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Diachronic Patterns of Lithic Raw Materials From the Middle to Epipaleolithic Periods Based on the Bawa Yawan Rock Shelter, Kermanshah, West-Central Zagros Mountains

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Abstract

The Bawa Yawan rockshelter and cave complex, located in the west-central Zagros region of Iran, stands out as a significant Paleolithic site due to its spanning the three periods of the Middle Paleolithic, Upper Paleolithic and Epipaleolithic. This site exhibits a wide range of lithic artifacts, which were used by Neanderthals and anatomically modern humans between ca. 83-13.4 kya (TU / OSL Dating). In this study, we present preliminary results from macroscopic analysis of approximately 1000 lithic artefacts. Our initial findings indicate that over 99% of the utilized raw stones materials belong to the micro-cryptocrystalline sedimentary rock category, primarily due to their widespread availability. Less than 1% of the material fall into other categories, such as metamorphic and igneous rocks. The main results of this research indicate that the Middle Paleolithic groups (Neanderthals) used a more diverse range of raw stone materials than later groups. In contrast to the Upper Paleolithic to Epipaleolithic periods, people (Homo sapiens) become more specialized in the use of higher quality resources. This finding shows a relative difference in lithic raw material procurement strategies among Neanderthals and Homo Sapiens in the study area.

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1. Introduction

Stone is among the most enduring remains found at archaeological sites, having been utilized by humans since deep antiquity. Unlike other raw materials such as wood and bone which rapidly decay stone resources are abundantly preserved in natural contexts. Beyond its durability, stone played a fundamental role in the cultural evolution of Paleolithic societies. However, the processes by which different hominin groups selected, extracted, and transported stone resources were complex and at times influenced by social and cultural factors. It is for this reason that anthropologists have long sought to understand the intricacies of these processes.

Although research on lithic raw material sources dates back to the 19^{th} century CE (Matias, 2016), prior to the 1970s, studies on raw stone were largely limited to brief notes by archaeologists and geologists concerning the presence of chert at ancient sites. It was only after this period that such investigations gained momentum (Delage, 2003). While the Oxford Dictionary records the first printed reference to "flint" as early as CE 700, documented use of the term "chert" does not appear until 1679 (Luedtke, 1992). Nevertheless, extensive research on lithic raw materials especially chert has notably expanded since the 1970s, continuing robustly for roughly four decades. Understanding how hominins acquired both siliceous and non-siliceous raw stone was the initial step in reconstructing lithic reduction sequences. Grasping the nuances of these sequences, alongside factors such as selection, procurement, transport, and management of lithic raw materials, offers considerable potential for documenting cultural diversity and economic activities across past landscapes. This includes insights into land use strategies, the extent of trade networks, settlement patterns, mobility, and the technical-economic organization of lithic production (Andrefsky, 1994; Binford, 1979; Delage, 2003; 2007; Doronicheva et al., 2023; Yue *et al.,* 2020).

Stone thus provides invaluable information on human presence and landscape dynamics from the distant past to the present. It preserves evidence of human interactions with their ecosystems and of the technologies employed in lithic tool production (Delage, 2007; Inizan et al., 1992), while also archiving geographic and anthropological dimensions such as the likely locations of stone sources, the distances traveled to acquire them, preferences in material selection, and the discernment of source quality.

Among the most critical areas of study for reconstructing spatial distribution patterns and hominin site selection behavior has been understanding how hominins accessed and used stone the most basic raw material of all. While natural and environmental factors such as geological structures, elevation, and climate fundamentally shape the distribution and location of archaeological sites (Brooks, 1982; Heydari, 2004), lithic raw material sources themselves also played an essential role in shaping Paleolithic settlement systems through to the end of the Neolithic.

Numerous questions surround lithic raw materials and their procurement in anthropological, archaeological, and geological research. As summarized by Inizan *et al.,* (2009), the following are regarded as fundamental questions that must underpin any such study:

- What is the geological context of occurrence? Is the raw material locally rare, or abundant?

- Is there only one sort of raw material, or are there several varieties ?
- Is the raw material easy, or on the contrary difficult, to collect or extract ?
- What is its quality, in what shapes and sizes does it occur ?
- Could it be easily transported in its original shape ? (Inizan *et al.,* 2009: 25)

Addressing such questions has prompted extensive studies across diverse global contexts (Slimak & Giraud, 2007; Spinapolice, 2012; Valde-Nowak & Cieśla, 2020). In Southwest Asia, particularly during the Paleolithic, the Levant remains at the forefront of such investigations, with more intensive research conducted there compared to areas such as the Zagros (Betts, 1983; Delage, 2007; Julig *et al.,* 2007). In contrast, studies specifically examining lithic raw material procurement and outcrops within Paleolithic archaeological contexts across the vast cultural and geographic expanse of the Zagros Mountains remain remarkably limited. Those few that do exist rely predominantly on surface collections and relative chronologies, and generally fall into the categories of macroscopic or microscopic analyses (Biglari, 2007; Heydari, 2004; Heydari-Guran & Ghasidian, 2020). This absence of systematic investigations grounded in absolute dating of Paleolithic sites concerning lithic raw materials not only affects our understanding of the Pleistocene but extends into the Holocene, thereby restricting researchers' ability to precisely reconstruct diachronic patterns of lithic consumption.

In light of these issues, through detailed macroscopic study of lithic raw materials utilized by Neanderthals and Homo sapiens over approximately 70 kay years of occupation at the Bawa Yawan Rockshelter an archaeological context with secure absolute dating we aim to: (1) classify the various lithic raw material types employed at the site; (2) elucidate diachronic changes in raw material use across the Middle Paleolithic, Upper Paleolithic, and Epipaleolithic periods; and (3) determine the geological sources of these raw materials in the surrounding region, thereby shedding light on land use patterns among Middle Paleolithic, Upper Paleolithic, and Epipaleolithic communities. Ultimately, these objectives will allow us to explore whether the economic behaviors of these successive prehistoric groups at Bawa Yawan can be effectively reconstructed through the study of lithic raw materials.

2. General Overview

2-1. Geology

A substantial body of evidence indicates that the complex topography of the Zagros Mountains has functioned as a humidity island (Oberlander, 1965), creating a region characterized by rich vegetation cover, abundant water resources, and plentiful lithic raw materials (Ghasidian & Heydari-Guran, 2018), thereby attracting both human communities and animal herds over millennia (Heydari-Guran & Ghasidian, 2020). The geological and geographical positioning of the Zagros, along with archaeological discoveries, demonstrates that this region held particular significance for the settlement of both Neanderthals and anatomically modern humans. The Zagros constitutes a macro-zone subdivided into four eco-zones (northern, west-central Zagros, central, and southern) based on geological formations, landforms, and hydrological conditions.

Structurally, it is also divided into three principal zones: the High Zagros (faulted or fractured), the Folded Zagros, and the Unfolded Zagros (Khuzestan Plain), (Heydari-Guran, 2014).

