



Middle Palaeolithic Human occupations, cultural behaviours and demographic dynamics during MIS 5a to late 3 in the Bawa Yawan Rockshelter, Kermanshah, West-Central Zagros Mountains

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ABSTRACT

Despite many years of research into the Middle Palaeolithic in the Zagros Mountains, numerous aspects of this period have not yet been sufficiently investigated. The topics of Middle Palaeolithic's cultural behaviours, temporal changes, chronology, and the nature of the transition from the Middle to the Upper Palaeolithic in this region have led to various opinions and debates. Three seasons of archaeological excavations at the Bawa Yawan Rockshelter, located in the west-central Zagros, have uncovered a continuous stratigraphic sequence spanning from the Middle to the Epipalaeolithic periods. The site yielded in situ Neanderthal remains along with a substantial assemblage of lithic and faunal materials. The findings suggest a relatively homogeneous Mousterian lithic trajectory throughout the Middle Palaeolithic period, with slight variations likely reflecting differences in hunting strategies. Furthermore, these data indicate a cyclical pattern in population size dynamics, likely in response to climatic variations during the late Marine Isotope Stage 5a to the middle of 3. The data reveal that the Neanderthals, after a relatively substantial period in late MIS 5, experienced a demographic stagnation in MIS 4. The same data shows that their population grew significantly just before extinction around 45,000 to 40,000 years ago.

This article represents a step forward in understanding human evolution during the Late Pleistocene in the Zagros Mountains, within the territory of Southwestern Asia.

1. Introduction and challenges ahead

The Middle Palaeolithic (MP) period encompasses a range of topics, including the identification of the responsible species, their lifestyle, and the beginning and cultural transition to the Upper Palaeolithic (UP), all of which are revised as new information emerges. In this context, Southwest Asia is of great importance as a strategic geographic area where two human groups, Neanderthals and Homo sapiens, lived and probably overlapped (Higham et al., 2014; Churchill et al., 2022; Guran et al., 2024; and references therein, Mazières et al., 2025). Therefore, it is essential to comprehend the cultural and behavioural occurrences of hominins throughout the determinant period around 130–30 kyr (MIS 5–3). The issue of MP occupations in the Zagros region—much like in Northeast Africa and Southwest Asia—holds considerable significance for understanding regional human evolution and adaptation.

From the beginning of investigations, researchers have noted

differences between the lithic techno-complexes of the Zagrosian MP and those of the European and Levantine regions. A limited number of Levallois elements and heavily retouched, narrow tools have been documented (Garrod, 1930; Bate and Garrod, 1937). Three groupings were identified because of Skinner's (1965) research of the MP assemblages in the Western Eurasian context: the Levallois-Mousterian (Group C), the Yabroudian (Group B), and the Zagros Mousterian (Group A). "Early expressions of cultural traditions" was the reason Skinner gave for the east-west disparities between groups A and B (Skinner, 1965:267, cited in Nymark 2021). In contrast to Europe, he proposed that the "lack of technological variability" in the Zagros technocomplex was a regional feature, which is how he came up with the term "Zagros Mousterian". Subsequently, comparative analysis by other experts has shown that the materials from the Zagros region are characterised by a significant presence of pointed and heavily retouched tools, notably Mousterian points and scrapers (Solecki and Solecki, 1984b, 1993; Dibble and

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Holdaway, 1993). Meanwhile, Dibble (1995) further argued that the limited variety of tools within the Zagros region is an indication of the availability and size of local raw materials, which affects resharpening and reduction.

Lindly (1997, 2005) proposed that the so-called "Zagros Mousterian" represents a techno-behavioural adaptation specifically tied to seasonal exploitation patterns, particularly suggesting that hominins utilized high-altitude environments in the Zagros exclusively during the summer months. This interpretation builds upon earlier work by Skinner (1965), who argued that the Mousterian industries of the Zagros formed a distinctive regional techno-complex.

However, this perspective has recently been challenged by Nymark (2021), whose re-analysis of MP assemblages from key sites including Houmian, Shanidar, and Warwasi in the Zagros, as well as Ksar Akil in the Levant, contests the validity of the "summer adaptation hypothesis." Nymark argues that the evidence does not support a model of strictly seasonal (i.e., summer-only) occupation. Furthermore, he questions the coherence of the "Zagros Mousterian" as a unified techno-complex. According to his findings, the variability in lithic technology and associated environmental proxies suggests a pattern of multi-seasonal site use, with no compelling evidence to support the notion of a specialised summer adaptation.

In summary, while Skinner (1965) characterised the Mousterian in the Zagros as a distinct regional complex and Lindly (1997, 2005) linked this complex to a model of high-altitude summer exploitation, Nymark (2021) challenges both claims. He asserts that the Middle Paleolithic assemblages from the Zagros are too diverse to be subsumed under a single techno-complex and that the archaeological and environmental evidence instead points toward more flexible, year-round patterns of hominin occupation.

Furthermore, the nature of the transition from the MP to the UP in the Zagros region remains the subject of intense scholarly debate. Due to the presence of UP deposits directly above the Mousterian layers of this region at several locations and in different technological orientations, some scholars have suggested that UP's possible origin may be from the MP (Hole and Flannery, 1967; Olszewski and Dibble, 2006; Otte, 2014; Shidrang, 2017). To summarise the current understanding of the Zagros Mousterian as an environmental adaptation/local tradition, I assess that biased data, interpretation, and a lack of chronological accuracy have influenced the findings to date. This has led to an oversimplified view of the lithic artefacts' techno-complex throughout the entire period across the whole Zagros Mountains, neglecting the variations brought about by different climatic phases. This was also observed among the UP lithic assemblages with the high diversity of culture defining different cultural groups throughout the Zagros Mountains (Ghasidian et al., 2019; Ghasidian, 2019). Furthermore, to effectively address the hypothesis regarding the transition from MP to UP, it is essential to implement site formation analysis and detailed chronostratigraphy at key locations where UP deposits are found directly atop MP layers (Smith, 1986; Heydari-Guran and Ghasidian, 2017). Addressing these old topics requires, above all, a comprehensive understanding of the spatial distribution of the key sites across the large region of the Zagros, as well as their chronological context, such as knowledge is essential for reconstructing the complex cultures during the MP and also the transition to UP.

1.1. MP sites in the Zagrosian landscapes, cultural materials and chronology

Located roughly in the centre of Southwest Asia, the Zagros Plateau is 1800 km long (approximately the same length as eastern France to Greece), stretching from the Armenian highlands and eastern Taurus Mountains run to the Persian Gulf, and span 10° latitude from 27° to 37° (Fig. 1)

One characteristic feature of the region is the formation of numerous fertile intermountain plains, surrounded by steep karst topographies

ranging from 400 to 4400 m above sea level (masl). The topographic appearance of the geological formations in the Zagros originates from tectonic activity, erosion and variable depositional processes (Heydari-Guran, 2014; Heydari-Guran and Ghasidian, 2020a,b). Due to the extensive northwest-southeast orientation of the Zagros Mountains, large latitude difference, and its diverse geomorphological structures and topographies, this region offers significant ecological diversity. Moreover, the Zagros highlands are considered moisture islands because they receive significantly more precipitation than the surrounding deserts of Iraq and central Iran (Oberlander, 1965:15). Broadly speaking, the Zagros highlands can be divided into four sub-ecological regions: northern, west-central, central and southern (Heydari-Guran, 2014), as illustrated in Fig. 1. Moving southward from the northern Zagros region, annual rainfall decreases while the annual temperature increases (Guran et al., 2024). Based on the global biogeographical classification, the northern to central regions of the Zagros Mountains are classified as part of the Palearctic, while the southern area is characterised by the warm, dry climate of the Saharo-Arabian regions (Holt et al., 2013). This is why, from a Paleoclimatic perspective, it has been suggested that the Zagros Mountains acted as a south-north corridor connecting the Afro-Arabian and Palearctic ecosystems during significant climatic shifts of the MIS 5 to 2 (Guran et al., 2024).

The Northern Zagros Mountains are located mainly in the Iraqi Kurdistan region (Fig. 1). The area measures approximately 400 km in length and 150 km in width, and is adjacent to the Taurus Mountains and the Armenian Highlands, which are associated with several Palaeolithic locations (Braidwood et al., 1961; Braidwood and Howe, 1960). The most important reliable stratified MP materials from this region come from the caves of Ashkot-i-Tarik (Dark cave) in the Hezarmerd cave complex (Garrod, 1930), Shanidar (Solecki, 1963) and Sarsyan-Rostam Agha (Bonilauri et al., 2022).

An exceptional example of a multi-period sequence in the Zagros is Shanidar Cave, which contains a stratigraphic sequence approximately 14 m deep, spanning the MP, UP, Epipalaeolithic, and Neolithic periods, along with the remarkable discovery of multiple Neanderthal skeletal remains (Solecki, 1963; Trinkaus, 1983; Pomeroy et al., 2017). Although there is some scholarly debate regarding the specific characteristics of the MP materials at Shanidar, most researchers agree that the cultural assemblage exhibits typical Mousterian features (Skinner, 1965; Akazawa, 1975; Solecki and Solecki, 1993; Lindly, 1997; Nymark, 2021). The lithic tools recovered include scrapers, points, and flakes produced using Levallois and discoid reduction techniques, primarily crafted from locally available raw materials (Solecki, 1963, 1971; Skinner, 1965; Dibble and Holdaway, 1993; Lindly, 2005). The presence of these Mousterian artefacts in the same stratigraphic layers as Neanderthal remains strongly suggests that this cultural material is associated with Neanderthal societies.

Recent excavations and renewed research at Shanidar have provided fresh insights into Neanderthal burial practices, lithic technology, and updated site chronology (Reynolds et al., 2022; Pomeroy et al., 2017, 2020a; 2020b).

Additional evidence of MP occupation in the region comes from the Hazar Merd Cave complex (mainly from Ashkawty Tarik cave)¹, where both MP and UP lithic artefacts have been recovered. While the MP materials are generally attributed to Mousterian technology, early observations by Dorothy Garrod noted that the assemblage closely resembled those from the Levantine sites of Shukba and Zuttiyeh in Israel (Garrod, 1930). Although Garrod's research came before most

¹ "Hazar Merd is a group of six caves and rock shelters first recorded by Dorothy Garrod in 1930 (Garrod, 1930). Most of the Palaeolithic finds come from the main cave, called 'Ashkawty Tarik' or the 'Dark Cave'. In Middle Eastern Palaeolithic studies, 'Hazar Merd' usually refers just to this main cave, not the whole group of sites. As a result, the names 'Hazar Merd', 'Ashkawty Tarik', and 'Dark Cave' are often used to mean the same place."

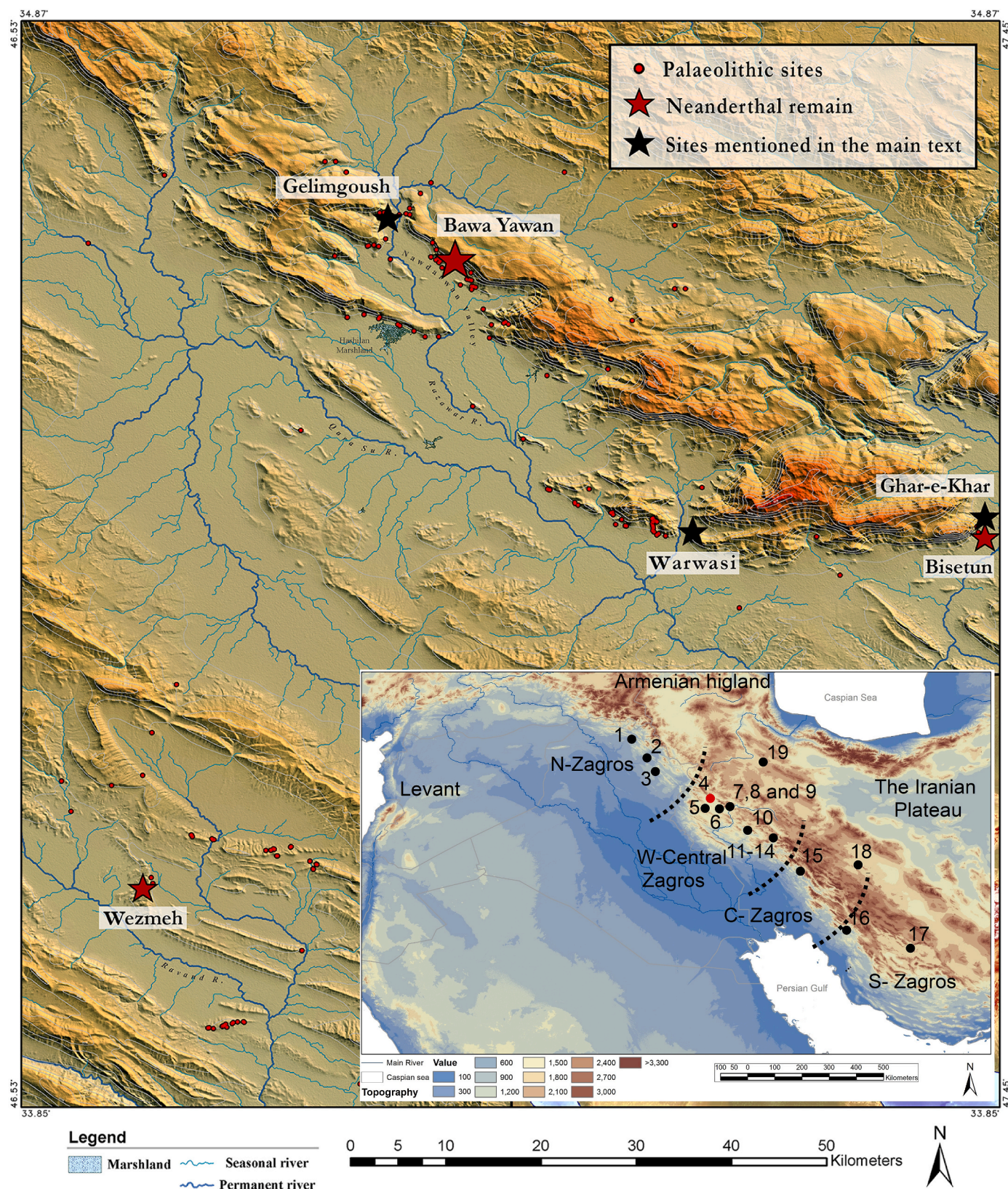


Fig. 1. The inset map shows the setting of the Kermanshah region in the Zagros Mountains and locations which are mentioned in the text :1. Shanidar, 2. Sarsyan-Rostam Agha, 3. Hazar Merd (Ashkawty Tarik), 4. Bawa Yawan, 5. Wezmeh, 6. Warwasi, 7. Bisetun, 8. Ghare Khar, 9. Mar Tarik, 10. Houmian, 11. Kunji, 12. Ghamari, 13. Gilvaran, 14. Kaldar, 15. Pebdeh, 16. Boof, 17. Tang-e Shikan, 18. Qaleh Bozi, 19. Qaleh Kurd). The main map shows the topography and hydrography of the Kermanshah region, the Bawa Yawan rockshelter in the Nawdarwan valley and the important sites mentioned in the text.

modern work in the Zagros and lacked the comparative data we now have, her hypothesis raises an interesting question about possible cultural links or technological similarities between MP populations in the Zagros and the Levant.

