



## The role of lithic technology in shaping mobility and decision-making: The case of Ararat-1 Cave

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### ABSTRACT

Studies of lithic technological organization have progressed from static typological classifications to analyses of dynamic processes of tool production, use, and discard. These analyses reveal the intricate interplay of human behavior and environmental adaptation. This paper investigates lithic technology, emphasizing the dichotomy of curated and expedient technologies by examining the differential strategies employed in raw material acquisition, tool production, and discard. It also explores how environmental, economic, and mobility factors interplay and shape lithic assemblages. Focusing on Ararat-1 cave, a late Middle Paleolithic site in the Armenian Highlands, we conducted an integrative techno-typological study of 1770 lithic artefacts spanning five stratigraphic units, identifying distinct raw material reduction strategies for obsidian and chert. Obsidian artefacts exhibited a focus on retouching and rejuvenation, indicative of curated technologies associated with high residential mobility, while the chert showed evidence of primary reduction and blank production, reflecting expedient strategies. By integrating module flake analysis and reviewing the Whole Assemblage Behavioral Indicators (WABI) framework, suggesting the addition of smaller debitage, we highlighted dual mobility patterns reflected in the site assemblage. This approach offers a refined understanding of lithic technological systems, providing insights into MIS 3 mobility and site function in the Armenian Highlands.

### 1. Review of Middle Palaeolithic sites in the Armenian Highlands and the Caucasus

The Caucasus is a geographically and ecologically diverse region that created a complex environment for past human populations and endemic species of flora and fauna. The region hosts a rich archaeological record, with the Middle Paleolithic (MP) being the most represented period, encompassing approximately 60 % of the over 450 known Palaeolithic sites (Gasparian and Glauberman, 2023). These sites include caves, rock shelters, open-air sites, and single-find spots. They are strategically positioned across diverse landscapes such as river

canyons, terraces, coastal peninsulas, mountain plateaus, hills, and lava domes. MP sites are skewed to the latter part of the period. Only four sites are dated to MIS 7, Jrurchula (Djruchula), Ilskaya I open-air-site, Myshtulagty Lagat cave, and Azokh-1 cave, with others falling within MIS 5 (Hovk and Alapars-1). Most archaeological occurrences, such as the site under study in this paper, Ararat-1 cave, fall within the time frame of earlier MIS 4 and late MIS 3 (Fig. 1).

Previous research has highlighted the persistence of MP lithic technology in the region until around 30,000 years ago (Egeland et al., 2016; Goder-Goldberger and Malinsky-Buller, 2022; Sherriff et al., 2019, 2024), suggesting that MP populations occupied a range of ecological

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settings and adapted their land-use strategies to seasonal environmental changes (Malinsky-Buller et al., 2021a,b).

While lithic techno-typological studies are few, particularly about the Late Middle Paleolithic (LMP), some research focuses on the Armenian Highlands and the southern Caucasus (Table 1).

The Armenian Highlands present a complex and diverse MP lithic technology record. While obsidian is the dominant raw material due to its abundance in the region, the technological features of the lithic assemblages showcase a range of traditions and influences. This makes straightforward classification challenging, particularly regarding positioning within a technological organization perspective. Until recently, techno-typological studies on MP assemblages focused heavily on the guide fossil attribution or cultural history approaches. These mainly stem from historical excavations that have not used chronometric methods. As a result, several traditions or “cultures” have been proposed to categorize MP sites in this region.

- Denticulate Mousterian: This industry, characterized by the presence of denticulate tools, is found at sites like Azokh-1 Cave (Asryan et al.,

2016; Fernández-Jalvo et al., 2010; King et al., 2004). A variation of this industry, the Tayacian, is observed at other sites like Shish Ghuzey, Ghayali, and Chakhmakhli (Doronicheva et al., 2023; Golovanova and Doronichev, 2003, 2017).

- Jruchula-Kudarian and Tskhinvalian cultures: These industries, found at sites such as Jruchula, Kudaro I and III caves, and Tsopi, are seen as having affinities with the Levantine Mousterian, based on similarities in core reduction techniques (Doronicheva et al., 2023; Golovanova and Doronichev, 2003; Meignen and Tushabramishvili, 2006, 2010).
- Zagros type Mousterian: This industry, found in the southern Caucasus (Sakajia) and the northeastern Armenian Highlands, is characterized by truncated-faceted tools, and its resemblance to artefacts from sites like Bisitun, Kunji, and Warwasi caves in Iran (Golovanova and Doronichev, 2017).
- Yerevan type Mousterian: First identified at Yerevan-1 cave, this industry is distinguished by the presence of small points with truncated-faceted bases (‘Yerevan points’). It is often considered to be a variation of the ‘Zagros type Mousterian’. Sites like Lusakert-1,

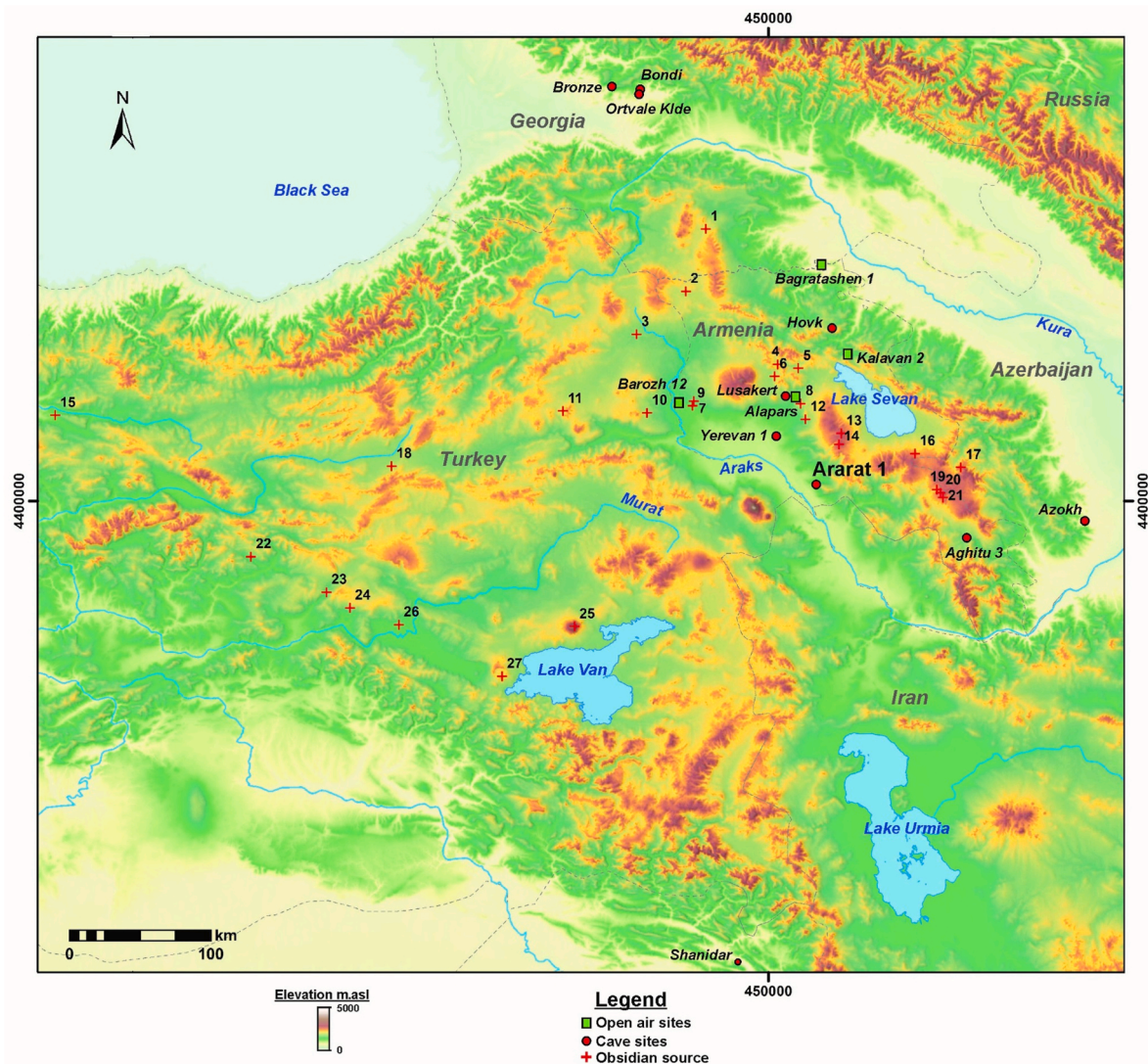


Fig. 1. Map of the altitude-conditioned landscape of Ararat-1 cave location map within the southern Caucasus, Armenian Highlands, and the Zagros showing mainly MIS 3 sites and obsidian sources. Green Squares = open-air sites, red circles = cave sites. Obsidian source: 1. Chikiani, Georgia; Aghvorik, Armenia; 3. Kars-Arpaçay, Turkey; 4. Damlık, Armenia; 5. Kamakar, Armenia; 6. Ttvakar, Armenia; 7. Mets Arteni, Armenia; 8. Gutansar, Armenia; 9. Pokr Arteni, Armenia; 10. Sarıkamış, Turkey; 11. Kars-Digor, Turkey; 12. Hatis, Armenia; 13. Spitakasar, Armenia; 14. Geghasar, Armenia; 15. Pascinler, Turkey; 16. Khorapor, Armenia; 17. Kelbajar, Azerbaijan; 18. Erzurum, Turkey; 19. Satanakar, Armenia; 20. Sevkar, Armenia; 21. Bazenk, Armenia; 22. Meydan Dağ, Turkey; 23. Bingöl B, Turkey; 24. Bingöl A, Turkey; 25. Suphan Dağ, Turkey; 26. Muş, Turkey; 27. Nemrut Dağ, Turkey.

Table 1

Chronometric, contextual data for selected Middle Palaeolithic sites in the Armenian Highlands and Caucasus. Modified from Gasparian &amp; Glauberan (2023).

Site	Context	Age ka BPa (method)	Artefact density	Lithic Raw Materials	References
Bondi Cave	477 m a.s.l. Layer VII	~38.7–35 cal BP (43–40 cal BPHulu) (AMS)	Low	Chert	(Le Bourdonnec et al., 2012; Pinhasi et al., 2012; Tushabramishvili et al., 1999)
Ortvale Klde rockshelter	530 m a.s.l. Layer 5 Layer 6 Layer 7	37.7 ± 1 (AMS) 45.6 ± 4 47.7 ± 4.2 (TL) 43 ± 1.15 (AMS) 59.4 ± 7.2 74.3 ± 6.5 (TL)	Moderate (Layer 5) High (Layers 6 and 7)	Chert, some obsidian, very little argillite.	(Adler, 2002, 2006a, 2006b; Adler and Bar-Oz, 2009; Le Bourdonnec et al., 2012; Moncel et al., 2015; Tushabramishvili et al., 1999)
Ilskaya I open-air-site	~100 m a.s.l. Upper layers	37.2 ± 1.8 40.8 ± 1.2 (14C) 47 ± 2 (Ionium)	Moderate	Chert	(Golovanova and Doronichev, 2003; Shchelinskii, 2007; Skinner et al., 2005)
Mezmaiskaya cave	1310 m a.s.l. Layers 2, 2A, 2B1–2B3 Layer 3	35–32 cal BP (14C) ~42–37–73–63 (ESR–LU)	Moderate-low	Chert, very few obsidian	(Doronicheva, 2021; Pinhasi et al., 2011; Ponce de León et al., 2008; Skinner et al., 2005; V. Golovanova et al., 1999)
Malaya Vorontsovskaya cave	~290 m a.s.l. Layer 3	35.68 ± 0.48 (14C)	Moderate-low	Mainly chert, schist, limestone, alevrolite	(Cohen and Stepanchuk, 1999; Golovanova and Doronichev, 2003; Kozłowski, 1998; Lyubin, 1984, 1989, 2006)
Akhshtirskaya cave	~200 m a.s.l. Layer 3a	35 ± 2 (U/Th, stalactite)	Moderate	Chert, schist	Lyubin (1984, 1989), Cohen and Stepanchuk (1999), Kozłowski (1998), Golovanova and Doronichev (2003, 2005), Lyubin and Belyaeva (2006)
Tinit 1 open-air site	~800 m a.s.l. Archaeological horizon 3 Archaeological horizon 8	43.9 ± 2 > 43.7 (14C)	Low	Chert	Amirkhanov (2015)
Kudaro I cave	~1600 m a.s.l. Upper Layer 3a	44.15 ± 2.4/1.8 (14C)	Low	Chert, alevrolite, limestone, sandstone	Lyubin (1984, 1989), Cohen and Stepanchuk (1999), Kozłowski (1998), Golovanova and Doronichev (2003, 2005), Lyubin and Belyaeva (2006)
Bronzovaya cave	(Tsutskhvatii Complex) ~230–235 m a.s.l. Layers MP1–MP2 Layers MP3–MP4	>44.1 >48.5 >50 (14C)	Low	Mainly chert, argillite, andesite, a few basalt, obsidian	(Adler and Tushabramishvili, 2004; Golovanova and Doronichev, 2003; Tushabramishvili, 2008)
Gazma cave	1508 m a.s.l. Layers IV–VI	26.867 ± 0.143 (14C)	Low	Obsidian, chert, few tufa	Zeynalov (2016)
Sakajia cave	~222–235 m a.s.l. Layer 2 (UP) Layer 3a (MP) Layer 3b (MP) Layer 3c (MP)	39.3–34.7 cal BP 41–36.6 cal BP 53–57 cal BP 63–55 cal BP (14C)	Low-moderate	Mainly chert, argillite, sandstone, quartzite, few basalt, andesite obsidian	Lyubin (1984, 1989), Golovanova and Doronichev (2003, 2005), Moncel et al. (2015), Pinhasi et al. (2012)
Bagratashen-1 open-air site	457 m a.s.l. Horizons 3a, 3b	30.5 ± 2.5 37.9 ± 2.2 (OSL)	Low-moderate	Dacite, chert, limestone, few obsidian	Egeland et al. (2016).
Yerevan-1 cave	913 m a.s.l. Layers 3–	31.6 ± 0.8 >49 (14C)	High	Obsidian, some dacite, basalt, chert.	Yeritsyan, 1970, Golovanova and Doronichev (2003, 2005; Doronicheva et al., 2023), Pinhasi et al. (2008)
Ararat-1 Cave	1034 m a.s.l. Unit 2a Unit 2b Unit 2d Unit 3 Unit 4	33.4 ± 2.5 35.1 ± 2.5 45.1 ± 3.0 44.3 ± 2.9 52.4 ± 3.6 (pIRSL)	Low-moderate	Obsidian (pXRF), Chert, Mafic Lava, Sandstone, Chalcedony, Quartzite.	(Frahm et al., 2025; Oikonomou et al., 2025; Sherriff et al., 2024)
Lusakert-1 cave	1417 m a.s.l. Exterior Units D–C Interior Units 1–12	26.92 ± 0.22–45.6 ± 2.3 (14C) ~60 (AMS, OSL, Tephra pending)	High	Obsidian (pXRF).	(Adler et al., 2012; Frahm et al., 2016; Gasparian et al., 2014b; Sherriff et al., 2019; Wilkinson et al., 2024)
Barozh-12 open-air site	1336 m a.s.l. Unit 2b Unit 3 Unit 5	31.3 ± 3.0 50.7 ± 6.1 60.2 ± 5.7 (pIRSL)	High	Obsidian (pXRF), few dacite.	(Glauberan et al., 2020a,b).
Alapars-1 open-air site	1774 m a.s.l. Unit 2	63 ± 6–67 ± 7 (pIRSL)	Moderate	Obsidian (pXRF).	Malinsky-Buller et al. (2021b)
Kalavan-2 open-air site	1636 m a.s.l. Layers 7, 19 Units 1–10	39.6 ± 0.8 cal BP 45.4 ± 0.8 cal BP (14C) 62.7 ± 4.5–32.2 ± 3.2 (pIRSL)	Low	Obsidian (pXRF), tuff, limestone, chert.	(Ghukasyan et al., 2010; Malinsky-Buller et al., 2021)
Hovk-1 cave	2040 m a.s.l. Units 4–6	35.5 ± 0.6 >46 54.6 ± 5.7 (14C, AMS, OSL)	Very low	Limestone, chert, Obsidian.	Pinhasi et al. (2008, 2011)

Taghlar, Dashsalakhli, Tsar, and Gazma caves exhibit variations of this industry, sometimes referred to as the 'Taghlar type' or the 'Yerevan-Taghlar type' (Doronicheva et al., 2023; Gasparian and Glauberan, 2023).

- Charentian: The materials from the Tsopi open-air site were previously classified as Charentian, but they have more recently been

linked to the Levantine Yabrudian (Golovanova and Doronichev, 2003).

