



Neanderthals' recolonizations of marginal areas: An overview from Eastern Germany

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ABSTRACT

The Middle Paleolithic in Eastern Germany presents a unique context for understanding Neanderthal populations' dynamics within environmental shifts. The cyclical ice-sheet growth and advancements during the late Middle and Late Pleistocene caused occupational gaps in North-western and Central Europe and recurring episodes of recolonization from the southern regions. From cold tundra and steppe landscapes to forested habitats during climatic amelioration, these environmental changes significantly influenced Neanderthal settlement patterns and adaptive strategies. In this study, the lithic assemblages from some Middle Paleolithic sites stretched between Saxony and Saxony-Anhalt are analyzed. Despite migrations occurring over millennia, our study reveals that the unidirectional reduction scheme was continuously applied to different knapping methods remaining a common technological substrate during the whole Middle Paleolithic. The introduction of asymmetric bifacial tools during MIS 5c/MIS 5a did not alter predominant flake production methods. Contrariwise to support a techno-cultural stasis lasted several millennia, this study reveals that this technical continuity could be related to the changes in raw material size occurred during the Middle Pleistocene. Large erratic flint nodules during the Elsterian glaciation promoted loss-making behaviors, while the transport of smaller nodules during the Drenthe glaciation encouraged more intensive exploitation of pebbles during the Late Middle Paleolithic. By shedding light on Neanderthal lifeways, technological adaptations, and settlement patterns in Eastern Germany, this research contributes to a nuanced understanding of their behavior amidst evolving environmental conditions.

1. Introduction

One of the most captivating aspects of human evolution is the study of the demographic expansion of hominins and their adaptive capacities to various environments and habitats. Since the Lower Paleolithic, the spread of archaic humans across different Eurasian territories was constrained to specific latitudes, with dispersal in areas above 45°N occurring only during periods of climatic improvement (e.g. (Parfitt et al., 2005; Parfitt et al., 2010; Moncel et al., 2013; Wragg Sykes, 2017)). The recurrent growth of the Scandinavian ice cap (Ehlers et al., 2011; Batchelor et al., 2019), along with the proliferation of boreal environments at mid-latitudes (Fletcher et al., 2010; Antoine et al., 2013; Kern et al., 2022) created significant ecological barriers for prehistoric hunter-gatherers seeking to settle in the landscapes of North-Central Europe.

In recent decades, there has been an emphasis on examining the impact of climatic changes on the recolonization processes of northern territories, primarily in animals and plants (Hewitt, 2000; Stewart and Lister, 2001; Koenigswald, 2007; Stewart et al., 2010; Baca et al., 2017).

There is a broad agreement that warm-adapted faunal and floral taxa in marginal areas were replaced by cold-adapted species during glacial stages (Hewitt, 2000; Koenigswald, 2007). Unlike the displacement to the south, it is more likely that these warm-adapted species demised, and populations from glacial refugia resettled the northern regions during climatic improvements (Koenigswald, 2011b). This concept is supported by the understanding that the most favorable habitats were already occupied during the glacial phases, and an increase in populations would have led to over-exploitation of biotic resources (Koenigswald, 2007). Glacial refugia in the Balkans, Iberia, and to a lesser extent, Italy have been identified as the primary locations where various temperate species survived cold fluctuations and later dispersed into North-Central Europe during periods of climatic improvement (Hewitt, 2000). While many taxa follow this "glacial refugia model!" others have shown more flexibility, surviving in cryptic and interglacial refugia at mid-latitudes, which adds complexity to the understanding of some species' distribution (Stewart et al., 2010; Feliner, 2011).

Neanderthals were particularly affected by these climatic fluctuations (Fiorenza et al., 2015) with the cold stages causing occupational

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gaps in North-western and Central Europe and indicating recurring episodes of recolonization (Goval, 2012; Wragg Sykes, 2017). The later part of the Middle Pleistocene saw areas above 50°N cyclically impacted by ice-sheet advancements, covering significant portions of Central Germany and Poland (Ehlers et al., 2011; Batchelor et al., 2019). During interglacial phases, the retreat of the ice margin provoked the production of large quantities of meltwater that drained into the Dover Strait. This process, known as *Fleuve Manche*, was slow and affected for a long period the environmental settings of the Northern European landscape, thereby creating temporary lakes and rivers (Toucanne et al., 2009). Aside from the climatic improvements during the MIS 7, MIS 5e (Eemian), MIS 5c (Brørup), and MIS 5a (Odderade) interval, Northern Europe was primarily characterized by expansive open landscapes, occasionally dotted with sparse shrubbery even during warmer periods (Fletcher et al., 2010). This open steppe/taiga habitat facilitated the *Mammuthus-Coelodonta* fauna from the Arctic zones (Kahlke, 1999) to spread, whereas certain local species (e.g., Irish elk, horse, red deer) exhibited resilience to climatic oscillations, ensuring their regional presence remained stable (Koenigswald, 2011a).

Similarly, to the pattern identified in plants and animals, the “glacial refugia model” is also suggested for Neanderthals that settled the northern regions. Therefore, rather than tracking favorable territories to the south, Neanderthals most likely declined during the harsh glacial phases, and only after an increase in average temperatures, new groups from glacial refuge zones repopulated the northern areas (Hublin and Roebroeks, 2009; Roebroeks et al., 2011). Some scholars broaden the regional extension of the glacial refugia proposing that the Levant was the Neanderthal population’s source area, with recurrent recolonizations stemming externally from the continent (Dennell et al., 2011; Bermúdez de Castro and Martínón-Torres, 2013; Hershkovitz et al., 2021; Mihailović et al., 2022). From an archaeological perspective, these models’ applications pose challenges due to the absence of prolonged cultural site comparisons within same regions.

Neanderthal groups in Saxony and Saxony-Anhalt documented continuous re-settlements and demographic expansions over several millennia, notably during the end of MIS 8, MIS 7, MIS 5e, MIS 5c, MIS 5a, and MIS 3. These regions are among the few areas where archaeological sites have been preserved that cover the entire span of the Middle Paleolithic, from its beginning in the late Middle Pleistocene to its conclusion in the Late Pleistocene during MIS 3. This continuity makes Saxony and Saxony-Anhalt crucial for understanding how Neanderthals adapted to new environments as they migrated from glacial refugia into unfamiliar territories. Throughout this period, the region experienced dramatic climatic and environmental changes, oscillating between cold, barren tundra and steppe landscapes to more temperate and forested habitats. These transformations significantly influenced Neanderthals’ settlement patterns, migratory behaviours, and lithic technologies. The variety of habitats and shifts in raw material availability further added to the complexity of their technological behaviours, offering key insights into their adaptive strategies.

To address these issues and deepen our understanding of Neanderthal technological and migratory adaptations in Eastern Germany, this study focuses on the following research questions.

1. How did Neanderthal stone tool technology evolve over time as they migrated and settled into new habitats?
2. How did raw material availability influence Neanderthal technological strategies and lithic production?
3. What differences can be identified in Neanderthal settlement systems during their repeated recolonization?
4. Can lithic assemblages from this region be used to trace the origins and migration routes of Neanderthal populations, linking them to specific glacial refugia?

By analysing lithic assemblages from sites in Saxony and Saxony-Anhalt, this study aims to contribute to a broader understanding of

Neanderthals’ technological continuity and flexibility, as well as explore potential connections to glacial refugia. These findings have significant implications for our understanding of Middle Paleolithic human behaviour and adaptations. Additionally, the study seeks to enhance current knowledge of Neanderthals’ migratory patterns, the challenges they faced during recolonization events, and the technical strategies they employed to exploit available resources. The significance of this research lies within the broader context of Middle Paleolithic evidence from Central Europe, where a nuanced understanding of regional adaptations offers key insights into Neanderthal cognitive and cultural evolution. By evaluating the complex interplay between environmental changes, raw material availability, technological choices, and migratory behaviours, this study provides an integrated perspective that enriches our understanding of Neanderthal life during the glacial cycles.

2. Archaeological sites

The region encompassing Saxony and Saxony-Anhalt in Eastern Germany holds a unique position in European Paleolithic research due to its exceptional preservation of archaeological horizons spanning the entirety of the Middle Paleolithic. This area is one of the few in Europe where sites have been preserved from the end of MIS 8 to mid-MIS 3, offering a continuous record of Neanderthal occupation over several hundred thousand years within a relatively small geographic area. This continuity, located at the margins of the Neanderthal settlement system, may have been favored by the abundance of biotic resources, making this territory an attractive location for seasonal expeditions. The presence of rivers, such as those at Markkleeberg and Zwochau, and lakes, including Rabutz, Neumark-Nord, and Königsau, would have provided essential resources, supporting both Neanderthal subsistence strategies and settlement choices.

The sites selected for this study (Fig. 1) were chosen based on both the abundance of lithic materials and their availability for research. This selection ensures that the analysis is comprehensive and representative of long-term technological and behavioral trends of Neanderthals during the Middle Paleolithic. Specifically, these sites will provide valuable insights into Neanderthal technological behaviors during recurrent repopulation events, helping to reconstruct how they adapted their strategies in response to the challenges of recolonizing northern Europe.

2.1. Markkleeberg

Markkleeberg open-air site is located at the village Markkleeberg Ost at about 10 km south of the city of Leipzig (Germany) on the eastern slope of the flat valley of the Pleiße River (Fig. 1, Table 1). Since the beginning of the XXI century, the district of Markkleeberg was extensively exploited by mining brown coal in open strip mines. Rescue archaeological excavations were conducted in 1977–1980 by Mania and Baumann (1983) over an area of 30 000 m², and in 1999–2001 by Schäfer et al. (2004) in four trenches. In 2006, the mining pit was flooded and turned into a recreational lake. The archaeological remains are found at the bottom of the sequence [find complex (FC)1] of one of the erosion channels that cut the Elster glaciation pavement (FC2) and at the top of the Early Saalian Main Terrace (FC3). Some luminescence dates on the sequence place the FC1 and FC2 at the second half of MIS8 and FC3 at the beginning of the MIS6 (Schäfer et al., 2003; Krbetschek et al., 2008; Lauer and Weiss, 2018a). Few animal bones of cold adapted fauna (e.g., horse, bovidae, *Coelodonta antiquitatis* and *Mammuthus trogontherii*) were discovered indicating an open environment of glacial period (Schäfer et al., 2004). In this study, the lithic assemblage discovered during the excavation of Schäfer et al. (2004) is analyzed.

