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Obsidian use during the Palaeolithic in the Armenian Highlands

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1. Introduction

In Southwest Asia, especially the Anatolian and Iranian Plateaus, Mesopotamian Lowlands, and Levantine Highlands (Fig. 1), the use and distribution of obsidian is frequently associated with the Neolithic Period, that is, the time during which agriculture and urbanism first emerged and spread between about 12 and 6 thousand years ago (ka). Moreover, obsidian has also been associated with the "Neolithic Revolution" (a term coined by archaeologist V. Gordon Childe in the 1930s) and the process of "Neolithization," in which Neolithic modes of subsistence and settlement proliferated to and were adopted by a population, whether in the ancient Near East (e.g., Binder 2002, Reingruber 2011, Carter et al. 2013, Ibáñez et al. 2015, Atici et al. 2017) or elsewhere (e.g., Zilhão 2014, Nicod et al. 2019). It has even been suggested that obsidian use is one component of the so-called "Neolithic Package," along with farming, settlements, pottery, and other roughly contemporaneous technical and social innovations (e.g., Whitehouse 1986, Çilingiroğlu 2005, Özdoğan 2014).

There are reasons that Near Eastern archaeologists have made this association and viewed obsidian as an aspect of the Neolithic. Consider, for example, one of the most famous Neolithic sites in this region. Çatalhöyük, located in the Kona Plain of the Anatolian Plateau and inhabited between 9.5 and 7 ka, has long been considered a key settlement for elucidating societal progression toward settled farming and early urbanism. Despite being more than 180 km from the volcanic sources, the

Çatalhöyük lithic assemblage is primarily obsidian, even as high as 98% in some stratigraphic units (Carter et al. 2006). From 1995 to 1999, the excavators recovered nearly 63,000 obsidian artifacts, corresponding to 97.2% of all the recovered lithics (Carter et al. 2006). Such quantities of obsidian led the site's original excavator, James Mellaart (1967), to suggest that the settlement largely arose and grew by controlling access to obsidian. Furthermore, Renfrew and colleagues (e.g., Renfrew et al. 1966, 1968; Dixon et al. 1968; Cann et al. 1969) developed obsidian sourcing in the Near East to investigate Neolithization. Transport of obsidian from village to village, they proposed, might have paralleled the expansion of agriculture, and their pioneering work revealed an unanticipated degree of regional interconnectivity between Neolithic sites in the Fertile Crescent.

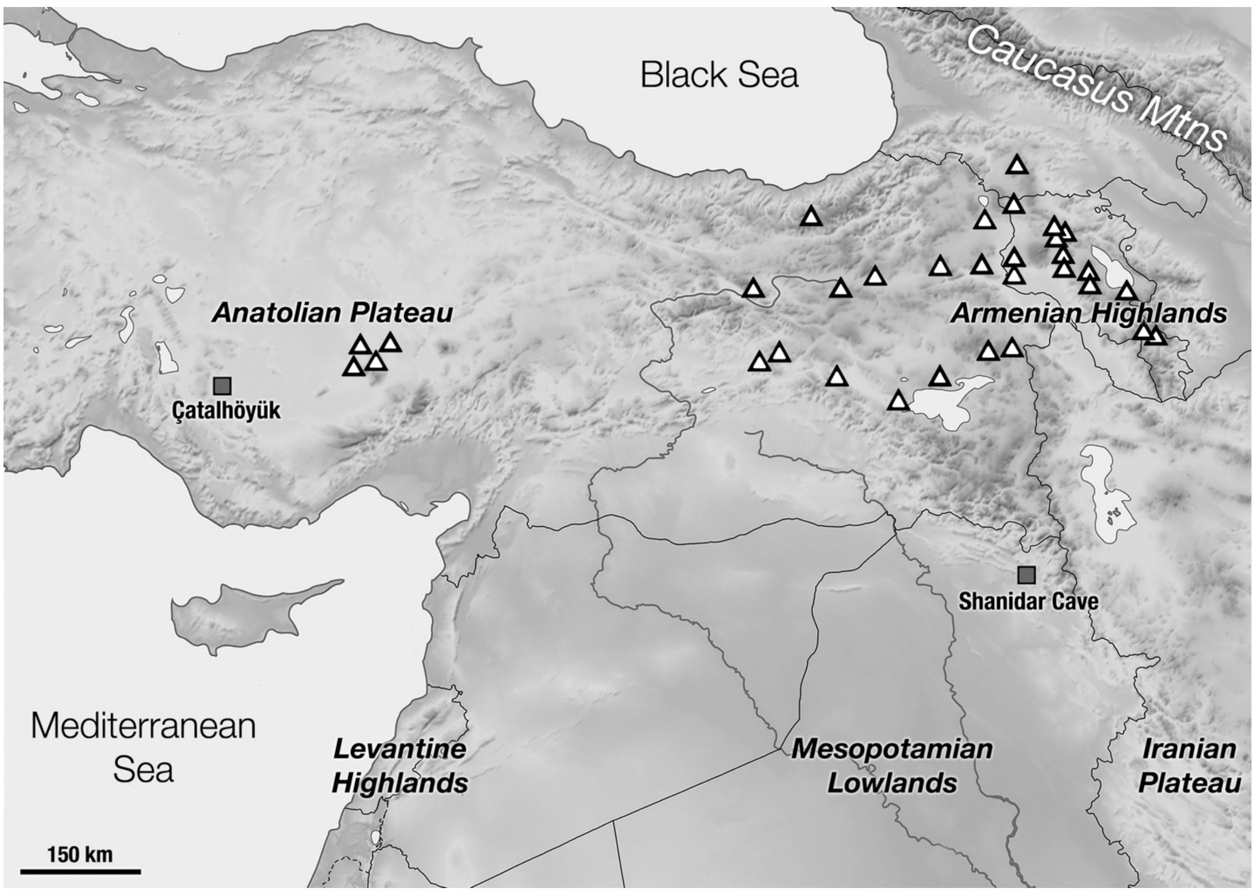

Figure 1. Map showing the location of the Armenian Highlands relative to the Anatolian and Iranian Plateaus, Levantine Highlands, and Mesopotamian Lowlands. Locations of the obsidian sources are denoted by white triangles, and archaeological sites mentioned in the text are denoted by the grey squares. Topography based on the public-domain digital elevation data from SRTM3 (Shuttle Radar Topography Mission dataset version 3).

Notions about the Palaeolithic exploitation of obsidian throughout the Near East have, until recently, principally derived from the regions on which Renfrew and colleagues focused. The most prominent example is Shanidar Cave in Iraq (Figure 1). It is most widely known for its Neanderthal skeletons, some of which appear to have been deliberately buried, in its Middle Palaeolithic Level D (Pomeroy et al. 2020 and references within). Small obsidian flakes, found in its Upper Palaeolithic Level C by Solecki (1963), are frequently cited as one of the earliest instances of obsidian use and transport outside of Africa. For example, in their seminal article, Renfrew et al. (1966:40) claimed: "The earliest stratified finds of obsidian in the Near East are from Layer C of the Shanidar Cave. The Upper Palaeolithic (Baradostian) industry there represented (Solecki 1963) is about 30,000 years old." Four decades later, Rapp (2009:85) wrote: "Obsidian was utilized at least as far back as Upper Paleolithic times in the Near East. It was found in Level C of the Shanidar Cave in Iraq and dated to approximately 30,000 BP" (also Rapp and Hill 2009:209). Similarly, Barge et al. (2018) list Shanidar Cave as the only obsidian-bearing site before the Last Glacial Maximum. Consequently, the use and transport of obsidian, other than what Renfrew et al. (1966:41) called "Upper Palaeolithic obsidian traffic from Armenia," was widely regarded as a rarity prior to the Neolithic. These studies, though, did not actually include modern Armenia and its surrounding regions.

The biogeographic region that encompasses the modern countries of Armenia, Georgia, and Azerbaijan as well as portions of northeastern Turkey and northwestern Iran has been described by a number of different terms, including the Southern Caucasus, Lesser Caucasus, and Transcaucasia, among others. Here we discuss this region as the Armenian Highlands, an upland zone bounded by equivalent geographic areas (i.e., the Anatolian and Iranian Plateaus, Mesopotamian Lowlands, and Caucasus Range; Fig. 1) rather than political borders. This region holds importance with respect to Palaeolithic exploitation of obsidian for two reasons. First, the Armenian Highlands has periodically been volcanically active since the collision of the Arabian and Eurasian tectonic plates during the Miocene era (Sherriff et al. 2019). Inside the borders of Armenia alone, more than 500 Quaternary (Pleistocene and Holocene) volcanic centers have been mapped (Weller et al. 2006). Several of the volcanic phases led to the eruption of obsidian-bearing felsic lavas (Karapetian et al. 2001, Sherriff et al. 2019). The oldest dated obsidian sources in the Armenian Highlands are more than 4 million years (Ma) old (i.e., the Tsaghkunyats sources; Chataigner et al. 2003).