Even if most of the sites are still being studied (Gasparian and Glauberan, 2023), there are several key “guide fossils” that help to categorize lithic technology in the Armenian Highlands preliminarily. Yerevan-1 Cave, for instance, comprises seven cultural horizons with a

depth of approximately 3 m. The lithic industry found in this cave primarily consists of obsidian artefacts. It is characterized by unidirectional flaking methods, a significant proportion of retouched tools, including side-scrapers and points, and the use of truncating-faceting techniques for tool production, Yerevan points, and the lower part of the sequence consist of a laminar reduction method (Gasparyan et al., 2014b; Golovanova and Doronichev, 2003; Yeritsyan, 1971, 1972; Yeritsyan & Semyonov, 1971). Radiocarbon dating suggests that layer 4 at Yerevan-1 dates to around 49,000 BP (Cohen and Stepanchuk, 1999; Frahm et al., 2016). The lithic assemblage at Yerevan-1 resembles that found at the site of Angeghakot (Liagre et al., 2006) in southeastern Armenia, as well as in the caves of Taglar and Zar in Azerbaijan (Djafarov, 1983; Mansurov, 1990) and Gazma cave (Zeynalov, 2016; Zeynalov et al., 2023). These industries exhibited similarities to the Zagros-Taurus Mousterian (Doronicheva et al., 2023; Golovanova and Doronichev, 2003). Similarly, in the cave of Lusakert-1, six archaeological levels were identified, demonstrating an alternation of different facies. The recurrent unidirectional Levallois and truncating-faceting techniques, characteristic of the Zagros-Taurus Mousterian, were prevalent throughout the stratigraphy (Adler, 2002; Frahm et al., 2016; Lukich, 2012; Wilkinson et al., 2024).

Lusakert-1, dated to a minimum age estimate of c. 35 ka BP (Adler, 2002; Brittingham et al., 2019; Frahm et al., 2016; Sherriff et al., 2019; Wilkinson et al., 2024), revealed three levels during excavation. The lithic assemblage at Lusakert-2 displayed a predominant use of the Levallois core reduction technique, along with side-scrapers, Mousterian points, and "Yerevan points". At Bagratashen 1, dated by OSL as  $37.9 \pm 2.2$  and  $30.6 \pm 2.5$  (Egeland et al., 2016), the lithic assemblage is mainly characterized by retouched points and Levallois points. As for Hovk-1 (Pinhasi et al., 2008; 2011), cave units 4 to 6 date between  $54.6 \pm 5.7$  to  $35.5 \pm 0.6$  (C14, AMS, and OSL). The lithic assemblage, with its very low density, is characterized by few tools, blanks, and no presence of cores. Late Microlithic Mousterian is a term used to describe the industry found at Angeghakot 1. This site, located in the Vorotan Valley, represents a significant understanding of the variability of MP facies in the Lesser Caucasus. It also features 'Yerevan points' and microlithic tools, alongside the 'truncating-faceting' technique. Beyond these classifications, several broader technological trends were proposed throughout the Armenian Highlands. Levallois techniques, unidirectional-convergent and unidirectional Levallois core reduction techniques, are consistently employed at numerous sites, including Barozh 12, Lusakert 1, Yerevan 1, Kalavan 2, and Bagratashen 1. The prevalence of Levallois points and blades further underscores the widespread use of these techniques. Regarding economic and mobility aspects, there is the long-distance transport of obsidian. Even when local obsidian and non-obsidian sources are exploited, the evidence from sites like Barozh 12 and Kalavan 2 shows that obsidian blanks, particularly those bearing signs of retouch, were transported over distances of up to ~190 km. This suggests a complex network of mobility and exchange during the MP (Frahm, 2016, 2023; Frahm et al., 2014, 2019, 2025).

Studying lithic technology in the Armenian Highlands is not without its complexities. Lithic assemblages from the LMP are known to bear high variability concerning reduction strategies and raw material preferences (e.g., the high frequency of tools at Kalavan 2 compared to the abundance of cores and primary flaking debris at Bagratashen 1 and Alapars-1 (Malinsky-Buller et al., 2021a,b)). With such coeval (namely, LMP) cultural variability within a short geographic radius, the Armenian Highlands are considered a field lab to test concepts of curated or expedient technologies linked with mobility patterns and raw material procurement strategies. To better understand the strategic decisions that shaped mobility patterns and economic strategies of the hunter-gatherers in the diverse eco-zones of the Armenian Highlands during MIS 3, we employ a multifaceted approach, conducting a detailed techno-typological analysis of the lithic assemblages. By examining lithic reduction strategies and tool types employed by LMP populations, the current research clarifies the relationship between raw material

availability, site location, and subsistence strategies at Ararat-1 Cave.

## 2. Understanding lithic technology organization: A multifaceted approach

Over the last 30 years, the study of lithic technology has undergone a significant diversification of approaches, moving beyond typological and morphological classifications (e.g. (Bordes, 1969), towards a more nuanced understanding of the processes and decisions involved in tool production, use, and discard (Bamforth, 1986; Barton, 1990; Dibble, 1987; Hiscock and Clarkson, 2009; Holdaway and Douglass, 2012; Kelly and Todd, 1988; Kuhn, 1992; Riel-Salvatore and Barton, 2004; Shott, 1996). This shift reflects a growing recognition that lithic assemblages are not static reflections of cultural norms but rather dynamic and responsive systems shaped by a complex interplay of environmental, social and economic factors (Geneste, 1985; Nelson, 1991).

These new approaches delve into the concept of lithic technology organization, which encompasses the strategies employed by past societies to manage the entire life cycle of stone tools (Boëda et al., 1990; Geneste, 1985; Soressi and Geneste, 2011). This includes decisions regarding a) raw material selection and acquisition (considering the availability, quality, and accessibility of different stone types) (Andrefsky, 1994; Bamforth, 1986; Dibble, 1987, 1991; Kuhn, 1994, 1995; Rolland and Dibble, 1990; Shott, 1989), b) production methods and techniques (choosing appropriate knapping strategies to create desired blank forms and tool types) (Bisson, 2001; Shelley, 1990), c) tool design and functionality (adapting tool forms and attributes to specific tasks and performance requirements) (Barton, 1991; Dibble, 1987, 1995; Sackett, 1988; J. R. Sackett, 1982), d) tool transport and curation (determining which tools to carry, maintain, and recycle based on mobility patterns and anticipated needs (Bamforth, 1986; Bousman, 1993; Clark and Barton, 2017) e) discard patterns and assemblage formation (understanding how the accumulation of lithic debris reflects past activities and land use strategies) (Collins, 1975; Schiffer et al., 2001).

Traditionally, research focused on techno-typological classifications, grouping artefacts based on shared morphological characteristics to establish cultural affinities and temporal frameworks (see above regarding the Southern Caucasus and adjacent regions). While valuable for establishing a preliminary understanding of lithic assemblages, this typological approach often falls short in explaining the variability observed across different contexts, masking the complexity of factors that influence tool production and use (Binford and Binford, 1966). The limitations of relying solely on typological and morphological classifications become particularly evident when considering the concept of curation. Curation can be perceived as a multifaceted behavioral phenomenon encompassing stone tool production, design, transport, maintenance, and recycling, linked with mobility and raw material availability, and how these human behaviors can influence technological choices (Binford, 1973, 1977, 1979; Shott, 1989, 1996; Shott and Sillitoe, 2005). As Bamforth (1986) mentioned, curation encompasses various activities such as tool design for multiple uses, transport, maintenance through reshaping, and recycling into different forms. These activities are not always practiced together, and their relative prominence can vary considerably depending on the specific context.

The use of the terms curated and expedient to describe lithic technologies often associates curation with a high degree of planning and investment in tool production, while expediency implies a more opportunistic and long-term approach (Barton, 1998; Bicho and Cascalheira, 2020; Clark and Barton, 2017). However, curation is not a monolithic behavior. Its individual components can occur independently and exhibit varying levels of efficiency depending on the context (Bousman, 1993; Torrence, 1989). This distinction is reflected in the archaeological record through variations in lithic volumetric density (LVD), retouch frequency, and the complexity of core reduction strategies.

Within raw material availability, factors like mobility strategies and settlement patterns also influence technological organization (Binford, 1977, 1979; Hovers et al., 2009; Kelly and Todd, 1988; Kuhn, 1992, 1995). One of the most significant factors influencing technological organization is the availability and distribution of lithic resources (Andrefsky, 1994; Bamforth, 1986; Nelson, 1991). When a high-quality raw material is readily accessible, groups may opt for an expedient strategy, producing tools with minimal shaping and readily discarding them after use. This scenario would likely result in a high lithic volumetric density (LVD) at the site, coupled with a low frequency of retouched pieces, indicating that tools were replaced rather than maintained (Clark and Barton, 2017). Conversely, in environments where high-quality lithic resources are scarce or located far from habitation locales, groups may adopt a curated technology (Andrefsky, 2008; Bamforth, 1986; Binford, 1979; Odell, 2000, 2001; Tsanova et al., 2024; White, 2021). This involves carefully shaping tools for multiple uses, and investing time and energy in maintenance activities such as reshaping and rejuvenating to extend tool use-life (Andrefsky, 2008; Torrence, 1989). Such a strategy would result in a lower LVD and a higher frequency of retouched pieces, reflecting the effort invested in maximizing the utility of limited resources (Clark and Barton, 2017; Morales et al., 2015; Morales, 2016).

The adoption of curated or expedient technologies is usually linked with mobility patterns (Fig. 2). Foragers with high residential mobility, frequently moving their campsites, tend to rely on a curated toolkit designed for versatility and durability, as carrying a large and diverse assemblage of tools would be impractical. In contrast, logistical mobility, characterized by longer stays at resource-abundant locales, often involves expedient technologies due to the reduced need for tool transport and maintenance. In doing so, a longer stay at a locale as part of logistical mobility may exhibit a greater degree of expedient technology, as tool replacement is less costly when operating within a resource-rich territory (Hovers, 2009, p. 197; Kuhn, 1992; Parry and Kelly, 1987; Riel-Salvatore and Barton, 2004). Also, suppose the rate of mobility is high but occurs within a known territory that is revisited regularly and is known to have adequate resources. In that case, foragers may also opt for expediency. One might draw the conclusion that humans adapt to their environment because of technological decision-making, as already explored by (Foley, 1985; Kaplan et al., 2000; Mithen, 1990).

### 3. Materials/methods

#### 3.1. Ararat-1 cave

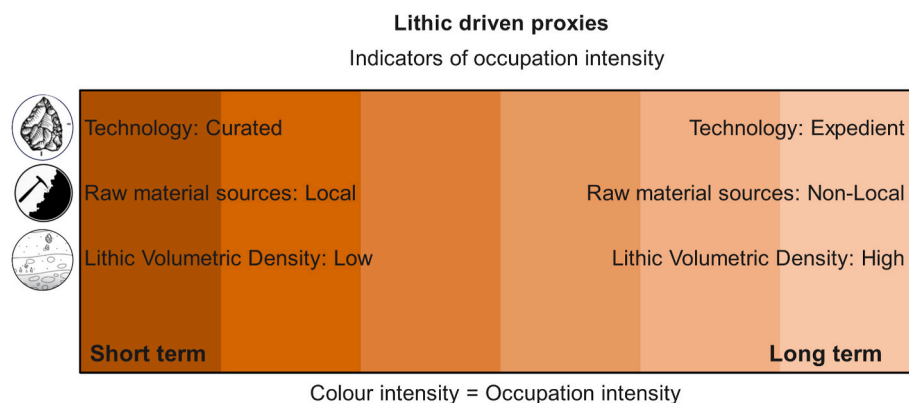
The Ararat Depression is a basin resulting from the collision of the Eurasian and Arabian tectonic plates. It has an extension of

approximately 1300 km<sup>2</sup>. The active Aragats and Gegham volcanic complexes are located on the northern and northwest peripheries of the depression. The imposing Mt. Ararat stratovolcano and its associated volcanic formations lie to the south. The northeastern part of the basin comprises steep Paleogene-Devonian limestones, shales, and quartzites forming the Urts Anticline, along with Quaternary alluvial deposits at the base of the slopes. The Ararat Depression experiences a semi-arid climate, with vegetation predominantly consisting of semi-desert and steppe ecosystems, with pockets of temperate forest occurring at higher elevations on the Urts anticline (Arutyunyan et al., 2007; Avagyan et al., 2018; Gevorgyan et al., 2020; Lebedev et al., 2013; Sherriff et al., 2019, 2024) and Karampaglidis et al., this volume). Ararat-1 cave is located northeast of the Ararat Depression, in the extension of the Devonian karstic system (Fig. 1). The cave, a dissolution cavity, features a main entrance, a central chamber (6 m high and 4 m long), and three small conduits. The stratigraphic sequence, 2 m thick, was exposed during excavation within the site's inner and entrance areas. The sequence is divided into five Sedimentological Units (SUs), encompassing late Pleistocene/Middle Palaeolithic and Holocene deposits. The current stratigraphic understanding has been refined and compared to Sherriff et al. (2024) by adding sedimentological units and lateral variations identified during the 2022–2023 excavations, Fig. 3 (see Oikonomou et al., 2025, this volume).

**SU4:** Inside the cave, from the bottom to the top, SU4 lies in direct contact with the inclined limestone bedrock. It consists of matrix-supported debris flow sediments deposited according to the natural slope of the bedrock. Throughout most of SU4, local slack-water formations rich in volcanic tephra are present, particularly near the bedrock and at the rear of the cave. This unit contains the first low-density MP Archaeological artefacts and is dated based on OSL and C14 as between  $52.40 \pm 3.60$  ka and  $43.515 \pm 1.145$  ka cal BP.

**SU3:** SU3 consists of bioturbated clast- and matrix supported debris talus deposits that erode or deform the upper part of SU4.1 (a sub-unit of SU 4), present only within the inner/rear parts of the cave (Northern Profile & partially Western Profile; mainly squares J15 & K14) (see Oikonomou et al. 2025, this volume). Bioturbation of this unit is particularly extensive to the rear of the cave. The second Middle Palaeolithic artefact concentration is contained within SU3, mostly at the interface between SU3 and SU1. The deposits of SU3 are dated to between  $45.10 \pm 3.00$  ka and  $37.90 \pm 1.61$  ka, based on OSL ages.

**SU1:** SU1 is composed of alternating matrix and clast-supported debris flow deposits, which are heavily bioturbated. The transition between SU3 and SU1.4 is erosive in nature, except in the rear parts of the cave, where contact is conformable. The lower sub-unit, SU1.4, contains Middle Palaeolithic artefacts and is dated to between  $37.90 \pm 1.61$  ka and  $35.10 \pm 2.50$  ka (OSL ages). The upper sub-units, SU1.3 through SU1.1, contain scattered archaeological material from the Holocene,



**Fig. 2.** Occupation intensity refers to the length of stay, frequency of visits, and number of people living at a given site (Munro, 2004; Stiner et al., 2012). All these variables strongly depend on human population size or density, and different proxy measures of site occupation intensity are commonly used in studies of Paleolithic demography (Barton, 1998; Clark and Barton, 2017; Hovers, 2009, p. 197).

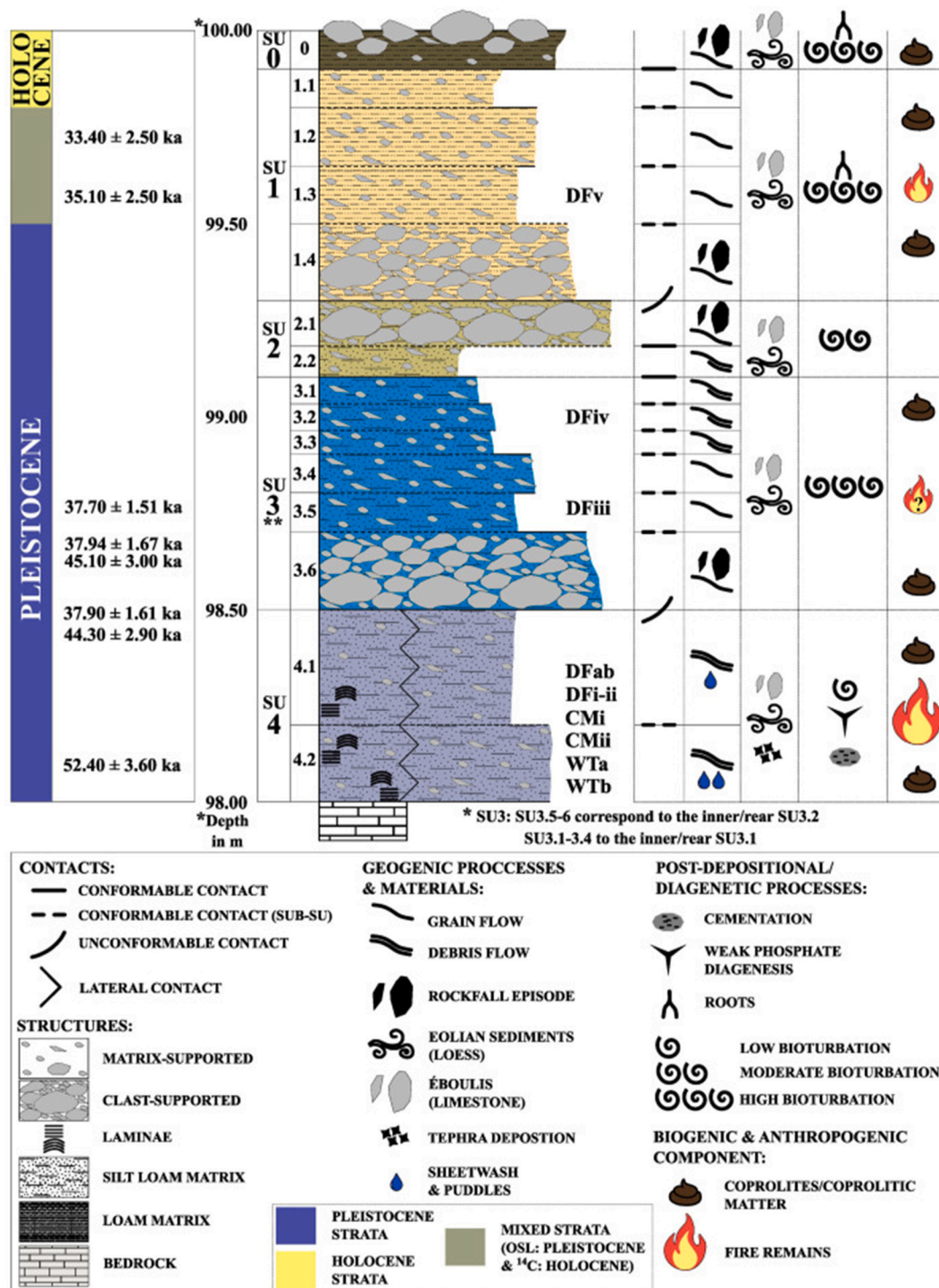


Fig. 3. Synthetic stratigraphic column summarizing the formation processes and materials of Ararat-1 Cave (Oikonomou et al., 2025).

likely dating to the post-Pleistocene period, with evidence from the Bronze Age and Middle Ages.