2.2. Zwochau

The open-air site of Zwochau is located 20 km north of Leipzig (Germany) in the town of Zwochau (Fig. 1, Table 1). After the discovery

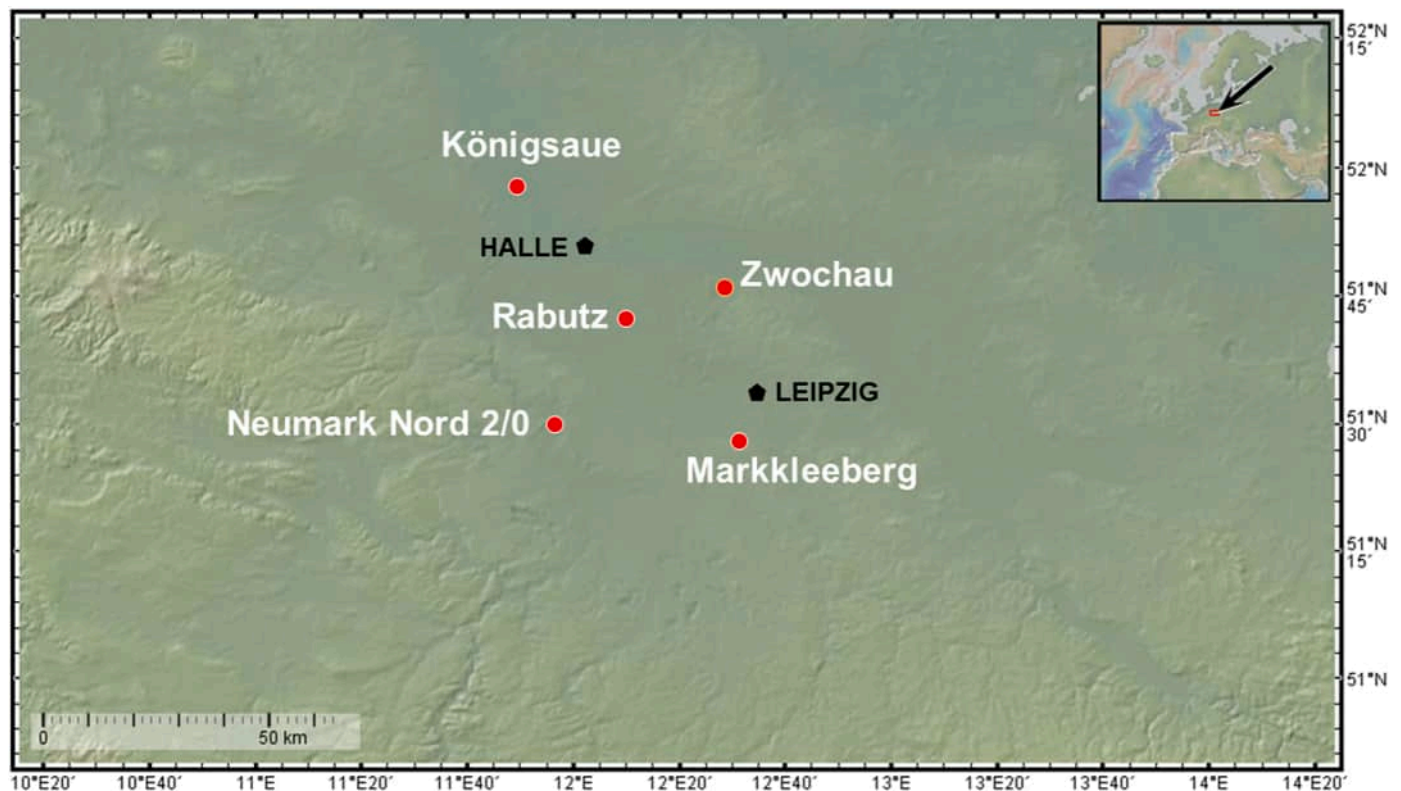


Fig. 1. Geographical location of the sites mentioned in the text (base map from GeoMappApp).

Table 1

Summarizing data from the sites discussed in the paper.

	Archaeological horizon	Dating method	Chronology	Environment	Cultural facies	References
Markkleeberg	FIC 3	pIRIR	164 000 ± 16 000 159 000 ± 17 000	Steppe	Early Middle Paleolithic	(Krbetschek et al., 2008; Lauer and Weiss, 2018b)
	FIC 1	IR-RF	236 000 ± 23 000 306 000 ± 23 000			
Zwochau	AH1	Geological correlation with late Delitzsch phase of the Saale complex	~250 000	Forest-steppe	Early Middle Paleolithic	(Litt and Field, 1996; Wansa and Wimmer, 1996)
Rabutz	AH1	Geological and faunal correlation with Eemian deposit	~125 000	Semi-open forest	Late Middle Paleolithic	Toepfer (1958)
Neumark - Nord 2/0	AH1	OSL	93 000 ± 7000	Forest-steppe	Late Middle Paleolithic (Micoquian)	Richter and Krbetschek (2014)
Königsau	A	¹⁴ C	41 820 ± 390	Forest-steppe	Late Middle Paleolithic (Micoquian)	(Mania and Toepfer, 1973; Picin, 2016)
			43 800 ± 2100 48 400 ± 3700			

of some lithic artefacts in an open strip coal mine, the Landesamts für Archäologie Sachsen (Dresden, Germany) carried out a rescue excavation on six trenches in 1994 (Pasda, 1996; Pasda and Pasda, 1996). The pit is now a recreational lake called Zwochauer Lake. The archaeological horizon (*Steinshole*) is located on the top of the erosion of the Elsterian glaciation moraines in a layer formed by a mixture of gravel and stones in a silty sand matrix, and correlated with the late Delitzsch phase of the Saale complex dated c. 250 ka BP (Wansa and Wimmer, 1996). The coarser component of the *Steinshole* is predominantly of Nordic origin with high percentages of flint (Wansa and Wimmer, 1996). Paleo-environmental reconstruction indicates a habitat of forest steppe with birches and open meadow spots (Litt and Field, 1996). Animal

remains are not preserved.

2.3. Rabutz

The open-air site of Rabutz is located about 15 km southeast of the present city of Halle (Fig. 1, Table 1). At the end of the XX century, the work on a brick quarry unearthed artefacts and faunal remains in Pleistocene limnic sediments of a small postglacial basin. The first report documents the discovery of an upper dentition of a *Stephanorhinus kirchbergensis* (Von Fritsch, 1880). In 1914, the archaeological excavation uncovered more mammalian fossils and few lithic artefacts (Soergel, 1920). The faunal remains included mostly remains of *Cervus*

elaphus and the presence of *Dicerorhinus kirchbergensis*, *Equus* sp., *Sus scrofa*, *Megaceros giganteus*, *Capreolus capreolus*, *Alces* sp., *Bos primigenius*, *Bison priscus*, *Ursus arctos*, *Panthera leo*, and *Canis lupus* indicating open and forested environments (Toepfer, 1958). The geological work on the region attributed the archaeological horizon to the Last Interglacial (MIS 5e) (Eissmann, 1990). However, a debate arose on the age of sediments covering the clay, suggesting an association with a late Saalian till and, consequently, a pre-Eemian chronology for the site (Erd, 1990).

2.4. Neumark-Nord 2/0

The open-air site of Neumark-Nord, located 20 km south of the city of Halle (Fig. 1, Table 1), was discovered in 1985 during the exploitation of lignite open-cast mines. In the following years, archaeological works in the area uncovered different localities of different chronologies (Mania et al., 1990; Mania, 2010; Gaudzinski-Windheuser et al., 2014). The site Neumark-Nord 2 is a lacustrine deposit containing a Last Interglacial (Eemian) infill overlain by fluvial gravels and Weichselian loesses. The level Neumark-Nord 2/0 is associated with the final stage of these sedimentation processes with an OSL age of 93 ± 7 ka (MIS 5c or MIS 5a) (Richter and Krubetschek, 2014). During the recent quarry activities, the soils overlain level NN2/0 were removed exposing the archaeological horizon to post-depositional disturbances caused by bioturbation and small mammal burrowing. The faunal assemblage is dominated by remains of *Bison priscus* and *Equus* sp., followed by cervids. Single evidence of *Asinus hydruntinus*, *Ursus spelaeus* and *Vulpes* sp. are also documented (Brühl and Laurat, 2010).

2.5. Königsau

The open-air site of Königsau is located near the town Aschersleben, 50 km northwest of the city of Halle (Fig. 1, Table 1). The site was discovered on the shore of Aschersleben Lake, an ancient lake 12 km long that was silted up in historical times (Mania and Toepfer, 1973). Open-cast mining was carried out until 1996 when the mining pit was turned into a recreational lake named Königsauer See. In 1963–1964, a rescue excavation unearthed three archaeological levels (A, B and C) (Mania and Toepfer, 1973). Sedimentological studies have suggested a MIS 5c chronology for the anthropogenic levels (Mania and Toepfer, 1973), while radiocarbon dates on bone and resins from level A and C reveal a late Middle Paleolithic age (Hedges et al., 1998; Picin, 2016). Level A and C are attributed to the Central-Eastern European Micoquian (or *Keilmessergroupen*) whereas level B is ascribed to Levallois-Mousterian facies. The palaeoecological study suggests an environment in the neighborhood of a lake characterized by forested and meadow steppe (Mania, 1999). In level A, the study of faunal remains revealed high frequencies of *Rangifer tarandus*, *Equus* sp., *Mammuthus primigenius*, and *Bison priscus* with occasional consumption of *Equus hydruntinus*, *Coleodonta antiquitatis*, *Dicerorhinus hemitoechus* and *Cervus elaphus*. In level B, the faunal remains show the hunting of horse, reindeer, and bison, and one example each of mammoth, wild ass, and red deer. Conversely, in level C, only a few fragments of reindeer were discovered (Mania and Toepfer, 1973).

3. Method

This study seeks to elucidate the technological trajectories of Neanderthals in eastern Germany during the Middle Paleolithic in light of the recurrent climatic changes that affected the territories of Central Europe. Due to the absence of paleogenetic data and Neanderthal fossils in the area, the lithic assemblages serve as the primary proxies for understanding Neanderthal behavioral strategies and potential migration routes. The analysis of stone tool technologies is focused on the technological processes themselves, as direct correlations between climate change and lithic technology cannot be established with the available data.

The lithic assemblages were knapped from Erratic (or Baltic) flint nodules, a raw material originating in primary contexts in Denmark and southern Sweden, and transported to Central Germany by moraine deposits during the expansion of the Fennoscandian glacier in MIS 12, MIS 6, and MIS 2 (Högberg and Olausson, 2007). The lithic collections are analyzed by using the *chaîne opératoire* approach, a methodological framework that reconstructs the various processes of flake production, starting from raw material procurement through manufacture and utilization to final discard (Pelegrin et al., 1988; Inizian et al., 1992; Boëda, 2013). The analysis of the core assemblage involves identifying the number of flaking surfaces, the presence or absence of hierarchical preparation of the core volume, the angle between the flaking surface and the striking platform, and the direction of the detached flakes. Levallois and discoid technologies are identified based on criteria defined by Boëda (1993, 2013), and intermediate core morphologies, characterized by the hierarchization of the flaking surface and core configuration with secant fracture planes, are discriminated based on the direction of detachments (e.g., unidirectional, bidirectional, or centripetal) (Vaquero and Carbonell, 2003; Picin, 2018). Volumetric shape estimation of cores is calculated using the Carination Index, representing the ratio between length and width/thickness. The study of the flake assemblage involves analyzing the presence or absence of cortex (cortex >50% = cortical flake; cortex <50% = semi-cortical flake), the number and direction of detachments on the dorsal face, the angle and type of striking platform, the flaking axis, and the presence of knapping accidents (e.g., overshot and hinged removal, silet fracture). In Table 2, to summarize the technological information, the category “Management flakes” includes the byproducts of core configuration and organization, such as predetermining Levallois flakes, trimming striking platform flakes, flakes related to the reshaping of the flaking surface, translation of the striking platform, and knapping accidents. The category “Production flakes” comprises ordinary flakes, Kombewa flakes, as well as unidirectional, bidirectional, and centripetal flakes. Retouch tools are distinguished following Bordes (1961)’s and Bosinski (1967)’s typological lists, while denticulates and notched tools are analyzed according to Picin et al. (2011). To comprehend the fragmentation of operative chains at the sites, we utilized the computation method published in Picin (2016) and Picin and Vaquero (2016), wherein the rate of flake productivity for Levallois and discoid technologies is calculated based on experimental knapping materials.

