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The Late and Final Middle Palaeolithic of Central Europe and Its Contributions to the Formation of the Regional Upper Palaeolithic: a Review and a Synthesis

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Abstract
For decades, the relationship of pre-modern hominins to anatomically modern humans (AMH) and the transition from mode 3 to mode 4 industries remain topics of ongoing scientific debate. Over the last 20 years, different disciplines have added new data and much detail to these questions, highlighting the demographic and social and cultural complexity underlaying these major changes or turnovers in human evolution. As with most other regions outside Africa, archaeologists faced long-lasting discussions whether or not the central European archaeological record is to be understood as a regional transition from the Middle Palaeolithic (MP) to the Upper Palaeolithic (UP) or if it is characterised by the replacement of Neanderthal MP techno-complexes by industries of overall UP character imported by modern humans. These debates have been re-fuelled by the discoveries of new sites, of new hominin fossil remains and by aDNA studies pinpointing towards the arrival of AMH in Europe several millennia earlier than previously thought (Slimak et al., *Science Advances, 8*, eabj9496, 2022; Hajdinjak et al., *Nature, 592,* 253-257, 2021; Prüfer et al., *Nature Ecology & Evolution, 5*, 820–825, 2021). Together with new radiometric age-estimates and detailed archaeological site studies, these developments call to recapture the present knowledge of the Late (LMP) and Final Middle Palaeolithic (FMP) of central Europe, viewed from the perspective of lithic technology and typology, raw material exploitation and land-use strategies. We will review and characterise this record as it represents the demographic and cultural substrate that AMH had met and will discuss to which degree this substrate contributed to the formation of the central European UP.

Keywords Late Neanderthals · Anatomical Modern Humans · Lithic assemblage variability · Lithic techno-complexes · Regionalised cultural signatures · Middle to Upper Palaeolithic transition

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Introduction

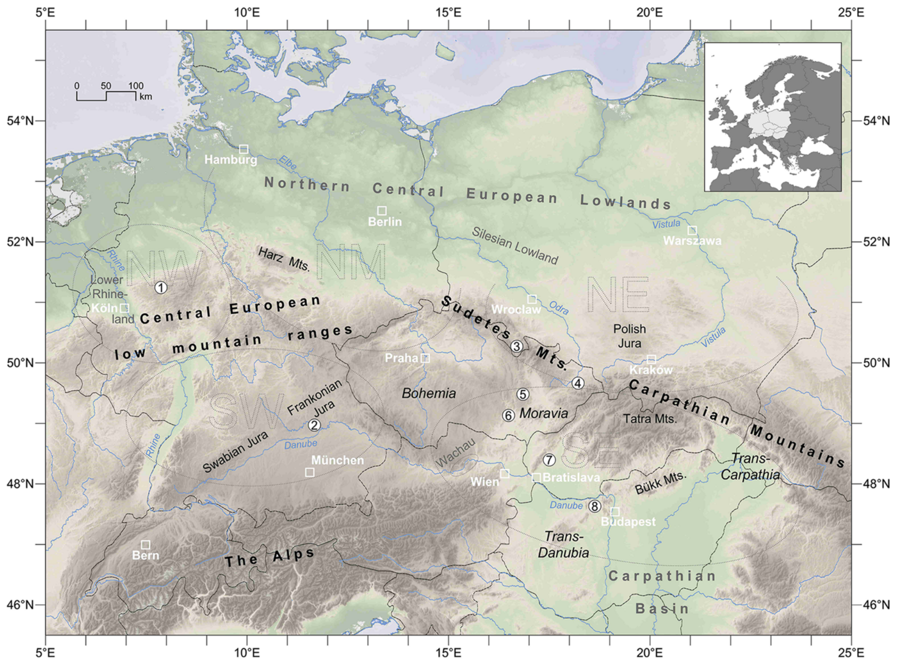
The Middle (MP) to Upper Palaeolithic (UP) transition marks one of the most significant turnovers in world prehistory. In Europe, the period roughly between 55 and 30 ka ago is generally viewed as a boundary between two “monolithic blocs”, with Neanderthals and related techno-complexes on the one side, and anatomically modern humans (AMH) who succeeded and replaced the earlier industries with their entirely different material culture, on the other (cf. discussion in: Higham et al., 2014; Jöris et al., 2011). Recent discoveries from Grotte Mandrin in the Rhône Valley, however, hint at potential initial AMH incursions into Europe at around 56.8–51.7 ka ago, i.e. several thousand years earlier than previously assumed (Slimak et al., 2022; cf. Harvati et al., 2019 for even earlier incursions of AMH into the south-east of the continent). If these data can be confirmed, these findings would indicate that the process that finally led to the replacement of Neanderthal populations in Europe lasted several millennia during which contacts between Neanderthals and AMH must have been more frequently than previously assumed. During the last two decades, other archaeological discoveries (e.g. Fewlass et al., 2020; Hublin et al., 2020), as well as major advances in genetic methods and analyses (e.g. Fu et al., 2014, 2015; Hajdinjak et al., 2021; Prüfer et al., 2021), had already re-shuffled the critical period into the centre of interdisciplinary research, indicating that a far more complex demographic and cultural amalgam of influences now needs to be considered (e.g. Jöris, 2004; Sankararaman et al., 2014; Uthmeier, 2004) than a bloc-like dichotomous view of Neanderthals as the makers of the MP and AMH of the UP would imply.

Lithic assemblages provide the richest evidence for tracing the cultural developments that underpinned the demographic changes during this time. However, direct links between lithic assemblage types and human populations or groups are difficult to reconstruct and may be largely misleading, giving the increasing evidence of genetic admixture. This problem is well illustrated for the Levantine Mousterian which is associated by both Neanderthals and AMH, employing virtually identical Levallois reduction strategies and tool concepts (e.g. Shea, 2014). In contrast to the Levant, the central European archaeological record that covers this transitional period is characterised by a far more complex patchwork of different techno-complexes of which (1) some seem to have their roots in the regional MP, indicative of autochthonous developments, whereas (2) others may indicate exogenous influences from outside Europe (e.g. Hublin, 2015, cf. Kozłowski, 2021). Both groups of assemblages contain technological elements that seem to foreshadow to a certain degree chracteristics of UP or UP-like material culture. Likewise, recent results from genetics indicate that these developments were paralleled by the successively intermixing of Neanderthal and AMH populations (e.g. Fu et al., 2014, 2015; Hajdinjak et al., 2021; Prüfer et al., 2021), resulting in a mosaic of groups with either Middle Pleistocene Neanderthal or early AMH, recent Neanderthal or mixed ancestry.

However, a synthetic interpretation of the demographic and cultural changes underlying the archaeological record requires a more thoroughly understanding of the preceding Late (LMP) and Final Middle Palaeolithic (FMP) record. A first step towards the formulation of new interpretations and hypothesis is provided in the present paper, in which we review the central European LMP/FMP from ~ 130 ka to ~ 45 ka ago and discuss its contribution to the formation of the so-called transitional industries and of the regional UP (cf. Figure 1).

Viewed from a techno-typological perspective, the Upper Pleistocene lithic assemblages of central Europe appear highly variable, complicating the interpretation of behavioural and demographic changes around the period considered here. To further characterise these assemblages, we aim to explore the most relevant parameters underlying this variability. We discuss the continuities and discontinuities in the central European MP and outline lithic assemblage variability and — more specifically — the variability in core reduction and blank production concepts in relation to raw material procurement, land use and mobility. We describe varying levels of tool standardisation, individual signatures in tool design and manufacture and discuss the evidence for the existence of regionalised cultural signatures (RCS) that can be recognised in lithic technology, reflecting "traditions" which can be featured in spatio-temporal scales. The latter topics are at key for the understanding of both the cultural and the demographic developments at the transition towards the Initial (IUP) and Early Upper Palaeolithic (EUP) of central Europe. Based on our evaluation of the record, for the Upper Pleistocene MP of central Europe, we suggest to distinguish the following phases (Table 1; cf. Figure 2): (1) the early LMP (e-LMP) which is often represented by small-tool assemblages (often subsumed under the term "Taubachian") on the one hand and by techno-complexes in the furthest west of central Europe, characterised by blade production on the other hand; (2) the late LMP (l-LMP) with bifacial tools, namely assemblages assigned to the *Keilmessergruppen* (KMG) or the "Micoquian"; and (3) a FMP phase characterised by Levallois and Levallois-like laminar blank or blade production (Fig. 1b). This comparably simple scheme is nevertheless blurred by the large amount of assemblages of questionable integrity, as many sites are not preserved in situ, with assemblages potentially mixed or partially preserved only, hampering a detailed reconstruction of underlying *chaînes opératoires*. Furthermore, by far, most MP assemblages in central Europe remain undated or only poorly dated. Additionally, many assemblages are dominated by unifacial scrapers of different shapes but lack more standardised, better defined tool types (e.g. Bosinski, 1967). Taken together, these aspects strongly restrict a more comprehensive understanding of LMP/FMP assemblage variability (cf. discussion in: Richter, 1997, 2001; Weißmüller, 1995).

These phases of the LMP/FMP are, however, succeeded by a period characterised by different, but most likely closely inter-related and to certain degree convergent trends of changes in material cultural traits, before a comparably high level of relative technological "homogeneity" is established across Europe during the EUP Aurignacian techno-complex (e.g. Uthmeier, 2004; cf. Bar-Yosef, 2006; Bar-Yosef & Zilhão, 2006; Bon, 2015; Fig. 1c). It appears that these developments mirror an increasing overprinting of locale or site specific signatures (largely determined by socio-economic factors) by socio-cultural conventions in blank production and tool design, which characterise the central European UP from the Aurignacian onwards (cf. Le Brun-Ricalens, 2005; Muller & Clarkson, 2022). As only few AMH remains

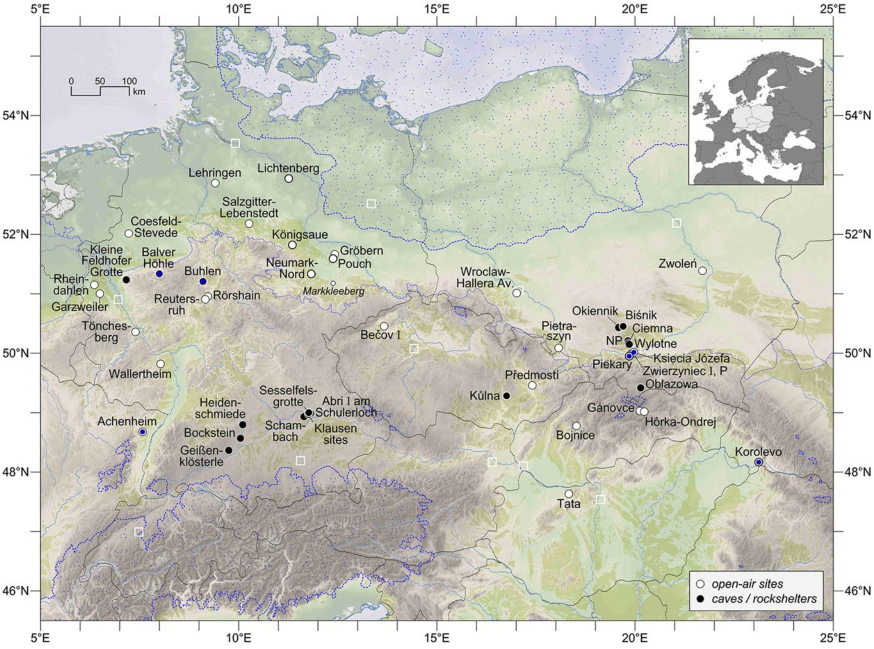


(a)

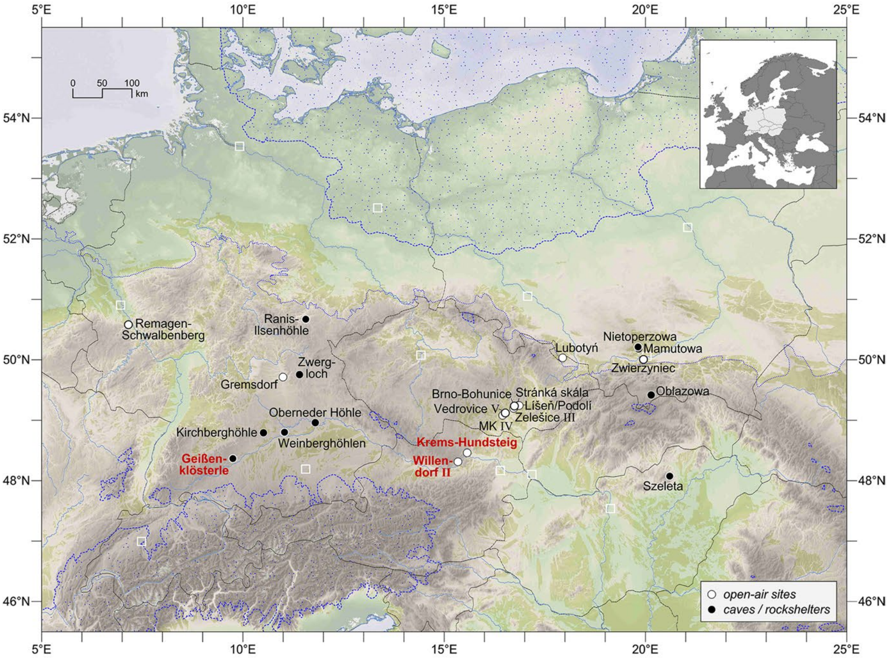
Fig. 1 **a** Map of central Europe with key geographic regions, structures and features. The macro-regions within central Europe, addressed archaeologically and shown in Fig. 2, are encircled in dotted lines: NW, north-western; SW, south-western; NM, northern middle; NE, north-eastern; SE, south-eastern. Smaller karstic regions are numbered: 1, Sauerland; 2, Lower Altmühl Valley; 3, Sudetes Karst area; 4, Štramberk Karst; 5, Moravian Karst; 6, Krumlovský les region; 7, West Carpathian caves; 8, Trans-danubian caves. Map created using QGIS 3.16, based on SRTM15 + data of Tozer et al. (2019). **b** Middle Palaeolithic (MP), Late (LMP) and Final Middle Palaeolithic (FMP) sites mentioned in the text. The small dot for Markkleeberg indicates the site's early MP age. Blue dots are added to sites that also contain FMP layers; NP, Nietoperzowa. Sites included in Fig. 2 are highlighted by their bold outlines. Plotted on top of the SRTM15 + ground map are ice shields and local glacier limits of the Last Glacial Maximum (blue dashed lines) for the northern European lowlands (Ehlers et al., 2011; Weckwerth et al., 2019), the Alps (Martinez-Lamas et al., 2020), Tatra (Kłapyta & Zasadni, 2018) and Carpathian Mountains (Kłapyta et al., 2021) and the southernmost limit of the distribution of erratic flint (blue dotted line between ~ 50°N and ~ 52°N which combines the phases of maximal ice advances of Middle Pleistocene glaciations, i.e. the Saalian and Elsterian: Ehlers et al., 2011). In addition, the central European loess cover is shown in half-transparent mustard-colour, following Lehmkuhl et al. (2020). Map created using QGIS 3.16. **c** Sites from the Middle (MP) to Upper Palaeolithic (UP) transitional industries (TRANS) mentioned in the text. MK, Moravský Krumlov IV. Early Aurignacian sites are shown in bold red. Sites included in Fig. 2 are highlighted by their bold outlines. Ground map identical to Fig. 1b, created using QGIS 3.16

are known from the Aurignacian (e.g. Kuzmin, 2021; cf. references therein), it is noteworthy to mention that no Neanderthal remains are known from Aurignacian and later UP contexts (cf. Higham et al., 2014).

