Journal of Archaeological Science: Reports 49 (2023) 103988

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Obsidian exchange networks and highland-lowland interaction in the Lesser Caucasus borderlands

Nathaniel L. Erb-Satullo[a,*], Matilda Rutter[b], Ellery Frahm[c], Dimitri Jachvliani[d], Paul G. Albert[e], Victoria C. Smith[b]

[a] Cranfield Forensic Institute, Cranfield University, College Road, Cranfield, Bedfordshire MK43 0AL, UK
[b] School of Archaeology, University of Oxford, 1 South Parks Road, Oxford OX1 3TG, UK
[c] Council on Archaeological Studies, Department of Anthropology, Yale University, New Haven, CT, USA
[d] Otar Lordkipanidze Archaeology Institute, Georgian National Museum, 3 Rustaveli Avenue, 0105 Tbilisi, Georgia
[e] Department of Geography, Swansea University, Singleton Park, Swansea SA2 8PP, UK

A R T I C L E I N F O

Keywords:
Provenance
pXRF
Electron microprobe
LA-ICP-MS
Late Bronze Age
Early Iron Age

A B S T R A C T

Obsidian sourcing studies have a long history in the Near East, but relatively few have focused on obsidian exchange after the Early Bronze Age. Here, we present a multi-technique analysis of an assemblage of 111 obsidian artifacts from excavated Late Bronze and Early Iron Age (LBA-EIA; c. 15th-6th c BCE) contexts at Mtsvane Gora, southern Georgia. Because the site is situated in the lowland Kura Valley and the nearest obsidian sources are in the highlands to the south and west, obsidian provenance can serve as a proxy for mapping highland-lowland interactions. Chemical compositions analyzed via portable X-ray fluorescence spectrometry (pXRF), electron microprobe analysis (EMPA), and laser ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS), were compared with existing geological datasets of chemical analyses to identify the source of all but one of the artifacts analyzed. The results show that Chikiani, a source in the highlands of southern Georgia, was the geological origin of >90% of the objects analyzed. While acknowledging that obsidian exchange is just one aspect of highland-lowland interaction, this finding implies that Mtsvane Gora's connections with the adjacent highlands were skewed towards greater engagement with some highland areas relative to others. More generally, the research suggests that geographic adjacency of highlands and lowlands does not necessarily mean that they were highly interconnected.

1. Introduction

Eastern Anatolia and the South Caucasus contain many obsidian deposits associated with volcanic lava flows, which have been exploited by humans from the Paleolithic until at least the Early Iron Age (Fig. 1). From the perspective of both geological constraints and analytical chemistry, obsidian is one of the most suitable materials for sourcing. It has chemically distinct sources in numbers manageable for reasonably comprehensive sampling over a large area (a situation that is quite different from clay raw materials in ceramic sourcing), while its glassy, nearly homogeneous character simplifies chemical analysis. For these reasons, obsidian sourcing studies are a major area of research in this region and the surrounding areas of the Near East where South Caucasus/Eastern Anatolian obsidian is found.

In a mountainous, ecologically diverse region, highland-lowland relationships are an inevitable touchstone in any discussion of interaction over long distances (Anderson et al. 2018). As these issues are prominent in wider study of the ancient Near East (Algaze 2005; Stein 1999) and in mountainous regions worldwide (e.g. Scott 2009; Van Buren 1996), the Caucasus provides a useful case study, one that until recently has not been appreciated in the global comparative archaeology of complex societies. Although the region is generally coded as "highlands" in the wider context of Near East Archaeology, it in fact contains a very wide range of ecological and topographic environments, including low-lying alluvial plains and coastal environments. Research on highland-lowland interactions *within* the South Caucasus allows us to move from broad generalized characterizations covering entire regions towards an analysis of specific dynamics of interaction on the human scale. Ultimately, this approach leads to a more robust, data-driven understanding of highland-lowland interaction at all spatial scales.

* Corresponding author.
E-mail address: n.erb-satullo@cranfield.ac.uk (N.L. Erb-Satullo).

https://doi.org/10.1016/j.jasrep.2023.103988
Received 8 December 2022; Received in revised form 20 March 2023; Accepted 21 March 2023
Available online 9 May 2023

Obsidian sourcing research in the Caucasus has largely focused on the Palaeolithic (Doronicheva et al. 2017; Frahm et al. 2014; Le Bourdonnec et al. 2012), Neolithic (historically the major focus of obsidian research in the wider Near East) (Badalyan et al. 2010; Keller et al. 1996; Nishiaki et al. 2019; Olshansky 2018), and Chalcolithic (Palumbi et al. 2018). Obsidian exploitation during Bronze Age—especially periods after the end of the Early Bronze Age in the mid-late 3rd millennium BCE—has been relatively understudied (see, e.g. Badalyan 2010; Chataigner and Gratuze 2014b). Yet, obsidian remained an important and widely distributed resource well beyond the "stone" ages. In the South Caucasus, obsidian arrowheads, some of them masterworks of pressure flaking, are found in Middle and Late Bronze Age contexts (Gobejishvili 1981:Pls. V-VI; Narimanishvili 2010:Pls. XVIII-XIX), and it seems that copper-alloy arrowheads only came into more regular use around the end of the 2nd and the beginning of the 1st millennium BCE (Erb-Satullo and Jachvliani 2022:318; Kuftin 1941:75, 309, 311).

The Late Bronze and Early Iron Age (LBA-EIA, c. 1500–800 BCE) represented a considerable change in settlement and subsistence patterns in relation to the preceding Middle Bronze Age (MBA; c. 2500–1500 BCE). From the mid-2nd millennium BCE, hilltop settlements and fortresses became a staple of the South Caucasus landscape, a pattern that continues into the early 1st millennium BCE, when the Kingdom of Urartu, ruled over parts of the South Caucasus (Erb-Satullo et al. 2019; Hammer 2014; Narimanishvili 2019; Smith 2006). Situated chronologically between MBA pastoral communities and the emergence of larger Iron Age states, the LBA/EIA period offers a tantalizing opportunity to gain a better understanding of long-term transformations in the expression of social hierarchy and the consolidation of political power. Studies of social dynamics during this period have often focused on the ways in which economic and religious activities concentrated power and authority within these communities (Lindsay et al. 2008; Smith and Leon 2014). Though the degree of centralization remains unclear, studies of production and exchange provide an opportunity to explore how these communities were situated within their economic landscape.

Identifying the origins of obsidian artifacts offers one way of examining the structure, patterning, and directionality of economic contacts in the South Caucasus. While the movement of obsidian is but one element of a varied landscape of contact and exchange, it is one that is particularly accessible due to the abundance and visibility of obsidian debitage as well as the favorable geochemical characteristics and material properties of obsidian. Furthermore, obsidian exchange networks do not exist in a vacuum, and it is reasonable to suggest that obsidian might serve as a useful proxy for other kinds of contact and exchange. Other materials were probably exchanged for obsidian, and such exchanges may have been facilitated by, or benefitted from, the movement of people across the landscape for other purposes, such as pastoral transhumance, metallurgical prospection, and even intercommunal raiding.

Obsidian found at Mtsvane Gora, a well-dated hilltop site in southern Georgia, presents an opportunity to investigate the connections and interactions between highland and lowland areas of the South Caucasus during the LBA-EIA. Its position, at the edge of the lowland Kura (Mtkvari) basin, with the foothills of the Lesser Caucasus range immediately to the south and west and multiple routes of access to the highlands, makes it an ideal location to explore these connections.

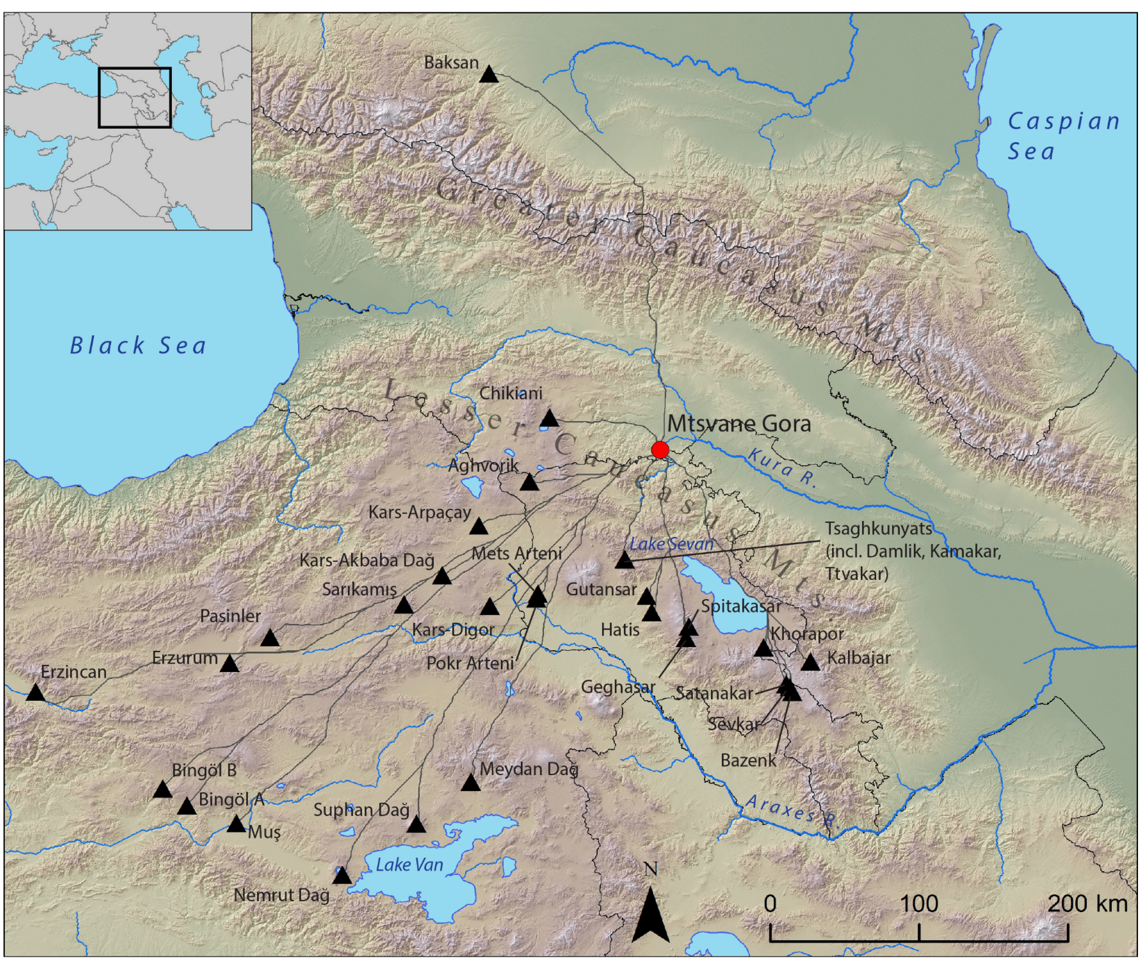

Fig. 1. Map of the South Caucasus showing Mtsvane Gora (red circle), key Caucasus and East Anatolian obsidian sources (black triangles). Least cost paths (gray lines) show the path of minimum walking time from Mtsvane Gora to each obsidian source.