**SU0:** SU0 represents the topsoil and cave soil, found throughout the entire extent of the site. It includes bioturbated archaeological material from the Holocene, as well as modern dung deposits.

Among the materials from the upper units were ceramics from the Middle Chalcolithic (ca. 4600–4400 BCE), Late Bronze Age (ca. 1450–1200 BCE), and Early Medieval (ca. 610–680 CE) Periods (Sherriff et al., 2024)

The stratigraphic sequence at the entrance of the cave and the surrounding areas shows some deviations from the internal sequence. SU4

at the entrance consists of alternating sub-units of matrix- and clast-supported debris flow and cone deposits, but without the presence of puddles. The formation of the debris cone, caused by rockfall events, dictates the depositional pattern of the overlying units, which dip towards the interior of the cave. The upper part of SU4 at the entrance is dated to 37.94 ± 1.67 ka (OSL ages).

**SU3 at Entrance:** SU3 at the entrance is composed of a series of matrix-supported, occasionally channel-like, debris flow deposits. Middle Palaeolithic archaeological artefact concentration are present at the cave's entrance, encapsulated within SU4 and SU3, respectively.

**SU2 at Entrance:** At the entrance, SU2 consists of matrix-supported

debris flow deposits (SU2.2) and clast-supported rockfall deposits (SU2.1). This unit is only present at the entrance of the cave.

Beyond the entrance, massive rockfall and debris flow events created a large talus extending towards the floodplain, likely eroding archaeological material deposited outside the current cave extent (see Oikonomou et al. 2025, this volume).

### 3.2. Obsidian sourcing methods: pXRF methods

Obsidian artefacts from Ararat-1 cave were analyzed by pXRF between 2019 and 2024. An Olympus Vanta VMR was used from 2019 to 2023, and an Olympus Vanta2 MAX in 2024, both courtesy of the Yale Archaeological Laboratories. Both models are outfitted with a 4 W X-ray tube, an Rh anode, and a 20 mm<sup>2</sup> Si drift detector (SDD) with a high spectral resolution (~134 eV). For the trace elements of interest in obsidian sourcing, the instruments were operated with a tube voltage of 40 kV, a current of ~65 µA, and a 2000 µm Al beam filter for 20s. For proper data correction, the major elements (e.g., Si, Al, K) were then measured with a voltage of 10 kV, a current of ~75 µA, and no beam filter for an additional 10s. The earlier measurements were calibrated using a predecessor of PYRO calibration and evaluation sets (Frahm, 2019), specifically a set of 24 geological obsidian specimens tested using multiple techniques (e.g., NAA, EDXRF, EMPA) in various laboratories. The later measurements used the published PYRO calibration and evaluation sets developed by Frahm (2019). Data correction employed the fundamental parameters (FP) approach, which uses a physics-based model to mathematically adjust for phenomena that affect spectra (e.g., attenuation coefficients for coherent and incoherent scattering, photoelectric absorption, and electron-pair production at specific excitation energies, including fluorescent and absorption-edge energies). Accuracy was checked using five certified standards – USGS (United States Geological Survey) RGM-1 (Glass Mountain, California obsidian) and NIST (National Institute of Standards and Technology) SRM 278 (Newberry crater, Oregon, US obsidian) – as well as a Little Glass Buttes (Oregon, US) obsidian, which was the subject of interlaboratory “round robin” testing (Glascok, 1999). Importantly, most of the obsidian artefacts are small, below the threshold typically considered feasible for pXRF (i.e., 81 % are small flakes <20 mm). Following the methods developed by Frahm (2016), ratios between key trace elements and discriminant functions were used to make source identifications. Every artefact was analyzed two or three times with repositioning, to avoid inaccurate measurements due to their size or irregular morphologies. Comparative source data were compared directly to a reference collection of geological specimens analyzed using the same instrument; descriptions, dates, and elemental data for these obsidian sources can be found in Frahm (2023). The procedures are in line with those that have been employed in the region since 2019 (e.g., (Frahm, 2024a, 2024b; Frahm et al., 2019; Frahm and Carolus, 2021, 2022; Malinsky-Buller et al., 2024; Malinsky-Buller et al., 2021).

### 3.3. Lithic attributes analysis

A detailed technological and typological analysis of the entire lithic assemblage (1770 artefacts (1095 < 20 mm)) from all stratigraphic units was conducted up to the size threshold of 5 mm. Flakes smaller than 5 mm were identified as such and categorized as either fragmented or complete. The assemblage was excavated during the 2019, 2022, and 2023 field seasons. Based on Hovers (2009) (see references therein), the technological analysis followed, the complementary aspects of making, using, transporting, and discarding tools, and the material needed for their manufacture and maintenance (Geneste, 1985; Nelson, 1991, p. 57). We used Vaquero (2008), a known terminology, to describe the assemblage in terms of size. “The five size classes used in this paper have been established taking into account the length and width of artefacts: very small (< 500 mm<sup>2</sup>), small (500–1000 mm<sup>2</sup>), medium (1000–1500 mm<sup>2</sup>), large (1500–2000 mm<sup>2</sup>) and very large (>2000 mm<sup>2</sup>).” In our analysis, in

order to reach a size category, we compute the morphological length and width of each artefact (see SOM for detailed info on used packages and software versions, scripts, and raw and processed data).

The attribute analysis combined qualitative and quantitative characteristics to classify the reduction methods, their extent, and the raw material economy. To understand procurement and mobility strategies linked to the different sources throughout the landscape, we classify the relative frequencies of raw material types and the percentage of cortex present in the lithic assemblage. Artefacts made from obsidian have a clearer geochemical identification of the main outcrops that can be identified (Frahm, 2016, 2019), although some obsidian sources remain unidentified because of method limitations (see the pXRF methods section). Raw materials from other sources present at the site, were classified based on their colors and textures. In the study of the Ararat-1 cave, we grouped the raw materials into two categories: obsidian artefacts, which include all artefacts distributed by the respective sources, and non-sourced artefacts. Non-obsidian artefacts encompass all the raw materials that are not obsidian. This grouping is intended to understand better the technological methods applied to two different raw materials units (Roebroeks, 1988).

The typological classification of the retouched pieces followed Bordes’ type list (Bordes, 1961) with additional categories (Hovers, 2009) to include specific tool types, such as retouched flakes on both sides and arrowheads (tool types retrieved from the upper layers). Non-retouched flakes and naturally backed knives were classified as debitage production rather than tools.

Special emphasis was placed on the edge modification sequence (Nora et al. submitted). This reduction method concerns the activities of retouching, reshaping, and rejuvenating a tool. In a previous paper (Nora et al., 2025; submitted), we suggested module categorization of the waste material resulting from those maintenance activities. These modules are divided into five categories that represent initial edge modifications (M0), retouching and reshaping (M1-M3), and tool reshaping and rejuvenation (M4) (see Nora et al., 2025 and references therein). The identification of the module flakes concept is based on a set of characteristics and the presence of scars on the byproducts (See SOM4 for more information about module flake categories). By analyzing the cores and the debitage production, preparation and exploitation phases were distinguished based on scar patterns and flake morphology. This strategy was chosen due to its significance within the site, since more than 1095 of the assemblage is smaller than 20 mm. All the data entry was done using the E5 software available at <https://github.com/surf3s/E5oldstoneage.com>, with a personalized configuration file for Ararat-1 Cave.

### 3.4. Refitting

The refitting analysis was carried out by one of us (DN). All artefacts were submitted to a preliminary refitting analysis. Artefacts were laid out on tables and divided first into raw material units (in the case of obsidian, grouped according to sources) by squares (Noten et al., 1980; Romagnoli and Vaquero, 2019; Vaquero et al., 2019; Villa, 1982). As a starting point, we consider that any connection greater than 2 m probably involves displacement, regardless of the causes of that displacement (Villa, 1982). This does not mean there can be no displacements at shorter distances. Connection lines have been defined according to the temporal order of removals (Cziesla, 1987). For each connection line, we considered the following variables: type of refit, breakage, production sequence, retouch. In the case of the Ararat-1 cave, we didn’t differentiate the types of areas. This work will be done in the future.

All data analysis and plotting were processed with R open-source software. A research compendium using the rtools package by (Marwick et al., 2018), including detailed info on used packages, software versions, and raw and processed data, is available here: <https://github.com/Nora-Arch/Ararat1caveLithicQSR>.

## 4. Results

The lithic assemblage of Ararat-1 cave consists of 1770 artefacts recovered from five main stratigraphic units, approximately 2 m in depth, Fig. 4. This assemblage is divided into obsidian and non-obsidian groups, 1245 and 525 artefacts, respectively. At Ararat-1 cave, we identified four knapping methods (method refers to any carefully thought out sequence of interrelated actions, each of which is carried out according to one or more techniques (Inizan and Féblot-Augustins, 1999, p. 30), that dictate technological preferences: edge modification, core on flake, Levallois, and indeterminate, mostly represented by high frequencies of flakes. The lithic assemblage was structured by dividing lithic raw materials into two groups: obsidian and non-obsidian. A total of 37 types of raw materials were identified. From that total, 25 are part of the different sources of obsidian, and 4 are chert, plus limestone, silicified and non-silicified, chalcedony, sandstone, quartzite, and an unidentified metamorphic rock, basalt, mafic lava, and one with no identification named, other.

The results start with an overall view of all units and then focus on two sedimentological units, SU3 and SU4. This option results from the collaborative work analysis of the lithic assemblage and the geo-archaeological and chronological proxies (Oikonomou et al., 2025; Sherriff et al., 2024). SU1 and SU2 are not discussed in detail since SU1 underwent several post-depositional processes, mostly associated with bioturbation, whereas SU2 is spatially localized at the front of the cave, next to the inflexion point. Therefore, we focused our analysis on the archaeological data that seems less affected by post-depositional processes.

The distribution of raw materials across the sedimentological units (SU), in Fig. 5, reveals distinct patterns in the use of obsidian and non-obsidian lithic materials, highlighting shifts in raw material availability and technological preferences throughout the site's occupation. In SU0, the assemblage is heavily dominated by obsidian, particularly Geghasar obsidian ( $n = 79$ ) and non-sourced obsidian ( $n = 51$ ), while non-obsidian materials such as chert and chalcedony occur only minimally. This suggests a primary reliance on local or easily accessible obsidian sources during this phase. In SU1, the raw material composition is more balanced, with Geghasar obsidian ( $n = 95$ ) and non-sourced obsidian ( $n = 73$ ) still prominent but accompanied by a notable increase in non-obsidian materials, particularly chert ( $n = 58$ ). This shift may indicate broader procurement strategies or activity-specific material use. At SU2, obsidian use is significantly lower compared with all the other sedimentary units, with only a minimal presence of Geghasar obsidian ( $n = 18$ ). Instead, non-obsidian materials, particularly chert ( $n = 143$ ), overwhelmingly dominate the assemblage. This marked shift likely reflects changes in raw material availability, technological

preferences, or occupational patterns at the site. In SU3, obsidian use is present, with Geghasar obsidian ( $n = 137$ ), non-sourced obsidian ( $n = 102$ ), and Gutansar obsidian ( $n = 77$ ) forming the majority of the assemblage. Non-obsidian materials, particularly chert ( $n = 189$ ), reflect a diverse raw material selection. SU4 displays a highly varied assemblage, with non-sourced obsidian ( $n = 85$ ) being the most prevalent, followed by Gutansar obsidian ( $n = 48$ ) and Geghasar obsidian ( $n = 55$ ). Non-obsidian materials such as chert ( $n = 40$ ) remain present, emphasizing the diverse technological organization and exploitation of available resources.

### 4.1. Obsidian sourcing results

The obsidian artefacts of interest derive from SU4 ( $n = 203$  sourced artefacts; dated ca.  $52 \pm 3$  ka and  $44 \pm 3$  ka by OSL,  $43.52 \pm 1.15$  ka cal. BP by radiocarbon) and SU3 ( $n = 335$ ; ca.  $45 \pm 3$  ka and  $38 \pm 1$  ka cal. BP). The units above ( $n = 381$  sourced artefacts; SU0 to SU2) are highly bioturbated and/or Holocene (e.g., Bronze Age, Medieval) in age. Artefacts without clear stratigraphic contexts ( $n = 10$ ; e.g., section cleaning, missing information) were also excluded. Therefore, 929 obsidian artefacts, in total, were both sourced and studied via attribute analysis.

Supplementary File 2 lists the source identifications and summarizes the attribute analysis of the studied obsidian artefacts from SU0 through SU4. As noted above, the Ararat-1 cave obsidian assemblage (70 %) is principally composed of small to very small to small flakes, which necessitated special data processing. Specifically, as items of analytical interest decrease in size, the XRF software relies more and more on certain spectral features (i.e., the elastic and inelastic X-ray scattering peaks) and algorithms to estimate the item's mass. To demonstrate, Fig. 6 is a scatterplot of the obsidian source dataset, measured using the same instrument, after discriminant function analysis (XLSTAT BASIC+) based on ratios of Sr, Y, Zr, and Nb to Rb. The first two functions, as shown, provide discrimination of 77.05 % and 17.50 %, respectively, for a total of 94.55 %. The third (3.81 %) and fourth (1.65 %) functions increase the total discrimination to 100 %, and all four are applied to the artefact data to make source attributions. Fig. 7 shows the outcome with a subset of 140 artefact analyses (for clarity) with the first two functions. SOM 1 Tables 1 and 2 report the source identifications for stratigraphically secure artefacts from SU4, SU3, and the upper units (see Table 3).

### 4.2. Exploitation and production phase

#### 4.2.1. Obsidian results

Obsidian artefacts are in the category of very small to small (Vaquero, 2008), predominantly falling under the 500 mm<sup>2</sup> category,

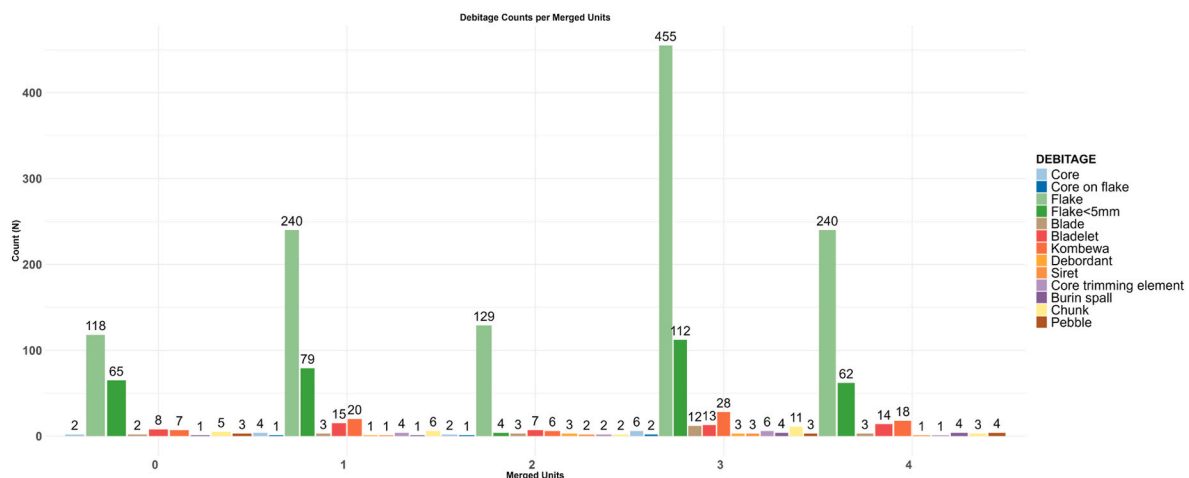


Fig. 4. Histogram of the lithic debitage per sedimentological units.

