrN–6586	19520	120	23800	23165	B	RD	Verpoorte (2004)
"	GrN–6659*	20580	170	25199	24266	B	RD	Verpoorte (2004)
"	GrA–16567	20590	110	25137	24368	B	AMS	"
"	GrN–6660*	20260	200	24924	23860	B	RD	"
"	GrN–6585*	19340	100	23739	23009	B	RD	"
"	**Poz–114222**	**20170**	**110**	**24555**	**23889**	**B**	**AMS**	**this paper**
Madaras (archaeological layer)	Hv–1619	18080	405	22888	20935	Ch	RD	Dobosi (1989)
"	**DeA–20438**	**19770**	**120**	**24142**	**23377**	**B**	**AMS**	**this paper**
"	**DeA–20439**	**19720**	**120**	**24046**	**23338**	**B**	**AMS**	**"**
Madaras (ca. level of arch. layer)	DeA–11860	20193	93	24560	23935	MS	AMS	Sümegi et al. (2020)
Madaras (ca. 1.0 m above arch. layer)	DeA–11901	18942	71	23015	22598	MS	AMS	"
Madaras (ca. 2.0 m below arch. layer)	DeA–11895	21381	82	25926	25599	MS	AMS	"
Madaras soil MAD-L1S1 lower boundary, (ca. 1.0 m above arch. layer)	DeA–11904	17870	71	21972	21426	MS	AMS	"
Mohelno–Plevovce KSA–B	Poz–57891	16280	80	19879	19480	Ch	AMS	Škrdla et al. (2016)
"	Poz–76195	18970	110	23068	22541	Ch	AMS	Demidenko et al. (2019)
"	Poz–76196	19100	110	23680	22732	Ch	AMS	"
Nadap	GrA–16563	13050	70	15850	15356	B	AMS	Verpoorte (2004)
"	**DeA–22901**	**13120**	**160**	**16211**	**15272**	**B**	**AMS**	**this paper**
Ságvár UL	GrN–1959	17760	150	22001	21036	Ch	RD	Vogel and Waterbolk (1964)
Ságvár LL	GrN–1783	18900	100	23009	22528	Ch	RD	"
Ságvár LL?	Deb–8822	18510	160	22894	22143	MS	RD	Krolopp and Sümegi (2002)
Ságvár LL?	Deb–8821	19770	150	24199	23345	Ch	RD	"
Ságvár LL?	DeA–11788	18350	65	22431	22146	MS	AMS	Molnár et al. (2021)
Ságvár 1936	**Poz–101177**	**17070**	**110**	**20885**	**20390**	**B**	**AMS**	**this paper**
"	**DeA–20435**	**17430**	**100**	**21379**	**20830**	**B**	**AMS**	**"**
"	**DeA–20977**	**16970**	**110**	**20821**	**20251**	**B**	**AMS**	**"**

Table 2 (*continued*)

Site	Lab Code	Date	±	Cal Bp 95.4%		Sample	Method	Reference
"	**DeA–20978**	**16910**	**110**	**20764**	**20157**	**B**	**AMS**	**"**
"	**DeA–20979**	**16870**	**110**	**20700**	**20088**	**B**	**AMS**	**"**
Sowin 7 above LL	n. a.	13830	860	15550	12110	SED	OSL (b2k)	Wiśniewski et al. (2017)
"	n. a.	14700	900	16500	12900	SED	OSL (b2k)	"
Sowin 7 LL	n. a.	15470	860	17190	13750	SED	OSL (b2k)	"
"	n. a.	16200	920	18040	14360	SED	OSL (b2k)	"
Stránská Skála IV	GrN–14351	17740	90	21892	21144	B	RD	Svoboda (1991)
"	GrN–13954	18220	120	22410	21918	B	RD	"
"	Poz–101463	18670	110	22911	22386	B	AMS	Svoboda et al. (2020)
"	**DeA–20210**	**19030**	**250**	**23732**	**22428**	**B**	**AMS**	**this paper**
"	**DeA–20212**	**18640**	**130**	**22919**	**22347**	**B**	**AMS**	**"**
Targowisko 10	Poz–14694	14520	70	17984	17414	Ch	AMS	Wilczyński (2009)
"	Poz–14691	14790	80	18251	17892	Ch	AMS	"
"	Poz–14692	14790	70	18248	17910	Ch	AMS	"
"	Poz–14695	14820	70	18261	17939	Ch	AMS	"
"	Poz–14693	13720	70	16903	16361	Ch	AMS	"
Zöld Cave layer 3	Poz–99669	13110	90	16008	15415	B	AMS	Béres et al. (2021)
"	Poz–103229	12930	50	15634	15278	B	AMS	"
"	DeA–19556	12702	55	15304	14974	Ch	AMS	"
"	Poz–103176	13820	70	17014	16536	B	AMS	"
"	**DeA–20980**	**12980**	**70**	**15746**	**15294**	**B**	**AMS**	**this paper**
"	**DeA–19968**	**13770**	**80**	**16984**	**16420**	**B**	**AMS**	**"**

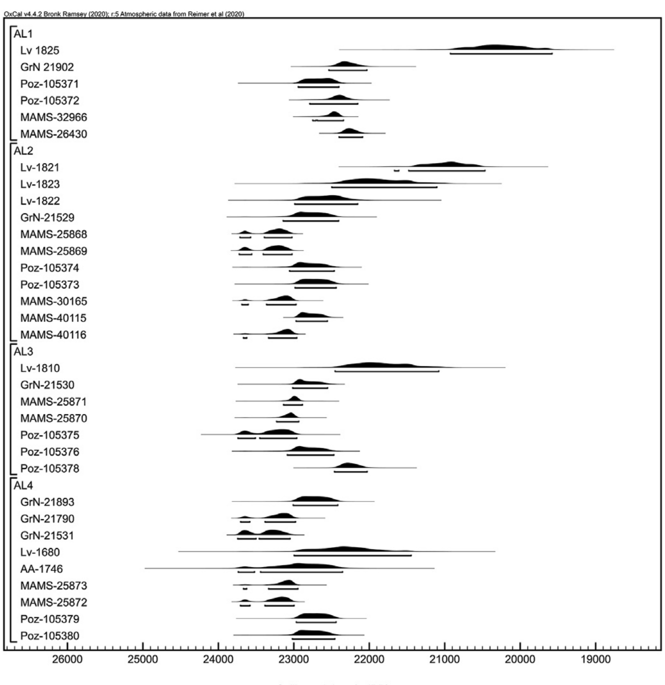

Fig. 3. Kammern-Grubgraben, sequence of all radiocarbon dates calibrated.

dates available for AL3, MAMS–25871, MAMS–25870, and Poz–105375 overlap between 23.7 and 22.9 ka.

AL4 new dates on two reindeer mandibles 23.0–22.4 ka (Poz–105379, Poz–105380) overlap GrN–21893, Lv–1680, and AA–1746. The new dates are younger than GrN–21790, GrN–21790, MAMS–25873, and MAMS–25872, which overlap each other between 23.7 and 23.0 ka.

When only AMS dates were included from Kammern–Grubgraben (Fig. 4), AL1 can be dated to ca. 23.0–22.1 ka. Dates of AL2–4 made two groups irrespectively of their stratigraphic order: 23.7–23.0 ka and 23.0–22.4 ka. Poz–105378 is alone to show an age contemporaneous with AL1, 22.5–22.0 ka. This dataset implied that AL1 likely is younger than AL2–4, and the chronological difference can be supported by the stratigraphic position of AL1, which was separated from AL2–4 by a varying thickness of archaeologically sterile loess while AL2, 3, and 4 were formed almost directly on top of each other (Haesaerts and Damblon, 2016).

The new dates of Madaras, 24.1–23.3 ka (DeA–20438, DeA–20439), were made on two horse molars. This age is older than the charcoal date 22.9–20.9 ka (Hv–1619) and overlaps the mollusc date 24.6–23.9 ka (DeA–11860) obtained from the level of the archaeological layer.

Ságvár new dates were obtained from three reindeer molars (DeA–20977, DeA–20978, DeA–20979), a reindeer tibia (Poz–101177), and a horse molar (DeA–20435) from the 1936 excavation (Vörös, 1982; Péan, 2001; Lengyel, 2010). These yielded the youngest age known for the site, 21.4–20.1 ka. As the layers of the 1935–1937 excavations were not correlated with that of 1957–1959, we cannot establish the stratigraphic order of the radiocarbon dates. The date of the UL of 1957–1959, 22.0–21.0 ka (GrN–1959), partially overlaps one of the new dates, 21.4–20.8 ka (DeA–20435), and the rest of the dates show a younger age 20.9–20.1 ka (DeA–20977, DeA–20978, DeA–20979, Poz–101177).

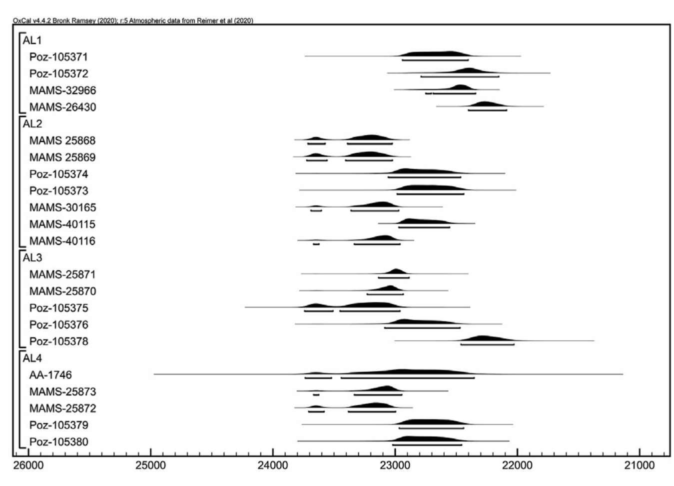

Fig. 4. Kammern-Grubgraben, sequence of AMS radiocarbon dates calibrated.

The charcoals of the LL of the 1957–1959 excavation dated to 23.0–22.5 ka (GrN–1783) could also mark another human occupational event, but the interlayer lithic refitting yet retains an uncertainty for the archaeological integrity of the LL (Lengyel, 2010). Further dates (Deb–8821, Deb–8822, and DeA–11788), however, also indicate an age 24.2–22.1 ka for one of the human occupations. Based on the AMS dates, we can however be certain that the duration of the human presence at the site lasted longer than previously estimated (Lengyel, 2008– 2009), up until the end of the LLGM.

Stránská skála IV new dates from two horse molars 23.7–22.4 ka (DeA–20210, DeA–20212) overlap previous AMS dates 24.1–22.4 ka and supported the older age estimation for the human occupation.

3.1.3. PLGM occupations

The dates of Brno–Štýřice III showed three possible ages for the human occupation: 19.1–18.8 ka (OxA–26961), 18.7–17.8 ka (GrA–20002, OxA–28114, OxA–28298), and 17.9–17.3 (GrN–9350). Most likely, the range of the three AMS dates between 18.7 and 17.8 ka represents the age of the human occupation.

Budapest–Csillaghegy was dated on the mammoth remain of the archaeological layer to 18.8–18.3 ka (Poz–101464). This age fits the stratigraphic sequence, as it is in a superposition with an older age 19.6–18.9 ka (Deb–3160) of a bulk mollusc sample taken 0.2 m below the archaeological layer. Our second sample, a horse tooth found in insecure archaeological context, gave a younger age, 16.5–16.0 ka (DeA–19964), which archaeologically is yet uninterpretable. Because the mammoth date is in a stratigraphic agreement with the older date underlying, we accept it as the age of the human occupation.