The fractured zone of the Zagros in the study area and its vicinity is further divided into three sub-units: (a) the southwestern sector, including Late Cretaceous limestone thrust sheets; (b) the northeastern sector, consisting of colored mélange masses composed of ophiolite and radiolaritic chert at tectonic contacts along the Late Cretaceous Urumieh–Dokhtar orogenic belt; and (c) the central sector of radiolaritic chert and detrital limestone (Brooks, 1989) situated within the thrust zone of the Zagros (Inner Zagros or High Zagros) and the folded-thrusted Zagros belt.

Within the High Zagros, the west-central Zagros region is itself divided topographically into four geographic zones A, B, C, and D in which several major groups of lithic raw material outcrops have been identified (Heydari-Guran & Ghasidian, 2020). Among these, the Kermanshah region, located in the west-central Zagros, is undoubtedly one of the key areas for Paleolithic research on the Iranian Plateau due to its significant prehistoric archaeological discoveries, large number of caves and rock shelters, and abundant lithic raw material sources. The numerous Paleolithic sites discovered here including open-air sites from the Lower Paleolithic, Neanderthal skeletal remains, and stratigraphic sequences ranging from the Middle to the Epipaleolithic attest to the area's attractiveness to successive human groups from the Middle to Late Pleistocene (Biglari & Shidrang, 2019; Coon, 1951; Ghasidian *et al.,* 2019; Hariri *et al.,* 2021; Heydari-Guran & Benazzi *et al.,* 2021; Heydari-Guran & Douka *et al.,* 2021; Heydari-Guran & Ghasidian, 2017; Yousefi *et al.,* 2020; Zanolli *et al.,* 2019).

Long-term paleoanthropological research worldwide has demonstrated that Paleolithic communities exploited a wide range of lithic raw material sources for tool production, encompassing sedimentary to igneous rocks. Among these, cryptocrystalline and microcrystalline siliceous rocks whether clastic or non-clastic commonly identified as flint, chert, or even radiolarite (Herrero-Alonso *et al.,* 2021), are among the most abundant in the west-central Zagros, particularly around Kermanshah. Geological investigations reveal that this region hosts an extensive bed of diverse lithic resources, with the renowned Kermanshah radiolarite belt (Fig. 1) standing out as one of the best, largest, and purest examples of such outcrops across the Zagros Mountains. This belt manifests in various forms depending on local geological conditions (Mohajjel & Biralvand, 2010) and has been thoroughly documented by scholars such as Broud (1987) and Brooks (1982).

The Kermanshah radiolarite belt constitutes part of an ophiolitic complex within the geological zone of the Zagros, oriented northwest-southeast across Kermanshah province (Broud, 1987). Radiolarite is a sedimentary rock primarily composed of the siliceous skeletons of radiolarians, which are marine micro-organisms. The radiolarite outcrops of Kermanshah are bounded to the north by the Bisotun fault and to the south by the Kuh-e Sefid fault (Abdi *et al.,* 2014). This siliceous unit extends over an area of approximately 35 kilometers, situated between the Bisotun limestone in the north and autochthonous Zagros deposits in the south (Abdi *et al.,* 2022). Parallel to this sedimentary complex and nearby to its east lies the Sanandaj-Sirjan metamorphic belt. This geological formation includes rocks such as schist, gneiss, and marble, which are significant in the tectonic history of the region and provide valuable insights into geodynamic processes (Mohajjel *et al.,* 2003).

Evidence from archaeological contexts indicates that Paleolithic human communities in Kermanshah intensively exploited stones from the radiolarite belt (Biglari, 2004; 2007; Heydari, 2004; Heydari-Guran & Ghasidian, 2020). Although the Human Evolution in the Zagros Mountains (HEZM) research group has undertaken preliminary surveys on the lithic raw material resources used by humans from the Lower to the Epipaleolithic (Heydari-Guran & Benazzi *et al.,* 2021; Heydari-Guran & Douka *et al.,* 2021; Heydari-Guran & Ghasidian, 2017; 2020), the vast scale and profound significance of the Kermanshah radiolarite belt on early human behavior underscores the urgent need for more systematic studies employing state-of-the-art scientific techniques (Hariri, 2024a, Hariri, 2024b).

2-2. Lithology Related to Lithic Artifacts

This section provides an overview of stone phenomena with an emphasis on rocks and minerals employed in the production of lithic artifacts in the study region. Rocks are generally classified based on their formation processes into three primary categories: igneous, sedimentary, and metamorphic.

Igneous rocks form the foundational basis of all other rock types and are created through the cooling and crystallization of magma or lava, either at the Earth's surface or at depth. They are subdivided into two broad categories: extrusive (volcanic) and intrusive (plutonic) igneous rocks. Extrusive igneous rocks form when magma reaches the surface and cools rapidly. Among these, basalt is notable; basalts erupt across a wide range of tectonic settings on Earth and represent the most voluminous volcanic rock type (Gill & Fitton, 2022; Philpotts & Ague, 2009).

Metamorphic rocks result from the alteration of pre-existing igneous or sedimentary rocks due to the physical and chemical changes brought about by pressure and heat within the Earth's crust. This process occurs at significant depths over extended timescales, modifying the texture and structure of the original minerals without reaching melting point. Among such rocks is phyllite, a fine-grained, low-grade metamorphic rock exhibiting well-developed foliation (Bucher & Frey, 2002; Bucher & Grapes, 2011). According to the 1:250,000 scale geological map of Kermanshah, a belt of volcanic and metamorphic rocks runs parallel to the Bisotun-Shaho limestone block, approximately 25 km (direct distance) north of our study area.

Sedimentary rocks form through the deposition of mineral particles and biological detritus in aquatic environments, or via diagenetic processes such as compaction and lithification over time. These rocks are often characterized by layering and may contain fossils. Sedimentary environments include lakes, oceans, and deserts. They are typically divided by genesis into four principal groups:

(a) Clastic sedimentary rocks (e.g., sandstones, mudstones, siltstones);

(b) Chemical sedimentary rocks;

(c) Biogenic sedimentary rocks (e.g., limestones, marls, and cherts); and

(d) Volcaniclastic sedimentary rocks (tuffs), (Boggs, 2009; Tucker, 2001).

Among the clastic rocks, sandstone is composed primarily of sand-sized detrital grains, often quartz, feldspar, and lithic fragments. These grains are cemented by diagenetic processes into coherent rock. Sandstones are deposited in fluvial, shoreline, or desert settings and occur in a variety of colors. Mudstones encompassing shale, siltstone, and claystone consist of very fine mineral particles (<0.063 mm), mainly clay minerals and fine silt. These rocks make up a large portion of sedimentary sequences and generally form in low-energy environments (Tucker, 2011).

Among the biogenic sedimentary rocks, limestone is composed mainly of calcium carbonate (most commonly as calcite), forming in aquatic environments such as shallow marine carbonate platforms and lakes that support rich biotic communities. Three major components typically characterize most limestones: carbonate grains, a micritic matrix, and cement. Many limestones resemble sandstones, consisting of sand-sized carbonate grains reworked on the seafloor, while others are finer-grained, arising from lithified lime mud (micrite or calcareous mudstone), (Tucker, 2001; 2011). Marl is a sedimentary rock containing variable proportions of clay and calcium carbonate, bridging properties between claystones and limestones (Boggs, 2006; Tucker, 2011).