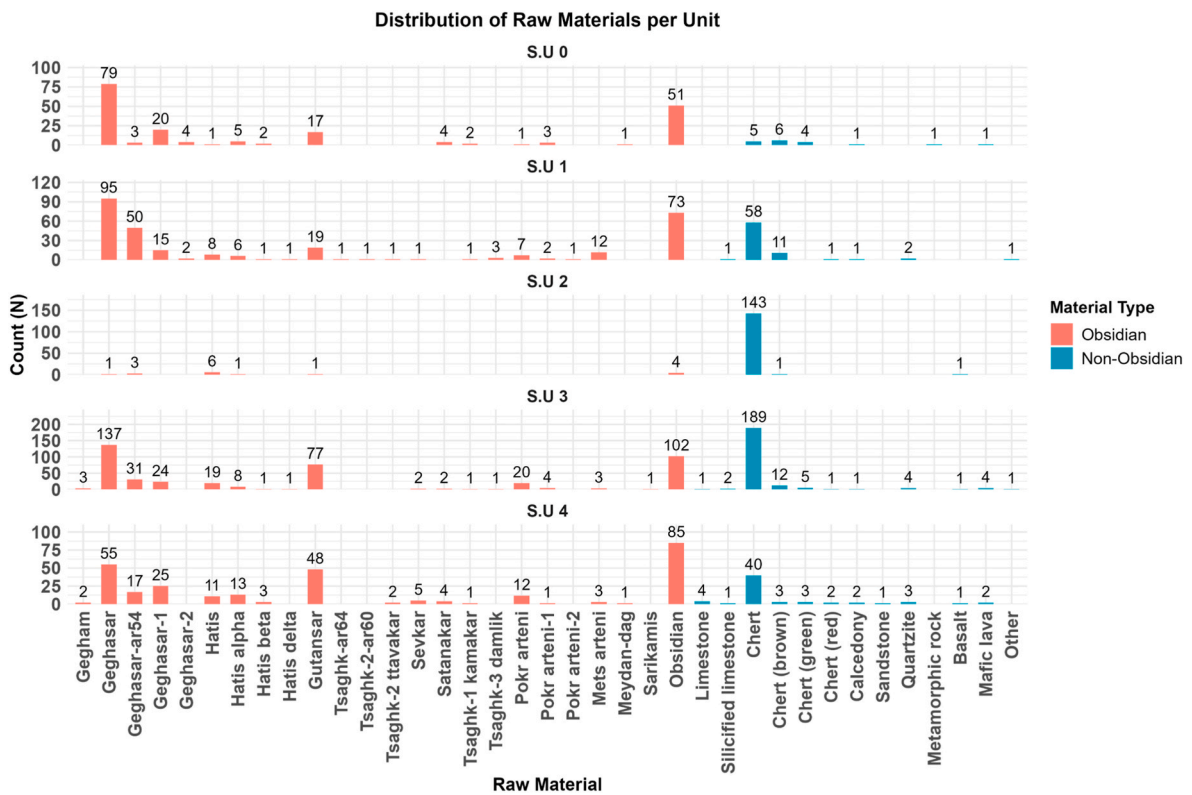


Fig. 5. Lithic raw materials distribution per Sedimentological Units, divided in colors by Obsidian and Non-Obsidian.

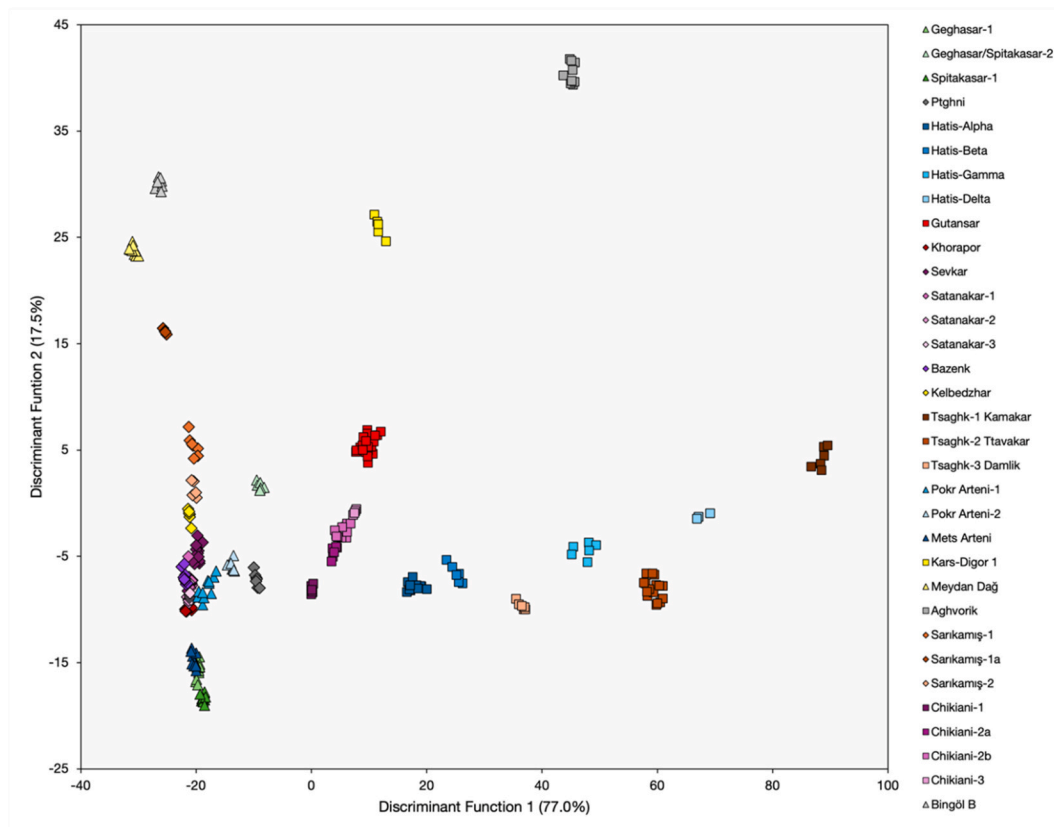


Fig. 6. The obsidian dataset after discriminant function analysis based on ratios of Sr, Y, Zr, and Nb to Rb. These first two functions, as shown, provide discrimination of 77.05 % and 17.50 %, respectively, totaling 94.55 %. Most, but not all, obsidian sources from the Armenian Highlands are shown here.

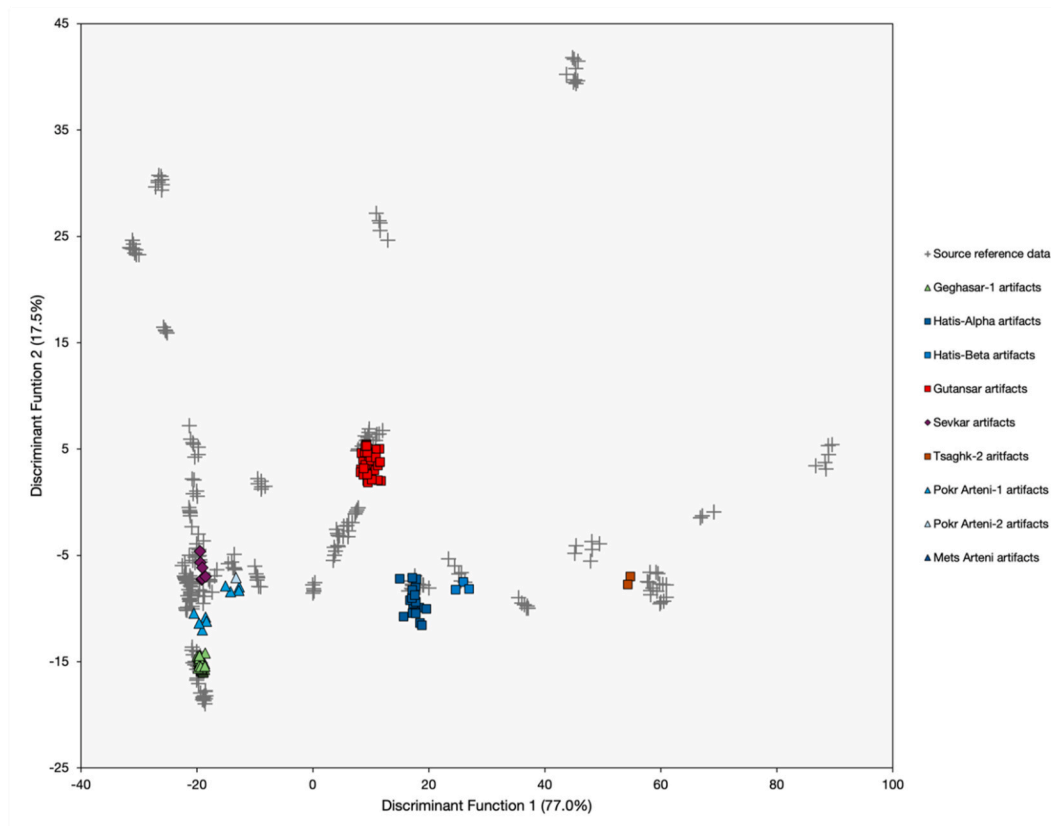


Fig. 7. An example batch of 140 artefact analyses for Ararat-1 cave (for clarity), classified according to the discriminant functions derived from the obsidian source data in Fig. 6.

Table 2

Typological table, according to (Bordes, 1961, 1969), with additional categories (Hovers, 2009), of the Non-obsidian artefacts separated by raw material units and sedimentological units.

Non-obsidian Retouched Pieces	Chert	Mafic lava	Quartzite	Sandstone	Non-obsidian Total
<b>SU. 3</b>	<b>3</b>		<b>1</b>		<b>4</b>
4.Retouched Levallois point	1				1
9. Single straight scraper	1				1
10. Single convex scraper			1		1
19.Convex-convergent scraper	1				1
<b>SU.4</b>		<b>1</b>		<b>1</b>	<b>2</b>
4.Retouched Levallois point		1			1
9. Single straight scraper				1	1
<b>Total</b>	<b>3</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>6</b>

with very few exceeding 1000 mm<sup>2</sup> (see SOM 1 Fig. 14/15) (see Fig. 13). Their vertical distribution shows prominent concentrations between elevations of 98.90 and 99.10 m (SOM 1 Fig. 14/15). These artefacts exhibit minimal post-depositional disturbance, as evidenced by their high degree of completeness (approximately 60 %) (see SOM1 Figs. 1–5) and their predominantly fresh or minimally abraded condition throughout the stratigraphy. Obsidian artefacts dominate the assemblage across all debitage products and almost all units, except SU 2, where 90 % of the items are non-obsidian (Fig. 5). Debitage analysis underscores a dominance of flakes, comprising 60.9 % for SU 3 and 73.1 % of SU4, and a minimal representation of core trimming elements (see SOM 1 Fig. 6/7). Scar pattern analysis and number of dorsal scars (see SOM 1 Fig. 8/9) show that in SU3, the Centripetal, Convergent, and Convergent side scar patterns exhibit the highest median number of dorsal scars (~7–10), with significant variability and a few outliers extending beyond 15 scars. Along axis and Along axis opposed show values, with medians around 4–6 scars.

In SU 4, centripetal stands out with the highest number of dorsal scars (~20 median, reaching 40 in extreme cases), showing considerable variation. Opposed (~10 scars) and indeterminate (~5 scars) also exhibit high values. along axis and along axis opposed maintain values (~4–7 scars).

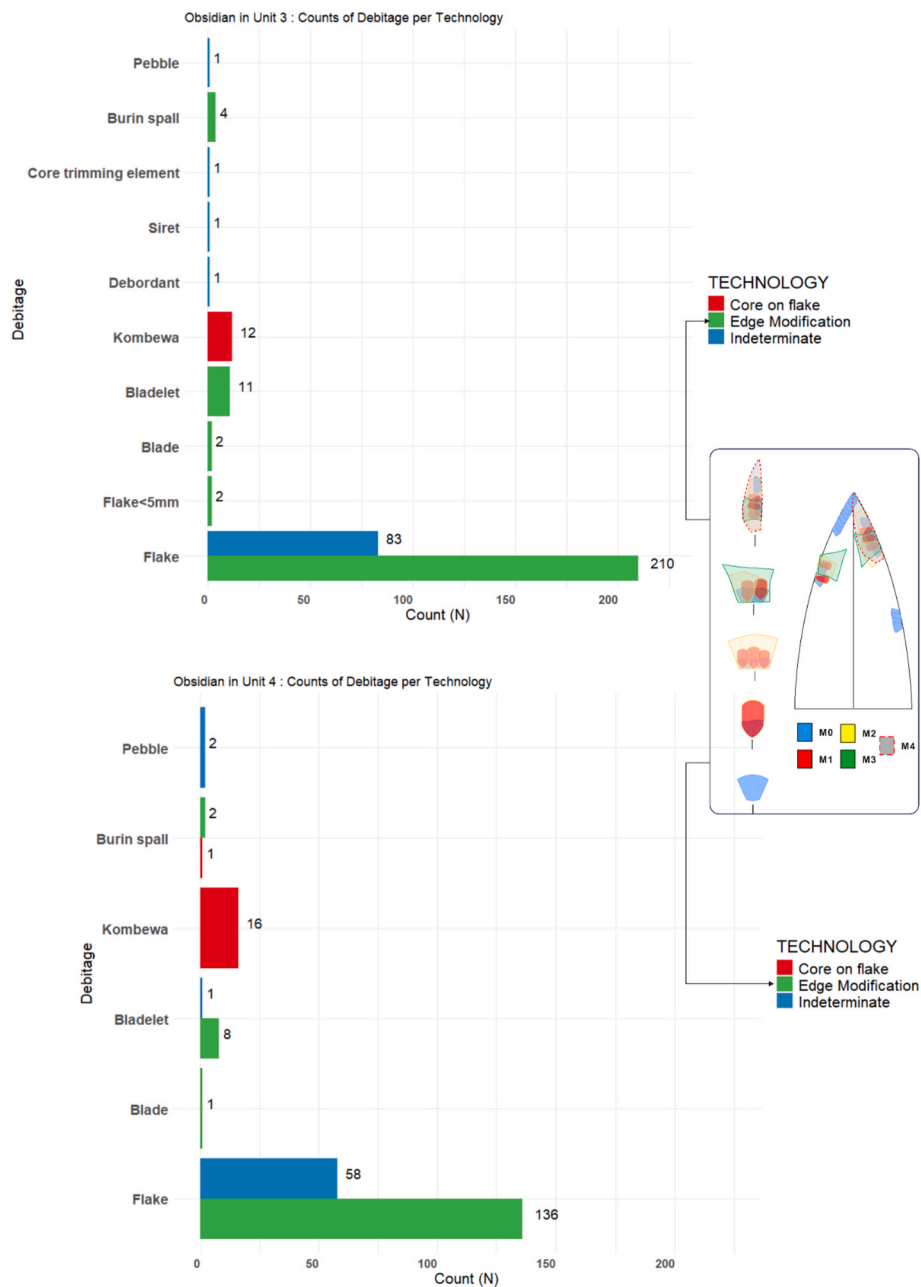
Technological dimensions of obsidian artefacts range from 2.23 mm to 40 mm in length and 1.86 mm to 30 mm in width, clustering predominantly between 10 and 25 mm in length and 5–15 mm in width (Fig. 11). The technological analysis reveals that obsidian artefacts are primarily associated with edge modification technology, with a significant number of flakes (n = 346) and bladelets (n = 19). Additionally, the presence of Kombewa flakes (n = 28) highlights the use of cores on flakes for specific reduction strategies.

The exploitation of obsidian in SU3 and SU4 (Fig. 8) demonstrates a selective application of reduction techniques, primarily focusing on edge modification with slight evidence of core-on-flake technology. Specifically, SU3 features significant quantities of Geghasar obsidian (n

**Table 3**

Typological table, according to Bordes (1961), with additional categories (Hovers, 2009), of the Obsidian artefacts separated by raw material units and sedimentological units.