The next region to the southeast is the West-Central Zagros, located between the Sirwan River in the north and the Khorramabad Valley in the south—a zone approximately 300 km long and 200 km wide (Heydari-Guran, 2014). This area has yielded some of the most important Palaeolithic data from the Zagros. In particular, two key sub-regions—the Kermanshah and Khorramabad valleys, located roughly 150 km apart—have been central to our understanding of MP occupation in this mountainous landscape.

Excavations at several sites in the Kermanshah Valley, including Warwasi (Braidwood et al., 1960; Braidwood, 1961; Dibble and Holdaway, 1993), Ghar-e Khar Cave (Smith, 1967), Kobe (Lindly, 2005), Mar Tarik (Jaubert et al., 2006, 2009), and Bawa Yawn (Heydari-Guran et al., 2021), have revealed substantial MP layers characterized by Mousterian cultural materials. Similarly, in the Khorramabad Valley, key MP sites such as Houmian (Bewley et al., 1984), Kunji (Baumler and Speth, 1993), Gar Arjeneh (Hole and Flannery, 1968; Bazgir et al., 2014), and Kaldar Cave (Bazgir et al., 2017) have produced extensive Mousterian lithic assemblages.

Notably, several of these sites display a cultural and stratigraphic continuity, with thick deposits of MP artefacts followed directly by UP occupations. This pattern provides crucial evidence for understanding regional cultural transitions and potential continuity between MP and UP populations in the Zagros. In addition to the rich MP lithic record (Roustaei et al., 2004), the discovery of Neanderthal physical remains at three sites in the Kermanshah region—Bisetun (Coon, 1957; Trinkaus and Biglari, 2006), Wezmeh (Zanolli et al., 2019), and Bawa Yawan (Heydari-Guran et al., 2021a)—provides compelling evidence for the presence and dispersal of Neanderthals into the West-Central Zagros Mountains.

The central Zagros, which is the next region to the south, has a steep and elevated topography. It is located between the Zohreh River and the Khorramabad Valley and stretches 450 km in length and 150 km wide, with an elevation of up to 4400 masl. The Pebdeh Cave is the only Palaeolithic stratified site where accurate dating between 42 and 41 kyr has been obtained (Shoae et al., 2024). Researchers suggest that findings at this site contain tools with characteristics of Levallois elements alongside laminar reduction, which puts it within the framework of Initial Upper Palaeolithic culture (ibid). The other sites are associated with surface finds (e.g. Roustaei, 2010; Jayez et al., 2019; Bahraminia et al., 2022).

Finally, the southern Zagros Mountains consist of an extensive region stretching some 300–600 km from the Zohreh Basin in the north to the Strait of Hormoz in the south (Fig. 1). Here, the intermountain plains are significantly larger than in the central and west-central Zagros. The area with a steep stepped topography, except for the shallow basin of the Persian Gulf, adjoins the desert of the Arabian Peninsula. Older investigations have resulted in possible MP and Mousterian tools (e.g., Rosenberg, 1988), but little is known about these assemblages, and they don't match much from the Mousterian culture in the northern and western Zagros. Nonetheless, recently found flak-based MP technology in the Ghār-e Boof site (Conard and Zeidi, 2019; Heydari et al., 2021) and Mousterian artefacts in the Tang-e Shikan cave site near Arsanjan (Rofes et al., 2024) are significant finds in the southern Zagros. Although complete information for MP materials of the Boof Cave has not yet been released, the age of the relevant layers is reported to be up to 80 kyr (Heydari et al., 2021a,b). Rofes et al. (2024) report Mousterian artefacts in the Tang-e Shikan, aged 70–45 kyr. Unfortunately, additional information such as detailed lithic features or illustrations is missing. But if typical Mousterian materials are proved, it will be the first reliable evidence of Neanderthals spreading as far as the southeast Zagros. It is likely that in one or more suitable climatic phases, such as MIS 5a, they had a much wider territory.

Two other MP sites located between the eastern Zagros Mountains and the central Iranian Plateau have broadened and diversified the scope of research in the region. According to Biglari et al. (2009), the first excavation at Qaleh Bozi yielded material from a relatively distinct MP cultural context, featuring lithic assemblages, such as bifacial tools and a notable scarcity of Levallois elements, that differ significantly in both facies and typology from those typically associated with the Zagrosian MP tradition.

Another recently excavated site, Qala-e-Kurd Cave, has revealed evidence of hominin occupation during the Middle Pleistocene, spanning approximately 452 to 165 kyr (Vahdati Nasab et al., 2024). This significantly extends the known record of human presence beyond that of the Zagros region. Notably, a human tooth was recovered from the site, offering valuable insight into its anthropological and cultural significance. Vahdati Nasab et al., (2024) argue that the lithic assemblages from Qala-e-Kurd exhibit traits associated with both early MP traditions of the Levant and Caucasus, as well as with later Zagros Mousterian industries. This suggests a complex cultural development and underscores the importance of Qala-e-Kurd for understanding early MP diversity and the origins of the Zagros Mousterian (ibid).

The most recent data suggest that the distribution of Mousterian sites (Table 1) in the Zagros Mountains indicates a geographic range reaching the Khorramabad Valley (Guran et al., 2024). It seems that we are dealing with different MP cultural subregions in the Zagros, which is in line with what was previously proposed for the UP diversity of culture (Ghasidian et al., 2019). This is the working hypothesis in the various zones, particularly the south (Guran et al., 2024).

Concerning the Zagros Mousterian cultural group on the regional scale, it is noteworthy that scholars from the 1970s to the 1990s identified parallels between the MP assemblages found in the southern Caucasus and those associated with the Zagros Mousterian-type (Golovanova and Doronichev, 2003). However, firstly, the designation 'Zagros Mousterian' was not originally attributed to the assemblages found in the Caucasus; but research conducted by Golovanova and Doronichev in 2003 revealed the presence of 'Zagros-like' Mousterian industries within the Caucasus. Consequently, this terminology began to be applied to MP assemblages located in the Lesser Caucasus and the Armenian Highland. More recently, Doronicheva et al., (2023) and again Golovanova et al., (2025) posited that the Zagros Mousterian industry is extensive throughout the Lesser Caucasus, suggesting that it predates the Zagros Mousterian. This statement requires further validation through additional research, but if substantiated, it may imply that the origins of the Mousterian Zagros culture can be traced back to the Caucasus and potentially even further north.

The availability of reliable dating for the stratified sites in Zagros is notably scarce, particularly concerning the ages of earlier occupations from the Marine Isotope Stages 5 and 4. The significant MP deposits found in stratum D of Shanidar Cave, which are linked to the Neanderthal occupations, have undergone multiple examinations. The most recent analyses utilising radiocarbon and optically stimulated luminescence obtained at Oxford, for the upper Neanderthal remains (Shanidar 1 and 3), yielded dates of approximately 55–45 kyr (Pomeroy et al., 2017). An OSL date of 75–73 kyr indicates that the lower part of layer D at Shanidar correlates with the late MIS 5 (Reynolds et al., 2022). Dating was also carried out for the Kaldar cave in Khorramabad valley, revealing a range of 54–46 kyr for the older deposits; however, this date has been claimed for the *Homo sapiens* species (Bazgir et al., 2017).

The Houmian site in the west-central Zagros, presents a complex chronological framework, with a somewhat dubious date of 148 ± 35 kyr, derived from thorium-uranium dating of MP layer 2a. However, palynostratigraphy analyses indicate that the Mousterian occupation of the Houmian rockshelter likely occurred between 70 and 60 kyr, as noted by Bewley et al. (1984). In contrast, more reliable dating from the southern Zagros region reveals late MIS 5 dates associated with the MP stratum, specifically at Ghār-e Boof, which has been dated to between 81 and 45 kyr (Heydari et al., 2020a,b).

Table 1

The table shows key Middle Paleolithic (MP) stratified sites—both caves and rock shelters—across the Zagros Mountains. Elevations marked with an asterisk (*) have been verified by the author. Qala-e-Kurd Cave does not appear in the table due to its geographic location (see main text for further details).

Zagros cozones	Site	Meter above sea level	Hominin remains	Absolute dating MP occupation	Depositional layer, depth	Lithic industries	References
Nothern	Shanidar (Cave)	770	Neanderthal	Around: 75,000–35,000 ka	Level D, 8m out of 13m, reached bedrock	Mousterian lithic artefacts	Solecki (1950), 1953, 1957, 1958, 1961, Lindly (2005), Reynolds et al., 2022, Pomeroy et al., (2022) Garrod (1930)
	Mar Tarik in Hezar Merd complex (Cave)	1180*	–	–	Level C: between 50 cm and 3.90 m out of 5m, partly reached bedrock	Mousterian culture: with no evidence of the Levallois technique.	
West Central	Sarsyan-Rostam Agha (Cave)	800	–	–	Unit-6	Mousterian lithic artefacts	Bonilauri et al. (2022)
	Bawa Yawan (Rockshelter)	1300	Neanderthal	Between 83 and 39 ka (C14 and OSL)	3.50m out of 4.50mn ot reached bedrock	Mousterian lithic artefacts	Heydari-Guran et al. (2021)
	Warwasi (Rockshelter)	1400*	–	–	3m out of 5mr eached bedrock	Mousterian lithic artefacts	Braidwood (1960), Dibble Holdaway (1993)
	Kobe (Cave)	1480*	–	–	3.40–3.60 m not reached bedrock	Mousterian lithic artefacts	Braidwood (1960), Lindly (2005)
	Bisetun (Hunter's cave)	1200	Neanderthal	–	4m out of 5mr eached bedrock	Mousterian lithic artefacts by strong Levallois components	Coon (1949), Dibble (1984),
	Ghar-e Khar (Cave)	1400	–	Around 80 cm	–	Mousterian lithic artefacts	Smith (1967), Shidrang et al., (2016)
	Mar Tarik (Cave) in (Bisetun area)	1450	–	148,000 ± 35,000	–	MP Mousterian lithic artefacts	
	Wezmeh (Cave)	1380	Neanderthal	Around 70 to 40 ka (uranium-series analyses)	–	–	Zanoli et al. (2019)
	Houmian (Rockshelter)	1750*	–	148 ± 35 kyr derived from thorium-uranium dating of MP layer 2a	Around 3 out of 4m reached bedrock	MP Mousterian lithic artefacts	Bewley 1984
	Gar Arjenh (Rockshelter)	1200	–	–	–	MP Mousterian lithic artefacts	Hole and Flannery (1968); Lindly (2005), Bazgir et al. (2014)
Centreal	Kunji (Cave)	1330*	–	–	–	MP Mousterian lithic artefacts	Baumler and Speth (1993)
	Gilvaaran (Rockshelter)	1246*	–	–	–	MP Mousterian lithic artefacts	Roustaei et al. (2004)
	Kaldar (Cave)	1306	–	54 to 48 kyr	1 out of 2mn ot reached bedrock	MP/UP lithic artefacts	Bazgir et al. (2014) Bazgir et al. (2017)
	Pebdeh (Cave)	660	–	–	Around 80 cm	Initial Upper Palaeolithic	Javad Shoaee et al. (2024)
	Qaleh Bozi 2	1750	-	-	1.60m , not reached bedrock	MP Levallois lithic artefacts	Biglari et al. (2009); Jaubert et al., (2010)
	Ghar-e Boof (Cave)	770	–	81 and 45 kyr (OSL)	reached bedrock	Levallois flake-based artefacts	Conard and Zeidi (2019); Heydari et al. (2021)
	Tang-e Shikan (Cave)	1600*	–	70-45 kyr	Layers 4–9, reached bedrock	MP Mousterian lithic artefacts (not illustrated or described in details)	Rofes et al. (2024)
Southern							

Recent systematic efforts have focused on the MP-UP transition period in the Zagros, as discussed by Becerra-Valdivia et al. (2017), Heydari-Guran et al. (2021b) and Heydari et al. (2024), which is linked to the late Mousterian phase, suggesting that the onset of the UP in the Zagros Mountains can be traced back to approximately 45–40 kyr. However, various interpretations have been proposed (e.g., Olszewski and Dibble, 1994; Tsanova, 2013; Shidrang et al., 2016; Shidrang, 2017), but the situation remains unclear as to whether the contact zones reflect: (1) true cultural overlap due to simultaneous habitation, (2) post-depositional processes that displaced artefacts, or (3) a short chronological gap separating the two techno-typological traditions.

1.2. Late Pleistocene paleoclimate records of the region

Even though numerous research projects have been carried out about the palynology, glaciation, speleothems and sedimentology in different parts of the Zagros Mountains and even the Iranian Plateau, high-resolution climate reconstruction data is still a long way off. However,

cave speleothem growth and $\delta^{18}O$ records from the Qale Kord (Mehterian et al., 2017) and Pir Ghar (Carolin et al., 2019) in the northern Zagros and eastern Iranian Plateau, respectively, demonstrate that the last interglacial or MIS 5e (~130–115 ka) was a time of higher humidity and temperature. Along with the development of forest soils in the loess-paleosol sequences (LPS) of the southern Caspian lowlands, the increased humidity also caused the spread of forest vegetation in the catchment areas of Lake Urmia (Djamali et al., 2008) and Lake Van (Litt et al., 2014; Pickarski et al., 2015).

During the stadial periods of MIS 5d and 5b (Carolin et al., 2019; Mehterian et al., 2017), the early last glacial was marked by arid conditions, with steppe vegetation advancing and forests retreating at Lake Urmia (Djamali et al., 2008) and Lake Van (Litt et al., 2014; Pickarski et al., 2015). At the same time, increased dust accumulation and lower intensity of soil formation observed in the LPS reflect the dry conditions of the southern Caspian lowlands (Kehl, 2009; Kehl et al., 2005; Kehl, 2010; Kehl et al., 2021; Vlamincck et al., 2018). Two strong interstadials, probably correlating with MIS 5a and 5c, are documented with

variations in vegetation cover as well as temperature, amount and source of precipitation recorded in speleothems, lake deposits and LPS. All these records show that interstadial and stadial periods were characterised by warm-wet and dry-cool climatic conditions, respectively. This fits well with other climate records, such as speleothems in the Levant (Bar-Matthews et al., 2019). The last pleniglacial (MIS 4 to MIS 2), which was characterised by strong millennial-scale climate changes during the Dansgaard-Oeschger cycles, is less well documented in the region's climate archives. No speleothems from the Iranian Plateau in the period between MIS 4 and MIS 2 have been dated, indicating overall dry climatic conditions without speleothem growth (Mehterian et al., 2017). In eastern Anatolia, pollen and abiotic records from Lake Van reflect the Dansgaard-Oeschger cyclicality, with peaks in percentages of tree pollen, a low input of detrital material into the lake during the interstadials, and a dominance of steppe elements and high clastic input with low vegetation cover during the stadials (Kwiecien et al., 2014; Pickarski et al., 2015).