Second, the Armenian Highlands (with the rest of the Near East and the Arabian Peninsula) was a dispersal corridor for hominin expansions out of Africa and into Eurasia (and back) during the Pleistocene epoch (Sherriff et al. 2019). The earliest known fossils of the genus *Homo* outside Africa were discovered at Dmanisi in Georgia (Lordkipanidze et al. 2007, Tappen et al. 2007). The fossils, including a series of five skulls, have been debatably attributed to various taxa since their discovery (e.g., *Homo erectus*, *ergaster*, or *georgicus*), whereas the dates are less ambiguous: circa 1.85 to 1.78 Ma (Ferring et al. 2011; Lordkipanidze et al. 2013). Although Dmanisi is ~30 km from the nearest obsidian source (i.e., the Chikiani or Paravani Lake source; >2.4 Ma, Chataigner et al. 2003), none of more than 8000 lithic artifacts have been reported to be obsidian. Instead, the lithic materials at Dmanisi – principally basalt, andesite, and volcanic tuff – are available nearby from outcrops or as cobbles in river beds (Baena et al. 2010). It is known that hominins during this time routinely used obsidian when locally available (e.g., at Melka Kunture, Ethiopia, ~1.7 Ma, ~7 km from the source; Piperno et al. 2009, Gallotti and Mussi 2015). Therefore, it is reasonable to expect that the Dmanisi hominins would have used obsidian when they were closer to a source.

Prior to 1991, much of the Armenian Highlands fell inside the borders of the Soviet Union, creating boundaries within archaeological scholarship as well. Knowledge of Palaeolithic obsidian use in the Western literature has been shaped by the fact that, throughout the Cold War, the most obsidian-rich region of the Greater Near East lay within Soviet territory and, as a consequence, was excluded from regional studies and syntheses by Western archaeologists. During this time, Soviet-era archaeologists identified a number of Palaeolithic sites across the Armenian Highlands (Section 3), but most of the findings were published only in Russian or regional journals. Therefore, among Western archaeologists, reports of Palaeolithic obsidian artifacts found in the Armenian Highlands were scarce and often fragmentary, such as surface finds mentioned by Kökten (1952) in the Kars Province of northeastern Turkey. On occasion, stratified sites such as Lusakert Cave-1 and Yerevan Cave-1, excavated in the 1960s under the direction of Armenian archaeologist B. G. Yeritsyan, came to the attention of Western scholars a decade or two later (e.g., Gábori 1976; Lyubin 1977, 1989). It was often overlooked or unappreciated, however, that the Middle Palaeolithic lithic assemblages of these sites – many thousands of artifacts from each – were *entirely* obsidian.

In the following sections, we briefly discuss those obsidian sources most frequently utilized during the Palaeolithic in the Armenian Highlands and some of the surrounding issues (Section 2), we summarize some of the most important Palaeolithic surveys and excavations conducted during the Soviet era (Section 3), we consider the issue of lithic transport distances from the Lower to the Upper Palaeolithic during obsidian datasets from a series of recently excavated sites (Section 4), and we highlight how the large, complex obsidian sources of the Armenian Highlands offer the potential for novel insights into other early and modern hominin behaviors (Section 5).

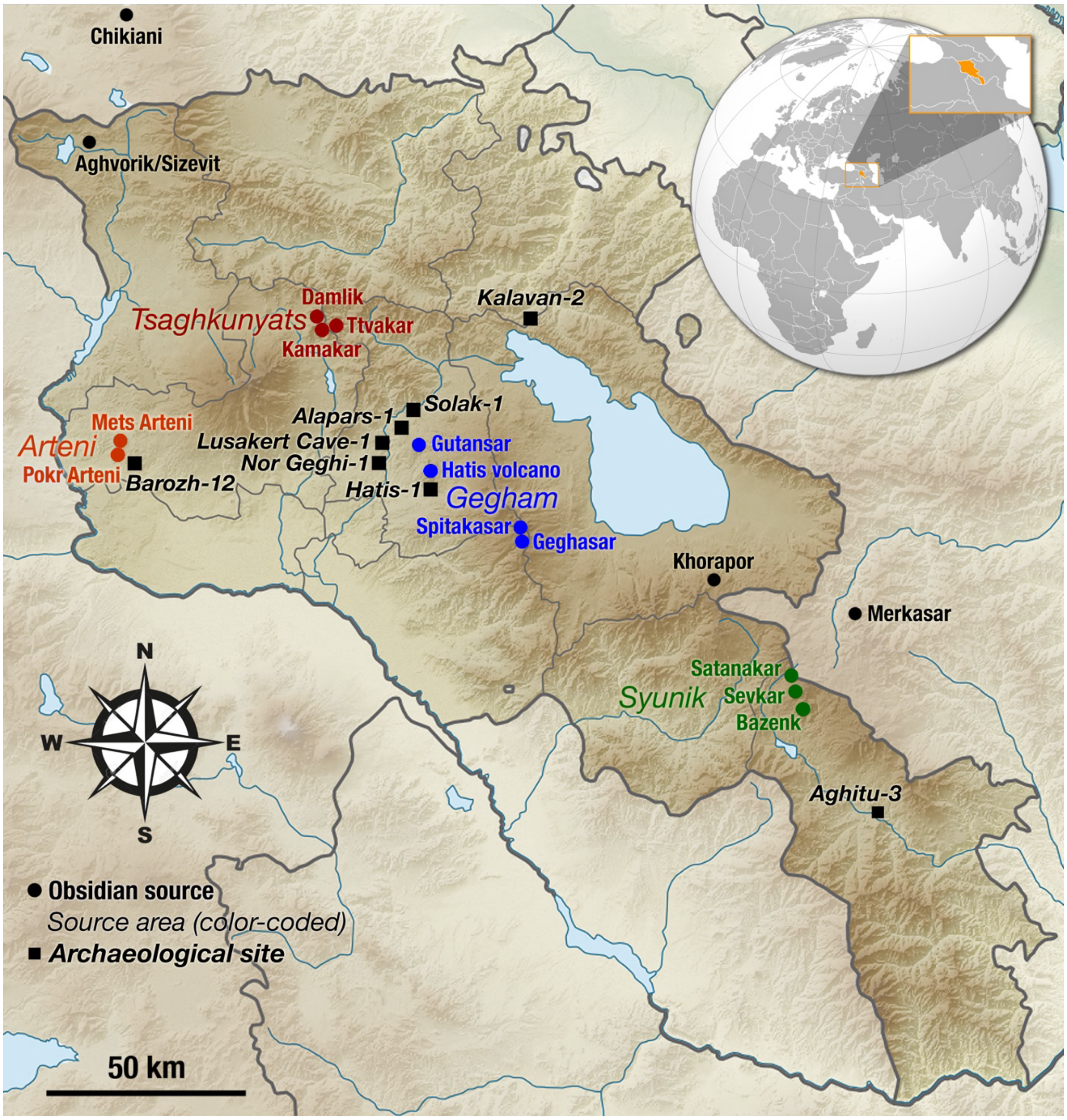

Figure 2. Obsidian sources (round dots) and source complexes/areas (color-coded labels) as well as archaeological sites mentioned in the text (black squares). Topography based on the public-domain digital elevation data from SRTM3.

2. Geological sources of obsidian

More than two dozen chemically distinctive obsidians occur in the Armenian Highlands, and a majority of their volcanic sources lie within the borders of Armenia (Figure 2). These sources are not as well studied as those in, for example, central Turkey or the Aegean. Consequently, discussing and documenting all of the obsidian sources within the Armenian Highlands is beyond the scope of this chapter, especially since some obsidian sources are of higher relevance to the Palaeolithic than others. For example, obsidian from the Khorapor source in eastern Armenia is so poor in quality and low in accessibility, according to Badalyan et al. (2004), that there is not even flaking debris to be found on its slopes. Other minor obsidian sources were exploited only in the immediate vicinity. For example, obsidian from Kel'bedzhar (also known as Kalbajar, Kechel Dağ, or Merkasar) has been noted only at nearby Zar Cave, a purportedly Upper Palaeolithic site that was excavated in the 1980s (Badalyan et al. 2004). Hence, we focus here on the main obsidian sources represented among sourced Palaeolithic artifacts.

It must also be kept in mind that Palaeolithic sites, especially those of considerable age, can predate certain obsidian sources. The Lower Palaeolithic site of Nor Geghi-1 (circa 310–440 ka by $^{40}Ar/^{39}Ar$ dating; Adler et al. 2014) does not – and cannot – have obsidian artifacts that derive from Geghasar volcano since its obsidian is too young (fission-track dated to 42–82 ka; Badalian et al. 2001, Chataigner et al. 2003). This issue is complicated by the uncertainties in dating of obsidian sources throughout the region. Most of the obsidian sources have only been dated by the fission track method; however, direct comparisons to $^{40}K/^{40}Ar$ and $^{40}Ar/^{39}Ar$ dates have shown that such dates are underestimates. For example, obsidian from Gutansar yielded a fission-track date of ~330 ka and a $^{40}K/^{40}Ar$ date of ~550 ka (Komarov et al. 1972). The same study produced a fission-track age of ~330 ka and a $^{40}K/^{40}Ar$ age of ~650 ka for Hatis obsidian (Komarov et al. 1972). Later geochronological studies of Hatis obsidian reported a fission-track date of 320 ± 90 ka (Badalian et al. 2001) and a $^{40}K/^{40}Ar$ date of 480 ± 40 ka (Arutyunyan et al. 2007). Accordingly, the timing of the Armenian Highlands obsidian sources is currently open to interpretation.

