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The Techno-typological and 3D-GM Analysis of Hatis-1: a Late Acheulian Open-Air Site on the Hrazdan-Kotayk Plateau, Armenia

Jayson P. Gill[1] · Daniel S. Adler[1] · Yannick Raczynski-Henk[2] · Ellery Frahm[3] · Jennifer E. Sherriff[4] · Keith N. Wilkinson[5] · Boris Gasparyan[6]

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Abstract
Hatis-1 is a Lower Paleolithic open-air site on the Hrazdan-Kotayk Plateau of central Armenia. Although the site was tested in the 1980s, little has been published regarding the material. Consequently, we reinvestigated the site by expanding the original test pit to better understand the stratigraphy and recover a new sample of artifacts. As a result, more than 300 obsidian artifacts were recovered from colluvial deposits found close to primary obsidian outcrops, which sourcing data show to be the exclusive areas of toolstone procurement used by the inhabitants. The recovered assemblages are Late Acheulian in character and are largely homogenous across strata in terms of techno-typology. Hatis-1 records the use of large flakes for production of cores and tools indicative of the Large Flake Acheulian, but also contains limited evidence for simple prepared cores and the recycling of bifaces as cores, suggesting expansion of the technological repertoire of hominins in this region during the Late Acheulian. The in-depth study of large cutting tools presented here reveals that differences in the shape and typology of these tools are largely determined by different production strategies. While samples suitable for direct chronometric dates were not recovered, constraining geological factors suggest this material was deposited after c.700/480 ka. This study expands our understanding of the Late Acheulian and further contextualizes the later Lower–Middle Paleolithic technological transition in the region. In a broader sense, our interpretation of the techno-typological patterns at Hatis-1 expands the current understanding of geographical and chronological variation in the Acheulian record.

Keywords Lower Paleolithic · Handaxe · Armenian Highlands · Caucasus · Obsidian · Geometric morphometrics

✉ Jayson P. Gill
jayson.gill@uconn.edu

Extended author information available on the last page of the article

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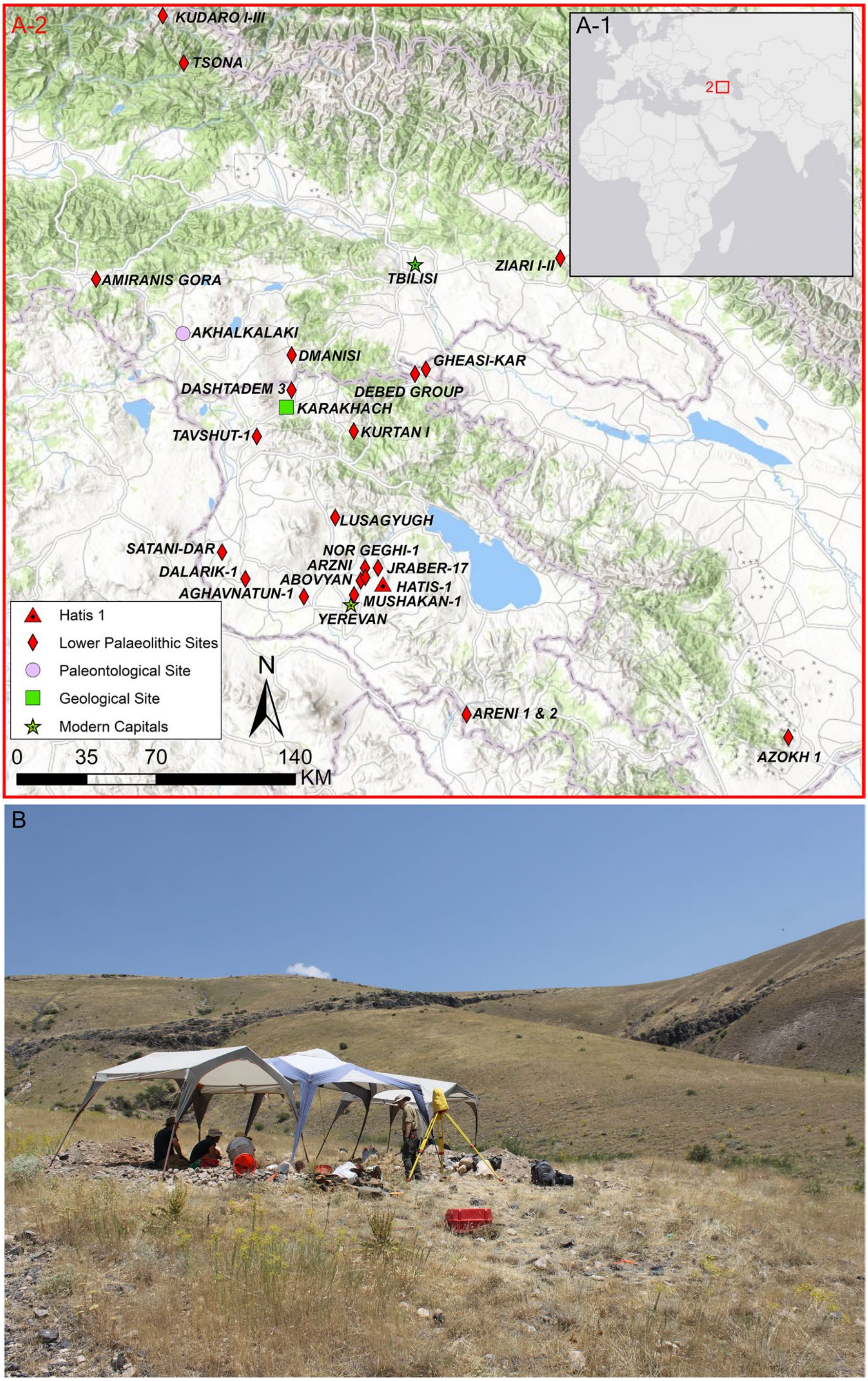
Fig. 1 **A**-1. location of the study region. **A**-2. Map of the northeastern Armenian Highlands and southern Caucasus showing the location of Hatis-1 and other sites mentioned in the text relative to modern capital cities. The Debed group includes the Ptghavan, Haghtanak, Bagratashen, and Ayrum sites. **B**. Overview photograph of Hatis-1 excavation area, facing north/northeast

Introduction

Research on Early and Middle Pleistocene hominin occupations and behaviors in the southern Caucasus (which we define as that part of the Caucasus ecoregion [sensu Bailey, 1989] lying south of the Greater Caucasus ridge line) is best summarized as uneven, particularly when compared to better studied nearby regions such as the Levant. Our current understanding of the chronological and techno-typological patterns in the region is limited by few stratified sites, poor dating, and an emphasis on later time periods (Gasparyan, 2010; Lindsay & Smith, 2006). Recent research in Armenia has increased the quantity and quality of archaeological data from the Late Pleistocene, in particular that relating to the Middle Paleolithic (MP) and Upper Paleolithic (UP), but the Lower Paleolithic (LP) is under-represented in comparison (Adler et al., 2012; Bar-Oz et al., 2012; Gasparyan, 2010; Gasparyan et al., 2014a, 2014b, 2020; Ghukasyan et al., 2010; Glauberman, 2016; Glauberman et al., 2020a, 2020b; Malinsky-Buller et al., 2020, 2021; Pinhasi et al., 2008). This leaves a chronological gap in our comprehension of hominin behavioral evolution and cultural diversity in a region central to understanding hominin dispersals during the Pleistocene, not least because the Armenian Highlands and Caucasus mountain ranges serve as a junction between the Levant and Eurasia (Bar-Yosef & Belmaker, 2011). The Armenian Highlands are southernmost of the Caucasus mountain ranges and are bordered by the Iranian Plateau to the east, the Anatolian Plateau to the west, and the Mesopotamian Plain to the south (Abich, 1845), while the Armenian Highlands merge with the Lesser Caucasus in northern Armenia and Georgia. However, it is likely that the Greater Caucasus Range to the north served as the natural barrier limiting hominin mobility during the Middle Pleistocene. Here, we report on the re-excavation and technological analysis of the LP open-air site of Hatis-1 in Armenia.

Hatis-1, located on the Hrazdan-Kotayk Plateau on the southern slopes of Mt. Hatis in the Gegham Range (Fig. 1), was originally test excavated in 1984, and although it was then described as a Late Acheulian workshop, detailed descriptions of the work were not published (Ghazaryan, 1986; Lyubin, 1989; Lyubin and Belyayeva, 2006; Gasparyan, 2010; Gasparyan et al., 2014a). Since the 1980s, however, K–Ar dating has been applied to volcanic strata of the Gegham Range and provides a broad chronology for the Hatis-1 site. These chronometric data indicate that the Hatis volcano on which the site is situated, formed c. 700 ka, while the obsidian on which the artifacts were made was emplaced at c. 480 ka (Arutyunyan et al., 2007; Karapetyan & Adamyan, 1973; Lebedev et al., 2013). The Late or Upper Acheulian can be broadly characterized as having smaller, more well-refined large cutting tools (LCTs; i.e., bifaces and large unifacial cutting tools) produced on fine-grained raw material, a shift towards retouched flake tool production, and often contains prepared cores and other technologies associated with MP/Middle Stone


A-2
KUDARO I-III
TSONA
A-1
2
ZIARI I-II
TBILISI
AMIRANIS GORA
AKHALKALAKI
DMANISI
GHEASI-KAR
DASHTADEM 3
DEBED GROUP
KARAKHACH
TAVSHUT-1
KURTAN I
LUSAGYUGH
SATANI-DAR
NOR GEGHI-1
ARZNI
JRABER-17
DALARIK-1
ABOVYAN
HATIS-1
AGHAVNATUN-1
MUSHAKAN-1
YEREVAN
Hatis 1
Lower Palaeolithic Sites
Paleontological Site
Geological Site
Modern Capitals
N
ARENI 1 & 2
AZOKH 1
0 35 70 140
KM
B

Age assemblages (Ajithprasad, 2005; Bar-Yosef, 1994; Clark, 1966; Kleindienst, 1961; Tryon et al., 2005).

On a regional level, the Late Acheulian of the Armenian Highlands is often defined as having refined LCTs, reduction in LCT size relative to earlier phases of the Acheulian, an emphasis on the use of flake blanks for LCT production, a prevalence of thinned ovate and cordiform LCTs, the appearance of developed blade technology, radially flaked cores, and a shift towards the dominant use of volcanic rocks (obsidian, dacite, basalt) and rare use of chert and limestone by hominins in the area (Lyubin, 1998; Doronichev & Golovanova, 2003; Lyubin and Belyayeva, 2006; Doronichev, 2008; Gasparyan, 2010). In this paper, we compare the lithic assemblage from renewed work at Hatis-1 to the Late Acheulian industries of the Levant and the nearby LP–MP transitional site of Nor Geghi-1 (NG-1), in order to address the validity of the original categorization of the site. Furthermore, we analyze the LCT technology at Hatis-1 using technological, typological, and geometric morphometric methods to better understand the variability of this tool category at the site as well as the behavioral foundation of this variance. Large flake production at the site allows us to discuss the placement of Hatis-1 in the Large Flake Acheulian (LFA), a phenomenon that is not well understood in the southern Caucasus (Sharon, 2007). We demonstrate that the evidence from Hatis-1 broadens our understanding of temporal and regional diversity during the late Middle Pleistocene and allows us to comment on the differential application of knapping behaviors related to artifact shape variation during the Acheulian.

The Lower Paleolithic of the Southern Caucasus and Armenian Highlands

The importance of regional Pleistocene research is exemplified by the site of Dmanisi in the Republic of Georgia. While recent work on the sites of Longgupo (Han et al., 2017) and Shangchen (Zhu et al., 2018) in China questions traditional narratives of early hominin expansions, Dmanisi remains the oldest, uncontested evidence for hominins outside of Africa at 1.85 Ma (Ferring et al., 2011). It is reasonable to predict that other sites of similar antiquity should exist, particularly in close proximity to Dmanisi; however, to date, few such sites have been discovered. A series of pebble tool and core-chopper sites in Armenia, some with limited evidence for crude biface production, such as Ptghavan-1 to 3, Haghtanak-1 to 3, Ayrum-2, Areni-1 to 2, Aghavnatun-1, and others, may represent exceptions to this pattern, but research at these locations is in its infancy (Egeland et al., 2014; Gasparyan et al., 2014a). A variety of recent papers document several sites located in the Lori Depression of northern Armenia reported to contain Oldowan and Acheulian assemblages (Belyaeva, 2020; Khokhlova et al., 2018; Presnyakov et al., 2012; Trifonov et al., 2016). On September 6, 2016, three of the present authors (DSA, JES, BG) visited two of these sites as part of a larger field excursion linked to a regional INQUA session during which they were invited to inspect newly cleaned stratigraphic sections, examine artifacts, and question the principal investigators. Karakhach is reported to contain choppers and bifaces and is dated to ~ 1.85 mya; however, these artifacts are derived from the poorly sorted gravels of Bed III, are unmodified by hominins, and represent natural angular rocks with rounded edges that simulated artifacts in general shape only (geofacts). Therefore, in this paper, we classify Karakhach as a purely geological locality highly significant for the insights it provides on the nature and timing of Early Pleistocene volcanic activity in the region. Similar questions of hominin agency plague some of the artifacts at Kurtan I, in particular those attributed to the Oldowan in the lowermost paleosol, and those attributed to the Acheulian in layer 2 and layer 5 (Belyaeva, 2020; Khokhlova et al., 2018; Presnyakov et al., 2012), while those attributed to the Middle Acheulian from layer 1 were clearly modified by hominins (Khokhlova et al., 2018). The unambiguous artifacts from Kurtan I are not stratigraphically associated with the dated samples which were taken from the opposite wall of the quarry (Presnyakov et al., 2012); therefore, it is impossible to estimate the actual age range for these artifacts (Gasparyan et al., 2014a). Taken together the issues outlined above leave little doubt that Dmanisi remains the earliest archeological site in the region.

Crudely formed handaxes thought to be indicative of the Early Acheulian have been recovered from Armenian surface localities such as Tavshut-1 and Mushakan-1, but placing them into a coherent chronology is difficult due to a lack of secure contexts and dates (Egeland et al., 2014; Gasparyan, 2010). Indeed, many Acheulian localities in Armenia, which are predominantly found on the margins of paleolakes in the Ararat, Lori, Aparan, Vorotan, and Shirak depressions and along riverbanks, contain relevant technological information, but they are currently undated or undateable. The majority of these assemblages are described as Late Acheulian in character, having refined handaxes with few or no cleavers and a small, retouched flake component (Gasparyan, 2010; Gasparyan et al., 2014a, 2020). Late Acheulian artifacts were first recovered in Armenia at Arzni (Hrazdan River gorge) in 1933 by geologist A. Demyokhin. Throughout the twentieth century, Late Acheulian artifacts were recovered from locations including Gheasi-kar and Satanidar; however, as with Early Acheulian examples, many of these find lack context and/or dates (Gasparyan et al., 2020). Only in Layer V of Azokh 1 cave in Nagorno Karabagh has Acheulian technology been reported in association with hominin fossil material, in this case a mandibular fragment (Djafarov, 1983; Doronichev, 2008; Fernández-Jalvo et al., 2010). The latter was originally described as belonging to a Neanderthal (Kasimova, 2001), but more recently has been ascribed to *Homo heidelbergensis* (King et al. 2016). Renewed work at this site has yet to confirm the presence of Acheulian tools in this layer, with only smaller flake tools and cores documented (Asryan et al., 2014, 2016). The recently discovered sites of Jraber-17 and Dalarik-1 in central Armenia contain bifacial material potentially related to the Late Acheulian from both surface and subsurface contexts, but more work is needed to confirm the technology present at these sites (Gasparyan et al., 2020). Surface finds from other Armenian localities, such as Bagratashen-1, appear to also belong to the Late Acheulian, but these locations tend not to have intact subsurface deposits that yield similar material (Egeland et al., 2014). Water resources and the ubiquity of high-quality toolstone are suggested as key features attracting hominins to the region during the Acheulian (Egeland et al., 2010; Gabunia et al., 2000; Gasparyan, 2010), but such occupations exist in regions without similar resource abundance, such as the Arabian Peninsula, suggesting that these may not be the only factors facilitating an early hominin presence (Scerri et al., 2018).