From Esztergom–Gyurgyalag two new dates on mammoth bones, 18.8–18.2 ka (DeA–21462, DeA–21463), showed an age younger than the bulk charcoal date 20.0–19.0 ka (Deb–1160) for the human occupation.

The new date of Nadap, 16.2–15.3 ka (DeA–22901), was obtained on a horse molar from the archaeological layer. The collagen preservation in the tooth was below the standard for acceptance, 0.2%. Although showing a close resemblance, we still accept the previously obtained age 15.9–15.4 ka (GrA–16563) as dating the human occupation.

Zöld Cave layer 3 new dates, 17.0–16.4 ka (DeA–19968) and 15.7–15.3 ka (DeA–20980), derived from a horse molar and a reindeer molar, respectively, support the previous observation that layer 3 was a palimpsest of subsequent human occupations. On the basis of the bone and tooth dates, one occupational period is 17.0–16.4 ka, and the other is 16.0–15.3 ka. The charcoal date of the site, 15.3–15.0 ka (DeA–19556), could indicate a third occupation, but since the sample did not derive from an archaeological feature, we are unable to confidently relate it with human activity.

3.2. The lithic tool typology

3.2.1. The tool blanks

ILGM and LLGM tools were made chiefly of blade/lets (Table 3). In LLGM Kammern–Grubgraben AL2–4 and Ságvár are the only assemblages dominated by flake tools. In PLGM, blade/lets were the most frequent tool blanks. The lowest portion of blade/let tools in PLGM was found at Targowisko 10, which is 63.6%. This proportion would be the third greatest in LLGM context. The frequency of blade/let tools in PLGM was statistically visible when compared to both LLGM ($r_{S(12)} = 0.726$, $p = 0.003$) and ILGM ($r_{S(8)} = 0.725$, $p = 0.027$).

3.2.2. Domestic versus armature component

The two ILGM toolkits were not uniform. The most frequent tool type of Trenčianske Bohuslavice A2–1 was the edge-retouched tool, at Langmannersdorf burins dominated, but in both assemblages the armatures are insignificant (Table 4).

At LLGM sites, the end-scraper ratio never declined under 10%, burin frequency always was over 20%, the proportion of edge-retouched tools was never lower than 23.4%, and the armatures never made up more than 12.5% of the toolkit (Table 4). One LLGM site, Madaras, and one ILGM site, Trenčianske Bohuslavice A2–1, did not have armatures. This meant a very strong domestic tool component for ILGM and LLGM toolkits.

In PLGM, armatures were more numerous, and even outnumbered domestic tools in Esztergom–Gyurgyalag, Sowin 7 LL, Nadap, and Zöld Cave layer 3. The PLGM Zöld cave record does not have domestic tools at all, and Budapest–Csillaghegy is the only one to lack armatures. The end-scraper ratio in PLGM may fall under 10%, or even be missing, which is never the case for ILGM and LLGM assemblages. The lowest ratio of armature, 10.9%, was found at Targowisko 10. Other PLGM sites had an armature portion greater than the largest one in LLGM. Armature frequency characterized PLGM when compared to LLGM ($rs_{(12)} = 0.568$, $p = 0.034$).

3.2.3. Domestic tool types

Correlating the ratio of tool types with the age of the sites, first involving ILGM and LLGM, did not show significant results. However, the low number of samples of ILGM human occupations hindered the efficiency of the statistical test.

Comparing LLGM and PLGM domestic tools, we found two typological differences. (1) Edge-retouched tools ($r_{S(12)} = -0.549$, $p = 0.042$) and (2) borers ($r_{S(13)} = -0.867$, $p = 0.000$) were correlated with LLGM. Although splintered pieces are present in almost each LLGM assemblage, this frequency is not statistically significant.

3.2.4. Armature tool types

ILGM armatures were retouched points, found only in Langmannersdorf (Fig. 5: 1). LLGM armatures were most frequently backed blade/lets (Table 5) (Fig. 5: 3, 7, 14, 18–24, 27–32, 34–39), which were also frequent in PLGM assemblages (Fig. 5: 50, 51, 61, 63), but their frequency did not differ from LLGM ($r_{S(12)} = -0.160$, $p = 0.584$). Backed-truncated blade/lets (Fig. 5: 4–6, 33, 59, 60) also were common in both LLGM and PLGM ($rs_{(12)} = 0.277$, $p = 0.338$). One PLGM site, Esztergom–Gyurgyalag, included geometric forms, such as the rectangle and the trapeze, which statistically also did not become a feature of the PLGM.

LLGM points are exclusively the retouched types (Fig. 5: 2). Compared to PLGM, their frequency is significant in LLGM point assemblages ($r_{S(12)} = -0.548$, $p = 0.042$). Backed points (Fig. 5: 56, 65–67) ($r_{S(12)} = 0.723$, $p = 0.003$) and curved back points (Fig. 5: 45–49, 52–55, 57, 58, 64) ($r_{S(12)} = 0.621$, $p = 0.018$) were correlated with the PLGM assemblages (Table 6). Esztergom is the only site which yielded a pseudo-Gravette point, the ventral retouch of which is not flat as it must be to make it a Gravette point.

3.2.5. Size of the tools

Domestic tools mean length (Table 7) in ILGM was greater than in LLGM ($U = 188040.5$, $p = 0.000$). PLGM tool lengths were greater than both ILGM tools ($U = 44871.5$, $p = 0.000$) and LLGM tools ($U = 158034.5$, $p = 0.000$). Domestic tool types were the smallest at Mohelno–Plevovce KSA–B, which was due to the high number of SMM that is typically shorter than 10 mm (Fig. 5: 40–44). At Mohelno–Plevovce KSA–B, 83.6% of all retouched blade/lets are shorter than 10 mm. A number of SMM was found in Kammern–Grubgraben AL2–4 (n = 7) (Fig. 5: 10–13). At other

Table 3
Blanks of the toolkits.

Age	Site	Flake	Blade/let	Debris	Rejuvenating flake	Crested blade/let	Neo-crested blade/let	Burin spall	Blade/let core	Flake core	Total
ILGM	Trenčianske Bohuslavice layer A2–1	3	5								8
		37.5%	62.5%								100%
	Langmannersdorf	134	174	8	3	1	3	1	3		327
		41.0%	53.2%	2.4%	0.9%	0.3%	0.9%	0.3%	0.9%		100%
	Total	137	179	8	3	1	3	1	3		335
		40.9%	53.4%	2.4%	0.9%	0.3%	0.9%	0.3%	0.9%		100%
LLGM	Ságvár	167	71	55	5	2	9				309
		54.0%	23.0%	17.8%	1.6%	0.6%	2.9%				100%
	Kammern–Grubgraben AL1	57	94	2	2		3				158
		36.1%	59.5%	1.3%	1.3%		1.9%				100%
	Kammern–Grubgraben AL2–4	255	128	7	2	1	4	1			398
		64.1%	32.2%	1.8%	0.5%	0.3%	1.0%	0.3%			100%
	Madaras	11	13								24
		45.8%	54.2%								100%
	Kašov I UL	153	170	1	2	1	10	1		5	343
		44.6%	49.6%	0.3%	0.6%	0.3%	2.9%	0.3%		1.5%	100%
	Mohelno–Plevovce KSA–B	35	87	7	1	0	0	1			131
		26.7%	66.4%	5.3%	0.8%	0.0%	0.0%	0.8%			100%
	Stránská skála IV	2	4			1	1				8
		25.0%	50.0%			12.5%	12.5%				100%
	Total	680	567	72	12	5	27	3		5	1371
		49.6%	41.4%	5.3%	0.9%	0.4%	2.0%	0.2%		0.4%	100%
PLGM	Esztergom–Gyurgyalag	26	317				1				344
		7.6%	92.2%				0.3%				100%
	Brno–Štýřice III	16	34	1			1				52
		30.8%	65.4%	1.9%			1.9%				100%
	Sowin 7 LL	48	101	3		2	4				158
		30.4%	63.9%	1.9%		1.3%	2.5%				100%
	Targowisko 10	20	28			1	6				55
		36.4%	50.9%			1.8%	10.9%				100%
	Nadap	4	59				3				66
		6.1%	89.4%				4.5%				100%
	Zöld Cave layer 3		5								5
			100.0%								100%
	Budapest–Csillaghegy	1	4				1				6
		16.7%	66.7%				16.7%				100%
	Total	115	548	4		3	16				686
		16.8%	79.9%	0.6%		0.4%	2.3%				100%

sites, retouched blade/lets are greater than 10 mm (Fig. 6).

The armatures mean length in ILGM was greater than in LLGM ($U = 11.0$, $p = 0.003$) and similar with PLGM ($U = 354.0$, $p = 0.101$). PLGM armatures were greater than LLGM armatures ($U = 4137.5$, $p = 0.000$) (Table 8).

3.3. The faunal record

An ILGM bone assemblage was available only from Langmannersdorf (Table 9). The faunal spectrum is similar to the Late Gravettian which is often dominated by mammoth (Wilczyński et al., 2019).

In LLGM, compared to the only ILGM fauna, there was an increase of reindeer and horse MNI and a disappearance of mammoth. Kammern–Grubgraben AL1, AL2–4, and Ságvár were dominated by reindeer and the second most preferred prey was horse. In the case of Mohelno–Plevovce KSA–B, the fauna also consisted of these two species, but they were too fragmentary to declare which one was present with more individuals (Škrdla et al., 2021). Three LLGM sites, Madaras, Stránská skála IV, and Kašov I UL were dominated by horse, but Kašov I UL preserved only two horse molars in a very fragmented condition.

The decline of the mammoth population in the LLGM is in agreement with the results of Nadachowski et al. (2011, 2018) which found a sparse mammoth population in ECE 24.0–18.0 ka. Archaeozoological studies also showed that the mammoth at LLGM sites is represented only by tusk fragments, meaning they were not part of the prey spectrum (West, 1997; Vörös, 2000). Several mammoth remains directly dated from the Carpathian Basin also showed a gap in mammoth presence between 24.0 and 20.0 ka (Magyari et al., 2021). The only mammoth in ECE dated to the LLGM is the Zók specimen in the Carpathian Basin, the tusk of which yielded contradictory dating results: 28.8–21.7 ka (Deb–14677) and 22.1–21.0 ka (AA–80678) (Konrád et al., 2010). This suggests a lack or scarcity of mammoths in ECE during the LLGM.

At PLGM sites, the faunal assemblages are less abundant. The MNI of mammals is never more than a few individuals. The only PLGM site that provided a considerable faunal material was Nadap. The five mandible fragments and the 39 isolated lower teeth of horses including single third molars allowed us to estimate an MNI of four individuals in contrast to the 35 reported earlier (Dobosi et al., 1988). In sum, the MNI of horse was higher than of every other taxa at Nadap, Targowisko 10, and Zöld Cave layer 3, and reindeer never was dominant. This seems to distinguish LLGM and PLGM sites. Another difference we found was the re-occurrence of mammoth with skeletal parts in the PLGM. This is congruent with the results of Nadachowski et al. (2011, 2018) and Magyari et al. (2021), which showed a recovery of the mammoth population between 18.0 and 14.7 ka in ECE.

Correlating the percentile distribution of the MNI of the three main hunted species (reindeer, horse, mammoth) (Table 10) with the three periods, there is no statistical association, even in spite of the fact that mammoths are absent in LLGM and reindeer in PLGM never grew over 50%. In contrast, horses, either alone or together

Table 4
Lithic tool types of the assemblages.