A related issue is the existence of unknown and hidden obsidian sources. Artifacts without currently known obsidian sources have been reported from various Palaeolithic sites (e.g., Ortvale Klde, Le Bourdonnec et al. 2012; Aghitu-3, Frahm et al. 2019; Barozh-12, Glauberman et al. 2020b), which indicates that undiscovered sources still exist. Given the volcanic and tectonic activity in the Armenian Highlights, there likely are obsidian sources which are buried and no longer accessible at or near the surface. Consider the vastly different ages of obsidian-producing rhyolitic volcanism in this region, from 4.3–4.6 Ma for the Tsaghkunyats sources to 42–82 ka for Geghasar, a mere 60 km away (fission-track dating in Badalian et al. 2001). For an obsidian source millions of years old, the shifts in landscape since its formation would be considerable. In fact, an unknown obsidian source, given the name Ptghni, has been recognized only by small obsidian pebbles within a sediment layer that was subsequently buried beneath lava flows (Frahm et al. 2017). That volcanic source must be somewhere upstream, but its precise location remains a mystery. Its existence, though, attests to a phase of rhyolitic volcanism within this region that is poorly understood. The challenge is clear: as we find older and older Palaeolithic sites, it becomes more and more likely that we will encounter obsidian artifacts about whose volcanic origins we know little or nothing.

Although Armenia is the geographical center of obsidian-creating rhyolitic volcanism within the region, a few important obsidian sources lie outside its borders. Just a single obsidian source is known in Georgia: the aforementioned Chikiani ("glass that glistens" in Georgian) or Paravani Lake source (also occasionally known as Kojun Dağ; Badalyan et al. 2004). Obsidian is accessible on the northern slope of the lava dome, which seems to be somewhat zoned such that there are outliers to its main composition, and pebbles of its obsidian occur along the banks of the nearby Khrami River (Le Bourdonnec et al. 2012). Badalyan et al. (2004) only report Chikiani obsidian at Early Neolithic through Iron Age sites; however, it has since been identified at Palaeolithic sites within the Imereti region of Georgia (e.g., Ortvale Klde and Bondi Cave, Le Bourdonnec et al. 2012).

Obsidian sources in northeastern Turkey, to the north of Lake Van, have not been surveyed or studied nearly as well as those in central Turkey, and reliable geological information about them is rare. Furthermore, it is possible that there are obsidian sources yet to be discovered in the region. Such problems date back to the original work by Renfrew and colleagues, who analyzed a museum specimen labelled "Kars" after the Erzurum-Kars Plateau, a broad volcanic field across northeastern Turkey rather than a specific source. The entire Kars Province seems to have abundant Pleistocene tuffs and pyroclastic deposits that can contain obsidian. Obsidian is known from multiple localities, including Kars-Digor, Kars-Akbaba Dağ, and Kars-Arpaçay, and there are at least two sources in the Sarıkamış district (Frahm 2010; Chataigner et al. 2013). Some of these sources have been identified in low numbers among obsidian artifacts from Neolithic (e.g., Aratashen) and later sites (Chataigner and Gratuze 2014), and corresponding artifacts quite rarely been reported from Palaeolithic sites (e.g., just one Kars-Digor 1 artifact at Kalavan-2; Malinsky-Buller et al. 2021).

The most important obsidian sources in Armenia fall into a few main clusters, as illustrated in Figure 2: the Arteni, Tsaghkunyats, Gegham, and Syunik source areas. As discussed in Sections 3 and 4, several of these areas were – and still are – a focus of archaeological surveys for Palaeolithic sites. The Arteni volcanic complex has two eruptive centers, known as Mets ("Big") Arteni and Pokr ("Little") Arteni, both of which yielded high-quality obsidian and large perlite deposits (Karapetian et al. 2001). Based on sourcing studies at Neolithic and later sites (e.g., Badalyan et al. 2004, 2007, 2010; Cherry et al. 2010; Chataigner and Gratuze 2014), Arteni was one of the most utilized source complexes in the Armenian Highlands, and this holds true back into the Palaeolithic as well. Three primary sources of obsidian – Ttvakar, Damlik, and Kamakar – are known within the Tsaghkunyats mountains. These are the oldest known sources in the Armenian Highlands, and as such, millimeter-scale obsidian pebbles from these sources can be found in alluvial-fluvial sedimentary deposits in the Ararat Depression where their fragments occasionally became incorporated into ceramics as a tempering agent (Palumbi et al. 2014). The Gegham mountain range sources are often divided into the northern (Gutansar and Hatis) and southern (Geghasar and Spitakasar) sources. In Section 5, we discuss Gutansar and Hatis volcanoes, where we have conducted extensive and detailed surveys . The outcrops of Geghasar and Spitakasar obsidian lie at high altitudes and are challenging to access, so these are the least studied of the major sources. The Syunik range has three chemically distinct sources: Sevkar, Satanakar, and Bazenk. While Bazenk is small and seems to have been very rarely exploited in the past, Sevkar and Satanakar are important sources. Large, cortex-free blocks are readily accessible at the primary outcrops, whereas rounded, cortex-covered cobbles in gullies and valleys decrease in size with distance (Frahm et al. 2019). The flaking quality of obsidian from all of the major sources (i.e., Arteni, Tsaghkunyats, Gegham, Syunik) is excellent, so there are no pressures or limitations exerted on the lithic technology by these different volcanoes.

3. Soviet-era discoveries

As discussed in the Introduction, geopolitical borders and tensions during the Cold War led to the near exclusion of the Armenian Highlands from the Western archaeological literature. During this time, however, Soviet-era archaeologists identified Lower, Middle, and Upper Palaeolithic finds and sites in the Armenian Highlands, many concentrated in certain locales. Given that most of these discoveries were published in Russian or regional journals, it is worth noting some of the obsidian-related finds for a readership principally familiar with the Western literature.

Lower Palaeolithic

Through the 1980s, many reports of Lower Palaeolithic artifacts in the Armenian Highlands reflected lithic scatters either near, immediately adjacent to, or even directly atop obsidian sources, without secure or datable stratigraphic contexts (e.g., Panichkina 1950, Zamyatnin 1950, Sardaryan 1954, *inter alia*), whereas surveys intended to locate stratified Lower Palaeolithic sites were largely fruitless (e.g., Panichkina 1950, Klein 1966, Ghazaryan 1986). In turn, this led to an impression that obsidian was principally used during Lower Palaeolithic only near its sources. In addition, over the decades, surface finds have included artifacts bearing some degree of resemblance to Oldowan-type choppers, but none have been reported to be obsidian. Even without contexts or a means to reliably date them, such artifacts were taken as evidence that obsidian was rarely used to create stone tools during this lithic technological phase within the Armenian Highlands.

During the 1940s, archaeological surveys near the major obsidian sources – Gutansar, Hatis, and the Arteni sources – discovered numerous lithic scatters, some of which included obsidian tools (e.g., hand axes, coarse choppers, Clactonian flakes) interpreted as Oldowan and Acheulian in type and age (e.g., Zamyatnin 1947, Panichkina 1950, Sardaryan 1954). The most famous of such surface scatters is Satani-Dar, which was long regarded as the earliest archaeological site within the Soviet Union (Panichkina 1950, Sardaryan 1954, Klein 1966). Located directly on the Mets Arteni source, however, Satani-Dar is wide open to alternative interpretations, such as it being the long palimpsest of obsidian quarrying and initial shaping over many millennia. Klein (1966), for instance, put forth the compelling argument that the purported "choppers" are instead cores.

In the 1950s and 1960s, Lyubin (1961, 1965, *inter alia*) continued surveys around Gutansar and the Arteni sources, and he described a number of Lower Palaeolithic finds in those areas (e.g., near Kaghsi and Talin villages, respectively). On Gutansar's slopes, he reported what he considered to be open-air Acheulo-Mousterian sites (e.g., Jraber I–X, Kyondarasi I–IV; Lyubin 1961, 1984), and based on his studies of those materials, he concluded that such sites, which lie near or even directly atop the obsidian outcrops, reflect short- or long-term blank-production workshops (Lyubin 1965, 1978). As with Satani-Dar, however, such an interpretation is open to reassessment. In the 1970s, limited excavations in caves along the Hrazdan River (e.g., Hamo-1) and at open-air sites along the river (e.g., Argel-1 and -2) uncovered obsidian artifacts regarded as Lower Palaeolithic in type and, consequently, in age (e.g., Azizyan 1979, 1982; Azizyan and Lyubin 1983).