Silicification of carbonate rocks is a diagenetic process involving extensive replacement of carbonate minerals ($CaCO_3$) by siliceous minerals (SiO_2 phases including opal, quartz, and moganite), as well as minor silica cementation in voids. When these processes are volumetrically significant, the resulting siliceous minerals (chert and opal) produce non-carbonate outcrops that resist weathering more effectively (Bustillo, 2010).

Among the most renowned siliceous rocks are cherts, which may occasionally include macrocrystalline quartz but are primarily composed of microcrystalline quartz grains too small to discern with the naked eye. Technically, grains measuring 2-50 microns are microcrystalline, while those <1-2 microns are cryptocrystalline (Luedtke, 1992). Cherts are distinguished into bedded and nodular types, a feature critical in archaeological raw material sourcing. According to Tucker (2011), most bedded cherts occur in relatively deep-water sequences, displaying layering akin to modern siliceous radiolarian and diatomaceous ocean floor oozes. These layers range from a few centimeters to tens of centimeters in thickness. Some bedded cherts are associated with pillow lavas and form part of ophiolitic sequences, indicating volcanic processes. Conversely, chert nodules are common in limestones, formed by diagenetic replacement, sometimes nucleated around fossils (e.g., echinoids, sponges) or arranged regularly within certain horizons (Tucker, 2011). The term flint is popularly used for such nodular cherts, especially in reference to dark, high-quality cherts of Cretaceous chalk formations in southern England (Luedtke, 1992). In Paleolithic literature, "flint" is sometimes imprecisely employed to denote all lithic tools regardless of material.

Beyond rocks, certain minerals and mineraloids also served as raw materials for lithic artifacts. Several mineraloids are characterized by significant water content and weak crystal structures, often closely related to silica minerals. Collectively, these are termed opal, subdivided into varieties such as Opal-A, Opal-CT, and Opal-C. Opal-A, for example, exhibits an amorphous glass-like structure (Luedtke, 1992). Chert-opal transformations refer to two distinct silica forms that may naturally interconvert; under specific geological conditions, opal can arise from chert through processes where silica-rich water gradually dissolves the silica in chert and reprecipitates it as amorphous silica, eventually forming opal (Liesegang *et al.,* 2018; Yanchilina *et al.,* 2020).

In general terms, the diachronic trajectory of lithic raw material preferences shows that earlier periods favored rocks such as basalt, limestone, dolomite, and sandstone, whereas the Middle and Late Paleolithic increasingly emphasized siliceous stones, reflecting evolving needs and recognition of material properties.

3. Materials and Methods

3-1. Materials

The Human Evolution in the Zagros Mountains Project was launched in 2009 (1388 SH) with the primary objectives of identifying the earliest hominin settlements, tracing late Pleistocene hominin occupations, and understanding the cultural and behavioral transition from the Middle to Upper Paleolithic in the Kermanshah region (Heydari-Guran, 2016; 2017; 2018; Heydari-Guran & Ghasidian, 2012; Ghasidian & Heydari-Guran, 2012; Heydari-Guran & Azadi, 2021; Heydari-Guran & Hariri, 2019; 2022; Hariri, 2021; Hariri *et al.,* 2021).

Within the framework of this project, intensive Paleolithic surveys were conducted in western Kermanshah Province during 2009 and 2010 (1388–1389 SH), including the Nawdarwan Valley (Fig. 1). These extensive surveys across the Kermanshah catchment resulted in the discovery of over 80 caves and rock shelters associated with the Paleolithic period, distributed along both sides of the Nawdarwan Valley, among which the Bawa Yawan cave and rockshelter complex stands out (Heydari-Guran & Ghasidian, 2020).

The Nawdarwan Valley, approximately 32 km long and varying between 5 to 15 km in width, contains 53 shelter sites. It represents one of the most strategic corridors linking the southeastern plain of Kermanshah with the Kamyaran plain to the northwest. The perennial Razawar River flows through the center of this valley from northwest to southeast. Significantly, this river originates from a completely different geological catchment, characterized by metamorphic and volcanic formations distinct from Nawdarwan.

Among the sites identified in this valley, the Bawa Yawan cave and rockshelter complex was selected for this research due to its exceptional stratigraphic and archaeological significance.

3-1-1. Bawa Yawan Rockshelter and Cave Complex

The Bawa Yawan rockshelter and cave complex (34°38’23.93”N, 46°55’48.11”E) is situated approximately 35 km northwest of Kermanshah city, along the road to Kamyaran, nestled within the Nawdarwan Valley and adjacent to Yawan village (Fig. 1). The complex comprises a high, vertical rock wall that offers a naturally elevated vantage point with easy access over the Nawdarwan Valley (Fig. 2). The rockshelter itself is located on the edge of the Nawdarwan plain,