Moreover, many key obsidian sources lie to the south and west of the site. This geographic disposition permits us to test different models of obsidian procurement—for instance, those that are highly eclectic, drawing on numerous sources and implying opportunistic connections, and those that are directional and selective, implying sustained links with specific highland zones. Prior research, focusing on earlier periods, has documented the widespread use of the Chikiani obsidian source, located in southern Georgia, noting its quantity, quality, and ease of access (Badalyan et al. 2004). Nevertheless, the numbers of analyzed LBA-EIA obsidian artifacts from the Kura basin remains low, and Chikiani is only one of several obsidian sources within 100 km of Mtsvane Gora. Here we present the analyses of 111 excavated LBA/EIA obsidian artifacts from Mtsvane Gora, providing a substantive picture of obsidian procurement patterns at the site—patterns which serve as a proxy for what was likely a wider range of interactions between lowland and highland zones of the Lesser Caucasus mountains.

2. Background

2.1. Mtsvane Gora

Mtsvane Gora is an LBA-EIA fortified site on the margins of the Kura River lowlands. It occupies an isolated hilltop along a key route of travel running along the Debeda River into the Lesser Caucasus highlands (Fig. 2). The lowlands and foothill zones of Kvemo Kartli (the present-day administrative region in which the site is located) are well known for their long history of settlement, with the Neolithic and Early Bronze periods receiving particular attention (Hamon et al. 2016; Lyonnet et al. 2012; Stöllner and Gambashidze 2011). The region is particularly rich in copper, iron, and gold deposits, located in the Khrami, Mashavera, and Debeda gorges and extending on both sides of the Georgian-Armenian border. Mining and metallurgical activities in the region stretch back to at least 3000 BCE (Stöllner and Gambashidze 2011), if not earlier (Lyonnet et al. 2012:84-85), and continued into the 1st millennium BCE and later (Erb-Satullo et al. 2020; Gzelishvili 1964:31-38). The position of the ore deposits along foothill valleys and gorges leading to highland pasturelands raises the possibility that seasonal pastoral transhumance, the procurement of obsidian, and the circulation of metal may have formed part of an interrelated system of highland-lowland connectivity. Identifying the geological source(s) of the obsidian artifacts at Mtsvane Gora, therefore, provides an opportunity to explore one dimension of this broader system.

Initial surface surveys at Mtsvane Gora identified a fortification wall encircling the hilltop, along with considerable quantities of LBA/EIA pottery, obsidian, and traces of metallurgical slag (Erb-Satullo 2018). Excavations at the site, focusing on the areas just inside the encircling wall on the southern slope, identified two periods of occupation (Erb-Satullo and Jachvliani 2022) (Fig. 3). The first phase was represented by a beaten clay surface with numerous flat-lying pottery sherds, stone implements, and animal bones, was dated via two radiocarbon dates on charcoal to the 14th-13th centuries BCE. An additional, slightly charcoal sample from a partially preserved structure slightly up-slope in trench 4 gave a slightly earlier date in the 15th-14th c. BCE. Charcoal from sediments overlying the floor surface in trench 1, with occasional patches of clay and poorly preserved pieces of stone collapse, were radiocarbon dated to the 8th-6th century BCE (Erb-Satullo and Jachvliani 2022: Fig. 4, Table 1). No evidence of substantial occupation in later periods was identified. The stratigraphic position of the slags showed that the metallurgical debris belonged to the later phase, with none identified on the earlier 15th-13th c. BCE layers. Both copper-alloys and iron objects were manufactured at the site, with the evidence showing that these activities took place within the same workshops (Erb-Satullo et al. 2020). While evidence suggests that the metallurgical activities were restricted to forging, alloying and casting metal smelted elsewhere, the presence of a chunk of mixed jarosite, pyrite, and elemental sulfur, which most likely derives from nearby copper deposits, also hints at a variety of material procurement networks oriented towards the highlands to the south and west.

Fig. 2. The hilltop site of Mtsvane Gora (black arrow) in the Debeda River Valley, with the foothills of the Lesser Caucasus range rising behind it. This view looks south up the valley, with the Debeda River in the valley bottom on the left.

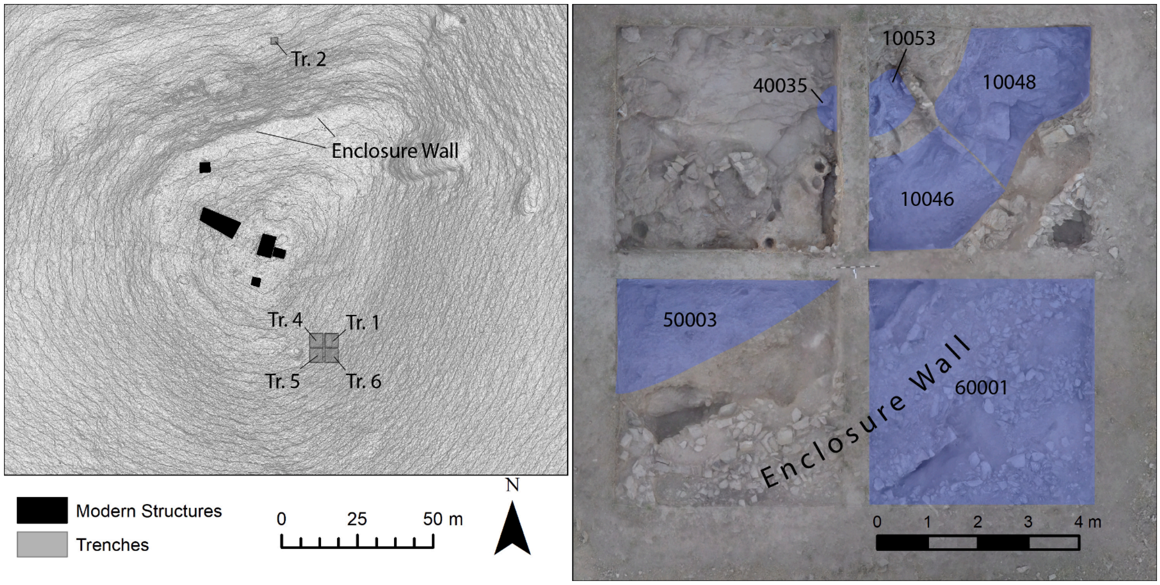

Fig. 3. Map of Mtsvane Gora showing locations on trenches (left) and a final orthophoto (right) of trenches, 1, 4, 5, and 6. Approximate horizontal extent of contexts from which obsidian analyzed in the present study came are overlaid in blue. See Table 1 for context descriptions.

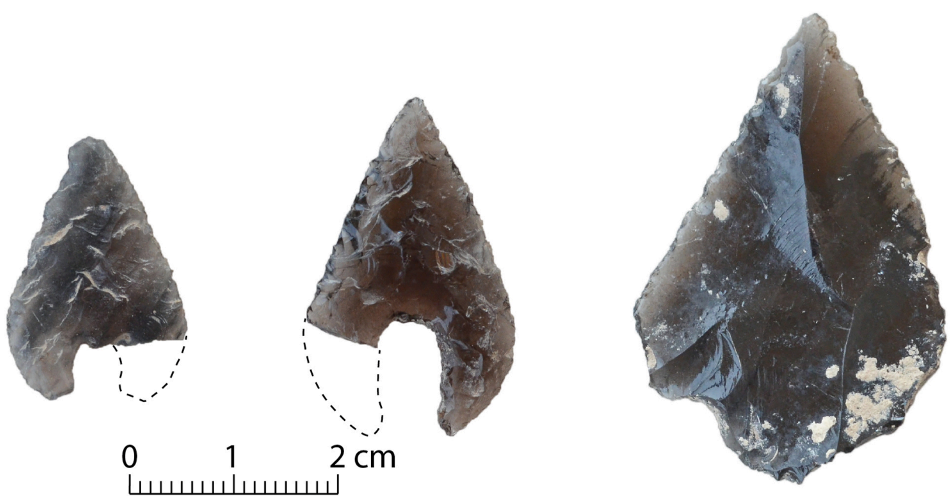

Fig. 4. Obsidian points from Mtsvane Gora. Arrowheads on left and center are characteristic of the Late Bronze Age.

Obsidian debitage was abundant throughout the excavation, as is typical of LBA-EIA sites in this area. In the 2017 excavation season, 983 pieces of chipped stone[1], virtually all of it obsidian, were recorded, totalling 3.1 kg (average 3.2 g per artifact). Conservative estimates would put the total quantity of obsidian at the site on the order of hundreds of kilos. Bronze Age chipped stone assemblages in the South Caucasus have rarely been the subject of comprehensive lithic analysis (Purschwitz 2018), so the full range of tools and techniques has yet to be appreciated. While comprehensive formal lithic analysis was not undertaken, it is clear that obsidian tools and other finished items were rare. Two obsidian arrowheads were found, one on a 14th-13th c. BCE floor surface, and one in the gravelly levelling fill below the beaten clay floor (Fig. 4). A third obsidian point with signs of retouch was found in the upper fill of Trench 4. Chipped stone sickle blade inserts were found at the site, but none were made of obsidian. Evidence from other excavations in the region suggests that sometime during the LBA-EIA, copper-alloy arrowheads begin to appear with more regularity, but the timing and character of this transition has not been examined in detail (compare arrowheads of varying materials in Erb-Satullo and Jachvliani 2022:317; Kuftin 1941:303-309; Narimanishvili 2010:Pls. XVIII-XIX). At Mtsvane Gora, obsidian was found both on the earlier 2nd millennium BCE floor level and in overlying 1st millennium BCE contexts. It is probable that some obsidian in these upper layers is detrital, deriving from erosion and redeposition of older deposits farther up the hill, but quite unlikely that it is entirely so. A more parsimonious explanation is that obsidian was knapped throughout the occupation at Mtsvane Gora.

2.2. *Obsidian sources*

Given its importance at other sites and time periods in southern Georgia, Chikiani was hypothesized to have been a significant source of obsidian found at Mtsvane Gora. It lies in southern Georgia at an elevation of about 2400 m, near Lake Paravani, and formed somewhere between 2 and 3 million years ago (Le Bourdonnec et al. 2012). Prehistoric use of Chikiani obsidian is well documented from western

[1] This figure excludes a small number chipped stone finds (e.g. obsidian arrowheads, points, and chert sickle inserts) collected as separate small finds at the point of excavation.