Several poorly developed syngenetic paleosols reflect moisture changes during the accumulation of pleniglacial loess in the Caspian lowlands (Kehl et al., 2021; Vlamincx et al., 2018). Similarly, the paleosols that developed in the alluvial sediments of the Kor River basin in southern Zagros (Kehl et al., 2009) during the late pleniglacial (MIS 2) indicate stable land surfaces and periods of increased moisture. However, the chronostratigraphic data are still insufficient to correlate the paleosols with the interstadials of the North Atlantic. Overall, the timing and amplitudes of climate change in the Iranian highlands after MIS 5 and before the Last Glacial Maximum (LGM) remain unknown. The study by van Zeist and Bottema (1991) and van Zeist and Wright, 1963 of lakes Zeribar and Mirabad shows that pollen during the LGM was dominated by *Artemisia*, a genus of plant typically found in dry steppe or semi-arid regions. This suggests that the area around these lakes was characterised by dry, steppe-like vegetation during the LGM, in stark contrast to the forested environments that later developed during the mid-Holocene. The dominance of *Artemisia* implies a cooler, drier climate during the LGM in the Zagros Mountains, with limited moisture available to support forested areas. These findings are significant because they offer insights into the climatic and ecological conditions during the LGM and highlight the shift from steppe vegetation to forest ecosystems that occurred in the region over thousands of years. The presence of *Artemisia* pollen at the time also underscores the broader climatic patterns of the period, which were marked by reduced precipitation and cooler temperatures compared to the warmer, wetter conditions that emerged later in the Holocene. The LGM is represented in pollen findings from lakes Zeribar and Mirabad, both located in the Zagros Mountains, northwestern Iran. The pollen is rich in *Artemisia*, indicating dry steppe vegetation within the catchment areas of the lakes (van Zeist and Bottema, 1991; van Zeist and Wright, 1963), contrasting with the forest vegetation types that have been established since at least the mid-Holocene.

1.3. New research in Kermanshah

From a decade ago, a Palaeolithic research project entitled "Human Evolution in the Zagros Mountains" (HEZM) has begun, focusing on the Kermanshah Region, the largest intermountain plains of the whole Zagros Mountains (Brookes, 1989) of the West-Central Zagros (Heydari-Guran and Ghasidian, 2017). This research encompassed comprehensive surveys (Heydari-Guran and Ghasidian, 2017, 2020), excavations (Heydari-Guran et al., 2021a, 2021b; Heydari, Guérin, and Heydari-Guran 2024), studies of human behaviour, environmental reconstruction, and computer-based modelling (Yousefi et al., 2020; Heydari-Guran et al., 2021a, 2021b and b; Ecker et al., 2023; Guran et al., 2024). The findings from these studies indicate that the Kermanshah region served as a crucial interglacial refuge for hominins during the Upper Pleistocene, potentially acting as a source for various dispersal events that enabled the colonisation and recolonisation of

southwestern Asia (Heydari-Guran and Ghasidian, 2020; Heydari-Guran et al., 2021a, 2021b). In pursuit of understanding the MP-UP transition, several computer-based predictive models were developed to identify Kermanshah's most promising areas for further exploration (Heydari-Guran and Ghasidian, 2020a,b). These models pinpointed the Nawdarwan Valley as the optimal site because it hosts numerous MP and UP locations. The valley of Nawdarwan, which extends 17 km along the Razawar River, serves as a natural corridor linking the fertile plains of Kermanshah and Kamyaran in a north-south orientation (Figs. 1 and 2). The region boasts over 50 Palaeolithic caves and rock shelters, all identified during the surveys (Heydari-Guran and Ghasidian, 2020a,b). The initial excavation involved a test trench at Gelimgoush cave (Fig. 1), revealing four geological layers containing UP cultural materials. Radiometric dating of horizons 2 to 4, associated with UP occupations, indicated a chronological sequence of approximately 42–33 kyr (Heydari-Guran et al., 2021b). The second excavation took place in Bawa Yawan Rockshelter around 10 km southeast of Gelimgoush.

1.4. Bawa Yawan rockshelter

The Bawa Yawan Rockshelter is in the heart of the Nawdarwan Valley, on the slopes of "Yawankuh Mountain". This mountain is part of the "Bisetun-Shahoo" geological Carbonate block range, which is also home to several notable Mousterian and Upper to Epipalaeolithic shelter sites, including Bisetun, Ghar-e Khar, Mar Tarik, Warwasi, and Do-Ashkaft (Heydari-Guran and Ghasidian, 2020a,b, and references therein). The climate of this region is significantly shaped by its proximity to the Zagros Mountains, characterised as a hot-summer Mediterranean climate into a humid continental climate (ibid).

Bawa Yawan is a limestone cliff, approximately 250 m in length and 50 m high, visible from significant distances and located at the edge of a flat plain to the southwest (see 2A and B). This site cannot be considered a normal rock shelter; rather, it resembles an open-air occupation located adjacent to a rock face. A karstic spring, which forms a natural pond, is situated 50 m from the site. It is evident from the morphology surrounding this spring that its size fluctuates significantly between the wet and dry seasons. Archaeological layers have accumulated on the southern slope of the cliff, covering a flat expanse of approximately 300 square metres, positioned 10 m above the plain level. Numerous large boulders on the talus slope protect the archaeological deposits (Fig. 2B).

2. Materials and methods

Excavations at the Bawa Yawan site were carried out over three field seasons (2016–2018) in two areas located 11 meters apart, adjacent to the shelter wall. These areas were designated as the Western trench (17 m²) and the Eastern trench (6 m²) (see Fig. 3). Among the 1 × 1 metre squares, six squares – H31, H32, I31 and I27, I28 and I29 – were excavated to significant depths, reaching 3.5 m below the surface. The excavation depths of the remaining squares were limited to the first or second geological horizons (GHs). During the excavation, it became evident that a dig for an Internet cable canal had disturbed the top metre of stratum in squares H27, H31, H32, I26, I28, and I32 (Fig. 3). The deposits at the Bawa Yawan Rockshelter are classified into five superimposed geological horizons, based on differences in colour and sediment texture. (see Fig. 3), with GH5 being the thickest at approximately 1.70 m GH4, GH3, and GH2 each measured between 90 and 80 cm in thickness and show considerable similarities. GH1 consists of newly-formed soil, approximately 10–20 cm deep, sloping outwards at about 10° from the rear wall, while remaining relatively flat to the east and west (see Fig. 3). The deposits are predominantly composed of clastic materials, with fine sediments entering the area through joints and bedding planes from the cliff face. Detailed information regarding the geological horizons is available in another publication (Heydari-Guran et al., 2021a). Due to the relatively coarse and dense sedimentary layers, no evidence of bioturbation or other disturbances has been detected



Fig. 2. (A) View of the Nawdarwan Valley, with the red arrow indicating the location of the Bawa Yawan rockshelter. (B) The Bawa Yawan cliff and the excavation area. (C) A deep trench within Bawa Yawan Rockshelter during excavation in 2017. (D) The position of the exposed Neanderthal tooth (BY1) at the moment of its discovery in 2017, within excavation square I31. (E) The lower left deciduous canine of Bawa Yawan Neanderthal (Heydari-Guran et al., 2021a) (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

within the strata. All archaeological artefacts and bones larger than 2 cm were documented using a total station. Both dry and water-sieving methods, employing 8, 4, and 2 mm mesh sieves, were applied to all excavated materials. Over three excavation seasons, a total of 10,411 lithic artefacts and more than 19,000 bone fragments were registered, including individual finds and those retrieved from sieving. When this total is divided by approximately 40 m³ of excavated materials, yielding an average of 250 lithic artefacts per m³, it indicates that Bawa Yawan is characterised by a low lithic artefact density; however, this figure varies depending on occupational deposits. The GH5 layer, approximately 1.85 meters thick, was fully exposed only in squares H31 and I31, which together represent just 12% of all excavated squares. Despite this limited area, these squares yielded over 1,000 lithic artefacts per cubic meter—accounting for 37% of all lithic finds—as well as a comparable quantity of faunal remains from the Bawa Yawan excavations. Therefore, GH5 can be regarded as relatively very rich in archaeological remains. At a depth of approximately 2.50 m (15.87 from datum: 20 m) in

the upper section of GH5, within square I31, where the density of MP cultural artefacts gradually decreased, an *in situ* Neanderthal tooth was discovered. This tooth is an exfoliated lower left deciduous canine (Ldc1) that exhibits a well-preserved crown (Fig. 2D and E) and approximately one quarter of the root (Heydari-Guran et al., 2021a). Quantitative analyses have been applied to techno-typological artefacts to contextualise the lithic materials from Bawa Yawan. The technological features of artefacts larger than 2 cm were examined individually and concerning the reduction sequence, facilitating the reconstruction of the chaînes opératoires (operational chain) for each archaeological horizon. Using methods such as core preparation and reduction sequences, along with analysis of flaking patterns, platform preparation, and tool retouching and re-sharpening, it was possible to identify cultural traits and compare them with those from key sites like Warwasi and Bisetun in Kermanshah. The remains of the bones were further examined using morphological identification and comparative analysis.

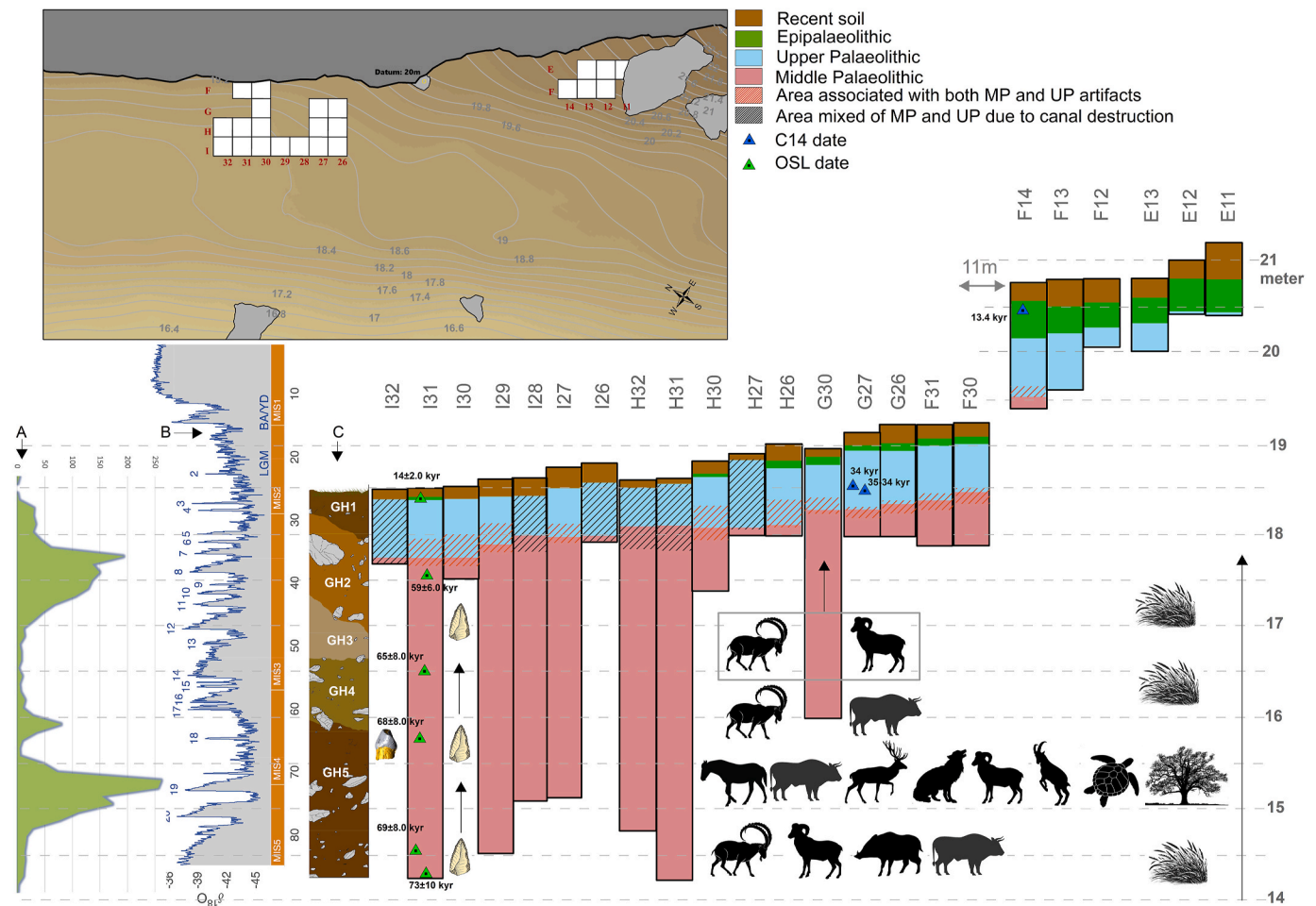


Fig. 3. The insert topographic map and plan of the Bawa Yawan Rockshelter, showing excavation areas and grid squares. The graph in panel A illustrates artefact density in the western trench. Notably, three depth intervals—15.00–15.50 m, 15.80–16.00 m, and 17.00–18.00 m—exhibit significantly higher concentrations of artefacts, suggesting zones of intensified activity or repeated occupation. (B) Oxygen isotopic composition ($\delta^{18}\text{O}$) record from Greenland ice cores (North Greenland Ice Sheet Project), adapted from Li and Born (2019). (C) Stratigraphic profile showing the geological horizons, along with labelled excavation squares that indicate trench depth and archaeological layers. Figures of animals represent some of the faunal remains identified within the stratigraphy (see fauna section in main text). Tree and vegetation symbols indicate inferred vegetation cover, based on oxygen isotope analysis adapted from Ecker et al. (2023).

3. Results

3.1. Chronology

To establish a reliable chronological framework for the Bawa Yawan Rockshelter, two principal dating methods were employed: radiocarbon dating (C^{14}) and optically stimulated luminescence (OSL). These complementary techniques have been instrumental in illuminating the occupational history of the site, particularly in distinguishing between its Epipalaeolithic and deeper MP layers (see Fig. 4).

Radiocarbon dating was applied to charcoal samples recovered from both the eastern and western trenches of the site. Out of numerous collected samples, eight yielded successful results. These were analyzed across three radiometric laboratories: one at the Oxford Radiocarbon Accelerator Unit (University of Oxford), another at the Beta Analytic Radiocarbon Dating Laboratory, and the remaining six at the Curt-Engelhorn Archaeometry Centre in Mannheim. The uppermost sample, associated with the most recent phase of human activity in the rockshelter, was extracted from the upper part of stratigraphic unit GH2 in the eastern trench. This sample, linked to Epipalaeolithic occupation, produced a calibrated date range of 13,4 to 13,3 kyr.

Deeper within the stratigraphy, two additional samples from the western trench, located in square G27, yielded dates between 34,700 and 34,400 and 34,600–34,400 cal. BP. These samples are associated

with Upper Palaeolithic cultural material, and their close agreement supports the reliability of this occupational phase. However, the five radiocarbon dates obtained from the MP layers—specifically from units GH4 and GH5—presented more problematic results. These samples, while spanning from approximately 44,100 to 39,400 cal. BP, exhibit considerable variation that raises questions about the preservation of organic material and potential contamination. For instance, one sample from GH4, situated 30 cm above the Neanderthal tooth level in square I31, yielded a date of 40,3–39,4 cal kyr, while a nearby sample, just 9 cm above the same level, dated slightly older at 42,1–41,8 cal kyr. Other samples located just above and below the Neanderthal tooth level produced dates ranging from 43 kyr to over 44,2 cal kyr. Despite their stratigraphic order, these radiocarbon dates do not consistently reflect the expected depth-age relationship, suggesting potential issues with the C^{14} results in the older deposits.