A diachronic trend in the Acheulian, based on raw material and artifact refinement, has been proposed by Gasparyan (2010). Artifacts made on non-obsidian siliceous raw materials such as cherts (and sometimes dacite), displaying lack of refinement, are ascribed to the earliest Acheulian, while assemblages produced largely, and often exclusively on obsidian showing increased refinement are considered Late Acheulian (Gasparyan, 2010). Volcanism between c. 500 and 200 ka in the Gegham Range, central Armenia, likely produced more readily accessible obsidian deposits relative to earlier periods (Sherriff et al., 2019) which may lend credence to the use of biface refinement and raw material type as relative chronological markers in volcanically active parts of the Armenian Highlands.

The site of NG-1 has helped to clarify the nature of the Final Acheulian from a regional perspective. The sediments at NG-1 fall between lower and upper lava flows dated by $^{40}Ar/^{39}Ar$ to 441 ± 6 ka and 197 ± 7 ka, respectively (Adler et al., 2014). $^{40}Ar/^{39}Ar$ dating of sanidine grains from cryptotephra in the highest stratigraphic unit at the site, Unit 1, to 308 ± 3 ka further confines the age of the deposits to between ~ 440 and ~ 310 ka. Stratified alluvial and lacustrine deposits at the site provide evidence for the local evolution of Levallois technology from earlier biface (Acheulian) and prepared core technologies. These findings are based on stratigraphic work focused on the northern end of the site. Analysis of the site's southern portion, excavated from 2015 to 2017 and containing deposits older than those found in the north, is ongoing, but initial results document an absence of Levallois methods and a heavier focus on bifacial technology (Frahm et al., 2020). Both simple prepared cores (sensu White & Ashton, 2003) and rare instances of LCTs with preferential removals have been recovered from the southern locus. Artifact-bearing deposits in the northern locus of NG-1 have been correlated with OIS 9e (335–325 ka). As the southern sediments underlie these, they must predate ~ 335 ka and may eventually be correlated with MIS 11c. Artifacts from NG-1 are produced exclusively on obsidian. Other sites in the region, such as Lusagyugh and Dashtadem-3, have previously been described as indicative of the LP–MP transition, which has often been typologically termed Acheulo-Mousterian (Egeland et al., 2014; Gasparyan et al., 2014a; Kolpakov, 2009). However, these sites are best understood as either mixed surface scatters, in the case of Lusagyugh, or the result of significant vertical mixing through repeated erosion and redeposition overprinted by later pedogenic processes. This interpretation is supported by the recovery of Bronze Age pottery, Levallois technology, and LCTs in the same "stratigraphic" unit at Dashtadem-3 (Gasparyan et al., 2014a). Therefore, NG-1 (335–325 ka) currently represents the oldest and best documented evidence for the transition between Late Acheulian and early MP technology in the region.

In the north, the Georgian site of Akhalkalaki likely dates between 980 and 780 ka based on faunal correlations and paleomagnetic work (Tappen et al., 2002). Original excavations by M. Gabunia reported Acheulian and Mousterian artifacts associated with vertebrate remains (Gabunia et al., 1994); however, large-scale excavations conducted by D.S. Adler and M. Gabunia in 1995 and 1996 recovered a faunal assemblage heavily modified by carnivores that bore no evidence of hominin modification (Tappen et al., 2002). Careful stratigraphic and taphonomic work as well as the documentation of serious post-depositional disturbance in the form of numerous large krotovina suggests that the few basalt artifacts recovered during earlier excavations likely became associated with the fauna following significant post-depositional mixing (Tappen et al., 2002). For these reasons, we classify Akhalkalaki as a paleontological locality (Fig. 1).

More recently, it has been argued that hominins bearing Acheulian technology did not expand into the southern Caucasus until c. 500 ka at the earliest, as evidenced at Kudaro III cave in South Ossetia (Mgeladze & Moncel, 2016). Kudaro III, along with the later sites of Kudaro I (~ 350 ka), and Tsona (undated) are found at 1600 m ASL on the southern slopes of the Greater Caucasus Range. Their high elevations have been used to suggest that hominins occupied these sites only during periods of climate amelioration. The assemblages at Kudaro III are composed exclusively of artifacts produced on siliceous raw material with Tsaldi-type bifaces and rare handaxes, referred to as the Kudarian variant of the Acheulian by some authors (Asryan et al., 2014; Doronichev, 2008; Lyubin, 1998). The utility of this site for understanding the Acheulian in the southern Caucasus has been questioned as only 91 lithics were recovered from five strata with TL dates of c. 560 ka and c. 245 ka (Doronichev, 2008; Tushabramishvili, 2020). The Kudarian variant of the Acheulian is also found in some assemblages at Kudaro I and Tsona; however, these sites also contain assemblages with numerous, highly variable handaxes, cleavers, prominent Quina retouch, and laminar production on volcanic raw materials (Lyubin, 1989; Lyubin and Belyayeva, 2006; Mgeladze & Moncel, 2016; Tushabramishvili, 2020). This techno-typological configuration has been referred to as a second regional Acheulian variant, but it is also comparable to contemporaneous Levantine sites (Asryan et al., 2014; Doronichev, 2008; Mgeladze & Moncel, 2016). It is argued that eastern Georgia was occupied by hominins producing "Clactonian-style" assemblages during the LP based on finds from the sites of Ziari I and II (Tushabramishvili, 2020). However, these assemblages have yet to be published in full and no dates have been reported for the sites. Acheulian sites of Amiranis Gora (Georgia) and Ganj Par (Iran) allegedly belong to the earliest Middle Pleistocene based on typological grounds, although without a more detailed techno-typological framework for the region it is difficult to assess this chronological placement (Biglari & Shidrang, 2006; Tappen et al., 2002). Evidence from eastern Turkey is also largely inconclusive, with Acheulian and core and flake assemblages being recovered during surface survey or from largely undated subsurface contexts, while sites in central and western Turkey, such as Kaletepe Deresi 3, are more well established but less relevant for understanding Lower Paleolithic occupations in the southern Caucasus (Kuhn, 2010; Ozherelyev et al., 2019; Sharon & Barsky, 2016; Slimak et al., 2008; Taşkıran, 2018). These issues with the context, dating, and publication of LP sites in the southern Caucasus leave multiple gaps in our understanding of the archeological record of the region, especially during the Late Acheulian. The reassessment of Hatis-1 detailed here is of particular significance in helping resolve the gaps in the regional record.

Landscape Setting

Hatis-1 is situated on the southern slope of Mt. Hatis within the Gegham Range. With an elevation of 1571 m ASL, the site is relatively low on the mountain and overlooks the Akunk River valley, a tributary of the Hrazdan River. The Gegham Range underwent at least six phases of volcanism during the Middle and Late Pleistocene with mafic-intermediate lavas leading to changes in fluvial and landscape development (Sherriff et al., 2019). Stemming from this volcanic activity, the Gegham Range became an important location for hominin toolstone procurement due to the formation of high-quality obsidian (Frahm, 2014; Frahm et al., 2014, 2016, 2020). The formation of the Hatis volcano is dated to c. 700 ka based on K–Ar dating of a lower rhyolite facies (Arutyunyan et al., 2007) and the formation of the obsidian from the volcano is K–Ar dated to c. 480 ka (Arutyunyan et al., 2007; Lebedev et al., 2013). Various obsidian outcrops (Fig. 2) from this later eruptive

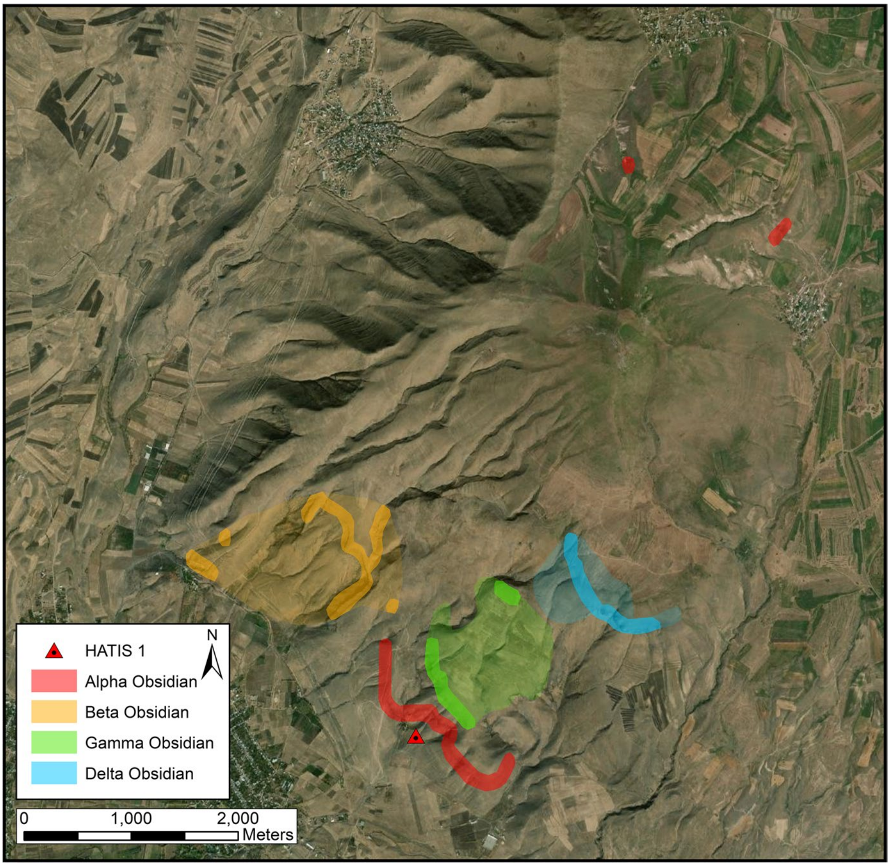


Fig. 2 Satellite image of the Hatis volcano with Hatis-1 and the locations of the four distinct obsidian sources (as determined by pXRF). Adapted from Frahm et al., 2021

phase were used by hominin groups during the Middle and Late Pleistocene (Frahm et al., 2020, 2021). Another consequence of the volcanic activity in this region was a cyclical damming of the Hrazdan River, the formation of paleolakes, and subsequent return to river environments after dam breaches (Sherriff et al., 2019; Sherriff et al. forthcoming). As the site is within 10 km of the modern-day course of the Hrazdan River, the inhabitants of Hatis-1 could have benefited from both the lacustrine and fluvial environments of the area.

Site History

An archeological survey of the southern slopes of Hatis began in 1983 and led to the identification and subsequent testing of the Hatis group of 10 open-air sites, Hatis-1 to Hatis-10 (Ghazaryan, 1986). Hatis-1 to Hatis-4 and Hatis-6 to Hatis-9 are considered Late Acheulian, Hatis-5 is Middle Paleolithic, and Hatis-10 is attributed to the Neolithic based on typological assessment (Gasparyan et al., 2014a, 2020). Surface collection and the excavation of a 2×2 m test pit at Hatis-1 led to the recovery of c. 2100 artifacts, including 420 handaxes. Eleven cores were also recovered, all described as unifacial and unilineal (Ghazaryan, 1986). While the majority of the assemblage is composed of non-diagnostic flakes, it is noted that some of these flakes are related to the production of handaxes. Ghazaryan (1986) described five lithostratigraphic layers to a depth of 1.3–1.5 m, all layers having similar artifact densities. It was speculated that the sequence reflected two distinct phases of the Late Acheulian; however, the reported assemblages were largely homogenous. Although general descriptions and artifact counts are in the public domain, the site and assemblage have yet to be published in full and much of the original material has not been relocated (Gasparyan, 2010; Gasparyan et al., 2014a; Ghazaryan, 1986; Lyubin, 1989;).

A 2004 survey of Mt. Hatis revealed an additional 10 artifact-bearing locations, Hatis-11 to Hatis-21 (Gasparyan et al., 2014a), and then the Hatis group of open-air sites was revisited by an American-Austrian team in 2006–2007, during which Acheulian and pebble tools were recorded from surface contexts. However, this latter work has yet to be published in full (Gasparyan et al., 2020). Analytical work stemming from these renewed efforts suggests that Late Acheulian sites in the Hatis group functioned solely as workshops based on their location and high concentration of refined lithic products (Gasparyan, 2010; Gasparyan et al., 2014a, 2020). However, these conclusions are based on a highly selective collection of surface material. Gasparyan (2010) has also suggested, based on the surface collections, that the shape of LCTs and other tools at open-air Hatis sites and other Late Acheulian sites are the consequence of the restrictions imposed by the shape of the available toolstone. These arguments are rooted in the history of Acheulian research in the Armenian Highlands (Gasparyan et al., 2020; Lyubin, 1965) and the Levant (McPherron, 2000) and are often invoked as explanations of assemblage and artifact-level characteristics for sites situated close to raw material sources. However, arguments of toolstone as the deciding factor in artifact form often fail to explain actual variation in stone tool morphology (Eren et al., 2014; Lycett et al., 2016). As Hatis-1 has not previously been published in detail, it is difficult to assess the reality of these contentions.

Renewed Study

Excavation Methods

Hatis-1 was reinvestigated by the authors in 2016–2017 in order to understand the stratigraphic context of the site and recover a new highly contextualized lithic assemblage. During this renewed work, the original test unit from 1984 was located, emptied of eroded sediments and artifacts, and expanded. Work focused on artifact recovery and the expansion of the original test pit by 0.5 m to the west so as to better document the stratigraphy. A small number ($n = 4$) of artifacts were recovered from the general cleaning of the eastern profile, and numerous artifacts were recovered from wall collapse sediments that infilled the test pit. A new site grid and three site datums were established using a Leica total station. GPS locations were recorded for each site datum using a handheld Trimble Geo XT data collector. While the dimensions of the original test unit were recorded using the total station, recovered artifacts and stratigraphy were recorded manually by measuring from an established level above the ground surface. The western profile was dug in 20-cm spits due to initial difficulty in reading the stratigraphy. All finds were later assigned to stratigraphic units based on their measured locations. Sediments were not sieved due to the difficulties posed by the ubiquity of gravels and cobbles in the stratigraphic units. The size cut-off for recording artifacts was 1 cm due to the prevalence of small, natural obsidian gravels in the sediments.