Georgia (Colchis) to central Azerbaijan, and from the North Caucasus to Armenia (Badalyan 2010; Badalyan et al. 2004; Malinsky-Buller et al. 2021). At Samshvilde, a multi-period site also located in the foothills of Kvemo Kartli roughly midway between Mtsvane Gora and the Chikiani obsidian source, a large proportion of the obsidian assemblage derived from this source (93%, 28 of 30). However, the dates of the analyzed artifacts are not specified, and the site spans from the Neolithic to the Medieval period. The dominance of the Chikiani obsidian at archaeological sites in Georgia probably derives from its relative isolation as the northernmost of the South Caucasus obsidian sources. While Chikiani obsidian has been documented at archaeological sites north of the Greater Caucasus mountain range in Russia (Badalyan et al. 2004; Doronicheva and Shackley 2014), obsidian from the single North Caucasus source (known as Baksan or Zayukovo; Fig. 1) is not documented to the south, even in western Georgia, where it is the closest site as the crow flies (Le Bourdonnec et al. 2012). At 2400 m in elevation, the Chikiani source is only a modest climb above the surrounding Javakheti and Trialeti Plateaus (c. 1500–2100 m), which were densely settled with LBA-EIA fortresses (Narimanishvili 2019).

Nevertheless, Chikiani is not the sole source of obsidian for archaeological sites in the Kura Valley. Comprehensive analysis of 901 obsidian objects—the entire assemblage from one trench—from Neolithic Göytepe in Azerbaijan, about 85 km southeast of Mtsvane Gora, showed that only a small minority (6.9%, n = 62) derived from Chikiani, while a far larger portion (39.8%, n = 359) derive from more distant sources in northeastern Turkey, (Nishiaki et al. 2019). The results from Göytepe indicate the value of analyzing large quantities of obsidian debitage from a single site; they reveal chronological shift between periods, and illustrate how the most proximate sources are not necessarily favored in an assemblage. No Late Bronze and Early Iron Age obsidian assemblage has received a similar treatment involving the analysis of many samples from well-dated contexts.

Other proximal obsidian sources to those at Mtsvane Gora include Aghvorik (sometimes called Ashotsk or Eni-Ël) in Armenia, and several deposits in the Tsaghkunyats Range (Damlik, Ttvakar, and Kamakar), which lie in the highlands upriver along the Debed gorge from Mtsvane Gora. These sources, along with Chikiani, are the closest to Mtsvane Gora, all between 70 and 90 km on a direct line, or about 90–100 km when following a least-cost path due to the mountainous terrain (Fig. 1). In terms of quantity and quality (ideal obsidian for knapping is homogeneous with few crystals), both Chikiani and the Tsaghkunyats deposits are prime sources, while the Aghvorik deposits are smaller and lower in quality and its obsidian has been identified only at the very nearest of archaeological sites (Badalyan et al. 2004).

The composition of obsidian sources in the Caucasus differ sufficiently to distinguish between most sources, especially when considering all major, minor, and trace elements. Nonetheless, there are complexities that have not always been recognized by researchers or acknowledged in the literature. For example, there are a series of named obsidian outcrops (e.g. Djraber, Gyumush, Nurnus) in the Gutansar volcanic complex (Fig. 1), all of which are exposures of the same extensive – and thus chemically consistent – obsidian flow (Frahm et al. 2014), whereas Hatis volcano exhibits different obsidian chemistries as one ascends its slopes (Frahm et al. 2021). Relying on a scatterplot of just two elements can lead to source overlaps (Chataigner and Gratuze 2014a); however, taking into account the other elements usually resolves such concerns. Importantly, this body of prior research has shown chemical separation among several sources close to Mtsvane Gora (e.g. Chikiani, Aghvorik, and the Tsaghkunyats sources) in both major, minor, and trace elements, so it is likely we would be able to distinguish between obsidian from these sources at Mtsvane Gora.

3. Materials and methods

3.1. Materials for analysis

A total of 111 obsidian artifacts from Mtsvane Gora were analyzed. Seven newly collected geological specimens from the Chikiani source were also analyzed for comparative purposes. Artifacts were selected from the chronologically-constrained 14th-13th c. floor assemblage (n = 66), but also a range of mixed upper fills (n = 45), which would likely include obsidian dating to the full range of LBA-EIA occupation (Table 1). Within these contexts, lots with larger quantities of obsidian were selected, and all pieces of obsidian in the selected lots were analyzed. Macroscopic appearance was therefore not a factor in the selection of artifacts for analysis. Because even brief episodes of knapping can yield significant quantities of debitage, an exclusive focus only on sampling the floor surface assemblages might underrepresent the diversity of obsidian sources used. This sampling strategy therefore mitigates the risk of overestimating the importance of a single source, in case all the debitage from the floor level came from a single cobble or knapping session. Macroscopically, the analyzed assemblage obsidian debitage was black with minor variations in opacity.

3.2. Portable X-ray fluorescence spectrometry (pXRF)

Calibrated measurements of Sr, Zr, Rb, and Nb concentrations were determined via an Olympus Vanta VMR portable X-ray fluorescence (pXRF) spectrometer in the Yale University Archaeological Laboratories, following standard analytical procedures (e.g. Frahm et al. 2019; Frahm and Tryon 2018). To ensure accuracy and reproducibility of the instrument, previously analyzed geological obsidian specimens were run alongside the Mtsvane Gora artifacts. Multiple analyses were undertaken for each artifact. Repeat analyses on artifacts were averaged, but as differences between measurements were almost always less than 5 ppm absolute and 5% relative, this had hardly any effect on the values ultimately used for source identification. A large analytical dataset for geological specimens of known volcanic origin was used to identify source locations of the Mtsvane Gora artifacts. These geological data include some replicate measurements for select specimens in order to establish the potential ranges of measurements for each geological source.

3.3. Electron microprobe analysis (EMPA)

Small samples were removed from the obsidian objects and mounted in epoxy resin. Major and minor element volcanic glass chemistry of

Table 1
List of contexts from which the analyzed obsidian objects derive. Field numbers refer to unique numbers given to finds, both individual (e.g. small finds) and collective (e.g. pottery sherds, and as in this case, chipped stone). Separate pieces of obsidian were given sequential numbers (e.g. 1012–1, 1012–2, etc.). See Erb-Satullo and Jachvliani (2022) for further discussion of site stratigraphy.

Trench	Context	Field #	Context Description	# of obsidian pieces analyzed
1	10046	SR568	14th-13th c. BCE floor assemblage	19
1	10048	SR776	14th-13th c. BCE floor assemblage	16
1	10053	SR1012	14th-13th c. BCE floor assemblage	13
4	40035	SR893	14th-13th c. BCE floor assemblage; ashy lenses close to bedrock	18
5	50003	SR826	Mixed fill. General LBA-EIA date	32
6	60001	SR952	Topsoil/collapse. General LBA-EIA date	13

individual clasts were determined using a JEOL JXA-8200 Superprobe in the Research Laboratory for Archaeology and the History of Art (RLAHA), University of Oxford. The instrument is equipped with five wavelength-dispersive X-ray spectrometers (WDS). The glasses were analyzed using a defocused (10 μm), 15 kV and 7 nA electron beam. The instrument was calibrated using a range of mineral standards, and the accuracy and precision of the data was assessed using analyses of three reference glasses (MPI-DING, see Jochum et al. 2006) analyzed alongside the Mtsvane Gora samples (all data reported in the Supplementary Material). The following elements were analyzed (with peak count times in brackets) and the data is presented as weight percent (wt%) oxide: Na (12 s), Mg (50 s); Al (30 s), Si (30 s), P (50 s), Cl (50 s), K (30 s), Ca (30 s), Ti (30 s), Mn (50 s) and Fe (30 s).

Multiple spots were analyzed on each sample and the backscattered electron imaging was used to ensure the positions were away from any small crystals that had formed in the obsidian lava during cooling. These compositions were averaged to avoid over-interpreting intra-sample variation, partially mitigate large spot size differences between pXRF and EMPA, and facilitate clarity in data visualization and discussion. Nonetheless, all individual spot analyses are provided in Supplementary File 1, and plots of individual EMPA non-averaged analyses are given in Supplementary File 4. Specimens with anomalous measurements or high variation were re-run to identify and remove clear outliers. Outliers most likely result from the beam sampling microscopic crystalline phases at depth, as these were sometimes visible at the surface. As these crystals are compositionally distinct from the matrix glass of the obsidian, analyses or partial analyses of these were not included in the averages. A total of 558 spot analyses were made, of which 526 were used for calculating averages. At least 3 analyses were taken for each object. In cases where the three analyses differed, further analyses made it clear which measurements were anomalous and which ones represented the glassy melt.

EMPA data on a wide range of geological sources in Eastern Anatolia and the Caucasus region collected by Frahm (2010; 2012), with minor updates to source names that have emerged in the last decade, were used to help determine the sources present in the Mtsvane Gora data. Both datasets were normalized to 100%, but analytical totals (typically 98–101%) are reported in Supplementary File 1.

3.4. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)

Trace element data was acquired on three archaeological samples and two geological samples using an Agilent 8900 triple quadrupole ICP-MS (ICP184 QQQ) attached to a Resonetics 193 nm ArF excimer laser-ablation in the Department of Earth Sciences, Royal Holloway University of London. Limitations on instrument access prevented analysis of the full assemblage via LA-ICP-MS. Furthermore, the other methods were sufficiently effective that LA-ICP-MS analyses served primarily as a supplementary validation. The samples chosen for LA-ICP-MS analysis include known geological samples from Chikiani, a suspected Chikiani-derived sample from Mtsvane Gora, and two suspected non-Chikiani samples from Mtsvane Gora.

The analytical procedures followed are the same as those outlined in Tomlinson et al. (2010). A spot size of 34 μm was used with a repetition rate of 5 Hz for the analyses. The NIST612 glass (GeoREM 11/2006) was used to calibrate the instrument and the MPI-DING reference glasses (Jochum et al. 2006) were used to monitor accuracy of the data. ^{29}Si was used as the internal standard with the Si values derived from EMPA. The LA-ICP-MS data reduction was performed in Microsoft Excel. Accuracies of LA-ICP-MS analyses of MPI-DING glass standards ATHO-G and StHs6/80-G were typically less than 5% most elements analysed. The obsidian glass data and MPI-DING reference glass analyses are provided in Supplemental File 1.