Obsidian Retouched Pieces	Geghasar	Geghasar-1	Geghasar-ar54	Hatis alpha	Sevkar	Pokr Arteni-1	Meydan-dag	Obsidian Total
<b>SU. 3</b>	<b>1</b>	<b>1</b>	<b>2</b>		<b>1</b>			<b>5</b>
9. Single straight scraper		1						1
43. Denticulate			1					1
45. Flake with irregular retouch on interior	1							1
64. Retouch flake			1					1
Indeterminate					1			1
<b>SU.4</b>			<b>1</b>	<b>1</b>		<b>1</b>	<b>1</b>	<b>4</b>
6. Mousterian point				1				1
9. Single straight scraper							1	1
11. Single concave scraper			1					1
19. Convex convergent scraper						1		1
<b>Total</b>	<b>1</b>	<b>1</b>	<b>3</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>9</b>



**Fig. 8.** Lithic technology divided per debitage. Obsidian in Units 3 and 4.

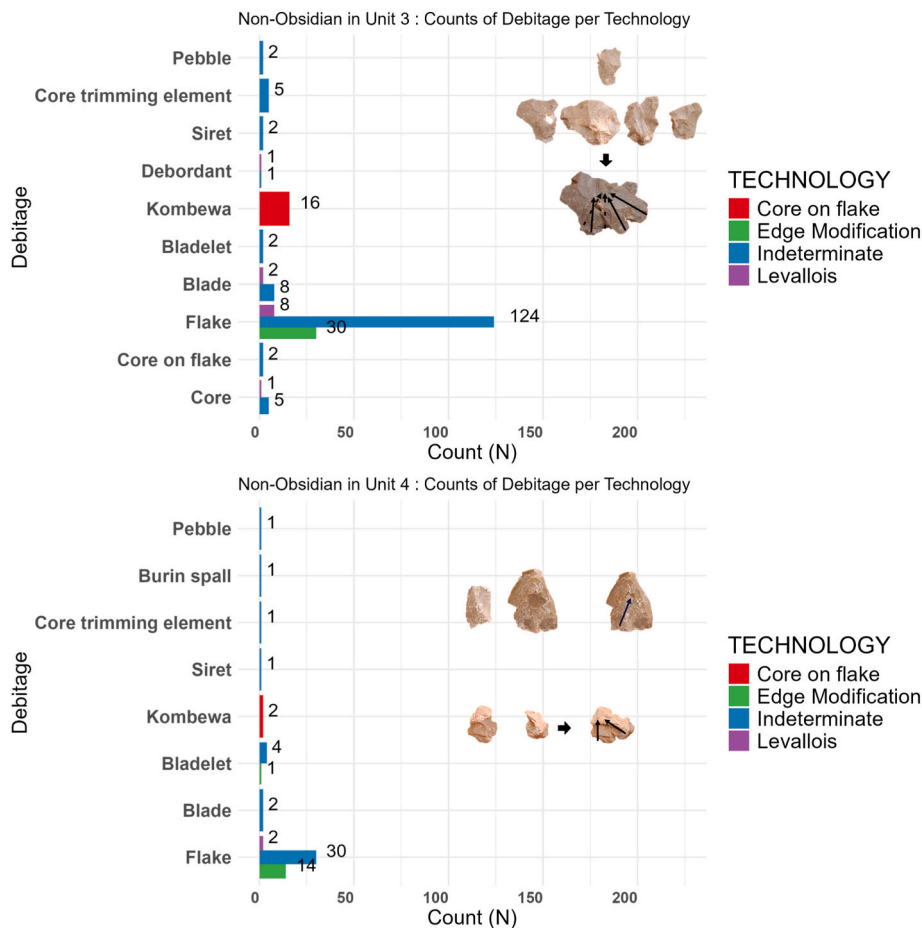


Fig. 9. Lithic technology divided per debitage. Non-Obsidian in Units 3 and 4.

= 137), non-sourced obsidian ( $n = 102$ ), and Gutansar obsidian ( $n = 77$ ). The technological processes are less diverse, emphasizing flake production and specific edge maintenance activities, with minimal evidence of core exploitation.

#### 4.2.2. Non-obsidian results

Non-obsidian lithic artefacts exhibit broader morphological variability compared to obsidian. Their lengths range from under 10 mm to approximately 80 mm, while widths fall predominantly below 30 mm. The artefacts show a significant size range, with areas extending up to 3000 mm<sup>2</sup> (SOM 1 Fig. 14/15). Vertical distribution patterns reveal primary concentrations between elevations of 98.90 and 99.10 m, with additional clusters observed between 98.40 and 98.80 m (SOM 1 Fig. 14/15). Non-obsidian artefacts encompass diverse debitage products, including cores, Kombewa flakes, debordant flakes and core trimming elements, suggesting varied reduction strategies.

The raw material analysis identifies chert as the dominant non-obsidian material (Fig. 5), especially in SU3 ( $n = 207$ ) and SU2 ( $n = 127$ ), while SU4 features fewer chert quantities ( $n = 48$ ). On this raw material unit, we also see the single occurrences of other lithic raw materials, such as chalcedony, sandstone, and basalt. At non-obsidian, flakes also dominate the debitage categories, although with more occurrences of other debitage products. The technological length of non-obsidian lithics ranges from 4.67 mm to 70 mm, while widths extend from 3.57 mm to 50 mm, with clusters appearing around 10–40 mm in length and 5–20 mm in width.

The percentage of the cortex and location (SOM 1 Fig. 10/11) illustrate their distribution. In this scenario, only chert artefacts were mentioned because other raw materials didn't show evidence of cortex. The first heatmap reveals the distribution of debitage types across

different cortex percentages for chert types in SU 3. Flakes dominate across all cortex percentage categories, with the highest counts observed in the 0 % of cortex ( $n = 417$ ) and 1–25 % ( $n = 18$ ) categories. As cortex coverage increases, the frequency of flakes declines, with only 7 occurrences in the 76–99 % range and two counts in the 100 % category. Other debitage types, such as Kombewa (28 counts) and bladelet (13 counts), appear mostly in low-cortex categories.

The second heatmap of SU 3 (SOM 1 Fig. 11) shows that for flakes, the highest frequency of cortex location is observed in the distal part ( $n = 10$ ), proximal to distal right ( $n = 5$ ), and proximal to distal left ( $n = 5$ ). Other debitage types, such as blades, core on flakes, and core trimming elements, are present in smaller frequencies, primarily in the proximal and indeterminate cortex locations. Debitage types such as debordant appear in lower frequencies, contributing only to specific cortex categories, mostly located in the proximal part of the artefact.

The analysis of debitage types in relation to cortex percentage and location in SU 4 (SOM 1 Fig. 12/13) follows a similar pattern to SU 3, with flakes being the dominant debitage type, particularly in the 0 % cortex category ( $n = 229$ ). As the cortex percentage increases, the number of flakes decreases significantly, with only 6 occurrences in the 100 % cortex category. Given the minimal number of artefacts with cortex on this unit, the location is not significant.

Scar pattern and the number of dorsal scars results in non-obsidian artefacts from SU 3 and 4, highlights key differences in scar pattern variability. In SU 3, the highest number of dorsal scars is associated with centripetal and convergent patterns, with some artefacts reaching up to 10 scars. Other scar patterns, such as along-axis opposed and along-axis side, exhibit moderate variation, while plain and opposed patterns show minimal dorsal scarring.

In SU 4, the number of dorsal scars is lower, with most artefacts

showing fewer than 8 scars. The centripetal pattern remains dominant, followed by along-axis side and opposed patterns, though with less variability compared to SU 3.

In SU3 and SU4, non-obsidian lithics exhibit greater technological diversity (Fig. 9). Flakes (n = 198) are linked to both edge modification and indeterminate technologies, while Kombewa flakes, bladelets, and other debitage types demonstrate diverse reduction approaches. In this paper, the reduction method core-on-flake is used in association with the Kombewa debitage, represented with some larger flakes (see method 1 (Tixier and Turq, 1999, p. 136). However, they are also represented by the outliers in the identification of module flakes, which are by-products that we could not identify and were removed from other flakes, but did not fulfill all the criteria to be classified as a module flake. The Levallois

concept is evident in flake (n = 10) and blade (n = 2) categories, further underscoring the complexity of non-obsidian material exploitation.

Compared to obsidian, the diverse technological processes associated with non-obsidian lithics reflect broader reduction strategies. Significant *in situ* production is evident across multiple attributes, highlighting the adaptability of knapping methods to various raw materials and their associated technological demands.

### 4.3. Refitting evidence

As many of the artefacts were recovered per square meter, we will not assign the exact horizontal distances (although a percentage was three-dimensionally documented). Our preliminary analysis showed the

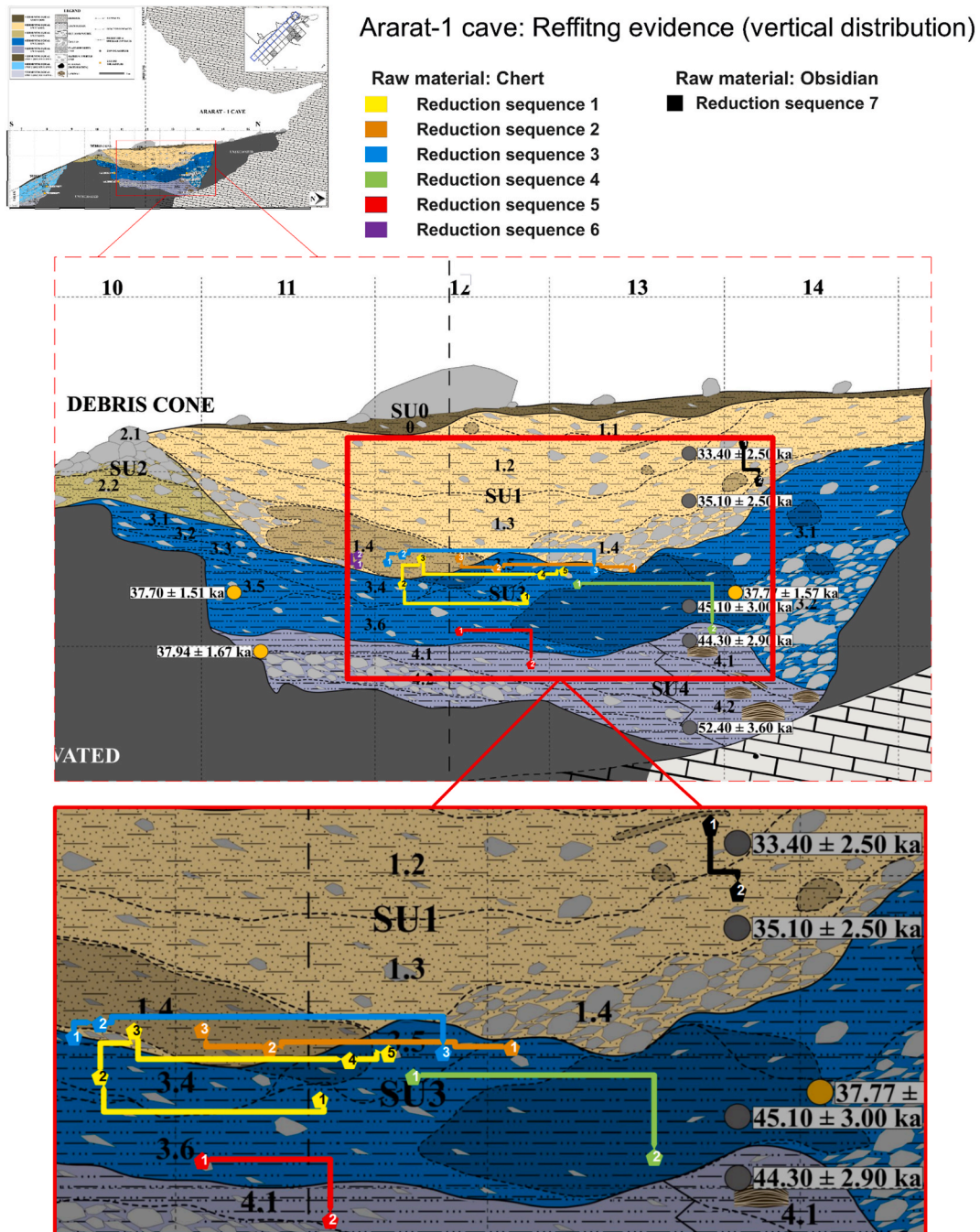
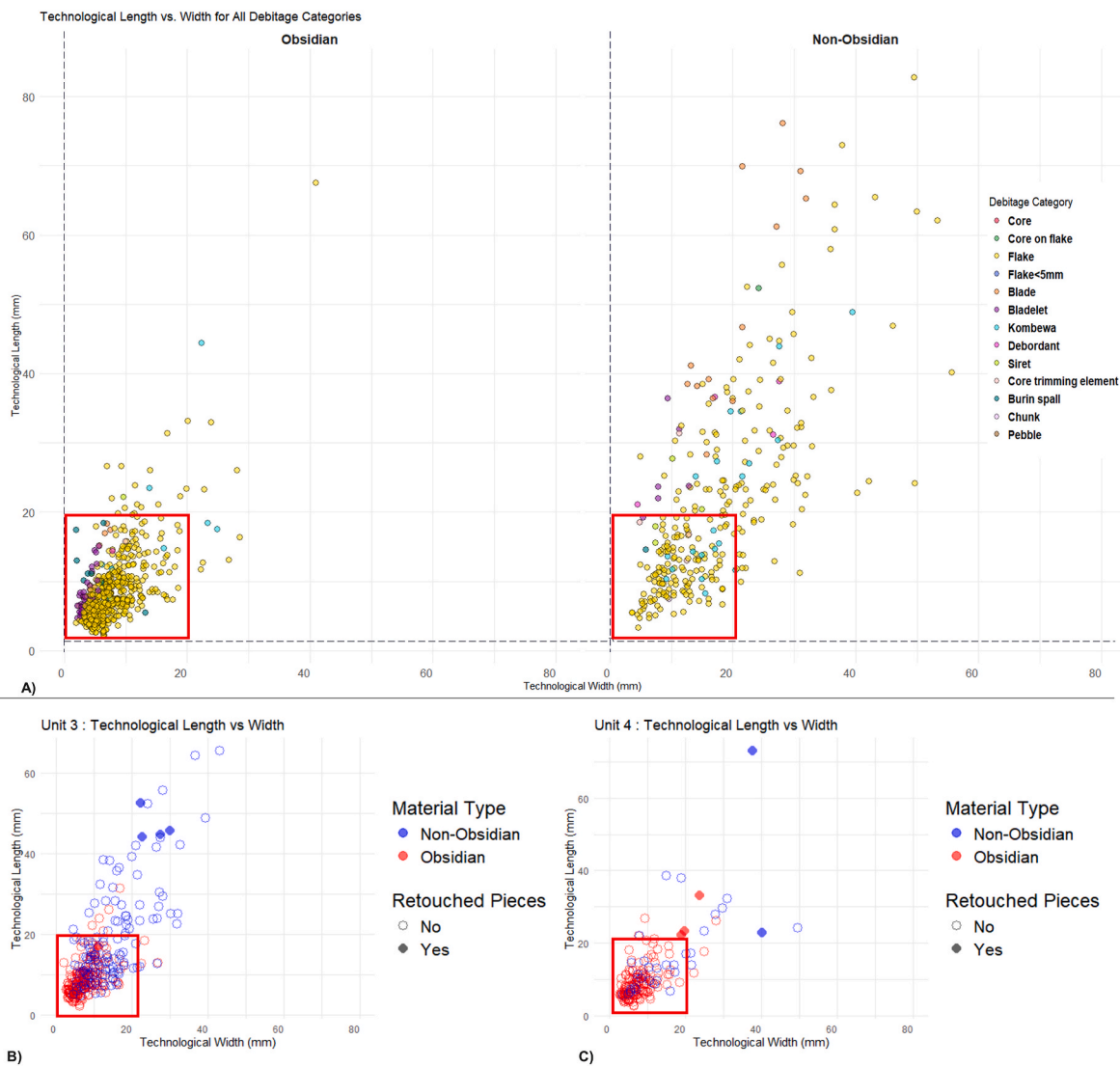


Fig. 10. Refitting sets found at Ararat-1 Cave, plotted on the western profile of the cave for stratigraphic reference (modif. from Oikonomou et al., 2025, in this volume).