Middle Palaeolithic

Archaeological surveys conducted during the 1940s by Sardaryan and Panichkina through the Hrazdan basin (near Gutansar and Hatis) and the surroundings of the Arteni obsidian sources recorded a multitude of open-air sites in the vicinity of the outcrops. Among more than a thousand obsidian artifacts they collected, Sardaryan (1954) and Panichkina (1950) identified Levallois and discoidal cores, discoidal tools, Levallois and Mousterian points, and various other lithic types that they attributed to the Middle Palaeolithic. Both archaeologists suggested that these two areas were crucial locations for Middle Palaeolithic sites, inside abundant caves and beneath the extensive lava flows, where Nor Geghi-1 was later found (Panichkina 1950; Sardaryan 1954).

In the 1950s and 1960s, surveys throughout Armenia identified various Middle Palaeolithic artifacts and sites. For example, there were surface finds of Mousterian obsidian artifacts on the slopes of the Arteni sources (Lyubin and Balyan 1961), within the Aparan Depression (Petrosyants

1988), and elsewhere in the region. From 1967 to 1968, Martirosyan (1968, 1969, 1970, 1974) led the Expedition for the Study of Stone Age Sites in Armenia, which conducted extensive surveys and documented numerous archaeological locales, spanning from Middle Palaeolithic caves to Iron Age fortresses. Among those discoveries were the aforementioned Yerevan Cave-1 and Lusakert Cave-1. The former site has yet to be fully published and lacks a detailed chronological framework, whereas the latter site has been a focus of recent re-excavation and obsidian sourcing.

Upper Palaeolithic

As with the early reports of Lower and Middle Palaeolithic artifacts, those attributed to the Upper Palaeolithic mostly came from unsecure contexts and were typically surface finds without a possibility of dating. Panichkina (1948, 1950) reported the first Upper Paleolithic artifacts, which were surface scatters that she encountered during surveys along the Hrazdan. Her attribution of the scatters to the late Upper Palaeolithic was based on techno-typologies (e.g., blades and blade cores, end and carinated scrapers, burins) and comparisons to other sites in the Near East. Concurrently, Sardaryan (1954, 1967) also surveyed the Hrazdan and Arteni areas near obsidian sources, and he located similar surface scatters (e.g., Arzni, Areguni Blur, Yerkaruk Blur), yielding more than 1700 lithic artifacts that he sorted typologically into the Aurignacian, Solutrean, and Magdalenian. Other archaeologists reported supposedly Upper Palaeolithic artifacts from the Hrazdan region, but their publications frequently lack in descriptions of the sites and even of the lithic finds themselves (e.g., Tadevosyan 1986, Yeritsyan et al. 1996). Later studies of the sites found by Panichkina, Sardaryan, and others instead suggest that they are instead probably Neolithic and/or Chalcolithic workshops for initial obsidian processing near the sources (Gasparyan et al. 2014). In contrast, Yeritsyan (1970) excavated the open-air site of Hatsut-1 within the Gugarats Range in northern Armenia, and given its location on a former river terrace, it is perhaps the only site among these early studies that can be attributed with some degree of confidence to the Upper Palaeolithic. Again, however, there was no chronometric dating of this site, where chert was used more than obsidian.

Generally, though, outside the Imereti area of Georgia (e.g., sites such as Ortvale Klde; Adler and Tushabramishvili 2004; Adler et al. 2006, 2008), the Upper Palaeolithic did not receive as much attention as elsewhere in the Near East (e.g., the “Zarzian” cultural complex within the Levant and Mesopotamia) or in the Northern Caucasus (e.g., the “Gubs” culture; Bader 1984). This, in turn, led Soviet archaeologists to suggest that the Armenian Highlands were largely uninhabited during this time, especially during the cooler climatic phases (e.g., Bader 1984, Lyubin 1989). Such views have since been overturned (or at least undermined) by additional discoveries of Upper Palaeolithic and

Epipalaeolithic deposits (e.g., Hovk 1–3; Pinhasi et al. 2008; Aghitu-3 cave, Kandel et al. 2011, 2014, 2017; Kalavan-1, Montoya et al. 2013; Solak-1, Adler et al., forthcoming).

4. Considering a specific issue with recent data

Rather than simply listing the Palaeolithic sites where obsidian has been either reported or scientifically sourced, it is more satisfying, we think, to consider a particular research question here and discuss recent obsidian sourcing results within that framework.

4.1. The issue of lithic transport distances

Transport of lithic artifacts across greater distances during the Upper Palaeolithic, relative to the Middle Palaeolithic, was observed by archaeologists investigating chert assemblages from sites in the Périgord region of France (e.g., Demars 1982; Geneste 1989a, 1989b; Larick 1986, 1987; Turq 1988). This observation has been upheld by later studies at French sites (e.g., Delagnes et al. 2006; Fernandes et al. 2008; Féblot-Augustins 2009; Meignen et al. 2009; Turq et al. 2017). This disparity in lithic transport has often been considered an outcome of cognitive and/or behavioral differences between Middle and Upper Palaeolithic populations, generally held to have been archaic hominins (e.g., Neanderthals) and modern humans, respectively (e.g., Mellars 1996; Mithen 1996; Tattersall 1999; Klein 2000; Pettitt 2000). By extension, the farther transport distances in the Périgord region for the Upper Palaeolithic have been interpreted as evidence of land use covering greater distances (i.e., extensive), rather than land use over a smaller area (i.e., intensive). Such a pattern is ostensibly upheld by rare obsidian artifacts unearthed from the Upper Palaeolithic levels of Shanidar Cave and Zarzi Cave in Iraq (Solecki 1963, Frahm and Tryon 2018), Yabroud Rockshelter II in Syria (Frahm and Hauck 2017), and Ksar Akil in Lebanon (Frahm and Tryon 2019). Within the Levant, however, differences in lithic transport distances between the Middle and Upper Palaeolithic appear to have been marginal (Ekshtain and Tryon 2019; Ekshtain et al. 2014, 2019).

Here we consider this issue in light of more than 8200 sourced obsidian artifacts from eight sites, spanning from the Lower to Upper Palaeolithic (Table 1). All of the artifacts were analyzed with portable X-ray fluorescence (pXRF) instruments, usually in the sites' field laboratories. Many of these data have been published (e.g., Adler et al. 2014; Frahm et al. 2014, 2016, 2019; Kandel et al. 2017; Malinsky-Buller et al. 2020, 2021; Glauberman et al. 2020a, 2020b), and the rest will be included in site-specific publications currently in preparation (e.g., Solak-1). Here we consider the most relevant findings to consider the diachronic nature of lithic transport in the Armenian Highlands.

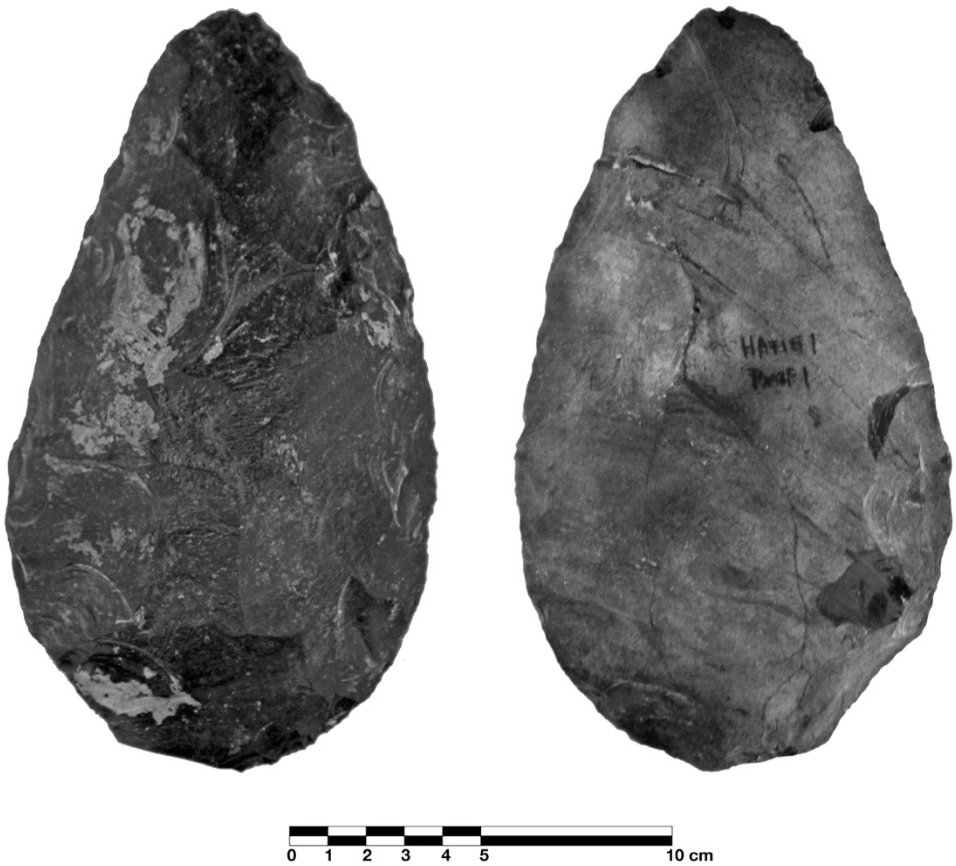

Figure 3. A large obsidian hand axe excavated from the Lower Palaeolithic site of Hatis-1. Photograph by Jayson Gill.

