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## Technology and taphonomy of the Middle Paleolithic assemblage from the Uzun Mera site in Macedonia

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### ABSTRACT

The open-air site of Uzun Mera in eastern North Macedonia provides new insights into Middle Paleolithic Neanderthal behaviour and site formation processes in the understudied Balkan Peninsula. Discovered in 2017, the site spans over 1.5 km<sup>2</sup> and contains lithic artefacts affected by both cultural and post-depositional processes. Technological analysis of 33 selected artefacts reveals a Middle Paleolithic industry featuring opportunistic, Levallois, and Discoid knapping methods, primarily using locally available jasper and flint. Taphonomic investigation identified two distinct alteration phases: mechanical modifications (edge crumbling, polishing, rounding) from trampling and fluvial transport, followed by chemical patination during burial in alluvial sediments. The post-depositional alteration sequence on the artefacts tells a story of a complex and dynamic past, during which geological processes impacted the primary location of the site and displaced the lithic artefacts to their current location in the alluvial plain. This study enhances understanding of Central Balkan Paleolithic human-environment interactions while highlighting the challenges of interpreting open-air sites with complex formation histories.

### 1. Introduction

Anthropological and archaeological discussions of the Late Pleistocene of Europe are primarily concerned with the Neanderthal population and their interaction with early modern humans. For over a century, the main source of information was the Western European archaeological record, which shaped the narrative of the whole European Middle and Upper Paleolithic (Stringer, 2006; Hublin et al., 2020). In recent decades, however, the perspective has expanded geographically, chronologically, methodologically, and conceptually, and certain aspects are starting to be re-evaluated [e.g., (Harvati and Ackermann, 2022; Harvati and Reyes-Centeno, 2022; Roksandic et al., 2018)]. New hominin species, such as the Denisovans, have emerged from the paleogenetic record, revealing a complex social behaviour and interaction within and between the different phylogenetic and cultural groups (Slon et al., 2018). The current archaeological record offers a diverse picture, the patterns of which we are still struggling to understand (Finlayson et al.,

2023). This is especially valid for the Balkan Peninsula, which serves as a crossroad and a stage for interaction between the different hominin groups. The unique position of the Peninsula made it not just a refugium during glacial maximums, but also a contact zone between Europe and Southwest Asia. However, the Balkan Peninsula, and especially its hinterland, has seen relatively less investigations compared to the rest of Europe. Recent discoveries in Serbia are confirming the significance of the Central Balkan region (Alex et al., 2019; Lindal et al., 2020; Mihailović, Kuhn, et al., 2022; Mihailović, Milošević, et al., 2022; Rink et al., 2013; Roksandic et al., 2022). Here, we present information on the technology and taphonomy of the lithic assemblage of the Uzun Mera site in eastern North Macedonia, with interpretations regarding the site formation and Neanderthal behaviour in the Central Balkans.

### 2. The site

Uzun Mera is an open-air site of over 1,5 km<sup>2</sup>, located in the center of

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the Ovche Pole valley in eastern North Macedonia, at the western edge of the village of Mustafino (Fig. 1). It was first discovered in 2017 and has been continuously investigated since (Stojanovski et al., 2018; Machkovski et al., 2021; Stojanovski and Nacev, 2022). The archaeological site is spread over several sloping terraces on the left bank of the Nemanjica stream, incorporating two discrete elevations, which have become the focus of investigation. The area is an active agricultural zone, producing mainly animal feed, wheat, corn, and sunflower. The lithic artefacts are exposed on the surface with different degrees of visibility and accessibility, depending on the yearly agricultural cycles and plant cultures.

Through initial survey of the spatial distribution of artefacts, we have detected a slightly higher concentration of surface finds at the two previously mentioned elevations, which we designated as sectors North and South, and were also the reference points for the successive trench excavations (Fig. 1). After excavating ten small trenches at different positions over the large area, we have established that there is a relatively consistent stratigraphy throughout the site, and the lithic artefacts are contained in the top 1–1,3 m (Stojanovski and Nacev, 2022). The archaeological material contained in the top 0,4 m of the stratigraphy has been continuously moved around by plowing over millennia and exposed to extreme temperature fluctuations through seasonal burning of the fields and freezing winter conditions. One of the main issues regarding Uzun Mera is its site formation, i.e., the chronological relation between the formation of the archaeological layers and the moment of making and use of the stone artefacts. To understand these processes, we assess the technology of lithic production and the post-depositional alterations detectable on the artefacts. In addition, we attempt to detect any use wear traces.