4. Results

4.1. Portable X-ray fluorescence spectrometry (pXRF)

The pXRF analysis of Sr, Zr, Rb, and Nb of Mtsvane Gora obsidian was successful in distinguishing samples of different composition, and in most cases revealed good agreement with known geological sources (Figs. 5 and 6). In the Sr-Zr plot, most of the samples plot along a roughly linear trend line that matches quite well with the Chikiani field. Several obsidian samples (1012-5, 568-12, 826-9, and 952-6) had higher measurements of Sr and Zr, but plot along the same trend line as the other Chikiani field and have no other plausible alternative matches. It is likely that these measurements represent compositional variation within the Chikiani source which would require further explanation through geological survey and detailed analysis of source chemistries. Eight samples have clear dissimilarities in their chemical composition compared to the main cluster. Seven of these fit well with other known obsidian sources, including Damlik, Aghvorik, Kars-Arpaçay (1 and 2), and the Arteni sources.

There is less separation between sources in the Rb-Nb plot, but the pattern is consistent. Nb values for samples clearly matching certain source fields in the Sr-Zr plot are slightly lower than expected, but these differences are small in absolute terms—about 3–4 ppm. The low overall concentrations of Nb, and surface irregularities in the debitage may explain these slight shifts.

While nearly all the samples were reasonably well-attributed to a particular source based on the pXRF results, sample 776–14 is an exception that is difficult to place. It plots somewhat close to the Kars-Arpaçay sources, but its Zr content is low for Kars-Arpaçay-2 and its Sr content is low for Kars-Arpaçay 1, and for a South Erzurum source described by Chataigner et al. (2014). Likewise, its Rb content exceeds those found in either of the two Kars-Arpaçay sources. Other conceivable sources based on Sr and Zr content of 776-14, such as Muş and Pasinler, both in eastern Anatolia, are excluded by significant differences in their Rb and Nb content. Finally, we note that given the overlapping fields, 1012-1, which we assign to Kars-Arpaçay 1, also has a composition close to South Erzurum source. However, given that the only a few geological samples of the latter have been analysed, while the former is a well-documented obsidian source for archaeological assemblages, we favor the Kars-Arpaçay 1 designation for 1012-1.

4.2. Electron microprobe analysis (EMPA)

Major and minor elemental compositions determined by EMPA complemented the results from XRF trace element analysis. While separation between potential geological sources among major and minor element chemistry is not as significant as seen in some trace elements, these analyses offer an independent check using a different method. Nevertheless, it is important to keep in mind that EMPA spot sizes (10 μm) are smaller than some heterogeneities in the melt, so individual spot measurements typically reveal more intra-object variation than pXRF measurements, which have spot sizes on the order of several millimeters. Small crystals were observed in backscatter images of the samples and these were mostly a few microns to tens of microns in size (microlites) (Fig. 7). It was sometimes possible to tentatively identify the crystalline phases from the analysis, even when they were small relative to the beam's excitation volume, based on which elements were anomalously higher or lower than the other analyses of the same sample. In many cases, they were probably pyroxene or feldspar. The glass of some samples had considerable variability in potassium and sodium, probably due to alkali exchange during slow cooling (Scott 1971).

Despite these considerations and caveats, the major and minor element analyses show the same correlations as those made with the pXRF-derived trace elements. The majority of samples cluster together in a more or less constrained field aligning with those of the Chikiani source, while the minority of samples that plot outside this main cluster

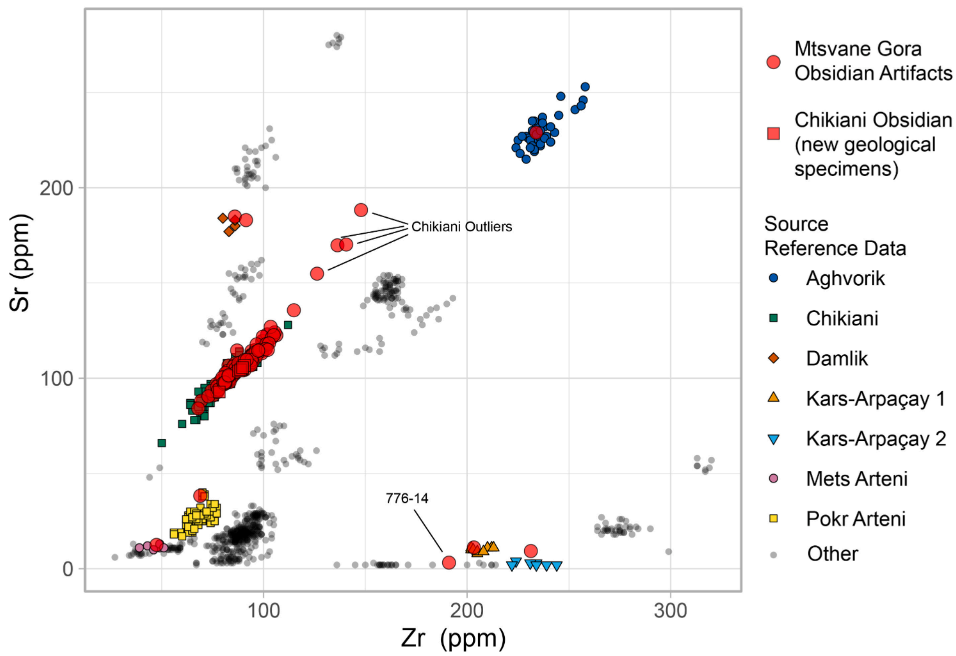

Fig. 5. Sr-Zr plot for Mtsvane Gora obsidian, plotted against geological data. Geological sources which match obsidian analysed from Mtsvane Gora are shown in color, geological source data without matches in the Mtsvane Gora assemblage are plotted in gray for reference.

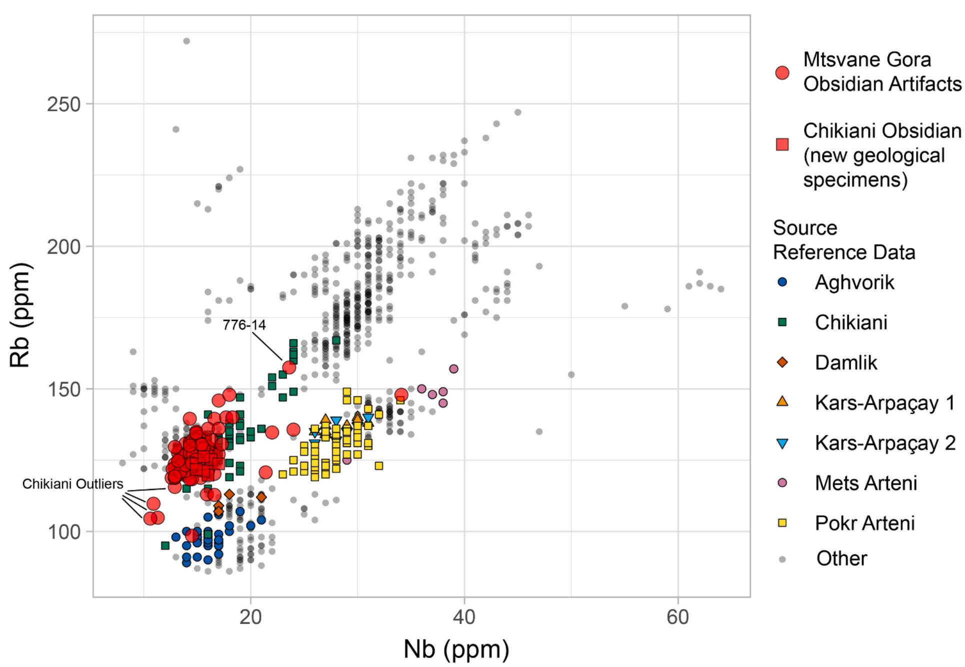

Fig. 6. Rb-Nb plot for Mtsvane Gora obsidian, plotted against geological data. Geological sources which match obsidian analysed from Mtsvane Gora are shown in color, geological source data without matches in the Mtsvane Gora assemblage are plotted in gray for reference.

are with the same samples that were identified as non-Chikiani source based on the pXRF data.

FeO-CaO plots are particularly illuminating in this regard (Fig. 8). Samples from Kars-Arpaçay plot on the low-calcium the spectrum, while Arteni, Chikiani, and Damlik form clusters of progressively increasing calcium content. Sample 826-3 has usually high CaO and FeO (>1 wt% for both), which is consistent with samples from Aghvorik. Interestingly, the unidentified sample 776-14 plots close to Kars-Arpaçay field; as with the trace elements, this seems the nearest plausible match, despite divergences, particularly in Rb content.

Plots of Na_2O, K_2O, SiO_2, and Al_2O_3, while showing more overlap between sources, likewise confirm these broad patterns (Figs. 9 and 10). Three exceptions are samples 776-3, 893-3, and 952-2, all samples which otherwise plot well within the Chikiani field, but which are marked by anomalously low sodium and high potassium. Such chemistries are likely the result of alkali exchange (Scott 1971), due to slow cooling, and are not necessarily indicative of a different source. Encouragingly, however, the two samples which match Kars-Arpaçay sources in the Sr-Zr plot have higher Na values as expected from Kars-Arpaçay, as does unidentified sample 776-14. Likewise, in the Al_2O_3-SiO_2 plot, sample 826-3, which matches Aghvorik trace element composition, also plots in the low Si, high Al range as expected.

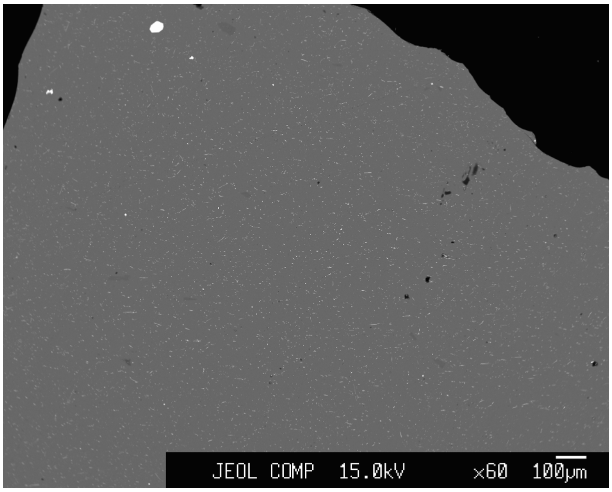

Fig. 7. Backscatter electron image showing example of fine microlite crystals (lighter flecks), which differ compositionally from the glassy melt. Image is from sample 1012–6.