4. Results

4.1. Markkleeberg

The lithic assemblage comprises 789 artefacts (Table 2). The technological analysis indicates that the main pattern of flaking surface exploitation is unidirectional followed by bidirectional and bifacial discoid (Table 2) (Picin, 2018, 2020). Nine cores are considered hierarchized unidirectional or “proto-Levallois” following the description of White and Ashton (2003). In these cores, the volume is divided into two hierarchical surfaces, one being a dedicated surface of striking platforms and the other a dedicated flaking surface but the direction of the removals is secant the line of intersection between the two surfaces. The striking platforms are roughly prepared and, in five examples, shaped by the removal of an invasive flake that creates a flat surface. The lateral and distal convexities are roughly configured by flakes detached parallel or secant to the direction of the flaking production. This type of configuration is also performed on core-on-flakes using the natural convexity of the ventral surfaces and managing only the lateral and distal convexities. At the site, early evidence of Levallois technology is also reported (Fig. 2). The use of similar methods in preparation of the convexities of the flaking surfaces suggests that the appearance of Levallois method is rooted in the unidirectional core technology and the development of hierarchized reduction strategy (Picin, 2018, 2020). The collection counts on two Levallois preferential core, one Levallois

Table 2
Number and percentages of the technological categories of the sites discussed in the text.

	MIS 8 - 7		MIS 5e		MIS 5a or 5c		MIS 3							
	Markkleeberg	%	Zwochau	%	Rabutz	%	N-N 2/0	%	König. A	%	König. B	%	König. C	%
Cortical flake	167	25.8	247	28.4	22	18.6	397	18.2	158	14.3	543	18.4	22	9.9
Management flake	117	18.1	187	21.5	17	14.4	281	12.9	291	26.3	685	23.2	50	22.4
Production flake	59	9.1	74	8.5	17	14.4	128	5.9	49	4.4	175	5.9	11	4.9
Levallois flake	11	1.7	17	2	2	1.7	1	0.0	30	2.7	74	2.5	4	1.8
Core-edge flake	27	4.2	46	5.3	9	7.6	62	2.8	39	3.5	216	7.3	9	4
Pseudo-Lev. point	2	0.3	2	0.2	5	4.2	8	0.4	8	0.7	73	2.5	2	0.9
Fragments	202	31.2	262	30.1	29	24.6	878	40.3	446	40.3	952	32.3	101	45.3
Levallois core	3	0.5	13	1.5			4	0.2	5	0.5	51	1.7		
Discoid core	9	1.4					10	0.5	2	0.2	9	0.3		
Hierarchized core	9	1.4	11	1.3			10	0.5	3	0.3	30	1		
Simple core	17	2.6	8	0.9	6	5.1	81	3.7	12	1.1	33	1.1	2	0.9
Core-on-flake	7	1.1	3	0.3	3	2.5	18	0.8	4	0.4	31	1.1	3	1.3
Core fragment	3	0.5	1	0.1	3	2.5	70	3.2	14	1.3	48	1.6	4	1.8
Retouched tools	12	1.9			4	3.4	167	7.7	27	2.4	24	0.8	12	5.4
Tool fragment	2	0.3			1	0.8	63	2.9	20	1.8	6	0.2	3	1.3
Total	647	100	871	100	118	100	2178	100	1103	100	2950	100	223	100

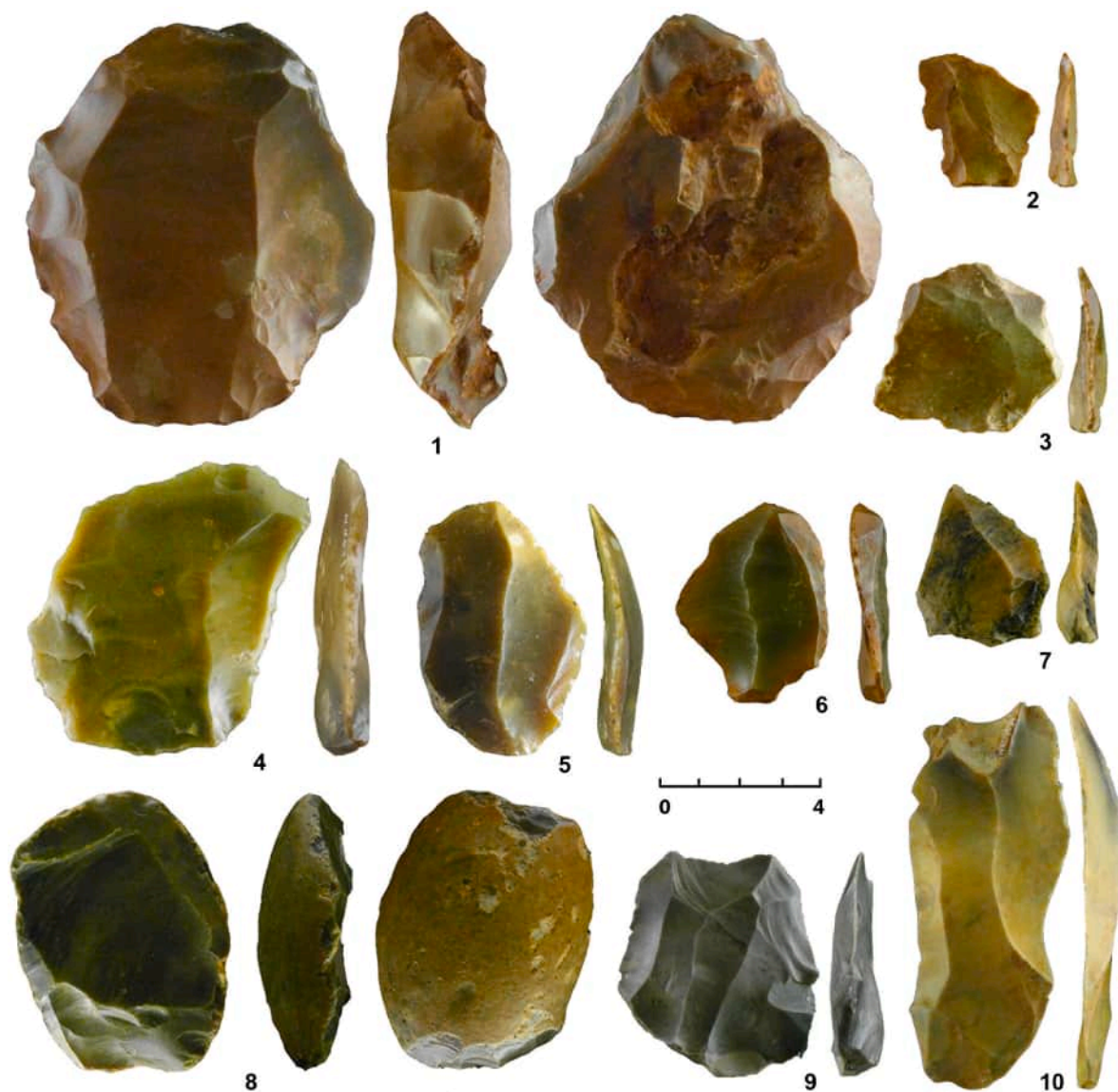


Fig. 2. Levallois preferential core (1, 8), Levallois flake (2, 3, 4, 10), Levallois point (7), unidirectional flake (5, 6), and core-edge removal flake (9) of Markkleeberg.

recurrent unidirectional cores and few Levallois flakes (Table 2, Fig. 2). The flake assemblage includes a big number of cortical flakes followed in less frequency by the byproducts of preparation of the core convexity (Table 2). Retouched artefacts comprise scrapers and single examples of Mousterian points and composite tools (Table 3).

4.2. Zwochau

The lithic assemblage of Zwochau comprises 1221 artefacts (Table 2). The technological analysis reveals the use of different knapping methods (Picin, 2018, 2020). The unidirectional exploitation of the flaking surface is documented in eight hierarchized cores and in two abrupt unidirectional cores. Nine artefacts show the use of two opposing striking platforms whereas on three cores is documented the migrating platform for an alternated flake production as described by White and Ashton (2003). In these latter cores, the direction of the detachments is secant and not parallel to the line of intersection of the two core surfaces and, thus, reentering in the category of hierarchized artefacts. In the assemblage, eleven preferential Levallois cores, one Levallois recurrent bidirectional, and one recurrent centripetal cores are also found (Table 2, Fig. 3). In preferential Levallois cores, the preparation of the core convexity is very similar to the assemblage of Markkleeberg in which the predetermining Levallois flakes are detached in the same direction of the flaking sequence or orthogonally. In the flake assemblage, are found many cortical flakes, several Levallois recurrent unidirectional flakes and few Levallois preferential and Levallois recurrent bidirectional flakes (Fig. 3). Retouched tools are absent (Table 2) (Picin, 2018, 2020).

4.3. Rabutz

The lithic assemblage of Rabutz includes 118 artefacts and 6 pebbles (Table 2). The technological analysis documents 5 unidirectional cores and 1 bidirectional core (Table 2, Fig. 4). These artefacts are characterized by cortical dorsal surfaces and roughly prepared striking platforms. The natural convexity of the nodule or the chunk is often used and the flakes production is short without any predetermined shape of the blanks. This opportunistic behavior is also documented in three core-on-flakes. In the flake assemblage are found few cortical flakes and byproducts for the maintenance of the core convexities, and single examples of Levallois recurrent unidirectional and recurrent bidirectional flakes (Table 2, Fig. 4). Retouched tools include only one scraper, one denticulate and two simple notches (Table 3, Fig. 4).

4.4. Neumark-Nord 2/0

The lithic assemblage of Neumark-Nord 2/0 comprises 2253 artefacts (Table 2) recovered from an area of 385 m² (Brühl and Laurat, 2010). The technological analysis documents that the flint pebbles used were very small and most of the cores are reduced opportunistically (Picin, 2021). The main pattern of reduction is unidirectional (Fig. 5). In this group, only 15 artefacts are considered simple unidirectional cores whereas 24 artefacts are abrupt unidirectional and 13 cores are characterized by the complete removal of the flaking surface due to the absence of preparation of the lateral and distal convexities. The bidirectional production is documented in 6 simple cores whereas the centripetal exploitation is found in 4 cores. Hierarchized artefacts are few and include 6 hierarchized unidirectional, 2 hierarchized bidirectional and 2 hierarchized centripetal (Table 2, Fig. 5). Secondary operative chains include Levallois technology, present in the modality preferential with four cores, and bifacial discoid with 10 artefacts (Table 2, Fig. 5). Polyhedral cores (n°5) could be the result of the changes in the knapping direction as attested by several flakes of translation of the striking platform. One small cobble was reduced with the salami slice method. Although the dimension of flakes is very small, 18 core-on-flakes were exploited on the ventral surface for the production of small blanks (Picin, 2021). In the flake assemblage are common cortical, semi-cortical flakes and knapping accidents, mostly hinged flakes, probably produced during the unidirectional exploitation (Table 2). Flakes of maintenance of the core volume and of full production are few (Table 2). For example, only one Levallois recurrent bidirectional flake is recorded. Retouched artefacts are numerous and comprises scrapers, Quina and demi-Quina scrapers and few symmetrical and asymmetrical bifacial knives (Table 3, Fig. 5) (Picin, 2021).

4.5. Königsau

The lithic assemblage of level A comprises 1478 flint and 12 quartzite artefacts (Table 2) scattered in 4 main locations. The quartzite assemblage suffered severe surface weathering alterations and were not included in this study. The technological analyses of level A report the use, in 4 cores, of the Levallois preferential method and, in one core, of the modality recurrent unidirectional (Fig. 6). The main secondary chaîne opératoire is the simple unidirectional (n°6) method followed by bidirectional (n°2), orthogonal (n° 2), hierarchized centripetal (n°3) and discoid (n°2). The diacritic lecture of the negative scars in Levallois and simple unidirectional cores reveals the repeated detachment of several flakes from the same striking platform. This behavior entails, in some cases, the production of secondary Levallois preferential flakes, a high

Table 3
Number and percentages of the retouched tools of the sites discussed in the text.