Table 1. Summary information about the eight archaeological sites in this study

Site name	*Site type*	*Period*	*Coordinates*	*Elevation*	*Province*	*Project*	*Site References*
Aghitu 3	cave	UP	39.5138° N, 46.0822° E	1601 m	Syunik	TAPP	Kandel et al., 2011, 2014, 2017
Alapars 1	open-air	MP	40.4049° N, 44.6810° E	1774 m	Kotayk	HGPP, PAGES	Malinsky-Buller et al., 2020a
Barozh 12	open-air	MP	40.3348° N, 43.7934° E	1345 m	Aragatsotn	PLATEAU	Glauberman et al., 2016
Hatis 1	open-air	LP	40.2739° N, 44.7032° E	1571 m	Kotayk	HGPP, PAGES	Ghazaryan, 1986; Sherriff et al., 2019
Kalavan 2	open-air	MP	40.6434° N, 45.1103° E	1640 m	Gegharkunik	ArMON	Malinsky-Buller et al., 2020b
Lusakert Cave 1	cave	MP	40.3718° N, 44.5972° E	1427 m	Kotayk	HGPP	Adler et al., 2012; Frahm et al., 2016
Nor Geghi 1	open-air	LP	40.3468° N, 44.5971° E	1402 m	Kotayk	HGPP, PAGES	Adler et al., 2014; Sherriff et al., 2019
Solak 1	open-air	UP	40.4572° N, 44.6878° E	1634 m	Kotayk	HGPP	Sherriff et al., 2019

Project abbreviations:
ArMON =Armenian Institute of Archaeology and Ethnography and MONREPOS Archaeological Research Centre
HGPP = Hrazdan Gorge Palaeolithic Project, University of Connecticut & University of Winchester
PAGES = Pleistocene Archaeology, Geochronology and Environment of the Southern Caucasus Project
PDAD = Pleistocene Hunter-Gatherer Lifeways and Population Dynamics in the Ararat Depression, Armenia
PLATEAU = Palaeolithic Populations in Armenia and Turkey: Expanding Archaeological Understanding
TAPP = Tübingen-Armenian Paleolithic Project, HGPP = Hrazdan Gorge Palaeolithic Project

4.2. Lower Palaeolithic: Hatis-1 and Nor Geghi-1

The open-air site of Hatis-1 lies immediately adjacent to obsidian outcrops on the slopes of Hatis volcano, where it was found and excavated in 1983 (Ghazaryan 1986). The excavations led to the collection of ~2100 lithic artifacts, including ~420 hand axes (Fig. 3), from both the surface and excavated sediments. Collection work and re-excavation in 2016–2017 yielded three dacite and 329 obsidian artifacts, including 18 hand axes (Gill et al. forthcoming). The assemblage is Late Acheulian in character with a notable large flake component (*sensu* Kleindienst 1962). No Levallois technology is evident, but two obsidian cores with large flake removals and simple preparation were recovered (Gill et al. forthcoming). Samples suitable for chronometric dating were not recovered, so a precise age for the site remains unknown; however, a $^{40}K/^{40}Ar$ date for Hatis obsidian suggests a *terminus ante quem* of 480±40 ka (Arutyunyan et al. 2007). Using portable XRF in 2016, we sourced ten of the 1983 hand axes, all of which originated from Hatis volcano.

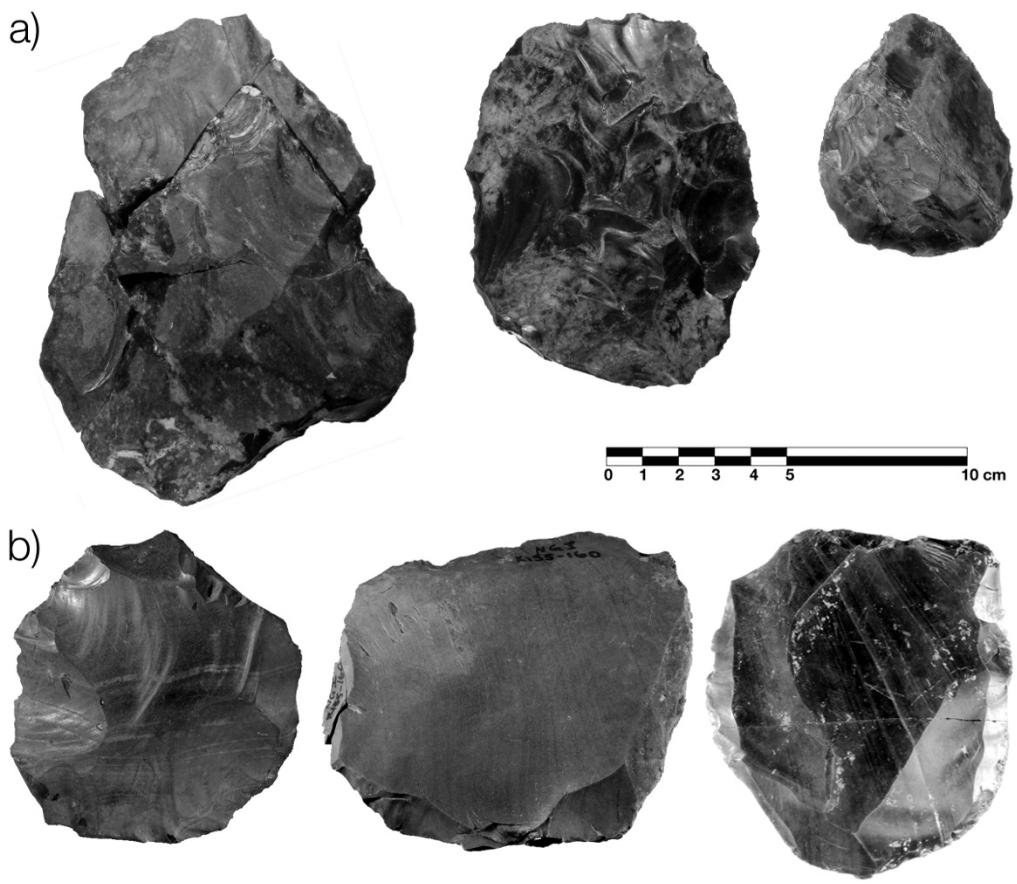

Figure 4. Obsidian artifacts excavated from the Lower Palaeolithic site of Nor Geghi-1: a) bifaces and b) Levallois cores. Photographs by Daniel S. Adler.

A short distance away (12 km NE) sits Nor Geghi-1, an open-air site that records the local development of Levallois technology within a Late Acheulian context (Fig. 4). Excavated from 2008 to 2017, this site was discovered within an exposed stratigraphic section where the Hrazdan River cut down through Pleistocene lava flows and fluvio-lacustrine sediments between them (Adler et al. 2014). The sediments that contain Nor Geghi-1 are sandwiched between the final lava in the area (197±7 ka) and an earlier flow (441±6 ka). The chronology is further constrained by the $^{40}Ar/^{39}Ar$ dating of volcanic ash from the topmost sedimentary unit (30 ±3 ka), yielding a *terminus post quem* (308 ± 3 ka) and a *terminus ante quem* (441±6 ka) date for the artifacts (Adler et al. 2014). A series of 316 obsidian artifacts were initially analyzed in 2012 (Adler et al. 2014), since which more than 2000 additional artifacts have been sourced. Gutansar obsidian predominates (93.6% in Adler et al., 2014; 97.0% in the larger dataset). The complete dataset also includes a small number (< 0.4%) of artifacts from the Tsaghkunyats obsidian sources (~20 km to the north). As reported in Adler et al. (2014), the farthest-traveled artifacts originated from the Arteni (~70 km west) and Syunik (~120 km southeast; ≥ 200 km on foot) sources. Given the occurrence of artifacts from these sources, the hominins at Nor Geghi-1 must also have had a presence in those regions.