### 3. Material and methods

Having in mind the formation processes and size of the site, the sampling strategy for this study aims to be representative in both horizontal and vertical perspective. The large area of the site was simplified by focusing on the two high-concentration areas (North and South sector). From both sectors, artefacts were selected from the surface/plough zone (above, Table 1) and from the undisturbed layers

underneath (below, Table 1). Thirty-three artefacts (Figs. 2–4) were selected and transported to the University of Ferrara, where a detailed assessment of the post-depositional alterations and the use wear traces was performed following previously developed and established protocols (Berruti and Arzarello, 2020).

The discipline of knapped stone taphonomy focuses on identifying and analyzing the processes that impact the appearance and context of lithic artefacts after their cultural use phases (Eren et al., 2011). Taphonomic investigations may include all the artefacts of a lithic industry. This study deals with analyzing specifically the post-depositional alterations (PDAs) that can affect each individual artefact. The post-depositional alterations (PDAs) represent diverse processes that affect a lithic artefact from the conclusion of its cultural use until its modern discovery. Throughout this period, these alterations were recorded on the surfaces of the lithic artefacts, often with multiple alterations over large time periods evident on a single artefact. Sometimes, these processes persisted for a limited duration before being replaced by other processes, which in turn were recorded by subsequent PDAs (Berruti and Arzarello, 2020). In such cases, the overlapping of different PDAs allows for the determination of their sequence, employing a conceptual methodology akin to the study of rock art (Arcà et al., 2008).

To proceed with the taphonomic study, each artefact underwent meticulous cleaning, first with warm water and soap, followed by a three-minute immersion in a solution comprised of demineralized water (75 %) and alcohol (25 %) within an ultrasonic tank, and finally air-dried. Subsequently, each artefact underwent observation and analysis in three stages: macroscopic examination with the naked eye, scrutiny through a Seben Incognita III stereomicroscope offering magnification ranging from 20x to 80x, and analysis via a metallographic microscope, Optika B 600 Met, equipped with 5 PLAN IOS MET objectives (5–10–20–50–100 ×). Most post-depositional alterations (PDAs) of mechanical origin, such as cracks, edge crumbling, fractures, and edge and ridge rounding, were readily discernible to the naked eye and subjected to detailed scrutiny under the stereomicroscope. Examination of bright spots and polished surfaces also occurred through the stereomicroscope and the metallographic microscope. Chemical modifications, including various degrees of patination, were primarily visible without magnification. Certain stains on lithic surfaces discernible at