	MIS 8 - 7		MIS 5e		MIS 5a or 5c		MIS 3					
	Markkleeberg	%	Rabutz	%	N-N 2/0	%	König. A	%	König. B	%	König. C	%
Scraper	7	58.3	1	25	82	49.1	15	55.6	15	62.5	2	16.7
Double scraper	1	8.3			6	3.6	1	3.7	4	16.7	1	8.3
Scraper + Denticulate	1	8.3										
Bifacial scraper					13	7.8						
demi-Quina scraper					18	10.8	3	11.1			3	25
Quina scraper					24	14.4					4	33.3
Leaf scraper					1	0.6						
Mousterian point	1	8.3			1	0.6						
Convergent tool	1	8.3			2	1.2	1	3.7				
Leaf point					4	2.4						
Denticulate			1	25	3	1.8			2	8.3	1	8.3
Notched tool			2	50	1	0.6						
Denticulate + Notch	1	8.3										
Faustel					3	1.8			1	4.2		
Keilmesser					9	5.4	6	22.2			1	8.3
Bifacial tool							1	3.7	2	8.3		
Total	12	100	4	100	167	100	27	100	24	100	12	100

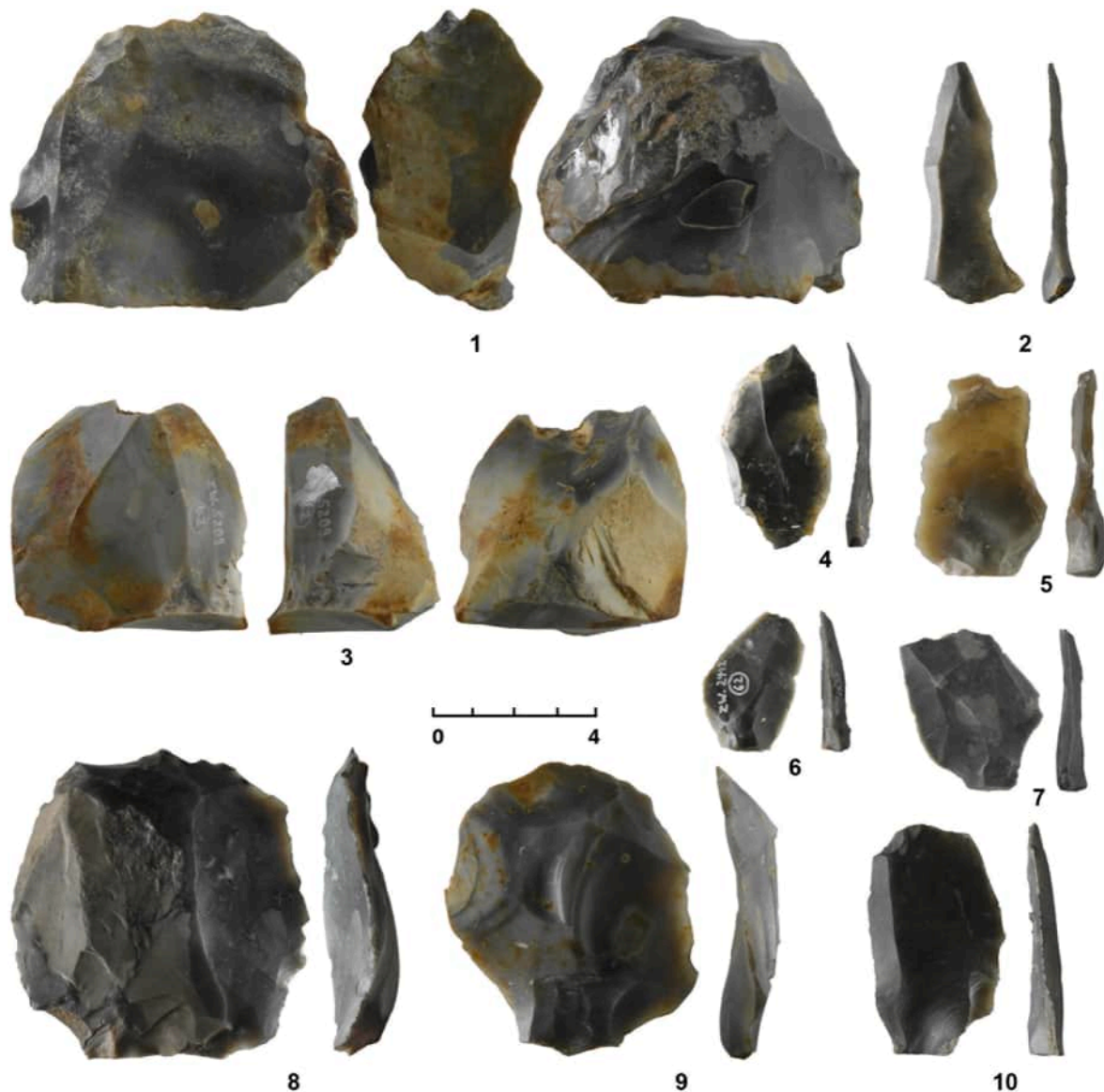


Fig. 3. Levallois preferential core (1, 3), Levallois flake (2, 4, 5, 6, 7, 10), and Levallois preferential flake (8, 9) of Zwochau.

frequency of hinged blanks and a significant decrease in the angle of the striking platform (Picin, 2016). In the flake assemblages, are common byproducts of the maintenance of the core convexity and cortical flakes (Table 2, Fig. 6). Levallois preferential flakes are very few whereas Levallois unidirectional flakes were numerous. The analysis documented also one Levallois point, three bidirectional, and one orthogonal Levallois flakes (Table 2). The assemblage of retouched tool is dominated by scrapers and *Keilmesser* knives (Table 3, Fig. 6) (Picin, 2016).

The lithic assemblage of level B includes 3966 flint and 25 quartzite artefacts (Table 2) scattered in 6 main areas. These latter lithic items suffered surface weathering alterations and were not included in this study. The technological analysis documents the most commonly use of Levallois technology in the modalities preferential (n°22) and recurrent unidirectional (n°12) whereas bidirectional (n°3), centripetal (n°3), and orthogonal (n°2) types were recorded less frequently (Fig. 7). In the assemblage, nine undetermined Levallois cores with an opportunistic detachment of few more flakes after the exhaustion of the ventral convexity were also discovered. The analysis indicates the common use of hierarchized methods in the modality unidirectional (n°7), bidirectional (n°10) and centripetal (n°13). Secondary *chaînes opératoires* are characterized by discoid (n°9), simple unidirectional (n°22), orthogonal

(n°3) and cores with an overshoot flake removal (n°8). As in level A, the behavior of detaching more flakes from the same striking platform has been documented in some simple unidirectional, bidirectional and Levallois preferential cores (Picin, 2016). Since the production of these atypical Levallois flakes would not reenter in the definition of Levallois preferential *sensu stricto* (Boëda, 1994), these artefacts are interpreted as secondary preferential flakes, an intermediate term for distinguishing the technical variability present at Königsau. This flaking strategy entailed the numerous productions of knapping accidents and in particular of hinged flakes (Table 2). The flake assemblage is also characterized by high percentage of cortical flakes and core-edge removal flakes. Levallois recurrent unidirectional flakes (n°33) are abundant whereas Levallois preferential (°19), Levallois recurrent bidirectional (n°10), Levallois orthogonal and Levallois point (n°2) are recorded in lesser frequency (Fig. 7). The category of retouched artefact is mostly composed of scrapers (n°19) whereas *Keilmesser* and by-products of their manufactures are absent (Table 3, Fig. 7) (Picin, 2016).

The lithic assemblage of level C comprises 295 flint, 1 quartzite, and 1 quartz artefacts (Table 2) scattered in 2 main areas. Due to the surface weathering alterations the quartzite and quartz artefacts are not

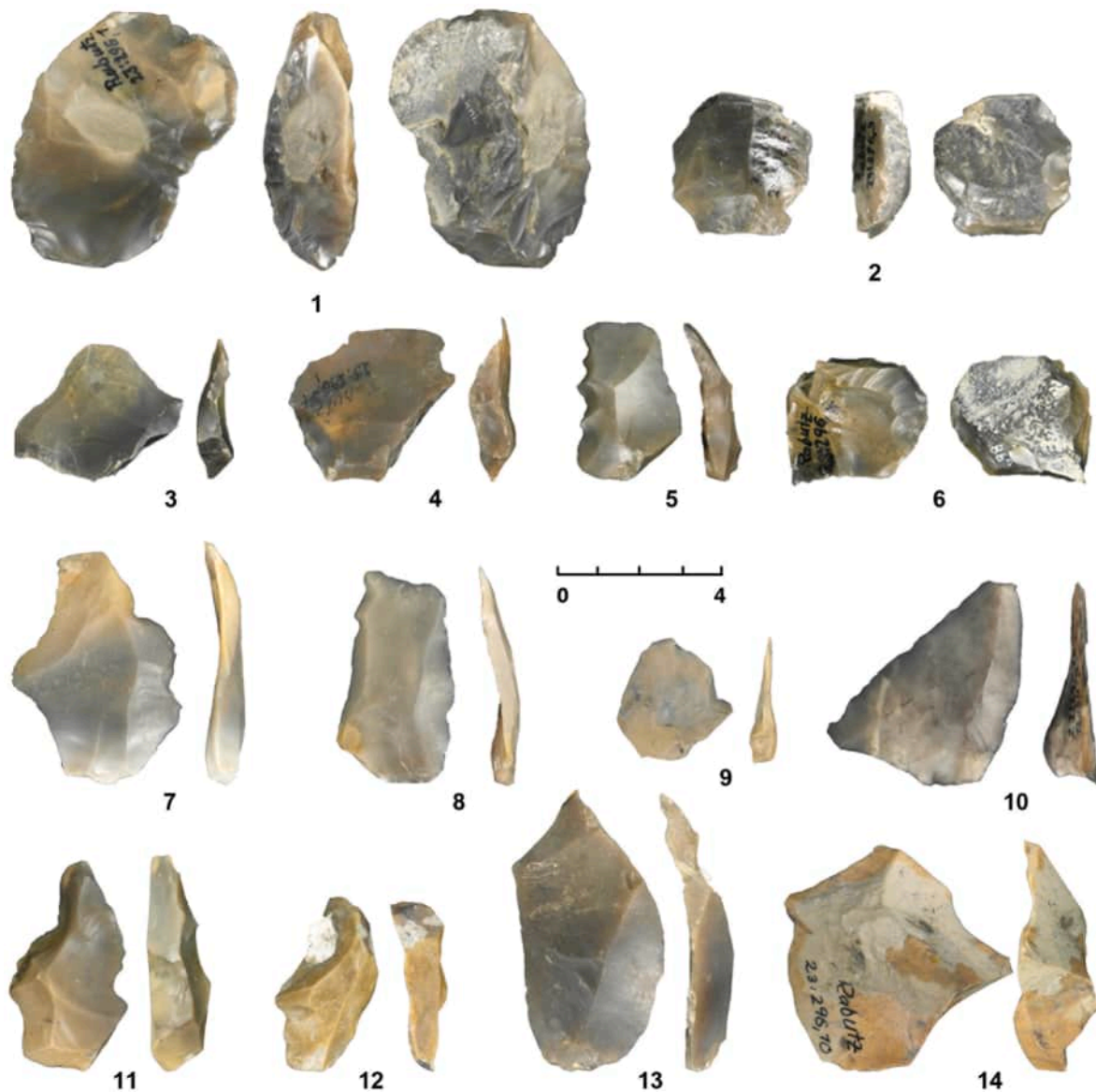


Fig. 4. Bidirectional core (1), unidirectional core (2, 6), Levallois flake (3), unidirectional flake (7, 8, 10) core-edge removal flake (9, 11, 13), pseudo-Levallois point (4, 14), cortical core-edge removal flake (12), and denticulate (5) of Rabutz.

included in the study. The technological analysis reveals that the few cores recovered are characterized by a marked expediency (Picin, 2016). The flake assemblage indicated the presence of cortical flakes and by-products of the core configuration and production (Table 2, Fig. 8). The use of Levallois is attested indirectly by the recovery of few Levallois flakes and by-products of the preparation of the convexity. The toolkit is composed of scrapers, Quina and demi-Quina scrapers, and one *Keilmesser* (Table 3, Fig. 8) (Picin, 2016).