In contrast, OSL dating has provided a more coherent and stratigraphically consistent chronology for the site (Heydari et al., 2024), especially in the deeper layers where radiocarbon dating is less effective due to the limitations of carbon preservation and the method's inherent age range constraints. The initial OSL age determination for sample BaYa1, from the upper portion of GH2, indicated an age of 14 ± 1 kyr, while another sample from the same unit dated slightly older at 18 ± 1 kyr, both aligning well with the Epipalaeolithic horizon established through radiocarbon methods.

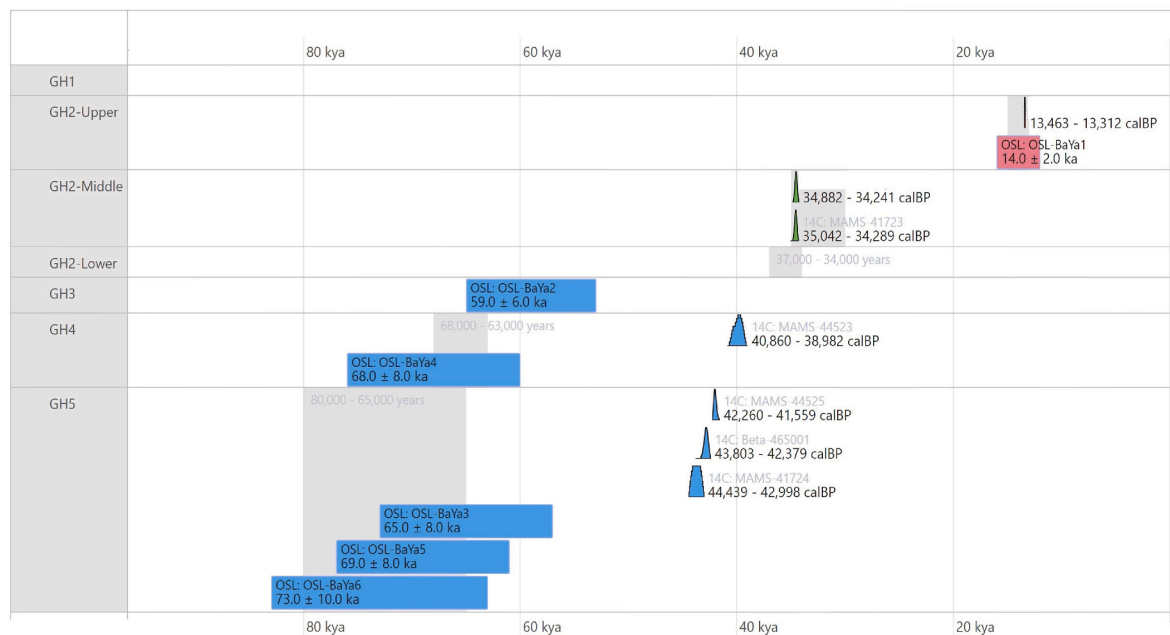


Fig. 4. Chronology of Bawa Yawan based on C14 (Heydari-Guran et al., 2021a) and OSL (Heydari et al., 2024). This figure (with some modifications) is adapted from the database available in: "Hellforge database (<https://github.com/merszym/hellforge>), Site: Bawa Yawan, <https://hellforge.merlin-szymanski.de/site/277>.

Below this layer, OSL analysis of sample BaYa2 revealed ages of 59 ± 3 kyr and 61 ± 3 kyr, using quartz OSL and pIRIRSL290 techniques, respectively, showing a close agreement within their margins of error. Further down, sample BaYa3 from GH4 yielded ages of 68 ± 4 kyr and 64 ± 3 kyr, again demonstrating consistency between dating methods. For GH5, ages of 65 ± 4 kyr (quartz) and 62 ± 3 kyr (polymineal) were recorded, and for GH6—the lowest layer investigated—sample BaYa5 produced ages of 69 ± 4 kyr and 73 ± 4 kyr. An additional sample from GH6, labelled OSL6, returned even older dates of 73 ± 5 kyr and 79 ± 5 kyr (ibid). The gradual and logical progression of these dates down through the stratigraphy affirms the reliability of OSL for reconstructing the site's deeper occupational history.

When the results from the two dating techniques are compared, it becomes evident that they correspond closely only in the upper layers, particularly in GH2, where both methods indicate an Epipalaeolithic occupation around 13–18 kyr. However, significant discrepancies appear in the deeper strata, where radiocarbon dates are up to 20,000 years younger than those produced by OSL for the same contexts. This discrepancy suggests that the radiocarbon dates for layers GH4 and GH5 may have been affected by contamination or other taphonomic processes that skewed the results, making them less reliable for establishing a precise chronology.

Furthermore, the archaeological evidence—including cultural artefacts—supports the timeline indicated by OSL. MP tools are found up to the middle of GH2, which logically corresponds to an age of around 40 kyr. This age, however, is more consistent with the lower part of GH2 according to the site's stratigraphy, rather than the lower GH4 or upper GH5, as the radiocarbon data might misleadingly suggest. Therefore, it is evident that radiocarbon dating is appropriate for dating only the uppermost deposits, particularly GH2, whereas OSL offers a more dependable framework for the deeper MP sequences of Bawa Yawan.

In sum, while both dating methods contribute important chronological insights, the results demonstrate the limitations of radiocarbon dating for older deposits at Bawa Yawan. OSL has emerged as the more accurate and stratigraphically coherent technique for understanding the site's earlier phases of occupation, especially in layers GH4 through GH6 (Heydari et al., 2024; Heydari-Guran et al., 2023).

3.2. Fauna remains

Owing to the large quantity of faunal remains recovered from the site, only a portion of the assemblage has been studied thus far (Heydari-Guran et al., 2023; Azizi, 2025). Specifically, the analysed material includes specimens from the first two excavation seasons (2016–2017; Heydari-Guran et al., 2023), as well as bone fragments larger than 1 cm from geological horizons (GH) 4 and 5. Due to poor preservation and the highly fragmented condition of the remains—mainly resulting from green bone breakage (Villa and Mahieu, 1991)—only 600 out of more than 17,490 recovered bone fragments could be taxonomically identified. Although Bawa Yawan functions as an open area abutting a vertical cliff—conditions also favourable for carnivore activity—the significant presence of cut marks and burnt bones suggests a predominantly anthropogenic origin for the assemblage (Azizi, 2025) (Fig. 5). The majority of the identified remains derive from GH5, which yielded 316 classifiable bone and tooth fragments. Tooth fragments were primarily from large- to medium-sized herbivores, while the bones included representatives of the Bovidae family and small- to medium-sized mammals such as *Capra*. Notably, within the Middle Palaeolithic layer, numerous fragmented shells and bones from the freshwater turtle (*Mauremys caspica*) were also identified (Fig. 6). GH5 is particularly rich in dental remains, along with several bones, and shows a marked increase in large mammal representation. This includes one bone fragment attributed to the Equidae family and six dental fragments from Bovidae. An additional six large mammal bone fragments are currently under further examination. Medium-sized mammal remains include Caprinae, Antilopinae, and two fragments attributed to the Cervidae family—marking the first occurrence of cervids at the site. In GH4, a total of 11 faunal fragments have been identified, primarily consisting of tooth remains. These reflect a broader taxonomic range and include representatives of large herbivores (Bovidae) as well as carnivores, indicating increasing faunal diversity in the later phases of site use.

In the section containing final MP lithic artefacts in GH2, 24 fragments, including bones and teeth, were retrieved. The collection is primarily composed of medium-sized mammals, with tooth fragments identified as belonging to herbivorous ruminants such as *Capra/Ovis* or *Gazella*. The faunal remains recovered from the GH5 at Bawa Yawan

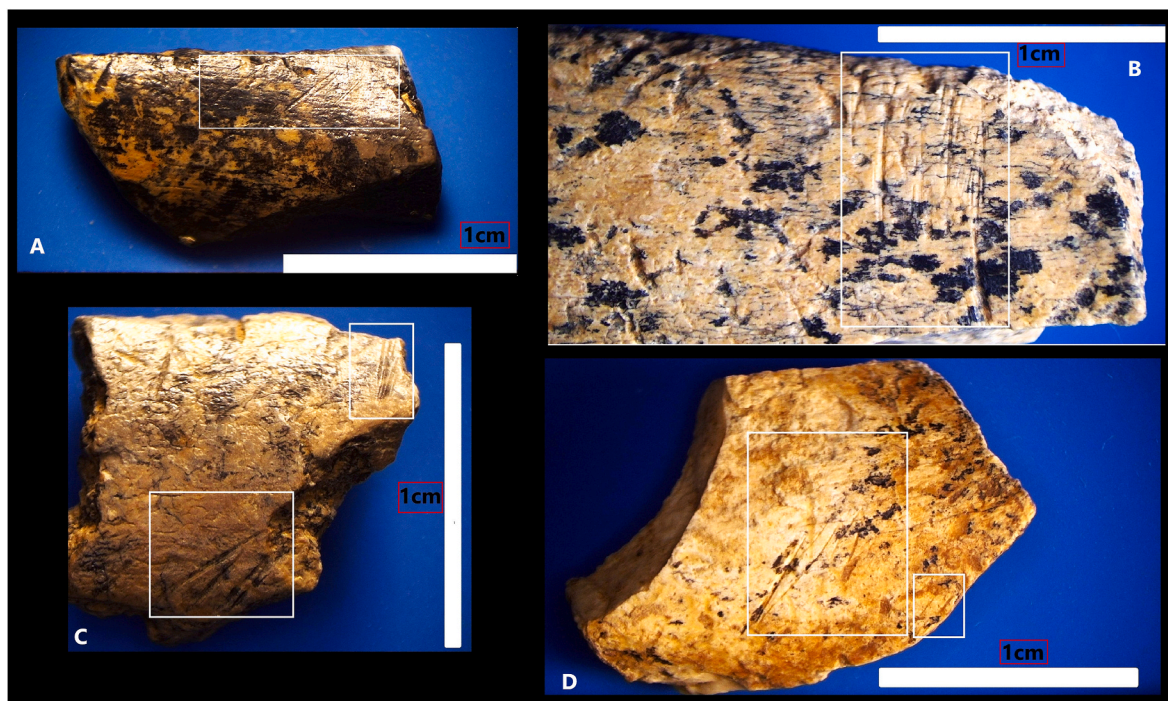


Fig. 5. Examples of anthropic cutmarks observed on faunal remains from the MP layers of the Bawa Yawan Rockshelter: (A) Metapodial of a large ungulate (equid or red deer-sized) from square I29 at 15.12 m depth. (B) Ulna of an aurochs-sized animal from square I31 at 14.62 m depth. (C) Unidentified bone fragment from an equid or red deer-sized animal, square I29 at 15.72 m depth. (D) Long bone fragment from an equid or red deer-sized animal, square H31 at 15.48 m depth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

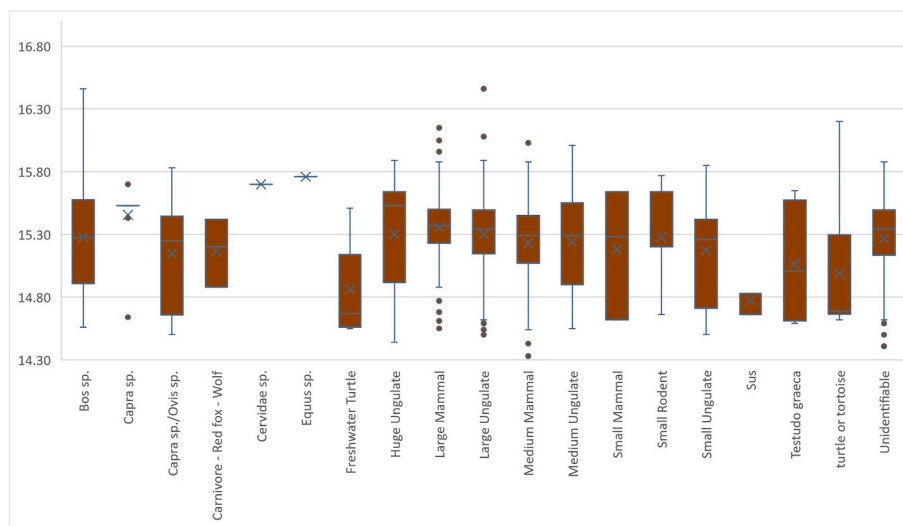


Fig. 6. Box plot of the distribution of the fauna remains (identified specimens) within the GH5 and 4 in the Bawa Yawan Rockshelter. The number at the left show the depth of the excavation.

support the reconstruction of Neanderthal subsistence strategies in the Zagros, as proposed through computer simulation modeling by Yousefi et al. (2020). A notable variety of species is present; however, micro-fauna and fish are notably absent, likely due to taphonomic processes. The quantity of faunal remains increases again in the upper layer GH2, with Ovis/Capra and Gazella being the most frequently encountered species. This indicates a transition in the size of fauna from large to medium/small as one moves from GH5 to the lower GH2.

In the central section of GH2, where artefacts from the final phase of the MP and the onset of the UP are found, there is a slight increase in the number of Ovis/Capra and Gazella remains (Fig. 6). Additionally,

fragments of freshwater river shells (*Unio crassus*) were recovered from the upper deposits of GH2, associated with the UP layer. Interestingly, no such remains were found in the underlying MP layers, which raises a potentially significant point for further investigation.

3.3. Lithic artefacts assemblages

The research revealed three distinct archaeological levels corresponding to the MP, UP, and Epipaleolithic periods throughout the entire stratigraphic profile. Out of a total of 10,411 lithic artefacts, 4408 items, representing 42 %, were categorized within the MP, and 657 (15

% of MP lithics exceed 2 cm in size. Among MP assemblages, 263 items (40% of 657 pieces) were identified as tools and utilised artefacts. Except for a few artefacts made of limestone, and two basalt pieces recovered from GH5, all lithic assemblages from the MP are composed entirely of local fine to medium-grained radiolarite chert (Hariri et al., 2024) (Fig. 7). Four separate dense bands, spanning from GH5 to GH2, contain MP lithic artefacts and faunal remains found in primary depositional context (Fig. 8). In ascending order, these bands show low density at the start of GH5, peaking in the middle, then declining sharply at the end of GH5. They increase slightly in layer GH4, declining throughout layer GH3, and then increasing from the beginning of GH2 to the middle, where there is evidence of both MP and UP materials intermixed within an area of about 50 cm thickness (Figs. 3 and 8). The graphic in Fig. 8 illustrates similar proportions of the lithic artefacts' composition technology across the stratum. Given the low number of cores, it is especially intriguing to note the prevalence of angular debris, micro (less than 5 mm in size) and small (between 5 mm and 1 cm in size) debitage in stone tools. Therefore, it is suggestable that the process of tool rejuvenation has continuously been carried out at the site. The high number of bladelets not systematically produced also strengthens this hypothesis.

In the middle of GH2, there are 40–50 cm deposits containing a combination of MP and UP artefacts in the final phase of MP and the

beginning of UP. The two lithic groups of Mousterian and UP are found within a small vertical area, suggesting a relatively thin stratigraphic layer. The depth range of approximately 17.50 cm–18.10 cm (this depth is varied among the squares) indicates that the transition between the two assemblages, potentially reflecting a shift in culture over a short time. In this area, the Mousterian lithic assemblage does not change in morphology, but artefacts like blades, twisted blades and cores indicative of the UP period appear. In this layer, significant Mousterian tools such as the convergent scraper, limace, were also discovered. From a macroscopic perspective in texture and colour, there is no sign of distribution in the deposits of this section (Fig. 9).