Age	Site	End-scraper	Burin	Edge-retouched	Borer	Splintered piece	Truncation	Composite	Armature	Total
ILGM	Trenčianske Bohuslavice layer A2–1	2	2	3		1				8
		25.0%	25.0%	37.5%		12.5%				100%
	Langmannersdorf	40	224	36	4	11	8		4	327
		12.2%	68.5%	11.0%	1.2%	3.4%	2.4%		1.2%	100.0%
	Total	42	226	39	4	12	8		4	335
		12.5%	67.5%	11.6%	1.2%	3.6%	2.4%		1.2%	100.0%
LGM	Ságvár	53	68	100	6	65	5	4	8	309
		17.2%	22.0%	32.4%	1.9%	21.0%	1.6%	1.3%	2.6%	100%
	Kammern–Grubgraben AL1	30	57	37	2	3	5	5	19	158
		19.0%	36.1%	23.4%	1.3%	1.9%	3.2%	3.2%	12.0%	100%
	Kammern–Grubgraben AL2–4	139	81	103	18	25	8	15	9	398
		34.9%	20.4%	25.9%	4.5%	6.3%	2.0%	3.8%	2.3%	100%
	Madaras	5	5	7	1	2	4			24
		20.8%	20.8%	29.2%	4.2%	8.3%	16.7%			100%
	Kašov I UL	100	119	90	4	10	10		10	343
		29.2%	34.7%	26.2%	1.2%	2.9%	2.9%		2.9%	100%
	Mohelno–Plevovce KSA–B	15	7	73	1	24	1		10	131
		11.5%	5.3%	55.7%	0.8%	18.3%	0.8%		7.6%	100%
	Stránská skála IV	1	2	3	1				1	8
		12.5%	25.0%	37.5%	12.5%				12.5%	100%
	Total	343	339	413	33	129	33	24	57	1371
		25.0%	24.7%	30.1%	2.4%	9.4%	2.4%	1.8%	4.2%	100%
PLGM	Esztergom–Gyurgyalag	4	30	63	3		8	1	235	344
		1.2%	8.7%	18.3%	0.9%		2.3%	0.3%	68.3%	100%
	Brno–Štýřice III	1	19	17		3	5		7	52
		1.9%	36.5%	32.7%		5.8%	9.6%		13.5%	100%
	Sowin 7 LL	21	36	50		1	7	5	38	160
		13.1%	22.5%	31.3%		0.6%	4.4%	3.1%	24.1%	100%
	Targowisko 10	24	11	4			9	1	6	55
		43.6%	20.0%	7.3%			16.4%	1.8%	10.9%	100%
	Nadap	5	11	1			2		47	66
		7.6%	16.7%	1.5%			3.0%		71.2%	100%
	Zöld Cave layer 3								5	5
									100%	100%
	Budapest–Csillaghegy	2	1	1		1	1			6
		33.3%	16.7%	16.7%		16.7%	16.7%			100%
	Total	57	108	136	3	5	32	7	338	686
		8.3%	15.7%	19.8%	0.4%	0.7%	4.7%	1.0%	49.3%	100%

with the mammoth, outnumbered the reindeer MNI in PLGM. Bison occurred in ILGM, LLGM, and PLGM with a few individuals, and the woolly rhino was found only in ILGM and LLGM fauna. The ibex appeared at two sites, the ILGM Langmannersdorf and the LLGM Kammern–Grubgraben. Hare was found also mostly in LLGM context, as well as the brown bear. Wolf and fox were mostly found in ILGM, and the only European elk and beaver remains are from Ságvár LLGM site.

3.4. Epigravettian relative chronology

Our typological analysis found negligible variances between ILGM and LLGM assemblages. The main difference was the lack of backing retouch in ILGM assemblages, which remained statistically invisible due to the small number of sites analysed. Backed artifacts also were missing in Madaras and Stránská skála IV LLGM assemblages. Therefore, our typological analysis was unable to securely differentiate an ILGM assemblage from a LLGM one.

The typological difference between LLGM and PLGM was measurable by several features. LLGM assemblages had a domestic tool dominance with a strong edge-retouched tool and borer component. The most obvious typological signal for PLGM was the higher frequency of armatures often consisting of backed and curved backed points. Points of the LLGM sites were not made with backing but with simple retouch at the tip.

Low or moderate blade/let rate in tool kit paired with shorter blade/let tools also are LLGM features against the blade/let-dominated PLGM tool kits. Thus the size of the tools is also a possible relative chronological marker. ILGM and PLGM tools tend to be larger than LLGM specimens, including both the domestic and armature types.

These data are suggested as justification for classifying ILGM and LLGM sites as Early Epigravettian and PLGM sites as Late Epigravettian, following the typological criteria earlier established (Lengyel, 2016, 2018). If more archaeological data were available, sites of ILGM could be separately classified under the term Initial Epigravettian.

A major issue in the cultural classification of the LLGM could be the coexistence of the Early Epigravettian and the EASMM in ECE (Demidenko et al., 2019; Škrdla et al., 2021). EASMM was distinguished from the Epigravettian by the lack of backed blade/lets and the presence of SMM. Demidenko et al. (2019) and Škrdla et al. (2021) classified Mohelno–Plevovce KSA–B and Kammern–Grubgraben AL2–4 as EASMM. Our results show that these sites included backed blade/lets (Fig. 5: 7, 34–39) and therefore they closely fit Early Epigravettian typological criteria.

The three main herbivorous prey taxa (reindeer, horse, and mammoth) appeared with different frequencies in the three periods. Though statistically unsupported, we expect that the presence of mammoth skeletal elements most likely argue for ILGM or PLGM age for a site. When the number of individuals by species in a faunal assemblage is greater than one and both reindeer and horse are present, the reindeer dominance most likely indicates an LLGM age for a site. The horse dominance alone must not be taken as a PLGM relative chronological marker, but there is a greater chance to identify a PLGM site when horse dominance is accompanied by

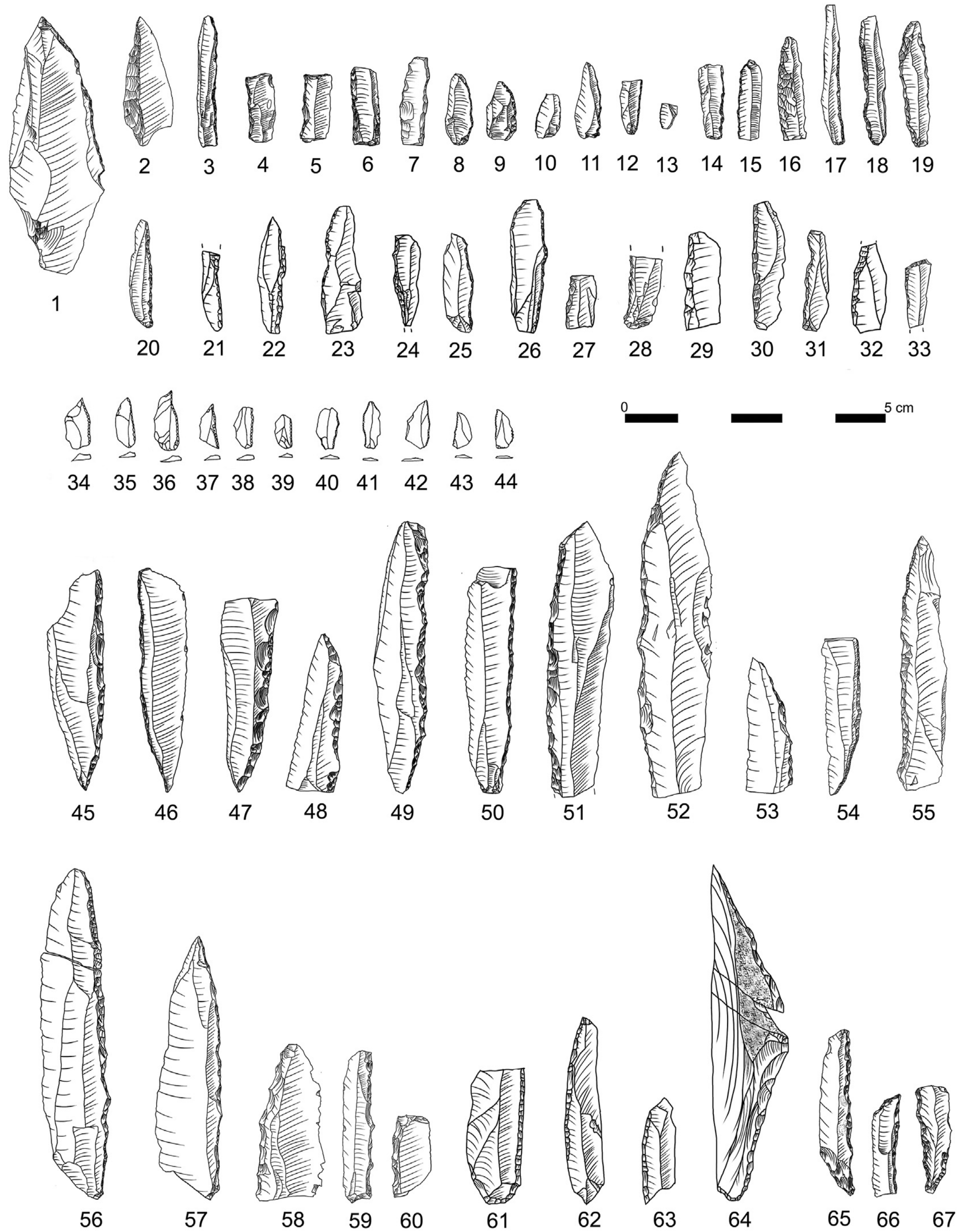

Fig. 5. Armatures of the assemblages. 1: Langmannersdorf, 2: Stránska skála IV, 3–13: Kammern–Grubgraben, 14–20: Kašov I UL, 21–33: Ságvár, 34–44: Mohelno–Plevovce KSA–B (after Škrdla et al., 2016: Figs. 6, 45–51: Sowin 7 LL, 52–54: Esztergom–Gyurgyalag, 55–56: Nadap, 57–60: Zöld Cave, 61–64: Targowisko 10, 65–67: Brno–Štýřice III.

mammoth.

The faunal elements alone, except for the mammoth, are not fully reliable relative chronological markers. Attaching the lithic features, however, one can be certain that, for instance, a domestic tool dominance accompanied by a moderate frequency of small sized armatures consisting only of backed blade/let and retouched blade/let points, short domestic tools, lack of mammoth, reindeer dominance over horse, together represent an LLGM Early Epigravettian human occupation (Table 11).

4. Discussion

We found that the twofold Epigravettian absolute and relative chronology can be applied for the eastern Central European archaeological record. This in turn challenges the current interpretation for MIS2 prehistory of ECE. The discussion of our results in the context of the available published archaeological data and environmental changes provides a new reading for the human population dynamics in MIS2.

Table 5
Armatures of the assemblages.