4.6. Comparison of the lithic assemblages

The technological analyses of the lithic assemblages of sites considered in this study indicate some differences in the technical behaviors over time (Table 2). Since the end of MIS 8, Levallois technology is present in Markkleeberg and Zwochau but its use is limited and its frequency increase in MIS 3 at Königsau (Table 2). Simple unidirectional cores and hierarchized unidirectional cores are more common in the area throughout the Middle Paleolithic while discoid technology remains a secondary operative chain used in opportunistic contexts rather than for the production of centripetal or core-edge flakes (Table 2).

Another discrepancy documented in the analyses is the different degree of cores reduction. After the logarithmic transformation, the comparison of the length and weight values in different categories of cores shows a clear chronological differentiation (Fig. 9). At Markkleeberg and Zwochau, Levallois and hierarchized cores were discarded at an early stage of reduction whereas, at Neumark-Nord 2/0 and Königsau, cores are smaller and more extensively reduced (Fig. 9). An overlapping in size is documented only in discoid cores although the cores values of Markkleeberg are again clustered in the upper area of the graph (Fig. 9). A comparison of Kruskal-Wallis test on the Carination Index confirms that only discoid cores have no significant differences between the median values while in Levallois and hierarchized cores statistically significant variations is documented (Table 4). This different pattern of raw material economy is also evident comparing the mean values of flakes length (Table 5). During the Early Middle Paleolithic, cortical and semi-cortical flakes are longer than those found in the other younger sites whereas flakes have similar values (Table 5). It is worth noting that the lithic items of Neumark-Nord 2/0 are the smallest between the sites (Tables 5 and 6).

Another chronological difference between the sites is the number



Fig. 5. Levallois preferential core (1, 2), hierarchized unidirectional core (3), unidirectional core (4), *Keilmesser* (5–8), leaf point (9–10), and leaf scraper (11) of Neumark-Nord 2/0.

and type of retouched tools. In Markkleeberg and Zwochau, the number of stone tools is small and include few scrapers and denticulates (Table 3). During the Eemian, a similar pattern is documented in Rabutz where few retouched tools are found (Table 3). At the onset of the Weichselian, a sharp increase is recorded in Neumark-Nord 2/0 where scrapers are found in great amount (Table 3). During the MIS 3, in Königsau, the number of stone tools decreases but it remains bigger than in the Early Middle Paleolithic (Table 3). The comparison of the length of scrapers shows that median values in Markkleeberg and Neumark-Nord 2/0 are similar while in Königsau the stone tools are bigger (Fig. 10). During the Late Middle Paleolithic, the toolkit in Neumark-Nord 2/0 and Königsau was improved with the introduction of asymmetric bifacial knives and bifacial scrapers. In Neumark-Nord 2/0, the length of bifacial tools ($n = 21$ $\sigma = 38.6$ mm S.D. = 11.9 mm) is similar to scrapers ($n = 66$ $\sigma = 38.3$ mm S.D. = 11 mm) and Quina/demi-Quina scrapers ($n = 38$ $\sigma = 39.8$ mm S.D. = 10.4 mm) with no significant variations in median values (Kruskal-Wallis test $p = 0.6494$). Conversely, in Königsau level A, the length of bifacial tools ($n = 8$ $\sigma = 92.4$ mm S.D. = 32.9 mm) is greater than scrapers ($n = 35$ $\sigma = 51$ mm S.

D. = 19.3 mm) and demi-Quina scrapers ($n = 3$ $\sigma = 37.6$ mm S.D. = 10 mm). This difference is also statistically significant (Kruskal-Wallis test $p = 0.0009$). A similar pattern is documented in level C where the *Keilmesser* (length = 91.1 mm) is bigger than scrapers ($n = 3$ $\sigma = 48.3$ mm S.D. = 17.8 mm) and Quina/demi-Quina scrapers ($n = 7$ $\sigma = 54.4$ mm S.D. = 18.6 mm).

Another aspect investigated in this study is the integrity of the operative chains in order to understand the patterns of mobility and settlement dynamics at the sites. Firstly, is examined the differences in length between flakes in each site. A significant difference is documented between the median values of cortical, semi-cortical and no-cortex flakes at Markkleeberg (Kruskal-Wallis test $p < 0.0001$), Zwochau (Kruskal-Wallis test $p < 0.0001$), Neumark Nord N2/0 (Kruskal-Wallis test $p = 0.0019$), Königsau level A (Kruskal-Wallis test $p = 0.0239$), level B (Kruskal-Wallis test $p < 0.0001$) whereas no difference is found in Rabutz (Kruskal-Wallis test $p = 0.0946$), and Königsau level C (Kruskal-Wallis test $p = 0.9331$).

Successively, the number of some categories of flakes is compared with the amount produced during experimental lithic series. Taking in

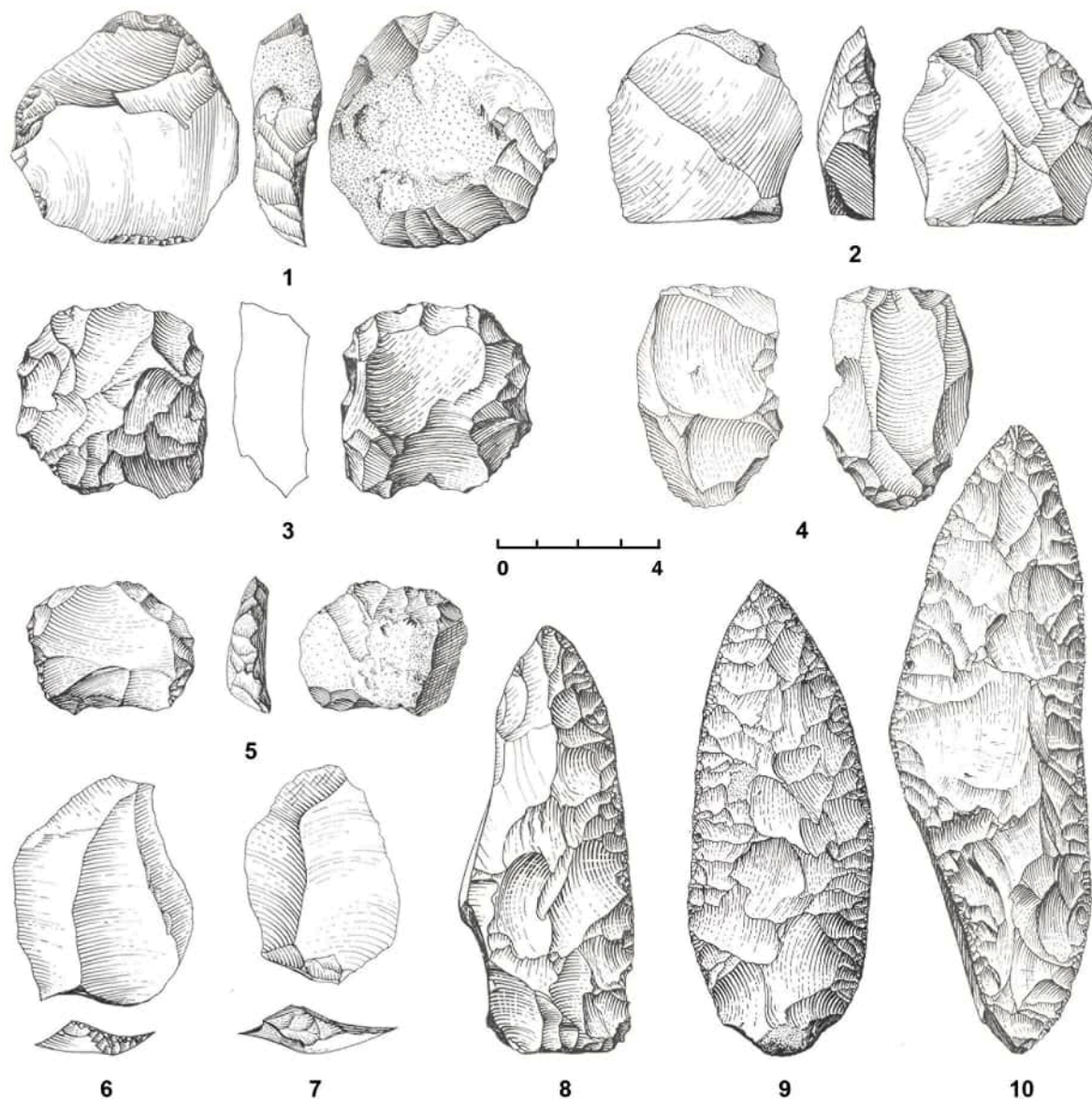


Fig. 6. Levallois preferential core (1, 5), Levallois recurrent unidirectional core (2), discoid core (3), unidirectional core (4) Levallois flake (6, 7), *Keilmesser* (8, 10), biface (9) of Königsau level A (modified from Mania and Toepfer, 1973).

account that Levallois and discoid cores were not fully exploited, the flake productivity rate is reduced (Table S1) than the original computation performed in Picin (2016) and Picin and Vaquero (2016). The calculation of the expected number of Levallois flakes by the number of Levallois cores, using a reduced flake productivity rate of 2 blanks for Neumark-Nord 2/0 and 5 blanks for the other sites, documents that several Levallois flakes are missing and, most likely, exported off-site (Table S1). The number of missing artefacts is also big when other categories of flakes are considered (Tables S2–S3). In hierarchized and un-hierarchized methods, core-edge removal flakes and pseudo-Levallois points are common byproducts for maintaining the core convexities (Delagnes, 1990; Boëda, 1993, 1994; Mourre, 2003; Martí et al., 2009; Picin, 2018). In each site, the deficit of core-edge removal flakes is significant except in Königsau level A where the number is comparable with the experimental series (Table S2). The discrepancy between the number of pseudo-Levallois point in archaeological and experimental data is instead reduced but present in Markkleeberg, Neumark-Nord 2/0 and Königsau A (Table S3).