Stratigraphy

The fresh stratigraphic section created by excavating the c.2.0–2.5 m thick western profile back 0.5 m led to the identification of seven stratigraphic units (Units I–VII) based on variations in composition, grain size, color, and inclusions (Fig. 3). The sediment in all units is poorly sorted with angular to subangular clasts.

Underlying the seven stratigraphic units is a dense tuff-like conglomerate containing fragments of mafic lava, perlite, and obsidian, cemented together with carbonates. At the base of the test pit, this conglomerate begins to surface as a solid, pinkish grey layer (Unit Ia) through which it was not possible to dig. Above this, Unit I is composed of a compacted pinkish grey lapilli with volcanic ashes, small gravels, and masses of the tuff-like conglomerate. Unit II is a thick layer of lapilli with numerous gravels and boulders varying in size from c. 10 to > 60 cm in maximum dimension. The gravels are mostly mafic lava and tuff, but two large, angular, core-like pieces of obsidian were documented in the north corner of the trench in this unit. Unit III exhibits a high density of small obsidian coarse gravels and cobbles, averaging 5–10 cm, in a matrix of light grey lapilli. Units IV and V look similar and consist of grey lapilli mixed with small, rounded cobbles,

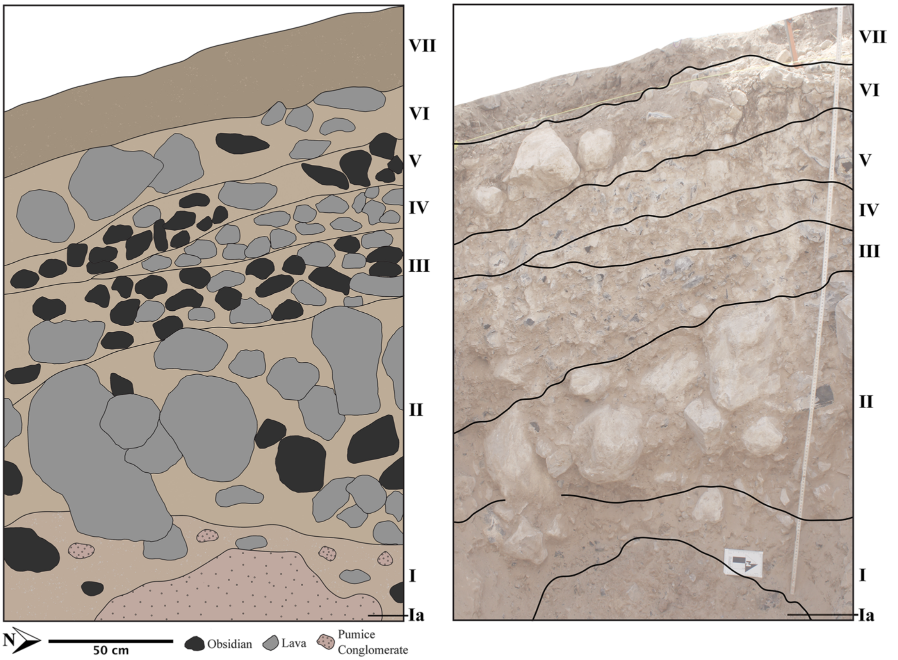


Fig. 3 Profile drawing (left) and photograph (right) of the Hatis-1 western section after excavation and cleaning. The photograph is taken at a slightly different angle to that of the profile drawing

5–10 cm on average; Unit IV contains almost exclusively mafic lava and perlite coarse gravels and cobbles, whereas Unit V consists mostly of obsidian. Unit VI is composed of clastic sediments with carbonate and large mafic lava and tuff boulders of an average size exceeding 30 cm in a grey lapilli matrix. Unit VII is composed of poorly sorted, slightly humic, light brown greyish lapilli mixed with rounded gravels averaging c. 5 cm in size, and contains roots and other organic materials.

Unit I is tentatively interpreted as the weathered top of Unit Ia, the solid conglomerate of tuff-like material, most likely formed as a result of a pyroclastic flow or fall during a volcanic eruption (Vincent, 2000). Unit II is interpreted as a high-energy slope deposit. The ash matrix contains gravels, cobbles, and boulders of a heterogeneous nature both in size and composition (obsidian, rhyolite, perlite, mafic lava, tuff, and conglomerate inclusions) that is indicative of high-energy slope processes resulting in the transportation of weathered volcanic material from the surrounding area (UI et al., 1995). Units III–VI are interpreted as slope deposits with different source locations based on the varying composition of the encased gravels. Judging by the relative homogeneity in size of the gravel content, the energy of these displacements was not very high. Unit VII is interpreted as a weakly developed A horizon soil formed in recent low-energy slope deposits.

As discussed elsewhere in this paper, most of the obsidian artifacts show signs of weathering and damage likely resulting from lateral transport in slope deposits due to mass movement processes. Based on these stratigraphic observations, we argue that the lithic assemblage from Hatis-1 is not in primary context.

Lithic Analysis Methods

The analytical methods employed at Hatis-1 were selected in order to maximize the potential for future comparisons with sites within and outside of the study region. All artifacts were treated with a hydrochloric acid (HCl) solution prior to analysis to remove heavy carbonate coatings that obfuscated most surface features. All handaxes, most cores, and a sample of complete flakes were 3D scanned as part of an ongoing multi-site project to document technological change in the Armenian Pleistocene. Ninety-three artifacts were digitized using a Geomagic Capture structured light scanner, with a resolution of 0.110 mm and an accuracy of 0.060 mm (3D Systems, 2019a). All scans were processed into a watertight mesh using Geomagic Wrap software and oriented to a common coordinate system in Geomagic Design-X; this is similar to the process used in OPTOCAD as described by Bretzke and Conard (2012) (3D Systems, 2019b). Completed meshes were used for landmark-based 3D geometric morphometrics (3D-GM) and to record highly accurate measurements in the subsequent analysis of diagnostic artifacts.

General attribute, metric, typological, and technological analysis of the Hatis-1 assemblages follows Bordes (1961), Sullivan and Rozen (1985), Tostevin (2013), and Goren-Inbar et al. (2018). Here, items are classified as core-on-flake if there are one or more removals from the original flake blank (Agam et al., 2015; Ashton, 2007; Dibble & Mcpherron, 2007; Schroeder, 2007). When discussing removal patterns on flakes and cores, the term bidirectional is used to refer to removals originating from any two directions, while opposed is used to refer to bidirectional scars removed from opposing directions. Where possible, measurements were taken on 3D models and using digital calipers to ensure the accuracy of the 3D meshes. Flakes and flake-based artifacts were placed into large (≥ 10 cm) and regular (< 10 cm) size categories (Kleindienst, 1962). Patination, edge damage, and wear on the ridges of flake scars were analyzed to determine artifact taphonomy (Burroni et al., 2002; Chambers, 2016; Glauberman & Thorson, 2012).

Following de la Torre (2016), we group both large and small bifaces as well as single large unifacial cutting tool into the LCT category for analysis. This allows for comparison of production strategies between the bifacial and unifacial LCTs. Two separate, but overlapping, approaches were used to address LCT variation in the assemblage. Bordes' (1961) metrics and indices for LCT type determination are used to investigate general trends in typological variation. However, here we follow a modification to this approach used at Gesher Benot Ya'aqov (GBY) (Goren-Inbar et al., 2018). The traditional measure of width at 3/4 the implement length is replaced with a measure at 4/5 the length to better discriminate between pointed and non-pointed varieties. Additionally, LCT subtypes defined using subjective criteria are not used here; instead, we favor groupings based on quantitative criteria alone.

The Western European Acheulean Project (WEAP) method (García-Medrano et al., 2020) is the second approach utilized for the study of the LCT component.

As the name implies, this method was created with western European assemblages in mind. However, the Acheulian can be considered a homologous cultural entity (Shipton, 2020), which allows for the application of this approach throughout Eurasia and Africa. This method combines the measures of Bordes (1961) and Roe (1968), additional metrics such as edge angles, and technical features such as Shipton and Clarkson's (2015a) scar density index (SDI). Here, the measures are taken using the aforementioned Geomagic Design-X software as opposed to the software utilized by García-Medrano et al. (2020). Using WEAP methodology, handaxes are viewed both as a complete implement and as the sum of three interconnected parts, the distal, medial, and proximal areas. Principal component analysis (PCA), a technique for reducing dataset dimensionality into new variables while minimizing data loss, of WEAP categorical variables one-hot encoded into binary variables and subsequent statistics were performed in the paleontological statistics software package PAST (Hammer & Harper, 2001; Nguyen & Holmes, 2019). Linear discriminant analysis (LDA), another method for reducing dataset dimensionality into new variables, and other statistical methods were performed using a subset of principal components (PCs) from PCA, the number of which was determined using a broken-stick null model (Jackson, 1993). The overall design of WEAP is well-suited for investigating inner- and inter-site patterns of variation.

LCT 3D scans were subjected to simple landmark-based 3D-GM analysis in order to address total shape variation in the assemblage. This type of statistical shape analysis is widely used in the field of biology and has seen increased use in archeology over the last two decades (Bookstein, 1991; Okumura & Araujo, 2018). The use of morphometric analysis to test for LCT type differences here is appropriate as the concept of shape is an essential component in classification schemes of lithic technology (Dibble & Chase, 1981; Odell, 1981; Riddle & Chazan, 2014; Roe, 1968). GM methods have been successfully applied to questions of variation in and relationships between artifact types (Archer & Braun, 2010; Costa, 2010; Lycett, 2009; Lycett & Gowlett, 2008; Porter et al., 2019). Handaxes were manually positioned in Geomagic Design-X prior to landmark placement to reduce orientation error in the subsequent analysis (Archer & Presnyakova, 2019). A template of 160 landmarks was created in dHAL Viewbox 4 using a randomly selected LCT from Hatis-1 (dHAL, 2014) (Fig. 4). Type III landmarks were placed on the proximal and distal extremes, as well as on the midpoint of each lateral convexity. These were used to guide the placement of the remaining 156 curve and surface semi-landmarks. A total of thirty-six sliding-curve semi-landmarks were evenly spaced along the plane of intersection between the upper and lower convexities. The remaining 120 sliding-surface semi-landmarks were evenly distributed on the upper and lower convexities. This methodology is similar to that used by Polychronis et al. (2013). Once complete, the landmark template was applied to the remaining LCTs based on the placement of the first four type III landmarks. Sliding and projection of all curve and surface landmarks was repeated, while minimizing bending energy, until optimum point position was attained. Generalized Procrustes analysis with partial Procrustes superimposition in the R package Geomorph was used to translate, scale, and rotate all landmark datasets (Adams et al., 2019; Goodall, 1991). This was done in order to assure all further analysis was strictly within shape space, removing size,

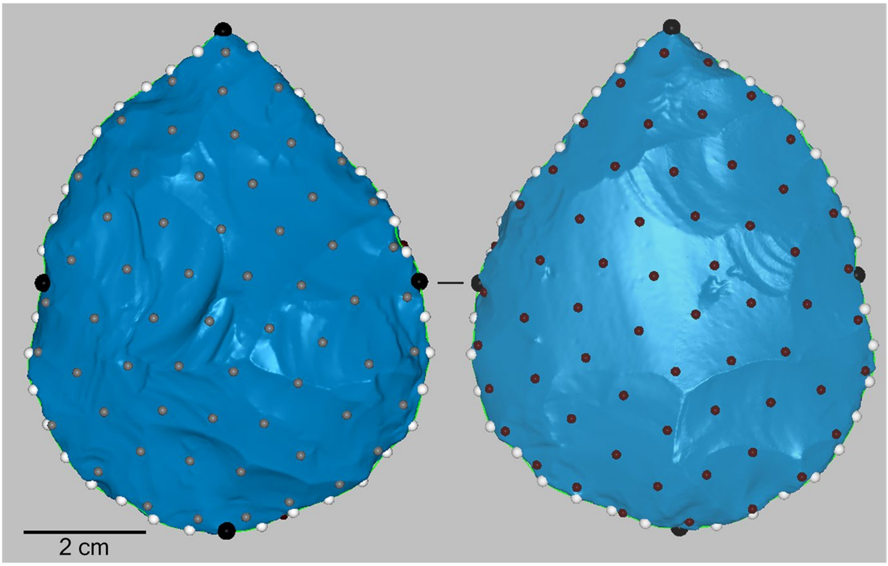


Fig. 4 3D scan of a cordate LCT from original excavation (Assemblage D) showing landmark placement for GM analysis. Larger black landmarks are type III used to guide the placement of curve (white), dorsal surface (grey), and ventral surface (dark red) semi-landmarks.

position, and orientation. PCA of the transformed dataset was performed using the R packages Geomorph, Shapes, and Morpho (Adams et al., 2019; Dryden, 2018; Schlager, 2017).

A set of 310 obsidian lithic artifacts was sourced in 2017 in our field laboratory using a Thermo Niton 950 XL3t GOLDD + portable X-ray fluorescence (pXRF) instrument. This model is equipped with a silicon drift X-ray detector (SDD; energy resolution ≤ 155 eV in practice) and a miniaturized 2-W tube (Ag anode, 50 kV maximum voltage, 200 µA maximum current). The elements of interest (i.e., Rb through Nb) were measured using the "main" filter and conditions (40 kV voltage, ≤ 50 µA current) in the "mining" analytical mode for 20 s. All measurements used the fundamental parameters (FP) approach to account for physical phenomena (e.g., absorption and fluorescence edge energies, incoherent scattering) that can affect the measured X-ray spectra and that must be "corrected" during quantification calculations. The instrument's factory-set calibration, which was based on standard reference materials (SRMs) principally certified by the United States' National Institute of Standards and Technology (NIST) as well as the United States Geological Survey (USGS), was "fine-tuned" using a collection of 24 well-characterized obsidian specimens (Frahm, 2014). Accuracy was evaluated using three additional well-characterized obsidian specimens: NIST SRM 278 (Newberry Volcano, Oregon, USA), USGS RGM-1 (Glass Mountain, California, USA), and MURR GBOR01 (Little Glass Buttes, Oregon, USA). Our measurements exhibited good agreement with the recommended or certified values for these obsidian sources and with the values from published datasets.

