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Middle Palaeolithic toolstone procurement behaviors at Lusakert Cave 1, Hrazdan valley, Armenia

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ABSTRACT

Strategies employed by Middle Palaeolithic hominins to acquire lithic raw materials often play key roles in assessing their movements through the landscape, relationships with neighboring groups, and cognitive abilities. It has been argued that a dependence on local resources is a widespread characteristic of the Middle Palaeolithic, but how such behaviors were manifested on the landscape remains unclear. Does an abundance of local toolstone reflect frequent encounters with different outcrops while foraging, or was a particular outcrop favored and preferentially quarried? This study examines such behaviors at a finer geospatial scale than is usually possible, allowing us to investigate hominin movements through the landscape surrounding Lusakert Cave 1 in Armenia. Using our newly developed approach to obsidian magnetic characterization, we test a series of hypotheses regarding the locations where hominins procured toolstone from a volcanic complex adjacent to the site. Our goal is to establish whether the cave's occupants procured local obsidian from preferred outcrops or quarries, secondary deposits of obsidian nodules along a river, or a variety of exposures as encountered while moving through the river valley or across the wider volcanic landscape during the course of foraging activities. As we demonstrate here, it is not the case that one particular outcrop or deposit attracted the cave occupants during the studied time intervals. Nor did they acquire obsidian at random across the landscape. Instead, our analyses support the hypothesis that these hominins collected obsidian from outcrops and exposures throughout the adjacent river valley, reflecting the spatial scale of their day-to-day foraging activities. The coincidence of such behaviors within the resource-rich river valley suggests efficient exploitation of a diverse biome during a time interval immediately preceding the Middle to Upper Palaeolithic "transition," the nature and timing of which has yet to be determined for the region.

1. Introduction

The strategies employed by Middle Palaeolithic (MP) hominins to fulfill their toolstone needs, including the occurrence or absence of specialized procurement or quarrying locations, have previously been discussed in terms of their movements through the landscape, social relationships with neighboring groups, and cognitive abilities, such as foresight behind the use and production of stone tools (e.g., Marks, 1988; Roebroeks et al., 1988). Such appraisals have, in turn, been incorporated into debates considering whether MP hominins had fundamentally different behaviors or abilities than modern humans (e.g., Mithen, 1994, 1996a,b; Klein, 1995, 2000; Mellars, 1996a,b; Pettitt, 1997, 2000; Kolen, 1999; Tattersall, 1999), or whether their behaviors are essentially indistinguishable from modern humans once variations within social and ecological conditions are taken into account (e.g., Grayson and Delpech, 2003; Adler et al., 2006; Shea, 2011; Hopkinson et al., 2013). Many of these assessments remain primarily based on an extensive corpus of research on chert procurement in southwestern France (e.g., Larick, 1986, 1987; Geneste, 1988, 1989a,b, 1990; Turq,

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1988a, b, 1989, 1990, 1992; Geneste and Rigaud, 1989; Demars, 1990a, b). These foundational studies, in which cherts were macroscopically attributed to outcrops and deposits in the region, revealed the frequent predominance of local (<5 km) cherts among MP lithic assemblages. This finding has been interpreted as evidence for the spatial scale of day-to-day foraging (e.g., Geneste, 1985, 1989a) and for toolstone procurement "embedded" within economic and subsistence activities that took place near residential sites (e.g., Féblot-Augustins, 1997a,b, 2008). It remains largely uncertain, however, how such local behaviors were manifested. For example, does an abundance of local toolstone at a given site reflect frequent encounters with different outcrops while foraging, or was a particular outcrop favored for some reason and, thus, preferentially quarried? This study examines such behaviors at a finer scale than has so far been possible, allowing us to investigate hominin movements through the local landscape and the ways in which they structured their behaviors in light of their daily technological needs. Here, using a newly developed approach based on the spatial dependence of obsidian's magnetic properties, we test hypotheses regarding the locations where MP hominins procured toolstone from an extensive obsidian source adjacent to a cave. Our goal is to establish whether the cave's occupants procured obsidian from preferred outcrops or quarries, secondary deposits of obsidian nodules along a river, or a variety of exposures as encountered while moving through the river valley or across the wider volcanic landscape during the course of other subsistence activities.

Hominin provisioning behaviors offer unique insights into foraging patterns and landscape use that might otherwise remain obscured. While most archaeological materials recovered from a given site were brought there by its occupants, it is often impossible to know where on the landscape those resources — be they stones, bones, or plants — originated and were procured. Economically important animals and plants have specific environmental requirements, but they typically occupy ranges far larger than those used by hominins during a single foraging episode. While the archaeological remains of animals and plants serve as important proxies for the broader environmental setting, it is often impossible to pinpoint the precise area(s) where these resources were procured, thus limiting our ability to recognize land use patterns. This study seeks to rectify this problem by linking specific obsidian artifacts to specific parts of the landscape and, thus, tie those sources to broader patterns of mobility and land use. Analysis of the dynamic interplays between fixed toolstone sources and procurement behaviors is among the most productive ways to directly test hypotheses regarding hominin foraging patterns and ranges.