4.3. *Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)*

As a comparison, three samples of obsidian which diverged from the core group in EMPA and pXRF analyses, as well as two recently-collected geological samples from Chikiani were analyzed via LA-ICP-MS (Table 2). Ch-1 and Ch-2 geological samples have the same chemistry with similar levels of Nb, Th and La. Archaeological samples 776-14, 826-12 and 826-3 each have distinct chemical compositions that do not match with the two samples from Chikiani. While the general patterns hold, however, the absolute degree to which the LA-ICP-MS matched the pXRF and EMPA data varied somewhat between elements. LA-ICP-MS results tended to exceed EMPA measurements for both Ca and Ti. LA-ICP-MS measurements for Ca in Sample 776-14 (2867 and 4683 ppm) both diverged from the EMPA measurement of 1001 ppm (equivalent to 0.14 wt% CaO). This is attributed to Ca-rich microcrystal present in these obsidians, these were avoided during EMPA, however during LA-ICP-MS their incorporation into the analysis was unavoidable. Only the Ca ablation signal appears affected by these inclusions, with no major signal variability observed during the individual measurements of the trace elements presented.

Agreement between the pXRF and LA-ICP-MS data was good for Rb and Zr, slightly less so for Sr. LA-ICP-MS values for Nb were consistently higher than pXRF results by 5–9 ppm or 33–43% relative—some of the difficulties may derive from the fact that overall Nb content is low compared to the other elements. Usefully, LA-ICP-MS confirmed the very low Sr content (2–3 ppm) in 776-14, which was observed in the pXRF data and which separated it from its closest match, Kars-Arpacay 1. These comparisons illustrate some of the challenges in cross-correlating datasets across instrument types. For these reasons, we favor source determinations that use data generated using the same analytical technique. Spot sizes for pXRF instruments are generally orders of magnitude larger than for both the LA-ICP-MS and the EMPA, so there is potential for the pXRF analysis to also include microlites and so may not just reflect the melt chemistry alone.

4.4. *Source identification*

The combination of EMPA, pXRF, and LA-ICP-MS analysis and comparisons with geological reference datasets provided secure or probable identifications all but one of the samples analyzed. Of the 111 samples identified, 99 are securely linked with the Chikiani source, with a further 4 attributed as probable Chikiani. Small quantities of obsidian from six other sources in modern day Armenia and northeastern Turkey, including Aghvorik (1), Damlik (one of the Tsaghkunyats sources) (2), Mets Arteni (1), Pokr Arteni (1), Kars-Arpaçay 1 (1), and Kars Arpaçay 2 (1) (Table 3, Fig. 11).

5. Discussion

The results of obsidian provenance analysis provide clear evidence for the importance of the Chikiani source in eastern Georgia through the Late Bronze Age and into the Iron Age. Prior research had suggested this was the case for the Chalcolithic and Early Bronze Age, but no prior work had examined such a large securely-dated obsidian assemblage from the Late Bronze and Early Iron Age.

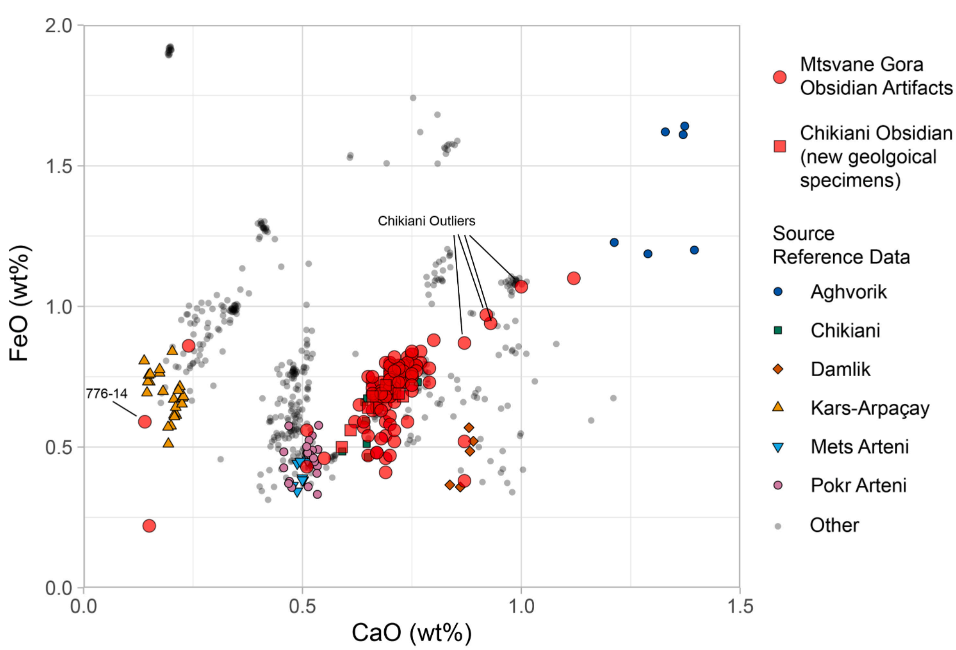

Fig. 8. FeO-CaO plot for Mtsvane Gora obsidian artifacts, plotted against geological data. Geological sources which match obsidian analysed from Mtsvane Gora are shown in color, geological source data without matches in the Mtsvane Gora assemblage (based on all elements) are plotted in gray for reference.

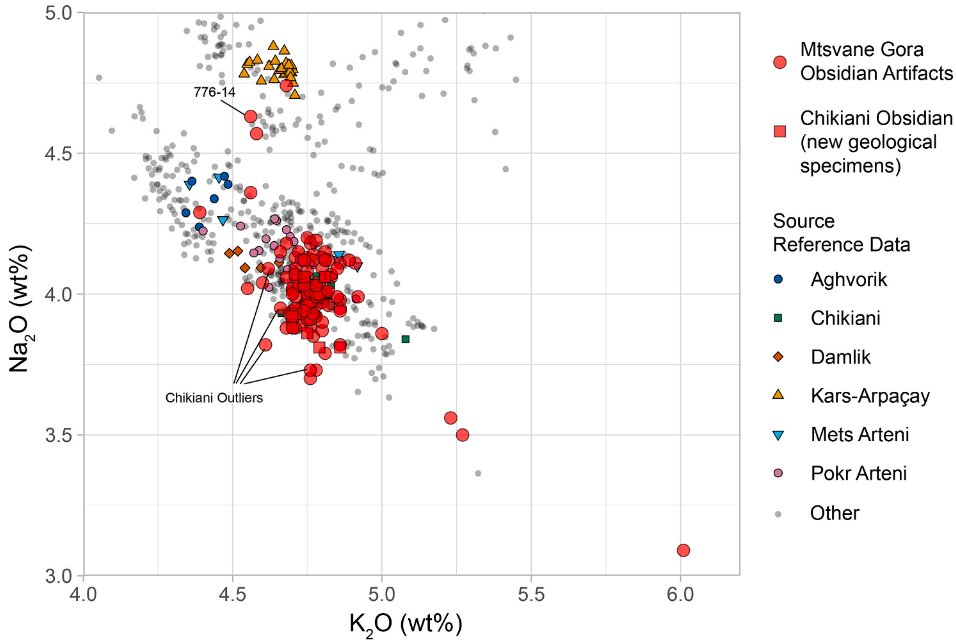

Fig. 9. Na_2O-K_2O plot for Mtsvane Gora obsidian, plotted against geological data. Geological sources which match obsidian analysed from Mtsvane Gora are shown in color, geological source data without matches in the Mtsvane Gora assemblage are plotted in gray for reference.

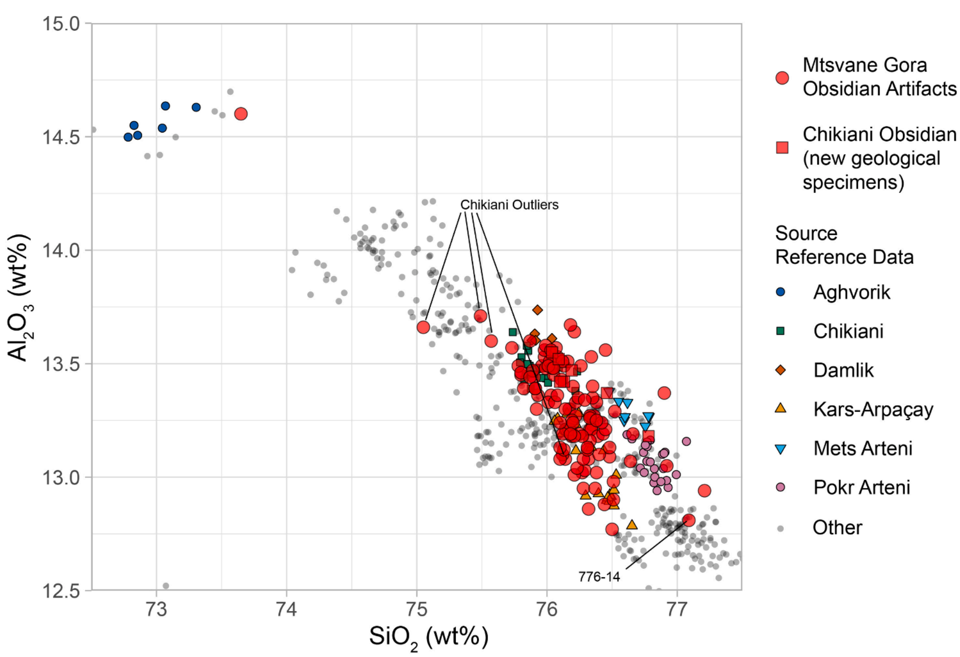

Fig. 10. Al_2O_3-SiO_2 plot for Mtsvane Gora obsidian, plotted against geological data. Geological sources which match obsidian analysed from Mtsvane Gora are shown in color, geological source data without matches in the Mtsvane Gora assemblage are plotted in gray for reference.

Before considering the implications of these results for highland-lowland interaction, it is worth considering the possibility of secondary transport. Some sources in the literature mention that Chikiani obsidian is carried downstream along the Khrami river, the lower reaches of which pass ~15 km from Mtsvane Gora (Chataigner and Gratuze 2014a:31; La Russa et al. 2019:6735). Details about the possible secondary deposits—specifically quantity and quality—are lacking, however, and it appears that most recent references to secondary transport in the Khrami can be traced to a brief comment in Badalyan et al. (2004:442). Secondary deposition of obsidian away from the primary source is certainly a possibility, but there is no data on quantities found at different points along the Khrami, and how suitable cobbles from the lower Khrami, carried >70 km, battered by rocks and river currents, and subject to freeze–thaw fracturing in an aqueous environment, might be for knapping. The primary Chikiani obsidian source is abundant and easily accessible; it is located as relatively high elevation, but the topography is gradual. Rather than scouring lower Khrami riverbanks for the occasional transported cobble that made it to the lowlands, it would have been simpler and more reliable to procure material from the highlands, nearer the primary deposit. Summer pasturelands in the plateaus, and abundant metal deposits in foothills would have facilitated the emergence of conduits for the flow of people, materials, and animals

Table 2
Laser Ablation ICP-MS Results, with corresponding pXRF and EMPA data for corresponding measured elements. All result listed in ppm except CaO and TiO_2 which is in wt.% LA-ICP-MS results were converted from elemental ppm to oxide wt.% for comparability; original ppm values reported in Supplementary File 3. "Art" indicates a Mtsvane Gora artifact, "Geo" indicates a geological sample collected from the Chikiani source.