Age	Site	Backed blade/let	Backed-truncated blade/let	Trapeze	Rectangle	Trapeze-rectangle	Points	Total
ILGM	Langmannersdorf						4 100%	4 100%
	Total						4 100%	4 100%
LLGM	Ságvár	7 87.5%	1 12.5%				0 0.0%	8 100%
	Kammern–Grubgraben AL1	13 68.4%	3 15.8%		1 5.3%		2 10.5%	19 100%
	Kammern–Grubgraben AL2–4	5 55.6%	2 22.2%				2 22.2%	9 100%
	Kašov I UL	6 60.0%					4 40.0%	10 100%
	Mohelno–Plevovce KSA–B	8 80.0%					2 20.0%	10 100%
	Stránská skála IV						1 100.0%	1 100%
	Total	39 68.4%	6 10.5%		1 1.8%		11 19.3%	57 100%
PLGM	Esztergom–Gyurgyalag	142 60.4%	51 21.7%	3 1.3%	1 0.4%	5 2.1%	33 14.0%	235 100%
	Brno–Štýřice III	2 28.6%					5 71.4%	7 100%
	Sowin 7 LL	23 60.5%	2 5.3%				13 34.2%	38 100%
	Targowisko 10	3 50.0%	1 16.7%		1 16.7%		1 16.7%	6 100%
	Nadap	36 76.6%	6 12.8%				5 10.6%	47 100%
	Zöld Cave layer 3	1 20.0%	2 40.0%				2 40.0%	5 100%
	Total	207 61.2%	62 18.3%	3 0.9%	2 0.6%	5 1.5%	59 17.5%	338 100%

Table 6
Point types within armatures.

Age	Site	Retouched point	Gravette/microgravette	Backed point	Curved backed point	Total
ILGM	Langmannersdorf	4 100%				4 100%
	Total	4 100%				4 100%
LLGM	Kammern–Grubgraben AL1	2 100%				2 100%
	Kammern–Grubgraben AL2–4	2 100%				2 100%
	Kašov I UL	4 100%				4 100%
	Mohelno–Plevovce KSA–B	2 100%				2 100%
	Stránská skála IV	1 100%				1 100%
	Total	11 100%				11 100%
PLGM	Esztergom–Gyurgyalag	6 18.2%	1 3.0%	5 15.2%	21 63.7%	33 100%
	Brno–Štýřice III	1 20.0%		4 80.0%		5 100%
	Sowin 7 LL	2 15.4%		4 30.8%	7 53.8%	13 100%
	Targowisko 10			1 100%		1 100%
	Nadap			2 40.0%	3 60.0%	5 100%
	Zöld Cave layer 3				2 100%	2 100%
	Total	9 15.3%	1 1.7%	16 27.1%	33 55.9%	59 100%

Table 7
Domestic tool mean lengths.

Age	Site	Mean	N	Std. Deviation	Median	Minimum	Maximum
ILGM	Trenčianske Bohuslavice layer A2–1	37.4650	8	24.76379	32.3950	5.85	82.15
	Langmannersdorf	34.7498	323	10.06042	33.8900	12.58	72.01
	Total	34.8154	331	10.58022	33.8000	5.85	82.15
LLGM	Ságvár	29.4654	301	9.58018	27.8000	10.60	78.50
	Kammern–Grubgraben AL1	35.4612	139	12.70824	34.7800	5.12	89.06
	Kammern–Grubgraben AL2–4	34.0090	389	12.15868	32.9000	7.91	78.36
	Madaras	24.7679	24	9.02682	23.0450	10.47	48.72
	Kašov I UL	37.8459	333	13.29784	35.9200	11.08	102.67
	Mohelno–Plevovce KSA–B	16.4491	121	10.20540	12.2500	4.23	60.40
	Stránská skála IV	40.6729	7	29.88230	31.5100	20.47	107.03
	Total	32.3417	1315	13.31803	31.2200	4.23	107.03
PLGM	Esztergom–Gyurgyalag	39.7569	109	17.16269	37.1000	9.10	103.80
	Brno–Štýřice III	44.3004	45	16.77014	42.5500	18.71	86.82
	Sowin 7 LL	39.5478	120	14.29552	39.7000	7.11	83.98
	Targowisko 10	38.8931	49	11.38280	40.0500	11.80	64.05
	Nadap	44.5626	19	18.14305	44.0000	9.10	87.10
	Budapest–Csillaghegy	37.7650	6	19.58141	28.2250	22.30	64.06
	Total	40.3787	348	15.54635	39.9150	7.11	103.80

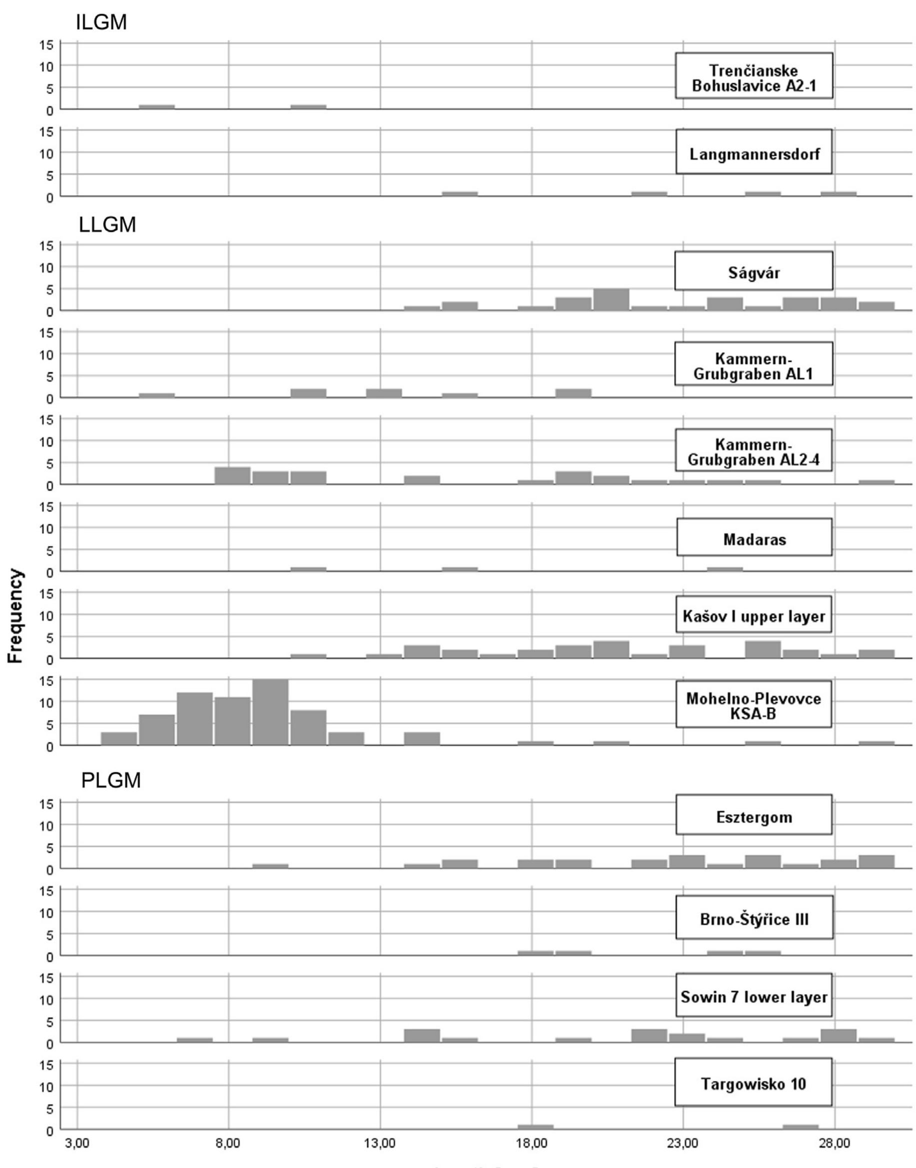

Fig. 6. Histograms of retouched blade/let lengths.

Table 8
Armature mean lengths.

Age	Site	Mean	N	Std. Deviation	Median	Minimum	Maximum
ILGM	Langmannersdorf	47.1025	4	24.19117	42.0250	26.45	77.91
	Total	47.1025	4	24.19117	42.0250	26.45	77.91
LLGM	Ságvár	18.4500	8	6.99816	19.2500	10.30	27.80
	Kammern–Grubgraben AL1	15.2068	19	4.99736	14.0000	8.85	25.13
	Kammern–Grubgraben AL2-4	23.4622	9	11.53860	23.7000	12.04	49.65
	Kašov I UL	26.1670	10	17.82220	20.0750	10.76	71.69
	Mohelno–Plevovce KSA–B	10.6800	10	5.28098	9.3950	6.53	25.24
	Stránská skála IV	23.2400	1	.	23.2400	23.24	23.24
	Total	18.2398	58	10.77091	15.6100	6.53	71.69
PLGM	Esztergom–Gyurgyalag	31.5409	235	13.13364	29.5000	9.60	71.20
	Brno–Štýřice III	23.4829	7	20.53030	19.1200	7.96	66.60
	Sowin 7 LL	28.1461	38	12.21368	28.7700	8.14	53.36
	Targowisko 10	25.1183	6	11.12850	23.9950	11.63	38.67
	Nadap	25.3498	47	11.58285	23.0000	7.90	65.60
	Zöld Cave layer 3	26.5960	5	15.44445	28.3800	9.18	49.59
	Total	29.9004	340	13.13687	28.0000	7.90	71.20

Table 9
Minimum number of individuals (MNI) at the archaeological sites.

Age	Site	Reindeer	Horse	Mammoth	Bison/ Bovid	Woolly rhino	Cervidae	Hare	Ibex	Brown Bear	Wolf	Beaver	Elk	Polar/Red fox	References
ILGM	Langmannersdorf	11	1	17	1	1	2	7	1	1	9			16	Salcher-Jedrasiak (2012)
LLGM	Ságvár	73	7									1	1	1	Péan (2001)
	Kammern–Grubgraben AL1	10	4					3	1						West (1997)
	Kammern–Grubgraben AL2-4	72	13		2			4	2	1					West (1997)
	Madaras		3												this paper
	Kašov I UL		1												this paper
	Mohelno–Plevovce KSA-B	1	1												Škrdla et al. (2016)
	Stránská skála IV	1	10		1	1									Boriová et al. (2020)
PLGM	Esztergom–Gyurgyalag	1	1	1											this paper
	Brno–Štýřice III		1	3			2								Roblíčková et al. (2015)
	Targowisko 10	1	2												this paper
	Nadap	1	4		1										this paper
	Zöld Cave layer 3	2	3					1							Béres et al. (2020)
	Budapest–Csillaghegy			1											this paper

Table 10
MNI turned into percentile frequency involving the three main hunted species.

Age	Site	Reindeer %	Horse %	Mammoth %
ILGM	Langmannersdorf	37.9	3.4	58.7
LLGM	Kammern–Grubgraben AL1	71.4	28.6	
	Kammern–Grubgraben AL2–4	82.7	17.3	
	Kašov I UL		100	
	Madaras		100	
	Mohelno–Plevovce KSA–B	50.0	50.0	
	Ságvár	91.3	8.7	
	Stránská skála IV	9.1	90.9	
PLGM	Brno–Štýřice III		25.0	75.0
	Budapest–Csillaghegy			
	Esztergom–Gyurgyalag	33.3	33.3	33.3
	Nadap	20.0	80.0	
	Targowisko 10	33.3	66.7	
	Zöld Cave layer 3	40.0	60.0	

4.1. The human population of ECE in the LGM

4.1.1. Southern Poland

While the territory of Poland was often regarded as sparsely populated through the LGM (Tallavaara et al., 2015; Wiśniewski et al., 2017; Maier et al., 2021), our results presume a complete depopulation. This emerges from a rather less than firm archaeological record.