The current paper aims at presenting the present state of research on the LMP/FMP (Fig. 1b), and the transition to the UP in central Europe (Fig. 1c), as this region is considered being central in models of AMH population expansion across Europe



(b)



(c)

Fig. 1 (continued)

Table 1 Major characteristics of central European techno-complexes ~ 130/125 ka until 25 ka cal BP and their relative frequencies, compiled for blank production concepts (left) and for retouched items (right)

				blank production								
				flakes				points	laminar			bladelets
				non-hierarchial			hierarchial					
period	techno-complex	start age ka / ka cal BP	end age ka / ka cal BP	polyhedrical / irregular	Quina	discoidal	Levallois	Levallois, uni- / bi-directional	bi-directional Levallois (-like)	bi-directional volumetric	uni-directional volumetric	blanks: cores, carinated scrapers / burins
MUP	Gravettian	< 34/33	~23							xxx	x	xxx
EUP	Zwierzyniecian	~40-33								xx	xx	
	Aurignacian	43/42	~34							(x)	xxx	xxx
	LRJ	~46/44	~39 (30)							xxx	x	
IUP	Bohunician	~49	~39					x	xxx	xx	xx	
TRANS	Altmühl- or Blattspitzengruppe(n) / Szeletian	45-42	40	x								
FMP	Lev.-Mousterian	~49	~47				xx	xx	xx	x	x	
	Lev.-M. alike	~55	~50/45	x		(x)	xx	x	x	x	x	
l-LMP	MTA	(in Central Europe poorly known)							x			
	KMG/M.M.O./ "Micoquian"	~95	~50	x	x	x	x	(x)	(x)			(xx)[1]
e-LMP	e-LMP blade assemblages	~110	~85				(x)			xxx	xx	(x)
	"Taubachian"	~130/125	~85	x		xxx*	(x)*				x	
MP	"Mousterian", undifferentiated	pre-dominantly > 85	but some potentially as young as ~45	x	(x)	x	x					

(e.g. Chu, 2018; Conard & Bolus, 2003). The paper does not provide a complete catalogue of sites. Nor does it refer to quantitative site-based numeric data as the state of publication is too heterogenous and assemblage integrity is often difficult or impossible to assess. With an emphasis on qualitative data, the study refers to a series of sites and assemblages instead, which we consider relevant in the discussion of techno-functional assemblage variability vs. techno-typological chronological trends (Fig. 2) that appear to change during the MP to UP transition. It refers to the most detailed studied and often best-dated sites which contribute significantly to our present model-building of understanding Palaeolithic lifeways and the demographic processes behind (Schmidt & Zimmermann, 2019). It will address the contributions of these aspects to understanding lithic assemblage variability (Fig. 3). The paper goes further than a review as it targets at synthesising our present knowledge and

Table 1 (continued)

retouched items												
(laminar) flake		flake	core / surface retouched blank				diverse**	blade				
unifacial			(semi-) bifacial					semi-bif.	unifacial			
diverse shapes	asymmetrical, backed	symmetrical		asymmetrical, backed			symmetrical			symmetrical or asymmetrical	asymmetrical, backed	
scrapers		Groszaki	handaxes	(backed) handaxes	backed bifacial knives (Keilmesser)	leaf-shaped knives	leaf-points**	blade points	end-scrapers	burins	backed bladelets	backed points
							(x)		xxx	xxx	xxx	xxx
(x)									xx	xx		xxx[10]
(x)							(x)		xxx	xxx	xxx[9]	
(x)							x	xxx	x			
x						(x)	(x)		xx[8]	x		
xx						xx	xxx	x	x	x		
xx[2]	x								x			
	x[4]								x			
xx	xx[5]		xxx[7]	x	(x)				(x)			
xx	xx	(x)	(x)	x	xxx	xx	x					
xx	x[6]									(x)		
xx[3]												
xxx												

Items in bold appear as rather standardised elements of regionalised cultural signatures (RCS)

Periods: MP, Middle Palaeolithic; e-LMP, early Late Middle Palaeolithic; l-LMP, late Late Middle Palaeolithic; FMP, final Middle Palaeolithic; TRANS, transitional; IUP, Initial Upper Palaeolithic; EUP, Early Upper Palaeolithic; MUP, Mid-Upper Palaeolithic

Techno-complexes: KMG, *Keilmessergruppen*; M.M.O., "Mousterian with Micoquian Option"; MTA, Mousterian of Acheulian Tradition, Lev./Levallois-Mousterian, Levallois-Mousterian; LRJ, Lincombian-Ranisian-Jerzmanowician

Relative frequencies: (x), occasional; x, present; xx, regular; xxx, frequent

*Often in miniature size

**In far most cases, these leaf points are made of elongated flakes, thin tabular raw material plaquettes or fragments of pebbles, but they are more or less completely bifacially shaped and refined

[1] At some sites: lateral tranchet blows/spalls

[2] Single or double side-scrapers (often marginally retouched) and transversal scrapers

[3] Small and often irregular tools of diverse shapes

[4] Marginally retouched items sometimes appear being backed

[5] *Coteaux á dos*

[6] Backed (laminar) tools

[7] Small, symmetrical handaxes (sometimes *bout coupe*-like)

[8] Frequently on blanks that converge towards the scraper tip and Aurignacian-like end-scrapers

[9] Marginally backed

[10] Arch-backed points

at resolving some of the inconsistencies between the different models that have preserved over the last few decades.

The Central European Middle Palaeolithic: Characterisation and Definition

The MP of central Europe approximately covers the period ~ 300–45 ka ago (Jöris, 2014; Richter, 2016; Roebroeks & Gamble, 1999). As in western Europe, the MP of western central Europe seems to have developed gradually out of the preceding Late Acheulian substrate (Adler et al., 2014). By contrast, Acheulian evidence in eastern central Europe is scarce, implying different explanations for the origins of MP industries (Cyrek, 2021; Wiśniewski, 2014). While in most of Eurasia bifacial industries are largely replaced by unifacial ("Mousterian") ones, characterised by laterally retouched, mostly unifacial scrapers (single or double scrapers, transverse scrapers) and points (or "pointed" scrapers) of various shapes, at around the Acheulian (Lower) to MP transition in the mid-Middle Pleistocene, central European MP assemblages often contain bifacial elements (Bosinski, 1967; Pettitt & White, 2012). This accounts especially for some LMP assemblages that have been ascribed as "Micoquian" (Bosinski, 1967, 1968) and related terms (e.g. Micoquo-Prondnikian: Chmielewski, 1969; cf. discussion in Frick, 2020a) or as "Keilmessergruppen" (KMG: Jöris, 2004, 2006; Mania, 1990; Veil et al., 1994), characterised by mostly (semi-)bifacially worked ("Micoquian") backed asymmetric knives (cf. Delpiano & Uthmeier, 2020: AKA: "Asymmetrical Knives Assemblages"). However, these bifaces show marked differences in tool design when compared to the handaxes of the western European "Mousterian of Acheulian Tradition" (MTA), with the former displaying a single acute edge, whereas MTA handaxes are largely characterised by high levels of symmetry and acute edges often around larger parts of the tool's perimeter (Ruebens 2013; cf. Soressi, 2002).

The presence of bifaces in the central European MP, however, remains the major difference to the predominantly unifacial industries subsumed in western Europe under the term "Mousterian". This difference was recognised early in the history of research into this period and was taken as an argument for the preferred use of the alternative term "Middle Palaeolithic" (Grahmann, 1955), within which unifacial "Mousterian" and bifacial "Micoquian" assemblages were strictly separated from each other (Bosinski, 1967). Some researchers interpreted "Mousterian" and "Micoquian" assemblages as reflecting two independent, but largely synchronous and possibly even long-lasting traditions thought to represent different demographic entities or populations (cf. Foltyn et al., 2000; Kozłowski, 2014, 2021). In contrast to such views, to acknowledge for the high levels of assemblage variability observed, other researchers have integrated both the uni- and the bifacial LMP assemblages into the concept of a "Mousterian with Micoque Option" (M.M.O.) that tries to explain the differences between assemblages as due to differentiations that result from a range of factors, above all occupation time and site function (Richter, 1997, 2001, 2012; Uthmeier, 2000, 2004).

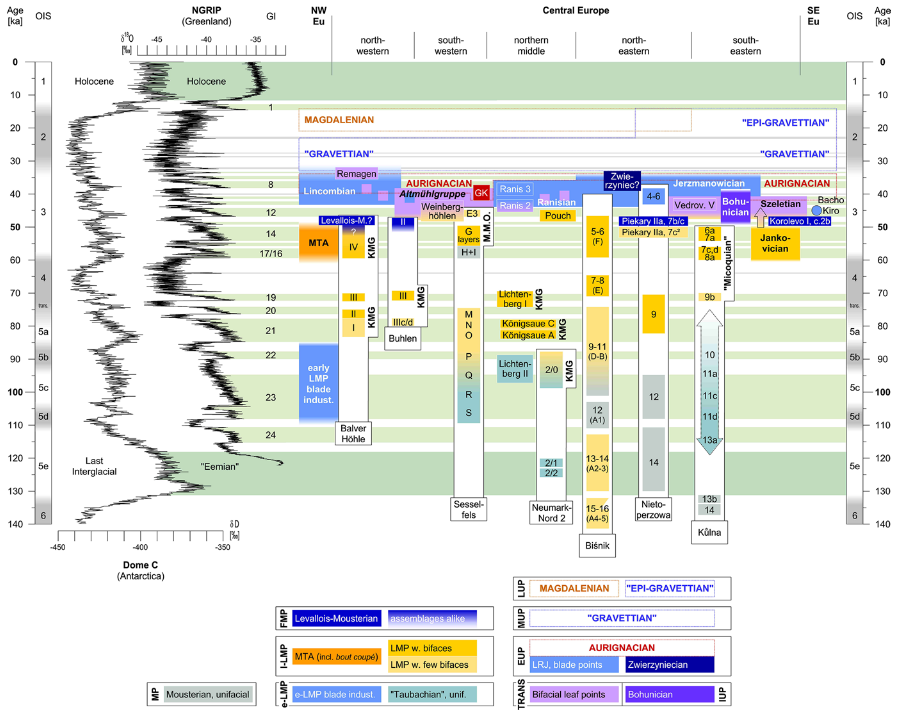


Fig. 2 Synthetic overview over the chronostratigraphy of the Late (LMP) and Final Middle Palaeolithic (FMP) record and the Middle (MP) to Upper Palaeolithic (UP) transitional industries (TRANS) of central Europe (Eu), shown against the background of Upper Pleistocene to Holocene palaeoclimate records (Dome C: Jouzel et al., 2007; NGRIP: Rasmussen et al., 2014). OIS, oxygen isotope stages; IUP, Initial Upper Palaeolithic; MUP, Mid-Upper Palaeolithic; LUP, Late Upper Palaeolithic. Horizontal bars represent densely forested interglacial (dark green), lightly forested (boreal-type forests) interstadial (light green) and unforested interstadial (grey) periods in central Europe, referred to the Eemian and the Holocene interglacials and to Greenland interstadial numbers (GI; cf. Johnsen et al., 1992), repectively. White vertical boxes represent selected long stratigraphical sequences for each of the macro-regions shown in Fig. 1a, with archaeological horizons labelled. In addition, key-sites with single find horizons or short stratigraphical sequences and major lithic techno-complexes (bold) are shown within their respective chronostratigraphic positions or dating ranges. Assemblages with largely laminar blank production are shown in blue (e-LMP, early LMP; FMP, Levallois-Mousterian-like assemblages; TRANS, Bohunician; LRJ, Lincombian-Ranisian-Jerzmanowician), those with bifacial technology in orange (MTA, Mousterian of Acheulian Tradition; KMG, *Keilmessergruppen*; M.M.O., "Mousterian with Micoquian Option"; "Micoquian"; Jankovician, see text) and those with bifacial leaf points in violet (*Altmühlgruppe*; Szeletian; Vedrov., Vedrovice). For completeness, the succeeding major Upper Palaeolithic techno-complexes (Aurignacian, Gravettian, Magdalenian) are shown in simplified manner. GK, Geißenklösterle-Aurignacian (AH II and AH III). Note that assemblages, sites, and techno-complexes > 50 ka have much larger dating uncertainties, compared to the record < 50 ka

Discontinuities in the Middle Palaeolithic of Central Europe

MP sites are not evenly dispersed over central Europe (Fig. 1b/c). This is explained by (1) past fluctuations in hominin presence in the region and by (2) differences in preservation that are largely linked to topography and relief and to the regional