3.3.1. Cores

Bawa Yawan MP cores are notably low in number, highly reduced, and reflect the final stages of the lithic reduction sequence. A total of 31 lithic items were identified as complete cores ($n = 17$), core fragments ($n = 10$), and four truncated faceted/core tools (Fig. 10: lithic no. 3, 9–12). Excluding two Levallois preferential cores, approximately 75 % of the remaining cores are classified as Levallois recurrent types, including centripetal, irregular multi-directional, discoidal, and parallel variants (Fig. 10). Several irregular multi-directional cores may represent the evolved forms of initially more structured Levallois cores. In some cases, these heavily reduced cores appear to have been repurposed

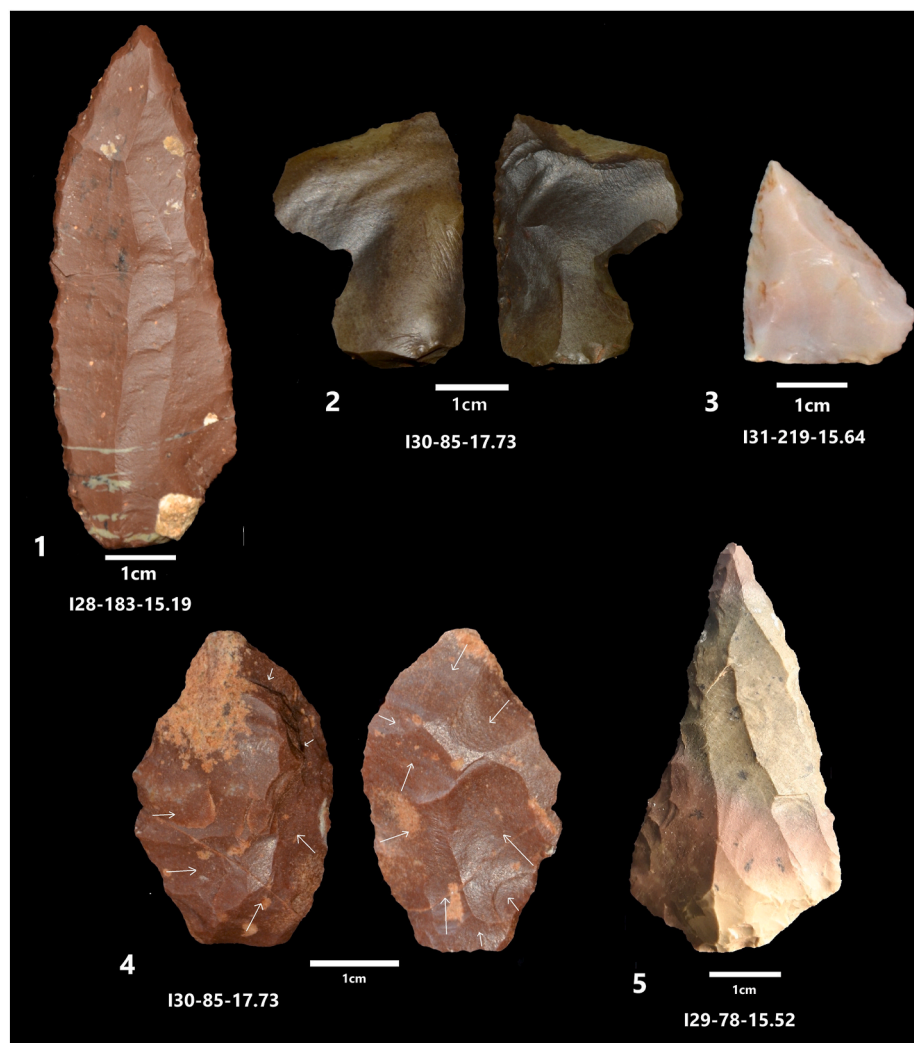


Fig. 7. Selected examples illustrating the variability of MP tools made on local fine- to medium-grained radiolarite chert, recovered from different stratigraphic levels at Bawa Yawan Rockshelter. Pointed blade (1), multiple tool combining borer, notch and side scraper (2), point/convergent scraper (3), bifacially flaked scraper with a convex dorsal and concave ventral surface, (4), point/convergent scraper (5).

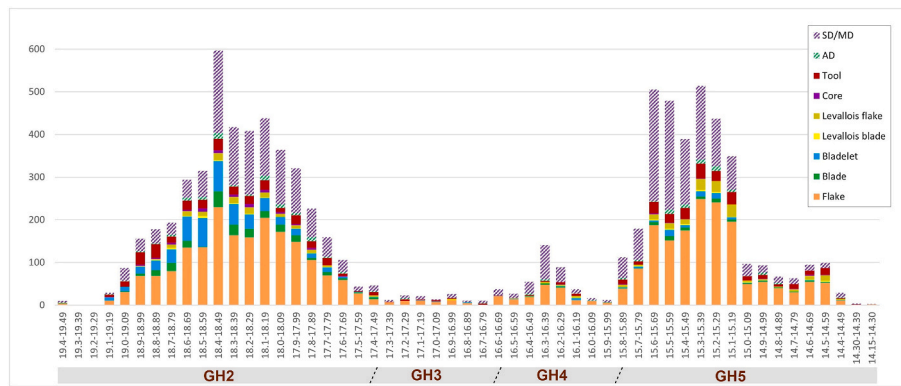


Fig. 8. Compositions of lithic artefacts from GHs 5 to 2. The columns of the graph each represent 10 cm of excavated deposits. AD (angular debris), MD (microdebitage less than 5 mm), SD (smalldebitage between 5 mm and 1 cm in size). Two diagnostic features of MP culture—Levallois flakes and blades—are included in the diagram to help determine the vertical extent of MP occupation within the stratigraphic sequence. The numbers on the left side indicate the quantity of lithic artefacts.

as tools, such as borers or truncated faceted implements (e.g., Fig. 10, no. 3).

The spatial distribution of these cores throughout the stratigraphic sequence makes it difficult to establish distinct diachronic shifts in their morphology or technology. However, a notable concentration of eight cores occurs within a 55 cm thick deposit between depths of 18.04 and 18.60 m—interpreted as representing the terminal phase of the Zagros Mousterian at the site. The technological features of these cores—including high reduction intensity, minimal shaping, and multi-phase use—show strong parallels with findings from other Zagros Mousterian sites (Fig. 10).

For instance, at Warwasi Rockshelter, Dibble and Holdaway (1993) describe a prevalence of Levallois recurrent flaking strategies, with both uni- and bi-directional radial cores dominating the assemblage. Similarly, Shanidar Cave in Kurdistan yielded recurrent and discoidal Levallois cores characterized by advanced reduction and occasional re-use as tools, as noted by Solecki (1963). At Bisetun Cave, Dibble (1984) identified both preferential and recurrent Levallois cores, some associated with convergent scrapers and Mousterian points. Sites like Ghar-e-Khar (Shidrang et al., 2016) and Mar Tarik (Jaubert et al., 2009) also exhibit Levallois elements and discoidal core technologies, reflecting technological consistency and flexibility across the region. These comparisons support the interpretation that Bawa Yawan belongs to a broader Zagros Mousterian tradition, distinguished by recurrent Levallois core strategies, extensive core exploitation, and occasional core-tool transformation. This alignment reinforces the regional pattern of conservative yet efficient lithic technology, adapted to local raw materials and mobility strategies or hunting methods during the MP.

3.3.2. Debitage ≥ 2 cm

Among the 657 identified artefacts larger than 2 cm from the MP layers, over half ($n = 348$; 53 %) consist ofdebitage and unretouched flakes. Notably, 52.9 % of these are Levallois flakes ($n = 184$), which exhibit the characteristic “chapeau de gendarme” platform. Additionally, 117 flakes and blades (34 %) are categorized as fractured, broken, proximal or unidentifiable, suggesting that the actual number of pieces with a prepared striking platform may be significantly higher. Among thedebitage, the presence of 23 Levallois blades, including several elongated flakes, is particularly noteworthy. Furthermore, 13 pieces are identified as core rejuvenation face flakes with centripetal negative scars. This data underscores the prevalent use of the Levallois technique at the nearby site of Bisetun (Coon, 1951; Dibble, 1984). The assemblages from Bawa Yawan exhibit a low quantity of cortex, with only 86 pieces (less than 8 %) recorded.

3.3.3. Tools

A total of 274 pieces, constituting 41.7 % of the 657 MP artefacts, have been classified as tools (Figs. 11, 12 and 13). The number of tools in Bawa Yawan is significantly higher compared to other Mousterian sites in the region, such as Warwasi, 15.4 % (Lindly, 2005), Bisetun, 9 % (Coon, 1951) and Houmian, 10.5 % (Nymark, 2021). However, this comparison may not be correct because of the selective system of collecting lithic artefacts from those sites. The high number of tools in Bawa Yawan may be linked to the site’s specific function and initial stages of the reduction process taking place off-site. Bawa Yawan demonstrates a considerable diversity in the range of tools, from simple to extensively retouched pieces and multiple-task tools (Fig. 7, number 1 to 5). The data indicates that of the most frequently created tools pieces are simple retouched and utilized on Levallois flakes and blades. Next categories are convergent scrapers, side scrapers and typical Point conversant scrapers. The rest of the tools include multiple task pieces such as knife/truncated, denticulate/Limace, end scrape/burin. The graph in Fig. 8 shows the distribution and percentages of the tools in Bawa Yawan. Several tool types occur consistently throughout strata, including single and convergent scrapers, unretouched and retouched points, as well as Dejeté, Limace, truncated, notched, and burin, among others (Figs. 12 and 13). In some cases, such as carinated end scrapers and borers, only a single example has been recorded throughout the entire excavation. 13.5 % of the retouched tools match Levallois blades (Figs 12 n.2, Fig. 13:25–6), and 47 % are made on Levallois flake blanks. The remaining tools are made of flakes and blades in which their precise techniques are non-Levallois. A significant portion of the retouched flakes and blades, (30 %), exhibits fine retouches. With some exceptions, particularly those made on blades or elongated flakes, the tools predominantly made on Levallois flakes display stepped Mousterian retouching along both edges. Within this category, approximately 15 % show heavy, stepped, and scaled retouching techniques characteristic of the Zagros Mousterian (Fig. 12 n. 6-21 and Fig. 13, n. 6,7, 15–19). Retouched tools are found almost uniformly across all layers. Scrapers constitute 14 % of the tool assemblage, with more than 60 % of these classified as Zagros Mousterian types, characterized by lateral, double-edge and transverse scrapers. In many cases the edges have scaled, steep, abrupt, and semi-abrupt retouches. Bawa Yawan yielded 7.3 % of convergent scrapers and 4.7 % of point/convergent scrapers as previously categorized under the general term “point,” including “true Mousterian points” and “convergent scrapers” for the Zagros Mousterian at Bisetun Cave (Dibble, 1984, p. 23). Here, convergent scrapers/points have a triangular, symmetrical shape, and in some of them, impact scars and traces of use can be seen on their tips (Fig. 12, n. 9–11, Fig. 13, n.5). The presence of these tools (83 %) within 14.30–16.12 in layer 5 is noteworthy. This is significant for Bawa Yawan Rockshelter and may be

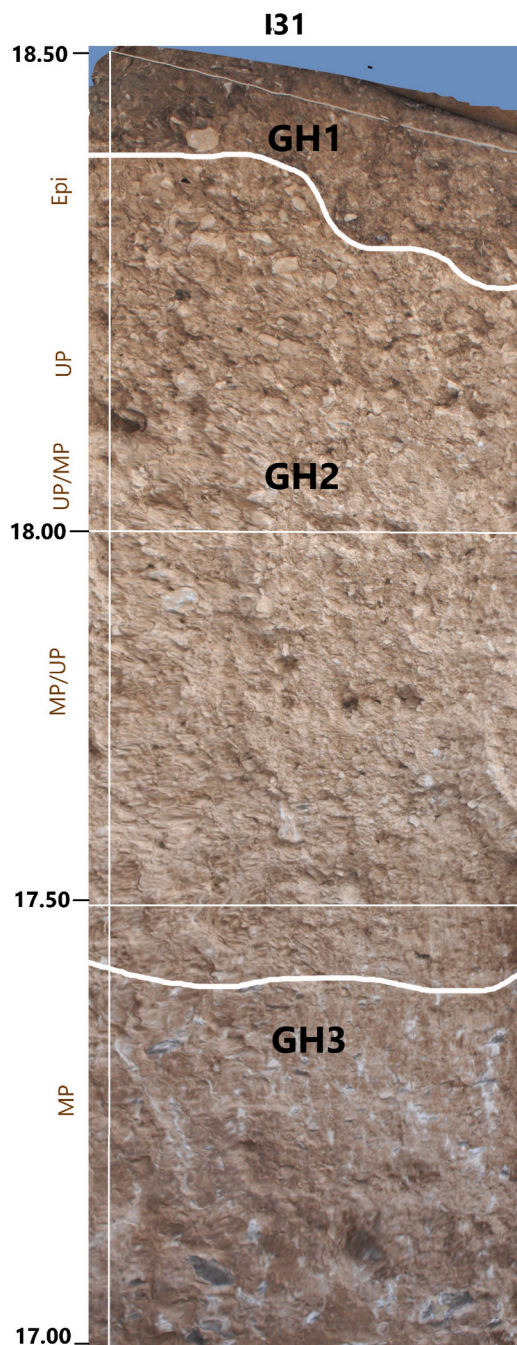


Fig. 9. The picture shows the in situ sedimentary deposits in the upper part of the section in square I31 (1.5 m high), covering GH3 to GH1, where three archaeological occupation layers—from the Middle Palaeolithic to the Epipaleolithic—are exposed.

closely associated with hunting strategies. A total of 10 Dejeete scrapers, representing 8 % of the tools have been identified (Fig. 13, n.12-19). Notably, the majority exhibit retouching that is stepped and substantial on thick Levallois flakes, although there are two with fine retouching present on thin Levallois flakes (Fig. 13, n.13-14). 6 typical limace tools associated with stepped retouched edges have been recovered in MP layers (Fig. 12, n.16-20, Fig. 14). There is also one tool that is categorized as a denticulate/limace. Limace represents a tool type that, although not numerous, is often observed across stratigraphic layers (Fig. 14). Their occurrence is evident even in layers adjacent to the

transitional phase leading to the UP, such as in square H26-180, which is situated at an elevation of 18.04 and H3-53 at elevation 18.07 (Fig. 12, n. 17 and 20). There are nine truncated, faceted tools present in the assemblage; the remaining tools are situated in GH5 (Fig. 14). Four tools have Quina retouch characteristics and are associated with a typical convex retouched edge and scalar/stepped retouched form (Fig. 12, n.6-7). These pieces, with lengths of 72, 72, 83, 53 and 40 mm and widths of 43, 30, 21 and 35 mm, comprise relatively larger tools among MP materials of Bawa Yawan.