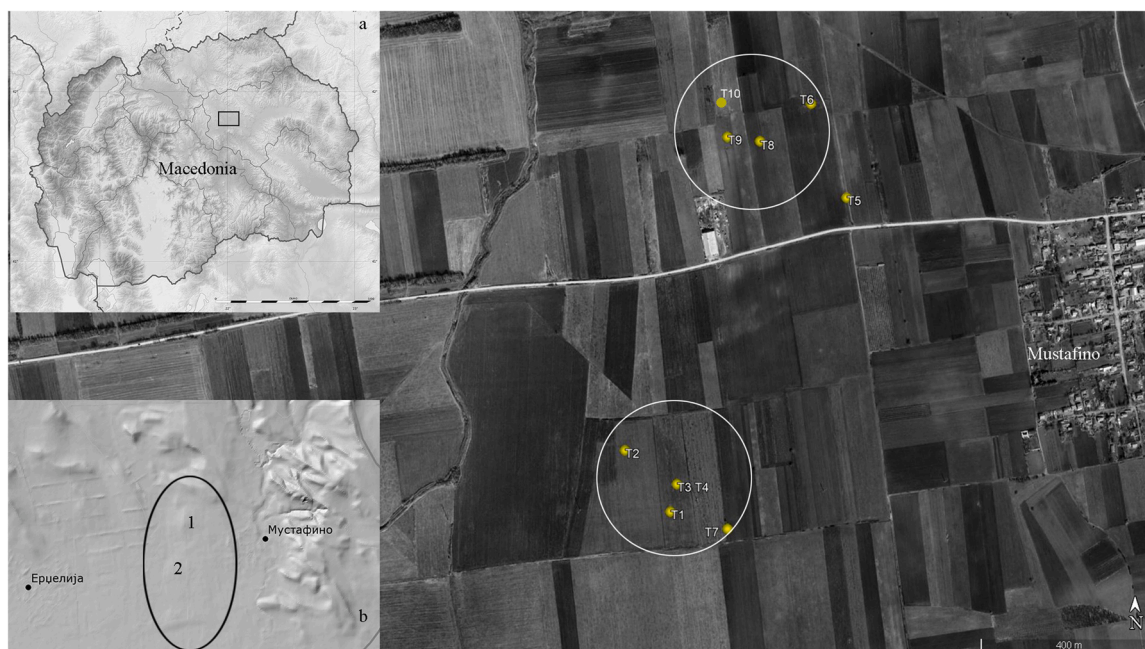


Fig. 1. The Uzun Mera site in relation to the modern day Mustafino (Мустафино). The circles mark the Northern and Southern sectors, and the points and labels mark the excavated trenches completed by 2022; a. map of Macedonia with the square marking the area of the site; b. relief map of the area, where 1 and 2 mark the two sectors.

**Table 1**

List of artefacts from Uzun Mera, used in this study.

ID (UM- )	NOTE	Type	Method	Description	direction negatives	L	l	s	PDA sequence	PDA phases
2	S/below	flake	Levallois		Unipolar	25	19	6	E-P = R	2
15	S/below	flake	Levallois		Centripetal	27	28	9	E = P = R	1
84	N/above	flake			Unipolar	30	24	7	P = R	1
93	N/above	flake	SSDA		Unipolar	24	16	10	E = P = R-M	2
103	S/above	Instrument on flake	SSDA	convergent sidescraper	Orth	90	41	24	E = P = R-M	2
108	S/below	Instrument on flake	Discoid	convergent side scraper	Centripetal	26	32	10	E-R = P-M	3
109	S/below	flake			Crossed	20	29	7	R = P	1
110	S/below	flake	Levallois		Centripetal	21	13	4	R = P-C-F	3
111	S/below	flake	Levallois		Centripetal	20	24	5	M-W-R = P	3
112	S/below	flake	Discoid		Centripetal	22	28	6	R = P-M	2
113	S/below	flake			Centripetal	40	20	9	E-R = P = M	2
116	S/below	flake	Levallois		Conv	21	10	3	R = P	1
130	S/above	core	Levallois	Preferential Levallois	Centripetal	42	30	14	R = P	1
140	N/above	Instrument on flake	SSDA	side scraper	Centripetal	41	26	14	R = P = W = Y = B-M	2
141	N/above	Flake	Discoid		Centripetal	27	28	10	E-R = P = W-M	3
142	N/below	Instrument on flake	SSDA	convergent sidescraper	Crossed	45	25	12	P = R-M	2
143	N/below	Flake	Discoid		Centripetal	22	28	11	E-R = P-B	3
147	N/above	Flake	SSDA		Unipolar	32	26	9	E-R = P	2
148	N/above	Flake			Centripetal	51	47	27	E-R = P	2
149	N/above	Instrument on flake	SSDA	sidescraper	Crossed	44	37	15	E-R = P-B-C	4
150	N/above	Instrument on flake		end scraper	Centripetal	40	38	8	R = P	1
152	N/above	Flake	Levallois		Unipolar	30	21	5	E-R = P	2
153	N/below	Core	Levallois	recurrent centripetal Levallois	Centripetal	50	35	24	E-R = P	2
154	N/below	Flake	Discoid		Unipolar	30	36	17	E-R = P-C	3
159	S/above	Instrument on flake	Levallois	Side scraper	Unipolar	39	25	7	E-B-R = P	3
160	S/above	Flake	Levallois		Centripetal	30	40	7		
161	S/above	Core	Levallois	Preferential Levallois	Centripetal	55	40	22	R = P	1
162	S/above	Core	Levallois	preferential Levallois		47	44	25	E-R = P-F	3
164	S/above	Flake				25	34	10	E-R = P-M	3
167	S/above	Core	discoid uniface	Discoid	Centripetal	55	50	33	E-R = P-W	3
169	S/above	Instrument on flake	SSDA	side scraper	crossed	50	35	16	E-R = P-W-M	4
171	S/above	Instrument on flake	Façonnage	convergent denticulate	Centripetal	41	29	16	E-R = P-W-M	4
175	S/below	core	SSDA	ssda		24	25	14	E-R = P	2

higher magnification were studied with the aid of a stereomicroscope. The overlap of different PDAs was assessed using the stereomicroscope.