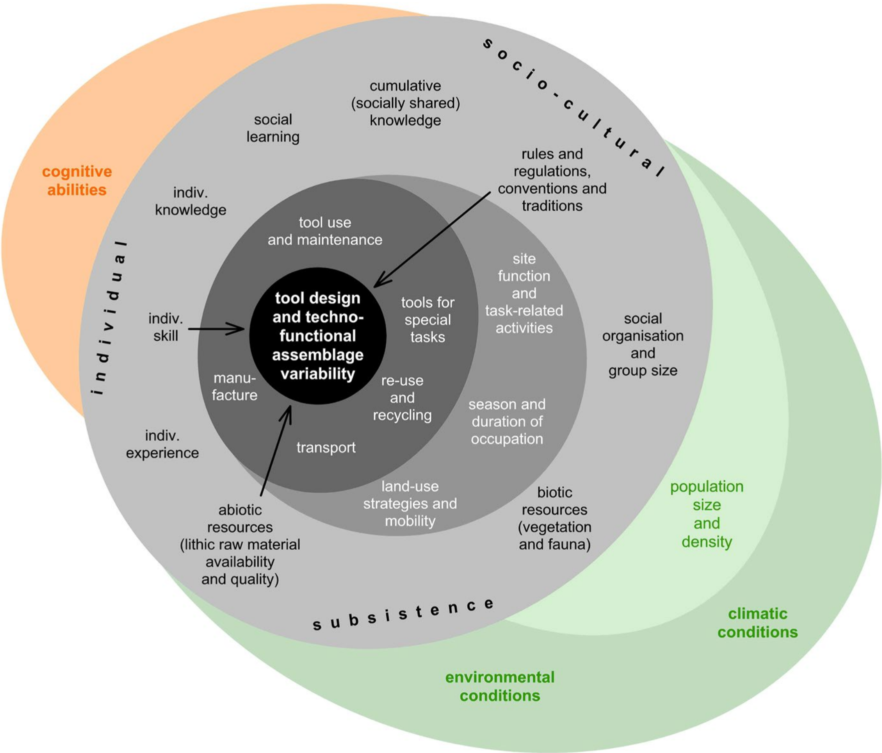


Fig. 3 Synthetical, polydimensional model to explain tool design and lithic techno-functional assemblage variability (commencing in the centre/black core of the diagram). In this model, at different levels, with different intensities, and with different levels of directness, conditions work from outer shells to inner, with external factors such as climatic and environmental conditions effecting the dispersal of human populations, as well as population size and density. Together with human cognitive abilities such external factors can have strong influences on human lives, at individual and socio-cultural aspects, as well as in all subsistence-related settings (outer grey shell). Interdependencies between these factors largely steered daily life over the course of the annual cycle (inner grey shell). Note that in this diagram, specific factors that are arranged more distally from the central (black) core on the outer grey shell, nevertheless, may have had more direct or proximate influence on lithic techno-functional assemblage variability than certain factors that are located on more inner shells. During certain periods, tool design, for example, may have been more directly influenced by certain aspects (arrows) than by others. Note also that some factors located on the inner shells may also have led to feedback processes, influencing factors on the other shells. Due to the complexity of the polydimensional web of interdependencies between these factors, a comprehensive model to explain lithic assemblage variability is still lacking today

differences in the geological background, as well as to the effects of past climatic and environmental changes.

In central Europe, karstic systems, which would have allowed for preservation of archaeological deposits in caves, are relatively scarce. Exceptions are the caves of the western German Sauerland, the southern German caves of the Swabian and Franconian Jura, the Polish Jura, the Sudetes karstic area, the Moravian and Štramberk Karsts in the Czech Republic, the West-Carpathian and the Transdanubian caves and the caves in the Bükk Mountains of Hungary (cf. Figure 1a). Furthermore, some caves have been destroyed through quarrying since the beginning of the industrial revolution and often remain poorly documented due to their early discoveries (e.g. compilation in: Andree, 1939). Given this situation, many cave sites have been lost long before they could be excavated scientifically. The most prominent example of this is the Kleine Feldhofer Grotte in the Düssel Valley ("Neanderthal"), where the 1856 discovery of the eponymous Neanderthal remains was made (Fuhlrott 1859; Schmitz, 2006).

Besides archaeological archives deriving from karstic formations, open-air sites had enormous impact on the history of research into the central European MP. Some of the most prominent examples are as follows: Achenheim (Wernert & Schmidt, 1910), Markkleeberg (Grahmann, 1955; Jacob, 1911), Wallertheim (Schmidtgen & Wagner, 1929), Lehringen (Adam, 1951), Salzgitter-Lebenstedt (Tode et al., 1953) and Piekary II and III (Krukowski, 1939–1948).

In the northern half of central Europe, i.e. in the northern central European lowlands, open-air sites in riparian systems along river terraces or finds from river gravel deposits are numerous (e.g. Baales, 2012; Kegler & Fries, 2018; Uthmeier et al., 2011). But besides the amount of sites in the northern lowlands, some interglacial lake shore sites that formed in natural depressions left within the formerly glaciated areas of northern central Europe have provided exceptional conditions of preservation. Sites are fairly numerous in such basins, particularly for the Last Interglacial (i.e. "Eemian": ~ OIS 5e; OIS — Oxygen Isotope Stage), notably Lehringen (Thieme & Veil, 1985), Gröbern (Mania et al., 1990) and Neumark-Nord (Kindler et al., 2020; Roebroeks et al., 2021; see also Wenzel, 2007 for a general survey). Other localities that belong to the Last Interglacial or into temperate interstadials preserved in travertine formations. Such sites are found mostly in Slovakia and Germany (cf. Wenzel, 2007). In some cases, e.g. at Hôrka-Ondrej (the sequence starts in the penultimate glacial), Gánovce and Bojnice III in Slovakia (Kaminská, 2014; Kaminská et al., 2000; Neruda & Kaminská, 2013), the superposition of several occupation layers enables the diachronic study of MP behaviour at these localities.

A substantial number of sites is preserved in the loess accumulation zone (cf. Lehmkuhl et al., 2021; Fig. 1b/c). The long loess–palaeosol sequences from Achenheim in the Alsace, France, in the west (Rousseau & Puisségur, 1990), from the German Lower Rhineland (Holzkämper et al., 2022), and from Korolevo in Transcarpathian Ukraine, in the east (Nawrocki et al., 2016), cover the last ~ 350 ka in the west and — at Korolevo — even reach back to a million years ago. Upper Pleistocene loess–palaeosol sequences may start in OIS 5 (e.g. Tönchesberg: Schmidt et al., 2011; Předmostí II: Svoboda et al., 1996a), but show highest accumulation rates from OIS 4 to OIS 2 (e.g. Remagen-Schwalbenberg: Fischer et al., 2021). As such, several open-air sites that date to the MP to UP transitional period are well preserved. This accounts especially for the Wachau region of Austria (e.g. Nigst, 2012 for an overview), for Moravia (e.g. Moravský Krumlov IV: Neruda & Nerudová, 2010) and for southern Poland (Valde-Nowak & Łanczont, 2021).

In the southern and eastern parts of central Europe with more pronounced topography, the Palaeolithic archaeological record is preserved less extensively. In southern Germany, the majority of sites derive from small caves and rockshelters (e.g. Swabian and Franconian Jura: Çep et al., 2021; Conard et al., 2015, 2019; Freund, 1963), whereas comparably few open-air sites are known from this region (e.g. the long loess–palaeosol sequences of Achenheim in the Alsace: Junkmanns, 1995). The situation is similar in Poland where important sites relate to the karstic areas (e.g. Polish Jura), whereas further south in Slovakia, open-air sites prevail (Kaminská, 2014). This also accounts for Moravia and Hungary in the Carpathian Basin.

MP sites significantly increase in number all over central Europe with the beginning of the last Interglacial-Glacial Cycle (cf. Bosinski, 1967; Kozłowski, 2014; Richter, 2016; Wiśniewski, 2016), which defines the beginning of the Upper Pleistocene and of the LMP. While the absolute number of sites increases, LMP occupation of central Europe remains discontinuous, largely because of central Europe's relatively northern latitude and relative proximity to the expansion of the ice sheets during glacial periods (Fig. 1b/c). For much of the MP, much of central Europe, especially its northern lowlands, was either overrun by the inland ice or — indirectly — strongly affected by severe cold or permafrost of the periglacial zones (e.g. Ehlers et al., 2011).

But the apparent discontinuities in the central European MP record also result from the scarcity of well-dated sites and stratigraphies, often in combination with poor preservational conditions. Due to geologically induced displacement effects such as erosion, solifluction and fluvial transport that characterised and strongly effected the former periglacial environments, stratigraphic sequences have most often experienced unconformities rather than having developed in continuously deposited sediments (e.g. Krajcarz et al., 2014). But, most importantly and contrasting with areas further to the south, the discontinuous MP record of central Europe directly relates to periods of changing presence and absence of people. Upper Pleistocene climatic and environmental changes had constantly been challenging past hominins' behaviours, adaptational strategies and lifeways. Under certain climatic and environmental conditions, however, much of central Europe seems to have been unfavourable for human occupation, whereas others appear to have been more advantageous (Jöris, 2004, 2014).

Whenever more precise palaeoenvironmental data is available, it appears that Neanderthals mainly occupied central Europe during the more temperate periods of interglacials and interstadials characterised by forested to steppe-like environments (Jöris, 2004; Nielsen et al., 2017; Hein et al., 2020; Kindler et al., 2020; Roebroeks et al., 2021; Skrzypek et al., 2011; cf. Serangeli & Bolus, 2008). There is, however, also growing evidence for the occasional occupation of tundra-like biotopes that developed during predominantly cold phases, notably the upper find horizon at Markkleeberg, dated to OIS 6 (Lauer & Weiss, 2018), Salzgitter-Lebenstedt, dated to OIS 5a-3? (Pastoors, 2001; Tode et al., 1953), stratified assemblages in the Garzweiler lignite mine (Uthmeier et al., 2011) and AH IV at Geißenklösterle (Richard et al., 2019), both dated to OIS 4 and Lichtenberg I, dated at the OIS 5a/4 transition (Weiss et al., 2022). The fluctuation of past climatic and environmental changes resulted in periods that were more favourable for Neanderthal presence in central Europe and those that were less favourable, the latter of which additionally contributed to the discontinuous nature of the central European LMP (Fig. 2). Wherever longer stratigraphies are preserved, in only a few cave sites, e.g. Balver Höhle (Jöris, 1992), Sesselfelsgrotte (Richter, 1997; Weißmüller, 1995), Kůlna Cave (Valoch, 1988), Ciemna Cave (Valde-Nowak et al., 2014, 2016), Biśnik Cave (Cyrek et al., 2014) and Nietoperzowa Cave (Krajcarz & Madeyska, 2010; Madeyska, 2002), archaeological horizons are often separated from each other by sterile deposits.

The LMP to FMP record of central Europe is therefore to be understood as a record of changing and discontinuous demographies of generally small overall meta-populations, characterised by periods of population presence and regional population retreat(s) (e.g. Jöris, 2004; Richter, 2016) or even extinction(s) (e.g. Hublin & Roebroeks, 2009) and by the (repeated) re-occupation of regions that were formerly abandoned.

From the number of sites that can be assigned to OIS 3, a significant increase in hominin population size can be assumed for central Europe, following a period of relative absence of hominins during the peak of OIS 4 (Richter, 2016; Wiśniewski, 2016; cf. Kozłowski, 2014). For most of OIS 5 and (especially numerously) for OIS 3, LMP/FMP sites are well-recorded in central Europe.

For the understanding of techno-functional variability in lithic adaptational strategies that can be observed during the central European LMP/FMP, understanding fluctuating Neanderthal demographies is at key. Late Neanderthal regional demographies are furthermore crucial for understanding the interplay with early AMH populations that entered Europe.

Variability in Middle Palaeolithic Blank Production and Core Reduction Concepts

In contrast with the Lower Palaeolithic, the MP is characterised by a general diversification of blank production strategies and related core reduction concepts. Exploitation strategies for lithic raw materials include — among many others — hierarchical reduction concepts (as, for example, employed in Levallois concepts and in volumetric blade production) as well as discoidal and Quina-type reduction concepts (Delagnes et al., 2007; Hérisson et al., 2016; Wiśniewski, 2014). This technological diversification especially applies to the LMP/FMP of central Europe (Table 1), where most assemblages are not characterised by the single application of one of the different concepts only, but rather by the parallel use of two or more of such concepts (e.g. Kraków — Księcia Józefa: Sitlivy et al., 2014; Heidenschmiede: Çep et al., 2021). Aside from these more standardised appearing reduction strategies, a pragmatic irregular exploitation of raw materials is frequently observed.

In central Europe, some early LMP (e-LMP: ~ 130 ka until ca. 95–85 ka) lithic inventories of Last Interglacial and early Last Glacial contexts (OIS 5e-5c/5b) are to a large degree characterised by the dominance of small artefacts and tools, like, for example, at Tata (Vértes, 1964; cf. Moncel, 2001, 2003); Kůlna, layer 11 (Valoch, 1988; cf. Moncel & Neruda, 2000); the middle sedimentary cycle of Předmostí II (Moncel, 1998; cf. Svoboda et al., 1996a); the Lower Levels at Sesselfelsgrotte (Weißmüller, 1995); or Lichtenberg II (Weiss et al., 2022). Such "small-tool" or "microlithic" assemblages are often classified as "Taubachian" (Collins, 1968; Valoch, 1971) and are interpreted as reflecting an intensive exploitation of raw materials (e.g. Moncel & Neruda, 2000) and/or explained as the result of the small initial dimensions and shapes of the raw material used (Weißmüller, 1995; Weiss et al., 2017, 2022). To a certain degree, however, it remains an open question as to whether the small-sized lithic items mainly result from a strong degree of reduction, a lack of larger-sized raw materials available in a certain region and/or at a certain time, from the targeted selection of small-sized raw materials chosen for knapping or from the selective export (removal) of larger items from the sites (Neruda & Kaminská, 2015; cf. Turq et al., 2013). Additionally, some "Taubachian" assemblages have been interpreted in relation to specific environmental conditions, particularly occurring in mountainous areas and/or near water sources (e.g. Cieśla & Valde-Nowak, 2016).

Similarly, the Last Interglacial archaeological deposits of Neumark-Nord 2 (NN2) are characterised by the intensive exploitation of small cores (NN2/2: Pop, 2014). In addition, frost-shattered shards were frequently used and directly transformed into formal tools by retouch. Nevertheless, discoidal (within "Taubachian" assemblages) and both discoidal and Levallois concepts — even when in miniature form — dominate some Last Interglacial and early Last Glacial assemblages. As with the Mesolithic period in central Europe, it has been repeatedly argued that raw material accessibility (cf. Figure 3) may have been limited within those environments characterised by dense vegetation cover, where only river banks — and to limited degree lake shores — would have allowed for the provisioning of raw materials of larger dimensions (Kozłowski, 2014; Weißmüller, 1995). A flexible adoption of reduction strategies to small-sized raw materials emphasises the pragmatic handling of reduction concepts (e.g. Conard et al., 2019) and often resulted in a higher variability of core exploitation patterns. But at the Kraków Zwierzyniec Last Interglacial site I (point P), where good quality local flint of decent size was available, preferential Levallois reduction was practised (Opara, 2006).