4.3. Middle Palaeolithic: four recent excavations

Situated along the Hrazdan River, just a short distance (<3 km) upstream from Nor Geghi-1, Lusakert Cave-1 formed in a cliff along a meander of the river, which flowed past the cave when it was occupied ~60–35 ka (Adler et al. 2012; Sherriff et al. 2019). After excavations during the 1970s and 1980s (Yeritsyan 1975; Yeritsyan and Korobkov 1979), this site was re-excavated between 2007 and 2011 (Adler et al. 2012; Gasparyan et al. 2014). Beneath the uppermost strata, stratified deposits contain *in situ* faunal remains and lithic artifacts, including 13,970 obsidian artifacts (> 25 mm; smaller debitage is even more numerous). The lithic assemblage includes Levallois flakes and blades, formal tools (e.g., side scrapers, end scrapers, burins), and cores. Select sourcing results have been reported (e.g., Frahm et al. 2014, 2016) in the context of method development. The full publication of the site's excavation and lithic assemblage, including the complete obsidian sourcing dataset, is forthcoming; however, some details can be shared here. A total of 91.9% of the obsidian artifacts came from the Gutansar complex, followed by Hatis (4.1%, ~13 km southeast). The rest (4%) derive from the Tsaghkunyats (~20 km north), Geghasar (~45 km southeast), Arteni (~70 km west), and Syunik (~120 km southeast; ≥200 km on foot) source areas.

The extensive open-air site of Barozh-12, as reported by Glauberman et al. (2016; 2020a,b), lies on a plateau along the edge of the Ararat Depression and a short distance (~1–2 km) from the two Arteni obsidian sources. Its stratified deposits have been dated to ~60–31 ka, making the site roughly contemporaneous with Lusakert Cave-1, ~70 km east. The assemblage shows that the site's occupants consistently utilized Levallois technology. The site consists of abundant obsidian artifacts in fine sediments that principally reflect low-energy alluvial deposition. A small test pit excavated in 2009 (50×50 cm, ~1 m deep) yielded 779 obsidian artifacts (>2 cm) as well as 395 pieces of small debris (<2 cm): that is, ~4700 obsidian artifacts/m^3. Glauberman et al. (2020b) report the obsidian sourcing data. Most of the artifacts (94.3%) match the Arteni sources, but the percentage varies by lithic class. For example, all of the cobble and core blanks derive from the Arteni sources; however, 22.4% of retouched artifacts came from farther sources. An elongated Levallois point/convergent scraper, for instance, matches Meydan Dağ (~140 km south), while one retouched blank matches Pasinler (~190 km west). A small portion (2.5%) have unknown origins, likely somewhere within northeastern Turkey. The remainder (4%) derive from the Tsaghkunyats (~60 km northeast) and the Gegham obsidian source areas (i.e., Hatis, Gutansar and Geghasar; ~85–110 km to the east linearly), approximately 100–130 km away on foot.

The open-air site of Alapars-1, as reported by Malinsky-Buller et al. (2020), is composed of a 6-m alluvial-aeolian sequence with multiple archaeological units, and it is immediately adjacent to an obsidian-bearing lava dome of the Gutansar complex (Sherriff et al. 2019). Luminescence dating put the site at ~110–65 ka. Faunal remains were not recovered, although conditions seem not have been favorable for preservation. Lithics from all horizons principally consist of Levallois reduction sequences. The earlier units suggest ephemeral occupations due to activities linked to tool use and maintenance, whereas the later ones are more intensive, as evidenced by core reduction and tool discard. Therefore, the sequence appears to exhibit greater occupational intensity amidst a climatic shift from warm to cool. Malinsky-Buller et al. (2020) document the obsidian sourcing results. It is not surprising that most of the artifacts (97.1%) derive from the Gutansar complex. In addition to Hatis, the remainder originated from the Tsaghkunyats sources (2%, ~50 km northwest), and there is a tool made of Pokr Arteni obsidian (~75 km west; ≥ 100 km on foot).

Lastly, the open-air site of Kalavan-2 lies in the mountains just north of Lake Sevan. The site was first excavated in 2006–2007, resulting in ^{14}C dates between 17 and 42 uncal BP (Ghukasyan et al. 2011), and it was re-excavated from 2017 to 2019 (Malinsky-Buller et al. 2021). Luminescence dating yielded a range of ~45–60 ka for the occupations. The renewed excavations recovered 2532 lithic artifacts from 13 units, and a sample of 928 obsidian artifacts has so far been assigned to both source and lithic class. This site is ~50 km (linearly) from the nearest obsidian sources, so its lithic assemblage reflects repeated use and maintenance of obsidian (in contrast to expedient use of the local materials), as evidenced by abundant obsidian chips produced by retouch and rejuvenation. Malinsky-Buller et al. (2021) report on the full sourcing results. The obsidian artifacts principally originated from the roughly equidistant Tsaghkunyats (30%) and Gegham (i.e., Hatis, Gutansar and Geghasar; 63%) source areas, followed by the Syunik area (~120 km south; 6%). Occasional tools from more distant obsidian sources (i.e., Chikiani, ~150 km north, ≥240 km on foot and Pokr Arteni, ~120 km southwest, ≥200 km on foot) have also been identified there.

4.4. Upper Palaeolithic: Aghitu-3 and Solak-1

Located along the Vorotan River valley, Aghitu-3 is, to date, the only deeply stratified Upper Palaeolithic cave documented in Armenia (Kandel et al. 2011, 2014, 2017). Excavations from 2009 to 2019 uncovered ~5.5 m of stratified sediments in a series of seven horizons. The most intensive occupation (Horizon III) dates to ~29–24 ka cal BP, and ~9500 lithic artifacts were recovered from this stratum, ~85% of which are obsidian. Both obsidian and chert were principally used to create bladelets from which tools were made. Obsidian sourcing, techno-typological analysis, and agent-based modeling supported an interpretation that, during the onset of the Last Glacial Maximum, the cave's modern human occupants not only moved greater distances more frequently but also more often encountered neighboring groups (Frahm et al. 2019). These sourcing results are reported by Kandel et al. (2017) and Frahm et al. (2019). Given that the site is nearest to the Syunik area (~40 km northwest), the obsidian artifacts primarily originated from those sources (93.5%). In addition, artifacts from the Gegham source area (Hatis, Gutansar, and Geghasar; ~110–150 km northwest) occur throughout the stratigraphic sequence (5.6%). Of particular interest are far-traveled obsidian artifacts (<1%) from a Tsaghkunyats source (Damlik, ~180 km northwest), Pokr Arteni (~220 km northwest), and Meydan Dağ in Turkey (~250 km linearly, ≥270 km on foot).

Solak-1 is a stratified open-air site where an area of 4 m^2 was excavated in 2015 (Adler et al. forthcoming). It is also situated along the Hrazdan River, upstream from Nor Geghi-1 (15 km) and Lusakert Cave-1 (12 km). The excavations revealed an obsidian-rich assemblage of bladelets, tools, cores, and flakes. These lithics occur in ~1.0–1.5 m of fine-grained sediments that rest atop a lava flow (BJN III; Sherriff et al., 2019). The site has not been directly dated due to challenges of making stratigraphic associations to datable materials, but it is attributed to the Late Upper Palaeolithic on techno-typological grounds. The complete findings from Solak-1 will be published separately (Adler et al. forthcoming); however, it can be reported here that a majority (91.1%) of its obsidian originated from Gutansar (~10 km south). Other artifacts derived from Hatis and Geghasar to the south (~20 and ~45 km, respectively) and all three of the Tsaghkunyats obsidian sources (~20 km northwest).

In addition, a small portion (<3%) of artifacts match Pokr Arteni (~80 km west), Sevkar (~120 km southeast), Meydan Dağ (~180 km southwest), and Pasinler (~260 km west).

4.5. Interpretation of the results

We can consider any diachronic trends in two ways. First, we focus on the three sites – Nor Geghi-1, Lusakert Cave-1, and Solak-1 – that have sizable sourced assemblages and are clustered along the Hrazdan River, making them roughly equidistant from obsidian sources. Gutansar is the predominant obsidian source at all three sites, but its proportion decreases from the Lower (97.0%) to the Middle (91.7%) and Upper Palaeolithic (91.0%). In addition, the number of obsidian sources identified in these assemblages rises from the Lower to Upper Palaeolithic (Table 2). Furthermore, the greatest transport distance increases from the Lower (120 km) to Upper Palaeolithic (180 km between Solak-1 and Meydan Dağ in eastern Turkey). Therefore, within the Hrazdan River valley at least, there is a trend in which reliance on farther obsidian sources increases.