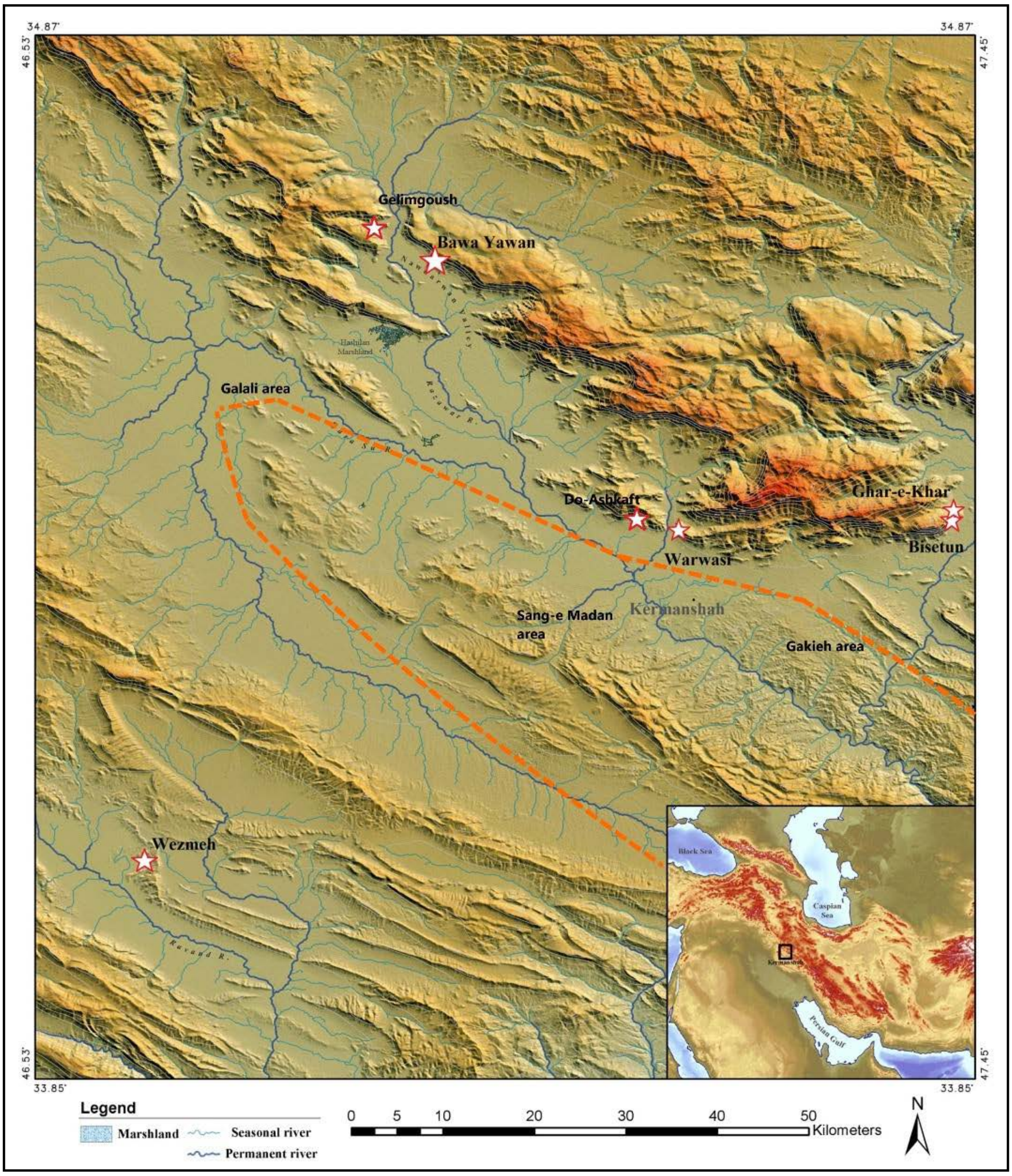

Fig. 1: The study area includes the Kermanshah Basin, Radiolarite belt (orange dashed line), Nawdarwan Valley, Cave and rockshelter Bawa Yawan Complex (Map by S. Asiabani).

about 10 meters above the valley floor. Additionally, a small karstic spring forming a pond is found approximately 70 meters southwest of the shelter.

Excavations at this site Started in early 2016 (1394 SH) and continued during 2017, 2018, and 2021 (1396, 1397, 1400 SH). Over the course of four excavation seasons, a total area of 25 m² was excavated across two main sectors, designated the western trench and eastern trenches (Fig. 3). Excavation squares reached depths ranging from 30 cm to 4.5 m, revealing five sedimentary layers associated with human occupation.

During the second excavation season, a Neanderthal tooth (BY1) was uncovered at the base of layer five. This find, dated by radiocarbon to approximately 45,000–40,000 BP and by TL/OSL to around 70,000–65,000 BP, is directly associated with Mousterian lithic artifacts, underscoring the exceptional significance of Bawa Yawan within the Paleolithic landscape of the Zagros.

Furthermore, the site preserves evidence of long-term human occupation, encompassing the Middle Paleolithic (layer five to early layer two), Upper Paleolithic (middle of layer two), and Epipaleolithic periods (upper layer two). Middle Paleolithic lithics primarily consist of Zagros Mousterian forms, such as convergent scrapers, side scrapers, Levallois cores and flakes. Upper Paleolithic assemblages are characterized by laminar technologies, including prismatic blade cores, blades and microblades, denticulates, notches, and burins. Finally, the Epipaleolithic toolkit is dominated by geometric microliths and backed microblades.

The quality and quantity of archaeological data retrieved (all layers were excavated in 3–5 cm thick spits) at Bawa Yawan make it possible to reconstruct diverse aspects of hominin economic behavior during the Late Pleistocene in the west-central Zagros. From this site alone, over 12,000 lithic artifacts have been recovered across four field seasons (including single finds and items recovered by both dry and wet sieving), representing a broad range of raw material types.

From the entire assemblage, approximately 10% or 1,159 lithic artifacts were selected for detailed study. These artifacts were recorded as single finds during the first, second, and third excavation seasons, meaning each has precise geospatial coordinates, was retrieved in situ, and measures at least 2 cm or larger, following established Paleolithic sampling standards (McPherron et al., 2005). This study sample encompasses cores, flakes, blades, tools, and debitage. Their distribution across geological layers and archaeological periods is summarized in Table 1.

Table 1: Distribution of the number of lithic artifacts in geological layers and their archaeological periods (Authors, 2021).

Period	Count	%	Layer 2	Layer 3	Layer 4	Layer 5
Middle Palaeolithic	658	56.8%	106	82	78	392
Upper Palaeolithic	400	34.5%	400	0	0	0
Epipalaeolithic	101	8.7%	101	0	0	0
Total	1159	100%	607	82	78	392

2-3 Methods

In general, studies of lithic raw material sources, their roles in the landscape, and their relationships with archaeological sites and lithic artifacts fall into two main categories: macroscopic (large-scale) and microscopic (small-scale) analyses. The first approach involves visual and field observations, followed by a comparative assessment between the geological raw stone and the lithic artifact raw materials (Ghasidian & Heydari-Guran, 2018; Namen & Cuthbertson *et al.,* 2022). The second approach, in addition to the previous method, incorporates quantitative laboratory-based analyses such as textural studies (using 3D microscopes, thin section petrography), mineralogical analyses (X-ray diffraction, XRD), and geochemical analyses (inductively coupled plasma optical emission spectrometry, ICP-OES) performed on stone materials (Doronicheva *et al.,* 2023; Herrero-Alonso *et al.,* 2021; Namen & Iovita *et al.,* 2022; Namen & Schmidt *et al.,* 2022).