Such pragmatic handling of reduction strategies that may have been strongly influenced by local factors contrasts with the systematic application of e-LMP laminar concepts, in, for example, Rheindahlen B1 (Bosinski et al., 1966; Schmitz & Thissen, 1998; for an alternative age-estimate of this assemblage, cf. Holzkämper et al., 2022), Tönchesberg 2B (Conard, 1992) and Wallertheim D (Conard et al., 1995). Evidence is growing that these assemblages represent a north-western and furthest western central European techno-complex that dates to around OIS 5c-5b (Conard, 2001, 2012; cf. Locht, 2002; Hoggard, 2017). The systematic and serial production of large blades, most frequently produced from (uni-directional) single-platform, and also (bi-directional) opposed-platform cores, has some similarities with FMP and Upper Palaeolithic (UP) blade production strategies including the preparation of crested blades and required provisioning and careful selection of high-quality flint nodules of decent size (Révillion, 1994; Révillion & Tuffreau, 1994). At Tönchesberg, however, small-sized pebbles and shards of limnic quartzites were used for the production of laminar products of bladelet size from volumetric cores (Conard, 1992). High frequencies of refits at some of these sites may be indicative of a specific provisioning facies (a.k.a. workshop) at these localities.

For the later phase of the central European LMP (l-LMP: ca. 95–85 ka until ~ 50 ka), it remains currently largely unclear whether or not specific spatio-temporal trends can be observed within the wide spectrum of different reduction strategies applied. The late OIS 5 (most likely OIS 5a: Jöris, 2004) site of Königsaue in the northern Harz foreland documents a sequence of three archaeological horizons that all date to the same interstadial sequence (Odderade interstadial, ~ Greenland Interstadial (GI) 21; for a discussion of an alternative younger, i.e. OIS 3 age-estimate see: Picin, 2016) and, of which, mostly the intermediate assemblage (Kö B) is characterised by (predominantly centripetal) Levallois reduction concepts (Mania & Toepfer, 1973). But also in the two other layers, Kö A and Kö C, blank production includes a high proportion of Levallois products of various degrees (Mania & Toepfer, 1973; cf. Weiss et al., 2017). A similar spectrum of Levallois methods was recognised in the lower horizon of Hallera Av. Site, Wrocław, in the Silesian Lowlands, dated to OIS 5a–c (Wiśniewski et al., 2013). Here, Levallois cores and products were found together with bifacial and unifacial tools. In some "Micoquian" horizons, which date at the OIS 5a/4 transition and into early OIS 3, e.g. Layers 9b, 7c, 7a and 6a of Kůlna Cave (Neruda, 2011; Valoch, 1988) or Bojnice I — Prepoštská jaskyňa (Neruda & Kaminská, 2013), the Levallois concept is absent and discoidal methods for blank production prevail. Besides these two main concepts, non-Levallois laminar production is present at Kůlna. It appears, however, to be rather experimental (opportunistic) and poorly standardised. In the aforementioned layers of Kůlna Cave, or at Heidenschmiede, such laminar blank production supplemented flake production (Çep et al., 2021; Neruda, 2011). This contrasts the OIS 3 sequence of the G-layers of the southern German Sesselfelsgrotte where blades were obtained in the course of the initial, i.e. decorticating, phase of the production of bifacial tools made from rather cubical blocks or plaquettes (Richter, 1997, 186–187). Here, the frequency of laminar Levallois production increases in time in parallel to centripetal Levallois strategies which generally prevail, whereas cores and flakes produced in a Quina flaking method that characterises the lower part of the G-layers sequence at Sesselfelsgrotte disappear (Richter, 1997, 2016). Quina-like reduction concepts are also reported from Bockstein III (Çep, 2014), potentially dating to OIS 5a (Çep & Krönneck, 2015), an assemblage which is characterised by its large proportion of bifacial tools, most of which resemble backed bifacial knives (cf. Wetzel & Bosinski, 1969). Discoidal and/or unidirectional flaking has been also recorded in all layers of the Wylotne Rockshelter, where the production and use of "Micoquian" backed knives is also exceptionally well represented (Jackowska, 2006; Targosz, 2006). Depending on the size and shape of the raw material used, bladelets were only occasionally produced in l-LMP contexts, but — when realised — follow a simple, opportunistic strategy (e.g. Balver Höhle: Pastoors & Tafelmaier, 2010). Given this huge variability (Table 1), it remains unclear in how far the core reduction concepts applied at LMP sites relate to raw material availability and abundancy, or to chronological trends and traditions, or if they reflect more versatile and pragmatic behaviours.

Raw Material Procurement, Land Use and Mobility

Knowledge of raw material accessibility has been of varying influence on land-use and mobility patterns (e.g. Féblot-Augustins, 1993, 1999; cf. Floss, 1994; cf. Figure 3). How patchy or regionally widespread raw materials had been available was of relevance for the predictability of lithic resources and demanded being anticipated in accordance with the planning of other activities (e.g. Çep & Krönneck, 2015).

Erratic flint is widespread in the northern European lowlands in secondary depositional contexts, from the northern Netherlands to Poland (Fig. 1b/c). During the Middle Pleistocene advances of the Fennoscandian ice sheets, so-called Baltic flint that originated from the southern Baltic region was glacially transported to the south, reaching the northern fringes of the central European low mountain ranges (*Mittelgebirge*), the Sudetes, as well as the western Carpathian foothills. Within this extant region, flint nodules of high quality and decent size are scattered all over the landscape and provided a relatively predictable and easily accessible resource that was not exclusively restricted to locally limited outcrops as long as vegetation cover was sparse. The fact that the largest flint nodules and highest quantities can be found along the large river valleys in the northern European lowlands, where the coarse erosional residuals from glacial tills accumulated (Weber, 2012; Weiss, 2015), underlines the pivotal role of fluvial gravel deposits for the procurement of raw material in this region, largely independent from the respective vegetation cover (Wiśniewski et al., 2013). Due to the high quality, size and shape of erratic flint nodules, in most of this region, it was Levallois reduction concepts that were used for the production of blanks. The material was additionally used for the production of larger and often bifacial tools like handaxes, backed bifacial knives (*Keilmesser*) or foliate tools such as leaf points (Böhner, 2016; Grote, 1975; Werben & Thieme, 1988). But, this does not imply that Levallois or bifacial tool technology were the only choices when raw materials were of larger size and properties favoured knappability. At Coesfeld-Stevede in Wesphalia, for example, Baltic flint nodules were reduced by the almost exclusive application of discoidal reduction strategies (Richter, 2013).

Further to the south, in and around the German *Mittelgebirge* and the Carpathians, raw material availability is more restricted to regional or even local occurrences of varying quality (e.g. Böhner, 2012; Burkert, 2012; Dobosi, 2011; Féblot-Augustins, 1997, 1999; Floss, 1994, 2012; Krajcarz et al., 2012; Marcó, 2008, 2009; Marcó et al., 2003; Neruda, 2011; Valde-Nowak & Kerneder-Gubała, 2019; Wiśniewski, 2014). In central Europe, several LMP/FMP sites (e.g. Reutersruh: Luttropp & Bosinski, 1971; Bečov I: Fridrich, 1982; Wiśniewski & Fridrich, 2010) and workshop sites assigned to the MP to UP transitional techno-complexes (e.g. Rörshain: Campen & Hahn, 1973; Luttropp & Bosinski, 1967) are known from local outcrops of specific raw materials. Good examples are those from the central German region of Hesse, where quartzite layers have been locally exploited over lengthy periods of time. At most of these spots, Levallois concepts of core reduction appear to dominate; this surely relates to the size and shape of the angular quartzite shards, often with naturally given angles well-suitable for knapping. But the different shapes and sizes of other types of raw material, such as the flat Jurassic chert plaquettes in southeastern Germany (Böhner, 2012), block-shaped materials such as silicified shists (Jöris, 2001) or pebble-shaped Krumlovský les type of chert of the Czech Republic (Oliva, 1997) that can be found in different regions of central Europe (Floss, 1994), required a highly pragmatic anticipation of raw material quality and shape, depending on the specific design (regarding shape and size) of the blanks or tools they were intended to produce. For some tool designs, however, raw materials with specific physical properties of hardness or brittleness that contribute to the (controlled) knappability of the material, such as felsitic porphyry or obsidian that is found in northern Hungary, may have been chosen purposely (e.g. Dobosi, 2011; Kasztovszky et al., 2008).

With regard to the enormous variability and flexibility in LMP reduction strategies, however, in most cases clear links between raw material quality and reduction concepts are difficult to establish. Nevertheless, it appears that Levallois strategies could not be realised when certain quality criteria were not met by the available raw materials (e.g. Wiśniewski, 2014). In Moravia, for example, evidence for the application of Levallois technology is scarce. This probably relates to the low quality of the raw materials regionally available, whereas in Bohemia Levallois concepts were implemented at several sites (Neruda, 2012) where good-quality quartzites were available (cf. Fridrich, 1982). In turn, at Sesselfelsgrotte in southern Germany, Quina reduction was undertaken on quartzite, whereas Levallois concepts were restricted to more brittle flints (Richter, 1997), and in Balver Höhle, if applied, Levallois strategies were realised in silicified shists, whereas the far less brittle greywacke was reduced according to discoidal or polyhedral concepts (cf. Günther, 1964).

At central European MP sites, those exogenous raw materials that were imported to a locale over larger distances (> 30 km) rarely exceed 10% of the assemblages (Féblot-Augustins, 1999; Floss, 1994). In most cases, the amount of such imported raw materials is much smaller or insignificant compared to the use of regional or local raw materials from closer to the sites (Floss, 1994). This observation contrasts strongly with UP contexts, in which assemblages may be composed of much larger amounts of materials imported over long distances. However, at some MP sites, single items have been imported over distances of up to ~ 120 km in western central Europe (Floss, 1994) and dozens (Moravia: Neruda, 2011; Slovakia: Neruda & Kaminská, 2015; Hungary: Dobosi, 2011; Marcó, 2008, 2009; Marcó et al., 2003) up to > 150 km (Cieśla, 2018) in eastern central Europe. Whereas these imports are mostly seen as evidence for the size of annual foraging ranges, it cannot be excluded that materials were picked up at sites occupied earlier by other groups (and moved stochastically) or exchanged "down the line" via several individuals.

Whenever refits are studied or artefacts are sorted for raw material units at rich sites that may have produced several tens of thousands of lithics (e.g. Buhlen, Sesselfelsgrotte), it becomes clear that we are confronted with typical palimpsest situations that result from repeated occupations (Richter, 1997; Weißmüller, 1995). From a lithic perspective, each of these occupations is generally interpreted as of ephemeral or short-term nature. In most cases, however, it remains unclear whether such ephemeral or short-term activities overlapped with each other and relate to the activities of a larger local or regional group, or whether they reflect the accumulation of largely isolated events occurring over longer time intervals (cf. Turq et al., 2013). As a rule of a thumb, the richer MP sites of central Europe tend to show strong degrees of lithic reduction and resharpening (e.g. Jöris, 2001; Richter, 1997). Although this observation is in good accordance with the common hypothesis that intensive reduction of lithic tools correlates with the longer duration of activities over the course of a single occupation, this pattern may also — at least to some extent — be explained by recycling of material (cf. Figure 3). Especially with the less complex manufactured tools, it is highly possible that the presence of material left during earlier occupations could have been exploited later as an on-the-spot raw material resource, which served items still usable for expedient activities that did not require manufacture of more elaborate tools.

At some exceptional LMP and FMP open-air sites, like e.g. Pietraszyn 49a (Wiśniewski et al., 2019, 2020) or Kraków — Księcia Józefa (Sitlivy et al., 2014), single raw material units derive from blank and tool production sequences that have been preserved in situ, revealing which stages of the reduction sequences were accomplished on the spot and which items were apparently transported away from the site. Other LMP open-air sites, such as Lichtenberg I (Veil et al., 1994) that have been excavated almost over their entire (but spatially limited) extent, may represent an inventory possibly left behind after a single ephemeral and relatively short-term occupation of a foraging group. Such small assemblages in some cases certainly, and in others probably, represent specialised provisioning activities.

Varying Levels of Tool Standardisation, Individual Signatures and Traditions

In contrast with the Lower Palaeolithic, most MP assemblages are characterised by much higher intensities of reduction (Iovita, 2010; Jöris, 2014; Richter, 2016), as is observed at often extreme levels in LMP contexts (e.g. Buhlen: Jöris, 2001; Sesselfelsgrotte, G-layers: Richter, 1997; Kůlna: Neruda, 2011; Boëda, 1995). This does, however, not only apply for core reduction but also more for the *chaîne opératoire* of tool production, resharpening, re-usage and recycling. A large amount of the shape variability of MP tools does result not only from the initial variability of blank shapes but also from the commonly-repeated modification of the active tool edge(s). This accounts for most of the scrapers and points but similarly — and often to more intensive levels — for most of the bifacial tools from central European l-LMP sites. Viewed from the perspective of tool morphology and edge angles (e.g. Iovita, 2014; Weiss, 2020), most MP tools are interpreted as cutting tools (Veil et al., 1994), implying that one single active edge of a tool was used at a time. Items that display two or more acutely retouched edges most probably represent objects that underwent multiple stages of use, palimpsests of usage within the same object. In addition, each of the different acute edges may have been used and resharpened (in the sense of retouch) repeatedly, thereby constantly changing the tool's shape (e.g. Dibble, 1987, 1995; Iovita, 2010). Furthermore, retouch may not necessarily have been targeted directly at improving the edge angle of an active edge but on its "refreshing" by removing adhesive and sticky fats through retouch.

The resulting high levels of shape variability in LMP tools blurs the recognition of morphologically standardised shapes or "types" and has governed the discussion of MP techno-complexes and the question to which degree lithic inventories and tool spectra may result from the adaptation to certain environmental constrains, the influence of situational circumstances (like the accessibility of raw materials or the duration of occupation at a certain locale: e.g. Richter, 1997) or reflect specific traditions (of certain hominin groups or within populations: Jöris, 2004; Ruebens, 2013). Surely, assemblage and/or tool spectra differences result from the combined influences of such aspects (Fig. 3; cf. Richter, 1997).