Each surface of the lithic artefact was catalogued for identified PDAs, their degree of development, and any sequential overlap. For recording the sequential overlap of PDAs, each PDA was treated as a consequence of distinct natural conditions, termed phases (each denoted by the first initial of the PDA, e.g., E for edge crumbling), which were then interconnected using two types of relations: consequentality (-) and contingency (=). Consequentality refers to clear temporal overlap between two PDAs (e.g., E-M). Contingency denoted instances where no clear overlap between different PDAs was identified (e.g., E = R = P), indicating an absence of clear temporal sequence between the PDAs (Berruti and Arzarello, 2020).

The selection process for artefacts intended for use-wear analysis adhered to two criteria: the presence of at least one functional edge, as per the criteria established by Terradillos-Bernal and Rodríguez-Álvarez (2017) and surface preservation, denoted by the absence of significant

post-depositional alteration (PDA) following Levi Sala's framework (Levi Sala, 1986).

## 4. Results

### 4.1. Technology

The complete lithic assemblage of Uzun Mera, according to the collecting conditions and the nature of the deposit, is characterized by a mix of lithic industries, unknapped raw materials, and geofacts

The geofacts (Raynal and Magoga, 2000) are recognizable based on the presence of multiple impact points and/or located at angles superior to 90°, by the disorganization and smallness of the negatives, and by the presence of stigmata not consistent with the basic rules of knapping (corners and convexities). Furthermore, the geofacts have an average size smaller than the knapped lithic assemblage (Stojanovski et al., 2018).