Artifact	Type	Suspected Source	Technique	CaO	TiO_2	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Er	Yb	Lu	Ta	Pb	Th	U
776–14	Art	Unknown	LA-ICP-MS	0.40	0.09	158.8	2.0	45.4	181.9	32.6	37.9	32.6	65.8	7.2	26.8	6.3	0.2	5.9	7.7	4.9	5.3	0.8	2.0	30.8	20.7	7.4
776–14	Art	Unknown	LA-ICP-MS	0.66	0.08	147.0	3.3	44.5	177.0	31.9	38.1	32.3	67.1	7.2	26.9	6.5	0.5	6.0	7.4	5.0	5.2	0.7	2.0	28.6	20.0	7.2
776–14	Art	Unknown	pXRF			157	3		191	24																
776–14	Art	Unknown	EPMA	0.14	0.08																					
826–3	Art	Aghvorik	LA-ICP-MS	1.49	0.36	108.5	186.8	15.4	230.9	20.7	922.1	48.7	80.9	7.4	24.8	3.7	0.9	2.8	2.6	1.6	1.9	0.3	1.2	19.1	17.1	3.8
826–3	Art	Aghvorik	LA-ICP-MS	1.55	0.36	108.9	185.1	15.5	232.8	20.6	927.2	48.9	80.7	7.3	24.6	3.8	1.0	2.9	2.6	1.7	1.9	0.3	1.2	18.7	17.3	3.7
826–3	Art	Aghvorik	pXRF			99	229		234	14																
826–3	Art	Aghvorik	EPMA	1.12	0.33																					
826–12	Art	Damlik	LA-ICP-MS	0.94	0.12	118.9	149.2	10.3	88.7	23.4	728.8	36.2	59.1	5.1	16.6	2.6	0.4	1.8	1.8	0.9	1.1	0.2	1.8	25.1	24.0	8.5
826–12	Art	Damlik	LA-ICP-MS	1.02	0.12	116.8	160.9	10.5	88.9	23.2	720.9	36.3	59.4	5.3	16.3	2.6	0.4	1.8	1.8	1.1	1.2	0.2	1.8	24.6	23.8	8.6
826–12	Art	Damlik	pXRF			113	183		91	17																
826–12	Art	Damlik	EPMA	0.86	0.10																					
Ch-1	Geo	Chikiani	LA-ICP-MS	0.78	0.12	136.4	91.7	13.6	90.4	21.8	781.0	25.7	48.9	4.8	15.8	2.8	0.6	2.4	2.2	1.4	1.4	0.2	1.6	22.4	15.8	5.8
Ch-1	Geo	Chikiani	LA-ICP-MS	0.75	0.13	138.6	87.3	13.6	91.2	22.2	799.7	26.4	50.0	4.9	16.2	3.0	0.6	2.5	2.4	1.4	1.4	0.2	1.6	22.6	16.2	5.8
Ch-1	Geo	Chikiani	pXRF			124	105		90	15																
Ch-1	Geo	Chikiani	EPMA	0.69	0.09																					
Ch-2	Geo	Chikiani	LA-ICP-MS	0.77	0.13	134.0	88.5	13.3	93.0	21.3	838.1	26.7	50.5	4.9	16.5	3.1	0.6	2.3	2.3	1.4	1.5	0.2	1.5	22.7	15.9	5.5
Ch-2	Geo	Chikiani	LA-ICP-MS	0.77	0.13	135.5	90.8	13.5	92.9	21.7	856.8	26.9	50.4	4.9	16.5	3.1	0.6	2.6	2.2	1.3	1.5	0.2	1.6	22.4	16.1	5.6
Ch-2	Geo	Chikiani	pXRF			120	107		91	16																
Ch-2	Geo	Chikiani	EPMA	0.72	0.11																					

Table 3
Summary of provenance determinations for analyzed obsidian.

Source	Total # of Artifacts	Notes
Chikiani	99	
Probable Chikiani	4	Plots along same linear trend in Sr-Zr plot as Chikiani; no other plausible matches based on reference dataset of the sources; likely due to as-yet-unmapped sub-sources or zoning in the Chikiani deposit.
Aghvorik	1	
Damlik	2	
Mets Arteni	1	
Pokr Arteni	1	
Kars-Arpaçay 1	1	South Erzurum source (Chataigner et al. 2014) also plots in a similar field.
Kars-Arpaçay 2	1	
Unidentified	1	Kars-Arpaçay sources are closest match for 776–14, but fit is not ideal (e.g. Rb content). The South Erzurum source is also a possibility.

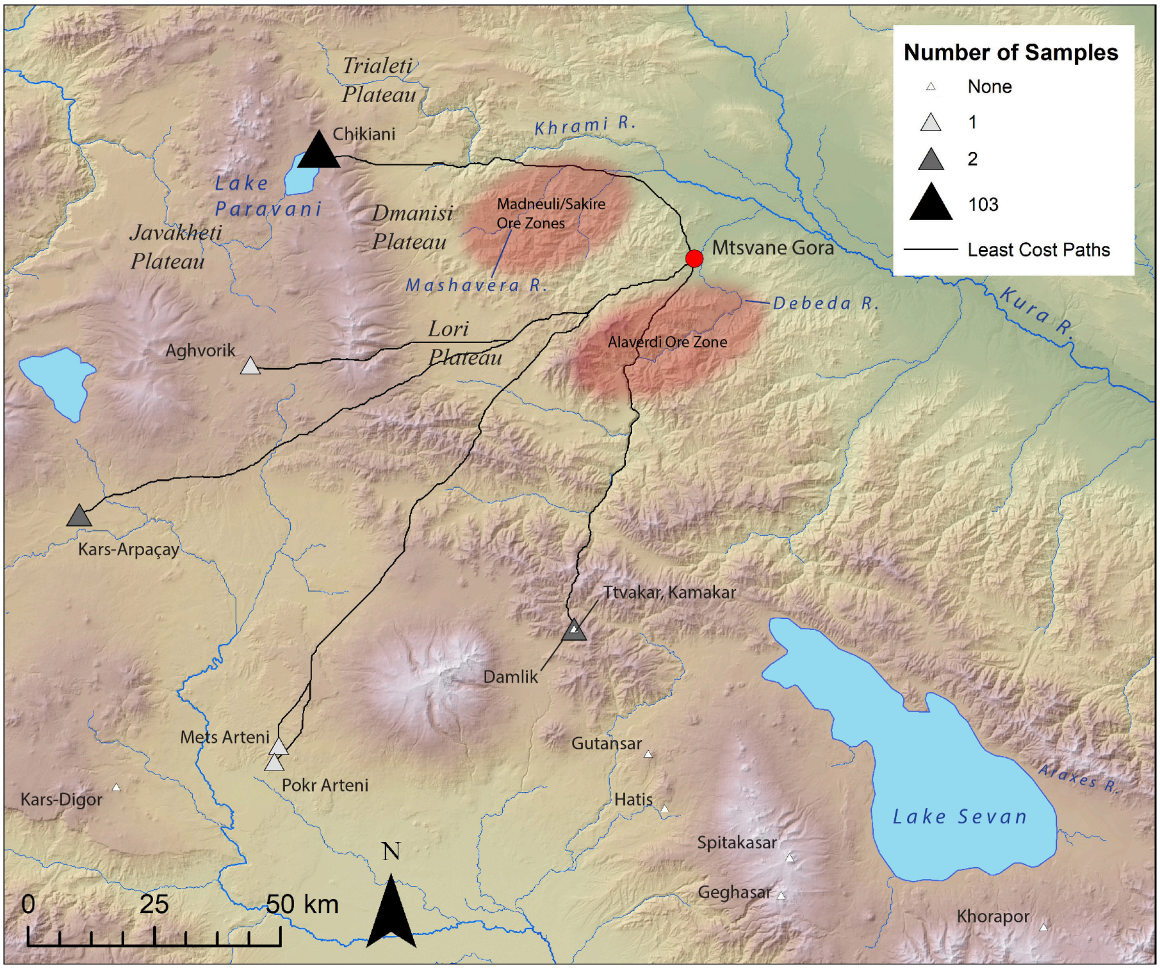

Fig. 11. Obsidian procurement patterns at Mtsvane Gora in the context of other natural resources (ore deposits and plateau zones suitable for summer pasture) that may have stimulated highland-lowland contact.

running from the highlands around Chikiani to the vicinity of Mtsvane Gora, so this is not an unreasonable assumption. While we cannot categorically rule out the possibility that knappers at Mtsvane Gora used fluvially transported Chikiani obsidian gathered from the lower Khrami, we consider it likely that most Chikiani obsidian at the site was gathered at higher elevations in the Khrami gorge, if not at the source itself. A raw materials survey of the Khrami river with an eye toward the quantity and quality of obsidian would help resolve this issue.

As noted above, selection of objects for analysis was guided by a desire to sample floor surface contexts as well as mixed LBA-EIA deposits in order to avoid sampling artifacts that might derive from only a single (and therefore possibly unrepresentative) knapping episode. Interestingly, among the non-Chikiani samples, six of eight came from 14th/13c. BCE floor level contexts. This is contrary to the possible scenario we intended to guard against when designing the sampling strategy. Rather, the rate of non-Chikiani obsidian was actually higher (~9%, from 6 non-Chikiani sources) in the 14th/13th c. floor assemblages than in the general LBA-EIA deposits (~4%, from 2 non-Chikiani sources), which probably includes obsidian dating from later periods of the site. These patterns are intriguing, but it would be presumptuous to argue for a chronological change in the diversity of obsidian sources over the LBA-EIA period. A Chi-squared test showed that chronological designation (14th/13c. BCE floor level vs general LBA-EIA) was not a significant predictor of the quantity of non-local obsidian ($\chi^2 = 0.86$, df $= 1$, $p = 0.35$), though it is worth noting that this test is not ideal for categorical data so unequally distributed (due to the low rates of non-Chikiani obsidian). Nonetheless, on a site with wider variety of securely dated floor contexts, it would be interesting to look for shifts in obsidian procurement patterns within the LBA-EIA. One could certainly conceive of scenarios in which obsidian exchange networks and technical skills shifted as metal gradually replaced obsidian as the material for arrowheads, a change that probably took place around this time.