Archaeologists have previously used a variety of approaches to investigate the procurement of lithic raw materials, including lithic analysis at technologically specialized sites where extraction and initial working of toolstone may have occurred. However, recognizing specialized quarrying sites has been challenging. Such sites could be buried beneath subsequent deposits or might have been destroyed by later quarrying. The nature of activities at such sites must also be considered. If largely unworked blocks or cobbles were removed, there may be no remnants of the procurement activities (e.g., Ross et al., 2003). The short distances involved in local procurement suggest that minimal processing would occur at extraction or quarrying locations (Metcalfe and Barlow, 1992). Sites interpreted as quarrying locations have typically been characterized by the presence of tested and/or partially worked blocks or nodules with high proportions of cortical flakes and low proportions of tools (e.g., Turq, 1988a, 1989), but it has been argued that such sites reflect a mixture of activities rather than specialization (e.g., Geneste, 1989a). Quarrying complexes, provisionally dated to the MP, have been reported in the Levant (Barkai et al., 2006; Barkai and Gopher, 2009; Gopher and Barkai, 2014), but such sites have been largely elusive in most other parts of the world. Key challenges include how we can identify quarrying activities without finding a quarry and how we can rule out quarrying with an absence of evidence rather than evidence of absence.

Issues of toolstone procurement, use, and resupply have traditionally been investigated using lithic analysis (e.g., Hayden et al., 1996; Prentiss, 1998, 2001; Cowan, 1999; Andrefsky, 2005). Commonly such data are linked to procurement in terms of energy or cost, whereby toolstone procurement strategies "embedded" in foraging and other subsistence activities are low cost while any special-purpose excursions to procure toolstone are high cost (Bamforth, 2006). Consequently, archaeologists typically seek evidence for or against economizing behaviors. For example, Blades (2001) examined variables such as tool type, retouch intensity, cortex amount, and core and blank morphology in Aurignacian assemblages in France and argued that earlier, more mobile groups acquired toolstone from greater distances than was the case for later groups. His conclusion was based, in part, on greater intensity of tool retouch in earlier assemblages and greater intensity of core reduction in later ones. In contrast, Kuhn (1991) studied the Mousterian assemblages from two Italian sites: one situated on a coastal plain with immediate access to abundant chert cobbles, the other in a similar setting but without chert deposits. His findings were the opposite of those of Blades (2001): retouch intensity was greater at the site with abundant chert, whereas cores at the other site were maximized by making greater numbers of unretouched flakes. Thus, there are certainly links among the decisions made at toolstone procurement locations and variables such as material abundance and mobility (Kamp and Whittaker, 1986; Andrefsky, 1994a,b; Beck et al., 2002; Odell, 2003; Bamforth, 2006), but the toolstone procurement hypotheses that we consider here may not be resolvable with this type of analysis, at least not in isolation.

A relatively recent approach to toolstone procurement is the use of cosmogenic isotopes (e.g., ^{10}Be) to establish if chert was obtained at or near the surface (<2 m) or had been sheltered from cosmic radiation. Isotopic analyses of artifacts from Levantine sites (Tabun Cave, $n = 19$; Qesem Cave, $n = 49$) have been interpreted as evidence that cherts originated from meters-deep quarries rather than primary or secondary near-surface exposures (Verri et al., 2004, 2005; Boaretto et al., 2009). This approach to elucidating toolstone procurement has yet to see widespread application, perhaps due, at least in part, to its destructive sample preparation (i.e., crushing artifacts to yield a powder), effort (i.e., two or three spectrometric techniques are preceded by a series of chemical treatments), and cost (i.e., several hundred dollars per specimen or artifact). Another approach is that of Fernandes and colleagues (e.g., Fernandes et al., 2007; Thiry et al., 2014), who use scanning electron microscopy (SEM) to examine artifacts' cortical surfaces. The micromorphology of these surfaces, they argue, reveal a palimpsest of geological environments from which chert nodules were initially collected (e.g., surface, colluvium, alluvium, marine) and in which artifacts were eventually discarded. Applying their techniques at Payre and Sainte-Anne 1 in southeastern France suggested that nodules had complex depositional histories before their collection as toolstone.