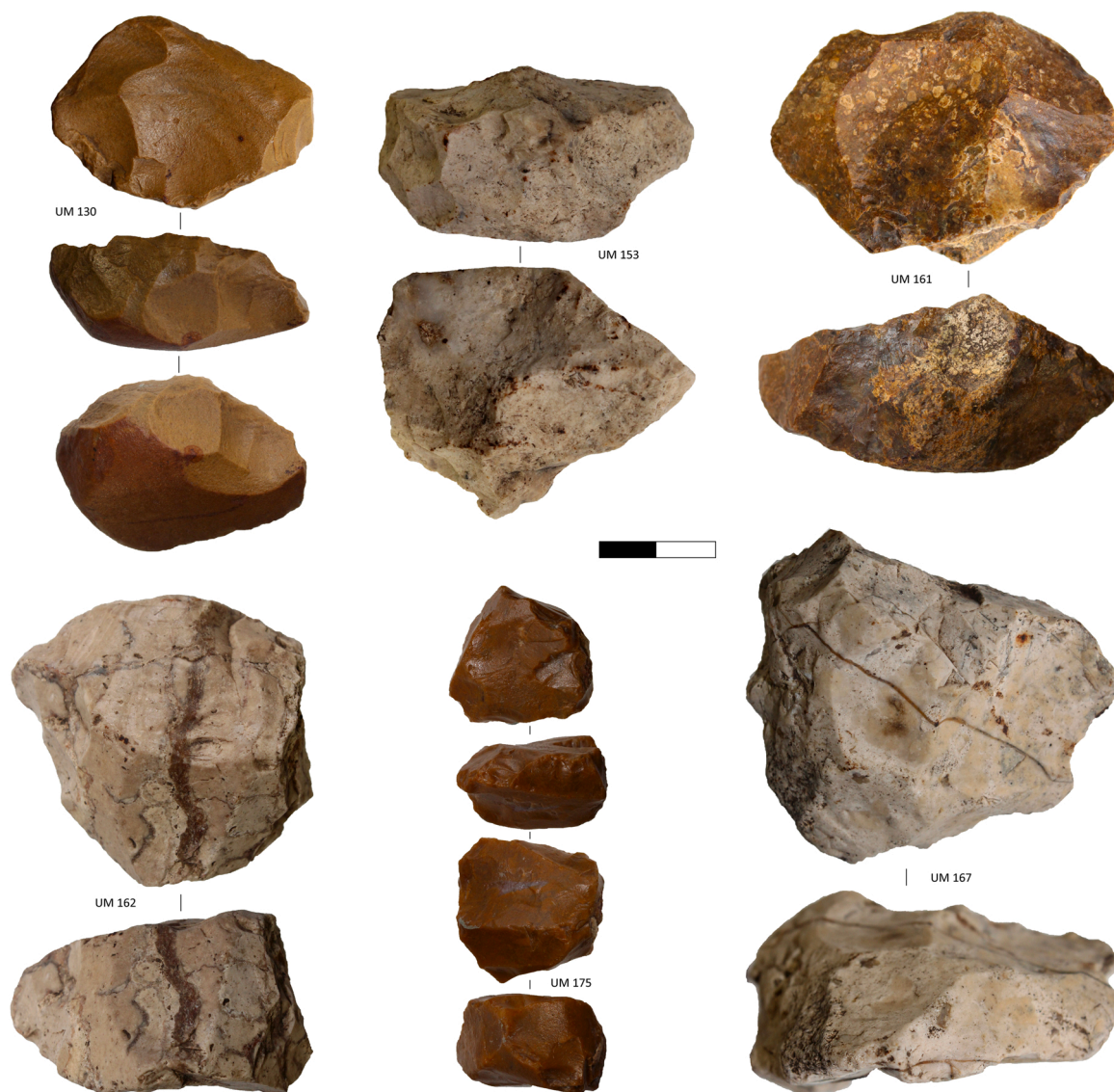


Fig. 2. Cores included in this study (Photos: Aleksandar Danev and Dejan Georgiev).

The most utilized raw material is jasper (jasp-agate or Chalcedony jasper, present in different morphologies and colours), followed by flint and andesite. Sandstone, limestone, and quartz have been also exploited but in smaller quantities. The choice of raw material does not seem to be linked to particular reduction sequences, but rather to its availability in the surroundings of the site. Furthermore, based on the cortex morphology and alterations, it can be stated that the majority of the exploited blocks were collected in secondary positions (detrital deposits, more rarely riverine).

The lithic assemblage is relatively small (just over 500 pieces by the end of the 2023 campaign), but the state of conservation, and above all, the importance of the discovery within a broader panorama, underlie the relevance of their study as this is only the second known/published Paleolithic site in the country.

The reduction sequences seem to be complete (cores, flakes, and retouched implements are present), though the presence of debitage from the initial decortication phase is likely underestimated. The only specific technique identified is the direct percussion by a hard stone hammer, as attested by the butts' morphologies and the pronounced bulbs. The presence of bipolar percussion on anvil cannot be excluded even if no distinctive character has been identified.

The knapping methods are typical of a Middle Palaeolithic site:

opportunistic debitage (c.f. SSDA, [Carpentieri and Arzarello, 2022](#); [Forestier, 1993](#)), Levallois debitage ([Boëda, 1994](#)) and Discoid debitage ([Mourre, 2003](#)). The opportunistic method is characterized by a low number of exploited debitage surfaces (mainly 1 or 2) by unipolar or centripetal scars. The discoid method, the second most represented after the opportunistic, is characterized both by the alternating exploitation of two convex surfaces and by the exploitation of a single surface in cases where the volume of the block of raw material does not allow the shaping of the two faces. The Levallois method is present in both the recurrent (centripetal) and preferential modes. The preparation of the striking platform is not always very accurate, as attested by the plain butts of some of the Levallois flakes, thanks to the favourable morphology of the raw material. For all knapping methods, the cores are exploited almost to exhaustion as evidenced by the debitage products, which have a maximum length of 10 cm and a minimum of 1 cm.

Retouched blanks are rare (9 selected for this study - [Fig. 3](#)). Their number could be greater, but it is not possible to identify them all definitively due to the presence of numerous pseudo-retouching which could have obliterated the original retouching. They are mainly side-scrapers obtained on opportunistic flakes, but there is also one recorded on a Levallois flake ([Fig. 3](#), UM 159).