Obsidian sourcing patterns at Mtsvane Gora indicate that the residents at the site were engaged networks of interaction with adjacent highland regions that were directional and asymmetric. Here we use the terms “directional” and “asymmetric” not in the sense of a trade imbalance in the value or quantity of goods moving along a trade route, but rather to describe Mtsvane Gora’s uneven or skewed engagement with different highland areas—at least with respect to obsidian supply. The predominant orientation appears to be toward the highlands to the west, towards the Tsalka and Javakheti plateaus, where the Chikiani source is located, rather than the south. (The lack of obsidian in the Great Caucasus range—except the Baksan source in the North Caucasus—precludes any comment about networks reaching across the Kura Valley in that direction.) These westerly networks would have followed either the Khrami or Mashavera rivers, which serve as avenues of access into the highlands. Not only is Chikiani obsidian dominant in the assemblage, the other sources present at Mtsvane Gora also suggest a more west or southwest orientation, rather than a southerly one. With the exception of two samples from Damlik in the Tsaghkunyats range, no samples came from the numerous Lesser Caucasus obsidian sources to closer to Lake Sevan (Fig. 11). Topography and land-use patterns may have played a role in this, as the lands between the upper reaches of the Kura and Araxes River, where Chikiani, Aghvorik, the Kars-Arpaçay and

Arteni sources are located, are highland plateau ecozones, which would have facilitated movement, and may have been important summer grazing areas. There are highland plateau areas to the south, to be fair, but those to the west and southwest closer than those of comparable size more directly to the south. It is certainly plausible that pastoral movements between the Kura lowlands and plateau zones would have brought animals and materials, through the foothills near Mtsvane Gora.

Given Mtsvane Gora's position where the Debeda River valley narrows as it enters the Lesser Caucasus foothills (Fig. 2), it is perhaps surprising that this corridor into the highlands to the south did not facilitate the transport of obsidian from sources like Gutansar, Hatis, Spitakasar, or Geghasar. Major copper deposits in Debeda gorge around Alaverdi (Mederer et al. 2014) would presumably have drawn people through this area, just as major ore deposits in the foothills between Chikiani and Mtsvane Gora probably facilitated the networks of exchange oriented to the west. Connections between Mtsvane Gora and these more southerly regions has been suggested by the ritual shrine assemblages, which are best attested at Gegharot and Metsamor, both of which lie to the south (Erb-Satullo and Jachvliani 2022). Whatever contacts or materials exchanges did occur, however, they clearly did not involve the movement of significant quantities of obsidian.

While we suggest that obsidian exchange networks may have been linked in some way with the movement of other materials, people, and animals between the lowlands and highlands, the specific mechanics of this trade remain somewhat obscure. Possible scenarios include, among others, direct procurement, in which people living at Mtsvane Gora travelled into the highlands themselves, or a trade involving intermediaries. We also cannot be certain whether obsidian was a secondary trade engaged in opportunistically on the back of other exchange networks, or whether it was systematically organized. Certainly, the quantities involved and the distances in question would not have required full time specialists to manage logistics, so it seems unlikely that the trade would have been carried out by merchants dealing exclusively with obsidian. On the other hand, it was a ubiquitous material in lowland Kvemo Kartli, so its movement into these areas was probably not entirely a matter of happenstance. Research on highland-lowland interaction in other spheres (e.g. metallurgy, pastoralism) would help to clarify whether this westerly orientation was a general phenomenon for the area, or something specific to obsidian. Resolving this question would also offer indirect insight into possible interdependencies between the obsidian trade and these other economic spheres.

6. Conclusions

The abundance of obsidian at Mtsvane Gora underlines the continued importance of the material well after metal became common. While there are notable exceptions, the bulk of research on obsidian (and indeed stone tools in general) in the Caucasus and the Near East has focused on Chalcolithic and earlier periods. In the broadest sense, research on Bronze and Iron Age chipped stone tools and debitage illustrates how certain technologies persist long after they have supposedly been superseded, in this case by the advent of metallurgical technologies (Frieman 2021; Rosen 1997).

In the case of the Caucasus, the continued dominance of Chikiani as the key source of obsidian for the Kura lowlands in Eastern Georgia for thousands of years suggests that certain complementary relationships and networks of exchange had remarkable stability. These patterns of acquisition appear to persist across several major transformations in lifeways and subsistence practices, including the steep decline in permanent settlement at the end of the Kura-Araxes culture (mid-late 3rd millennium BCE), the rise of kurgan-building elites in the Middle Bronze Age (mid-3rd to mid-2nd millennium BCE), the re-emergence of more sedentary settlement and the beginning of fortress-building in the Late Bronze and Early Iron Age.

The precise provenance determinations afforded by obsidian analysis enable us to deconstruct vague generalizations about lowland-highland relationships in the Caucasus and beyond. The mere fact of geographic adjacency is not sufficient to show that proximate highland and lowland zones were interconnected. Highland-lowland relations are rightly an enduring theme of Near Eastern archaeology, but scholarship must investigate the structure and character of these relationships empirically, rather than making assumptions based on ethnographic or recent historic analogy (for an analogous critique of assumptions in research on pastoralism, see Hammer and Arbuckle 2017). Obsidian is just one dimension of networks of highland-lowland exchange within the South Caucasus, albeit one that is both archaeologically visible and suited to accurate sourcing studies. Among the wide array of materials, animals, and people that may have moved through the foothill zones around Mtsvane Gora, some are less amenable to provenance research, some have yet to be studied in detail, some can only be investigated indirectly, and others are nearly invisible to archaeological investigation. Though it remains only a small part of the broader economic interaction between lowland and highland areas, the obsidian trade serves as a proxy (admittedly imperfect) for wider exchange patterns, since other things were probably traded for and alongside it. The results suggest that different highland and lowland zones engaged with each other in different ways, structured by patterning in natural resources, local ecologies, and cultural practices. Lowland sites like Mtsvane Gora were not linked to all adjacent highlands areas in the same way, and the converse is likely true for sites in the highlands vis-à-vis their relationship with lowland zones. It is only by reconstructing the articulations between these different economic components (see Erb-Satullo 2022), that we can move beyond enduring, yet homogenizing narratives about topography and socioeconomic relations in the archaeology of the greater Near East.

CRediT authorship contribution statement

Nathaniel L. Erb-Satullo: Conceptualization, Software, Resources, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Data curation, Supervision, Project administration, Funding acquisition. **Matilda Rutter:** Investigation, Writing – original draft, Writing – review & editing. **Ellery Frahm:** Conceptualization, Investigation, Resources, Data curation, Writing – review & editing. **Dimitri Jachvliani:** Investigation, Resources, Supervision, Writing – review & editing. **Paul G. Albert:** Investigation, Writing – review & editing. **Victoria C. Smith:** Conceptualization, Investigation, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Frahm is an editor-in-chief for the journal; however, he was not involved in any decisions regarding its publication, and he was blinded to the review process since the article was handled by a different editor. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is included in the supplementary files.

Acknowledgements

Fieldwork at Mtsvane Gora was funded by the American Research Institute of the South Caucasus, the Rust Family Foundation, a Spatial Archaeometry Research Collaborations (SPARC) Grant, the Harvard University Davis Center for Russian and Eurasian Studies, and the Harvard Department of Anthropology. Paul Albert is supported by a UKRI

FLF (MR/S035478). The authors would like to thank Project ARKK team members for their support during fieldwork.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.103988.

References

Algaze, G., 2005. The Uruk World System: The Dynamics of Expansion of Early Mesopotamian Civilization. University of Chicago Press, Chicago.

Anderson, W., Negus Cleary, M., Birkett-Rees, J., Krsmanovic, D., Tskvitinidze, N., 2018. Gateway to the Yayla: The Varneti Archaeological Complex in the Southern Caucasus Highlands. Eur. J. Archaeol. 1–22.

Badalyan, R., 2010, Obsidian in the Southern Caucasus: The use of raw materials in the Neolithic to Early Iron Ages, in *Von Majkop bis Trialeti. Gewinnung under Verbreiung von Metallen und Obsidian in Kaukasien im 4-2 Jt. v. Chr.* (eds. S. Hansen, A. Hauptmann, I. Motzenbäcker, and E. Pernicka), Rudolf Habelt GmbH, Bonn, 27-38.

Badalyan, R., Chataigner, C., Kohl, P.L., 2004. Trans-Caucasian obsidian: The exploitation of the sources and their distribution. In: Sagona, A. (Ed.), A View from the Highlands: Archaeological Studies in Honour of Charles Burney. Peeters, Herent, Belgium, pp. 437–465.

Badalyan, R., Harutyunyan, A., Chataigner, C., Le Mort, F., Chabot, J., Brochier, J.-E., Balasescu, A., Radu, V., Hovsepyan, R., 2010. The settlement of Aknashen-Khatunarkh, a Neolithic site in the Ararat plain (Armenia): Excavation results 2004–2009. Tüba-Ar 13, 187–220.

Chataigner, C., Gratuze, B., 2014a. New Data on the Exploitation of Obsidian in the Southern Caucasus (Armenia, Georgia) and Eastern Turkey, Part 1: Source Characterization. Archaeometry 56, 25–47.

Chataigner, C., Gratuze, B., 2014b. New Data on the Exploitation of Obsidian in the Southern Caucasus (Armenia, Georgia) and Eastern Turkey, Part 2: Obsidian Procurement from the Upper Palaeolithic to the Late Bronze Age. Archaeometry 56, 48–69.

Chataigner, C., Işıklı, M., Gratuze, B., Çil, V., 2014. Obsidian Sources in the Regions of Erzurum and Kars (North-East Turkey): New Data. Archaeometry 56, 351–374.

Doronicheva, E., Golovanova, L., Doronichev, V., Nedomolkin, A., Shackley, S., 2017. The first Middle Palaeolithic site exhibiting obsidian industry on the northern slopes of the Central Caucasus. Antiquity 91.

Doronicheva, E.V., Shackley, M.S., 2014. Obsidian exploitation strategies in the Middle and Upper Paleolithic of the Northern Caucasus: New data from Mesmaiskaya Cave. PaleoAnthropology 2014, 565–585.

Erb-Satullo, N.L., 2018. Patterns of settlement and metallurgy in Late Bronze-Early Iron Age Kvemo Kartli, southern Georgia. In: Anderson, W., Hopper, K., Robinson, A. (Eds.), Finding Common Ground in Diverse Environments: Landscape Archaeology in the South Caucasus. OREA, Austrian Academy of Sciences, Vienna, pp. 37–52.

Erb-Satullo, N.L., 2022. Towards a spatial archaeology of crafting landscapes. Camb. Archaeol. J.

Erb-Satullo, N.L., Jachvliani, D., 2022. Fortified Communities in the South Caucasus: Insights from Mtsvane Gora and Dmanisis Gora. J. Field Archaeol.

Erb-Satullo, N.L., Jachvliani, D., Kakhiani, K., Newman, R., 2020. Direct evidence for the co-manufacturing of early iron and copper-alloy artifacts in the Caucasus. J. Archaeol. Sci. 123, 105220.