5. Discussion

During the late Middle and Late Pleistocene, the territory stretched between the regions of Saxony and Saxony-Anhalt in Eastern Germany documented great environmental shifts changing from tundra and steppe during the cold phases to forested habitats during the climatic amelioration (Fletcher et al., 2010; Ehlers et al., 2011). Since during the cold stages the ecological settings and the high seasonality of resources were challenging, this area documented continuous re-settlements by Neanderthals from the end of MIS 8 with demographic expansions during MIS 5e, MIS 5c, MIS 5a and MIS 3 (Gaudzinski-Windheuser et al., 2014; Picin, 2016, 2018, 2020; Lauer and Weiss, 2018b; Picin et al., 2020; Gaudzinski-Windheuser et al., 2023a,b). Although these migrations were spaced out by several millennia, the technological approaches in the area remain similar over time without any sharp technological breaks conversely to the pattern documented in other European territories (e.g., Western France (Delagnes et al., 2007)). The introduction of asymmetric bifacial tools since MIS 5c/5a did not influence the methods of flake production. The unidirectional reduction scheme was continuously applied to different knapping methods

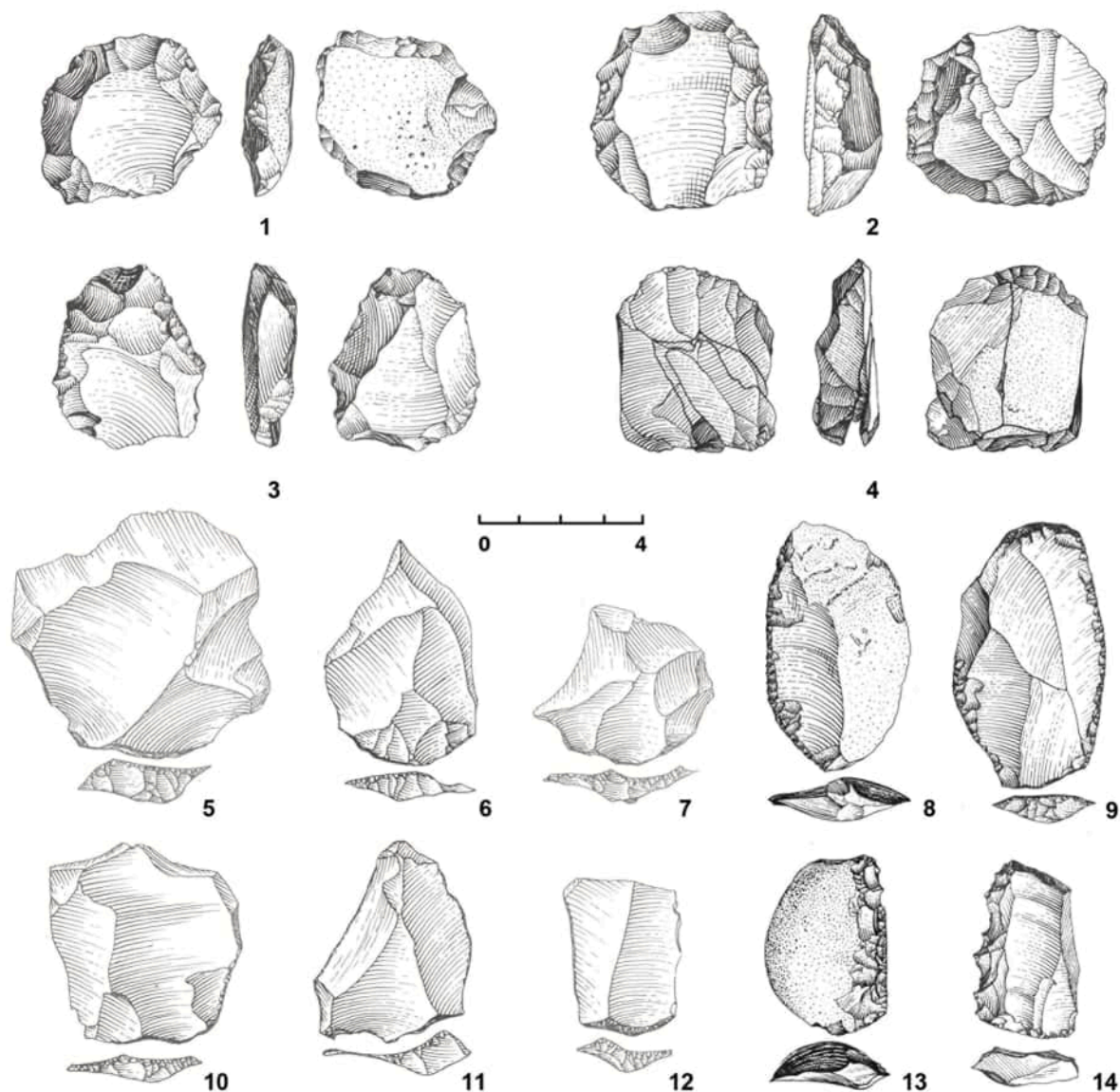


Fig. 7. Levallois preferential core (1, 2, 3), Levallois recurrent bidirectional core (4), unidirectional core (3, 4), Levallois flake (5–7, 10–12), scraper (8, 9, 13) and denticulate (14) of Königsau level B (modified from Mania and Toepfer, 1973).

remaining a common technological substrate during the whole Middle Paleolithic while centripetal methods, frequent in the Mediterranean glacial refugia (e.g., (Vaquero and Carbonell, 2003; Picin et al., 2013; Torre et al., 2013; Dogandžić and Đuričić, 2017)), are used little and in opportunistic contexts.

Generally, Levallois technology is interpreted as a key technical improvement in which the preparation of the core's convexities allows a decrease of the blank thickness and an increase of the flake productivity (Eren and Lycett, 2012; Picin and Vaquero, 2016), a feature that was more appealing during longer foraging movements (e.g., (Geneste, 1988; Delagnes and Rendu, 2011; Picin and Carbonell, 2016)). In eastern Germany, Levallois technology was present but did not dominate the cultural landscape of the area, except in Königsau level B (Table 2). Simple unidirectional method remains over time the most common technical behavior implying that elongated blanks were sought-after both in forested and open environments. Contrariwise to support a techno-cultural stasis lasted several millennia, this study reveals that this technical continuity could be related to the changes in raw material size occurred during the Middle Pleistocene. In North-Central Germany, erratic flint nodules were transported by the advancement

of the ice-sheet from Fennoscandia and, during the major glaciation events, the area under study was at the edge of the ground moraine (Ehlers et al., 2011). The fluvial erosion and the formation of the Early Saalian Main Terrace (*Hauptterrasse*), during MIS 8, exposed the Elsterian ground moraine (MIS12) making available layers with high content of erratic flint. Nodules recovered at Markkleeberg and Zwochau confirm the presence of cobbles large at up to 5 kg (Pasda and Pasda, 1996; Picin, 2020). Conversely, the Drenthe ground moraine (MIS 6) transported smaller flint nodules (Picin, 2016, 2021). Although in other locations, large nodules could have been available as the examples documented in Neumark-Nord 2/0, where erratic blocks weighing up to 25 kg were found (Brühl and Laurat, 2010), and in Königsau level A and C, where bigger cobbles were selected for shaping bifacial tools (Picin, 2016), the lithic analysis of Late Middle Paleolithic assemblages indicates the use of small nodules (Tables 4–6, Fig. 9). This evidence is supported by the size of flint pebbles discovered at Neumark-Nord 2/0 (*weight*: $n = 26$, $\sigma = 73.35$ gr, S.D. = 69.94 gr; *length*: $n = 26$, $\sigma = 53.4$ mm, S.D. = 17.92 mm) and Königsau level B (*weight*: $n = 3$, $\sigma = 47.6$ gr, S.D. = 9.8 gr; *length*: $n = 3$, $\sigma = 46.3$ mm, S.D. = 3.2 mm).

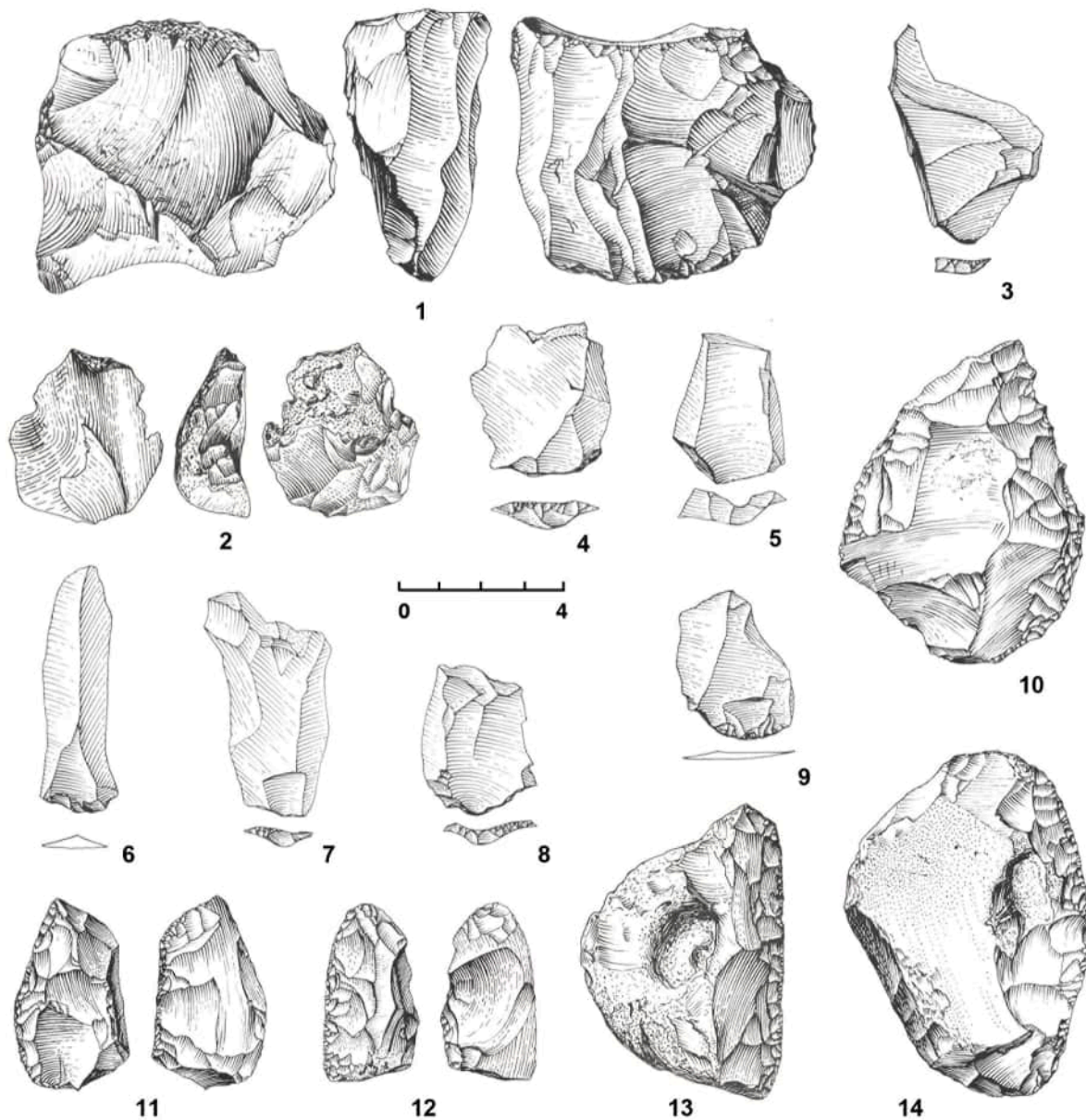


Fig. 8. Bidirectional core (1), core-on-flake (2), pseudo-Levallois points (3), Levallois flakes (4, 5, 8), flake (6, 7, 9), demi-Quina scraper (11, 12), Quina scraper (10, 13), *Keilmesser* (14) of Königsau level C.