The size of the sample and its nature make comparisons or precisely

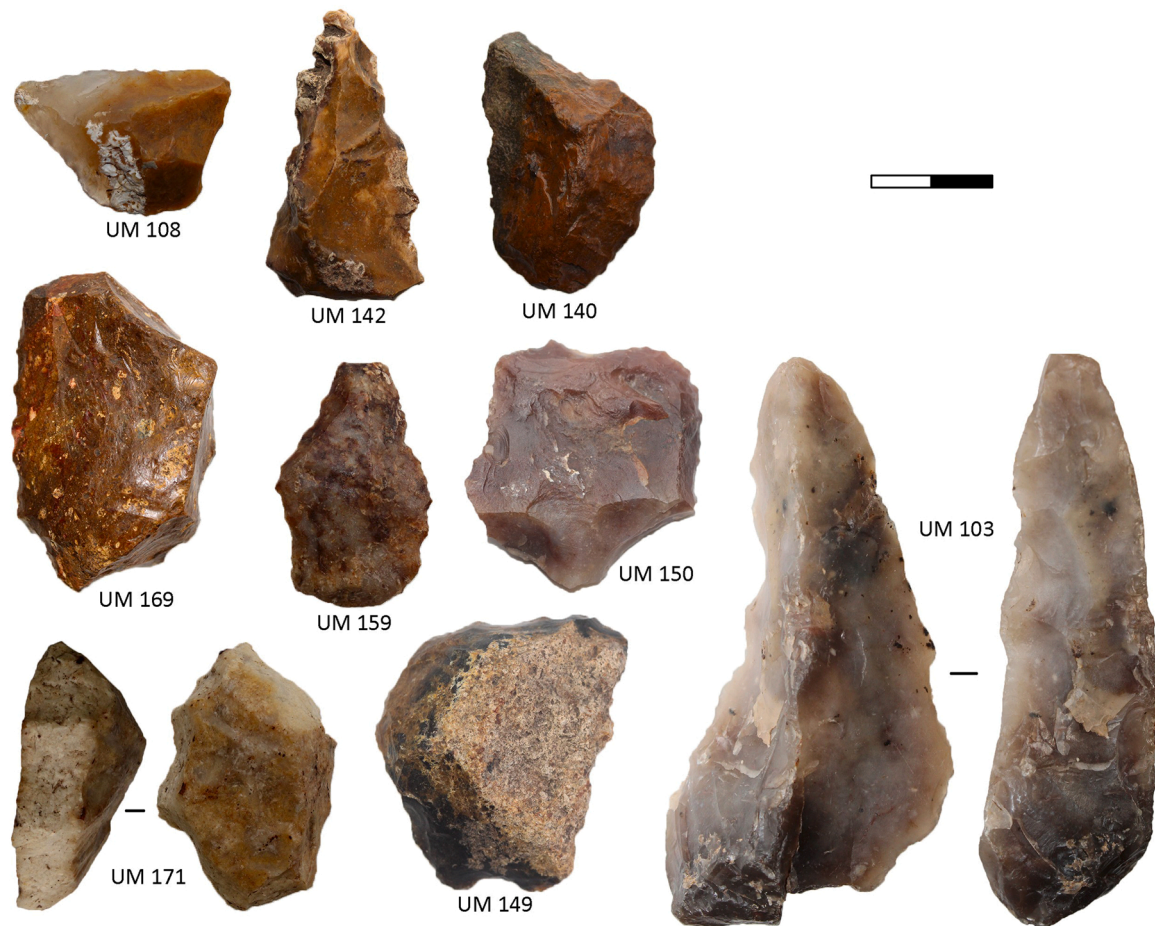


Fig. 3. Retouched flakes (instruments) included in this study – see Table 1 (Photos: Aleksandar Danev and Dejan Georgiev).

defining the possible uses of the site difficult, but the presence of the Levallois method, well represented here, allows us to ascribe the site to the Middle Paleolithic and likely the typical Mousterian of the Balkans (Mihailović, 2014; Stojanovski et al., 2018).

#### 4.2. Taphonomy

Among the analyzed artefacts with PDAs, 63.6 % (21 out of 33) exhibit edge crumbling (E) as the initial phase, followed by a subsequent phase characterized by polishing and rounding (E-P = R). Moreover, a contingency relation between polishing and rounding is evident in 100 % of the artefacts. In 48.5 % (16 out of 33), the final stages involve the presence of Fe-Mn patina (M), brown patina (B), yellow patina (Y) and/or white patina (W), with these patinas overlapping all other post-depositional alterations. In two cases, it was possible to identify the deposition of concretions (C): one corresponds to the last recorded phase; while in the second case, it is followed by thermal alterations caused by fire (F). The thermal alterations caused by fire (F) are present only on two artefacts (in both cases as the last phase). Analysis of the collected PDAs sequence data from the lithic assemblage reveals two distinct macro-phases. The first phase is characterized by mechanical alterations, including edge crumbling, polishing, and rounding (Burroni et al., 2002; Mazzucco et al., 2013). In contrast, the second phase is marked by chemical alterations, specifically the presence of Fe-Mn oxide patina, brown patina (B), yellow patina (Y) and/or white patina (Burroni et al., 2002; Glauberman and Thorson, 2012; Marín-Arroyo et al., 2014; Mazzucco et al., 2013).