Results of Lithic Artifact Analysis

Results by Assemblage

A total of 332 lithic artifacts larger than 1 cm from both the original excavation ($n=13$) and recent re-excavation ($n=319$) are reported here. Of the artifacts included in this study, 169 have no context as they are from the original excavation or were recovered during general cleaning of the original test pit and are not associated with stratigraphic units. The remainder of the assemblage was recovered from the expansion of the western section ($n=159$) and light cleaning of the eastern section ($n=4$). Artifacts recorded in 20-cm spits against sloping stratigraphy made it difficult to assign finds from Units III to VI to their exact stratigraphic unit; therefore, these artifacts are grouped together and should be understood as a palimpsest of material from different depositional units. Lithic artifacts can be assigned to Units I and II with a high level of confidence due to the relative lack of slope and ease of differentiating these units during excavation. The artifacts recovered during initial cleaning of collapsed profiles and those from the original excavation without context are grouped together here to allow for a general understanding of technology at the site, but should not be mistaken for a discrete assemblage. In light of this, lithics are placed into four analytical assemblages: Assemblage A (Unit I), Assemblage B (Unit II), Assemblage C (Units III–VI), and Assemblage D (no context). Obsidian is almost exclusively used at the site, with the exception of three artifacts produced on dacite, all of which are LCTs. The analyzed assemblage contains cores (21), a core trimming element (CTE) (1), bifacial LCTs (17), a unifacial LCT (1), retouched flake tools (22), thinning flakes (2), a discoid flake (1), Kombewa (sensu lato) flakes (7) (Owen, 1938), elongated flakes (9), non-diagnostic flakes (234), debris < 2.5 cm (3), and angular fragments (14) (Table 1). Large flakes, those ≥ 10 cm, comprise 45.1% of all complete flakes and artifacts produced on flake blanks (i.e., cores, LCTs, and retouched tools) ($n=191$) (Table 2).

In Assemblages A–D, there are low to moderate degrees of edge damage and ridge wear indicative of low to moderate levels of rolling and other movement (Burroni et al., 2002; Chambers, 2016). As blank damage can mimic retouch, only the most obvious signs of retouch are used to categorize artifacts as tools (McBrearty et al., 1998). Complete flakes make up the majority of debitage at the site, with incomplete flakes accounting for 43.3% ($n=254$). The majority (> 80%) of artifacts in all assemblages are moderately to highly patinated, many of which show greater degrees of patination on one face relative to the other (Fig. 5), and in some cases, the degree of patination obscures flake scar directionality, complicating this part of the analysis. Many artifacts also retain some degree of carbonate crust after being treated with HCl, which also affects artifact legibility. The overall condition of the artifacts at Hatis-1 suggests some degree of lateral gravity- or water-driven movement commensurate with the colluvial depositional environment of the site, as well as chemical weathering from prolonged surface exposure and/or sedimentary processes (Glauberman & Thorson, 2012). The

Table 1 Techno-typological summary of the lithic artifacts recovered from Hatis-1during the renewed excavation. Assemblage D contains 13 artifacts from original excavation. % Total-2 is based on the total count of lithic artifacts excluding the Debris (angular and < 2.5 cm). *Elongated here refers to elongated blanks that are blade-like with parallel edges and triangular cross sections, but may not be the result of intentional blade production

Class	Assemblage A	Assemblage B	Assemblage C	Assemblage D	Total	%Total ($N=332$)	%Total-2 ($N=315$)
Core ($N=21$)	2	8	1	10	21	6.3%	6.7%
Core-on-flake	1	5	0	5	11	52.4%	
Simple prepared	0	0	0	2	2	9.5%	
Multi-platform	1	3	1	2	7	33.3%	
Discoid	0	0	0	1	1	4.8%	
Ind	0	0	0	0	0	0.0%	
Long cutting tool ($N=18$)	0	1	0	17	18	5.4%	5.7%
Unifacial LCT	0	0	0	1	1	5.6%	
Bifacial LCT	0	1	0	16	17	94.4%	
Retouched tool ($N=22$)	0	5	3	14	22	6.6%	7.0%
Side scraper	0	2	1	7	10	45.5%	
Transverse scraper	0	1	1	4	6	27.3%	
Convergent scraper	0	1	0	0	1	4.5%	
Notched types	0	0	0	3	3	13.6%	
Truncated/faceted	0	0	1	0	1	4.5%	
Ind. tool	0	1	0	0	1	4.5%	
Debitage ($N=254$)	31	80	18	125	254	76.5%	80.6%
Complete	14	43	15	72	144	56.7%	
Distal	7	14	1	7	29	11.4%	
Medial	9	19	2	30	60	23.6%	
Proximal	1	4	0	16	21	8.3%	
Debitage technology	Assemblage A	Assemblage B	Assemblage C	Assemblage D	Total	% total	
Biface	0	0	0	2	2	0.8%	
CTE	0	1	0	0	1	0.4%	
Discoid	0	1	0	0	1	0.4%	

Table 1 (continued)

Kombewa	3	1	1	2	7	2.8%
*Elongated**	0	2	0	7	9	3.5%
Non-diagnostic	28	75	17	114	234	92.1%
Total	31	80	18	125	254	100.0%
Debris (N = 17)	2	12	0	3	17	5.1%
< 2.5 cm	1	2	0	0	3	17.6%
Angular	1	10	0	3	14	82.4%
Total (N = 332)	35	106	22	169	332	100%

Table 2 Measurements of complete blanks, tools, and cores-on-flakes by assemblage at Hatis-1

	Unretouched	Retouched	Core-on-flake
Assemblage A			
n	14	0	1
Length	42 ± 20.2	-	154.6
Width	44.4 ± 25.4	-	136.4
Thickness	12 ± 8.4	-	66.7
n Large (> 10 cm)	1	-	1
Assemblage B			
n	43	5	5
Length	59.9 ± 22.2	70.6 ± 25	90.3 ± 22.8
Width	53.2 ± 19.8	65.4 ± 18.5	96.3 ± 30.4
Thickness	16.8 ± 8.3	35.1 ± 32.3	42.6 ± 21
n Large (> 10 cm)	4	1	3
Assemblage C			
n	15	3	0
Length	77.8 ± 33.3	104.2 ± 33.7	-
Width	75.7 ± 27	108.3 ± 26	-
Thickness	22.1 ± 10.6	66.4 ± 8	-
n Large (> 10 cm)	5	3	-
Assemblage D			
n	72	14	5
Length	87.8 ± 30.7	91.1 ± 25.4	102.6 ± 33.8
Width	75.5 ± 25.2	82.4 ± 33.5	113.6 ± 43.8
Thickness	37.7 ± 10.6	23.7 ± 7.4	42.7 ± 27.9
n Large (> 10 cm)	47	7	3

Fig. 5 Selected obsidian blank from renewed excavation (Assemblage D) showing difference in degree of patination between the dorsal surface (left) with low patination and the ventral surface (right) with high patination

original location of all assemblages is likely upslope to the north of the current site, approximately 250 m from the lowest series of ridgelines, regardless of the energy level of the depositional process.

All of the 310 obsidian artifacts sourced by pXRF derive from Hatis volcano itself. As recently documented by Frahm et al. (2021), this volcano is highly unusual, perhaps unique, in that its obsidian changes in composition with elevation. Four different chemical types of obsidian occur on the volcano's southern slopes (Fig. 2). Outcrops of two obsidian types, which have been termed Hatis-alpha and Hatis-gamma (Frahm et al., 2021), occur directly above the site of Hatis-1. All but 6 of the 310 artifacts (98%) are Hatis-alpha obsidian, and the remainder (only 1 of which derives from a stratified context during the new excavations) are Hatis-gamma obsidian. These results, which reveal no exogenous obsidian artifacts (contra NG-1 in Adler et al., 2014), indicate an essential relationship between the site and these nearby obsidian outcrops (Table S1). The findings also provide some evidence about the degree of transport of the assemblage. If the assemblage derived from much farther up the slopes of the volcano, the artifacts would likely reflect a much higher proportion of Hatis-gamma (and, potentially, Hatis-delta) obsidian. Given that the lithics are overwhelmingly Hatis-alpha obsidian, it seems unlikely that the assemblage has been transported farther than the 250 m from the nearest ridgeline of Hatis-alpha obsidian. The closest Hatis-gamma obsidian outcrop is less than 400 m from the site, and its knapping quality equals that of Hatis-alpha obsidian, meaning that there is no pressure to preferentially select one of these obsidian types over another, thereby ruling out such a hypothesis for the abundance of Hatis-alpha obsidian relative to Hatis-gamma obsidian. An initial depositional location of the lithics closer to the Hatis-alpha obsidian outcrops is the most plausible interpretation for these findings.

Assemblage A consists of 35 artifacts dispersed vertically over c. 35 cm in Unit I. The majority ($n = 30$) of this assemblage is composed of flakes and debris. This includes one small piece of debitage and one larger angular fragment. Three Kombewa (sensu lato) flakes were recovered from this unit. Retouched tools do not appear in Assemblage A. This assemblage also contains two cores: one broken multi-platform core and one core-on-flake. The multi-platform core is polyhedron in form with flake scars being used as platforms for subsequent removals. All artifacts from Assemblage A are sourced to the proximate Hatis-alpha obsidian outcrop (Fig. 2). Two blanks fall into the large flake category, one of which is a Kombewa flake and the other is the core-on-flake.

Assemblage B is composed of 106 artifacts dispersed vertically over c. 80 cm in Unit II. Much like Assemblage A, the majority of this assemblage is composed primarily (83%) of flakes and debris. One Kombewa (sensu lato) flake was recovered in this unit. Two elongated flakes with high length/width (L/W) ratios (> 2.5) and triangular cross sections were also recovered, as was a CTE with a L/W ratio of 4.7. While these artifacts may not be the product of systematic blade production (Boëda et al., 1990), they could suggest a different flaking strategy relative to the rest of the assemblage. Assemblage B also contains five steeply retouched tools, including single side, transverse, and convergent scraper types. One retouched tool is fragmented and therefore is not attributed to a type.

Assemblage B contains eight cores, five of which are core-on-flake and three are multi-platform cores. The multi-platform cores are polyhedron in form with all removals utilizing other flake scars as striking platforms. The five cores-on-flake are classified as such as the original flake's ventral surface is used as the detachment surface for subsequent removals. Furthermore, this assemblage contains the only LCT recovered from a stratigraphic unit during the re-excavation of Hatis-1. This cordiform LCT is described in more detail below. Two large natural obsidian cobbles (> 3000 g) recovered from this unit may have been tested, but their overall condition, which is more rolled than the associated artifacts, suggests the visible removals may be entirely natural. All lithics from this assemblage are sourced to the proximate Hatis-alpha source (Fig. 2), except for one core-on-flake and one flake, which are obsidian but were not analyzed by pXRF. Eight blanks fall into the large flake category, three of which were used as cores, and one is retouched.

Assemblage C contains 22 artifacts dispersed vertically over c. 70 cm and four stratigraphic units (III–VI). This includes four artifacts recovered from corresponding units in the eastern profile. The assemblage is composed of non-diagnostic flakes ($n = 17$), one Kombewa flake (sensu lato), one cobble core with a polyhedron form and opposed scar morphology, and three steeply retouched tools, including a side scraper, a truncated/faceted piece, and a transverse scraper. Much of this assemblage is sourced to the nearby Hatis-alpha source ($n = 20$), with one flake coming from the higher elevation gamma source (Fig. 2) and the obsidian cobble core was not analyzed by pXRF. Eight flakes are definable as large (≥ 10 cm), three of which are the retouched tools.

Assemblage D contains 169 lithic artifacts including finds from the surface, general cleaning of the original excavation pit, and the few finds from the original excavation that could be located. The majority (69.2%) are flakes and debris, two of which are classified as Kombewa (sensu lato) flakes. Elongated flakes with triangular cross sections and parallel lateral edges make up 3.6% of this assemblage. Two overshot flakes recovered from the initial pit cleaning have parallel edges, high curvature, flake scar patterns, and faceted platforms indicative of biface resharpening/thinning (Bergman et al., 1990; Sharon & Goren-Inbar, 1999). Retouched tools make up 8.3% of assemblage and include transverse, single side, multi-location, convergent, denticulated, and complex notch varieties (Fig. 6a). More variation in retouch type is evident in this assemblage with steep ($n = 5$), light non-invasive ($n = 5$), invasive ($n = 2$), inverse ($n = 1$), and complex notching ($n = 1$) styles.

Assemblage D contains ten cores, including five cores-on-flakes, two multi-platform cores, two simple prepared cores, and one discoid core. Four of the five cores-on-flakes are typological Kombewa (sensu lato) with the blanks' ventral surfaces utilized as a flake detachment surface. The ventral surface on the fifth core-on-flake is used as the striking platform, with flakes detached from the original dorsal surface. The two multi-platform cores include a broken polyhedron and a complete cobble core. The two simple prepared cores are unique to this assemblage. Both have limited, small lateral removals around a larger preferential removal (Fig. 6b). These cores are hierarchically organized around an intersecting plane between the reduction and preparation surfaces. Most of the cores' volumes are on the surfaces opposite the main flake detachment surfaces, which is

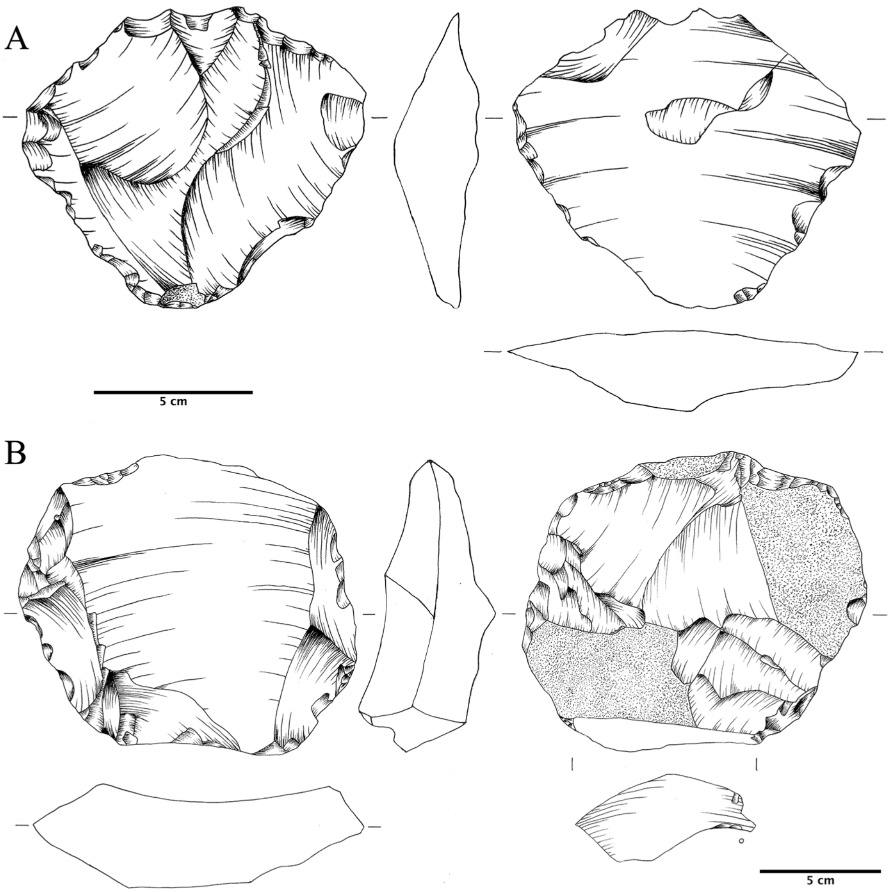


Fig. 6 Select Hatis-1 artifacts from renewed excavation (Assemblage D). **A** Retouched tool. **B** Simple prepared core

shaped by smaller, more irregular removals. The preferential removals from these cores are both > 10 cm in length and the corresponding flakes would fall into the large flake category. The main detachment surface of each core has bidirectional removals, with the opposite surface being semi-centripetally worked. While we err on the side of caution here and report these as simple prepared cores, they share many attributes with early Levallois cores recovered from the northern component of NG-1 and the simple prepared cores from both loci at NG-1 (Adler et al., 2014). The size of these prepared cores is also reminiscent of large Levallois variants from the late Early Stone Age of Africa (Kuman, 2001; McBrearty & Tryon, 2006; McBrearty et al., 1996; Tryon et al., 2005). The recovered discoid core is also organized around an intersecting plane; however, there is no hierarchical relationship between the surfaces, as each surface is exploited equally. Assemblage D also contains seventeen LCTs, which are described below.