Table 2. Obsidian sources and their propotions at three sites along the Hrazdan River valley

Source areas	Sources	***Lower Palaeolithic*** **Nor Geghi 1** **n = 2351**	***Middle Palaeolithic*** **Lusakert Cave 1** **n = 1435**	***Upper Palaeolithic*** **Solak 1** **n = 1375**
Gegham range	Gutansar	97.02%	91.71%	91.05%
	Hatis	1.70%	4.32%	2.25%
	Geghasar		0.49%	0.73%
Tsaghkunyats	Kamakar	0.04%	0.63%	0.36%
	Ttvakar	0.13%	0.14%	2.04%
	Damlik	0.21%	1.32%	0.65%
Syunik	Sevkar	0.13%	0.07%	0.22%
	Satanakar			
Arteni	Pokr Arteni	0.68%	1.18%	2.55%
	Mets Arteni	0.09%	0.14%	
Eastern Turkey	Meydan Dağ			0.07%
	Pasinler			0.07%
Number of sources present		*8*	*9*	*10*

Second, we can consider the results for all eight sites when these different obsidians sources are recategorized by linear source-to-site distance. This step helps to account for the Tsaghkunyats obsidian sources being ~15 km from Solak-1 but ~180 km from Aghitu-3. A variety of schemes have been used to categorize source-to-site distances. It is common to see such distances broken down into equal units (e.g., Moutsiou 2012: <50 km, 50–100 km, 100–150 km, etc.). Many researchers, however, have favored schemes that are at least vaguely exponential (e.g., Féblot-Augustins 1993: local: < 5 km, intermediate: 5–20 km, distant: 20–100 km, etc. and Geneste 1989a: local: < 5 km, regional: 5–20 km, exotic: 20–80 km, etc.). These distances are usually intended to reflect the daily foraging range and other radii (e.g., longer walks, extended hunting trips) around a home base. Such schemes are also consistent with the logarithmic "fall-off curves" of Renfrew et al. (1968) and the exponential "neutral model" of Brantingham (2003). Here we (1) choose to use natural exponents (e^1, e^2, etc.) to derive source-to-site distance ranges for comparison (<2.7 km, 2.7–7.4 km, 7.5–20 km, 21–54 km, 55–148 km, and >148 km) and (2) consolidate these first three ranges into a "<20 km" category, which is equivalent to the combined "local" (0–5 km) and "regional" (6–20 km) ranges of Kandel et al. (2016) that are intended to reflect a day's walk from a home base. Figure 5 illustrates that the increased source-to-site distances reflected among the obsidian artifacts over time is more than a phenomenon restricted Palaeolithic sites within the Hrazdan Basin.

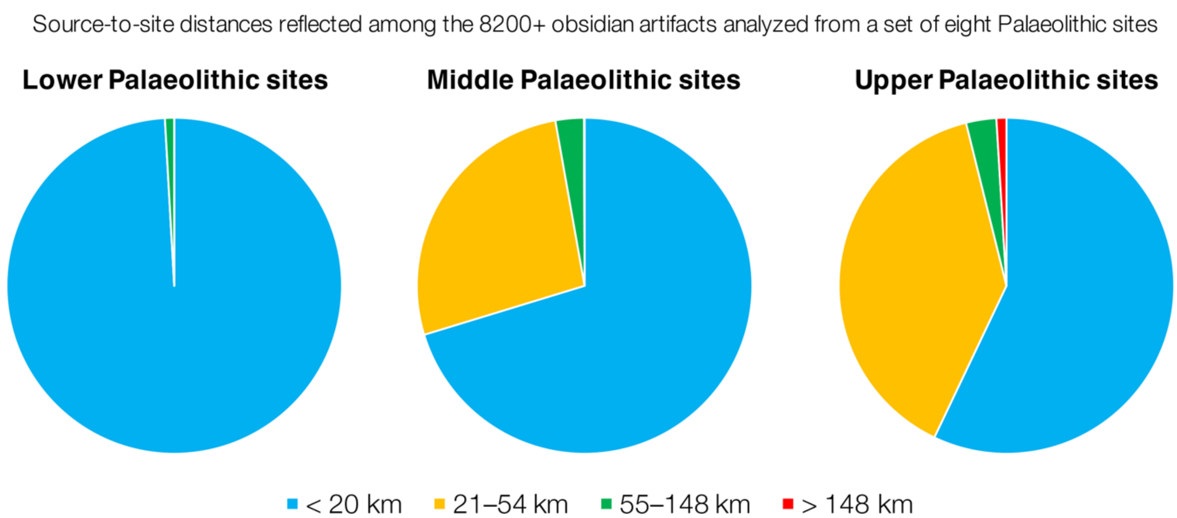

Figure 5. Diachronic changes in source-to-site distances from the Lower to Upper Palaeolithic reflected among greater than 8200 analyzed obsidian artifacts from the eight sites listed in Table 1. Over time, a greater and greater proportion of these obsidian artifacts derived from more and more distant geological sources.

These results are consistent with transport of lithic artifacts across greater distances during the Upper Palaeolithic relative to the Middle and Lower Palaeolithic. Such an outcome is consistent with an interpretation that earlier hominins practiced a more intensive use of the local landscape in comparison to later hominins, who more often covered more expansive territories. A change from intensive to extensive land use, though, need not primarily reflect cognitive capabilities. In fact, the presumed link between cognition and mobility has been called into question (Raichlin et al. 2014).

Instead, it could correspond to a shift from more productive environments with higher population densities to less productive ones with low population densities, perhaps reflecting the peculiarities of global climate in the Upper Palaeolithic (i.e., occupation during a cooler phase at Aghitu-3 versus warmer interglacial habitations at Nor Geghi-1). In such a situation, the perennial need for hunter-gatherers to maintain interactions with neighboring groups widely dispersed across the landscape could only be met via increasing their mobility (e.g., Grove 2018; Gallagher et al. 2019). This pattern also appears consistent with the creation and maintenance of expanding exchange networks through time due, perhaps, to hominins' behavioral changes and/or cognitive ones.

5. Additional behavioral insights from obsidian

As discussed in the Introduction, geopolitical borders meant that the abundance of obsidian sources in the Armenian Highlands was long misunderstood by Western researchers. For example, in a review article about the wider area, Williams-Thorpe (1995) accurately discusses the obsidian sources across the Mediterranean region and Anatolia, but her map reveals the limits of Western knowledge regarding obsidian sources in Armenia at that time. She placed a star on the map near Yerevan for a purported "Erevan" obsidian source and a second star near Lake Sevan for a "Sevan" source, neither of which is correct. A similar trend is found in the geological understanding of these sources. Models of obsidian-producing rhyolitic volcanism have long been based on the tectonically simple setting of the Pacific Northwest of North America (e.g., Fink 1980, 1987, 1994; Eichelberger et al. 1986; Fink and Manley 1987; Hughes and Smith 1993). Armenian geologists, however, noted that such models do not properly describe volcanism within their research area, where a series of tectonic plates interact, and thus, the "volcanoes of Armenia are represented by fan-like, stratified, and more complicated forms" (Shirinian and Karapetian 1964:26).

For instance, obsidian-bearing lava flows and domes within the Armenian Highlands can be more voluminous than those elsewhere in the world. Gutansar is one such example. Most silica-rich rhyolitic lava flows typically extend no more than 4 km from their eruptive centers or cover more than 10 km^2 (Walker 1973). Two large obsidian sources within North America, for example, are Big Obsidian Flow in Oregon (2.5 km^2) and Glass Mountain in northern California (9 km^2). In contrast, Gutansar obsidian covers at least 70 km^2 and is chemically indistinguishable across that area. That is, elemental analysis is unable to differentiate outcrops on one side of the volcano from those on another (Frahm et al. 2014). Variation in the physical and, in turn, the magnetic properties of sub-millimeter mineral inclusions, especially magnetite (Fe_3O_4) grains, provides a means to distinguish obsidian from different parts of this extensive flow (Frahm and Feinberg 2013; Frahm et al. 2014, 2016). Magnetic measurements were also taken of obsidian artifacts from Nor Geghi-1 and Lusakert Cave-1 to investigate procurement behaviors of the sites' occupants (Frahm et al. 2016, 2020). If, for instance, the occupants preferred to collect obsidian from a particular outcrop or deposit, it would be revealed in the magnetic data (Fig. 6). The data from both sites instead support an interpretation that the Lower and Middle Palaeolithic hominins collected obsidian from exposures throughout the adjacent Hrazdan River valley, corresponding to the scale of their daily foraging and indicating that lithic raw material procurement was embedded in other subsistence activities (Frahm et al. 2016, 2020). Such behavioral interpretations were possible due only to the combination of such a sizable obsidian source and the novel application of rock magnetic characterization.