Several tools have been classified as multiple tools, including retouched flake/notched, scraper/notched and convergent scraper/borer (Fig. 7, N.3, Fig. 12, n.25-26). Their occasional presence does not follow a repeated pattern in the stratigraphy (Fig. 14), suggesting that their manufacture was based on immediate needs, and therefore, these tools are considered as expedient tools that were readily available. The Bawa Yawan Mousterian tools (often referred to as GH5) exhibit several distinctive morphological characteristics, suggesting deliberate design for specific functions. These include bulb removal, lateral edge scarring, acute piercing angles, proximal thinning or width reduction, proximal notches, and diagnostic impact fractures at the tip, as well as scarring at the base. These traits are considered indicative of Mousterian tool use, particularly in relation to penetration, impact damage, and damage linked to or facilitated by hafting (Ruebens et al., 2022:4). The evidence of purposeful morphological features is found in at least 22 Mousterian tools (Figs. 12 and 13). Among them, 15 tools have an acute penetrating angle. Diagnostic impact fractures are noted at the tip of the tools, highlighting evidence of impact damage. Some of the 12 tools show scarring at the base, indicating additional impact damage (Fig. 12, n. 4, 9,10 and 21, Fig. 13, n. 5 and 8). Eight tools demonstrate bulb removal (for instance Fig. 13 n. 21), a characteristic that likely facilitates hafting. These findings underscore the functional diversity and specialised use of the Mousterian tools in the Bawa Yawan context, and provide important insights into the technological adaptations of the period. The presence of these tools in GH5, which to penetrate the prey body, and the remains of animals such as large ungulates (Aurochs, Equid, red deer-sized) in the same horizon may be related.

3.3.4. Lithic dimensions and temporal trends in sizes

To have a temporal trend of changing sizes of unretouched MP flake and blade lithic artefacts (n.631) and tools (n. 200), the size distribution was calculated. The lengths of the flakes and blade artefacts concentrate in the range from 18 mm to 44 mm, and the width distribution is from 15 mm to 28 mm (Fig. 15). The lengths of tools range from 16 mm to 41 mm, and the width distribution is from 14 mm to 26 mm. The statistical analysis of the regression model has been applied to calculate the temporal trends in both unretouched artefacts and tools (Fig. 15). The results reveal no significant change in the sizes of flakes and blades over time (GH5-2). The R^2 values for both length (0.0003) and width (0.0015) are very low, indicating that the size distribution remained stable throughout the MP period (Fig. 15). For tools, there is a slight trend toward increasing length (Fig. 15G) and width (Fig. 15H) as the stratigraphy moves into older periods. This could suggest that tools in earlier periods may have had slightly larger dimensions, especially in width, though the overall trend is weak. The R^2 values for tool dimensions are still low but higher than for flakes and blades (R^2 for length: 0.0113; R^2 for width: 0.0101). The graph of the tools shows more variation in size compared to debitage (unretouched flakes and blades ≥ 2 cm), potentially suggesting an evolution or development in tool-making practices. This could reflect a shift from simpler forms (flakes) to more complex forms (blades) over time. This trend hints at a possible change in the tool production method and perhaps an increasing complexity in the functionality and forming of tools. Another possibility that cannot be ruled out is that this trend may be related to the transitional shift from the MP to UP, although confirming this requires further investigation.

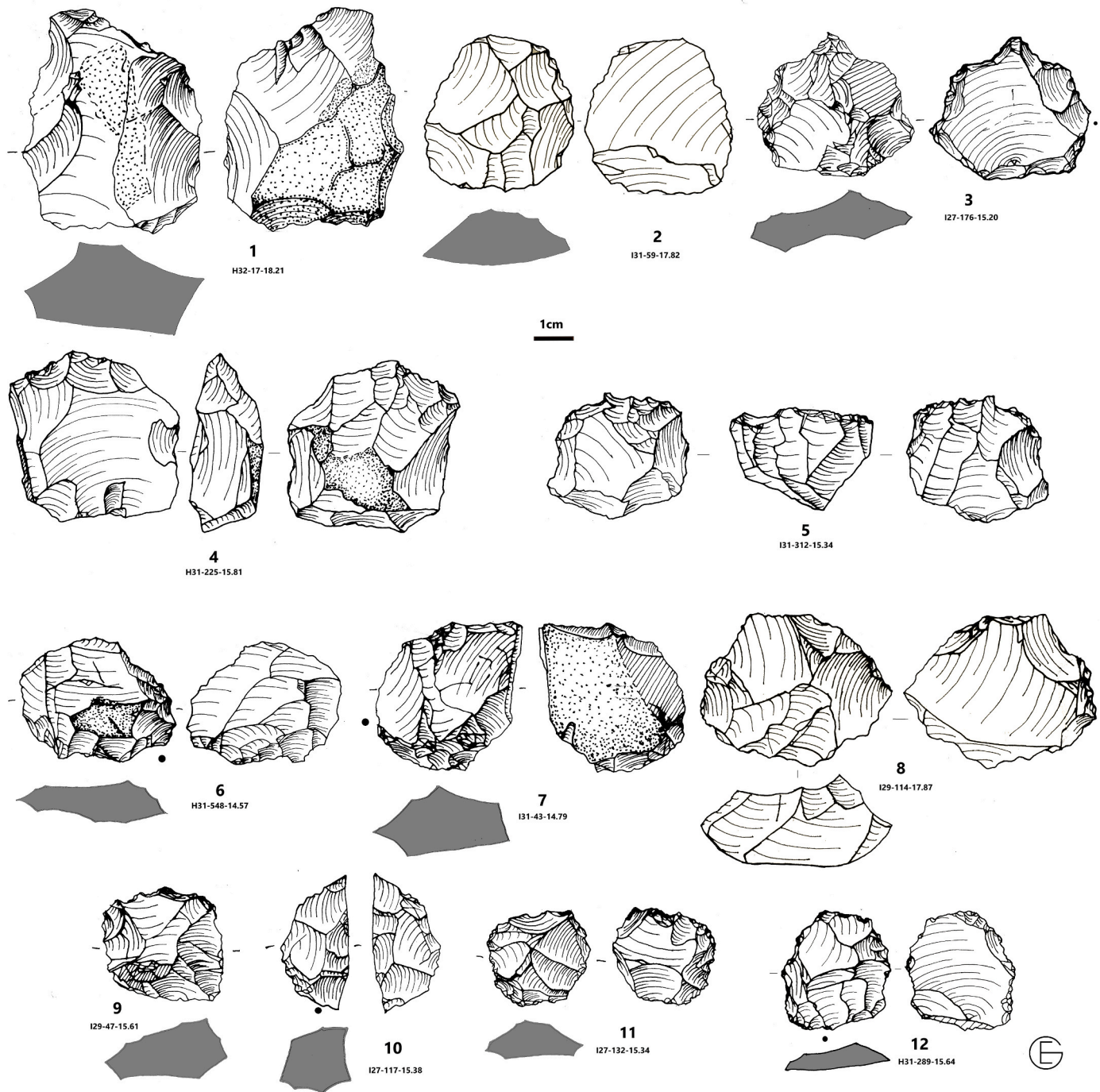


Fig. 10. Examples of cores and truncated faceted pieces from Bawa Yawan Rockshelter: Levallois recurrent core (1, 4, 6–9, 11), Truncated faceted/Levallois core (2, 10, 12), Truncated faceted/borer (3) (Drawing by E. Ghasidian). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.3.5. Comparative insights for lithic artefacts of the Bawa Yawan and other Zagros and adjacent MP sites

Technologically, Bawa Yawan MP stone materials align with a broader Levallois-centred lithic tradition. Retouched tools are mainly made on Levallois on flakes and blades comparable to assemblages from Hummal (Wojtczak, 2011, 2015; Hauck, 2013), Yabrud (Al Kassem, 2021) Hayonim Lower E (Meignen and Bar-Yosef, 2024) and F (Meignen et al., 2000a, 2000b), Abou-Sif (Wojtczak and Malinsky-Buller, 2022) and Tabun D type industry as well as in transitional Mousterian contexts at Ksar Akil levels XXVIA to XXVIIIB (Marks and Volkman, 1986).

First of all, what is striking about the MP lithic artefacts at Bawa

Yawan is the lack of significant changes in tool style and size over time (Figs. 14 and 15). Despite some variation in the frequency of tool types across different stratigraphic layers, the assemblage reflects a relatively homogenous Mousterian culture throughout the sequence. This pattern is comparable to observations from other regions, such as the Late MP in Iberia, as discussed by de la Torre et al. (2013).

Bawa Yawan displays a notably higher tool frequency than other prominent Zagros MP sites such as Warwasi (Dibble and Holdaway, 1993; Dibble, 1995), Bisetun (Dibble, 1984), and Houmian (Nymark, 2021). This higher ratio likely reflects both distinct activity patterns at the site and a more comprehensive collection strategy. Unlike earlier

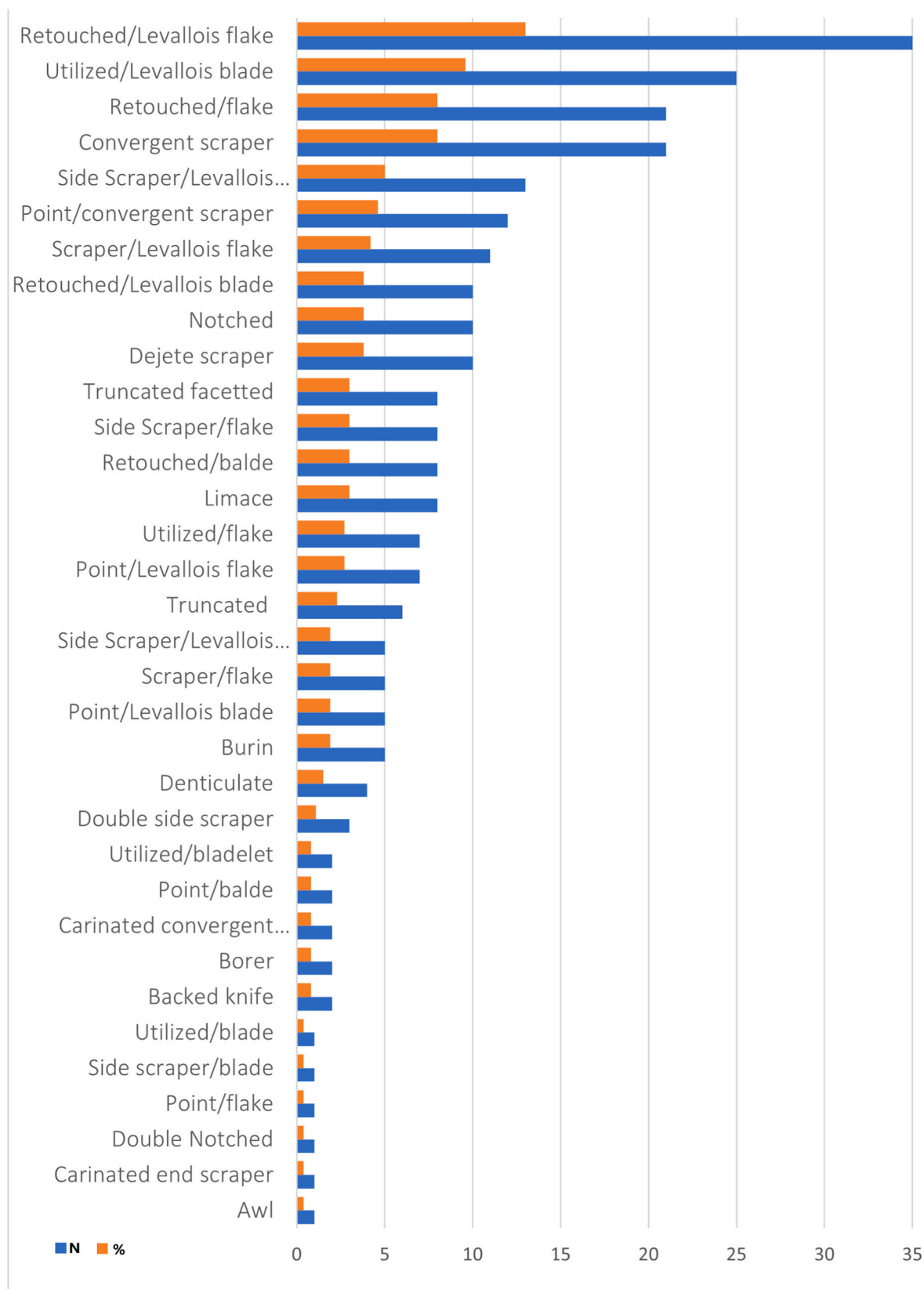


Fig. 11. Main categories of tools in number and percentage in MP layers of the Bawa Yawan Rockshelter.

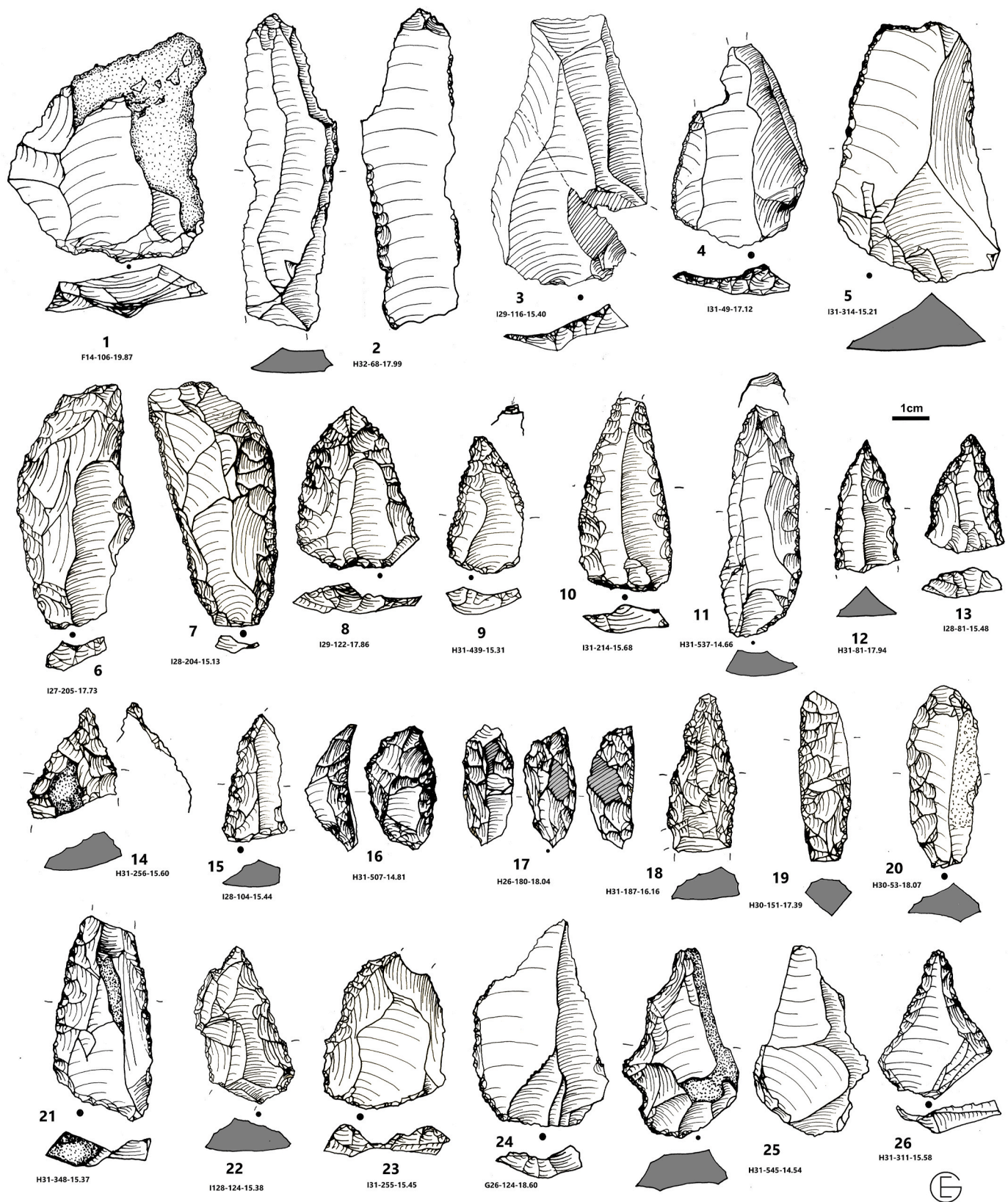


Fig. 12. Examples of lithics from MP layers of the Bawa Yawan Rockshelter: Levallois flake (1,3), retouched Levallois blade with modified tip (2), fine retouched Levallois flake (4-5 and 24), semi-Quina side scraper (6 and 7), convergent scraper (8-13), borer (14), side scraper (15), Limace (16-20), scraper (21-23), denticulate tool with removed flake on ventral surface (25), convergent side-scraper/borer (26). (Drawing by E. Ghasidian).