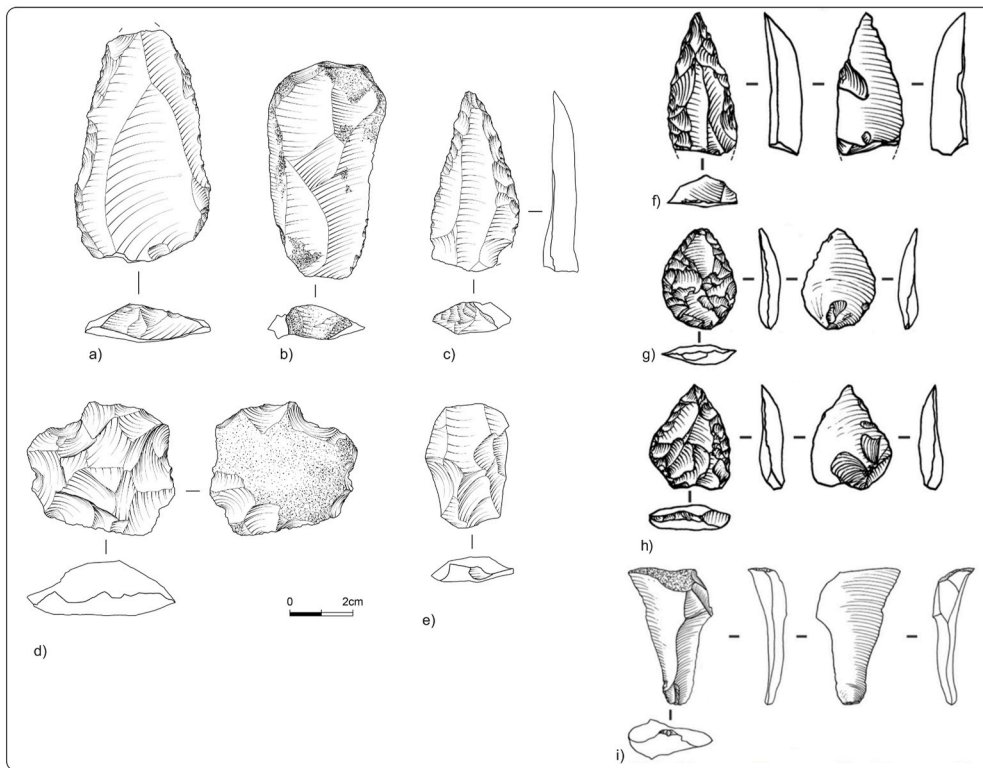


**Fig. 11.** A) Scatter Plot of technological length and width distribution of obsidian and non-obsidian per debitage. B) Scatter Plot of SU3 technological length and width distribution of obsidian and non-obsidian per retouched pieces. C) Scatter Plot of SU4 technological length and width distribution of obsidian and non-obsidian per retouched pieces. In all plots, the red box (20 × 20 mm) is representative of a common threshold applied to lithic assemblages; see more in [Nora et al.](#)

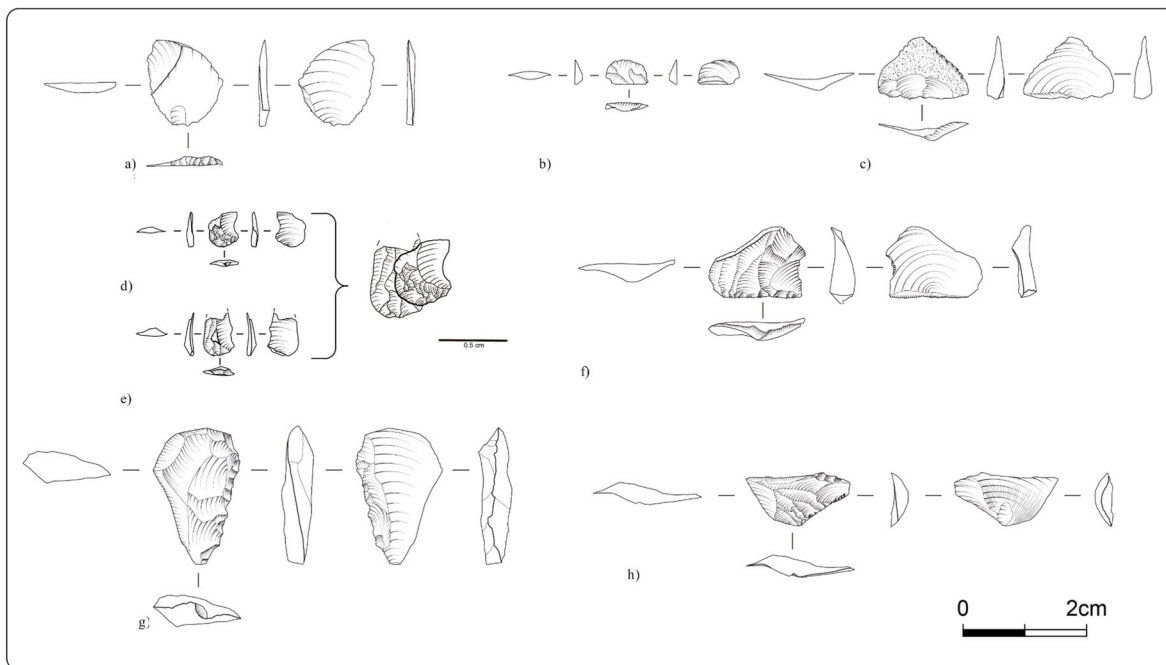
vertical distribution of lithic artefacts (Fig. 10). It highlighted two aspects: an accumulation of refits associated with SU3 and the technological difference between obsidian and non-obsidian assemblages. Most refitted lithics are attributed to two main square lines, 11 and 12. The vertical distribution of the refitted pieces was documented between a maximum distance of 0.29 cm (reduction sequence 4) and a minimum of 0.06 cm (reduction sequences 2 and 6). All the possible reconstructed reduction sequences fit into the chert exploitation and are linked to flake debitage, with no presence of cores. Chert was exploited at the production stage in the reduction sequence. At least two sets of the sequences focus on cortex removal. Fig. 9 (and SOM 3) shows the most significant reconstructed sequence (reduction sequence 3), comprising five flakes. From this refit, we can observe the direction of flake removals, which aligns with centripetal Levallois reduction (Boëda et al., 1990). The refitted obsidian was specifically related to edge modification activities.

#### 4.4. Retouched pieces

The typological attribution of the retouched pieces across non-obsidian and obsidian materials (Fig. 12 and SOM 3 Fig. 1/2) at SU 3 and 4, are down to 0.8 % of the entire assemblage without metric limitation (down to 5 mm length). From Table 2, we can observe that the presence of different raw materials (Mafic Lava, Quartzite, Sandstone) in the non-obsidian unit are tools. In both raw materials, the typological make-up is mostly towards the scrapers, which vary from convex straight to convergent. A single Mousterian point appears in obsidian, as does the denticulate type. According to the retouched pieces, the dichotomy between the raw materials is indicated by technological measurements. Fig. 11 C/D shows us that non-obsidian retouched pieces are larger than obsidian ones and, in most cases, are double in size.



**Fig. 12.** Selected artefacts from Ararat-1 Cave. a) Retouched Levallois point (Mafic Lava), b) Naturally backed knife (chert), c) Convergent scrapper (chert), d) Centripetal Levallois core (chert), e) Levallois flake (chert), f) Mousterian point; g) Convex convergent scrapper, h) Convergent scrapper, i) Core trimming element (chert).



**Fig. 13.** Selected artefacts from Ararat-1 Cave. a) Module flake-0, b) Module flake-1, c) Module flake-2 (chert), d) Module flake-2, e) Module flake-2, f) Module flake-3, g) Module flake-4, h) Module flake-4.

4.5. Edge modification sequence (Module flakes)

Ararat-1 cave has a high incidence of tool retouching, reshaping and rejuvenation activities on obsidian artefacts Fig. 13. Based on the module flake categorization, we intend to delve into this behavior (Nora et al.).

Fig. 14.A/B shows the lithic metrics across stratigraphic SUs 3 and 4 for the module flakes at Ararat-1 cave. Flake size increases across the modules. Modules 0 and 1 present smaller flakes with lower medians for technological length, width, and thickness. Module 2 shows greater variability, reflecting more diverse edge reduction sequences. Modules 3 and 4, consistently from the results of the retouching and reshaping processes, have an outcome of larger flakes, with Module 3 showing the highest medians. Thickness remains consistent across all modules and stratigraphic units, suggesting a uniform approach to the retouching and reshaping of tools regardless of length or width. The edge modification technology in both Units 3 and 4 has the same patterns. Modules 0 and 1 are representative of smaller flakes, while module 2 represents a transitional stage. Modules 3 and 4, as before, are representative of larger flakes. Module 4 exhibits slightly more variability in SU 3 than 4, but the general trend of increasing flake size with higher modules remains consistent. As for differences, we can observe that Module 0, at least in

and 4, consistently from the results of the retouching and reshaping processes, have an outcome of larger flakes, with Module 3 showing the highest medians. Thickness remains consistent across all modules and stratigraphic units, suggesting a uniform approach to the retouching and reshaping of tools regardless of length or width. The edge modification technology in both Units 3 and 4 has the same patterns. Modules 0 and 1 are representative of smaller flakes, while module 2 represents a transitional stage. Modules 3 and 4, as before, are representative of larger flakes. Module 4 exhibits slightly more variability in SU 3 than 4, but the general trend of increasing flake size with higher modules remains consistent. As for differences, we can observe that Module 0, at least in

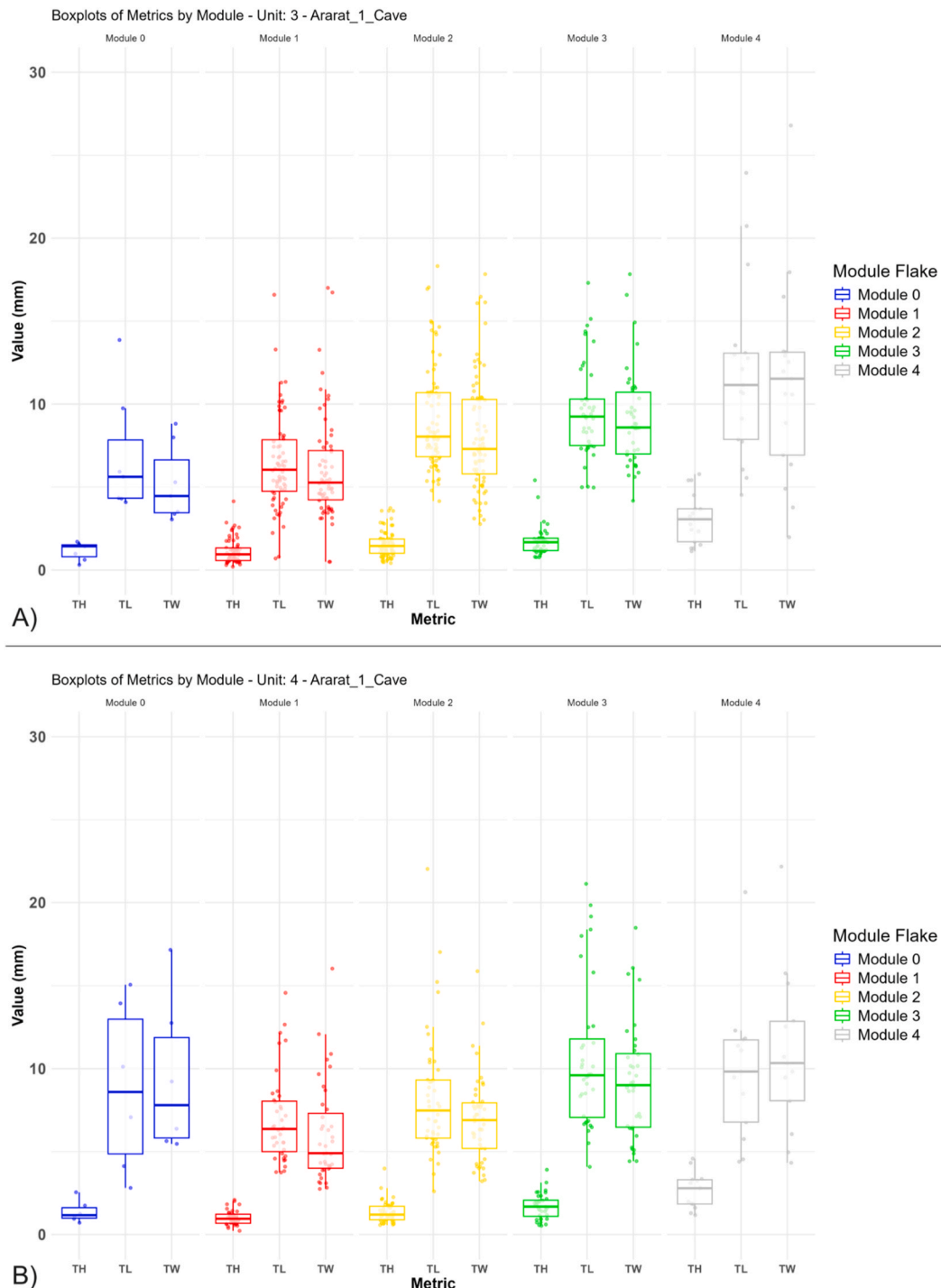


Fig. 14. Box plots of the technological metrics of edge modification module flakes per sedimentary unit. TL (Technological Length), TW (Technological Width) and TH (Thickness). A) Sedimentary Unit 3. B) Sedimentary Unit 4.

SU4, is larger than Module 1, so the primary edge removal, at least according to this specific data, initially removes a bigger area, followed by smaller retouched flakes (Module 1).

From Fig. 15-A/B, the analysis of dorsal scar patterns reveals distinct trends in the intensity and variability of edge modification strategies associated with different modules of flakes. Modules 0 and 1, pointing to primary edge modification, consistently display lower dorsal scar counts and limited variability, such as "Along Axis" and "Plain," indicative of primary edge modification. In Fig. 15, we can show in more detail that

Module 2 flakes are indeed a transitional stage because most of the same dorsal patterns are present as in Module 1, but with higher frequencies of scars, a pattern expected from the perspective of a continuum of reduction (Dibble, 1987, 1995). Modules 3 and 4 exhibit higher dorsal scars and more complex patterns like "Centripetal" and "Convergent", suggesting intensive reduction and retouch activities to maximize raw material management and utility.

In SU3 and SU4, scar counts increase significantly, particularly in Module 4, where scar patterns like centripetal, along-axis opposed, and

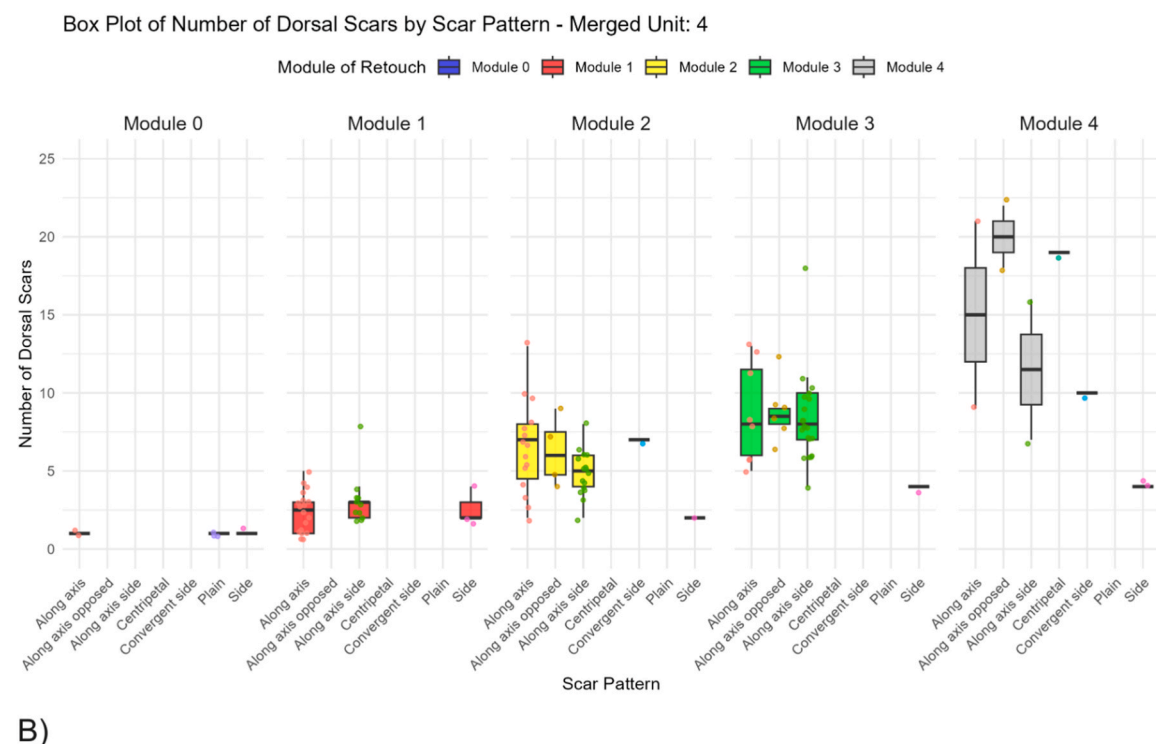
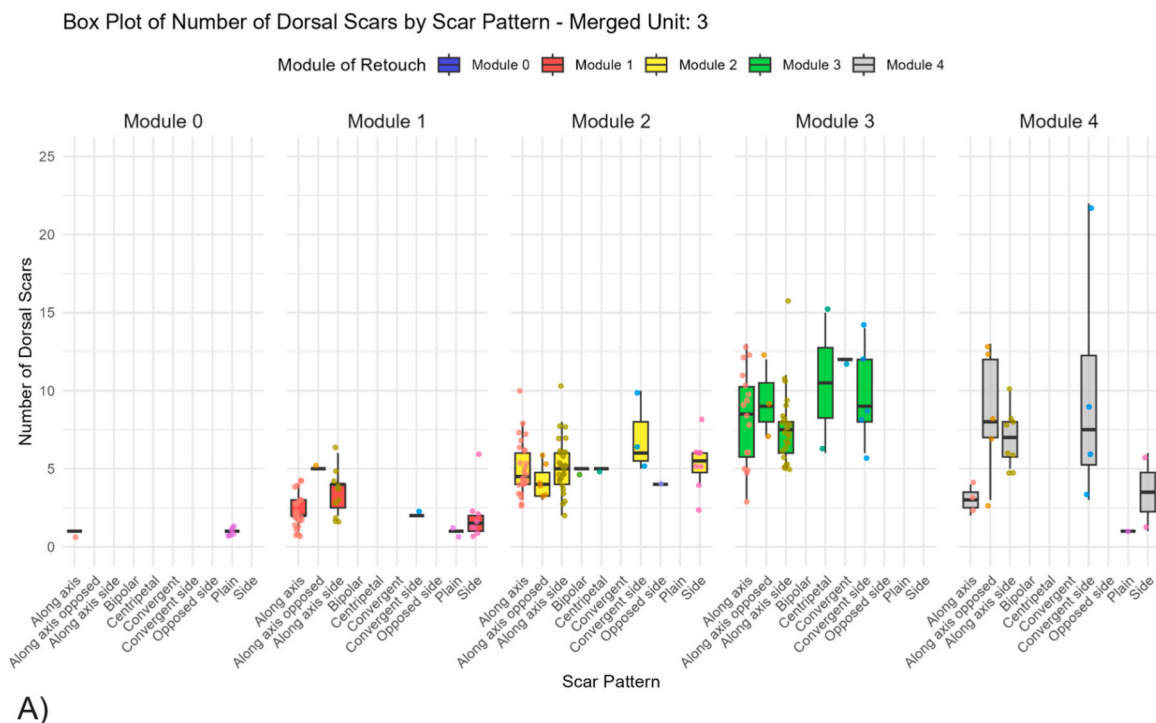


Fig. 15. Box plots for each module flake showing the scar pattern plotted with the number of dorsal scars. A) Sedimentary Unit 3. B) Sedimentary Unit 4.