Cave sites of Poland frequently preserved pre-LGM and/or PLGM but LGM layers. Such sites are Biśnik Cave, Dziadowa Skała Cave, Obłazowa Cave, and Komarowa Cave (Wojtal, 2007; Nadachowski et al., 2009; Lorenc, 2013; Piskorska et al., 2015). When caves yielded LGM radiocarbon dates, those always derived from admixed stratigraphy.

For instance, Deszczowa Cave layer VIII–VIIIa has a wide range of radiocarbon dates between 32.9 and 14.1 ka made on different animal species (Cyrek et al., 2000; Nadachowski et al., 2009; Lorenc, 2013) (Table 12). The accumulation of these remains, however, was related with carnivore activity (Cyrek et al., 2000; Wojtal, 2007). Human made cut-marks were found on an arctic fox bone and several cave bear bones (Wojtal, 2007; Wojtal et al., 2015), one of which was dated to 29.2–28.4 ka (Poz–28284) (Nadachowski et al., 2009). The lithic tools are atypical except a retouched blade point that has a Late Gravettian character (Cyrek et al., 2000, Fig. 13; Wilczyński et al., 2020). We test dated a reindeer molar having no signs of human impact. The result, 32.9–31.2 ka (DeA–20982) (Table 12), further reduced the possible examples of LGM evidence.

Mamutowa Cave layer 2 also was dated on a wide chronological scale, between 41.1 and 13.5 ka (Kowalski, 1967; Kozłowski and

Table 11
The relative chronology of the Epigravettian in ECE.

Age	ILGM	LLGM	PLGM
Cultural phase	Early Epigravettian	Early Epigravettian	Late Epigravettian
Dominant species	Mammoth	Reindeer/Horse	Horse
Sub ordered species	Reindeer Horse	Horse/Reindeer	Reindeer Mammoth
Dominant lithic tool type	Domestic	Domestic	Armature
Lithic armatures	Retouched blade/let points	Retouched blade/let points	Backed points Curved backed points
Dominant tool blank	Flake	Flake	Blade
Mean domestic tool size [mm]	34.8 ± 5.3	32.3 ± 6.5	40.4 ± 7.5
Mean armature tool size [mm]	47.1 ± 12.1	18.2 ± 5.4	29.9 ± 6.6

Kozłowski, 1996; Wojtal, 2007; Lorenc, 2013; Nadachowski et al., 2016). The LGM was represented by dates on animal bones lacking traces of human activity (OxA–14409, Poz–25171, and Poz–22680). Carnivore activity, however, was relatively plentiful (Wojtal, 2007). The lithic tool kit consists of a number of backed-truncated blade/lets (Chowaniak, 2018, tablica 8–10), comparable to Late Epigravettian typology, but as bones having cut-marks remained undated, the age of the human activity in layer 2 remains unknown.

Ujazd open-air site contained prehistoric ceramics and atypical knapped lithics in a stratigraphy of reverse chronology (Valde-Nowak et al., 2005). The archaeological layer was OSL dated to 24.8–12.4 ka (Gd–5880), and another OSL sample located 0.4 m under Gd–5880 was dated to 18.5–11.7 ka (Gd–5881). In our opinion, this site cannot be assigned to the Epigravettian.

The open-air site Kraków Spadzista C2 LGM age radiocarbon date 22.0–20.4 ka (Ly–2541) indeed was related with the Late Gravettian occupation (Wilczyński et al., 2015). Area B–B1 layer 5 Epigravettian flint workshop, due to the lack of organic remains is yet undated (Wilczyński, 2007).

A third open-air site, Piekary IIa layer 5b, was tentatively dated to 25.0 ka (Sitlivy et al., 2008; Van Vliet-Lanoë and Morawski, 2008). Its lithic toolkit contained chiefly burins and no armatures (Morawski, 1981). We dated a stored reindeer phalange that was boxed together with two mammoth task fragments, (Table 12) but Morawski (1981) did not mention reindeer remains when listing the tusk fragments, so provenance is uncertain. Our date, 20.4–19.7 ka (Poz–24205), thus can only be conditionally associated with the lithic collection and the human occupation in layer 5b.

4.1.2. Moravia

Compared to southern Poland, Moravia yielded secure LLGM archaeological data from Stránská skála IV and Mohelno–Plevovce KSA–B. Based on their time span, humans left the territory in the course of the LLGM by 22.4 ka (Fig. 7).

4.1.3. Lower Austria

In Lower Austria, beside Langmannersdorf, the radiocarbon date of Rosenburg, 25.5–23.1 ka (Lv–1756D) (Ott, 1996), could indicate another ILGM Early Epigravettian site. The fragmented fauna consisting of woolly rhino and horse would confirm this proposal. The dated sample, a burnt bone (Ott, 1996), yielded an age probably younger than actual. The lithic toolkit was similar to Mohelno–Plevovce KSA–B LLGM site (Demidenko et al., 2019), which further supposes indifferentiable lithic appearance for ILGM and PLGM Early Epigravettian.

Saladorf dated to 22.4–21.4 ka on a horse molar and humic acids of a hearth is a potential LLGM site (Simon and Einwögerer, 2008). A third date of Saladorf, 31.1–30.3 ka (VERA–3242) of a stray charcoal generates a contradiction, but as it lacks archaeological association, the other dates from the tooth and the sediment most likely represent the age of the site. The lithic toolkit also supports Early Epigravettian affiliation by the dominance of domestic types and the few armatures (backed blade/lets). The fauna also included LLGM elements, primarily reindeer and secondarily horse. As no other LLGM site of Lower Austria can be dated to the LLGM, we can conclude that the human population left this territory at 21.4 ka (Fig. 7).

4.1.4. The Carpathian Basin

In contrast to Moravia and Lower Austria, the Carpathian Basin was continuously occupied in the LLGM. In addition to those we studied, Mogyorósbánya can be listed among LLGM sites (Dobosi and Hertelendi, 1993), as it has been dated to 24.8–22.4 ka (Deb–1169 and Deb–9673) on charcoal samples. The fauna is dominated by reindeer (Dobosi, 2015). The lithic tools are essentially domestic types, and the armatures (backed blade/lets, retouched blade/let points, including a "Gravette point") make up a small percentage of the toolkit (Dobosi, 2016). The Gravette point, however, was reported unseparated from “blade and atypical shouldered points” (Dobosi, 2016: 18). Taking into account that Dobosi's typology allows recognizing marginally retouched specimens as Gravette points (Dobosi, 2000b), in the context of our typological criteria, the radiocarbon dates, and fauna, we doubt the presence of this tool type at Mogyorósbánya.

The number of LLGM sites in the Carpathian Basin can be enlarged due to new dates obtained from Pilismarót–Bitóc I. Bitóc I is one of the seven sites (Bánom, Basaharc, Bitóc, Diós, Pálrét, and Tetves) in the Pilismarót site cluster (PSC) excavated between 1980 and 1995 (Dobosi, 2006). Two reindeer molars of the main (lower) archaeological level situated 0.6 and 0.9 m below surface in loess (Dobosi, 2006; Biller, 2009), were dated to 23.3–22.5 ka (DeA–21598) and 22.9–22.4 ka (DeA–23681) (Table 12). The upper archaeological level, situated at the border of the ploughed topsoil and the loess, yielded sporadic finds, and eventually the two levels and the two other adjacent excavation areas (Bitóc II and III) were interpreted as a single human occupation (Dobosi, 2006; Biller, 2009).

Dating Bitóc I affects the chronology of the whole PSC. These assemblages were regarded as contemporaneous on the basis of the stratigraphic association with a humic soil horizon (Dobosi et al., 1983; Dobosi, 2006, 2014; Markó, 2019). This soil, h1, was dated on charcoals to 16.8 ± 0.4 uncal BP (Hv–1615) in the Tápiósüly loess section. This might seem to date the PSC to after the cold maximum, but in fact when calibrated the age 21.3–19.3 ka better fits the LLGM.

An attempt to directly date the PSC involved Pálrét site's mollusc samples. The result, 16.1–15.4 ka (Hv–12988) mismatched the age of h1 due to holocene isotopic exchange (Dobosi, 2006). Another sample, type unreported, from above the archaeological layer, yielded an age 19.8–18.9 ka (no lab code) (Sümegi et al., 1998). This already inferred that Pálrét could also be of LGM age.

Table 12
Radiocarbon dates mentioned in the discussion (sites in alphabetic order) and their calibrated ages (Reimer et al., 2020). B: bone. teeth; Ch: charcoal; MS: mollusc shell; S: soil; SED: sediment; *: date made of the same sample; n. a.: not available; RD: radiometric dating, OSL: optically stimulated luminescence dating; b2k: before 2000. Text in boldface marks the dates obtained in our research.