Of the 169 artifacts from Assemblage D, 82.2% are from the immediate Hatis-alpha obsidian source, 3% are from the higher Hatis-gamma source (Fig. 2), 1.8% are produced on dacite, and 13% were not analyzed by pXRF but still produced on obsidian. The Hatis-gamma sourced artifacts include three LCTs and two undiagnostic flakes. The three dacite artifacts are all LCTs. Fifty-seven flakes from this assemblage fall into the large category, three of these are recycled as cores and seven are retouched tools. As Assemblage D resembles A–C, we can reasonably assume that it is derived from these units and there is little change in assemblage composition from top to bottom of the sampled section.

In all assemblages with retouched tools (B, C, and D), the blanks selected for retouch are on average larger than unmodified blanks (Table 2), but these differences are not statistically significant (two tailed *t* tests, $p > 0.05$). Likewise, in assemblages with cores-on-flakes (A, B, and D), the blanks selected for use as cores are larger, on average, than unmodified blanks (Table 2), but again these differences are not significant (two tailed *t* tests, $p > 0.05$). However, this may be an important qualitative observation as many of the blanks selected for use as cores and retouched tools fall into the large flake category. In each assemblage, flakes and retouched tools are mostly expanding or ovoid in shape, with mainly triangular or trapezoidal cross sections, and predominantly straight profiles (Table 3). Flake platforms are largely crushed or missing in all assemblages, but when present are mainly plain with limited occurrences of dihedral and faceted platforms (Table 3). The general lack of platform preparation speaks to the expedient nature of flake production at the site. Scar directionality on flake dorsal surfaces is primarily unidirectional and bidirectional across all assemblages, but opposed, semi-centripetal, and centripetal patterns were observed (Table 3). Scar patterns recorded on cores are largely opposed or bidirectional, with no unidirectional patterns recorded, and multiple amorphous patterns on polyhedron forms (Table 3).

Results of LCT Analysis

The LCT component of Hatis-1 is made up of eighteen artifacts, of which only one was recovered during the excavation (Assemblage B in Unit II). LCTs have the most toolstone variation of any typological class at the site. Eleven of the LCTs are produced on Hatis-alpha obsidian, with three produced on Hatis-gamma obsidian, three on dacite, and one obsidian piece that was not analyzed by pXRF. Blank selection at the site favors large flakes for handaxe production, with fourteen of the LCTs having clear remnants of ventral surfaces. Only one thick, relatively unrefined, handaxe appears to be produced on a nodule, with a further three having their original blank type obscured by the reduction process. Three of the LCTs produced on flakes fall below the large flake threshold, but two of these have a high SDI suggesting they are the most heavily reduced at the site (Shipton & Clarkson, 2015a). All other ($n = 15$) LCTs have an SDI range of 8.2–20.0, with an average of 13.9 ± 4.4, while the two smallest have SDIs of 30.0 and 40.9. The third handaxe has an SDI of 15.7, well within the range of most LCTs, but is only marginally below the large flake threshold at 9.3 cm in length. The three smaller LCTs were likely initially produced

Table 3 Attributes of blanks, tools, and cores by assemblage at Hatis-1. Counts (n) reported here represent the number of complete, or near complete, blanks, tools, and cores on which it was possible to ascertain data in most of the reported categories and as such may not match counts reported for each assemblage in Table 1.*Patina denotes scar direction is unreadable due to patination. **Amorphus denotes scar patterns that appear entirely random or cores with amorphus shape which prevents an accurate reporting of the scar patterning

	Assemblage A (*n* = *14*)		Assemblage B (*n* = *47*)		Assemblage C (*n* = *17*)		Assemblage D (*n* = *83*)	
	n	%	*n*	%	*n*	%	*n*	%
Blank shape								
Expanding	6	42.9%	19	40.4%	6	35.3%	38	45.8%
Ovoid	4	28.6%	19	40.4%	10	58.8%	24	28.9%
Convergent	3	21.4%	4	8.5%	0	0.0%	6	7.2%
Parallel	1	7.1%	5	10.6%	1	5.9%	15	18.1%
Cross section								
Trapezoidal	8	57.1%	21	44.7%	10	58.8%	35	42.2%
Triangular	3	21.4%	19	40.4%	4	23.5%	32	38.6%
Domed	1	7.1%	4	8.5%	1	5.9%	13	15.7%
Lenticular	2	14.3%	3	6.4%	2	11.8%	3	3.6%
Curvature								
Curved	1	7.1%	5	10.6%	2	11.8%	12	14.5%
Straight	13	92.9%	42	89.4%	15	88.2%	70	84.3%
Twisted	0	0.0%	0	0.0%	0	0.0%	1	1.2%
Platforms								
Plain	1	7.1%	16	34.0%	4	23.5%	26	31.3%
Dihedral	0	0.0%	2	4.3%	0	0.0%	4	4.8%
Faceted	0	0.0%	1	2.1%	3	17.6%	0	0.0%
Crushed	1	7.1%	1	2.1%	10	58.8%	10	12.0%
Missing	12	85.7%	27	57.4%	0	0.0%	43	51.8%
Scar directionality								
Flakes								
Unidirectional	6	42.9%	11	23.4%	5	29.4%	27	32.5%
Bidirectional	5	35.7%	21	44.7%	5	29.4%	21	25.3%
Opposed	0	0.0%	2	4.3%	2	11.8%	15	18.1%
Semi-centripetal	0	0.0%	1	2.1%	0	0.0%	0	0.0%
Centripetal	0	0.0%	1	2.1%	1	5.9%	5	6.0%
*Patina**	3	21.4%	11	23.4%	4	23.5%	15	18.1%
Cores	(*n* = *2*)		(*n* = *8*)		(*n* = *1*)		(*n* = *10*)	
Unidirectional	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Bidirectional	1	50.0%	5	62.5%	0	0.0%	3	30.0%
Opposed	0	0.0%	0	0.0%	1	100.0%	0	0.0%
Semi-centripetal	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Centripetal	0	0.0%	0	0.0%	0	0.0%	4	40.0%
*Patina**	0	0.0%	0	0.0%	0	0.0%	1	10.0%
*Amorphous***	1	50.0%	3	37.5%	0	0.0%	2	20.0%

on large flakes and then reduced to their current state before discard. The original ventral surface of LCTs produced on flakes is less intensively worked than the dorsal surface with an average of 11.6 ± 4.7 flakes removed from ventral surfaces and 18.6 ± 5.2 flakes removed from dorsal surfaces. The use of large flakes for LCT production is a feature of LFA assemblages in other regions (Sharon, 2010).

Using edge roundness and location of maximum width, the LCTs largely fall into Bordes' shape zones III and IV, with one in shape zone II (Fig. 7). The shape zone II LCT has a low flatness ratio and is typologically categorized as a lanceolate type of this sub-triangular category (Fig. 8). Nine of the LCTs are metrically assignable to shape zone III, which contains both cordiform and amygdaloid types (Fig. 9). Seven of the nine are flat in form and fall into the cordiform type, while two have low flatness ratios and are better described as amygdaloid. The eight LCTs in shape zone IV includes five ovate, one discoid, and two core-like types (Fig. 10). The discoid forms have low elongation ratios and are generally flat. Ovate types are also flat forms, but have moderate elongation ratios. The core-like LCTs are by definition thick forms in shape zone IV, but the two reported here also have high elongation ratios. Three LCTs described here have large, preferential removals suggesting their use as cores (Fig. 11). However, neither of those categorized as core-like have these removals.

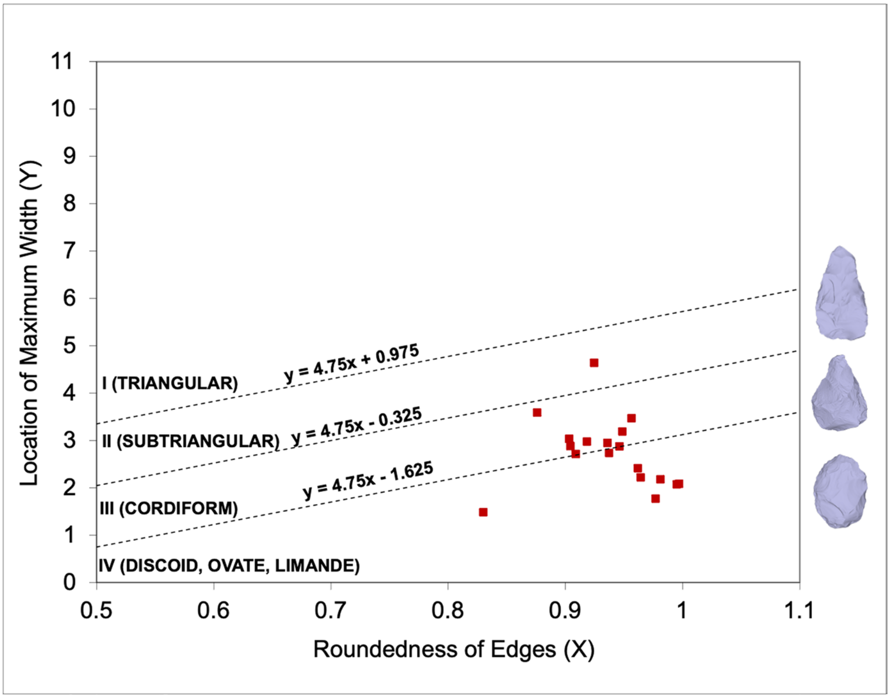


Fig. 7 Hatis-1 LCTs from original excavation and renewed work (assemblages B and D) plotted as Bordian types based on location of maximum width and roundness of edges (following Bordes, 1961). Images of 3D scans along right serve as examples of each type from the site. LCT from Assemblage B is in cordiform category

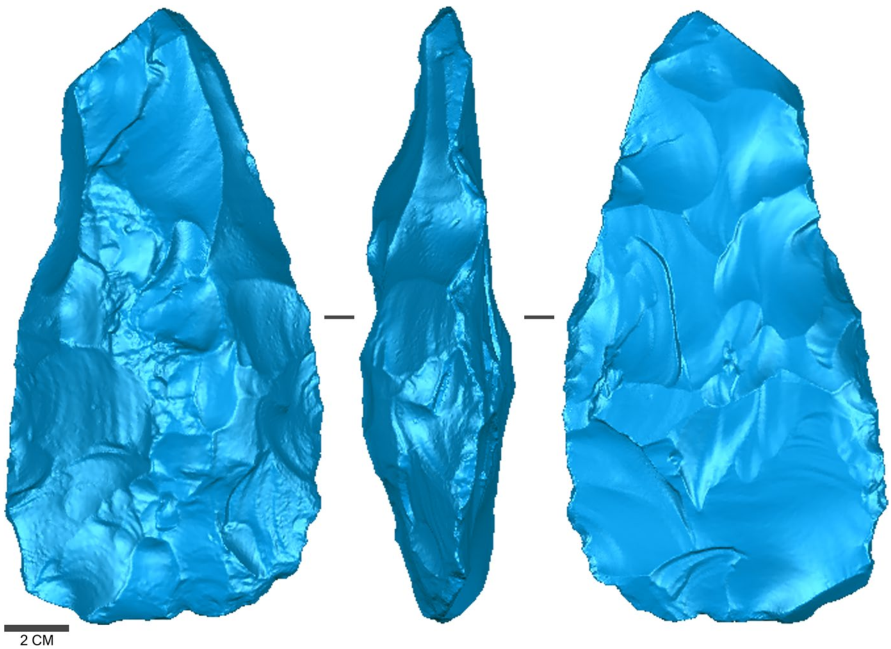


Fig. 8 The only LCT from Hatis-1 (Assemblage D) metrically assigned as lanceolate type, sub-triangular zone II

To simplify the following discussion of handaxe shape zones those falling into shape zone III subcategories will be referred to as cordates, those in shape zone IV subcategories will be referred to as ovoids, and the singular handaxe in shape zone II will be referred to as a lanceolate.

PCA of the technological features recorded using the WEAP method show some distinction between ovoid and cordate LCTs, which suggests these types may reflect differences in reduction strategy. Technologically, the singular lanceolate handaxe is no different than ovoid LCTs. MANOVA (Wilk's Lambda) of PC1 through PC5 (68.3% of variance) reveals the difference in the technological criteria recorded for ovoids and cordates is significant ($p = 0.049$). Further reducing the dimensionality of the first five PCs to two axes using LDA shows a similar pattern in groupings as those expressed by the first two PCs (Fig. 12). However, the PCA-LDA reveals less overlap between the two major shape groupings, while visualizing the lanceolate handaxe outside of these clusters. Using a confusion matrix, LDA correctly classifies LCTs into their a priori defined shape groups 83.3% of the time. While these results are encouraging, it is important to remember the sample size here is small and should thus be considered with caution. Loadings on PC1 (19.6% of variance) show that blank type, tip shaping strategy, depth of removals along the length of the implement, and removal sequences at the midpoint have a sizable effect on the variation of this axis (Fig. S1). Ovoid LCTs are less likely to be produced on flakes, more likely to have a general shaping strategy at the tip, more likely to have two removal sequences at the midpoint,

Fig. 9 Select LCTs from Hatis-1 (Assemblage D) metrically assigned as cordate type, cordiform zone III ▶

and more likely to have marginal removals along the length of the implement. Cordate LCTs are more likely to be produced on flakes, more likely to have final retouch or specific shaping strategies at the tip, more likely to have one removal sequence or final retouch at the midpoint, and more likely to have mixed or deep removals along the length of the implement. PC2 (15.6% of variance) is heavily driven by edge delineation, profile symmetry, and removal sequences at the base (Fig. S1). These results suggest that the differential application of production schemes is responsible for the two prominent types of handaxes at the site, rather than them being the outcome of restrictions imposed by raw material.

To maximize the difference between these predefined groups, between-group PCA was performed. All variance here is on PC1 (76.8%) and PC2 (23.2%). Between-group PCA places the lanceolate handaxe outside of the other groupings based on technological criteria. Loadings on PC1 suggest that blank type, profile symmetry, edge delineation, depth of removals at the tip, and general shaping strategy of the tip drive a large amount of variation on this axis (Fig. S2). Loadings on the second PC show that tip and midpoint removal sequences, as well as depth of removals at the midpoint and base, account for high degrees of variation on this axis. Taken together, the between-group and normal PCA results suggest some quantifiable differences in technology between the two main shape groupings at Hatis-1 centered around blank type, tip shaping strategies, and depth of removals. Reduction percentage does not seem to explain any difference between the two main shape types as there is no significant difference in their SDI (two tailed t test, $p = 0.171$). The outcome of the WEAP analysis along with the sorting of LCTs into Bordian types suggests that the application of various shaping strategies aligns well with the typological placement of each implement into either cordate or ovoid categories, which supports the utility of these categories as indicators of underlying behavioral variation.