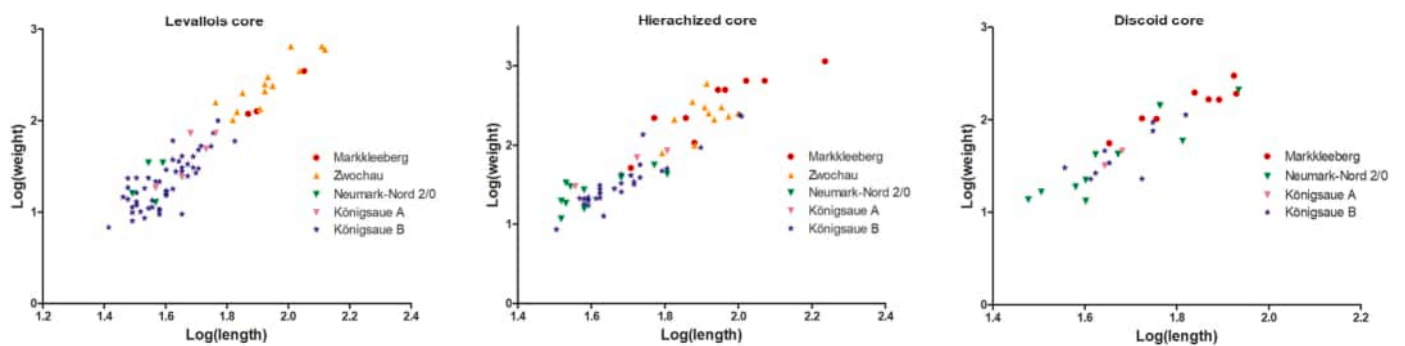


Fig. 9. Bivariate plot of the relation between the Log(length) and the Log(weight) of different categories of cores of Markkleeberg, Zwochau, Neumark-Nord 2/0, Königsau level A and B.

Table 4
Counts, mean (μ) and standard deviation (σ) of the Carination Index of the core assemblages.

	Levallois core			Hierarchized core			Discoid core		
	N°	μ	σ	N°	μ	σ	N°	μ	σ
Markkleeberg	3	29.53	4.87	9	58.24	27.16	9	39.91	18.62
Zwochau	13	44.78	14.12	11	66.68	57.34	2	49.58	15.75
Neumark-Nord 2/0	4	14.63	4.31	4	18.65	7.21	10	31.59	12
Königsau A	5	14.62	3.42	3	33.1	2.84	2	20.2	29.4
Königsau B	50	19.63	21.45	30	25.73	9.87	9	29.4	12.08
<i>Kruskal-Wallis test</i>	$p < 0.0001$			$p < 0.0001$			$p = 0.0816$		

Table 5
Counts, mean (μ) and standard deviation (σ) of the length of cortical and no-cortical flake.

	100-50%			49-1%			No Cortex		
	N°	μ	σ	N°	μ	σ	N°	μ	σ
Markkleeberg	46	57.6	34.2	121	49.6	27.8	165	39.4	19.2
Zwochau	80	50.1	26	167	50	22.1	244	39.6	19.8
Rabutz	8	48	15.2	14	37.2	15.3	44	35	14.3
Neumark-Nord 2/0	129	29.8	8.7	268	31.4	29.8	322	28.7	8.7
Königsau A	46	35.8	12.5	112	39.0	16.8	222	33.7	13.3
Königsau B	127	36.0	14.1	416	37.7	15.1	976	32.6	11.92
Königsau C	3	33	8	19	32.3	8.8	52	33.1	9.38

Table 6
Counts, mean (μ) and standard deviation (σ) of the length of Levallois flakes, core-edge removal flakes and pseudo-Levallois points.

	Levallois flake			Core-edge flake			pseudo-Lev. point		
	N°	μ	σ	N°	μ	σ	N°	μ	σ
Markkleeberg	11	53.82	22.71	27	47.74	25.85	2	82.5	7.77
Zwochau	17	54	19.2	46	47.02	24.44	2	41.5	13.44
Rabutz	2	39	11.31	9	38.56	17.1	5	37.4	13.39
Neumark-Nord 2/0	1	29	0	62	29.98	9.89	8	26.5	10.03
Königsau A	30	41.27	12.75	39	30.46	11.9	8	32	11.98
Königsau B	74	35.73	11.96	216	35.09	12.02	73	32.5	10.76
Königsau C	4	34.75	4.27	9	31	8.98	2	29	7.07

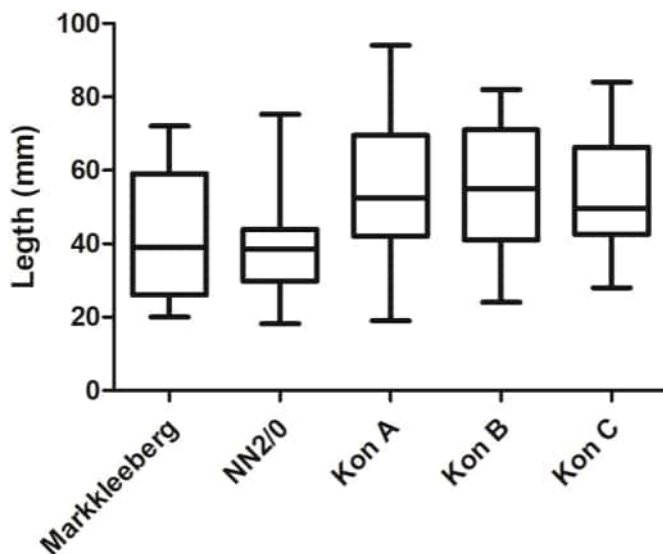


Fig. 10. Comparison of the length of scrapers in Markkleeberg, Neumark-Nord 2/0 and Königsau level A, B and C.

These differences in size between the Elsterian and Drenthe flint nodules influenced the technical behaviors. In Markkleeberg and Zwochau, the abundant availability of high-quality raw material promoted loss-making behaviors with the discard of prepared cores after few

flaking events and reduction strategies focused on the production of large flakes (Tables 2 and 3) (Picin, 2018, 2020). Conversely, during the Late Middle Paleolithic, the reduced size of the flint nodules encouraged more intensive exploitation of the pebbles and ramified operative chains. In the open-air site of Rabutz, the few cores discovered were made on chunks, fragments and flakes (Table 2). In Neumark-Nord 2/0, the small flint pebbles were exploited unidirectionally in order to achieve longer blanks that often were also turned into core-on-flakes (Table 2) (Picin, 2021). In Königsau, the cores are hyper-exploited and the repeated unidirectional detachments produced secondary Levallois preferential flakes or cores with a pyramidal morphology, as consequence of the significant decrease of the angle of the striking platform (Picin, 2016). Therefore, while in the Early Middle Paleolithic, the production of unidirectional flakes could have been related to foraging strategies in the context of high mobility, in the Late Middle Paleolithic it was more likely a technical expedient for exploiting more efficiently the core volume. These approaches were not restricted to the investigated area but common also in other Middle Paleolithic open-air sites of north-eastern Germany, where the main source of raw materials was Erratic flint (Weber, 1990; Weber and Litt, 1991; Brühl and Laurat, 2010; Pop, 2014; Weiss, 2016; Hein et al., 2021).

Another aspect investigated in this study is the understanding of the patterns of settlement dynamics at the sites. In Markkleeberg, the frequencies of lithic items is very low (1–3 artefacts by m^2) while in Zwochau is higher (8–36 artefacts by m^2) (Picin, 2020). Cortical and core-management flakes are abundant in both lithic assemblages suggesting that most of the decortication activities and preparation of the core convexities were carried out at the sites (Table 2). However, at Markkleeberg conjoining flakes and cores are absent implying that

nodules arrived at the site at different stages of preparation and, probably, cores were also exported off-site within core-edge removal flakes and pseudo-Levallois points (Tables S2–S3) (Picin, 2020). Conversely at Zwochau, the conjoining of some cortical and simple flakes, and of several blanks with a Levallois recurrent unidirectional core allows to identify discrete knapping events at the riverbank. Therefore, while Markkleeberg could be interpreted as a palimpsest of short-term occupations spread in time, at Zwochau, the fluvial terrace was used as a lithic workshop for the production of Levallois flakes and core-edge Levallois flakes (Tables S1–S2) intended to be transported to other locations (Picin, 2020).

In Rabutz, the flakes assemblage is composed of several blanks from different technological phases, including Levallois artefacts, but hierarchical and un-hierarchical cores are missing (Table 2). The few cores discovered were reduced opportunistically and aimed to the production of the simple flakes. Flakes refittings are absent and the stone tools were distributed over a wide surface. This data supports the hypothesis of repeated and short Neanderthals' visits at the lakeshore.

In Neumark-Nord, the exposure of the level NN2/0 and the following bioturbation activities strongly affected the integrity of the archaeological floor with the vertical displacements of the faunal and lithic remains (Brühl and Laurat, 2010). The site is extremely low density with an average of 6 lithic items by m². The technological analysis pointed out high frequencies of cortical flakes and byproducts of the core managements (Table 2) but the similar size of cortical and no-cortical flakes (Table 5) suggests that cores at different degree of reduction were transported at the site (Picin, 2021). The core reduction is aimed to the production of simple unidirectional flakes whereas the byproducts of hierarchized and un-hierarchized cores are very few. The comparison with the experimental lithic series indicates that some Levallois, core-edge removal flakes and pseudo-Levallois points are missing probably due to the transport of the cores off-site as part of the toolkit (Tables S1–S3). In comparison with the other sites, Neumark-Nord NN2/0 is abundant of retouched tools (Table 2). The small dimension of the blanks probably favored the reshaping of the blunted cutting-edges instead of promoting the production of other flakes. This behavior is observed also in the use of thick cortical flakes, lithic items that generally are discarded, that were instead converted in Quina and demi-Quina scrapers (Table 3). In the assemblage of retouched tools, were also found some symmetrical (*Faustkel*) and asymmetrical (*Keilmesser*) bifacial knives (Table 3) (Picin, 2021). The study shows that the settlement at Neumark-Nord 2/0 was ephemeral with repeated short-term visits aimed to bivouac and butchering horses, bison, and cervids.

In Königsau, the Neanderthals settlements at the lakeshore are located in different areas scattered over few hundred meters (Mania and Toepfer, 1973; Picin, 2016). The Micoquian level A and C shows some similarities not only in terms of production of symmetrical and asymmetrical bifacial knives but also in the goals of the flake knapping, aimed to the production of Levallois and unidirectional flakes. Moreover, the small number of cores in comparison with the frequencies of cortical flakes, byproducts of core-managements artefacts and Levallois flakes suggest an export off-site of Levallois cores (Table 2, S1–S3) (Picin, 2016). In level B, although Micoquian stone tools are absent, the knapping activities had similar targets (Table 2). However, the main difference is identified in the mobile toolkit characterized by the export off-site of a large number of Levallois flakes and core-edge removal flakes (Table 2, S1–S3) (Picin, 2016). The spatial distribution and the fragmentation of operative chains suggests that the three archaeological levels A, B, and C were palimpsests of repeated short-term occupations by Neanderthals that temporally visited the lakeshore.

These results on the settlement dynamics point out that Neanderthals occupying the fluvial terraces and the lakeshores in the investigated area moved frequently in the landscape and the locations analyzed were not preferred for base camps and longer stays. Unfortunately, the faunal remains are scanty impeding to understand the seasonality of the

hunting activities and the stays. Although longer settlements could have occurred in other Eemian archaeological sites such as Neumark-Nord 2/2 (Gaudzinski-Windheuser and Roebroeks, 2014) or Neumark-Nord 1 (Gaudzinski-Windheuser et al., 2023a), the evidence from Rabutz, and the nearby sites of Taubach (Moncel and Rivals, 2011) or Gröbern (Gaudzinski-Windheuser et al., 2023b) support the hypothesis of temporal visits.