Site	Lab Code	Date	±	Cal Bp 95.4%		Sample	Method	Reference
Balcarka Cave	GrN-28448	13930	100	17290	16579	n.a.	RD	Valoch and Neruda (2005)
Biśnik Cave layer 2	Poz–46803	13350	70	16284	15825	B	AMS	Piskorska et al. (2015)
Bratčice	n. a.	14395	70	17838	17342	B	AMS	Nerudová et al. (2019)
Csajág mammoth	GdA-2011	13315	35	16165	15840	B	AMS	Katona et al. (2010)
Deszczowa Cave VIII	Poz–3751	19250	120	23726	22945	B	AMS	Lorenc, 2013
″	Gd–10212	17,480	150	21716	20766	B	RD	Cyrek et al. (2000)
″	Poz–22668	18900	400	23790	22102	B	AMS	Lorenc (2013)
″	OxA–11060	20800	150	25562	24636	B	AMS	Wojtal (2007)
Deszczowa Cave VIIIa	Gd–9464	16150	280	20208	18887	B	RD	Cyrek et al. (2000)
″	Poz–22667	12340	60	14836	14094	B	AMS	Lorenc (2013)
″	Poz–22669	19280	120	23733	22960	B	AMS	″
″	Poz–22666	20280	130	24780	23945	B	AMS	″
″	Poz–25169	19530	130	23809	23154	B	AMS	Nadachowski et al. (2009)
″	Poz–25075	22530	160	27194	26428	B	AMS	″
″	Poz–28284	24580	200	29206	28353	B	AMS	″
″	Poz–25324	28600	400	33987	31797	B	AMS	″
″	**DeA–20982**	**27760**	**330**	**32858**	**31154**	**B**	**AMS**	**this paper**
Dzierżysław 35	Poz–10136	14150	70	17382	17046	B	AMS	Wojtal (2007)
″	GdA–69	13500	80	16541	16021	B	RD	Ginter et al. (2005)
″	GdA–193	13370	80	16328	15826	B	RD	″
″	GdA–70	13220	70	16101	15656	B	RD	″
″	Poz–1035	13180	60	16015	15631	B	AMS	″
Dunaújváros h2 soil	Hv–2591	20520	290	25539	23911	Ch	RD	Pécsi (1985)
Dunaszekcső h2 soil	Hv–4189	21740	320	26902	25338	Ch	RD	″
Herman Ottó Cave layer 5	Poz–29297	18650	90	22885	22385	B	AMS	Szolyák, (2008–2009)
″	Poz–29296	18480	90	22583	22198	B	AMS	″
″	Poz–29295	24290	140	28820	27994	B	AMS	″
Jászfelsőszentgyörgy	Deb–1674	18500	400	23673	21396	B	RD	Hertelendi (1993)
Kamegg	GrN-22883	13840	120	17091	16386	B	RD	Verpoorte (2004)
″	GrN-23182	14130	110	17455	16904	B	RD	Verpoorte (2004)
″	MAMS-40114	13840	50	17000	16605	Ch	AMS	Händel et al. (2021)
Kraków Spadzista C2 layer 6	Ly–2541	17400	310	21993	20352	Ch	RD	Wilczyński et al., 2015
Kůlna Cave layer 6 reindeer	OxA-V-2793-53C	12650	50	15254	14925	B	AMS	Reade et al. (2021)
Kůlna Cave layer 4 horse	OxA-25286	11070	50	13096	12846	B	AMS	″
Lakitelek charcoal rich layer	Deb–1562	22110	300	27100	25890	Ch	RD	Sümegi (2005)
Madaras soil MAD-L1S1 upper boundary	DeA–11905	17368	63	21168	20794	MS	AMS	Sümegi et al. (2020)
Madaras soil MAD-L1S1	DeA–11903	17858	64	21947	21425	MS	AMS	″
Madaras soil MAD-L1S1 lower boundary, (ca. 1.0 m above arch. layer)	DeA–11904	17870	71	21972	21426	MS	AMS	″
Mamutowa Cave layer 2	Poz–22680	19720	120	24046	23338	B	AMS	Lorenc (2013)
″	Poz–22685	13040	40	15784	15447	B	AMS	″
″	Poz–1152	11820	60	13794	13513	B	n. a.	Wojtal (2007)
″	Poz–1151	12000	60	14044	13770	B	n. a.	″
″	OxA–14409	20650	100	25182	24557	B	AMS	″
″	OxA–14410	35460	260	41125	39999	B	AMS	″
″	OxA–14406	26010	150	30739	30007	B	AMS	″
″	Poz–3746	29800	400	35198	33452	B	n. a.	″
″	Poz–3747	31300	500	36687	34644	B	n. a.	″
Mamutowa Cave layer 2	Poz–25171	19530	130	23809	23154	B	AMS	Nadachowski et al. (2016)
″	KIA–39225	14855	60	18273	18003	B	AMS	Kozłowski et al. (2012)
″	KIA–39226	15025	50	18622	18210	B	AMS	″
″	KIA–39227	15015	50	18619	18205	B	AMS	″
″	KIA–39228	15155	60	18651	18270	B	AMS	″
Mogyorósbánya	Deb–9673	19000	250	23725	22407	Ch	RD	Dobosi and Hertelendi (1993)
″	Deb–1169	19930	300	24819	23200	Ch	RD	″
Moravany–Žakovska	GrA–16159	24230	150	28765	27934	Ch	AMS	Verpoorte (2002)
″	Gd–4915	18100	350	22784	21000	Ch	RD	Hromada et al. (1995)
″	**DeA–20981**	**20830**	**160**	**25608**	**24658**	**B**	**AMS**	**this paper**
″	**DeA–21470**	**24440**	**180**	**29130**	**28160**	**B**	**AMS**	**″**
″	**GrA–23114**	**22340**	**150**	**27125**	**26300**	**B**	**AMS**	**″**
Piekary IIa	**Poz–24205**	**16600**	**90**	**20351**	**19656**	**B**	**AMS**	**″**
Pilismarót–Bitóc I	**DeA–23681**	**18670**	**150**	**22944**	**22350**	**B**	**AMS**	**″**
″	**DeA–21598**	**19010**	**150**	**23293**	**22488**	**B**	**AMS**	**″**
Pilismarót–Pálrét	no code	16000	200	19826	18889	n. a.	n. a.	Sümegi et al. (1998)
″	Hv–12988	13130	100	16062	15413	MS	RD	Dobosi (2006)
Rosenburg	Lv–1756D	20120	480	25540	23086	B	RD	Ott (1996)
Saladorf	VERA–3072	18350	80	22441	22121	B	AMS	Simon and Einwögerer (2008)
″	VERA–3244	17880	75	21986	21430	S	AMS	″
″	VERA–3242	26540	200	31110	30335	Ch	AMS	″
Święte 9 below archaeological layer	Lub–6379	15500	1200	17900	13100	SED	OSL	Łanczont et al. (2021)
Tápiósüly brickyard “h1” soil	Hv–1615	16750	400	21348	19270	Ch	RD	Pécsi (1985)
Trenčianske Bohuslavice A2–1	GrA–42311	22330	110	26996	26356	Ch	AMS	Vlačiky et al. (2013)

Table 12 (*continued*)

Site	Lab Code	Date	±	Cal Bp 95.4%		Sample	Method	Reference
"	Poz−97252	22370	150	27116	26343	Ch	AMS	Wilczyński et al. (2020)
Velké Pavlovice	GrN−16139	14460	230	18207	17085	B	RD	Svoboda et al., 2020
Verőce P1 soil	n. a.	n. a.	n. a.	22140	20890	Ch	n. a.	Bradák et al. (2014)
Zawalona Cave	n. a.	15380	340	19497	18018	B	RD	Alexandrowicz et al. (1992)
"	n. a.	14060	340	18127	16203	B	RD	"
Zók mammoth tusk	Deb−14677*	20500	1500	28787	21713	B	RD	Konrád et al. (2010)
"	AA−80678*	17760	200	22076	20955	B	AMS	"

The fauna of the PSC is dominated by reindeer, which is a match with LLGM (Vörös, 1981; Dobosi et al., 1983; Dobosi, 2006, 2014; Biller, 2009). Apparent chronological contradiction could be that mammoth remains were mentioned for PSC (Dobosi, 2014), but their sites were not specified, and the references cited to support mammoth presence in the fauna listed none (Vörös, 1981; Dobosi et al., 1983; Biller, 2009).

PSC lithic features also support an LLGM chronological position, as domestic tools are dominant and there is a low number of armatures that are backed blade/lets (Dobosi, 2006). The only "Gravette point" of PSC was listed for Bitóc I–III, but it is not specified as typical or atypical. This, and all the other absolute and relative chronological considerations let us assume the absence of a real Gravette point in the PSC. Accordingly, we claim that PSC enlarges the number of Early Epigravettian sites and the LLGM human occupations in the Carpathian Basin.

There are further dated sites of LLGM age in the Carpathian Basin, but with contradictory ^{14}C results. Jászfelsőszentgyörgy−Szúnyogos was dated to 23.7–21.5 ka on a bone of unknown species lacking collagen (Hertelendi, 1993), associated with lithics of Early Epigravettian character (Priskin, 2011; Lengyel, 2018). Herman Ottó Cave layer 5 was dated to 22.9–22.2 ka on two reindeer bones in association with a backed blade/let, but there is also an older reindeer date, 28.8–27.9 ka, which implies an admixture of the fauna in layer 5 (Szolyák, 2008 – 2009).

An eventually dismissed LLGM site of the Carpathian Basin is Moravany–Žakovska. It was first dated to 22.8–21.0 ka (Gd−4915) on charcoals from archaeological level 2 (Hromada et al., 1995). Another charcoal date, 28.8–27.9 ka (GrA−16159) (Verpoorte, 2002), and a bone date 27.1–26.3 ka (GrA−23114), both without known stratigraphic position, showed that the human occupation may not be of LGM age. We dated a horse molar of level 1 to 29.1–28.2 ka (DeA−21470), and a reindeer molar of level 2 to 25.6–24.7 ka (DeA−20981) (Table 12). The latter fits the ILGM, but the reverse chronological order denotes a post-depositional admixture for the archaeological material. The faunal assemblage also contained mammoth, roe deer, and red deer (Hromada et al., 1995), which does not illustrate an LLGM fauna. The lithics can no longer be studied by archaeological levels due to inventory issues. The shape of the retouched blade/let points, the frequency of backed blade/lets, and the presence of a Late Gravettian rectangle (Hromada et al., 1995) signal a Late Gravettian occupation, which is a match with most radiocarbon data.

The absolute chronology of the Carpathian Basin, as we claim, refers to a continuous human presence during the LLGM (Fig. 7), and disagrees with the population hiatus seen 22.0 and 20.0 ka in the whole ECE (Maier et al., 2021). The Carpathian Basin was the solely occupied territory in ECE after 21.4 ka, likely due to having the most favourable environmental conditions in the LGM (Klein et al., 2021).

4.2. LGM environmental conditions in ECE

4.2.1. The Carpathian Basin

The pollen record of northeast Hungary (Feurdean et al., 2014) showed a strong conifer presence in early ILGM, but their frequency decreased by the LLGM (Fig. 7). In south Hungary, ILGM vegetation changed oppositely, and at the ILGM–LLGM border conifers sharply rise in frequency. During LLGM in northeast Hungary, steppe–tundra vegetation is only slightly dominating over woody taxa, but in south Hungary it is a lesser landscape component. The lowest frequency of conifers both in northeast and south Hungary can be correlated with GI–2.2 and GI–2.1 (Fig. 7). At the LLGM–PLGM border, conifers are slightly depleted in the south but increase in the northeast, keeping steppe–tundra vegetation in minority. The pollen record thus indicates that GI periods are associated with dry summer seasons and decreased conifer frequency, and GS periods had wet summers with boreal parkland or forest expansion in the LLGM (Feurdean et al., 2014; Újvári et al., 2017; Sümegi et al., 2020).

The dental remains of the beaver in the faunal assemblage of Ságvár LLGM site also bespeak a wet and woody environment in the latter half of the LLGM (Péan, 2001), as do the charcoal remains in combustion features at Ságvár, Madaras, and Mogyorósbánya sites.

Weakly developed humic soils in loess sequences are also correlated with stadials (Fig. 7). Charcoals of these soils (h2) were dated to 28.9–23.9 ka (Sümegi, 2005), which largely coeval with GS–3 27.5–23.3 ka, and several of them overlap the ILGM. After a chronological gap between 23.9 and 22.1 ka that corresponds with GI–2.2 and GI–2.1, there are again directly dated humic soils (h1) overlapping 22.1–19.3 ka in association with GS–2.1c 22.9–20.9 ka (Fig. 7). These data link LGM humic soil formations in the Carpathian Basin with GS periods instead of GI.