PCA results of 3D landmark data show less differentiation between LCTs in each shape group. The first three PCs account for 73.6% of all variation, and all groupings largely overlap in shape space along these components. The broken-stick null model for these components retains only the first PC, which explains 48.9% of the shape variance. Ovoid and cordate group means are not significantly different on the first PC (two tailed t test, $p = 0.2765$). Bordes' shape zones are based on the interaction of two ratios that fail to capture the actual variation in 3D shape. However, the zones may better reflect subtle variations in technology that is obscured when focusing on overall 3D shape. The ratios used to calculate shape zones generally record shape outline and ignore surface topography; therefore, a PCA was run on the 3D landmark dataset a second time while excluding surface landmarks. The 3D outline PCA finds a similar pattern to the WEAP-PCA/LDA and Bordian typology (Fig. 13). The broken-stick null model for the components retains only the first two PCs, which account for 61.2% of variance. LCT examples in Fig. 13 illustrate the more rounded distal ends of ovoids and the more pointed tips of the other shape groups along the axis of the second principal

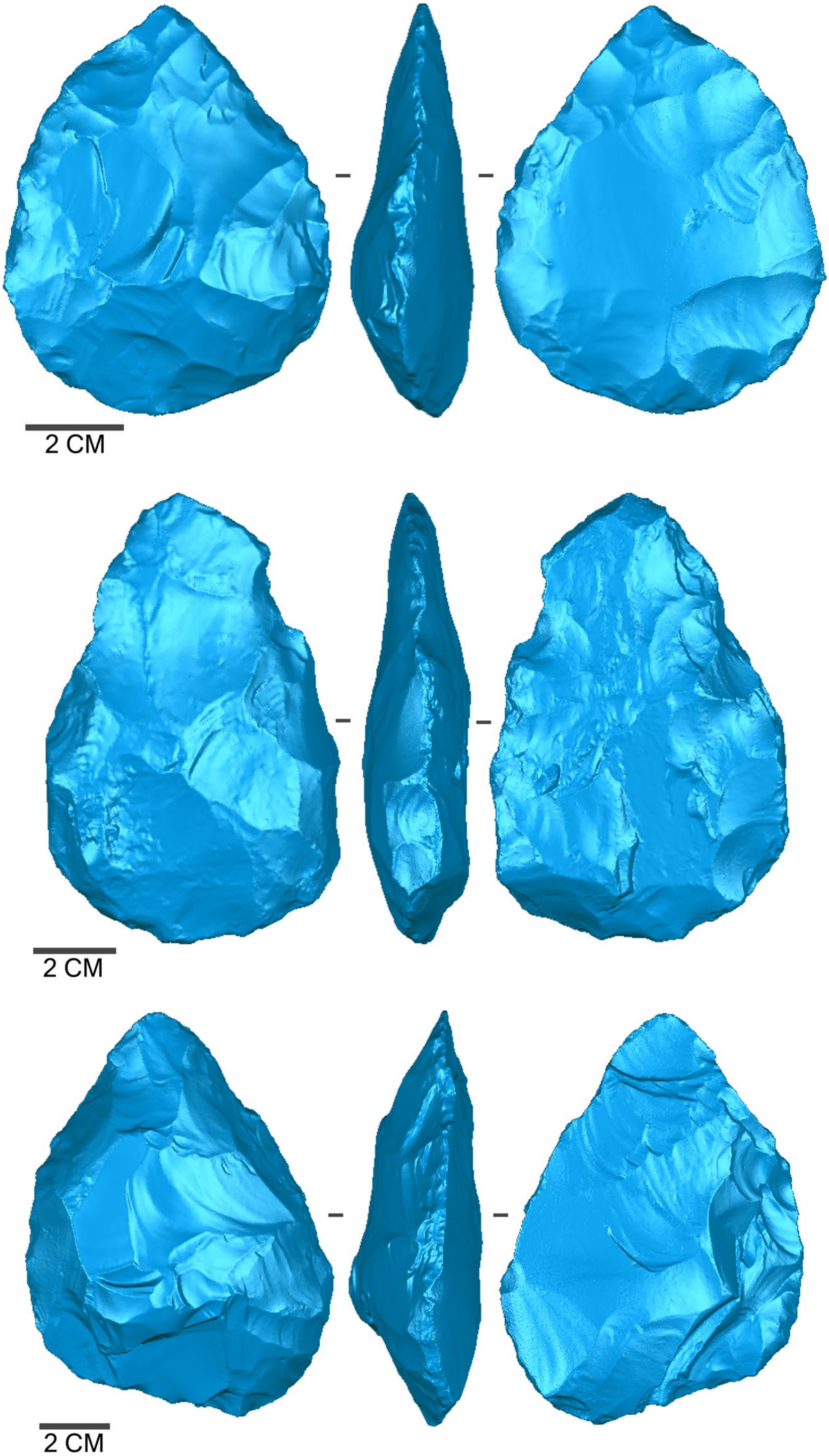

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Fig. 10 Select LCTs from Hatis-1 (Assemblage D) metrically assigned as ovoid type, ovate zone IV ▸

component. MANOVA (Wilk's Lambda) of PC1 and PC2 signifies that the difference in outline shapes of the two major shape zones, ovoids and cordates, is significant ($p = 0.001$). Combined with the WEAP analysis, this further supports the utility of sorting the LCTs at the site into the two main Bordian types, as these categorizations represent implements with statistically significant differences in their outline shape as the outcome of the application of various shaping strategies by the knappers responsible for the assemblages.

Discussion

Assemblages A–D at Hatis-1 document Late Acheulian occupations in close proximity to obsidian outcrops and within easy reach of resource-rich fluvio-lacustrine environments in the Hrazdan valley. Outcrops of the two closest obsidian chemical types (alpha and gamma) are used to the exclusion of all other obsidian sources, both those on the mountain and those in the surrounding landscape, and to the near exclusion of non-obsidian volcanic material. While no suitable samples for direct chronometric dating were recovered during the re-excavation, two factors constrain the age of the site. The site itself must postdate the formation of the Hatis volcano at c. 700 ka and the obsidian at c. 480 ka (Arutyunyan et al., 2007; Lebedev et al., 2013). Out of caution, we favor using c. 700/480 ka as the earliest possible date for the Hatis-1 material due to small sample sizes of obsidian and large uncertainties related to the obsidian dating (Arutyunyan et al., 2007; Frahm et al., 2021; Lebedev et al., 2013) and well-known issues involving the application of K–Ar to obsidian (Cerling et al., 1985; Morgan et al., 2009). Our team's ongoing geochronological work in the Hrazdan valley will help resolve these issues. The current techno-typological study of the lithic material and the reports from the original excavation suggest that the site techno-typologically predates the published assemblage from the nearby transitional site of NG-1, c. 335–325 ka (Adler et al., 2014). While both sites contain assemblages that are generally Late Acheulian in character, Hatis-1 contains less developed and fewer examples of prepared core technology and other typologically MP technologies when compared to NG-1. NG-1 contains more refined, small handaxes and developed blade production technology relative to the larger LCTs and elongated triangular flakes of Hatis-1. NG-1 is better understood as a Final Acheulian/transitional site, while the technology of Hatis-1 is more firmly Late Acheulian.

The technological behaviors documented at Hatis-1 are largely consistent across assemblages. While the small size of Assemblages A and C preclude any meaningful discussion about their composition, they generally contain the same core-on-flake and polyhedron core reduction technologies identified in the other assemblages. Cores-on-flakes are the most abundant core type found in both Assemblage B and Assemblage D (Fig. 14c). These cores point to a secondary state of lithic production, the first being the production of the original flake, possibly as part of a

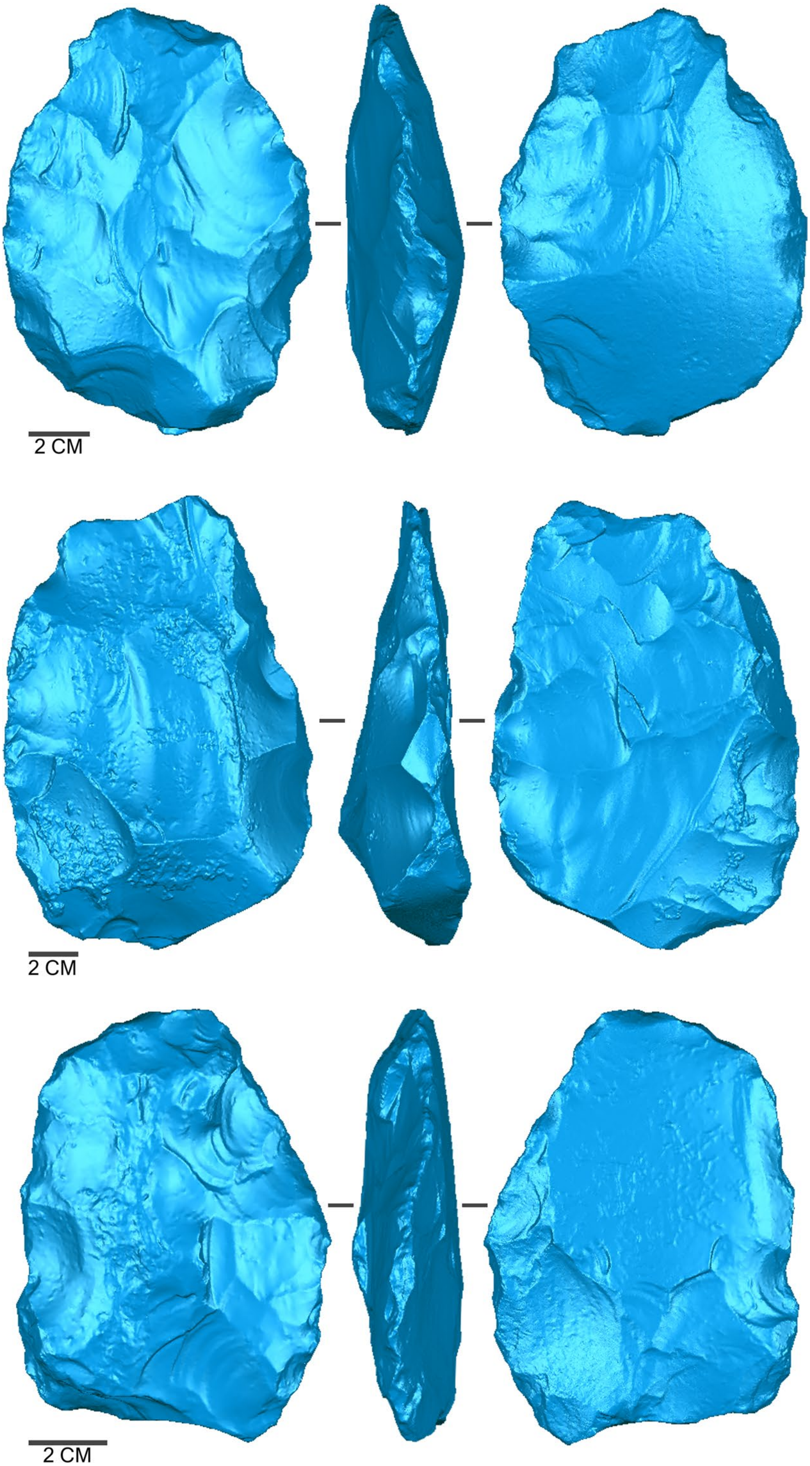
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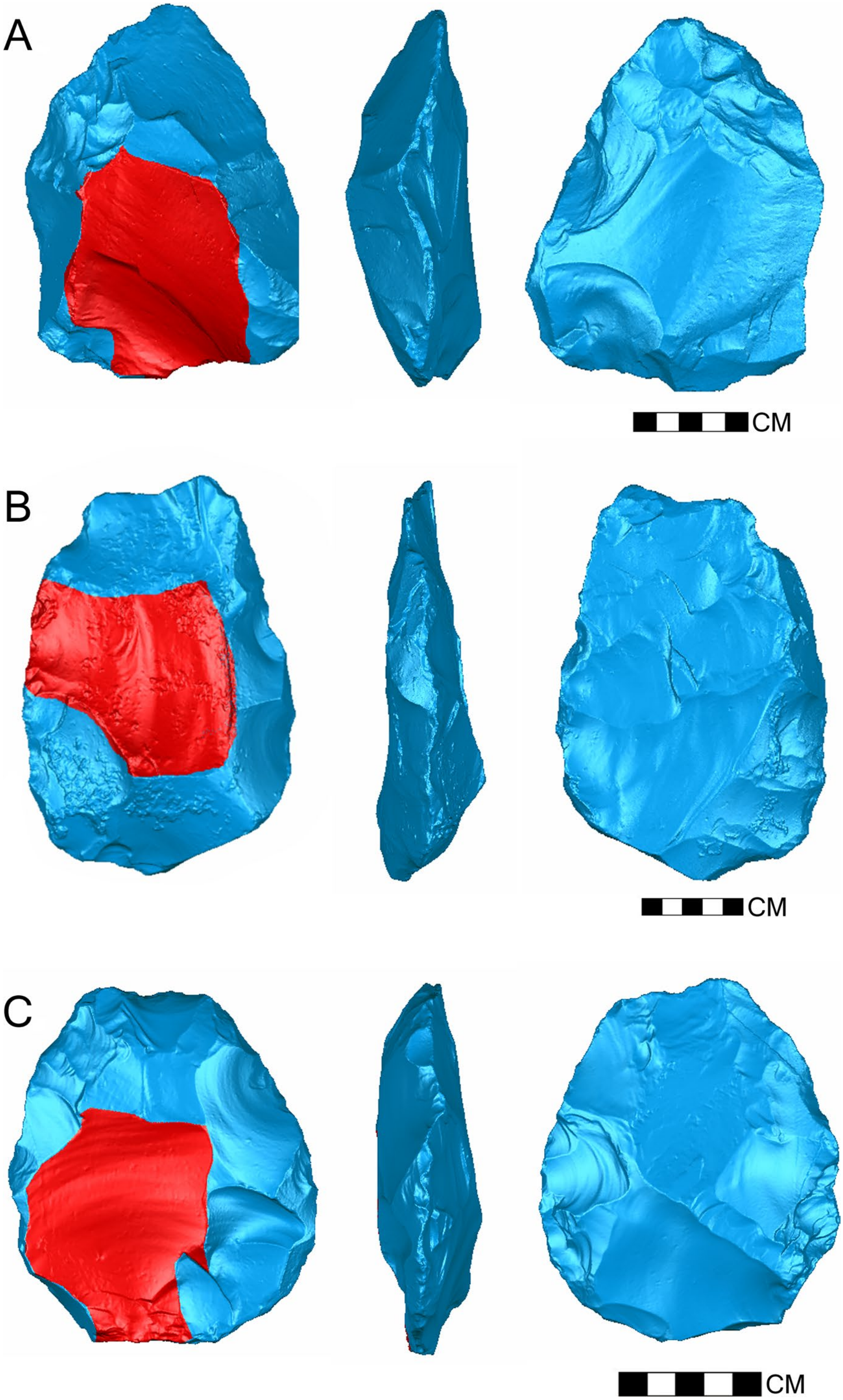
Fig. 11 3D scan images of three LCTs from Hatis-1 with large, preferential removals (highlighted in red) ▶ suggesting their use as cores. **A** From original excavation (Assemblage D) and produced on dacite. **B** From renewed work (Assemblage D) and produced on obsidian. **C** From original excavation (Assemblage D) and produced on obsidian.

branching exploitation strategy (ramification) used at the site (Bourguignon et al., 2004). After the initial production of larger flakes, they are then selected for use as cores, retouched into tools, or refined into LCTs. It is difficult to determine if these flakes were utilized for other purposes before being worked into their discarded form as any signs of this would be obscured by later removals and the rolled condition of the artifacts. Core-on-flake products, such as Kombewa flakes (sensu lato*)*, are found in low quantities in all assemblages ($n=7$). The use of flakes as cores may be indicative of opportunistic recycling of larger flakes not appropriate for LCT production or other tasks rather than ramification due to the lack of preparation prior to the removal of flakes from the original ventral surface of the core (Mathias, 2016). However, the abundance of these cores supports that the secondary exploitation of these flakes was likely part of an intentional strategy. The secondary use of flakes as cores is common in Late Acheulian contexts in the Levant (Agam et al., 2015; Malinsky-Buller, 2016). Utilizing flakes as cores has been seen as a response to a dearth of available toolstone (Dibble, 1984; Malinsky-Buller, 2016). The abundant use of core-on-flake production at Hatis-1 is then of note, as there is no scarcity of high-quality raw material in the immediate vicinity of the site. However, this is likely a consequence of the obsidian sources on the southern slopes of Hatis presenting as large blocky outcrops, instead of the smaller nodules found on the northern face (Frahm et al., 2021) (Fig. 2). This suggests a part of the toolstone exploitation strategy at Hatis-1 was the removal of large flakes from these outcrops to use as more mobile cores. Blanks used as cores-on-flakes are larger, on average, than unmodified blanks, supporting this contention. However, as previously noted, these differences are not significant (two tailed t tests, $p>0.05$).