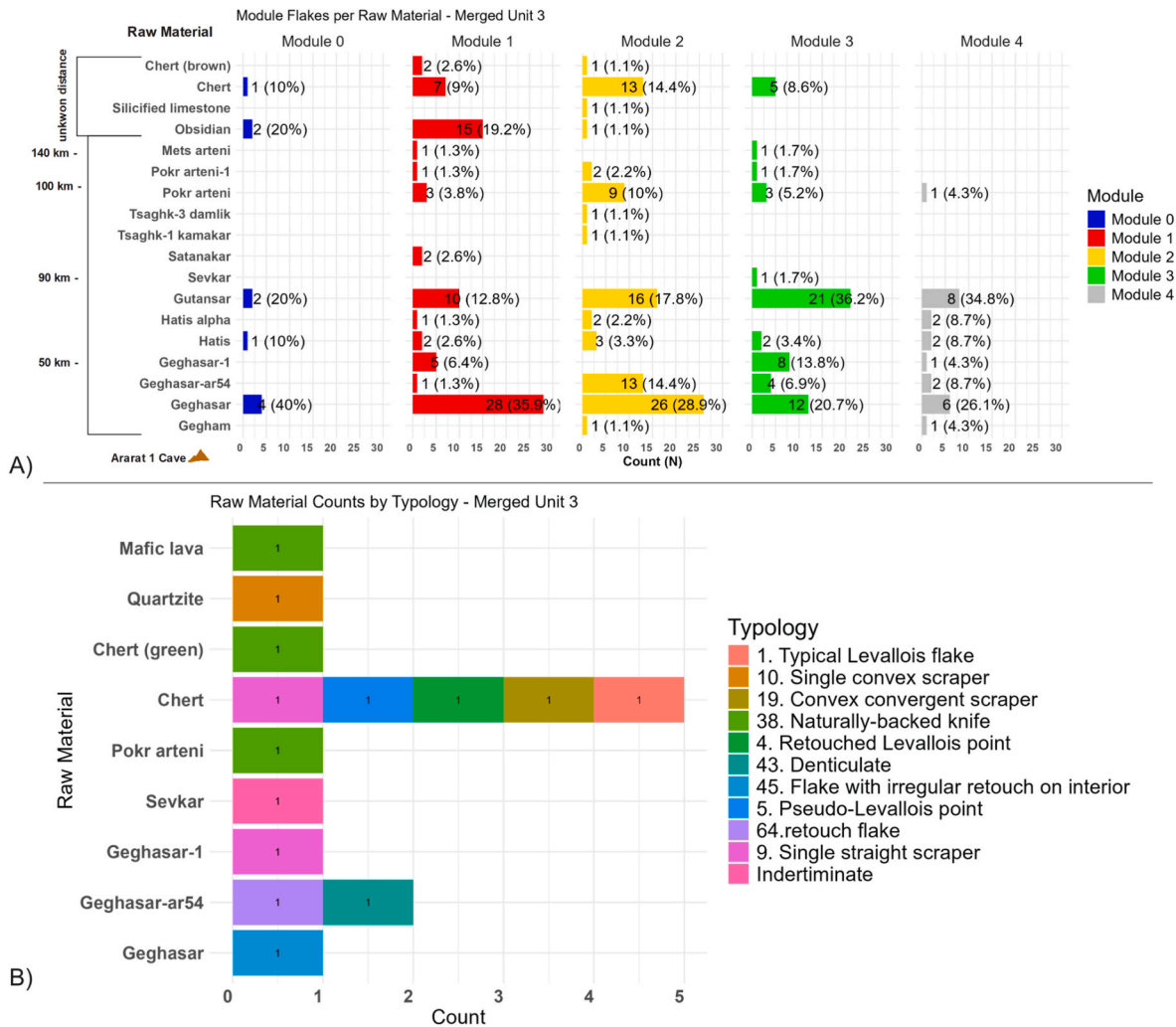


Fig. 16. A) Module Flakes frequencies per raw material units on SU 3. For obsidian, each source is discriminated and attributed the distance to the site in a straight line in Km. B) Typological chart showing the presence or absence of tools (retouched or shaped, e.g., Levallois flake) that share the same source as module flakes.

axis-side dominate. These patterns exhibit the highest dorsal scar counts, indicating more intensive retouching and reshaping. The variability and intensity of scars observed in SU3 and SU4 highlight an increasing complexity in lithic maintenance strategies over time, with Modules 3 and 4 consistently associated with higher dorsal scar counts and more diverse scar patterns.

The lithic assemblage from Ararat-1 Cave demonstrates a dynamic distribution of raw materials across the five module flakes categories (Module 0 to Module 4) (Fig. 16/17). Each module exhibits distinct patterns in raw material frequencies and types, reflecting shifts in mobility strategies and raw material availability over time, specifically between SU3 and SU4.

In SU 3 (Fig. 16-A), Module 0, raw materials show a narrow variety, with Geghasar (40 km) contributing the largest share, accounting for 4 flakes (40%), followed by Gutansar (20%) and obsidian (20%). Other raw materials and obsidian sources include chert (10%) and Hatis (~50 km, 10%). Module 1 maintains a strong reliance on Geghasar (35.9%), while obsidian increases to 19.2%, and Gutansar contributes 12.8%. Additional raw materials, including Chert (9%), Sevkar (2.6%), and Pokr Arteni (3.8%), are also present, suggesting a wide acquisition range.

Module 2 demonstrates a broader range of materials, with Geghasar (28.9%), Gutansar (17.8%), obsidian (14.4%), and chert (14.4%) becoming more representative, which reflects an increased diversification of raw material sources. In Module 3, Gutansar (36.2%) dominates,

followed by Geghasar (20.7%) and Geghasar-1 (13.8%). Still, in Module 3, we attest to a decrease in artefacts from more than 90 km. The same pattern is observed in Module 4, which shows a concentration around Geghasar (26.1%), with smaller contributions from Gutansar (8.7%) and other materials.

In SU4 (Fig. 17-A), Module 0 reflects similar patterns compared to SU3, with Geghasar (40%) as the primary raw material, followed by Gutansar, Hatis, Chert, Basalt, and Quartzite (each at 10%). Module 1 shifts to greater reliance on Obsidian (30.6%), followed by Gutansar (16.3%) and Geghasar (12.2%). Other contributors include Pokr Arteni, Geghasar-1, and Hatis.

Module 2 shows an even distribution of Obsidian (14%), Gutansar (14%), and other materials like Geghasar-1 (10%) and Hatis alpha (8%). Module 3 is dominated by Gutansar and Geghasar (20% each), with additional amounts of obsidian (17.5%). Finally, Module 4 highlights obsidian (23.1%), Gutansar (15.4%), and Geghasar (15.4%), with smaller amounts from Hatis alpha and Sevkar.

The presence and absence of specific raw materials further illustrate the dynamics of lithic production. At SU3, several raw materials, including Geghasar, Gutansar, obsidian and chert, are consistently present across all modules. Some materials, such as Hatis, Sevkar, Pokr Arteni, and Tsaghk-3 Damlik, are more common in earlier modules (Modules 0–2) but diminish or disappear in later modules (Modules 3–4). Similarly, at SU4, while Geghasar, Gutansar, obsidian, and chert persist across all modules, materials like Quartzite, Basalt, Geghasar-1,

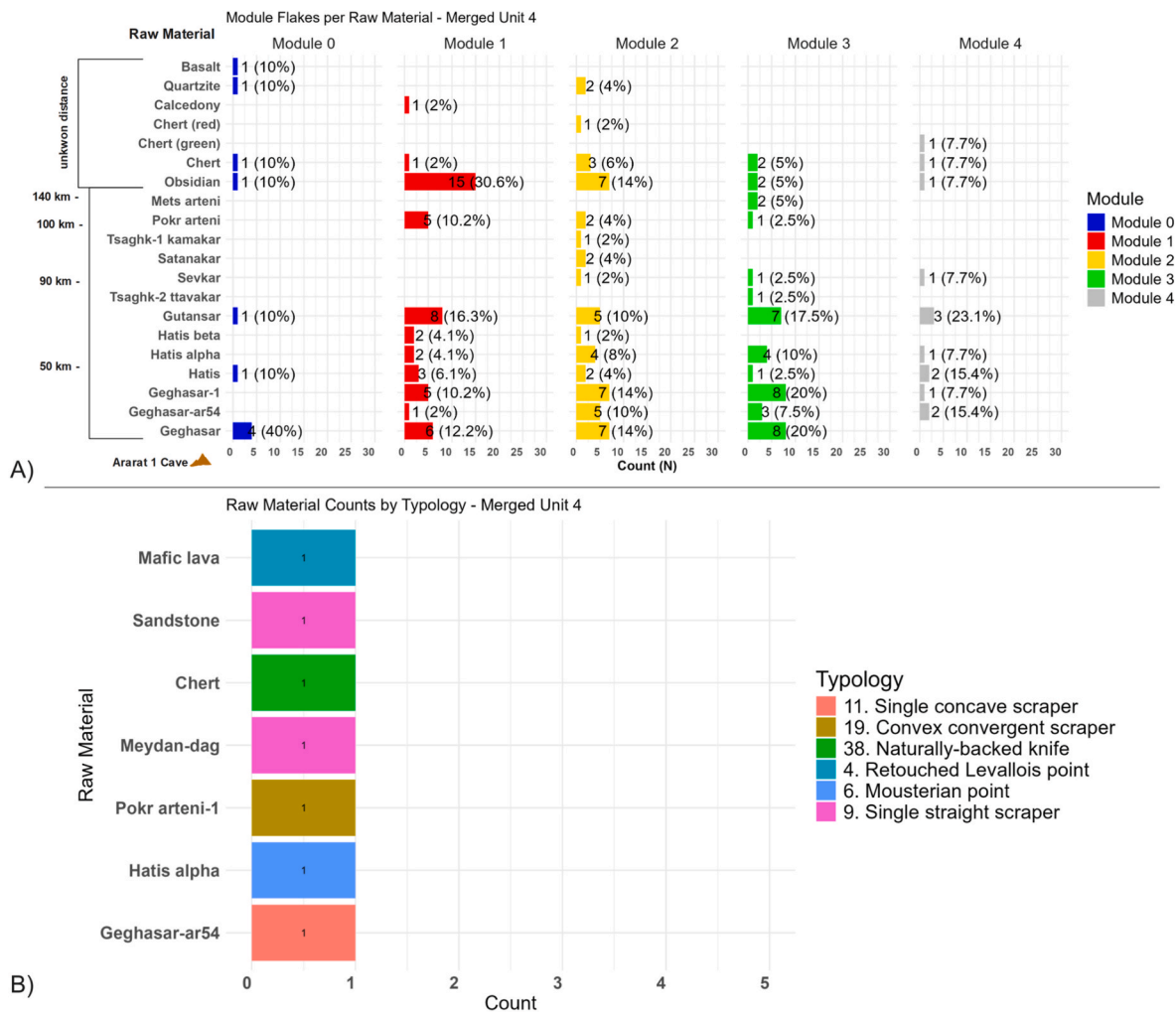


Fig. 17. A) Module Flakes frequencies per raw material units on SU 4. For obsidian, each source is discriminated and attributed the distance to the site in a straight line in Km. B) Typological chart showing the presence or absence of tools (retouched or shaped).

Hatis alpha, Hatis beta, and Calcedony appear predominantly in Modules 0–2 and disappear or decline in Modules 3 and 4. These shifts in raw material presence highlight the changing dynamics of resource availability, procurement strategies, and technological choices throughout SU3 and SU4.

### 5. Discussion

#### 5.1. The dichotomy of lithic production: reduction methods of obsidian and non-obsidian

The lithic assemblage from Ararat-1 cave reveals significant differences in reduction methods and production strategies for obsidian and non-obsidian (mostly chert), underscoring a clear dichotomy in raw material utilisation. The assemblage is characterized by two primary reduction methods: obsidian use, predominantly associated with edge modification activities, and chert exploitation, emphasizing early-stage flake removals and blank production.

Obsidian reduction at Ararat-1 cave is predominantly focused on retouching, reshaping and rejuvenation activities, with the assemblage featuring a high proportion of edge-modification flakes, such as module flakes linked to tool maintenance. This reflects a technological strategy of curation, tied to long-distance transport and tool portability (Bleed, 1986). The prevalence of small flakes (<20 mm) and the limited presence of cortical elements suggest that obsidian was brought to the site in

semi-prepared or fully prepared forms, showing evidence of curated toolkits. This indicates a structured approach to raw material procurement and reliance on high-quality raw materials such as Geghasar and Gutansar.

In contrast, chert reduction involves a broader range of technological activities, encompassing initial preparation, blank production, and occasional tool maintenance, as evidenced by the low number of module flakes (Fig. 18/19). The presence of cortical elements, including flakes with partial or complete cortex, suggests that chert was often transported within the vicinity of the site in its raw form. Debitage associated with primary reduction stages, such as cores and core trimming elements, indicates that chert exploitation included more comprehensive on-site knapping activities. The chert raw material economy reflects a more expedient approach in comparison with the obsidian, with a focus on local and readily available materials (see Fig. 19).

Although small, the refitting analysis helps us to understand the fragmented nature of lithic technology at Ararat-1 Cave. Refitting results indicate that chert reduction sequences, although incomplete, occurred as on-site knapping activities. A single refit was found in the obsidian sequence (two module flakes; Fig. 11, note their size), reinforcing its role as a curated material brought to the site as blanks for retouching or retouched blanks rejuvenated on-the-spot. One of the key insights from the refitting analysis is the identification of the Levallois method at the site, particularly in chert assemblages. As demonstrated by the refitted sequence of centripetal flaking, the use of Levallois strategies contrasts

### Ararat-1 Cave

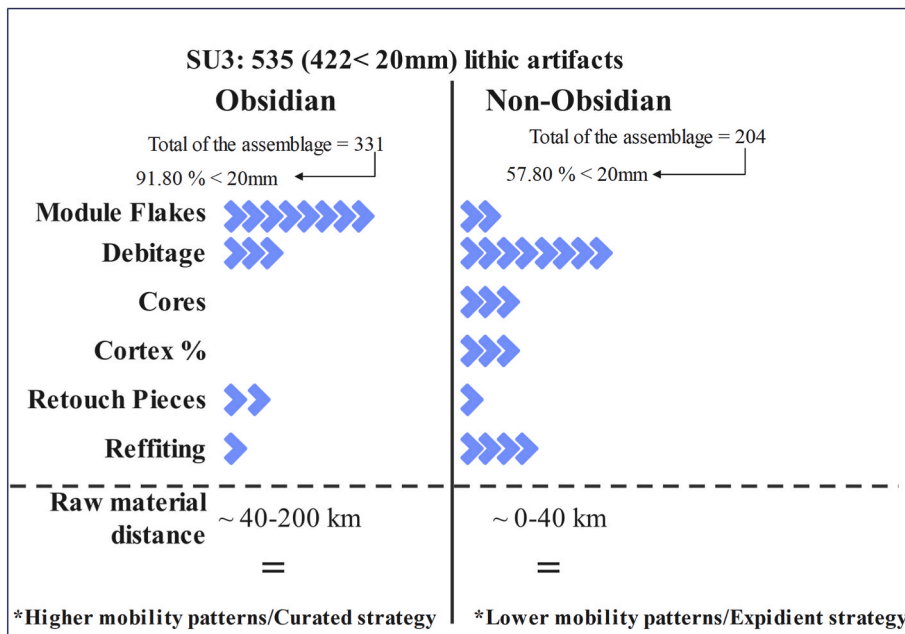


Fig. 18. Technological parameters for mobility in SU3, at Ararat-1 Cave. This figure represents a simplification of the lithic results, incorporating the module flakes as a signal for tool maintenance.