Loess mollusc assemblages are often used to show climatic changes in MIS2 (Sümegi and Krolopp, 2002). Hungarian faunas (Sümegi, 2019, Fig. 1) illustrate 12–14 °C mean July temperature (T_{July}) for MIS2 stadials, interrupted by temperate periods T_{July} 14–17 °C (Fig. 7). Certainly, T_{July} must not have been under the 10 °C threshold, only above which is possible the growth of boreal forest (Frelich, 2020) that was present throughout the LGM in the Carpathian Basin in a mosaic landscape shared with steppe–tundra vegetation (Feurdean et al., 2014). According to a temperature reconstruction from mollusc data for the whole Carpathian Basin (Fig. 7), the ILGM was temperate and the LLGM suffered several climatic fluctuations. Ságvár loess section mollusc record somewhat contradicts this overall estimation showing a lack of warmth-loving and the abundance of cold-loving species in the ILGM

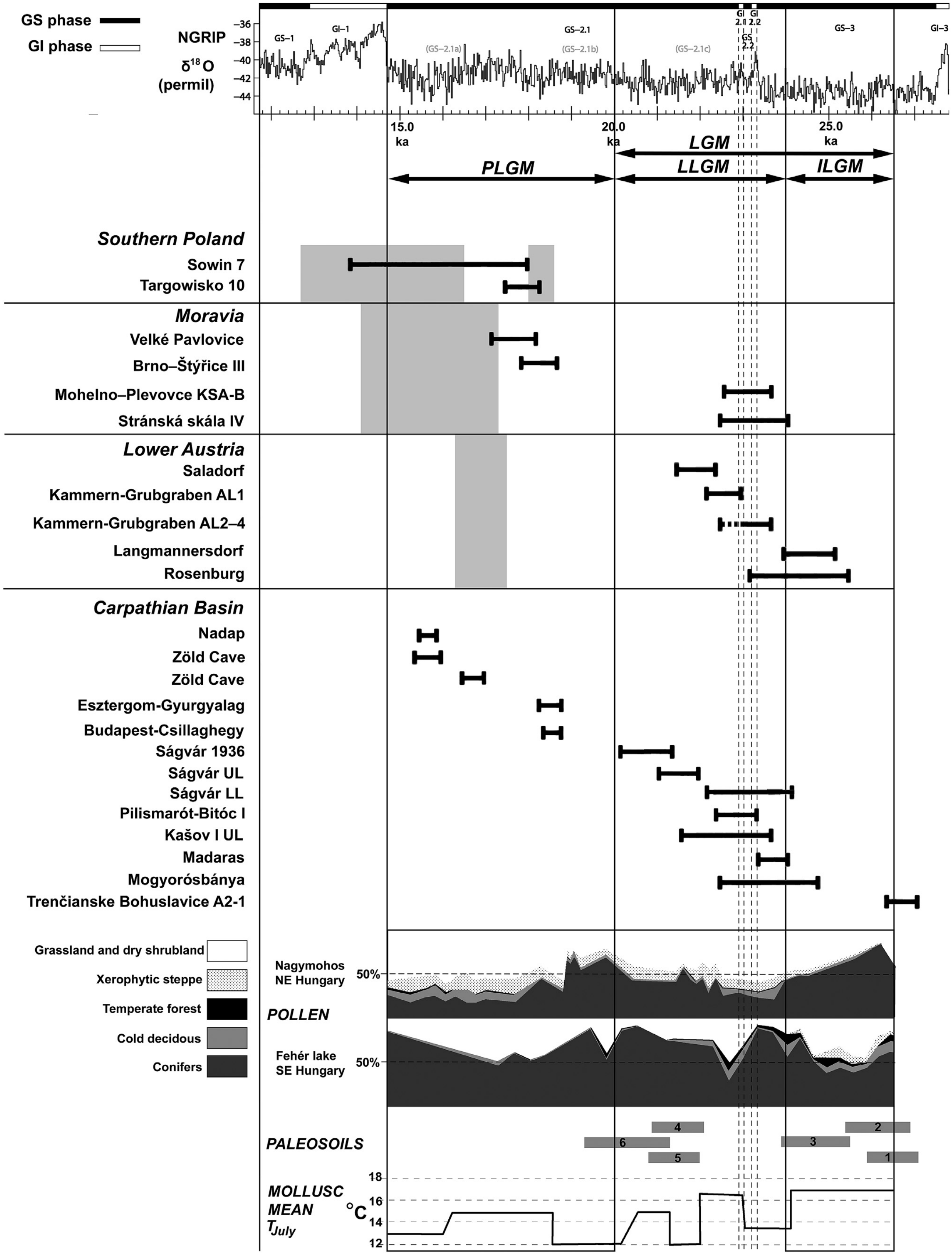

Fig. 7. The absolute chronology of the Epigravettian in ECE and the environmental changes in the ILGM, LLGM and PLGM of the Carpathian Basin. Shown are the most likely ages of the human occupations. Grey rectangles mark the chronological positions of Magdalenian human occupations. Pollen diagram was adopted from Feurdean et al., 2014. Fig. 3. Paleosoils: 1) Lakitelek charcoal rich layer, 2) Dunaszekcső h2, 3) Dunaújváros h2, 4) Verőce P1, 5) Madaras MAD–L1S1, 6) Tápiósüly h1. References for paleosoil ages are listed in Table 12. Mollusc based mean T_{July} is adopted from Sümegi (2019). Fig. 1.

(Molnár et al., 2021). However, other mollusc phases can be correlated to the pollen and loess–paleosol succesions. For instance, the temperate phase 23.0–22.0 ka fits the decreased forest vegetation in the pollen curve, and the subsequent stadial 22.0–21.3 ka is contemporaneous with the forest development and the h1 soil (Fig. 7). Compared to other regions of ECE, the presence of warmth-loving mollusc species in the LLGM indicate a temperate climate for the southern Carpathian Basin (Hupuczi and Sümegi, 2010; Molnár et al., 2021), and temperate mammal distribution in this region is another sign of a milder climate (Sommer and Nadachowski, 2006).

4.2.2. Southern Poland

The few LGM environmental data of southern Poland bespeak extremely cold and dry climate with treeless tundra and periglacial geomorphological processes under a continuous permafrost (Van Vliet-Lanoë and Morawski, 2008; Moska and Bluszcz, 2013; Marks et al. 2016, 2019, 2019; Ruszkiszay–Rüdiger and Kern, 2016; Krawczyk et al., 2017; Zieliński et al., 2019; Skurzyński et al., 2020). T_{July} was calculated < 5 °C (Marks et al. 2016, 2019), or at least 9 °C lower compared to the southern Carpathian Basin (Ludwig et al., 2021), which supports only treeless tundra vegetation (Serreze, 2020).

4.2.3. Moravia

In Moravia, LGM environmental data are also sparse. The upper part of the Dolní Věstonice loess wall included two weak incipient tundra gleys dated to between 27.0 and 23.0 ka (Antoine et al., 2013), which usually develop under permafrost conditions (Tarnocai, 2009). There is no dated malacofaunal record for the LGM (Ložek, 2001), but a loess steppe landscape was reconstructed (Ložek, 1996). Stránska skála IV LLGM loess yielded a few pollen grains which show broad-leaved tree species dominance over herbs (Svoboda et al., 2020). This is likely the results of contamination since the evidence for LGM vegetation is sparse in Moravia (Kuneš and Abraham, 2017). The only LLGM charcoals (birch, juniper, and willow) were found at Mohelno–Plevovce KSA–B (Škrdla et al., 2016).

4.2.4. Lower Austria

Lower Austrian LGM environmental record is meagre (Zöller et al., 1994; Thiel et al., 2011; Terhorst et al., 2015; Sprafke, 2016; Carobene et al., 2020). Generally, this area is characterized by increased loess deposition and dry climate in MIS2 (Terhorst et al., 2015), which was likely influenced by the extension of glaciers in the Alps (Wirsig et al., 2016). The Kammern–Grubgraben sediment record included two humic loess horizons in AL4 and AL3 (Haesaerts, 1990). Between AL2 and AL1, three gley horizons occurred (Haesaerts and Damblon, 2016), referring to periglacial conditions after 23.0 ka. Interestingly, no charcoals were identified in any of the layers of Kammern–Grubgraben (Montet-White, 1990; Händel et al., 2021), probably indicating a treeless tundra vegetation in LLGM.

4.3. The LGM and the archaeological record

Maier et al. (2016) claimed a human adaptation to cold and dry climate in treeless tundra in ECE during LGM. In contrast, according to environmental data, a milder climate, greater humidity, the absence of continuous permafrost, probably greater plant abundance, and the permanent presence of woody vegetation in boreal parkland forest can be correlated with the continuous human occupation during the LLGM in the Carpathian Basin. These environmental conditions are comparable to those created by mild and wet climate in the LGM human refugium in Western Europe (Maier et al., 2016). Thus our findings support the theory that the Carpathian Basin was a glacial refugium for humans (Verpoorte, 2004) due to having the best tolerable climatic conditions in the whole ECE (Klein et al., 2021).

The generally colder and dryer climate, all the effects of the continuous permafrost, and the sparseness of wood vegetation in Moravia and Lower Austria in the second half of the LGM might have resulted in their thin archaeological record. The Early Epigravettian population likely withdrew those territories from the foraging area. Foraging solely in the Carpathian Basin in the late LLGM may have enlarged the number of archaeological localities in this territory. When the Carpathian Basin became the solely populated area of ECE, the local climate was indeed cooler than in the early LLGM, but the effect of GS–2.1c likely caused even drier and colder environment for Moravia and Lower Austria. As this period is coeval with the younger LGM soil formations indicating more expanded woody vegetation, we find an association between site density and forest expansion. The permanent availability of wood as fire fuel and raw material could have given a substantial advantage for a territory to be chosen by hunter-gatherers, as it was pointed out in Moravia for the Pavlovian culture between ~ 31.0 and 29.0 ka (Pryor et al., 2016).

The environmental conditions of the Carpathian Basin generally could have attracted herbivores due to greater plant density (Verpoorte, 2009). This may have concentrated the reindeer and horse populations of ECE into the Carpathian Basin, which in turn, providing plentiful animal food resources for humans, probably primarily attracted the Early Epigravettian hunter-gatherers. We hence conclude that the milder climate, the wood availability, and the prey density was a substantial attraction for LLGM humans in ECE.

4.4. The PLGM occupation of ECE

4.4.1. Southern Poland

In southern Poland, the earliest PLGM site could be Piekary IIa layer 5b, but as the association between the dated sample and the artifacts is uncertain, the age estimation of the site is yet insecure. Zawalona Cave layer E also was dated to the PLGM to 19.5–18.0 ka and 18.1–16.2 ka on bones of unidentified species (Alexandrowicz et al., 1992). The fauna, consisting of horse, reindeer, woolly rhino, and alpine chamois, could fit PLGM but the lithic assemblage is too atypical to be another support.

The first securely dated PLGM human occupation in Poland is Middle Magdalenian at Maszycka Cave layer 2. Two antler tools and two human bones were dated to 18.7–18.0 ka (Kozłowski et al., 2012). The next human occupation, however, is Late Epigravettian at Targowisko 10, the radiocarbon dates of which partially overlap the chronology of Maszycka layer 2 (Fig. 7). The uncertainty in radiocarbon dating and the earliest potential start of the OSL dated Late Epigravettian Sowin 7 LL gives a possibility to conclude that the Late Epigravettian occupation of Poland started after the Middle Magdalenian. Święte 9 in eastern Poland was also reported as an Epigravettian site dated by OSL to younger than 17.9–13.1 ka (Łanczont et al., 2021). The small toolkit that includes a single armature type that is an abruptly retouched blade/let also could represent Late Magdalenian, thus we do not count it as Late Epigravettian. The end of Targowisko 10 at 17.3 ka co-occurred with an early Late Magdalenian date in southern Poland, site Dzierżysław 35 dated to 17.4–17.0 ka (Poz–10136) (Wojtal, 2007), but the dates 16.5–15.6 ka were considered to represent the age of the human occupation, which is still the earliest Late Magdalenian in Poland (Wiśniewski et al., 2017). As the end of the OSL dated Sowin 7 LL Late Epigravettian site is indefinite, relying upon the chronology of Targowisko 10 and the Epigravettian–Magdalenian stratigraphic superposition at Sowin 7, we again see no contemporaneity between Late Epigravettian and Magdalenian. This supports Model 2 of Wiśniewski et al. (2017) versus Model 1 that assumes a coexistence of these cultures in the same geographic area.