In most cases, the enormous morphological variability is probably best interpreted as a reflection of pragmatic solutions to manage certain generally short-term tasks. In such task-related situations, a specific tool design may not have necessarily been required. On the other hand, certain l-LMP tool categories show high levels of conceptual standardisation (Jöris, 2001, 2004, 2006, 2012; Veil et al., 1994). This phenomenon is not necessarily expressed in standardised shapes and sizes, but in allometry and in the relative homogeneous phasing of production and reduction techniques applied and in the methods employed in tool manufacture (Iovita, 2010; Jöris, 2001; Uthmeier, 2016). Backed bifacial knives (*Keilmesser*) represent the best-studied examples of such standardised LMP tool categories (Krukowski, 1939–1948; Chmielewski, 1969; Veil et al., 1994; Jöris, 2001, 2012; Richter, 1997; Pastoors, 2001; Ruebens, 2013; Frick et al., 2017; Frick & Herkert, 2020; Iovita, 2010; Delpiano & Uthmeier, 2020; Weiss, 2020; Wiśniewski et al., 2020). *Keilmesser* appear in the central European LMP from OIS 5c (?) on, like in the Weichselian layers of NN2/0 (Richter & Krbetschek, 2014; Strahl et al., 2010) or in the upper part of the “Lower Layers sequence” at Sesselfelsgrotte (Weißmüller, 1995), and they are found frequently at sites until the first half of OIS 3 (until ~ 50 ka). Typically, these knives represent bifacially shaped asymmetric tools with a single acute edge and a natural or roughly/crudly worked back (Jöris, 2006, 2012). Maintenance of the sharp edge was the key (Iovita, 2010, 2014; Jöris, 2001; Weiss, 2020). Detailed technological analysis from central European KMG sites, e.g. Buhlen III (Jöris, 2001), Ciemna (Krukowski, 1939–1948; Urbanowski, 2003; Alex et al., 2017), Lichtenberg I (Veil et al., 1994; Weiss, 2020) or the G-layer complex at Sesselfelsgrotte (Delpiano & Uthmeier, 2020; Richter, 1997), has documented that considerable attention was paid to the long-term maintenance of tool usability through different and often (even recurrently) repeated phases of reduction and resharpening, resulting in significant morphological transformations in shape and size. Experimental series have been provided in full support of these observations (Migal & Urbanowski, 2006). In addition to the above-mentioned case studies, other important assemblages with high amounts of backed bifacial knives are Bockstein III (Wetzel & Bosinski, 1969), Klausennische (Bosinski, 1967), Schambach (Rieder, 1992), Abri I am Schulerloch (Böhner, 2009), Wylotne Rockshelter (Kozłowski, 2006), Piekary III (Tomaszewski, 2004), Pietraszyn 49a (Wiśniewski et al., 2019) and Zwoleń (Schild, 2005).

In order to facilitate such long tool use lives, the characteristic morphology of the backed bifacial knives combines a plano-convex cross section with a single acute edge opposite a back that was envisaged already during the selection of suitable raw material shapes and during the initial manufacturing phase of its roughing-out (e.g. Veil et al., 1994; Wiśniewski et al., 2020). Functional maintenance of tools for long-term usage demanded skilled control over the different reduction stages that had to follow a relatively strict sequence (Jöris, 2001). Nevertheless, technological flexibility (Frick & Herkert, 2020) to a certain degree allowed the tool’s function to be maintained even when compromises had to be made relating to raw material morphology and quality or when knapping accidents occurred.

Arguments have been forwarded that asymmetric backed bifacial knives were optimised for individual hand-preferences (Jöris, 2001, 2006). Given this, tool users most likely made their own tools. In consequence, it appears highly likely that some tools, such as these backed bifacial knives, may have also become personalised items (Jöris & Uomini, 2019). Long-term usage and maintenance, however, will only have worked in cases when the user/producer was familiar with the entire history of mistakes that occurred throughout the production and reduction process. Given this, it is the *Keilmesser* concept with its specific morphology, in combination with well-defined sequences of reduction, that was socially transmitted and learned within KMG social groups (Jöris & Uomini, 2019; Uthmeier, 2016) — perhaps best comparable to the highly standardised manufacture of MTA handaxes documented for western and southwestern Europe (cf. Soressi, 2002). Within the KMG, such "high standards" are especially apparent in assemblages characterised by the regular application of a specific mode of the removal of a lateral tranchet blow along the distal part of the acute active edge, the so-called Prądnik method which functioned to further enhance the edge angle (Krukowski, 1939–1948; Bosinski, 1969; Jöris, 1992, 2001; Frick & Herkert, 2020; Frick et al., 2017). The levels of skill required to actively execute the entire manufacture and reduction process required training and experience (Jöris & Uomini, 2019), as did the need to deal flexibly with all the unexpected occurrences resulting from the interplay between flaking, tool use and inherent raw material properties (Frick & Herkert, 2020; Frick et al., 2017).

The overall design of backed bifacial knives was therefore extremely important, requiring high levels of planning depth and anticipation, skill and experience (Fig. 3; for further literature, cf. Kuhn, 1992). However, items that were less elaborately produced and that do not display evidence of such long use life histories may have been made either by less experienced knappers (probably children or novices) or used in more opportunistic or expedient situations, as has been argued for on base of the Buhlen III KMG assemblage (Jöris & Uomini, 2019) and in case of the Balver Höhle material (Jöris & Schunk, 2022). From a functional perspective, backed scrapers could — in theory — easily substitute for backed bifacial knives — probably when long use lives were not required (Delpiano & Uthmeier, 2020). But the latter type of tools could also replace the former once they could not be used or resharpened any longer (Krukowski, 1939–1948). The open-air site of Pouch near Leipzig may serve as a further example of flexibly dealing with the *Keilmesser* concept. The site is characterised by abundant high quality and large-sized raw materials, focussing on flake production. A high amount of large, naturally backed flakes has served as blanks for unifacial backed knives (Weiss, 2015; Weiss et al., 2018).

KMG assemblages are distributed widely from the eastern part of Western Europe across central to Eastern Europe, from which a large number of sites are known. It seems that these sites represent groups with high levels of shared concepts of tool design, production and maintenance that were quite different from the concepts that were employed in other regions (Jöris, 2004; Uthmeier, 2016). The recent discovery of *Keilmesser* even further to the east at Chagyrskaya Cave in southern

Siberia (Kolobova et al., 2020) has been interpreted as resulting from LMP population niche expansions towards that region (cf. Picin et al., 2020).

At the present stage of research, however, the central European KMG record is spatially and chronologically discontinuous (Jöris, 2004), and the relation of KMG sites to sites that are predominantly characterised by unifacial tools (Richter, 1997, 2001, 2012) is still poorly understood. A high-resolution view inside the complex composition of LMP assemblage variability was offered by the G-layers-complex of Sesselfelsgrotte, where almost all assemblages analysed were both stratigraphically and spatially constrained as they derive from single concentrations that were spatially closely related to fireplaces. The presence of MP unifacial ("Mousterian") tools associated with Quina and Levallois concepts of core reduction with only few bifacial tools (including some *Keilmesser*) on the one hand, and more-or-less contemporaneous assemblages using the same core reduction concepts, but showing high frequencies of ("Micoquian") bifacial tools on the other, led Richer to argue that the two assemblage types reflect facies of the same industry which he therefore termed "Mousterian with Micoque Option" (M.M.O.) (Richter, 1997, 2016). Whereas even technical details, such as the ventral thinning of side scrapers (i.e. turning them semi-bifacial), occur in both types of assemblages, they differ in the intensity of tool use and raw material procurement strategies. In the underlying conceptual and explanatory model, under certain conditions (i.e. duration of occupation, etc.: Richter, 2001, 2016), the bifacial "Micoquian"/KMG tool component adds to a "Mousterien"-like assemblage but is not necessarily among the discarded part of the initial tool kit when a locale was occupied for short time only. At first glance, the idea that bifacial tools were added to the tool kit after an extended time of occupation of a site seems to contradict the evidence that backed bifacial knives were designed to have a long use life making them perfect for flexible use during periods of high mobility (Jöris, 2001). The Buhlen III case, for example, shows not only that exogenous raw materials are quite rare, but also that almost all exogenous materials are represented by resharpening flakes and lateral tranchet blows, whereas the backed bifacial knives made of these exogenous materials were transported away from the locality. To explain the findings from Sesselfelsgrotte, one may assume that bifacial tools were among the longest-lasting elements of the mobile tool-kit, which almost certainly resulted in a discard pattern that strongly relates to the individual tool's degree of wear and, therefore, to being-out-of-phase with most of the unifacially retouched lithic equipment. Consequently, this model explains some very ephemeral ("initial") assemblages of Sesselfelsgrotte that already contain strongly reduced bifacial tools (Richter, 1997, 206–207), whereas the likelihood of exhaustion of bifacial tools (and their discard) increases when the time spent at the site approached the maximal use life of these items.

Site-specific interpretations, forwarded for assemblages from locales such as Lichtenberg I, viewed as ephemeral in nature and characterised by a relatively high number of bifacial tool forms, suggest that they represent palimpsests of activities either under raw material constraints (use of imported bifacial tools) or potentially distant to possible base camps. The KMG assemblage of Lichtenberg I probably exemplifies the spatio-temporal dynamics of lithic tool production that could have started at almost all types of locales, interrupted by relocations in the landscape before their manufacturing process was completed or when a tool had reached the end of its potential use life, highlighting the “fragmented character” or “nature” of MP lithic assemblages (Turq et al., 2013). Therefore, we must consider the continuing transport of half-products or initial, ready-made prepared cores or tools parallel to those already being in active use.

This picture is further complicated by the occasional presence of other tools in “Micoquian”/KMG contexts that also appear to be fairly standardised in size and shape and that are characterised by their coin-like morphology entirely different from the shape of other MP retouched forms: the Groszaki. These (singular: Groszak; cf. Krukowski, 1939–1948) are small, about 1–2 cm in diameter, regular round and thin flakes that are most often retouched around their entire perimeter. In most cases, retouch is rather marginal but may be located on the dorsal or the ventral face of the blank or even on both (Kozłowski & Kozłowski, 1977). Only a few assemblages have so far produced Groszaki, among them Okiennik Cave in Poland, Kůlna in the Czech Republic or the sites of Heidenschmiede (Çep et al., 2021), Hohler Stein near Schambach and Sesselfelsgrotte in southern Germany (Hillgruber, 2006). Of particular note is a small series of 67 Groszaki that were unearthed during the 1997 and 2000 excavations in the Neander Valley (Hillgruber, 2006). Although the items derive from the redeposited cave sediments of the Kleine Feldhofer Grotte — the Neanderthal type site — convincing arguments were forwarded (Feine, 2006; Schmitz, 2006) that this series formed part of a MP assemblage characterised by MP blank production that contains backed bifacial knives, fragments of other bifacial tools and scrapers of different shapes (Hillgruber, 2006). Interestingly, the Kleine Feldhofer Grotte Groszaki are made predominantly from more homogenous flint varieties, whereas a larger proportion of the larger MP artefacts, especially the bifacial ones, is additionally made of quartzites (Feine & Hillgruber, 2006), highlighting the potential relevance of site-specific and especially functional aspects for understanding MP assemblage variability. The Groszaki made of exogenous raw materials highlight that they were essential parts of a mobile tool kit (cf. Richter, 1997).

Whether or not unifacial “Mousterian” LMP assemblages are to be seen as entities different from bifacial “Micoquian”/KMG assemblages (cf. Kozłowski, 2014), the entire later phase of the LMP (l-LMP: i.e. ca. 95–85 ka until ~ 50 ka) or M.M.O. of central Europe reflects entirely different modes of blank production, tool manufacture and maintenance than are reflected in the lithic assemblages of the preceding earlier part of the LMP (e-LMP). The highly standardised *Keilmesser* production and maintenance concept documented over a lengthy period of time and at many sites in an extensive region of Europe may be interpreted in favour of well-recognizable RCS, implying the establishment of modes of social transmission of technical knowledge and the training of skills that in the end result in specific spatio-temporal traditions (Jöris, 2004; Ruebens, 2013; Uthmeier, 2016). During the following millennia, such developments became increasingly fine-grained, both in geographical and in temporal scales.

Transitional Developments Towards the Initial and Early Upper Palaeolithic

Given the discontinuous sedimentary sequences of central Europe, the mid-OIS 3 FMP that succeeded the KMG assemblages between 55/50 and ~ 45 ka are poorly documented. It is marked by a notable decline in the frequencies of bifacial tools (e.g. Sesselfelsgrotte E3: Böhner, 2009; cf. Conard et al., 2019). In central Europe, it appears that sequences in caves and rockshelters are often truncated at around this time (e.g. unconformity following layer 6a at Kůlna Cave; erosional channels following level E3 at Sesselfelsgrotte) and/or that occupational gaps have been noted, as for example at Geißenklösterle GH 17 (Richard et al., 2019). Occasionally, however, open-air sites from this period have preserved well in the loess archives of eastern central Europe, for example in the area around Kraków, at Kraków-Zwierzyniec I, sector P (Chmielewski et al., 1977; Madeyska, 2006) and Piekary IIa, layers 7b-7a (Sitlivy et al., 2008; Valladas et al., 2008; cf. Valde-Nowak & Łanczont, 2021). The latter two sites have produced assemblages that are characterised by Levallois and uni- as well as bi-directional blade production technologies. These assemblages lack bifacial tools entirely, but stratigraphically succeed a KMG assemblage (Piekary IIa: layer 7c[2]). Similarly, in western central Europe, the Buhlen II assemblage succeeds stratigraphically the KMG inventory of Buhlen III and is characterised by Levallois concepts of predominantly uni-directional or bi-directional reduction targeted at the production of elongated, laminar blanks, in addition to the occasional production of Levallois points. Depending on the morphology of the relatively volumetric and angular raw material blocks often used at the site, however, knapping strategies were flexibly adjusted. Retouched items are dominated by single or double side-scrapers (often marginally retouched), transversal scrapers and some end-scrapers, while pointed tools are comparably rare (Jöris, 2001). Similar flexibility in blank production is evident at layer III of the Księcia Józefa site in Kraków. Here, the reduction of globular flint nodules often resulted in the adoption of polyhedral reduction strategies dominated by not only uni- and bi-directional organisation, but also orthogonal and discoidal reduction. Occasionally Levallois reduction is also present, including the production of Levallois points. The restricted spectrum of retouched forms resembles Buhlen II, while marginally retouched items sometimes appear to be backed (Sitlivy & Zięba, 2006; Sitlivy et al., 2009, 2014).