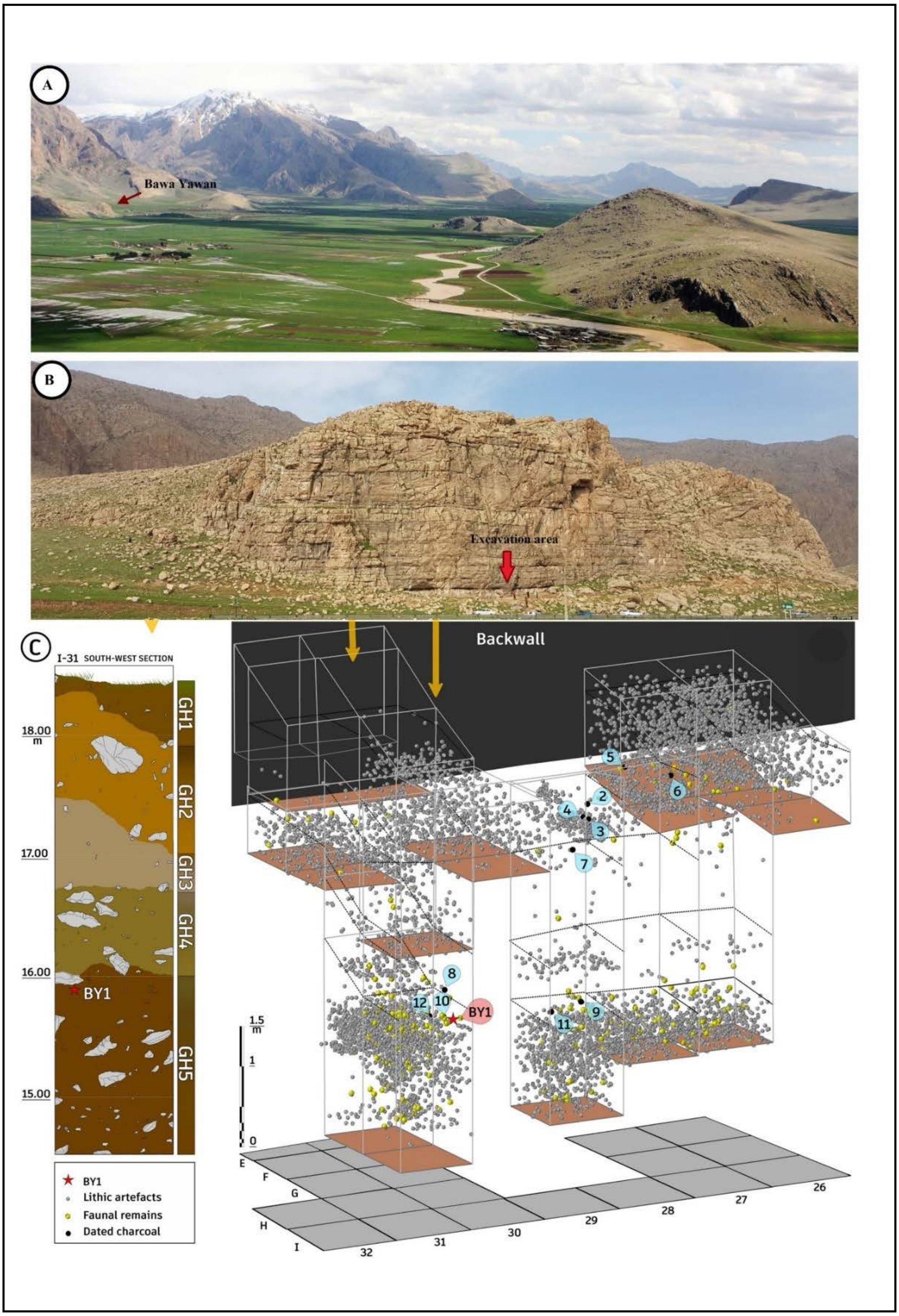

Fig. 2: A: Nawdarwan Valley; B: Bawa Yawan rockshelter; and C: Geological layers along with a three-dimensional model of lithics (Heydari-Guran & Benazzi *et al.,* 2021).

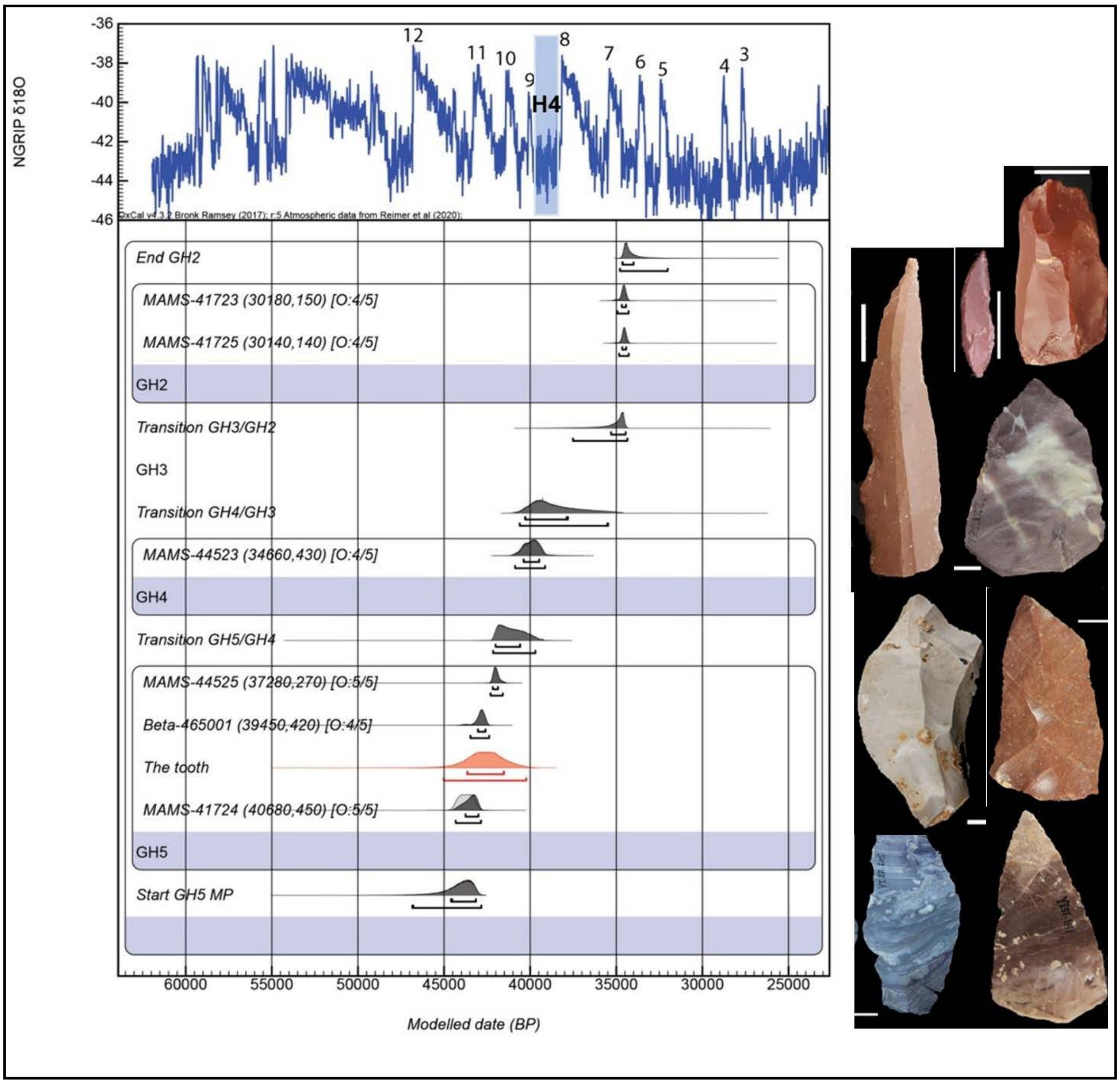

Fig. 3: Left side: Bayesian model of the dating of the Bawa Yawan rock shelter; Right side: Sequence and variety of Bawa Yawan lithics from the Middle Paleolithic to the Epipaleolithic (Heydari-Guran & Benazzi *et al.*, 2021).

In this research, we adopted the first approach (macroscopic study), using methodological references such as Delage (2007) and Suga et al., (2022), (Delage, 2007; Suga *et al.,* 2022). To this end, in addition to identifying the lithic raw material type for each artifact, we implemented three principal classifications for recording and documenting raw stone features in our database:

a) Textural grades: categorized as amorphous (non-granular), very fine-grained, fine-grained, medium-grained, coarse-grained, and very coarse-grained.

b) Luster Categories: vitreous (glassy), resinous, waxy, and dull.

c) Translucency Categories: transparent, highly translucent, moderately translucent, slightly translucent, and opaque.

For determining the internal and external colors of the stones, we employed the Munsell Color Chart specifically designed for rocks. Additionally, other characteristics such as the percentage of cortex and the degree of patination (low, medium, and high) were visually assessed and recorded.