4.4.2. Moravia

In Moravia, the earliest PLGM site is Late Epigravettian, Brno–Štýřice III, 18.7–17.8 ka (Fig. 7). Another site, Velké Pavlovice, was found in a sand pit by mining when a knapped flake, horse bones, a cut-marked mammoth tusk fragment, and a rhino tooth were unearthed (Svoboda et al., 2020). The archaeological layer contained charcoals and further horse bones in a humic level of the loess. A horse bone from the excavation was dated to 18.2–17.1 ka, which can only mark a Late Epigravettian occupation in the LUP chronology of Moravia. The first Late Magdalenian in Moravia at Balcarka Cave dated to 17.3–16.6 k (Valoch and Neruda, 2005) seems to precede the likely earliest Polish occurrence at 16.5 ka in Dzierżysław 35. The Magdalenian disappears from Moravia until ~ 14.6 ka and the LG is associated with Epimagdalenian occupations (Reade et al., 2021).

4.4.3. Lower Austria

In Lower Austria, the first and also the last PLGM human occupation is the Magdalenian site of Kamegg dated to 17.5–16.4 ka (Händel et al., 2021). So far this is the earliest Late Magdalenian occupation in ECE, which presumes an arrival of the Late Magdalenian from Western Europe along the Danube towards Poland (Maier, 2015). No Late Epigravettian occupation was yet found in Austria.

4.4.4. The Carpathian Basin

During the PLGM the Carpathian Basin hosted only Late Epigravettian occupations according to our data (Fig. 7). Further directly dated PLGM-aged reindeer of Jankovich Cave LUP layer and mammoth of Feldebrő open-air site suggest a frequency of human presence similar to the LLGM, but the duration of the site occupations could have been shorter as fewer individuals of prey were hunted. Moravia and southern Poland have at least nine dated Late Magdalenian sites, respectively (Valoch and Neruda, 2005; Maier, 2015; Wiśniewski et al., 2017), while the dated Late Epigravettian sites in the Carpathian Basin are still fewer. This archaeological record argues for a difference in the population density between these cultures. The Late Epigravettian eventually disappeared from the absolute and relative chronology by the start of the LG from ECE.

4.5. PLGM environmental changes

4.5.1. Southern Poland

The PLGM brought a gradual climatic amelioration with T_{July} 15–17 °C and increased precipitation for southern Poland (Marks et al., 2019). Loess accumulation restarted including weak tundra gley formations (Van Vliet-Lanoë and Morawski, 2008; Wiśniewski et al., 2012; Łanczont et al., 2015; Krawczyk et al., 2017). Pollens, small mammals, and birds remains specify dry grass and shrub species and the presence of boreal forests in a mosaic environment (Łanczont et al., 2015; Lemanik et al., 2020). At Targowisko 10, charcoal material of the hearths also signals tree vegetation in the landscape as early as 18.0 ka, indicating a precipitation increase in the Carpathian foreland. The great expansion of tree vegetation, however, postdates 15.0 ka (Starkel et al., 2012; Moska et al., 2021).

4.5.2. Moravia

For Moravia, detailed PLGM paleoenvironmental reconstructions are rare due to the lack of dated vegetational remains, pollen sequences, mollusc records, and analysed sediments (Ložek, 2001; Kuneš and Abraham, 2017). Brno–Štýřice III and Velké Pavlovice humic horizons are relics of a humid climate, but Reade et al. (2021) argued for a steppe–tundra vegetation for the entire PLGM in Moravia, and they found that significant increase in precipitation started at 16.0–15.0 ka. Animal bone stable isotope analyses from Kůlna Cave pointed out nutrient-poor soil development in GS–2.1a (17.5–14.7 ka) and the expansion of forest started with the GI–1 (Reade et al., 2021).

4.5.3. Lower Austria

There is no sediment dated to the PLGM with paleoenvironmental data in Lower Austria. This might be the consequence of severe geomorphological changes due to the termination of glaciers in the Eastern Alps (Wirsig et al., 2016).

4.5.4. The Carpathian Basin

The pollen record in northeast Hungary showed that conifers increased between 20.0 and 19.0 ka during GS–2.1b (Feurdean et al., 2014), indicating wetter summers of a GS period (Újvári et al., 2017). Between 19.0 and 16.2 ka steppe–tundra vegetation expanded at the expense of boreal forest, indicating warmer and drier growing season, and at 16.2 ka broad-leaved species started occurring in the pollen record (Magyari et al., 2019; Šolcová et al., 2020), showing an increase in T_{July}, which ignited the disappearance of the Pleistocene environment from the Carpathian Basin (Magyari et al., 2019). This warm phase does not appear as an interstadial in the Greenland record (Fig. 7). At 14.6 ka, cold adapted vegetation disappeared in the northern Carpathian Basin (Šolcová et al., 2020) and most of the loess sections terminates in the LG (Sümegi, 2005; Bösken et al., 2018).

The only humic soil dated to the PLGM could be at Esztergom–Gyurgyalag 18.8–18.2 ka, but its identification was not supported by sedimentological analysis (Dobosi and Kövecses-Varga, 1991). Generally, there is a lack of humic soil horizons in PLGM loess (Sümegi, 2005), which also reflect steppe–tundra environment.

The loess malacofauna of Hungary (Sümegi, 2019, Fig. 1) indicated cold climate between 20.2 and 18.6 ka (GS–2.1b: 20.9–17.5 ka). This was followed by temperate conditions until 16.2 ka, correlating the steppe–tundra landscape dominance. Mollusc data showed another cold period after 16.2 ka until the onset of LG, which contradicts the pollen data indicative of mild climate until the onset of the Holocene.

4.6. The PLGM and the archaeological record

The trigger of the environmental changes of the PLGM in ECE was the retreat of EIS, which freed the Baltic Sea shore by ~ 15.0 ka (Hughes et al., 2016; Stroeven et al., 2016; Patton et al., 2017). As a consequence, the Pleistocene climate, environment, and fauna began moving northward. Magyari et al. (2019) claimed that at ~ 16.2 ka when broad-leaved trees began gradually expanding in the landscape the Pleistocene megafauna started leaving the Carpathian Basin, indicating drastic environmental change (Magyari et al., 2021).

The latest directly dated mammoth in the Carpathian Basin is the Csajág specimen, 16.2–15.8 ka (Katona et al., 2012). The youngest horses and reindeers were found at Zöld Cave dated to 15.7–15.3 ka but a directly dated reindeer bone of Jankovich Cave LUP layer suggested that this species disappeared from the Carpathian Basin just before the LG (Magyari et al., 2021). These data coincide with the last of the Late Epigravettian occupations. The disappearance of the Late Epigravettian by the onset of the LG period thus was a consequence of the transformation of the

Pleistocene environment. Similarly, the latest Epigravettian in Eastern Europe also can be dated to this period associated with the last specimens of Pleistocene megafauna (Iakovleva and Djindjian, 2005; Marquer et al., 2012; Kitagawa et al., 2018; Gavrilov, 2021).

In Moravia the youngest directly known age on a mammoth is from Bratčice, dated to 17.8–17.3 ka (Nerudová et al., 2019). This is contemporaneous with the end of the local Late Epigravettian. Mammoth and rhinoceros remains in the Late Magdalenian loessic layer 11 of Barová Cave, not dated directly but aligned within the biostratigraphic sequence of malaccological and microfaunal records, could represent the last of these species in Moravia (Seitl et al., 1986; Horáček et al., 2002). The youngest reindeer, 15.3–14.9 ka, was already associated with the Late Magdalenian culture, and the last horse, 13.1–12.8 ka, with the Epimagdalenian (Reade et al., 2021).

While absent in Moravia and the Carpathian Basin, mammoth, reindeer, and horse existed in southern Poland during the LG, and gradually inhabited the Baltic region and Scandinavia (Bratlund, 1996; Ukkonen et al., 2006, 2011, 2011; Aaris-Sørensen et al., 2007; Lasota-Moskalewska, 2014; Nadachowski et al., 2018).

In our reading, the disappearance of the Late Epigravettian can be part of the recolonization of northern Europe that was due to the northern retreat of the Pleistocene environment and prey spectrum (Riede, 2014; Wygal and Heidenreich, 2014). This resulted in a near absence of human population in the Carpathian Basin during the LG, as the chronologically secure archaeological record is scanty until the Early Mesolithic (Jánossy, 1961; Sümegi et al., 2012; Sajó et al., 2015; Horváth and Ilon, 2017; Marton et al., 2021). In Moravia, after the reindeers and the Magdalenian population left, the archaeological record also became nearly absent during the Epimagdalenian until the Mesolithic (Oliva, 2005; Svoboda, 2008; Reade et al., 2021). In Lower Austria there is a complete lack of humans after 16.5 ka. Meanwhile, and in contrast, the number of archaeological sites during the LG in Poland became as high as never before in the UP (Sobkowiak-Tabaka, 2017; Sobkowiak-Tabaka and Winkler, 2017; Stefański, 2017; Sauer and Riede, 2019), with human groups subsisting on glacial fauna (Street et al., 2001; Płonka et al., 2020). Late Epigravettian type curved backed points, however, were also found in the Arch–Backed Point Technocomplex of the LG period in northern ECE (Kabaciński and Sobkowiak-Tabaka, 2010; Sobkowiak-Tabaka, 2017). This means that the co-occurrence of these tools and glacial fauna could be the outcome of a similar subsistence strategy which once had been practiced earlier in the Carpathian Basin (Béres et al., 2021). Such archaeological data indicate that most Late Pleistocene humans were devoted to a fixed subsistence strategy without the motivation to adapt to a new environment until there is no choice (Freeman et al., 2020).

5. Conclusion

Our data refined the absolute chronology of the Epigravettian human population in ECE and established relative chronological keys of primary lithic armature and secondarily of faunal evidence. ILGM Early Epigravettian armatures are few, consisting of only retouched blade/let points, and they lack backed artifacts; they are related with mammoth, reindeer, and horse. Early Epigravettian of LLGM has a low frequency armature component, chiefly backed blade/lets of small size, secondarily retouched points and backed-truncated blade/lets, associated especially with reindeer, secondarily with horse, and a lack of mammoths. PLGM Late Epigravettian armatures are abundant, mostly backed blade/lets, often elongated, backed points, curved backed points, associated with horse, mammoth, and reindeer.

We supposed a lack of human population in southern Poland throughout the LGM. Human populations of Moravia and Lower Austria seem to have moved to the Carpathian Basin in the second half of the LLGM, and the Carpathian Basin was the most densely populated Early Epigravettian territory in ECE during the LGM. The abundant human population seems to have been associated with the lack of continuous permafrost, the permanent availability of tree vegetation, and climatic conditions milder than in Southern Poland, Moravia, and Lower Austria.

After the LGM, the Carpathian Basin hosted most of the Epigravettian population, which penetrated into Moravia and Poland only for a short period between ~ 18.0 and 17.3 ka. During the Late Magdalenian occupation of Moravia, Lower Austria, and Southern Poland, the Late Epigravettian was the sole population in the Carpathian Basin until 14.7 ka.

The association between archaeological and environmental data proposes that the northward displacement of Pleistocene climatic and biotic conditions led humans adapted to hunting glacial-age fauna to withdraw from southern ECE. As a consequence, in the LG period the human presence is archaeologically hardly visible in Moravia, Lower Austria, and the Carpathian Basin until the Mesolithic.

Author contribution

Research design, artwork, paper realization: G. L.; Lithic analysis: G. L. and J. W.; Archaeozoology: P. W. and J. W.; Radiocarbon dating: M. M. and I. M.; Chronology: G. L., A. V.; Excavated radiocarbon samples: S. B., C. F., A. N., and J. S.; Provided radiocarbon samples from public collections: A. B., M. G., and A. N.

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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