Multi-platform polyhedron cores are the second most abundant core type at the site ($n=7$), and they are present in all assemblages (Fig. 14b). These show expedient, multi-directional flaking of obsidian cobbles with no preparation of striking platforms and are high variability in size and shape (Vaquero & Romagnoli, 2018). A single discoid core was also recovered from the site and exhibits centripetal removals around a secant plane with both sides used interchangeably as striking platform and removal surfaces (Fig. 14d). This differs from later MP discoid cores that show a level of preparation and differential utilization of each surface (Boëda, 1993; Thiébaut, 2013). Unidirectional and bidirectional flake scar patterns are dominant on both cores and flakes throughout the site. The two simple prepared cores in Assemblage D are qualitatively similar to cores found in Late Acheulian contexts throughout Eurasia, including cores recovered from both loci at the nearby site of NG-1 (Adler et al., 2014; Di Modica & Pirson, 2016; Malinsky-Buller et al., 2011; Moncel et al., 2020; White & Ashton, 2003; White et al., 2011) (Fig. 14a). These prepared cores are similar to both the simple prepared and Levallois cores from NG-1. The large size of these cores is also broadly similar to larger variants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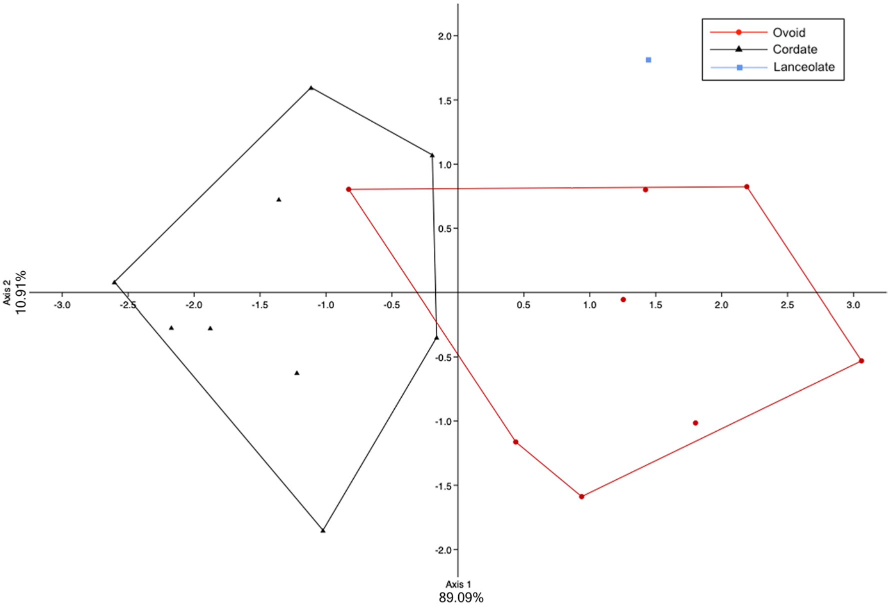

Fig. 12 Plot of LDA of the first five principal components from PCA of variables from WEAP technological analysis of the LCTs organized into their Bordian types. Convex hulls show the extent of each LCT grouping with minimal overlap between types. Includes LCTs from both renewed work and original excavation. One cordate (black triangle) LCT is from Assemblage B and the rest are from Assemblage D

of Levallois cores found in the African Early Stone Age (Kuman, 2001; McBrearty & Tryon, 2006; McBrearty et al., 1996; Tryon et al., 2005). The presence of Levallois-like prepared cores is consistent with evidence from African sites that suggest that Levallois and other prepared core technologies can be considered a Late/Final Acheulian phenomenon (Tryon et al., 2005), further supporting the designation of Late Acheulian for Hatis-1. The presence of prepared cores with LCTs here suggests broad techno-typological similarities exist between Hatis-1 and both loci at NG-1.

Blanks modified by retouch are found in all assemblages, with the exception of Assemblage A. These are on average larger than unmodified flakes in each assemblage, but these differences are not statistically significant (two tailed *t* tests, $p > 0.05$). The retouched tools can generally be considered scraper types with steep removals that are likely due to the selection of thicker blanks for retouch. The steep blank retouch at Hatis-1 is reminiscent of Quina retouch found in the Acheulo-Yabrudian (AY) of the Levant and specific tools from the Late Acheulian site of NG-1 (Adler et al., 2014; Agam, 2020; Barkai et al., 2003; Weinstein-Evron et al., 2003). Small unmodified blanks dominate all assemblages at Hatis-1, with high frequencies of expanding and ovoid blanks in all assemblages. This points to a tendency for knappers at the site to choose to strike along expanding or diffuse ridge systems of cores (Bergman, 1987; Tostevin, 2013). The even predominance of trapezoidal and triangular cross sections across assemblages suggests that there is no preference among knappers for the number of *nervures* guides, or guiding ridges, used for the removal of subsequent blanks (Tostevin, 2013). Blanks are overwhelmingly straight

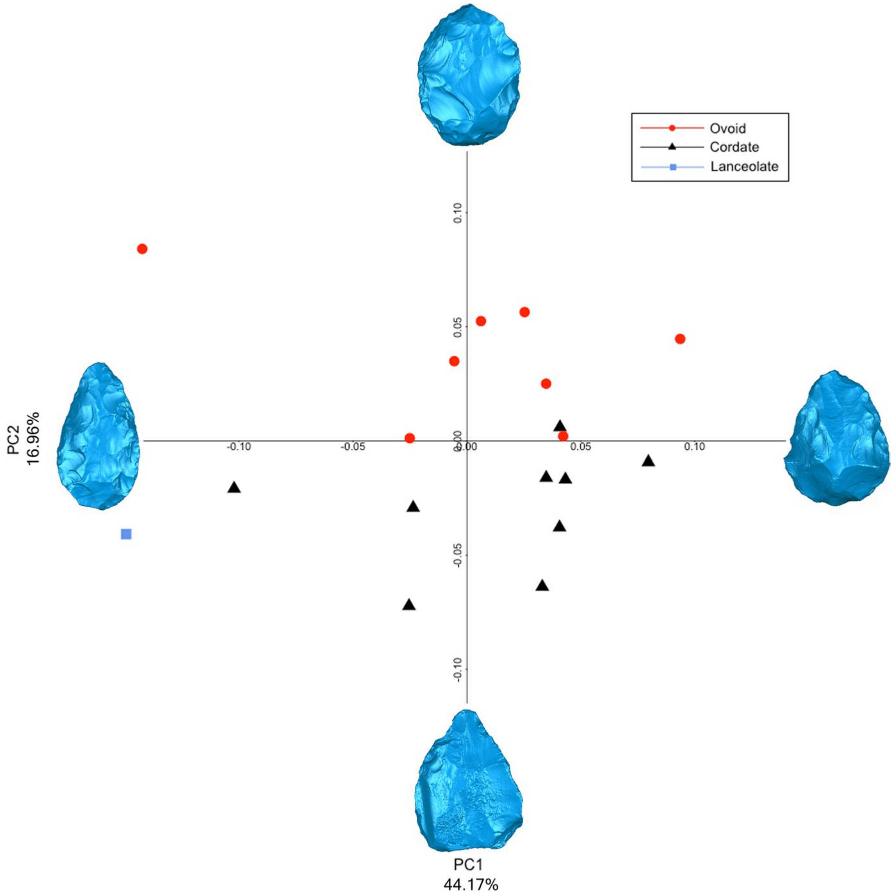

Fig. 13 PCA of LCT 3D outline landmark data. 3D scan images on each axis are examples of the LCT shape of the nearest LCT at the positive and negative ends of each component. Includes LCTs from both renewed work and original excavation. The cordate (black triangle) LCT used as an example on the negative end of the Y-axis is from Assemblage B. All other plotted LCTs and examples are from Assemblage D

in profile, indicating the exploitation of flat core surfaces, which is commensurate with the use of large blocky outcrops of obsidian on the southern slopes of Hatis. The debitage of Assemblage B contains one CTE, which demonstrates that some degree of core management took place at the site (Boëda et al., 1990). Elongated blanks are sparse at the site ($n=9$), only appearing in Assemblages B and D. These blanks are produced along a central ridge and have parallel lateral edges and their overall morphology suggests intentional production of elongated forms (Bar-Yosef & Kuhn, 1999). This is another broad similarity with the nearby NG-1, where blade production in a Late Acheulian context has been documented.

The outcome of the analysis of typological, shape, and production variation sees the singular large unifacial tool fit comfortably within the variation of the bifaces

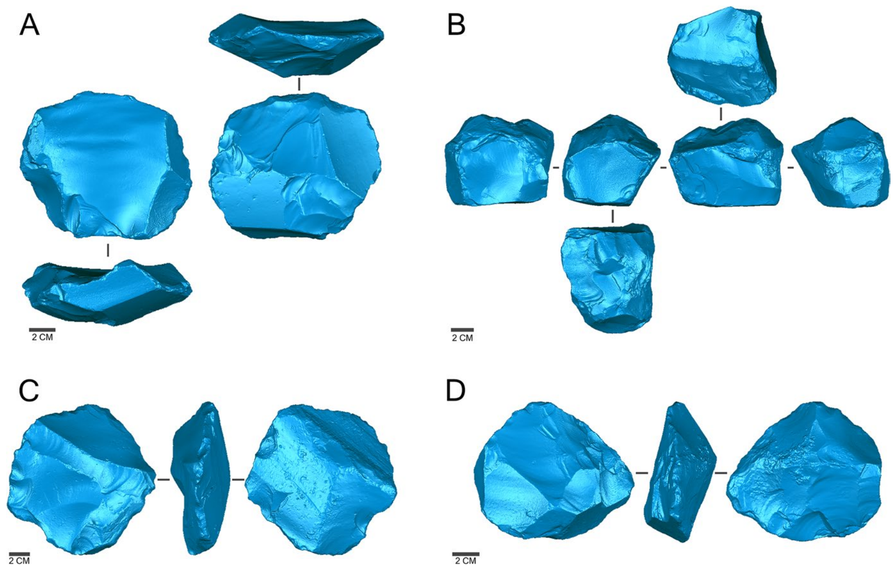

Fig. 14 3D scan images of select cores exemplifying the four core categories recovered from Hatis-1. **A** Simple prepared core with preferential removal on left image (Assemblage D). **B** Multi-platform core (Assemblage B). **C** Core-on-flake with original ventral surface on left (Assemblage D). **D** Discoid core (Assemblage D).

reported. The LCT component of Hatis-1 is best described as flake-based, non-elongated, thin, and generally non-pointed in shape. The tendency for rounded handaxe forms is not unlike that documented at the Levantine Late Acheulian/AY sites of Misliya Cave (Zaidner et al., 2006), Qesem (Agam et al., 2019), and Holon (Chazan, 2016). While Bordian measures separate the Hatis-1 LCTs into different shape zones, 3D-GM suggests they mostly occupy the same shape space, with few outliers. However, when ignoring surface topography and focusing on outline shape, 3D-GM supports the groupings found by traditional zone analysis. The maintenance of specific plan view shapes may have been more important to the knappers than the shaping of upper and lower convexities. These results are commensurate with those of Key (2019), which show there are stronger limitations to 3D variation of LCTs due to volume and refinement requirements and that diversity in this tool category may be best understood through analysis of plan view shape. A comparison of the recently excavated material from the renewed testing with a limited number of LCT illustrations from the original excavation at Hatis-1 suggests that the previously recovered artifacts qualitatively fit within the shape and typological diversity reported here (see Fig. 16 in Gasparyan et al., 2020).

The technological features recorded for LCTs demonstrate some differentiation in production between LCTs placed into the different shape zones; however, this is better thought of as a continuum rather than a discrete technological boundary between types. Cordate LCTs are more likely to have tips with specific shaping strategies, such as final retouch, which explains their less rounded forms. While blank type and raw material shape may have an influence on the final form of LCTs at the site, these likely did not impose restrictions. The final shape of these tools is better understood as the product of specific shaping strategies. It has been suggested elsewhere (Emery, 2010; Iovita & McPherron, 2011; McPherron, 1999) that the different shapes of LCTs are the outcome of the amount of reduction an implement has undergone during its uselife. However, learned cultural preferences, differential application of reduction strategies, knapping skill, and raw material shape, among others, have also been proposed as factors explaining variation in the shape of LCTs (Lycett & von Cramon-Taubadel, 2008; Eren et al., 2014; Shipton & Clarkson, 2015b; Herzlinger et al., 2017; Shipton and Nielsen, 2018; Wynn & Gowlett, 2018). As we can largely rule out reduction intensity due to the limited differences between types, as measured by SDI, as an explanation for the shape variation at Hatis-1, the final shape of the LCTs are best understood as the product of specific rules guiding the reduction and shaping of the artifacts. Whether the different shaping strategies applied at the site are the result of learned cultural preferences, desire to create different shaped tools for task specific purposes, or as a situational response to the toolstone itself is harder to ascertain. It is also possible that shaping strategies of the two main types of LCTs, ovoids and cordiforms, from Hatis-1 represent temporal variation in behaviors as the assemblages are palimpsests of hominin occupations, but this possibility is currently untestable. The limited number of LCTs included in this study makes it difficult to further assess the behavioral significance of these shaping strategies. This does not necessitate that all LCT variation across the Acheulian is due to shaping strategy, as different sites, regions, or time periods may evidence different explanations for shape and type variation in this tool category.