4. Discussion

Preliminary macroscopic analyses of over one thousand single-find artifacts throughout the sedimentary sequence at Bawa Yawan Rockshelter indicate the utilization of three principal lithological groups: igneous, sedimentary, and metamorphic rocks (Fig. 4). Less than one percent of the lithic raw materials at Bawa Yawan consist of extrusive igneous rocks, specifically basalts, which were exclusively used during the Middle Paleolithic period (Fig. 4; Table 2). These basaltic materials most likely originate from the Sanandaj-Sirjan zone within the broader geological context of the region. Similarly, less than one percent of the lithic raw materials are metamorphic rocks, represented by phyllite (Fig. 4; Table 2), which were also only exploited during the Middle Paleolithic.

In stark contrast to the igneous and metamorphic rocks, siliceous sedimentary rocks constitute the overwhelming majority of the raw materials consumed at Bawa Yawan, accounting for approximately 99 percent of the total lithic assemblage. Clastic sedimentary rocks, including sandstones, mudstones, and siltstones, make up about 3.8 percent of all sedimentary stones used. Among these, sandstones (a single specimen from the Upper Paleolithic), as well as mudstones, were utilized during the Middle Paleolithic, whereas siltstones were exploited in both the Middle and Upper Paleolithic periods. None of these three types appear to have been used in the Epipaleolithic assemblage. Additionally, only a single sample of tuff classified as a pyroclastic sedimentary rock was recovered from the Middle Paleolithic layer (Fig. 4; Table 2).

Biogenic sedimentary rocks dominate the spectrum of consumed stones at Bawa Yawan, primarily comprising various grades of limestones and radiolarian cherts. The limestone category at this site includes multiple gradations of silicified limestone, marls, red pelagic limestones, and low to highly silicified carbonate rocks, collectively constituting nearly five percent of the studied assemblage (Fig. 4). Of these, only the highly silicified limestone appears across all three periods, while the remainder is exclusively found in the Middle Paleolithic (Fig. 4; Table 2).

Siliceous micro- to cryptocrystalline rocks, broadly termed “cherts,” encompass multiple subtypes with differing definitions in the literature. For the sake of methodological consistency and future sourcing studies, we grouped these under the overarching concept of “chert,” further subdividing them into categories such as radiolarian chert, chert nodules, flint, and chert-opal (Fig. 4). Approximately 92 percent of the lithic raw materials at Bawa Yawan fall within this extended chert group, with radiolarian chert being the most abundant and radiolarian-bearing siltstones the least.

Among the 907 pieces classified as radiolarian chert, 52 percent were exploited during the Middle Paleolithic, 38 percent during the Upper Paleolithic, and roughly 10 percent during the Epipaleolithic. Of the 37 radiolarian chert-siltstone artifacts, approximately 70 percent were used during the Middle Paleolithic, with the remaining 30 percent appearing in the Upper Paleolithic (Table 2).

In addition to a limited presence of pure opal, Bawa Yawan yielded materials representing transitional phases between radiolarian chert and opal, here categorized as “chert-opal.” We examined both opals and these transitional chert-opal varieties under the broader cryptocrystalline-microcrystalline category (Fig. 4). Among the 134 chert-opal artifacts, 67 percent date to the Middle Paleolithic, 28 percent to the Upper Paleolithic, and approximately 5 percent to the Epipaleolithic (Table 2).

Table 2: Consumption of various types of raw material stone in different periods of the Bawa Yawan Rockshelter (Authors, 2021).

Type	Count	%	MP Count	MP %	UP Count	UP %	EPI Count	EPI %
Radiolarite chert	907	78.1%	472	52.1%	348	38.3%	87	9.6%
Radiolarite-opal chert	134	11.5%	90	67.1%	38	28.3%	6	4.4%
Radiolarite-siltstone chert	37	3.1%	26	70.3%	11	29.7%	0	-
Highly silicified limestone	46	3.8%	36	80%	2	4.4%	6	13.3%
Moderately silicified limestone	9	0.8%	9	100%	0	-	0	-
Low silicified limestone	2	0.1%	2	100%	0	-	0	-
Limestone	7	0.6%	7	100%	0	-	0	-
Marl	3	0.2%	3	100%	0	-	0	-
Red pelagic limestone	1	0.1%	1	100%	0	-	0	-
Sandstone	4	0.3%	3	75%	1	25%	0	-
Mudstone	5	0.4%	5	100%	0	-	0	-
Basalt	2	0.1%	2	100%	0	-	0	-
Phyllite	1	0.1%	1	100%	0	-	0	-
Tuff	1	0.1%	1	100%	0	-	0	-
Total	1159	100%	658	-	400	-	101	-

5. Conclusion

The geological characteristics of any region have a profound impact on the way human groups utilized stone resources (Kato 2017; Namen & Cuthbertson *et al.,* 2022). In some instances, these characteristics may directly influence human settlement patterns or even dictate raw material procurement strategies. At times, constraints in primary raw material availability can paradoxically create opportunities by pushing beyond accessibility barriers due to anthropological factors (Slimak & Giraud 2007). Thus, understanding the geological substrate forms the essential first step in studies of lithic raw materials and provenance analysis, a topic we have addressed here. The well-known radiolarite geological belt of Kermanshah has long been recognized from both geological and archaeological perspectives (Broud, 1987; Braidwood *et al.,* 1961; Biglari, 2004; 2007; Heydari, 2004). Although research on lithic raw materials for post-Neolithic periods is somewhat better developed (Darabi, 2013; Nezafati & Hesari, 2017; Young & Smith, 1966), this topic has yet to be systematically examined in a diachronic manner at a single Paleolithic archaeological site.

Kermanshah is recognized as one of the principal centers of Paleolithic occupation in the Zagros. Consequently, various hypotheses have been proposed in Paleolithic studies regarding the raw material sources used for tool manufacture. In this regard, Dibble suggested that continuous use of limited local raw materials in Mousterian sites such as Warwasi rockshelter impacted the