5.1. Puzzling Neanderthals movements to eastern Germany

A broad consensus suggests that Neanderthals living in north-central Europe experienced recurrent extinctions during the glacial stages and these territories were recolonized by new groups from the southern refugia in conjunction with the climatic ameliorations (Hublin and Roebroeks, 2009; Roebroeks et al., 2011). Thus far, the “glacial refuge model” with migrations to northern direction has been confirmed by technological changes in North France (Goval, 2012) and England (Wragg Sykes, 2017) as well as isotopic studies on Neanderthal fossils from Goyet Cave (Wißing et al., 2019). Conversely, studies on raw materials transport in the western Mediterranean reveal frequent movements to the southern territories (Slimak and Giraud, 2007; Lebegue and Wengler, 2014) whereas aDNA analyses, so far, indicate long-distance migrations from Central Europe to Northern Caucasus (Hajdinjak et al., 2018; Picin et al., 2020) and Altai (Slon et al., 2018; Mafessoni et al., 2020; Skov et al., 2022). Therefore, although in phylogeographic studies on animal, small mammals and plants strongly suggest migration northwards (Hewitt, 2000; Stewart and Lister, 2001; Koenigswald, 2007; Stewart et al., 2010; Baca et al., 2017), the archaeological record of the Middle Paleolithic portrays a more complex scenario.

The chronometric data from sites in the area between Saxony and Saxony-Anhalt indicates Neanderthals' occupations during the end of MIS8, early MIS 7, MIS 5e, MIS 5c/5a and MIS 3. In the Early Middle Paleolithic, archaeological evidence of eastern Germany shows more similarities with sites from North-Central Europe rather than those from the glacial refugia (Picin, 2018, 2020). The high frequencies of simple unidirectional cores and the progressive evolution of Levallois technology from the substrate of hierarchized recurrent unidirectional method has been documented in other riverbanks locations, such as at Kesselt-Op de Schans (Van Baelen, 2017), Maastricht-Belvédère (Roebroeks, 1988; De Loecker, 2005), Biache-Saint-Vaast (Hérison, 2012) and Purflett (White and Ashton, 2003; Moncel et al., 2020). Conversely, in southern regions, technological approaches are different, and un-hierarchized and hierarchized centripetal methods are used in higher frequencies (Kozłowski, 1982; Moncel and Combier, 1992; Jarry et al., 2007; Ginter et al., 2011; Picin et al., 2013; Santonja et al., 2014; Villa et al., 2016; Soriano and Villa, 2017; de Lombera-Hermida et al., 2020; Fernández-Peris et al., 2020). This discrepancy could be the result of different regional trajectories in the elaboration of the Levallois technical developments rooted in the Acheulean bifacial and/or core technologies (Wiśniewski, 2014; Hérison et al., 2016; Picin, 2018, 2020; Moncel et al., 2020). These different approaches could be related also to the different strategies of exploitation of the territories. Although the climatic deterioration of MIS 8 affected the landscape of the southern regions, as showed by the increase of steppic species in the pollen spectra of the Tenaghi Philippon (Tzedakis et al., 2003; Fletcher et al., 2013), the ice masses in Northern Europe were smaller than in MIS 12 and MIS 6, and the glacier expanded in Central Asia, covering the territories east of the Urals (Hughes et al., 2020). In these cold but ice-free territories of Central Europe, Neanderthals could have prompted the development of large stone tools for coping with the hunting of cold adapted species, animals that migrate over large distances. The persistence in the archaeological record of these technological approaches suggest that these strategies continued to be successful also during the climatic amelioration of MIS 7 (Roebroeks, 1988; De Loecker, 2005; Hérison, 2012).

After the glacial stage of MIS 6, a period in which the Fennoscandian

ice cup expanded up to Central Germany (Ehlers et al., 2011) and most likely caused an extended fragmentation of Neanderthals' groups, the rapid warming of the climate of MIS 5e promoted the development of a thick deciduous forest throughout Europe, including the northern areas previously occupied by glaciers and permafrost (Gaudzinski-Windheuser and Roebroeks, 2011; Gaudzinski-Windheuser et al., 2014). Some scholars argue that these densely forested environments were unsuitable for Neanderthals (Gamble, 1986; Defleur and Desclaux, 2019; Bringmans, 2024), suggesting similar arguments on the perceived scarcity of carbohydrate-rich plants and protein-rich fauna in tropical forest (e.g. (Bailey et al., 1989), but see (Wedage et al., 2019a, 2019b; Picin et al., 2022)). Although the number of sites is low in comparison with the Late Middle Paleolithic, data from Central Europe reveals that Neanderthals were able to fully exploit the interglacial faunal and vegetal resources (Toepfer, 1958; Dusseldorp, 2009; Gaudzinski-Windheuser et al., 2014, 2018, 2023, 2023; Dabkowski et al., 2016; Gaudzinski-Windheuser et al., 2023a,b). From a technological perspective, the simple flaking methods and the reduced dimension of the stone tools documented at Rabutz are common in other neighboring sites such as Neumark-Nord 1 (Brühl and Laurat, 2010), Neumark-Nord 2/2 (Pop, 2014; Pop et al., 2018), Taubach (Moncel, 2004; Moncel and Rivals, 2011), Gröbern (Weber and Litt, 1991), Grabschütz (Weber, 1990) and far north at Lichtenberg (Hein et al., 2021). In Central-Eastern Europe between the Eemian and the beginning of the Weichselian, the production of small stone tools, known as Taubachian (Valoch, 1984), was widespread in Poland (Cieśla, 2013; Cieśla and Valde-Nowak, 2016; Valde-Nowak et al., 2016), Slovakia (Wenzel, 2007), Czech Republic (Moncel and Neruda, 2000; Neruda, 2012) and Hungary (Moncel, 2003). Although it is tempting to associate this microlithic production to the diffusion of some Neanderthal groups from the Pannonian basin to Eastern Germany, the contexts of this technical behaviors indicate several differences. While in Czech Republic (e.g., Kulna layer XI) (Moncel and Neruda, 2000) or in Poland (at Ciemna layer VI, at Oblazowa layer XXb, XIX, XVII) (Valde-Nowak and Nadachowski, 2014; Valde-Nowak et al., 2016) the use of small pebbles was a cultural choice of the Neanderthals groups since other bigger cobbles were available, at Rabutz or Neumark-Nord 2/2 it was imposed by the size of the flint nodules available.

The deteriorations of the climatic conditions at the beginning of the Last Glacial caused a population contraction in Eastern Germany and the recolonizations of Central Europe was improved with the development of a new stone tool, the asymmetric bifacial knife (or *Keilmesser*) (Bosinski, 1967; Jöris, 2006). This innovative retouched tool, particularly efficient in the European periglacial environments from MIS 5c to MIS 3 and diffused from western France to Poland, the northern Caucasus and Siberia, is known as Central-Eastern European Micoquian (CEEM) (Jöris, 1992, 2001; Cieśla and Valde-Nowak, 2012; Demidenko, 2015; Blaser and Chaussé, 2016; Doronicheva et al., 2016; Weiss, 2016; Frick and Floss, 2017; Golovanova et al., 2017; Wiśniewski et al., 2019; Kolobova et al., 2020). The earliest evidence at Neumark-Nord 2/0 indicates that the *Keilmesser* artefacts and bifacial knives were rooted in the technological context of the Quina scrapers, and in some tools, the extension of the retouch on the dorsal side is very similar to the scalar/steep retouch. The ventral surface is often less modified, and, in some examples, invasive and large detachments were performed for regularizing the cutting edges rather than for creating two convex surfaces (Picin, 2021). During MIS 3, conversely, at Königsau, the *Keilmesser* are characterized by the use of plano-convex reduction, the shaping of a long, straight cutting edge, and the recurrent rejuvenation of the cutting edges (Picin, 2016). Therefore, once this new stone tool entered in the repertoire of Neanderthals in Central Europe, similar approaches were applied to different matrix of raw materials resulting in a varied typological list (Bosinski, 1967). Although a close association between the *Keilmesser* shapes and chronology has been proposed (Jöris, 2003), a recent chronometric reassessment of the Middle Paleolithic deposits of Ciemna Cave challenges the hypothesis of the presence of

"*Prądnik Keilmesser*" as temporal marker and limited to MIS 4 (Valde-Nowak et al., 2014).

In terms of size, the comparison of the length of asymmetrical bifacial knives in several sites in eastern Germany, dated MIS 5c/5a and MIS 3, show similar median length values (Kruskal-Wallis test $p = 0.2716$) whereas significant statistical differences are present only when samples from Neumark-Nord 2/0 are added (Kruskal-Wallis test $p < 0.0001$) (Table S4). This data suggests that even if the raw material was small, slighter bigger Erratic flint pebbles were selected for the production of asymmetric bifacial knives. From a technological perspective, the development of the *Keilmesser* at Neumark-Nord 2/0 shows several similarities with the open-air site of Tata, where small pebbles were shaped bifacially in a similar way (Dobosi, 2004). Although the chronometric data are still too coarse grain for identifying the area of origin and dispersal, paleogenetic data from different Neanderthal individuals suggest that, after MIS 4, the southern Micoquian fringes (eastern France and/or Hungary) could have been the sink areas that contributed to the repopulation of Central Europe during the climatic amelioration of MIS 3. Then, after the recolonization of the northern territories, other Neanderthal groups dispersed back into the Caucasus moving south across the Prut and Dniester basins (Hajdinjak et al., 2018; Picin et al., 2020; Andreeva et al., 2022).

The current data pose significant challenges in tracing the territories and origins of Neanderthal movements from glacial refugia during the Middle Paleolithic. A primary obstacle stems from the scarcity of sites in the Balkans, the central area that likely facilitated the majority of these recolonization events. Furthermore, the uneven resolution of the archaeological record hinders our ability to pinpoint when and where Neanderthal groups sought refuge in intermediate regions between the "glacial refugia" and Central Europe. Paleogenetic studies emerge as a promising solution to this dilemma, as demonstrated by the late CEEM example, which narrows down potential diffusion territories, thereby reducing the range of plausible scenarios. In conclusion, while challenges persist in tracing Neanderthals' movements, future fieldwork in key Balkan areas and advancements in paleogenetic research offer promising avenues to clarify their complex migratory patterns during the Middle Paleolithic.

6. Conclusion

This study sheds light on the intricate dynamics of Neanderthal populations in Eastern Germany during the late Middle and Late Pleistocene, particularly focusing on the region between Saxony and Saxony-Anhalt. The environmental shifts experienced in this territory, from tundra and steppe during cold phases to forested habitats during climatic amelioration, shaped the settlement patterns and adaptive strategies of Neanderthals. Notably, despite the spaced-out nature of these migrations, the technological approaches remained remarkably consistent over time, without sharp technological breaks, unlike patterns observed in other European regions. The introduction of asymmetric bifacial tools since MIS 5c/5a did not significantly influence flake production methods, with the unidirectional reduction scheme remaining predominant throughout the Middle Paleolithic. Furthermore, the technological analysis elucidates how the size differences in flint nodules between different glacial stages influenced Neanderthal technological behaviors. The availability of large erratic flint nodules during the Elsterian stage promoted loss-making behaviors and the production of large flakes, whereas smaller nodules during the Late Middle Paleolithic encouraged more intensive exploitation of pebbles and ramified operative chains. The exploration of settlement dynamics at these various sites reveals that Neanderthals frequently moved within the landscape, using the locations in fluvial terraces and lake shores as short-term occupations rather than base camps for longer stays. In conclusion, this study provides valuable insights into Neanderthal lifeways, technological adaptations, and settlement patterns in Eastern Germany during the Middle Paleolithic. By integrating archaeological,

paleoenvironmental, and lithic analysis, it contributes to a more nuanced understanding of Neanderthal behavior and their interactions with changing environmental conditions. Future research efforts should continue to integrate multidisciplinary approaches, including archaeology, paleoenvironmental studies, and genetic analyses, to further elucidate the patterns of Neanderthal adaptations and dispersals in Central Europe.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.qsa.2024.100260>.

Data availability

Data will be made available on request.

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