Two bifacial thinning flakes in Assemblage D evidence onsite handaxe production and refinement. Three LCTs were further used as cores, as evidenced by their large preferential removals (Fig. 11). The recycling of LCTs as preferential cores is not uncommon in Late Acheulian contexts (Breuil & Kelley, 1956; Chazan, 2016; Copeland, 1995; DeBono & Goren-Inbar, 2001; Marder et al., 2006; Rolland, 1995; Shipton et al., 2013; Zaidner et al., 2006). LCTs and other large cutting tools have low ratios of cutting edge to mass and the removal of preferential flakes may simply be a way to increase the amount of cutting edge available from the mass by producing flakes with high cutting-edge ratios (Shea, 2012). This serves as a possible conceptual link between LCTs and later prepared core technology (DeBono & Goren-Inbar, 2001). LCTs repurposed as cores are a technological element shared between Hatis-1, NG-1, and several Late Acheulian sites in the Levant (Rosenberg-Yefet et al., 2021). It is difficult to differentiate intentional preparation of these removals from general biface shaping mechanics; therefore, it is entirely plausible the removal of these flakes is the unintentional consequence of mistakes made during the shaping process. However, the similarity between these LCT removals and those found at the LP–MP transitional site of NG-1 and elsewhere during the Late Acheulian suggest that even if accidental they are likely still important in contextualizing the appearance and spread of prepared core technologies in this region. Together with the simple prepared cores this shows simple combination of preexisting elements, i.e. generativity (sensu Shipton et al., 2013), that is broadly similar with finds from the southern locus of NG-1 and may presage the prepared core technology that becomes better established by the timing of the NG-1 northern locus.

The assemblages at Hatis-1 fits many of the criteria for inclusion in the LFA (Sharon, 2010). Fourteen of the eighteen LCTs are produced on flakes, eleven of which are larger than 10 cm in maximum dimension, fitting LFA criteria. Furthermore, the ventral surface of the LCTs produced on large flakes are minimally exploited (Fig. 15a). The two simple prepared cores from Assemblage D have removals larger than 10 cm, which partly fits criteria for predetermination of large flake removals in the LFA. However, most cores are expediently produced on flakes or cobbles

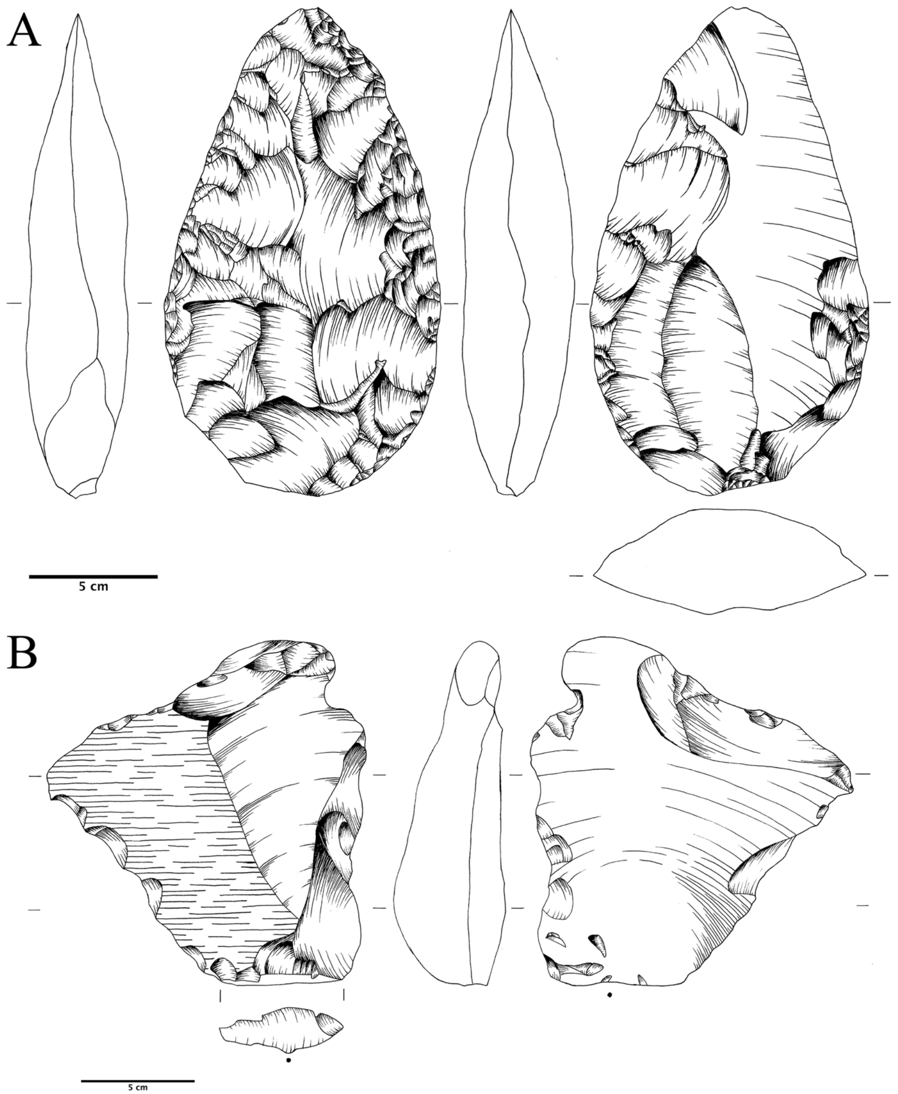

Fig. 15 Select artifacts from Hatis-1. **A** LCT from original excavation (Assemblage D) produced on a flake as evidenced by the retention of ventral surface (right) of original blank. **B** A large (> 10 cm) flake blank. From renewed excavation (Assemblage C)

and do not fit the predetermined expectations or larger sizes of the LFA (Madsen & Goren-Inbar, 2004; Sharon, 2009). The proximity of the site to the Hatis-alpha source may explain the lack of cores with large removals and predetermination. The nearest outcrops of Hatis-alpha on the southern slopes yield large blocks of obsidian (Frahm et al., 2021). These large blocks were likely used as cores that allowed for the removal of large flakes that could be used as templates for LCTs, retouched tools, and mobile cores (Texier & Roche, 1995). This would also explain the origin of the core-on-flake component of the assemblage, which accounts for 11 of the 21 recovered cores, seven of which are produced on large flakes. Across the four assemblages there are 57 unmodified large blanks, which accounts for 39.6% of all complete, unmodified blanks ($n=144$). Just under half (45.5%) of retouched tools from all assemblages ($n=22$) are produced on large flakes.

The use of high-quality obsidian, lack of unambiguous "true" cleavers, and low occurrence of pointed LCTs do not fit LFA expectations. The use of obsidian instead of coarse-grained material seen in most LFA assemblages is a consequence of the ease of accessibility and abundance of the raw materials in the area surrounding Hatis-1. This is distinctly different from LFA assemblages reported in other regions where knappers show a preference for course-grained raw material even when high-quality material is available (Sharon, 2008). The lack of "true" unifacial cleavers at Hatis may simply be the result of cultural preference or the outcome of the sampling strategy used to revisit the site. Some of the implements included in the LCT category here may fit into some authors' definitions of unifacial or bifacial cleaver types, but do not fit criteria for "true" cleavers (de la Torre, 2016; Rollefson et al., 2006; Santonja & Villa, 2006). It is also possible that some of the large expanding flakes reported could be utilized as expedient cleaver types (Fig. 15b). The low occurrence of pointed types may relate to the production systems in use, the types of blanks selected for production, learned preferences, or to assure their utility for secondary use as cores. Scarcity of publication on the Acheulian of the Caucasus left previous discussions of the LFA in this region restricted to vague descriptions of large flakes produced on coarse-grained material and some use of large flakes for cleaver production (Sharon, 2007). Hatis-1 helps to increase this to an understanding of large flake production on high-quality obsidian and the use of these large flakes for LCTs, cores, and retouched tools among the presence of large, unretouched blanks. The specific production of large blanks fits the categorization of the Hatis group as workshop locations, but it is difficult to assess if this was the exclusive purpose of Hatis-1 (Gasparyan, 2010; Gasparyan et al., 2014a; Lyubin, 1965).

The technology at Hatis-1 is characteristic of a LFA variant of the Late Acheulian. Core-on-flake production, steeply retouched tools, and simple, unprepared elongated blanks can be compared to Late Acheulian and AY assemblages in the Levant (Agam, 2020; Agam et al., 2015; Shimelmitz et al., 2016; Weinstein-Evron et al., 2003). The mean length of LCTs reported here (130.3 ± 32 mm) is larger than averages reported from the Levant for both AY (81.9 ± 10.8 mm) and Late Acheulian (90.1 ± 12.6 mm) assemblages (Shea, 2012). However, Hatis-1 handaxe length does overlap with those from the Levantine Late Acheulian at one standard deviation. The general larger size of LCTs at Hatis-1 compared to nearby regions may be a consequence of the proximity of the site to a raw material source. This would reduce the necessity for higher levels of curation and therefore size reduction (Ashton, 2008; Marks et al., 1991). The dominance of rounded LCTs and their subsequent use as cores along with the presence of simple prepared cores supports the Late Acheulian character of Hatis-1 (Chazan, 2016; DeBono & Goren-Inbar, 2001; Malinsky-Buller et al., 2011; Shipton et al., 2013; White & Ashton, 2003). It stands to reason that this Late Acheulian variant may indicate the early stages of a technological radiation (sensu Chazan, 2016) that acts as a pool of variation for the later technological transition in the region documented at NG-1.

Future comparative research on the Acheulian of the southern Caucasus and Armenian Highlands can look beyond the Levant to the expanding record of the Arabian Peninsula. The recently reported Acheulian sites of An Nasim and Saffaqah contain assemblages that have potential to help contextualize the variation at Hatis-1. The LCT shape variation at Hatis-1 bears both similarities and differences to the MIS 9 site of An Nasim in the Nefud Desert of Arabia. Scerri et al. (2021) demonstrate the presence of cordiform, ovate, and triangular LCTs at An Nasim using 2D-GM and Canonical Variates Analysis. While the methodology is different to that reported here, the results are broadly comparable. Unlike the overlap between the major shape groups at Hatis-1, the three LCT types at An Nasim do not overlap in shape space (see Scerri et al., 2021 Fig. 4). Also unlike Hatis-1, all LCTs at An Nasim are the result of tabular block reduction instead of large flake shaping. All LCTs at An Nasim are finely flaked with broadly similar reduction processes applied across the different shape groups, but the WEAP method was not used in the study making it difficult to directly compare this to the variation in shaping strategies at Hatis-1. The focus on large flakes as blanks for LCT manufacture at Hatis-1 is similar to the MIS 7 site of Saffaqah in central Arabia, which like Hatis-1 is situated in close proximity to a toolstone source (Scerri et al., 2018; Shipton et al., 2018). Shape variation, broadly speaking, appears to be comparable between the two large flake LCT sites, but more equivalent methodologies are needed to be certain of this (Shipton et al., 2018). The broad similarities and differences between these sites and Hatis-1 suggest that the Arabian Peninsula may be a key area for future comparative research with the southern Caucasus and Armenian Highlands in order to build a more comprehensive understanding of Acheulian variability in SW Asia.

Conclusions

This paper highlights new stratigraphic work and techno-typological analyses at the Lower Paleolithic site of Hatis-1 on the Hrazdan-Kotayk Plateau in Armenia. The site is located on the southern slopes of Mt. Hatis in course-grained, colluvial volcanic deposits. While the site was originally excavated in 1984, little has been reported regarding the composition of the material culture other than its general Late Acheulian character (Ghazaryan, 1986; Lyubin, 1989; Lyubin and Belyayeva, 2006; Gasparyan, 2010; Gasparyan et al., 2014a, 2020). The site must postdate the formation of the Hatis volcano and its obsidian at c. 700/480 ka (Arutyunyan et al., 2007; Lebedev et al., 2013). The analysis of excavated and non-contextualized lithic material reported here supports the placement of the site in the Late Acheulian. Furthermore, the techno-typological composition of the assemblages at Hatis-1 indicates that it likely predates the neighboring Lower–Middle Paleolithic transitional site of Nor Geghi-1, c. 335–325 ka (Adler et al., 2014). Hatis-1 provides additional data on the Large Flake Acheulian of the Armenian Highlands, and bears many similarities to later Acheulian contexts in the Levant and recently discovered sites in Arabia, although the technology still has a local character, in terms of diversity of artifact types, sizes, and shapes, likely related to the ubiquity of high-quality obsidian. While traditional views consider hominin behavior largely homogenous during the Acheulian (Tattersall et al., 1988), this new understanding of LFA production reinforces recent assessments that recognize that regional variations in the application of Acheulian technologies do exist and should be expected as a response to differences in environmental circumstances and/or cultural drift or development (Lycett & Gowlett, 2008; Lycett & von Cramon-Taubadel, 2008; Shipton, 2020; Shipton & White, 2020). A firmer understanding of the Late Acheulian in this region is pivotal to better contextualizing the local transition from Acheulian to Middle Paleolithic technologies and the broader hominin behaviors during the Late Middle Pleistocene of the Armenian Highlands and southern Caucasus. The proximity to abundant high-quality obsidian and the utilization of large flakes for a multitude of artifacts suggests that Hatis-1 may be a workshop location aimed at the production and exploitation of large flakes. The variance in the typology of LCTs at the site is related to the application of specific shaping strategies by the knappers responsible for the assemblage, applying different shaping techniques to produce ovoid and cordiform types. While further work is needed to fully appreciate and understand the nature of the Late Acheulian in the Armenian Highlands and southern Caucasus, the technology present at Hatis-1 along with Nor Geghi-1 suggests a gradual expansion of the technological repertoire of hominin groups during this period that presages the development of prepared core and other technologies indicative of the MP. This generally supports a polycentric model of MP technologies with multiple regional centers (sensu Rolland, 1995) of experimentation and innovation (Adler et al., 2014). Hatis-1, along with other sites in the Hatis group, contains future potential to answer questions regarding Late Acheulian technology and hominin behaviors in this region.

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Code availability Available upon request.

Declarations

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Authors and Affiliations

Jayson P. Gill[1] · **Daniel S. Adler**[1] · **Yannick Raczynski-Henk**[2] · **Ellery Frahm**[3] · **Jennifer E. Sherriff**[4] · **Keith N. Wilkinson**[5] · **Boris Gasparyan**[6]

[1] Department of Anthropology, Old World Archaeology Program, University of Connecticut, Storrs, CT, USA

[2] Department of World Archaeology, Humans Origins Group, Leiden University, Leiden, Netherlands

[3] Council On Archaeological Studies, Department of Anthropology, Yale University, New Haven, CT, USA

[4] Department of Geography, King's College London, London, UK

[5] Department of Archaeology, Anthropology and Geography, University of Winchester, Winchester, UK

[6] Institute of Archaeology and Ethnography, National Academy of Sciences, Yerevan, Armenia