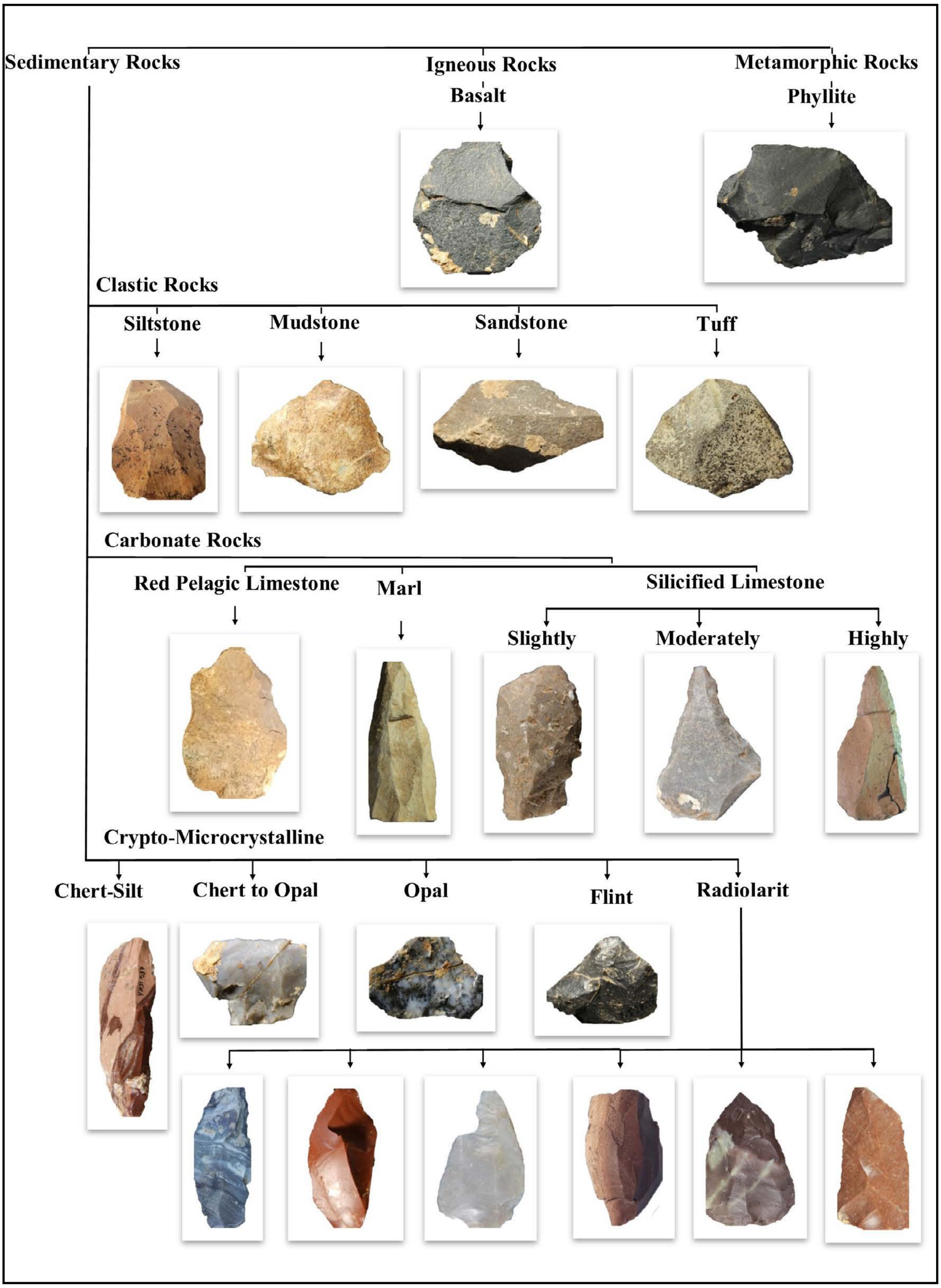

Fig. 4: A general overview of the variety of raw materials used throughout the Paleolithic sequence at the Bawa Yawan rockshelter (Authors, 2021).

typology of tools. He argued that the small size of available cobbles did not allow Neanderthal knappers to produce fresh flakes, thus leading them to repeatedly retouch pieces, which over time reduced the size of scrapers. Therefore, availability of raw materials should not always be assumed constant across repeated occupations of the same site (Dibble, 1991a; 1991b; Dibble & Holdaway, 1993).

Similarly, Biglari (2012) concluded that lithic raw materials used at the Middle Paleolithic site of Do-Ashkaft in Kermanshah were largely of local rather than regional origin, estimating a maximum procurement territory of less than 15 km around the site (Biglari, 2012). Shidrang and colleagues, based on their analysis of Mar Kheril cave (Donky cave), found that most raw materials across all stratigraphic layers were radiolarian chert, suggesting that Late Pleistocene occupants preferred high-quality radiolarian cherts from plains over the lower-quality local resources surrounding the site (Shidrang *et al.,* 2016).

More recently, other researchers (Adibzadeh & Vahedi-Nasab, 2016; Mokhtari *et al.,* 2022; Ghasrian & Mohammadi, 2017; Chehri & Vahedi-Nasab, 2020; Ghasrian *et al.,* 2017) based on surface collections from various Middle Paleolithic sites within the Kermanshah region, argued for the local use of raw materials and its role in shaping these Paleolithic sites.

Over the past decade, studies from the Lower Paleolithic through the Epipaleolithic in the Kermanshah region have increasingly addressed lithic raw materials (Heydari-Guran & Ghasidian, 2020). Heydari-Guran and Ghasidian (2020) proposed a broad-scale geographical zonation (zones A, B, C, D) for the Kermanshah area, identifying distinct raw material sources in each. Based on surface data, they argued for pronounced differences among these geo-zones in the west-central Zagros, with each likely maintaining independent lithic sources and suggesting that inter-zonal raw material transport did not occur during the Paleolithic (Heydari-Guran & Ghasidian, 2020).

This study investigated the diversity of lithic raw materials employed across the Middle Paleolithic, Upper Paleolithic, and Epipaleolithic periods at Bawa Yawan. Situated in the geological macrozone of the west-central Zagros, the area encompasses sedimentary formations including the Cretaceous limestone block of Bistun-Shahu, the Kermanshah radiolarite belt, and the folded zone. As a result, the overall raw material basket at Bawa Yawan, from a geological perspective across all periods, demonstrates over 99% reliance on sedimentary stones.

Broadly speaking, the raw material consumption patterns in the Middle Paleolithic layers at Bawa Yawan, inhabited by Neanderthal groups, can be divided into local and non-local categories. Earlier studies (Heydari, 2000; 2004; Biglari, 2004; 2007) have generally outlined raw material procurement in Paleolithic sites as follows: (1) high-quality layered radiolarites from plains, and (2) low-quality brecciated radiolarite-limestone exposures on the slopes of the Bistun-Shahu block (termed “radiolarite windows” by Jean Broud). Our observations indicate that such outcrops, either in situ or as colluvial fragments, exist within close proximity to Bawa Yawan. At this stage, precisely distinguishing Middle Paleolithic exploitation of these two sources (plain vs. mountainous) is not feasible; it is likely that these groups utilized both with varying emphasis. This combined pattern of using locally accessible low-quality sources along with distant high-quality ones shows notable parallels with other Paleolithic regions worldwide. In many other geographic contexts, local raw materials typically predominate (Dibble *et al.,* 2009; Gómez de Soler *et al.,* 2020; Matias, 2016; Mayor *et al.,* 2022; Suga *et al.,* 2022), with only minor proportions of high-quality stones transported over distances exceeding 50 km (Karkazi *et al.,* 2024; Brandl *et al.,* 2011; Cieśla, 2018; Doronicheva *et al.,* 2023; Slimak & Giraud, 2007; Turq *et al.*, 2017).

It appears that in some communities, Neanderthals employed low-quality local stones for expedient, non-formalized tools, reserving high-quality and rarer raw materials likely procured from beyond their immediate subsistence territory for standardized or functional tools (Bringmans, 2024). Such patterns are observed, for example, at Qasem Cave in the Levant (Agam, 2020). Certain high-quality materials may also have been carried as part of personal toolkits, as evidenced in Epipaleolithic sites of Neshar Ramla in the Levant (Ekshtain & Zaidner, 2022). The deliberate selection of high-quality stone for manufacturing specialized implements like Quina scrapers procured from distant sources has also been documented in Dordogne, France (Hiscock *et al.,* 2009), and Waldozelt-Hezerwater, Belgium (Bringmans, 2024).