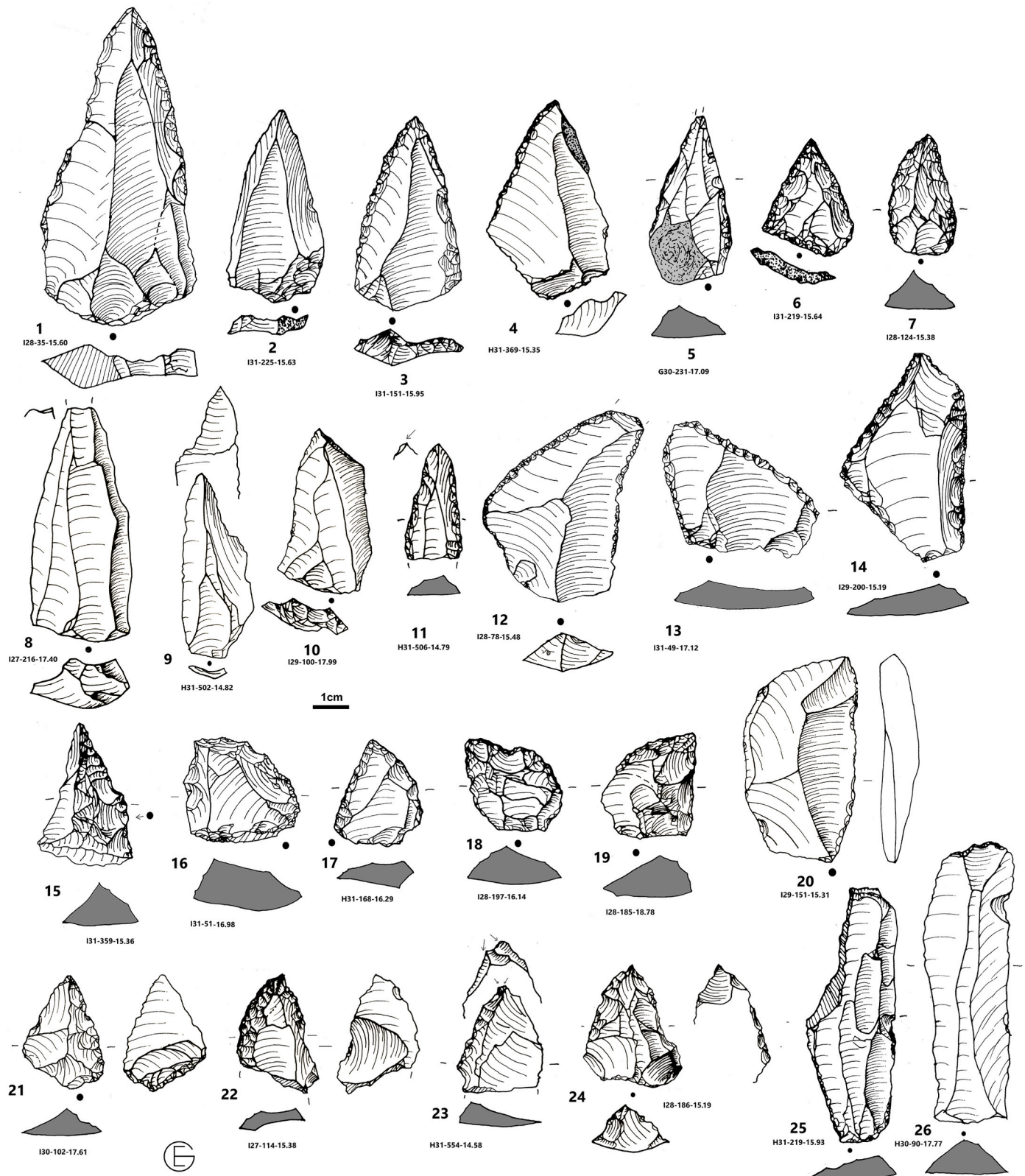


Fig. 13. Example of tools from the MP layers of the Bawa Yawan Rockshelter: convergent scraper/point on Levallois flake (1, 3–5,11), Levallois point (2, 8–10), Dejeete scraper (12–19), Retouched Levallois flake (20), bifacially modified convergent scraper (21–22and 24). Burin (23), Retouched Levallois blade (25 and 26). (Drawing by E. Ghasidian).

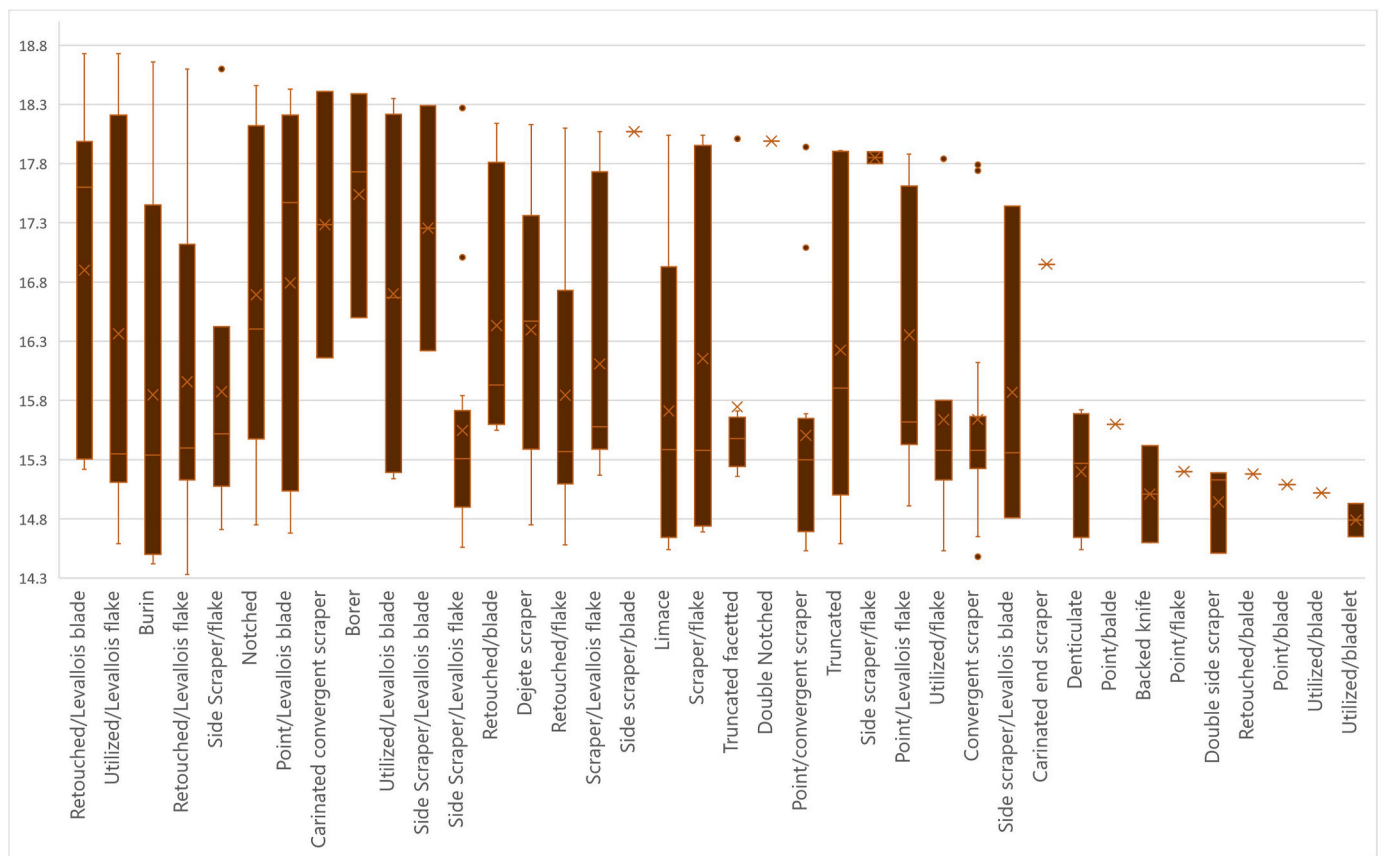


Fig. 14. Graph shows the box-whisker plot of the tools in Bawa Yawan.

excavations that often prioritized diagnostic or complete artefacts, the method of recovering cultural materials in the Bawa Yawan offers a broader and not selectively filtered assemblage.

Scrapers make up 14 % of the tool assemblage, which places the site in the classic Zagros Mousterian cultural tradition. Typological diversity is high, including convergent scraper, déjeté scraper, point, limace, and truncated-facetté tools—types also observed at Warwasi (Dibble and Holdaway, 1993) and Bisetun (Dibble, 1984), as well as at Levantine sites such as Tabun Cave D (Shimelmitz and Kuhn, 2013; Al Kassem, 2021), Dederiyeh Cave (Akazawa et al., 2000a,b; Meignen, 2007, 2019), suggesting widespread regional technological continuities but with local characteristics (Zaidner and Weinstein-Evron, 2012 and Zaidner and Weinstein-Evron, 2020), however the Bawa Yawan GH5 MP is belong to later periods

At Shanidar Cave, Solecki (1963) documented a high frequency of pointed and convergent tools, often interpreted as components of hunting toolkit. This functional focus finds strong parallels at Bawa Yawan—particularly in GH5, where tool morphology and impact-point patterns support their use in hunting and carcass processing. Comparable hunting-related toolkits have been reported from Dederiyeh, Skhul and Qafzeh where Levallois points and scrapers dominate, (Akazawa et al., 1995; Shea, 2013 and references therein). Finally the stepped and scaled retouch at upper MP levels of Bawa Yawan resembles that of the upper layers of Kaldar Cave (Bazgir et al., 2017), possibly reflecting increased specialization in tool function across the late MP.

The site is particularly rich in functionally diagnostic tools. At least 22 artefacts show hafting traces, impact fractures, or piercing tips. While these features are rarely emphasised in earlier studies from West central Zagros sites, similar traits have been noted at Shanidar Layer D (Solecki, 1963), and in the southern Caucasus region (Doronicheva et al., 2022). Another distinctive trait is the presence of expedient, multi-functional

tools—e.g., scraper/borer and denticulate/limace hybrids—suggesting flexible and responsive tool-making strategies. While rarely highlighted in earlier Zagros studies, similar behavioural flexibility is documented at Tabun Layer D (Bar-Yosef, 1994) and the southern Caucasus region (Doronicheva et al., 2022), where complex reduction sequences generated mixed-use implements.

4. Discussion: Neanderthals at Bawa Yawan — their behaviour, subsistence strategies and demographic dynamics

Archaeological evidence from Bawa Yawan suggests that the site most likely served as a hunting station for human groups exploiting a diverse range of prey in the surrounding environments, including Yawan Lake, the Nawdarwan Plain below, and the steep, rocky slopes above the cliffs. This discussion explores new insights into Neanderthal behaviour in the Zagros region, with particular focus on their population dynamics as inferred from lithic artefacts, patterns of prey exploitation, sediment composition, and chronological data derived from the Bawa Yawan site.

The lithic assemblages are tied to Neanderthal groups, as evidenced by the finding of a tooth with clear Mousterian characteristics among MP's stratigraphy. Accompanying the Bawa Yawan Neanderthals, the Mousterian culture showcased a consistent of style over a long span of occupations, maintaining constant characteristics. Slight degrees of change in the lower layer to upper in the diversity and size of tools show not strong shifts in hunting techniques and other subsistence practices. Such homogeneity could indicate a common cultural or mental construction in all Neanderthal societies, which enabled them to exchange all requisite knowledge and skills of tool making. This consistency in lithic technology could imply there was little development or local variation in how tools were made, which might have been due to the social consistency of the Neanderthal populations over a long period. In terms of the varying arguments offered by Lindly (2005) and Nymark

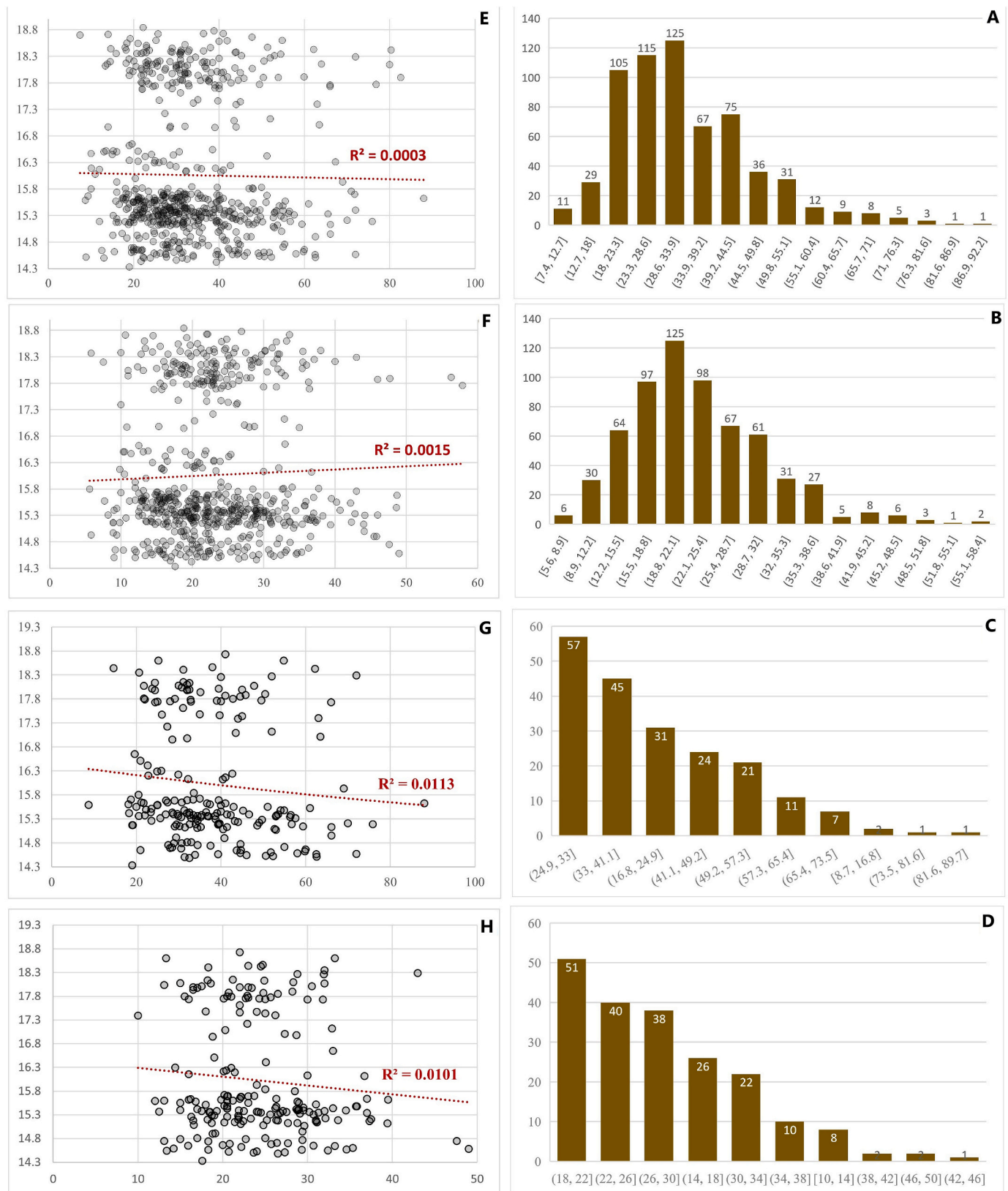


Fig. 15. The bar graphs on the right side of the image illustrate the size distribution of all lithic artefacts from the Bawa Yawan Middle Palaeolithic layers (excluding cores). Specifically, they show: all artefact lengths (A), maximum artefact widths (B), all tool lengths (C), and maximum tool widths (D). The scatter plots on the left display the same measurements plotted over time: artefact lengths (E), artefact widths (F), tool lengths (G), and tool widths (H). A linear trendline is included in each scatter plot, indicating minimal change in size across the stratigraphic sequence. The R^2 values for the length and width of tools are 0.0113 and 0.0101, respectively, suggesting a weak trend toward increasing tool width and length over time.