The analysis of post-depositional alterations (PDAs) within a lithic assemblage provides insights into the various processes contributing to

the formation of an archaeological deposit (Burroni et al., 2002). By examining the PDAs sequences identified within the considered lithic industry, distinct taphonomic phases emerge. Based on the obtained results, it is feasible to construct a general sequence that encompasses and elucidates all the individual sequences detected during the taphonomic analysis. This general sequence comprises edge crumbling, rounding, and polishing, followed by chemical alterations with some additional sporadic phases. Due to the distinct origins of these alterations (chemical and mechanical), the interpretation of post-depositional alterations (PDAs) will be segregated into the two identified macro-phases.

The first macro-phase likely resulted from two separate taphonomic processes occurring at different times, making their disentanglement challenging. The initial process is associated with the abandonment of the lithic artefacts in an open-air site, originally situated on a higher position from the current location, during which it endured trampling-induced edge crumbling (e.g., Asryan et al., 2014; McPherron et al., 2014). The second process is linked to the transportation of the lithic assemblage from the open-air site to the plains, characterized by the formation of rounding, polishing, and a subsequent round of edge crumbling (Burroni et al., 2002; Mazzucco et al., 2013).

The second macro-phase represents the processes occurring during the burial of the lithic artefacts on the plains. As previously mentioned, these macro-phases are typified by chemical alterations requiring aqueous solutions, a complex process occurring in sediments with varying pH levels (Dove and Nix, 1997; Burroni et al., 2002; Dove et al., 2008; Glauberman and Thorson, 2012). This aligns well with the deposition of artefacts in an alluvial plain, in which it is possible to assume the lighting of fires, including for agricultural purposes.

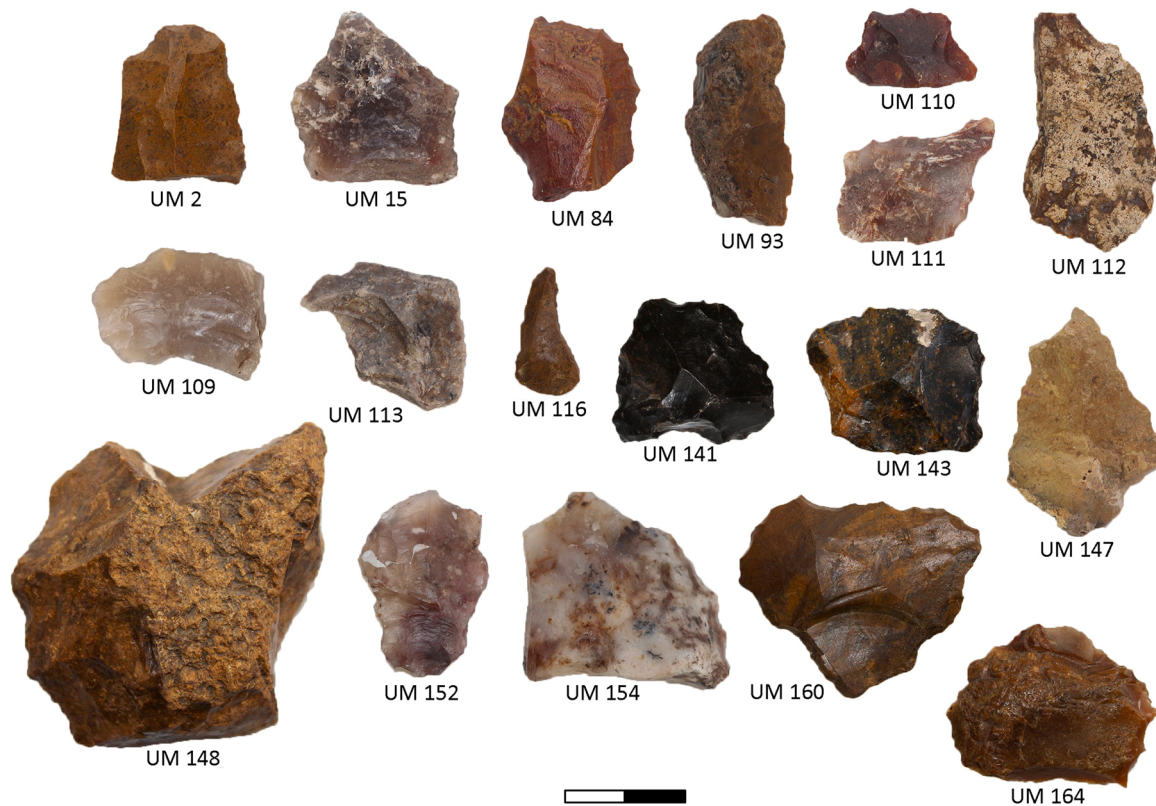


Fig. 4. Flakes included in this study – see Table 1 (Photos: Aleksandar Danev and Dejan Georgiev).