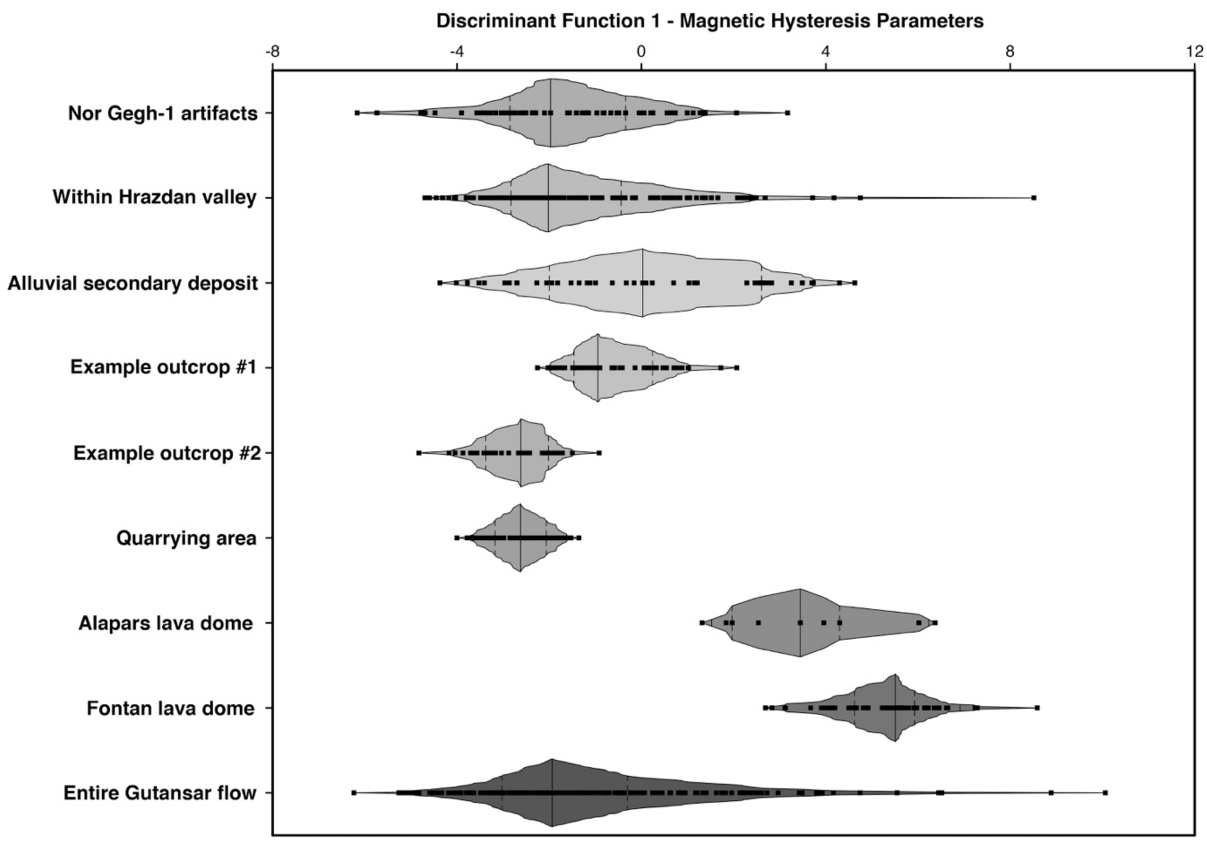

Figure 6. A box-percentile plot (Esty and Banfield 2003) of the first discriminant function applied to the rock magnetic data (i.e., magnetic hysteresis parameters) for the different obsidian sampling areas at the Gutansar volcanic complex and to the measured artifacts from the Lower Palaeolithic site of Nor Geghi-1. The artifacts, based on the first two discriminant functions, most closely match geological specimens collected throughout the Hrazdan River valley. Additional information can be found in Frahm et al. (2016, 2020).

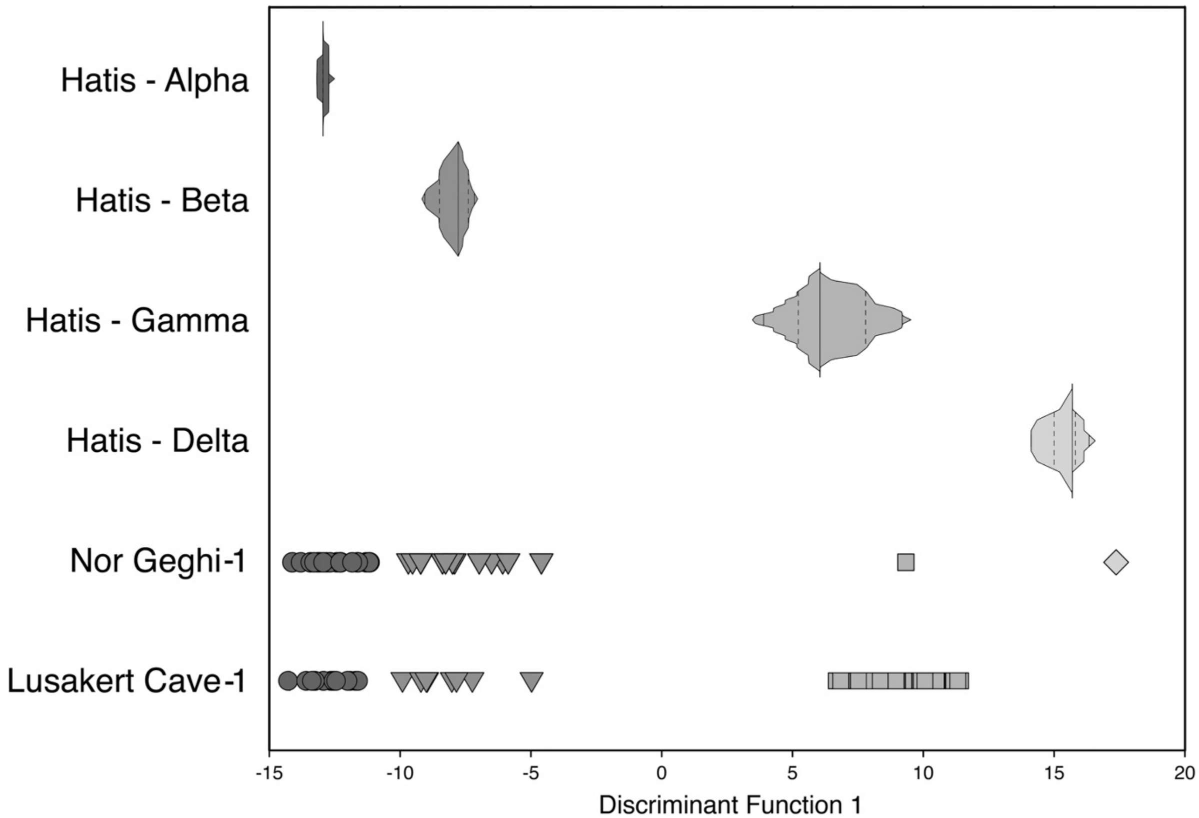

Figure 7. A discriminant function (based on Rb, Sr, and Zr measurements) separates the Hatis obsidian types in (top) the geological specimens using a box-percentile plot (Esty and Banfield 2003) and (bottom) the Nor Geghi-1 and Lusakert Cave-1 artifacts. Greater spread among the artifacts is primarily due to analyzing weathered, irregular artifact surfaces rather than fresh, flat outcrop surfaces. Additional information can be found in Frahm et al. (2021).

Another complex obsidian source is Hatis volcano, just south of Gutansar, which exhibits the stratification first mentioned by Shirinian and Karapetian (1964). Hatis volcano is highly unusual, if not unique, in that its obsidian chemistry varies with elevation (Frahm et al. 2021). In particular, as one climbs the volcano, obsidian in distinct elevation ranges falls into four chemical types known as the alpha, beta, gamma, and delta varieties (from lowest to highest elevation; Frahm et al. 2021). A multivariate statistical approach (i.e., a discriminant function based on three so-called "mid-Z" trace elements – Zr, Rb, and Sr – that accounted for 99.99% of the dataset variability) was applied to the Hatis-derived artifacts from Nor Geghi-1 (n = 40) and Lusakert Cave-1 (n = 59) to attribute them to one of the different obsidian varieties (Fig. 7). The two higher-elevation obsidian varieties (gamma and delta) comprise 5% of the Hatis-derived artifacts from Nor Geghi-1 but are a majority (58%) of those at Lusakert Cave-1 (Frahm et al. 2021; Frahm, unpublished). Passing by the lower-elevation alpha and beta obsidian outcrops to instead collect the higher-elevation gamma and delta obsidian necessitates additional energy, the expenditure of which makes little sense given that there are no clear differences in flaking quality. The collection of the higher-elevation types thus is indicative of embedded procurement, consistent with the findings from the magnetic minerals. Acquiring either high-elevation obsidian variety makes the most sense within the context of other activities, such as wayfinding or observing the distribution of resources on the landscape below. This insight is possible only due to the exceptional way in which Hatis obsidian reflects its elevation.

6. Concluding remarks

Our intent with this chapter is to establish that obsidian use in the Near East is not simply a Neolithic phenomenon. Such notions can be found within the Western archaeological literature due to the geopolitical borders that existed as obsidian studies, particularly the technique of chemically sourcing artifacts, came to the forefront. These same boundaries also shaped – and even limited – Western geologists' ideas about and models of obsidian-creating rhyolitic volcanism. Having entire lithic assemblages composed of obsidian artifacts – and the technological capability to analyze such assemblages with portable instruments – makes the Armenian Highlands an excellent region within which to reconstruct the behaviors of mobile foraging groups through time and to test widely held ideas about Palaeolithic technology, such as long-standing debates regarding the link between lithic types and degree of reduction (e.g., Dibble 1984). Combining the sourcing results with datasets for environmental and other behavioral proxies can also offer, for example, a means to elucidate such pressing issues as human behavioral adaptations to a fluctuating climate.

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