(2021), Bawa Yawan has revealed that each argument may hold validity, although their acceptability is dependent on distinct environmental contexts during the late Pleistocene climate conditions. For instance, it is possible to apply the issue of “summer-seasonal exploitation of high-altitude environments” for Zagros Mousterian cultural behaviors to GH4 and 3, and to some extent also to GH2, with its limited toolkit during glacial periods, but GH5 is considered a permanent Neanderthal occupation in the high latitude area of Kermanshah and adjacent regions. However, a solid view about this requires further investigation and larger data, particularly dating.

Layer GH5 dating indicates 73 ± 10 for the lower part, 69 ± 8 for the middle and 68 ± 8 ky for the upper section. As a result, approximately 10,000 years pass with a sedimentary thickness of 1.75, and this depositional rate is relatively fast when it comes to geological processes. The presence of clay-sized grains rich in brown iron oxide, along with the absence of rock spalls from rock wall, as a result of freeze and thaw processes (*ebolis*) during a glacial period, strongly suggests a humid, likely water-saturated environment. Brown iron oxide can form in conditions where there is abundant water and oxygen, indicating a well-aerated environment (Hariri, 2022). The date of GH5 is consistent with the interglacial period, ending with two final moderate climate signals 5a of Dansgaard-Oeschger cyclicity 19 and 20 (Andersen et al., 2004). The pollen and abiotic records of Lake Urmia (Djamali et al., 2008) and Lake Van (Kwiecien et al., 2014; Litt et al., 2014; Pickarski et al., 2015) clearly reflect peaks in the percentages of tree pollen for this time period. Fauna and lithic artefacts among the various Bawa Yawan layers are at their highest level at GH5. Some scenarios can be imagined for this situation. The abundance of remains could reflect factors like increased seasonal activity, larger groups coming to the site intermittently, and a variety of other ecological or social reasons. It also suggests that the site was frequently utilized and might have been inhabited by a large, permanent Neanderthal group. A recent study has suggested that the Dansgaard-Oeschger events during the Late Pleistocene effectively increased the hominin population in the northern hemisphere (Timmermann, 2020). Recent research on the carbon and oxygen isotope values of herbivores from the Bawa Yawan Rockshelter (Ecker et al., 2023), discusses the dietary habits and environmental preferences of various herbivore species. Huge and larger herbivores such as *Bos* (cattle) and *cervids* (deer) show $\delta^{13}\text{C}$ values compared to *Capra* (goat)/*Ovis* (sheep). Most herbivores from the GH5 have carbon isotope values of between -9‰ and -11‰ , suggesting that their diet consisted primarily of C3 plants, typical for wetter environments. The low $\delta^{13}\text{C}$ values ($<-11\text{‰}$) are attributed to either bovids or cervids and could indicate animals that spent time in both open and forest environments. The presence of larger species in the GH5 layer may also be the result of their migration from the Palearctic region into west central Zagros during the 5a period. This record was previously noted in the fauna from the Mousterian layers at the Kaldar and Gilvaran sites in the Khorramabad valley (Bazgir et al., 2014).

These conditions change abruptly from a warm, humid environment (GH5) to a cold, dry period in the Bawa Yawan stratigraphy. The abundance of lithic artefacts and faunal remains declines in GH4, reaching their lowest levels in GH3. Although the sedimentary characteristics of Layer 4 indicate a tendency towards coldness, this dilution of cultural and fauna material occurs at a stepped gradient. It is not unlikely that another factor such as overhunting of large prey (Speth and Clark, 2006) caused the decline of cultural materials following hominin emptying from the area.

The chronology of Bawa Yawan associated with the nature of deposits and fauna suggest a period occurring from 65 ± 8 kyr to 59 ± 6 kyr, covering roughly 5 to 6 thousand years with a 70 cm sedimentation rate. This period is more than coincidentally related to the period of MIS4's cold event (Andersen et al., 2004). Sedimentological evidence indicates elevated levels of calcium carbonate, along with the absence of organic matter and iron oxide (Hariri, 2022). Furthermore, there is no longer any evidence of large herbivores such as cattle and deer. It should

be noted that Bawa Yawan is surrounded by high mountains ranging from 2000 to 3300 masl (Heydari-Guran and Ghasidian, 2021). Glaciation studies in the Zagros indicate a long-lasting permanent snow line at about 1800 to even 1500 masl during Last Glacial Maximum (Wright, 1962). This issue suggests that the significant decline in archaeological material density in layers 4 and 3 is directly related to a decline in the Neanderthal population, highly probable due to falling temperatures and disappearing large herbivores (Fig. 3). The Caprines in the upper layer (GH3 and 2) have lower $\delta^{13}\text{C}$ values, likely reflecting their preference for cooler habitats, such as mountainous areas with more shrubbery and higher water availability (Ecker et al., 2023). This suggests a preference for C3 plants in environments like steep limestone slopes and high-altitude areas, typical landscapes in the Nawdarwan valley. Animals with higher $\delta^{18}\text{O}$ values indicate a potential influence of leaf water (water taken up by plants) in the caprine's body water (ibid). The significant presence of freshwater turtle remains during this period likely aligns with the expansion of Lake Yawan adjacent to the shelter, which coincided with humid climatic conditions. The wide range of $\delta^{18}\text{O}$ values (up to 10 ‰) in *Capra/Ovis*, despite similar mean values across three geological layers from 4 to 2, might reflect seasonal variations. These variations are often observed in hypsodont teeth, which are sensitive to seasonal dietary changes (ibid). The zooarchaeological studies conducted in the Ghar-e Khar Cave in the Bisetun area provide evidence supporting seasonal utilization for these taxa during the MP period as well (Hesse, 1989).

The geographical orientation of Yawan Mountain and even cliff of Bawa Yawan rockshelter, appear to have significant functional and environmental benefits (Figs. 1 and 2). The northwest-southeast alignment of the mountains ensures these areas are exposed to maximum sunlight throughout the day, particularly during the colder months. The vertical slope of the rocks enhances this effect by minimizing shadow, allowing more of the surface to absorb sunlight at different times of the day. Additionally, the greyish colour of the limestone rocks plays a key role in reflecting and retaining heat. Lighter or neutral-coloured surfaces tend to reflect more sunlight, which can further warm the rock during the day. At night, the rocks may slowly release the stored heat, creating a more temperate microclimate in the surrounding area. This combination of sunlight absorption and heat retention can make the location more hospitable. As a result, these specific conditions probably allowed small groups of Neanderthals to survive in the area during MIS 4. The climatic evidence from the Zagros region suggests that approximately 57 to 35 kyr was a relatively mild period and followed the more severe conditions of glacial MIS 4 in the Northern Hemisphere (Andersen et al., 2004). The assertion that Layer GH2 at Bawa Yawan is linked to an increase in Mousterian cultural materials provides an interesting perspective for interpreting the demographic dynamics of Neanderthals. The sedimentological attributes of layer GH2 of the however, differ from the brown clays of GH5, exhibiting a distinct contrast with the sediments of levels 4 and 3. The concentration of carbonates has decreased, whereas there is a minor increase in iron oxide. The diameter of the Mousterian layer in GH2 is between 60 and 70 cm for a period around 55 to 40 kyr is very slow. The climate records (Li and Born, 2019) exhibit comparatively temperate climatic conditions, neither extremely cold nor excessively warm (Fig. 3 B). If we interpret the increase of hominin remains at this site as indicative of population growth, it suggests that Neanderthals were not facing a severe demographic decline closely before their extinction, roughly between 45 and 40 kyr.

The evidence from Bawa Yawan reflects population dynamics comparable to those observed in the Levantine Middle Palaeolithic. An early phase corresponds with the occupation of Tabun Cave, Layer C (~MIS 5e–5a), associated with temperate interglacial conditions and early Neanderthal presence (Mercier et al., 1993; Bar-Yosef, 2000; Shea, 2003). A later phase at Bawa Yawan (GH4–3) parallels occupations at Kebara and Amud Caves (~MIS 4–3; ~70–50 ka), during cooler, more arid periods (Valladas et al., 1987; Meignen et al., 2000a,b; Akazawa et al., 1995). These patterns suggest that Bawa Yawan fits within

broad regional shifts in various hominin occupations and climatic adaptation (Langgut et al., 2018). However, this evidence is not consistent with Western European data (Timmermann, 2020; Slimak et al., 2024).

The adaptation of the Mousterian people to high-altitude mountain environments, as discussed in the context of Bawa Yawan Rockshelter, can be viewed as a broader example of Neanderthal adaptation to local environmental and climatic conditions. The Mousterian toolkits in the Zagros Mountains and Arminian Highland/Lesser Caucasus showcase a complex adaptation to the hunting challenges posed by these high landscapes, where pronounced seasonal variations probably shaped the evolution of particular technological and survival tactics, including specific tools type manufacturing (Adler et al., 2006; Heydari-Guran, 2014; Malinsky-Buller et al., 2021). The evidence of Neanderthal subsistence strategies is diverse and reflects a complex understanding of their environment. Regardless of the habitat, the main implication of Neanderthal prey selection is a subsistence strategy focused on the most nutritionally abundant animals (Churchill, 2014). In some cases, Neanderthals specialised in a small number of taxa or, in certain situations, a single species, according to zooarchaeology studies (Bar-Yosef, 2004; Churchill, 2014; Patou-Mathis, 2000).

The data from the North European Plain indicate Neanderthals focused on open landscape mammals, especially mammoths, horses, steppe bison, ibex, which are more common in uplands, and red deer, which are more common in forested areas (Churchill, 2014). The relative abundance of animal species in layer GH5 of the Bawa Yawan indicates that Neanderthals were more focused on selecting high-ranking prey, especially horses and bovines, and the remains of other ungulates, such as boar, goats/sheep, turtles and probably medium-sized carnivores, although in lower proportions. This indicates the diversity of species hunted during this long period. In the same vein, the Mousterian tool collection exhibits a relatively greater diversity during this period, which is believed to be indicative of the diversity of dietary sources and the diversity of tool requirements (Fig. 3 and 14).

As the amount of large-sized remains in GH5 is disproportionately higher than that of smaller preys such as boar and capra, Neanderthals in their biological domain likely had a high level of contact and exposure to higher-ranking animal species. There is relatively little information on Neanderthal hunting methods around the world (Gaudzinski-Windheuser et al., 2018); however, it is accepted that Neanderthals lacked long-range projectiles such as bows and assisted spear throwers (Villa and Soriano, 2010). This may have increased the energetic cost of hunting and increased risk of mortality due to hunting at closer range (Power 2019). Evidence for Neanderthal use of hafting adhesives (such as plant-based resins, as reported by Koller et al., 2001) does suggest they had the technical knowledge to attach spear points to shafts, which is an indicator of sophisticated toolmaking. Hafting would have allowed them to create more effective weapons, and this technology could have been used for both thrusting and throwing. Therefore, although the small size of the Zagros Mousterian tools has been related to the area's limited raw materials (Dibble, 1984), it is important to consider that the complex and enclosed topography of the Zagros may have required ambush hunting techniques (Heydari-Guran and Ghasidian, 2024) that relied on light projectile tools. This topic has been examined for the Levant by some scholars (Sisk and Shea, 2009).

5. Conclusion

Despite extensive research about the MP in the Zagros region, particularly in the Northern Zagros, significant gaps remain in our understanding of hominin behaviours and environmental conditions during this key period. This paper has focused on the findings from three seasons of excavation during 2016–18 in the Bawa Yawan Rockshelter, Kermanshah, west central Zagros Mountains of Iran. Stratigraphy in the MP deposits of Bawa Yawan, in conjunction with lithic artefacts, faunal remains and dating, present significant issues for consideration. These

concerns relate to the analysis of Bawa Yawan Neanderthals' behaviour and its environmental context. Although cultural materials and remains at the Bawa Yawan site are relatively sparse within the stratigraphic sequence, they offer evidence of climatic and anthropogenic events during the Late Pleistocene, spanning from Marine Isotope Stage (MIS) 5a to the middle of MIS 3. The site features a human-associated technology characteristic of the Zagros Mousterian, with lithic artefacts covering an estimated duration of approximately 40,000 years. This suggests that Neanderthal groups in this area maintained a relatively stable and homogenous cultural tradition over a long period, despite environmental and other changes between humid to cold periods of the Late Pleistocene. There are at least three fluctuations in Neanderthal populations in response to environmental conditions, such as changes in humidity, temperature and most importantly, availability of food resources. The density of Mousterian lithic artefacts in the GH2 of Bawa Yawan, attached to area UP materials, suggests that before extinction, Neanderthals might have been living in relatively large groups. This demonstrates the adaptability and resilience of Neanderthal populations during climatic fluctuation at late Pleistocene, and emphasises the mystery surrounding the disappearance of the Neanderthals.

Author contributions

I conceived and designed the analysis, collected the data, contributed data and analysis tools, performed the analysis, and wrote the paper: Middle Palaeolithic occupation, cultural behaviours and demographic dynamics during MIS 5a to late 3 in the Bawa Yawan Rockshelter, Kermanshah, West-Central Zagros Mountains.

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Declaration of competing interest

The author declares 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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Data availability

All data and/or code is contained within the submission.

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