The functional assessment commenced with an initial evaluation of the preservation state of all lithic artefacts under consideration. The selection process for artefacts intended for use-wear resulted in the selection of no artefacts since they were all found to be too affected by PDAs, which compromised their functional study.

## 5. Discussion and conclusion

Post depositional analysis has allowed us to reconstruct aspects of the site history of Uzun Mera. The two identified phases of PDA contribute to our understanding of the sequence of events and the taphonomic life of the lithics. The lithics were likely produced at a site at a higher elevation, but at some point, in the Late Pleistocene or Holocene, a landslide or other geological process brought the sediment and lithics to the center of the Ovche Pole valley where they currently rest. This movement influenced the preservation state of the artefacts, introducing mechanical alterations such as edge crumbling, polishing, and rounding, followed by chemical patination. Fire, plowing, and other agriculture activities partially contributed to the second phase of PDA at the current location of the site. Survey efforts in 2021 around the edges of the valley, to identify where the sediment may have come from, were unsuccessful. Nevertheless, the first phase of PDAs attest that the lithic manufacture is unlikely to have occurred at the current site of Uzun Mera. These processes also complicate direct behavioural interpretations of the lithic production but provide a crucial framework for understanding the site's formation.

The tangled site-forming dynamics have proven challenging for absolute dating attempts so far, namely OSL and thermoluminescence. This long site history also makes the use-wear analysis of the Uzun Mera lithics difficult. Nevertheless, their general anatomy suggests they likely share makers with other Middle Paleolithic Balkan sites such as Crvena Stijena (Montenegro), Hadži Prodanova cave and the upper layers of Velika Balanica and Mala Balanica (Serbia), and Kozarnika 10a-10b (Bulgaria), generally dating to late MIS 7 to early MIS 5 (Sirakov

et al., 2010; Mihailović, 2014; Stojanovski et al., 2018). These assemblages are characterized by a dominance of opportunistic debitage, with the presence of both discoid and Levallois reduction strategies. This technological variability reflects a high degree of adaptability among the site's inhabitants, potentially influenced by raw material availability and functional demands. The high-quality jasper from Uzun Mera would have been a draw for the immediate region's Neanderthal inhabitants, and they used a flexible, expedient production strategy that allowed for efficient exploitation of this raw material. Besides Uzun Mera and the Middle and Upper Paleolithic in situ cave site of Golema Pešt in the northwestern part of the country (Šalamanov Korobar, 2010), no other Paleolithic sites have been investigated and our survey for new sites continues.

This study also highlights some of the limitations of the site of Uzun Mera. It is difficult to establish a precise chronology for the assemblage due to the complex site formation processes. Unlike in situ contexts, open-air sites like Uzun Mera are more susceptible to post-depositional disturbances, complicating direct associations between lithic artifacts and potential dating samples. Also, the absence of faunal remains limits our understanding of subsistence strategies. The role of Uzun Mera within broader Neanderthal mobility patterns remains an open question—was it a long-term occupation site, a short-term hunting station, or a location for specific tasks such as tool production? The technological evidence suggests a degree of continuity with other Middle Palaeolithic sites in the Balkans, but further excavations and interdisciplinary studies are needed to clarify the function of the site within Neanderthal landscape use.

Despite these challenges, Uzun Mera contributes significantly to the broader discourse on Neanderthal presence in the Balkans. The assemblage not only expands the regional dataset but also provides evidence for technological continuity and innovation in the Middle Palaeolithic. Considering the increasing recognition of the Balkans as a key corridor for hominin dispersals, Uzun Mera underscores the need for further research in under-explored regions to fully capture the complexity of

Neanderthal adaptations. Future investigations potentially integrating geoarchaeological, paleoenvironmental, and archaeological methods will be essential in refining our understanding of this site's role in Neanderthal settlement dynamics. Expanding research in the region will also contribute to broader discussions on Neanderthal adaptations and interactions across Europe and Southwest Asia during the Middle Palaeolithic.

### CRediT authorship contribution statement

**Danev Aleksandar:** Visualization, Project administration. **Nacev Trajche:** Project administration, Investigation, Funding acquisition. **Lacy Sarah A:** Writing – review & editing, Investigation. **Arzarello Marta:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Berruti Gabriele L. F.:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stojanovski Darko:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization.

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### 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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