In some regions, such re-occurrences of Levallois technology close to the end of the MP (i.e. FMP) have frequently been subsumed under the term "Levallois-Mousterian" to which few other sites of central Europe (e.g. Achenheim, layer 14; Balve IVb) may be ascribed (Bosinski, 2008) and which — to some degree — resemble assemblages from other regions dating close to the end of the MP (Fig. 1b). For example, comparable sites or industries are reported from Western Europe (Slimak, 2008) and south of the Alps (Peresani, 2012), from Eastern Europe (e.g. Korolevo I, complex 2b: Demidenko & Usik, 1993; for an overview: Sitlivy & Zięba, 2006) or from the Levant (e.g. Abadi et al., 2020; Hauck, 2011; Nishiaki et al., 2012), where they are associated with both Neanderthals and AMH (e.g. Bar-Yosef & Meignen, 2001; cf. Shea, 2014).

Roughly dating to the interval 48–38 ka cal BP, the MP to UP transition in central Europe reveals a complex mosaic of several techno-complexes that overlap geographically and chronologically. This is the period in which AMH reached central Europe and probably met with Neanderthal populations (cf. Hublin et al., 2020; Fewlass et al., 2020). Due to remaining chronological problems (Jöris & Street, 2008) and to the scarcity of hominin remains from this period (Kuzmin, 2021; Prüfer et al., 2021), the question of authorship of the different techno-complexes remains largely unanswered (Hublin, 2015; cf. Hajdinjak et al., 2021). As a result of such uncertainties, different models for the interpretation of the techno-typological developments during this time interval have been forwarded, all based on the interpretation of the cultural (archaeological) record (e.g. d'Errico et al., 1998, Nigst, 2012; Tostevin, 2012; Neruda & Nerudová, 2013; cf. Neruda, 2021).

In central Europe, the FMP trend towards the production of more laminar Levallois products including (few) Levallois points visible at Buhlen II and at sites from Eastern Europe (Sitlivy & Zięba, 2006) contrasts with the blank production strategies of the Bohunician of southern Moravia that is characterised by a more pronounced focus on the removal of regular blades (Fig. 1c). To achieve high frequencies of blades produced in series, both Levallois-like prepared cores, usually reduced bi-directionally from opposed platforms (to obtain Levallois-like blades and points), and volumetric cores with parallel production (to obtain blades) were employed. Depending on the raw material and the stage of reduction, discarded cores can be sub-prismatic, prismatic or bifacially flat (resembling Levallois-like production) and, with regard to the direction of the target products, uni- and bidirectionally reduced. The individual reduction sequences are similarly variable, which may start with a prepared and extracted crest, although they end in the form of Levallois-like cores used for the production of points (Sitlivy & Zięba, 2006; Svoboda, 1990; Svoboda & Škrdla, 1995; Valoch et al., 2000). The marked variability in the preparation and reduction of cores is associated with some UP tool types such as end-scrapers that are frequent elements in Bohunician assemblages. Most authors consider the Bohunician laminar technology as being intrusive to the region, due to the technological similarities between Brno-Bohunice and the transitional industry of Boker Tachtit, level 1, which was recognised first by Karel Valoch (Valoch, 1986; cf. Valoch, 2008), and by the more recent comparisons of the Bohunician assemblages of Stránská skála III, IIIa Layer 4, and IIIc (Svoboda & Škrdla, 1995) with level 2 of Boker Tachtit (Škrdla, 2003). These inventories do display not only unidirectional concepts, but also bi-directional blank production realised in some nodules, involving the preparation of crested blades and — in both cases — the frequent removal of core tablets (Škrdla, 2003). To a certain degree, these concepts resemble the blade production strategies described above for some western European e-LMP assemblages (cf. Valoch et al., 2000, 2009).

On the basis of thermoluminescence dating, the Bohunician-type locality, Brno-Bohunice I, can be placed between ~ 50/49 and 47 ka, whereas calibrated radiocarbon dates from the Bohunician layers at Stránská skála (III, IIIc and IIId) range around ~ 45/44–39 ka cal BP (Richter et al., 2008, 2009; cf. Škrdla, 2017a). These age-estimates are in agreement with stratigraphic observations that place the

Bohunician into two succeeding interstadial soils that probably correspond to GI 12 and GI 11/10 (cf. Škrdla, 2017a; cf. Figure 2).

In the Brno-Bohunice I lithic assemblage and at some further sites assigned to the Bohunician, the presence of bifacially worked leaf points, seen as characteristic of the Szeletian (cf. discussion in: Mester, 2021), is of interest (Svoboda et al., 1996b; see also Oliva, 2021). Pedostratigraphically, at Vedrovice V, the Szeletian is found in the lower of these palaeosols (Valoch, 1993) and must therefore be considered as roughly contemporaneous with Brno-Bohunice and other Bohunician assemblages within the lower palaeosol (Valoch, 2012; Nejman et al., 2011; cf. Škrdla, 2017a). Also, the Vedrovice V assemblage contains end-scrapers on blanks that converge distally towards the scraper tip and Aurignacian-like end-scrapers, as found in some Bohunician assemblages (cf. Svoboda et al., 1996b). Taking into account the presence of industries with a combination of leaf points and Levallois products in the contact zone between the Bohunician and the Szeletian, and the analogous dates for both techno-complexes, all indicate a significant chronological and spatial overlap between these two kinds of assemblages.

At Vedrovice V and at Moravský Krumlov IV, layer 0, foliate tools — especially the more symmetrical leaf points — are overwhelmingly made on elongated flakes, tabular thin raw material plaquettes or fragments of pebbles, but are more or less completely bifacially shaped and refined (e.g. Neruda & Nerudová, 2019; Valoch, 1993). Semi-bifacially worked blade points (sensu Jacobi et al., 2007) are lacking in Moravský Krumlov IV, but they are present in almost all Szeletian assemblages (e.g. Oliva, 1991; Vedrovice V: Valoch, 1993; Želešice III: Škrdla, 2017b). Regionally, variable production methods are demonstrated by leaf points, e.g. from the eponymous site of Szeleta Cave (Mester, 2010). Bifacial leaf point production is characteristic of sites assigned to the Szeletian of eastern central Europe (Prošek, 1953; cf. Allsworth-Jones, 1986, 1990, 2004) and the *Altmühl-* or *Blattspitzengruppe(n)* of western central Europe (Bosinski, 1967; cf. Bolus, 2004; Richter, 2009). Even though the stratigraphic integrity of the Szeletian at the eponymous site has been questioned due to the early commencement of fieldwork at the locality (Lengyel & Mester, 2008), new radiocarbon dates from remnant deposits in the Szeleta Cave and a review of other dated Szeletian assemblages place this industry at ~ 44–40 ka cal BP (Hauck et al., 2016; cf. Jöris & Street, 2008).

Based on technological considerations, notably the method of thinning bifacial leaf points, the Szeletian/*Blattspitzengruppen* seem to have developed autochthonously within central Europe (Fig. 2; cf. Kozłowski, 2021) from preceding l-LMP bifacial industries (a.k.a. KMG/ "Micoquian": cf. Neruda & Nerudová, 2010, 2013; Jöris, 2004; Bosinski, 1967; or — though poorly defined and dated — a.k.a. Jankovician: Gábori-Csánk, 1990) that often contain leaf point-like foliate bifacial tools in variable (but usually small) numbers (Uthmeier, 2004; Hopkinson, 2007; cf. Wetzel & Bosinski, 1969; Valoch, 1988; Jöris, 2001; cf. Rots et al., 2021, for a single leaf point in a non-KMG/ "Micoquian" context). Another aspect that possibly connects the KMG/"Micoquian" and the Szeletian/*Blattspitzengruppen* is the presence of a lateral back opposed to a single active cutting edge on some of the foliate bifaces, which led to the identification of "leaf-shaped knives" (Kot, 2016), or "leaf knives", especially at the well-known *Blatspitzengruppen* site of the Weinberghöhlen Cave near Mauern (Kot & Richter, 2012). The "leaf knives" from Mauern exhibit an unusual bottom-top–bottom-top sequence to produce the plano-convex cross sections, which closely resemble the *wechselseitig-gleichgerichtete Kantenbearbeitung* described by Gerhard Bosinski (1967) for the "Micoquian", in so far as not the surfaces were subsequently flaked, but the lateral edges one after another. These similarities, the occurrence of leaf points in the l-LMP and — vice versa — the association of bifacial leaf points with MP blank production and tool spectra in assemblages of the southern German *Blattspitzengruppen*, have provoked the interpretation that the latter may reflect a special task camp facies of the regional l-LMP (Uthmeier, 2000, 2004). The high degree of techno-typological similarity between l-LMP assemblages with bifacial tools and the *Blattspitzengruppen* in that region has already been recognised by Hansjürgen Müller-Beck (Müller-Beck 1974; cf. Uthmeier, 2004). A potential temporal gap between the youngest securely dated bifacial l-LMP KMG/ "Micoquian" assemblages ~ 50 ka (or shortly thereafter; cf. Alex et al., 2017) and the beginning of the Szeletian should, however, be revisited, since the available radiometric dates have been obtained using different methods and protocols which hamper fine-chronological comparisons. Another yet not resolved question concerns the relation between the Early Szeletian represented, for example, by assemblages from Vedrovice V and Moravský Krumlov IV, layer 0, and the Late Szeletian of Moravany-Dlhá type which postdates the Campagnian Ignimbrite eruption at ~ 40 ka and the succeeding Greenland Stadial (GS) 9 or Heinrich 4 cold interval (cf. Kaminská et al., 2011; Oliva, 1991).

Transitional assemblages that are characterised by (Jerzmanowice-type) blade points, i.e. elongated semi-bifacially surface-retouched broad blades that were pointed at both ends by application of flat retouch (Jacobi, 1990; Jacobi et al., 2007), resulting in elongated ovate shapes (Wiśniewski et al., 2022), should probably be separated from the Szeletian (*sensu stricto*). Among the more intensively retouched Jerzmanowician blade points, retouch is most regularly located on the ventral face at both ends, probably in order to reduce the blank's longitudinal curvature. An extensive study of such points has recently argued that they were primarily used as hunting weapons (Wiśniewski et al., 2022). In the Nietoperzowa Cave sequence at Jerzmanowice (Chmielewski, 1961), a large portion of these points displays concepts of uni-directional blade production, whereas the majority of the blanks have been struck from bi-directional opposed-platform cores (Flas, 2011). Such assemblages, generally subsumed under the term Lincombian-Ranisian-Jerzmanowician (LRJ; cf. Figure 2), are dispersed across the northern European lowlands from southern Poland to northwestern Europe (Fig. 1c; cf. Flas, 2008, 2011), dating roughly to 44–41 ka cal BP (Cooper et al., 2012; Flas, 2011), but are possibly as young as 39–36 ka cal BP (Kot et al., 2021). New dates from the Nietoperzowa sequence confirm age estimates of 44–42 ka cal BP for the lower boundary of the LRJ at the site, but may also indicate LRJ continuation until ~ 31–30 ka cal BP (Krajcarz et al., 2018) — temporally overlapping with the Aurignacian and early Gravettian.

On technological grounds, with regard to UP-"style" laminar blank production, such blade point assemblages are mostly classified as Early Upper Palaeolithic (EUP) (Jacobi et al., 2007). Based on the current state of research, however, and inferred from anthropological, archaeological and chronological data from the Spy

Cave in Belgium, Jerzmanowician blade points may be associated with Neanderthal fossil remains (Semal et al., 2009). As a result, Flas (2008, 2011, 2012) interprets LRJ blade production technology as a local development of Neanderthal authorship, as it differs technologically from the predominant uni-directional Aurignacian blade production of the subsequent EUP made by AMH. The Spy Neanderthals date as young as ca. 36,000 ^{14}C (uncal) BP (Semal et al., 2009), roughly corresponding to 41 ka cal BP (cf. Reimer et al., 2020). An additional argument in favour of associating the Neanderthals with the LRJ is the occasional presence of small numbers of bifacial leaf points in some LRJ assemblages (e.g. Jacobi et al., 2007). Vice versa, some stratified Szeletian sites (e.g. Vedrovice V and Želešici III: Škrdla, 2017b) include small numbers of Jerzmanowician blade points that add to the numerous bifacial leaf points. In this regard, the presence of Jerzmanowician blade points at the recently excavated site of Líšeň I/Podolí with Bohunician techno-typological features and personal ornaments dated to ~ 44 to 39 ka cal BP (Škrdla, 2017b, 95–110) complicates the overall mosaic picture. However, the most recent analyses assign the Líšeň I/Podolí and Zelešice III assemblages to the Jerzmanowician (Demidenko & Škrdla, 2020). Finally, however, due to a lack of human fossil remains undoubtedly associated with the LRJ, the question of "who made the LRJ" still remains open.

At Ilsenhöhle in Ranis (Hülle, 1977), fully bifacially worked leaf points appear in large numbers associated with Jerzmanowician blade points, amounting in total to about half of the Ranis 2 point assemblage. This high proportion of fully bifacially worked points is rather uncommon for LRJ assemblages. The Nietoperzowa assemblage, for example, contains only a single fully bifacially worked blade point. Here the tool spectrum is dominated by typical Jerzmanowician blade points made from local Jurassic flint and non-local raw materials such as Turonian flint, chocolate flint or radiolarite. Some of the tools were transported from distances of up to ~ 160 km (Chmielewski, 1961). Long-distance raw material transport is also visible at Ranis 2, where two fragments of bifacially worked points made from Jurassic chert (Hülle, 1977) that potentially originates from the Baiersdorf outcrops (Weber, 1990) near the confluence of the Altmühl and the Danube rivers, some 230 km to the south (Fig. 1c). Despite some fragments made of quartzite, all the other bifacial leaf points, as well as the Jerzmanowician blade points, where manufactured on erratic Baltic Flint that was imported from distances of at least 40–60 km to the north (Weber, 1990). If one attempts to strictly separate the "Szeletian-like" fully bifacially worked leaf points, which arguably originate from the l-LMP of central Europe and which, therefore, were most likely made by Neanderthals (see above; cf. Flas, 2012; cf. Stapert et al., 2021, for further discussion), from the LRJ-type Jerzmanowician blade points, one may interpret the Ranis 2 assemblage as a palimpsest of occupations of both the *Blattspitzengruppen* of southern central Europe and the LRJ blade point techno-complex from the north (cf. Richter, 2009). Additional support for this interpretation is the fact that some of the bifacial leaf points from Ranis 2 are slightly asymmetrical and sometimes display notches on the tool edges (Hülle, 1977), by which they strikingly resemble techno-morphological characteristics of some *Blattspitzengruppen* "leaf knives" from the Weinberghöhlen Cave (see above). Some of the bifacial points made on Jurassic chert that most likely originated from the Altmühl Valley further south support the technological ties of the Ranis 2 bifacial point component to the southern German *Blattspitzengruppen*. Unfortunately, the stratigraphic data available for the site do not allow the fine resolution required in order to test such a hypothesis (Hülle, 1977).