Erb-Satullo, N.L., Jachvliani, D., Kalayci, T., Puturidze, M., Simon, K., 2019. Investigating the spatial organisation of Bronze and Iron Age fortress complexes in the South Caucasus. Antiquity 93, 412–431.

Frahm, E., 2010. The Bronze-Age Obsidian Industry at Tell Mozan (Ancient Urkesh) Syria. University of Minnesota. PhD Unpublished PhD Dissertation,.

Frahm, E., 2012. Non-destructive sourcing of Bronze age near eastern obsidian artefacts: Redeveloping and reassessing electron microprobe analysis for obsidian sourcing. Archaeometry 54, 623–642.

Frahm, E., Feinberg, J.M., Schmidt-Magee, B.A., Wilkinson, K., Gasparyan, B., Yeritsyan, B., Karapetian, S., Meliksetian, K., Muth, M.J., Adler, D.S., 2014. Sourcing geochemically identical obsidian: multiscalar magnetic variations in the Gutansar volcanic complex and implications for Palaeolithic research in Armenia. J. Archaeol. Sci. 47, 164–178.

Frahm, E., Lassen, A.W., Wagensonner, K., 2019. Gods and demons, Anatolia and Egypt: Obsidian sourcing of Mesopotamian amulets and cylinder seals using portable XRF. J. Archaeol. Sci.: Reports 24, 978–992.

Frahm, E., Martirosyan-Olshansky, K., Sherriff, J.E., Wilkinson, K.N., Glauberman, P., Raczynski-Henk, Y., Gasparyan, B., Adler, D.S., 2021. Geochemical changes in obsidian outcrops with elevation at Hatis volcano (Armenia) and corresponding Lower Palaeolithic artifacts from Nor Geghi 1. J. Archaeol. Sci. Rep. 38, 103097.

Frahm, E., Tryon, C.A., 2018. Origins of Epipalaeolithic obsidian artifacts from Garrod's excavations at Zarzi cave in the Zagros foothills of Iraq. J. Archaeol. Sci. Rep. 21, 472–485.

Frieman, C.J., 2021. An Archaeology of Innovation: Approaching Social and Technological Change in. Human Society Manchester University Press, Manchester.

Gobejishvili, G., 1981. Bedenis gorasamarxebis k`ult`ura. Metsniereba, Tbilisi.

Gzelishvili, I.A., 1964. Zhelezoplavil`noe Proizvodstvo v Drevney Gruzii. Metsniereba, Tbilisi.

Hammer, E., 2014. Highland fortress-polities and their settlement systems in the southern Caucasus. Antiquity 88, 757–774.

Hammer, E.L., Arbuckle, B.S., 2017. 10,000 years of pastoralism in Anatolia: a review of the evidence for variability in pastoral lifeways. Nomadic Peoples 20, 214–267.

Hamon, C., Jalabadze, M., Agapishvili, T., Baudouin, E., Koridze, I., Messager, E., 2016. Gadachrili Gora: Architecture and organisation of a Neolithic settlement in the middle Kura Valley (6th millennium BC, Georgia). Quat. Int. 395, 154–169.

Jochum, K. P., Stoll, B., Herwig, K., Willbold, M., Hofmann, A. W., Amini, M., Aarburg, S., Abouchami, W., Hellebrand, E., Mocek, B., Raczek, I., Stracke, A., Alard, O., Bouman, C., Becker, S., Dücking, M., Brätz, H., Klemd, R., de Bruin, D., Canil, D., Cornell, D., de Hoog, C.-J., Dalpé, C., Danyushevsky, L., Eisenhauer, A., Gao, Y., Snow, J. E., Groschopf, N., Günther, D., Latkoczy, C., Guillong, M., Hauri, E. H., Höfer, H. E., Lahaye, Y., Horz, K., Jacob, D. E., Kasemann, S. A., Kent, A. J. R., Ludwig, T., Zack, T., Mason, P. R. D., Meixner, A., Rosner, M., Misawa, K., Nash, B. P., Pfänder, J., Premo, W. R., Sun, W. D., Tiepolo, M., Vannucci, R., Vennemann, T., Wayne, D., and Woodhead, J. D., 2006, MPI-DING reference glasses for in situ microanalysis: New reference values for element concentrations and isotope ratios, Geochem. Geophys. Geosyst., 7.

Keller, J., Djerbashian, E., Pernicka, E., Karapetian, S., and Nasedkin, V., 1996, Armenian and Caucasian obsidian occurrences as sources for the Neolithic trade: Volcanological setting and chemical characteristics., in *Archaeometry 94: Proceedings of the 29th International Symposiun on Archaeometry, 9-14 May 1994* (eds. A. M. Özer and G. D. Summers), Ankara, 69-86.

Kuftin, B.A., 1941. Arkheologicheskie Raskopki v Trialeti. Akademii Nauk Gruzinskoj SSR, Tbilisi.

La Russa, M.F., Randazzo, L., Ricca, M., Rovella, N., Barca, D., Ruffolo, S.A., Berikashvili, D., Kvakhadze, L., 2019. The first archaeometric characterization of obsidian artifacts from the archaeological site of Samshvilde (South Georgia, Caucasus). Archaeol. Anthropol. Sci. 11, 6725–6736.

Le Bourdonnec, F.-X., Nomade, S., Poupeau, G., Guillou, H., Tushabramishvili, N., Moncel, M.-H., Pleurdeau, D., Agapishvili, T., Voinchet, P., Mgeladze, A., Lordkipanidze, D., 2012. Multiple origins of Bondi Cave and Ortvale Klde (NW Georgia) obsidians and human mobility in Transcaucasia during the Middle and Upper Palaeolithic. J. Archaeol. Sci. 39, 1317–1330.

Lindsay, I., Minc, L., Descantes, C., Speakman, R.J., Glascock, M.D., 2008. Exchange patterns, boundary formation, and sociopolitical change in Late Bronze Age Southern Caucasia: preliminary results from a pottery provenance study in northwestern Armenia. J. Archaeol. Sci. 35, 1673–1682.

Lyonnet, B., Guliyev, F., Helwing, B., Aliyev, T., Hansen, S., Mirtskhulava, G., 2012. Ancient Kura 2010–2011: the first two seasons of joint fieldwork in the Southern Caucasus. Archäologische Mitteilungen aus Iran und Turan 44, 1–191.

Malinsky-Buller, A., Glauberman, P., Ollivier, V., Lauer, T., Timms, R., Frahm, E., Brittingham, A., Triller, B., Kindler, L., Knul, M.V., Krakovsky, M., Joannin, S., Hren, M.T., Bellier, O., Clark, A.A., Blockley, S.P.E., Arakelyan, D., Marreiros, J., Paixaco, E., Calandra, I., Ghukasyan, R., Nora, D., Nir, N., Adigyozalyan, A., Haydosyan, H., Gasparyan, B., 2021. Short-term occupations at high elevation during the Middle Paleolithic at Kalavan 2 (Republic of Armenia). PLoS One 16, e0245700.

Mederer, J., Moritz, R., Zohrabyan, S., Vardanyan, A., Melkonyan, R., Ulianov, A., 2014. Base and precious metal mineralization in Middle Jurassic rocks of the Lesser Caucasus: a review of geology and metallogeny and new data from the Kapan, Alaverdi and Mehmana districts. Ore Geology Reviews 58, 185–207.

Narimanishvili, D., 2019. Sakartvelos tsik`lop`uri simagreebi/Cyclopean Fortresses in Georgia (Georgian and English). Shota Rustaveli National Science Foundation and the Georgian National Museum, Tbilisi.

Narimanishvili, G., 2010. Trialeti in the 15th and 14th Centuries BC. In: Gamkrelidze, G. (Ed.), Rescue Archaeology in Georgia: The Baku-Tbilisi-Ceyhan and South Caucasian Pipelines. Georgian National Museum, Tbilisi, pp. 312–369.

Nishiaki, Y., Maeda, O., Kannari, T., Nagai, M., Healey, E., Guliyev, F., Campbell, S., 2019. Obsidian provenance analyses at Göytepe, Azerbaijan: Implications for understanding Neolithic socioeconomies in the southern Caucasus. Archaeometry 61, 765–782.

Olshansky, K., 2018. Obsidian Economy in the Armenian Highlands During the Late Neolithic: A View from Masis Blur. PhD, UCLA.

Palumbi, G., Guilbeau, D., Astruc, L., Chataigner, C., Gratuze, B., Lyonnet, B., Pulitani, G., 2018. Between cooking and knapping in the southern Caucasus: Obsidian-tempered ceramics from Aratashen (Armenia) and Mentesh Tepe (Azerbaijan). Quat. Int. 468, 121–133.

Purschwitz, C., 2018. Chalcolithic and Middle Bronze Age obsidian industries at Karmir Sar: A mountain view on the lithic economies of the Southern Caucasus. J. Lithic Stud. 5.

Rosen, S.A., 1997. Lithics after the Stone Age: A Handbook of Stone Tools from the Levant. Altamira, Walnut Creek.

Scott, J.C., 2009. The art of not being governed :an anarchist history of upland Southeast Asia. Yale University Press, New Haven.

Scott, R.B., 1971. Alkali exchange during devitrification and hydration of glasses in ignimbrite cooling units. J. Geol. 79, 100–110.

Smith, A.T., 2006, Before Argishti: the roots of complex societies in Caucasia. Notes from the Tsakahovit Plain, Armenia, in: Beyond the Steppe and the Sown: Proceedings of the 2002 University of Chicago Conference on Eurasian Archaeology (eds. D. L. Peterson, L. M. Popova, and A. T. Smith), Brill, Leiden, 172-182.

Smith, A.T., Leon, J.F., 2014. Divination and sovereignty: the Late Bronze Age shrines at Gegharot, Armenia. Am. J. Archaeol. 118, 549–563.
Stein, G.J., 1999. Rethinking World Systems: Diasporas, Colonies, and Interaction in Uruk Mesopotamia. University of Arizona Press, Tucson, AZ.
Stöllner, T., Gambashidze, I., 2011. Gold in Georgia II: The oldest gold mine in the world. In: Anatolian Metal, V. (Ed.), Ü. Yalçin), Deutsches Bergbau-Museum, Bochum, Germany, pp. 187–199.
Tomlinson, E.L., Thordarson, T., Müller, W., Thirlwall, M., Menzies, M.A., 2010. Microanalysis of tephra by LA-ICP-MS — Strategies, advantages and limitations assessed using the Thorsmörk ignimbrite (Southern Iceland). Chem. Geol. 279, 73–89.
Van Buren, M., 1996. Rethinking the vertical archipelago: ethnicity, exchange, and history in the South Central Andes. Am. Anthropol. 98, 338–351.