### Ararat-1 Cave

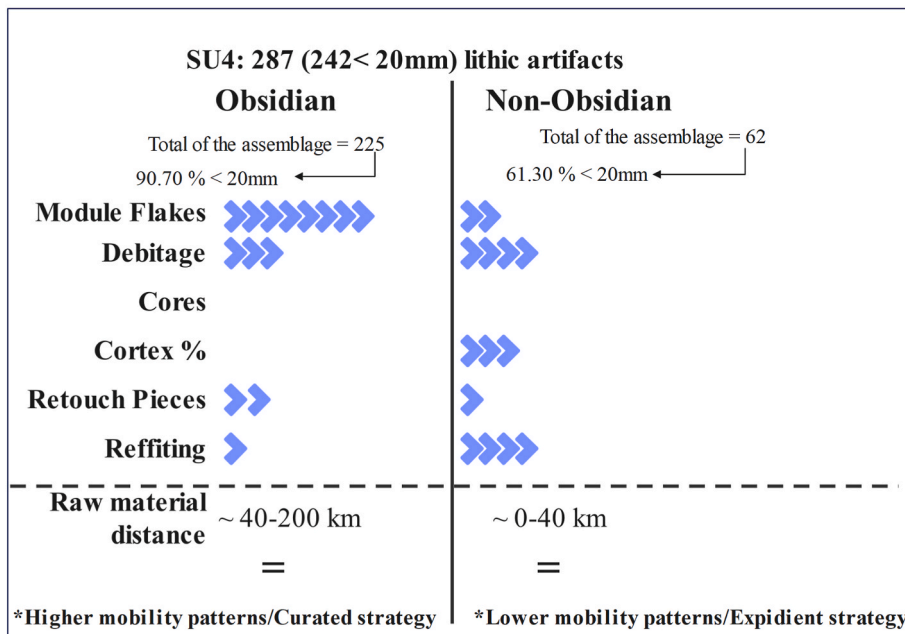


Fig. 19. Technological parameters for mobility in SU4, at Ararat-1 Cave. This figure represents a simplification of the lithic results, incorporating the module flakes as a signal for tool maintenance.

the scar pattern observed on most of the debitage (mainly unidirectional and unidirectional side), see SOM 3.

Within this refitted sequence, the absence of the core may suggest it was removed from the site, giving another testimony to the spatially fragmented nature of the lithic assemblage (Turq et al., 2013). Additional indications of this fragmentation can be seen in the diversity of raw material units at the site (37 types), including isolated presence of dacite and chalcedony, sandstone as retouched pieces, and obsidian technological patterns. The presence of a Levallois centripetal core and

the occasional use of single raw materials highlights the flexibility of decision-making within lithic production methods at Ararat-1 Cave. Although less frequent, these materials provide further evidence for the diverse resource base and the technological preference utilized by the site's inhabitants.

As it is, Ararat-1 Cave leaves us with a conundrum regarding the ways to interpret the mobility signature. Within the same sedimentary units, we observe two distinct interpretive scenarios for mobility: a higher mobile toolkit, represented by the obsidian assemblages, and a

less mobile one, as indicated by the chert. These two signatures led us to question whether either chert or obsidian can be an outlier in terms of technological strategy (curated vs. expedient). This, in turn, is reflected in mobility behavior, which is later translated into short or long-term occupations (see Fig. 2), or whether chert is a nuanced signal within the ephemeral short-term occupation. It should also be noted that Ararat-1 Cave, based on the chert raw material economy, can be interpreted as a longer-term occupation. Obsidian, on the other hand, especially in regard to the module flake category system, provides insights into the production, use, and maintenance of 'ghost tools'-tools that are no longer present in the archaeological record. Such curated behaviours and economic decisions regarding raw materials were previously difficult to discern Nora et al..

### 5.2. Rethinking mobility: integrating WABI with technological and raw material proxies

Archaeologists explore past hunter-gather technological decisions by applying analytical methods to understand lithic technological organization from the perspective of the curated vs. expedient dichotomy. The Whole Assemblage Behavioral Indicators (WABI) attempt to quantify the technological indexes to infer past behaviors, particularly in the context of land use and mobility strategies (Clark and Barton, 2017). This approach was developed by Michael Barton (Barton, 1998; Barton and Riel-Salvatore, 2014; Riel-Salvatore and Barton, 2004) and later modified by Barton and Alexandra Miller (Miller and Barton, 2008). The focus of WABI shifts from individual artefact types to the analysis of entire assemblages, considering various attributes like raw material types, reduction sequences, tool morphology, and artefact densities. WABI's method allows for interpreting lithic densities and retouch frequencies used as proxies for residential and logistical mobility. This method is based on a size threshold of 20 mm for all the debitage to overcome biases in site formation processes.

In base camps associated with logistical mobility, high lithic densities coupled with low frequencies of retouched pieces typically signify extended occupations where tools, blanks or blocks are stockpiled to accommodate future demands. Conversely, residentially mobile groups, characterized by frequent relocations, exhibit a greater reliance on portable and versatile toolkits (Barton, 1998; Clark and Barton, 2017; Miller and Barton, 2008; Riel-Salvatore and Barton, 2004). These are often represented by a higher proportion of curated tools with intensive retouching, reflecting strategies to extend tool use-lives in resource-scarce contexts (Dibble, 1995; Shott, 1996; Shott and Sillitoe, 2005).

While the WABI approach offers valuable insights into understanding long-term settlement patterns and forager mobility, there are some limitations in applying WABI to the study of short-term occupations (Bicho and Cascalheira, 2020), have argued that the WABI's reliance on the inverse relationship between retouch frequency and LVD may not accurately capture the nuances of short-term site occupations. The same holds for the tendency to equate curated technologies with residential mobility and expedient technologies with logistical mobility. The authors also cautioned against the difficulty of disentangling multiple occupations within a palimpsest, a challenge that significantly impacts the WABI's effectiveness (see also (Mitki et al., 2021)).

However, applying the WABI analytical method at Ararat-1 cave presents unique challenges due to the high presence of artefacts smaller than 20 mm. This fraction is fundamental to decoding the economic organization of the obsidian assemblage. The post-depositional processes and a generally low frequency of retouched pieces can limit the traditional calculations of retouch frequency, undermining one of the WABI key metrics. These conditions necessitate an adaptation of the framework to better suit the site's archaeological context.

To overcome this problem, we shift the analytical focus from retouched pieces to the byproducts of edge modification activities, referred to as "module flakes." These flakes represent the waste material

generated during retouching, reshaping and rejuvenation activities. By emphasizing this component, we align with the WABI postulation that retouching prolongs the use-lives of tools. Importantly, traditional lithic attribute analyses often exclude artefacts smaller than 20 mm, a threshold that in Ararat-1 cave would result in the exclusion of nearly all module flakes (see Fig. 11). By incorporating artefacts below this size threshold, our approach captures edge modification strategies that would otherwise remain invisible. This methodological adjustment underscores the need for greater flexibility in analytical frameworks when dealing with assemblages dominated by small debitage.

Another critical adaptation involves disaggregating the lithic assemblage by raw material types and sources, a departure from the traditional WABI method, which treats assemblages as unified wholes. At Ararat-1 cave, this disaggregation reveals markedly different technological approaches to obsidian and non-obsidian materials (mostly chert). According to the module flakes frequencies, we can infer the presence of tools that were provisioned out of the locale (Kuhn, 1995), as well as explore the discarded tools. The comparison of module flakes and tool raw materials highlights critical patterns in tool use-life, maintenance, and discard practices at Ararat-1 cave. The overlap in dominant Obsidian sources (Geghasar (SU3/4) across both datasets reflects their centrality to lithic production and use at the site. However, the presence of raw materials in module flakes but not in tools (e.g., Silicified Limestone, Chert (brown), and Satanakar Tsaghuniak-3 Damalik, to mention a few) points to tools that were maintained or exhausted but are no longer part of the archaeological record. Conversely, raw materials appeared predominantly in tools (Meydan-dag, approximately 150 km from the site) but not in module flakes, suggesting that specific raw materials were utilized for durable tools, minimally maintained on-site. These patterns underscore the dynamic interplay between raw material acquisition and tool use-life in SU3 and SU4 (Fig. 18/19). Aggregating the assemblage as a whole would obscure these distinct behaviors and lead to erroneous interpretations of site use and mobility.

By adopting this nuanced approach, we reconcile the seemingly contradictory evidence of "curated" obsidian and "expedient" chert within a single sedimentary unit. Future research could further refine this approach by integrating spatial and temporal analyses to explore the interplay between lithic production strategies and site use in greater detail across the MIS 3 sites in the region.

Stating this, where do we stand in terms of mobility patterns and procurement strategies? Ararat-1 Cave presents us with contradictory proxies, as it would traditionally be interpreted as a long-term occupation, given its stand-alone assemblage, which suggests a lower range of mobility based on the chert technological signatures. According to standard proxies based on the WABI, such as LVD and retouch intensity, we would not get a strong signal for either occupation term, because of the issues pointed out by (Bicho and Cascalheira, 2020), and due to site formation processes (Oikonomou et al., 2025 in this issue). However, by applying our new categorization of module flakes coupled with a distance of raw materials, we can shift this interpretation. Instead of a long-term occupation, our results suggest that Ararat-1 Cave reflects a repeated short-term occupation(s), despite the chert technological behavior initially can be interpreted as signifying a longer stay. In this case, chert can be understood within the framework of short-term occupation as indicating a relatively longer stay at the locale, or potentially as a signal of seasonality.

### 5.3. Ararat in the MIS 3 in the Southern Caucasus - the integration of Ararat 1 within other MIS 3 sites

Site comparison within the Armenian Highlands and the Caucasus region is still grounded in an archaeological theory that focuses on guide fossils, with specific typological lists or indexes used as the basis for such comparisons. However, more variables should be considered when referring to the causes and manifestations of those lithic technological variations between sites. Parameters such as technological organization

in relation to fluctuating resource availability (lithic and other), the site function within the settlement system, and/or the duration of occupation within a locale all play a significant role in shaping lithic technological variance within the MIS 3. However, that plethora of causes hampers our ability to conduct an in-depth comparison between those assemblages. We do not argue that those typological assumptions are not based on valid comparative data. Instead, we propose that to reach a state of lithic cultural affiliations, we must go beyond those typological lists and bridge more proxies to reach an in-depth comparison between archaeological sites. This conceptual shift reflects the understanding that lithic assemblages are not static reflections of cultural norms but rather dynamic and responsive systems shaped by a wide range of factors, including mobility and the role of a locale within a settlement system (Bamforth, 1986; Holdaway and Douglass, 2012; Hovers, 2009; Nelson, 1991). Positioning Ararat-1 cave, for example, with other sites in the region using only a typological or indexation approach would be challenging (Doronicheva et al., 2023; Gasparyan et al., 2014b; Golovanova & Doronichev, 2003, 2003, 2003). If we use the Levallois index, as discussed in Doronicheva's work (et al., 2023), we will find that the Ararat-1 cave does not fit the culture scheme because of the lower recognized frequencies of the Levallois debitage. As stated above, refitting analysis showed the variability within the Levallois concept and in chert assemblages through a refitted sequence of Levallois centripetal flaking.

As well the quantification of Levallois index technology during MIS 3 was only published for a handful of assemblages (Adler, 2002; Glauberman et al., 2020a,b; Malinsky-Buller et al., 2021). For other sites, relevant data is unavailable, hampering direct comparisons between sites.

On the other hand, if we take the typological approach and try to fit the Ararat-1 cave lithic assemblage to either a denticulate Mousterian, 'Jruchula-Kudarian', 'Tskhinvalian', Zagros type Mousterian, Yerevan point type Mousterian, or even Charentian, only considering the type of tools and frequencies, we would end up with yet another typological box, because the lithic assemblage in Ararat-1 cave do not fit in any typological cultures presented for the region. The absence of "Yerevan points," a hallmark of the "Yerevan type" Mousterian, further distinguishes Ararat-1 cave from other regional MP sites such as Yerevan cave (Gasparyan et al., 2014b; Yeritsyan, 1972), Angeghakot 1 (Liagre et al., 2006) and Lusakert-1 (Birtwistle and Yeritsyan, 2012; Frahm et al., 2016; Lukich, 2012; Wilkinson et al., 2024). However, in Yerevan cave, Barozh 12 there are M4 flakes (flakes that remove a saturated retouched edge (Gasparyan et al., 2014a; Glauberman et al., 2020a,b; Yeritsyan & Semyonov, 1971) identical to our M4S in Ararat-1 Cave as well to other site under study by the author, Kalavan 2, so this could become the new link that binds these assemblages, not the static typological frame, but rather the dynamic way of rejuvenating a tool that is heavily retouched.

As such, Ararat-1 Cave epitomizes a transit-oriented mobility strategy within the late Middle Palaeolithic of the Armenian Highlands. The dominance of maintenance products (notably Module flakes) and the import of partially reduced packages from sources up to ~200 km away signal a highly fragmented *chaîne opératoire* executed across the landscape (Turq et al., 2013; Frahm et al., 2025). Although all major obsidian sources offer equally high knapping quality, the occupants channeled 55 % of their artefacts from the Gegham source 40 km to the north-east while simultaneously transporting smaller loads from the Arteni (105 km), Syunik (90 km), and even Sarikamış (~180 km) provinces (Frahm et al., 2025). Such directionally diverse procurement could be seen as embedded in routine foraging rather than dedicated trips (Binford, 1977, 1979), paired with low-density, short-term occupations and a toolkit geared to maintenance rather than production, points to lithic residential mobility threaded through mid-altitude woodland-steppe corridors.

Catchment envelopes for Kalavan-2, Lusakert-1 and Ararat-1 cave overlap markedly, delineating a high-elevation interaction corridor that knits together sites spanning 900–2000 m asl (Frahm et al., 2025 for

details). Shared technological hallmarks, flexible unidirectional-convergent Levallois schemes, selective retouch pieces production, systematic maintenance practices, and long-distance obsidian procurement strategies. All this could imply information flow and perhaps seasonal aggregation along this corridor, enabling LMP groups to buffer risk and maintain social ties in an ecologically patchy highland setting. Within this network, Ararat-1 Cave could have functioned mainly as a maintenance-and-rest locale, anchoring a foraging circuit whose logic was shaped less by least-cost distance than by habitual routes, social memory, and the distribution of predictable refugia across a rugged MIS 3 terrain in the Armenian Highlands.

## 6. Conclusion

In this paper, we aim to show that understanding lithic technology requires moving beyond rigid typological and morphological comparisons to embrace a more holistic and nuanced approach. Site function and occupation can be achieved with a multifaceted approach, including a more fitting the whole assemblage behavior index (WABI) integrated with a more in-depth technological analysis and a new way of documenting edge modification technologies. This integrated perspective paves the way for a more insightful exploration of lithic technology within environmental constraints, raw material availability, mobility patterns and economic strategies, to gain an understanding of the dynamic relationship between technology and human behavior. The presence of maintenance activities can be parsed even when tools are absent from the archaeological record, bringing a new understanding of the site function. We implemented our approach on the assemblage from the late Middle Palaeolithic (MP) site of Ararat-1 cave in Armenia. The results of our study demonstrate a dichotomy of raw materials, each with discrete reduction strategies. Among chert artefacts, we observe the initial stages of production, while obsidian raw materials are characterized by low tool frequencies compared to the high frequencies of module flakes (smaller than 20 mm). Those two complementary economic strategies shed light on the role of mobility at Ararat-1 cave, pointing us to perceive it as a maintenance-and-rest locale within the LMP landscape system of the Armenian Highlands.

## CRediT authorship contribution statement

**David Nora:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Ellery Frahm:** Methodology, Resources, Validation, Writing – review & editing. **Ioannis A.K. Oikonomou:** Investigation, Data curation. **Theodoros Karampaglidis:** Investigation, Data curation. **Boris Gasparyan:** Investigation, Funding acquisition, Project administration, Resources, Writing – review & editing. **Artur Petrosyan:** Investigation, Funding acquisition, Project administration, Resources, Writing – review & editing. **Ariel Malinsky Buller:** Conceptualization, Investigation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

## 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.quascirev.2025.109524>.

## Data availability

A link to the data and/or code is provided as part of this submission.

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