More generally, one may argue that the major differences between the two technocomplexes may relate to a combination of certain aspects of the quality (in terms of size and shape) of the available raw materials. In southern central Europe, smaller and sometimes tabular raw materials were generally used, large and broad laminar blanks were difficult to produce and leaf points needed to be manufactured as large and completely surface-shaped bifacial tools, often on thin plaquettes. In the northern European lowlands, by contrast, the abundance of flint nodules of large volume enabled the production of blades long and broad enough to serve as blanks for the production of Jerzmanowician blade points. However, the sporadic presence of locally produced Jerzmanowician blade points in southern Germany, as, for example, at Oberneder Höhle (Freund, 1987), Gremsdorf (Beck et al., 2017), Zwergloch (Freund, 1963) and Kirchberghöhle/Schmähingen (Uthmeier et al., 2018), underlines the ability of the makers of Jerzmanowician points to cope with the different regional raw materials.

Leaf and Blade Points in the Central European Aurignacian?

With the Evolved to Late Aurignacian (for definition cf. Teyssandier & Zilhão, 2018), between roughly 38 and 34 ka cal BP, AMH appear to have established viable populations all over Europe (e.g. Kuzmin, 2021 and references therein; cf. Schmidt & Zimmermann, 2019; Shao et al., 2021a, b). This is reflected — on a pan-European scale — in the Aurignacian material record which appears entirely different compared to that of preceding periods, and which is characterised by its fully UP lithic technology and tool kit, dominated by specific types of bladelets, end-scrapers and burins and laterally retouched Aurignacian blades. Blades are produced predominantly uni-directionally from volumetric cores. From a technological point of view, most characteristic is the appearance of new concepts of bladelet production (cf. papers in: Le Brun-Ricalens, 2005, 2006), exploiting "specialised bladelet cores" (Teyssandier & Zilhão, 2018, 111: e.g. nosed or carinated "scrapers" or busked "burins"). In addition, a radiation of organic artefacts (e.g. Doyon, 2020) and of personal ornaments (e.g. Vanhaeren & d'Errico, 2006) is observed in the Aurignacian across the continent. Evidence of figurative art and music adds to this record (Floss & Rouquerol, 2007) — considered to be milestones in human cognitive and behavioural evolution — whereas the timing of their earliest appearance within the Aurignacian chronology is still debated (e.g. Higham et al., 2012; Jöris & Street, 2008; Jöris et al., 2011; Teyssandier & Zilhão, 2018).

The most relevant sites in the discussion of the earliest Aurignacian in central Europe are Willendorf II in the Wachau, Austria (Nigst, 2012; Nigst et al., 2014; cf. discussion in: Teyssandier & Zilhão, 2018) and Geißenklösterle in the Swabian Jura (Higham et al., 2012), located in the Middle and Upper Danube regions, respectively (Fig. 1c). Both sites provided oldest age estimates for Aurignacian layers > 38 ka cal BP, reaching back to ca. 43/42 ka cal BP. As such, they overlap chronologically with the so-called Protoaurignacian (for definition cf. Teyssandier & Zilhão, 2018) which is older than ~ 40 ka cal BP and stratigraphically precedes the Early Aurignacian in other parts of Europe, where it dates into GS 9, i.e. roughly into the time interval 40–38 ka cal BP (Banks et al., 2013). In central Europe, the Protoaurignacian is potentially represented at Krems-Hundsteig in Austria (Hahn, 1977; cf. Banks et al., 2013). More recent comparative studies, however, conclude that the emphasis on a strict distinction between Protoaurignacian and Early Aurignacian assemblages over the past decades has blurred the large amount of techno-typological similarities between the two assemblage types and highlights that the two are much more alike than previously thought (Bataille et al., 2018; Falcucci et al., 2017). The remarkable supra-regional pan-European "homogeneity" of the Aurignacian noted above is probably best explained by a model of information and knowledge transmission on multiple lines and levels, enhancing the spread of inventions and innovations through multiple levels of local, regional and supra-regional interconnectedness of individuals and groups (cf. Bataille et al., 2018).

Whereas this interpretation is in favour of an inner-Aurignacian "continuity", implying that AMH have also been the makers of the Proto-/Early Aurignacian, within the different parts of Europe significant differences are to be noted for the earliest appearance of Aurignacian assemblages. Whereas most of the southern German Aurignacian sites (Conard & Bolus, 2003; Higham et al., 2012), Willendorf (Haesarts & Teyssandier, 2003; Nigst et al., 2014) and Krems-Hundsteig (Neugebauer-Maresch, 2008), along the Danube, are, as discussed above, of an early age, the Moravian (e.g. Neruda, 2021) and Polish (discussion in: Kot et al., 2021) Aurignacian appears to date slightly younger. In these regions, it does not start earlier than 40–38 ka cal BP and 36 ka cal BP, respectively. Given such regional differences, in the interval ~ 43/42–36 ka cal BP, the Aurignacian of central Europe chronologically overlaps with techno-complexes of the MP to UP transitional period and those of the IUP and early EUP already presented above, i.e. the Bohunician as well as the leaf and blade point assemblages of the Szeletian/*Blattspitzengruppen* and the LRJ (e.g. Hauck et al., 2016; Neruda, 2021; Richter, 2009). From a stratigraphical point of view, it is important to emphasise that Bohunician assemblages at Stránská skála IIa, IIIa and IIIb are superimposed by Aurignacian ones (Svoboda & Bar-Yosef, 2003). The statistical probabilities of potential chronological overlaps of the Aurignacian with "Micoquian"/M.M.O. assemblages are minor (cf. Neruda, 2021; Richter, 2001) and should be excluded on the basis of the present dating evidence.

Regarding their assemblage composition, Aurignacian assemblages with leaf or blade points have been discussed as either representing a specialised site functional facies or as giving evidence for their roots in the preceding Szeletian, with the latter interpretation implying a certain regional continuity since the l-LMP. Although leaf points cannot be seen as Szeletian type fossils (Mester, 2021), the relationship between the Szeletian and the Aurignacian has been debated, as quite a number of central European Aurignacian sites indeed contain leaf points. In this context, some authors have argued that the Szeletian would rather represent an activity-related facies of the Aurignacian than an entity of its own (Ashton, 1983; Adams, 2007, 2009: "Aurignacian with leaf points"; cf. Oliva, 1990, 2017). In Moravia, however, leaf points have never been documented in stratified Aurignacian contexts, but derive from surface sites where they are associated within Aurignacian lithic find clusters (Oliva, 2017; Škrdla, 2016). At several Aurignacian sites, leaf points are made of raw materials different from the major part of the assemblage (Hopkinson, 2007; Oliva, 2017). Few "Aurignacian elements" found at the Szeletian open-air site Lubotyń 11 in Silesia, dated to between 49 and 39 ka (Bobak et al., 2013; Połtowicz-Bobak et al., 2013), are best explained as the result of palimpsests of different occupations at the same locale. The mixed character is indicated not only by new technological and typological analyses but also by the wide scatter of dating results, with the youngest dates most likely reflecting short-term ephemeral activities some 10,000 years later during the Aurignacian (Bobak et al., 2016). Summing up this evidence, one would have to assume that leaf points in *unstratified* Aurignacian contexts would be best explained as intrusive from earlier occupations at the same locale and not as evidence for the potential persistence of traditions that root in the transitional techno-complexes that are characterised by leaf points. This seems to similarly account for the presence of blade points in Aurignacian contexts, as had been reported for the Belgium site of Spy: Recent studies of the context of the Jerzmanowician blade points found here have emphasised the recognition of the LRJ as an entity of its own, pre-dating the Aurignacian (Flas, 2012; Semal et al., 2009).

The appearance of leaf or blade points in other, potentially even younger assemblages is of further relevance in the context of this discussion. Unifacial blade points appear in the Ranis 3 assemblage of the Ilsenhöhle site (Hülle, 1977), yet still undated, but stratigraphically above and separated by a sterile layer from the Ranis 2 LRJ assemblage. Besides the blade points mentioned, the assemblage consists of blades, pointed blades and end-scrapers, all made of Baltic Flint. In this regard, also the lithic assemblage from layer 12 (and 13) at Kraków–Zwierzyniec is of interest here, as it comprises both bifacial leaf points as well as arch-backed points made on regular laminar blanks together with burins that resemble Aurignacian types (Kozłowski, 2000; Kozłowski & Sachse-Kozłowska, 1975; Stefański, 2018). Based on pedostratigraphic correlations (Komorniki or L1S1 pedocomplex), the site has been assigned to the period ~ 40–35 ka — an age-estimate that would be in agreement with the presence of leaf points at the site and with the similarities of the arch-backed points that resemble Uluzzian types, which — when well-stratified — pre-date the Campagnian Ignimbrite eruption almost 40 ka ago (Jöris & Street, 2008; Jöris et al., 2011). Detailed microscopic analyses, however, have shown that both find categories had undergone different postsedimentary alterations, implying that the leaf points at Kraków–Zwierzyniec would pre-date the arch-backed point assemblage. Based on the stated similarities of the arch-backed points with Uluzzian artefacts and the regular laminar blank production at the site, Kozłowski (2000) argues that this "Zwierzyniecian" industry may have developed from late "Mousterian" contexts. Similar arch-backed points have also been recognised in the Obłazowa and Mamutowa Caves (Stefański, 2018). But the chronology of Kraków–Zwierzyniec remains problematic, as direct dates are lacking and as the find-bearing layers most likely represent only the upper part (loess L1-l2 and soil L1-s1 on its top) of the L1S1 pedocomplex (see Moska et al., 2018; cf. Valde-Nowak & Łanczont, 2021) for which age-estimates in the range of ~ 34–33 ka have been established (Moska et al., 2018), i.e. somewhat younger than the "Lohne soil" of Western central

Europe (cf. Antoine et al., 2009) which corresponds to ~ GI 8–7, some 38–35 ka ago (Prud'homme et al., 2022).

Of comparably young age is the transitional industry of Remagen-Schwalbenberg (cf. App et al., 1995), located near the confluence of the Ahr River into the Rhine. The Schwalbenberg assemblage represents an ephemeral occupation around a single hearth and is characterised by the direct stratigraphic and spatial association of tools usually assigned to the UP, like burins, splintered pieces and a few end-scrapers, with a series of side scrapers that are commonly found in MP contexts (cf. App et al., 1995). Two bifacial tools or tool fragments have been interpreted as half-fabricated leaf points, whereas bladelets are absent. Blank production is based on irregular and Levallois flake production as well as bi-directional laminar production. Most noteworthy is that the age of the Schwalbenberg assemblage is well-fixed through the embedding of the archaeological horizon in a long, high-resolution loess–palaeosol sequence (Fischer et al., 2021), dated by OSL and numerous radiocarbon measurements on earthworm calcite granules (Prud'homme et al., 2022) to ~ 33.5 ka cal BP, i.e. GI 6, near the transition of the Aurignacian to the Gravettian (cf. Jöris et al., 2010).

The two assemblages from layer 12 at Kraków-Zwierzyniec and from the Schwalbenberg site give intriguingly evidence that the transition from the MP to the UP cannot be viewed as a simple or gradual replacement of earlier (Neanderthal) by later (AHM) technology and typology, but that the cultural changes observed around the transitional period were more mosaic-like than they would reflect a "turnover" in the material cultural record. Some MP traits would have locally persisted until the end of the Aurignacian (cf. Uthmeier, 2004), also showing how poorly understood the socio-cultural changes from the MP to UP transitional period until the Aurignacian to Gravettian transition still remain today.

Discussion

The central European LMP/FMP does not display a clear chronological sequence of techno-complexes that can be interpreted in terms of a well-defined cultural succession as is recognised for the UP in different regions of Europe. On the contrary, the record is characterised by high levels of assemblage diversity. To a certain degree, the difficulty recognising well-defined spatio-temporal patterns of RCS may relate to the poor amount of radiometric dates available for much of the period, especially that preceding ~ 50 ka, but the record is also heavily biased by its chronological discontinuities. Instead, LMP/FMP lithic assemblage variability in central Europe is probably best interpreted to a large degree in relation to subsistence-related factors and/or factors that relate immediately to individual knowledge, skill and/or experience (Fig. 3), combined with other individual factors such as hand-preference. Some case studies have highlighted the contribution of such factors that closely relate to individual competences and their influences on tool design and lithic assemblage variability (e.g. Jöris & Uomini, 2019). However, the impact of subsistence-related factors is most important for understanding lithic assemblage variability. Their influences largely stem from the access to resources, their distribution and use throughout the year: biotic factors that affect land-use strategies, mobility and seasonality and also abiotic ones such as raw material availability, quality, size and shape. The influence of the latter on lithic assemblage variability is surely the most direct, although some of these factors closely interplay with individual-related aspects, especially when they were confronted with low-quality raw materials and how the difficulties imposed by these were anticipated and overcome technically and through experience and skill. As such, the impact of subsistence-related influences on lithic assemblage variability strongly relates to the specificities of a certain site or locale, as has been extensively acknowledged in the discussions in the preceding sections. Other site-functional or task-related specificities or those related to the duration of an occupation will have added further to assemblage variability, often complicating our still rudimentary understanding of the differences between assemblages, even when they are more or less contemporaneous. Many of these problems relate to the fact that most assemblages represent palimpsests that resulted from repeated occupations at the same locale. In rare cases, it has been possible to disentangle short events within an occupation horizon from each other, through a combination of raw material studies and spatial information (Richter, 1997; Weißmüller, 1995). But at the greater majority of sites, such palimpsests cannot be deconstructed in similar manner. This is most problematic for inter-site comparisons, when these palimpsests are composed of the material remains of different types of activities and/or if different groups with different material culture visited the same locale within short time intervals.