Based on several models (Uerpmann, 1996; Heydari-Guran, 2014; Doronicheva *et al.,* 2023), procurement zones have been categorized as local (<30 km), non-local (30–100 km), regional (100–250 km), and supra-regional (>250 km). Applying this framework, we would classify the plain radiolarite sources as non-local and the mountainous outcrops as local relative to Bawa Yawan. Our observations place the nearest part of the radiolarite belt (Galali) at about 20 km, and Gakia at roughly 40 km from Bawa Yawan.

At this phase of research, a noteworthy point is the high diversity of lithic raw materials utilized by Neanderthal groups, indicating no narrow dependence on a few sources. This aligns with an opportunistic procurement model regardless of raw material quality or acquisition via exchange or cobble transport suggesting Neanderthals at Bawa Yawan exploited all available stone types to meet their needs. The opportunistic model emphasizes availability and quick access to raw materials within the residential landscape (Delpiano *et al.,* 2018).

Our preliminary observations also indicate that for manufacturing certain specialized tools, such as Levallois points and Mousterian convergent scrapers, Neanderthal groups appear to have practiced selective raw material choice a topic that warrants further investigation (Hariri & Heydari-Guran, in preparation).

During the Upper Paleolithic at Bawa Yawan, three main categories of stone radiolarite chert, radiolarite-opal chert, and radiolarite-silt chert exhibit relatively similar patterns of use. However, there is a notable absence of diverse stones such as marl, tuff, basalt, and phyllite (see: Table 2). As a result, the variety of raw materials in the Upper Paleolithic becomes more limited compared to the Middle Paleolithic, while simultaneously demonstrating a certain organizational pattern. The most striking difference in this period relative to the Middle Paleolithic lies in the management of high-quality raw material resources and a reduced use of low-quality local stones. It appears that anatomically modern humans increasingly targeted more distant sources than their

Middle Paleolithic predecessors. However, the precise extent of the procurement range for raw materials in the study area remains to be fully established.

Analysis of Bawa Yawan's Upper Paleolithic assemblages compared to global examples reveals similar dynamics. Extensive studies by Parow-Souchon & Purschwitz (2020) on Upper Paleolithic raw material procurement in the southern Levant show a narrower spectrum of stone types and highly targeted, direct acquisition from source outcrops. A comparable situation is noted in northern and northeastern China, where modern humans traversed distances of approximately 300 to 450 km to obtain high-quality raw materials (Kato, 2017).

The Epipaleolithic lithic assemblage at Bawa Yawan is much smaller than the preceding periods, primarily due to the limited excavation area and thinner stratigraphic deposits. Nevertheless, in terms of raw material quality, despite following a similar trend to the Upper Paleolithic, this period reveals an increased ability to identify and discriminate high-quality sources. The discovery of several lithic artefacts from this layer made of the same stone type, suitable for refitting (highly silicified limestone), suggests that initial core reduction and cortex removal took place at the raw material source itself, with the partially prepared blocks then transported to the site. This economic behavior is not evident in earlier periods.

Given the absence of nearby high-quality sources comparable to the Kermanshah radiolarite belt, and the very low proportion of cortex-bearing tools relative to fully decorticated ones, it implies that the early stages of decortication occurred away from the site and that finished or semi-finished tools were brought to Bawa Yawan. Consequently, Bawa Yawan appears to have functioned both as a residential rockshelter and as a major butchering station, extensively used by both Neanderthal and modern human groups, who sourced their raw materials both locally and from extra-local regions such as the Kermanshah radiolarite belt.

What stands out is the aspect of conscious selection differing between these two hominin groups. It seems that anatomically modern humans achieved a higher level of deliberate selection. Although Neanderthals also had access to these sources, their procurement strategies leaned more toward opportunistic use. Therefore, the scarcity of primary cortex among the lithic assemblage partially answers the question: was collecting and extracting raw material easy or difficult? In reality, it could be both depending on human choices. As previously discussed, both primary (radiolarite belt) and secondary (hill slopes, margins, and the bed of the Razavar River in the Nawdarwan vally) sources of both high and low quality, available as small to large cobbles, were within reach.

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Authors' Contribution

Dr. Nemat Hariri (corresponding author) conceptualized the research, designed the methodological framework, conducted the macroscopic analyses of lithic artifacts, and prepared the database. Dr. Mohsen Ranjbaran supervised and guided the identification and characterization of lithic raw materials. Dr. Elham Ghasidian critically reviewed and enriched the Persian manuscript and conducted the initial techno-typological classification of the lithic assemblage.

Dr. Saman Heydari-Guran reviewed and enhanced the manuscript and led the archaeological excavations at Bawa Yawan. All authors contributed to the discussion, reviewed the final manuscript, and approved its submission.

Conflict of Interest

Authors declared no conflict of interest.

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چکیده

مجموعهٔ غار و پناهگاه صخره‌ای باوه‌یوان به‌عنوان یکی از محوطه‌های شاخص پارینه‌سنگی در غرب ایران، دارای سه دورهٔ پارینه‌سنگی میانی، نوین و فراپارینه‌سنگی است؛ این محوطه دارای طیف وسیعی از انواع دست‌افزارسنگی بوده که توسط جوامع شکارورز-گردآورنده در هر سه دورهٔ یادشده و به‌طور مشخص توسط دو زیر گونهٔ انسانی نئاندرتال و هوشمند در بازهٔ زمانی تقریبی بین ۸۰ تا ۱۳٫۴هزار سال پیش‌ازحال استفاده شده است. در این پژوهش ما نتایج اولیهٔ سنجش کلان‌نمایی (ماکروسکوپی) مجموعه‌ای تقریباً هزار قطعه‌ای را ارائه می‌دهیم. نتایج پژوهش حاکی از این است که در طول زمان، استفاده از مواد خام سنگی دست‌خوش تغییر می‌شود به این ترتیب که جوامع پارینه‌سنگی‌میانی از طیف متنوع‌تر موادخام‌سنگی استفاده کرده‌اند، اما در جوامع پارینه‌سنگی‌نوین و فراپارینه‌سنگی به‌تدریج شاهد راهبرد استحصال مواد خام‌سنگی انتخاب‌گرایانه که بازتاب آن منابع محدودتر و با کیفیت‌تری هستیم. این دست‌آورد نشان از رفتارهای متنوع انسانی از دورهٔ پارینه‌سنگی‌میانی تا فراپارینه‌سنگی منطقهٔ مطالعاتی دارد. هم‌چنین بیش از ۹۹٪ از سنگ‌های خام مصرفی توسط جوامع پارینه‌سنگی از انواع سنگ‌های کریپتو-میکروکریستالی رسوبی است که در محیط زمین‌شناسی اطراف باوه‌یوان وجود دارند و کمتر از ۱٪ سنگ‌های استفاده شده از سایر انواع سنگ‌های آذرین و دگرگونی است.

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