Closely related but independent of these questions, the LMP/FMP to transitional period displays growing levels of standardisation in the conception of both blank production and tool manufacture, resulting in the much better recognition of RCS and in a more precise differentiation of distinct techno-complexes (Table 1). In contrast to flake production concepts, good examples of largely standardised blank production comprise the *chaînes opératoires* of blade production in the e-LMP furthest to the west or the production of Levallois-like points in the Bohunician. Examples of the standardised conception of tools gain momentum from the l-LMP onwards. They are apparent in the design of *Keilmesser* as well as in their reduction concepts, especially of those that are characterised by the “Prądnik” method application of lateral tranchet blows, furthermore in Szeletian leaf points, Jerzmanowician blade points and in the convergent end-scrapers of the Bohunician, to name but a few. Acknowledging the evidence of such elevated levels of standardisation within the lithic archaeological record and their increasing visibility towards the younger phases of the MP, it is best interpreted as an overprinting of tool design by conventions and standards that derived from social sets of rules and regulations which manifested in the material expression of traditions. This socio-cultural overprinting of lithic technology and tool design seems to have enhanced over time and can be interpreted as the result of socially learned strategies, concepts and conventions that were based on sets of rules and regulations that were transmitted supra-regionally at different spatial scales between closely interlinked individuals and groups and temporarily between generations within the same group. These key elements of the formation of traditions appear to have played an increasingly important role over time.

Against a background of such problems, and with regard to the polydimensonal network of factors that influenced lithic assemblage variability (Fig. 3), research over the past decades has perennially faced the question as to what degree lithic assemblages can be interpreted as reflecting the material cultural signatures of groups or individuals that shared (a) common set(s) of rules and regulations that may be interpreted in regard to the existence of a certain level of group identity and which were shaped through a persistence of social conventions over time, a.k.a. "traditions". With lithic assemblages, the potential existence of such levels of group identity of socio-culturally closely interconnected individuals may only be recognised for periods and regions when rather standardised *chaînes opératoires* were implemented, thus allowing a better-defined characterisation of techno-complexes.

Despite the large variability of lithic assemblages emphasised above, over the last decades, certain regional and chronological trends have become increasingly apparent in the Upper Pleistocene MP record of central Europe. One can broadly distinguish three different phases of the LMP/FMP, followed by different developments towards the UP (Table 1; Fig. 2), with:

(1) e-LMP sites dating into the Last Interglacial period and into early Last Glacial contexts, from ~ 130 ka to ca. 95–85 ka ago, being characterised either by blade production or by small-tool assemblages.
(2) Towards the end of the e-LMP, i.e. from around 95–85 ka, bifacial tools began to appear, gradually at first, but quickly becoming a defining feature of the central European l-LMP. Until ~ 50 ka, l-LMP assemblages were often comprised of backed bifacial knives, i.e. *Keilmesser* that define the KMG/"Micoquian". The highly standardised *Keilmesser* represent a phase of supra-regionally shared concepts of tool design, production and maintenance that differed to some degree from the concepts employed in other regions (see above; Jöris, 2004; Uthmeier, 2016), as is the case for the techno-morphologically different tool design in the MTA of western Europe (see above). These macro-regional differences between western and central Europe of virtually synchronous techno-complexes do not follow a strict "border", but a rather "fuzzy" one, as assemblages that closely resemble the KMG are also known from eastern France (Frick & Herkert, 2020; Frick et al., 2017; Herkert & Frick, 2020) and from the Abri des Musée site in the Dordogne (Bourguignon, 1992; Frick, 2020b), and, as noted above, a few western central European handaxe assemblages show similarities with the MTA (e.g. Bosinski, 2008; discussion in: Jöris, 2004; Ruebens, 2013). After ~ 50 ka, bifacial tools, especially *Keilmesser*, gradually disappear in central European assemblages. In the same time interval, however, several unifacial assemblages are known, and one of the key questions remaining in this context is whether the latter were made by groups different to those responsible for the former (Jöris, 2004). The concept of a "Mousterian with Micoque Option" (M.M.O.; Richter, 1997, 2016) would tend to explain the unifacial assemblages largely as short-term occupations or relating to a special function, to which bifacial tools would have been added the longer a locale would have been occupied.

(3) Succeeding this LMP are on the one hand assemblages known from few central European sites only that can be assigned to a Levallois-Mousterian-like FMP with Levallois and Levallois-like production of points and laminar/blade products.

In parallel to this FMP, from ~ 45 ka onwards, we observe on the other hand assemblages that are still characterised by bifacial tools which seem to have developed out of the preceding l-LMP. Now, however, leaf points characterise assemblages that are often subsumed under terms such as Szeletian and/or the *Altmühl*- or *Blattspitzengruppen*. These are most generally classified as "transitional" between the MP and the UP in terms of chronology as well as in terms of some technological aspects. In support of the technological argument and among other lines of evidence, we recognize a coarse-grained chronological trend towards increasingly thinner and more symmetrical bifaces that already began in the l-LMP. The succession started with the asymmetric backed bifacial knives and continued with the much thinner but slightly asymmetric "leaf knives". Leaf points, which display more symmetrical shapes and cross sections (Kot & Richter, 2012), are found mostly at low numbers since ca. 70 ka in l-LMP assemblages (e.g. Kůlna 9b: Valoch, 1988; Buhlen III: Jöris, 2001) or possibly slighly earlier (Bockstein III: Wetzel & Bosinski, 1969, of potential OIS 5a age: Çep, 2014; Çep & Krönneck, 2015). In some later, i.e. OIS 3, KMG/ "Micoquian" or "M.M.O" contexts, they seem to become more frequent (e.g. Richter, 1997) and may finally dominate over other bifacial tools in early *Blattspitzengruppen* assemblages (Müller-Beck, 1974; Richter, 2009; cf. Uthmeier, 2004). The question remains, however, if the leaf points successively replaced other bifacial tools, i.e. *Keilmesser* and "leaf knives", or if the former added to the latter, as they were serving other purpose(s). Whereas *Keilmesser* and "leaf knives" are interpreted generally as cutting tools (cf. Veil et al., 1994), at least some leaf points may have served as projectiles (cf. Rots et al., 2021). While backed bifacial knives were most likely unhafted, we have strong evidence that the thin "leaf knives" and the leaf points were hafted indeed (Kot, 2014; Rots et al., 2021; similar arguments were forwarded for the hafting of Jerzmanowician blade points, cf. Wiśniewski et al., 2022). At present, however, the data is still too scarce to state that the differences in tool design would allow to strictly separate cutting tools, i.e. backed bifacial knives and "leaf knives", on the one hand from the leaf point projectiles on the other. The versatility of LMP reduction and resharpening strategies outlined above would more likely speak against the unifunctional character of tools, but favour a more flexible use instead. The coarse-grained chronological development outlined above has repeatedly been interpreted as evidence for the in situ cultural evolution of leaf points out of the l-LMP substrate of the preceeding KMG/ "Micoquian" or "M.M.O" (e.g. Bosinski, 1967; cf. Richter, 2009; Kozłowski, 2021). In line with these interpretations, Szeletian and/or the *Altmühl*- or *Blattspitzengruppen* leaf point assemblages would most likely have been made by Neanderthals and have been interpreted as a reflection of a special task camp facies of the regional l-LMP (Uthmeier, 2000, 2004).

This picture is, however, further complicated by the character of different techno-complexes that are subsumed under the regional IUP or EUP and that chronologically overlap with the Szeletian and/or the *Altmühl*- or *Blattspitzengruppen* (Figs. 1c and

2). Both IUP and EUP industries in central Europe are characterised by a predominant focus on laminar blank production and higher proportions of tool types typical of the UP, namely end-scrapers, whereas other tools, which are typically classified as MP such as side scrapers, become less frequent or disappear (Table 1).

In central and eastern Europe, an association of lithic industries classified as IUP (or EUP) with AMH remains has, however, only been demonstrated for the so-called Bachokirian (Kozłowski, 1979, 2004) at the eponymous site of Bacho Kiro in Bulgaria, recently dated to ~ 45 ka cal BP (cf. Fewlass et al., 2020; Hublin et al., 2020). The Bachokirian lithic industry comprises a few fragments of blade points made of blanks that were obtained from uni-directional, but also from bi-directional cores (Tsanova, 2008, 2012; Tsanova & Bordes, 2003), just as is the case for the LRJ, hinting at its potential AMH authorship. Alternatively, the LRJ may have developed autochthonously out of the Szeletian and/or the *Altmühl-* or *Blattspitzengruppen* (and their KMG/"Micoquian" predecessors) of central Europe, with which it overlaps chronologically. From a technological perspective, one could view the LRJ blade point sites as representing nothing but a facies of the former industries, just being characterised by different blank production concepts that could be realised at sites where higher-quality raw materials that allowed for the production of long and broad blade blanks. Following these lines of arguments, one could interpret the LRJ blade technology and points either as the outcome from *in situ* innovations of European Neanderthals (e.g. Flas, 2012; Semal et al., 2009) or as the result of the adoption to or assimilation of new technologies introduced by AMH (cf. discussion in Neruda, 2021; cf. Swainston, 1999; Wiśniewski et al., 2022) at around this time in the immediate eastern European neighbourhood. In case of the latter hypothesis, a westward spread of the last Neanderthals across the northern European lowlands to the British Isles could be considered as a potential scenario underlying LRJ dispersal (cf. disussion in Stapert et al., 2021).

The Bohunician, with its close similarities to eastern Mediterranean sites that date to the MP-UP transitional period, adds further complexity to the spatio-temporal patchwork of lithic assemblage types of central Europe in this time interval, as it largely overlaps chronologically with both the transitional industies of the Szeletian and/or the *Altmühl-* or *Blattspitzengruppen* as well as with the LRJ. According to radiometric dates and stratigraphic evidence, at least some Bohunician sites appear to pre-date the other techno-complexes by a few millennia and may date back to roughly 49 ka. Bohunician sites occasionally also contain bifacial foliate tools, as discussed above, but lack Jerzmanowician points made on broad blades derived from volumetric cores. Bohunician blank production concepts resemble to certain degree Levallois and Levallois-like laminar and point production. This having been said, and having highlighted the autochthonous developments that can be deduced from the regional archaeological record, to evaluate the potential origins of blade-based blank technology at this time makes us alternatively look at the Levallois-Mousterian-like assemblages of central Europe that have been classified above as FMP and which may date back to a similar age-range as the potential evidence for early AMH incursions into Europe from Grotte Mandrin in the Rhône Valley (cf. Slimak et al., 2022). Unfortunately, at present state of research, the central European Levallois-characterised FMP and the few sites in question remain poorly understood.

The apparent contradiction between different models which favour either autochthonous developments from the regional MP towards the UP or the import of UP technologies by AMH can only be solved in favour of population admixture(s) of Neanderthals and AMH in central Europe during the time interval ~ 49 to 39 ka (cal) BP, as indicated by aDNA studies (cf. Hajdinjak et al., 2021; Prüfer et al., 2021). With such a scenario, most explanations for the major differences between the MP and the UP and for a strict separation of the Szeletian and/or the *Altmühl*- or *Blattspitzengruppen* on the one hand and the LRJ on the other, or to separate all these from the Bohunician supposedly due to potential (cognitive?) differences between two hominin species, would be largely misleading and would not acknowledge the growing evidence for the successive ingression of AMH individuals and their genetic admixture with Neanderthals in the critical period (e.g. Villanea & Schraiber, 2019; Wolf & Akey, 2018). The question arising from this discussion is whether or not a black-and-white distinction between AMH vs. Neanderthals really takes us forward in understanding the complex socio-cultural changes underlying the archaeological record. In fact, this way of thinking in "monolithic blocs" may instead hamper important insights into the demographics and social mechanisms that influence the variability of lithic assemblages. The large chronological overlap between Szeletian and/or the *Altmühl*- or *Blattspitzengruppen*, LRJ and Bohunician assemblages and their different geographies, including assemblages with mixed techno-typological features, means that far more complex models must be considered (cf. Neruda, 2021) to understand this cultural and behavioural mosaic in a socio-cultural landscape of growing complexity — a mosaic of socio-cultural admixture which seems to have persisted until the Aurignacian to Gravettian transition some 34–33 ka cal BP ago.

Conclusion and Outlook

As shown in the preceding chapters, social transmission and learning of certain concepts or strategies of blank production and tool design led to the formation of some spatio-temporally clearly defined RCS. To some degree, these may reflect "traditions" of cultural entities that can be identified in spatio-temporal scales (cf. discussion in: Conard & Fischer, 2000). These developments seem to have accelerated in their dynamics and speed of material cultural changes *before* the first evidence of AMH in the region and *before* the beginning of the EUP Aurignacian. In an over-simplified view, one would argue that such RCS can be recognised most clearly when reduction strategies and tool concepts appear to have been conceptually highly standardised, i.e. when socio-cultural conventions resulted in the implementation of stricter rules and regulations and in — hypothetically — less flexible but well-established strategies of social learning. In central Europe, this seems to apply especially to the l-LMP KMG in which lithic technological variability in core reduction and blank production seems to be overprinted by the more standardised *chaînes opératoires* of tool production and maintenance that appears comparably homogeneous over more narrowly defined time intervals (cf. Figure 3). Generally, it seems that the visibility of RCS increases during the LMP (Table 1). At the same time, they seem to have diversified to a maximal extent during the MP to UP transition.

The pace of cultural change reflected in assemblages from the MP to UP transitional period appears more similar to the "runtime" of UP techno-complexes. If this is correct, it implies that LMP/FMP lithic assemblage variability was governed by factors and circumstances that were fundamentally similar to those that determined techno-functional assemblage variability in the subsequent UP techno-complexes. Only the strategies of social transmission and learning and the content of such were different. Such a perspective further allows a far more complex modelling of the emergence of the European UP, involving highly complex modes of (potential) interactions in a landscape populated in a patchy mosaic of different, but contemporaneous and to different levels interconnected individuals and groups (cf. Le Brun-Ricalens, 2019; Neruda, 2021). The evidence presented above hints that close to the end of the central European MP, successive changes in social organisation fostered new or more intensive modes of interaction, social learning strategies and/or the transmission of knowledge, accelerating the pace of cultural changes in a way that groups and populations became prepared to develop new cultural concepts that we tend to subsume under the category "Upper Palaeolithic". The underlying demographic and social processes most likely enhanced levels and concepts of group identity and convergent technical developments towards the UP.

As such views are more suitable to explain certain elements of cultural continuity and discontinuity observed in lithic technology across the MP to UP transitional period, this review represents the archaeological baseline for more thorough studies on the demographic and social mechanisms and processes involved in the MP to UP transition in central Europe and beyond.

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Declarations

Conflict of Interest The authors declare no competing interests.

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