Here we report on the first application of a new approach, based on a combination of portable X-ray fluorescence (pXRF) and rock magnetic characterization, to Lusakert Cave 1 (LKT1), a MP site along the Hrazdan River valley in central Armenia (Fig. 1a). The stratum on which we focus in this study is provisionally dated between MIS (marine isotope stage) 4 and MIS 3. The lithic assemblage is entirely obsidian, and the cave is adjacent to the Gutansar volcanic complex (GVC; Fig. 1b), one of the most important obsidian resources in the region. Geochemically indistinguishable obsidian, produced simultaneously by the GVC, occurs

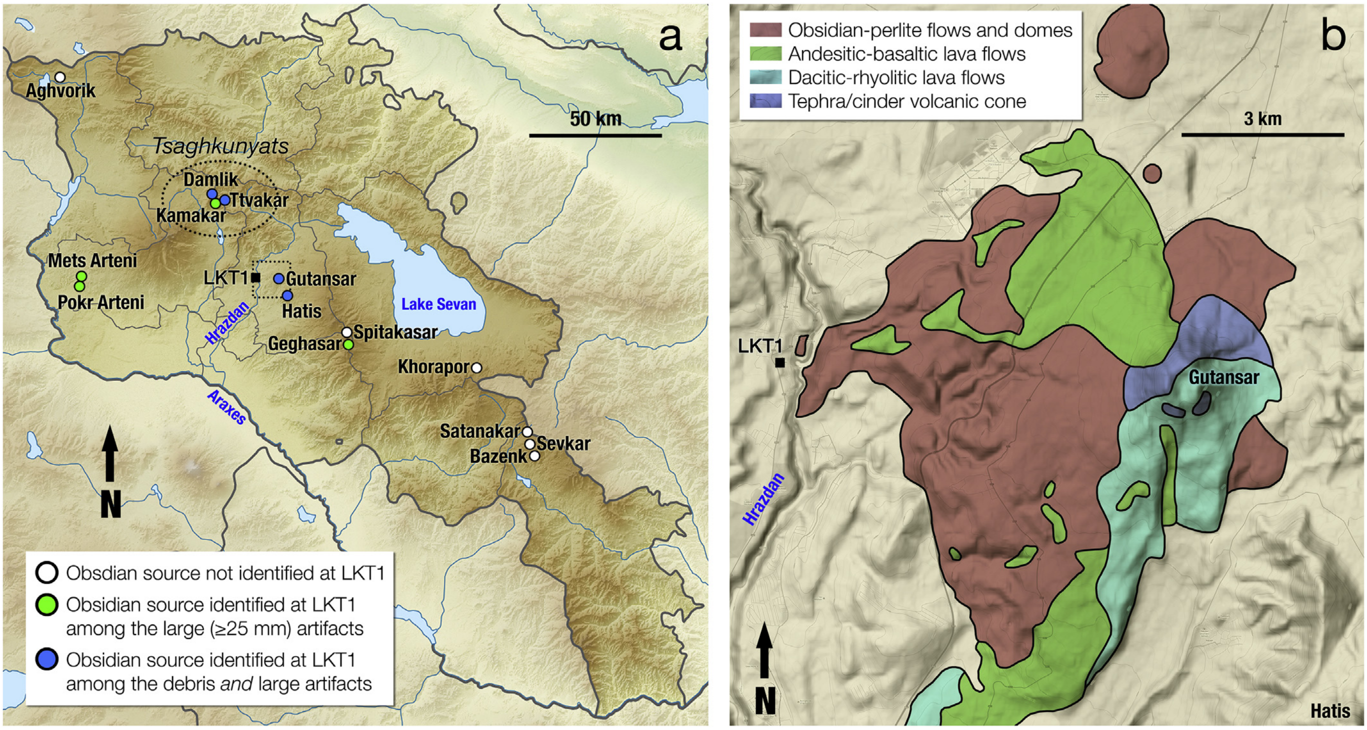

Figure 1. (a) Armenian obsidian sources (circles), the Gutansar volcanic complex (GVC; dotted box), and Lusakert Cave 1 (LKT1; black square). Green and blue circles denote which obsidian sources have been geochemically identified among the LKT1 artifacts so far. "Tsaghkunyats" is sometimes transliterated as "Tsakhkunyats," and "Gutansar" is sometimes transliterated as "Gutanasar." No effort is made here to represent the entire primary and secondary distributions of these obsidians. DEM from SRTM3. (b) Simplified geological map of the GVC highlighting the distribution of its obsidian and other surface features. DEM based on Google Earth, and geological map based on Karapetian et al. (2001) and our field observations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

across ~70 km^2, extending ~10 km east–west and ~13 km north–south. Thus, conventional geochemical obsidian sourcing can match LKT1 artifacts to the GVC (>90%; Frahm et al., 2014a) but is less useful when seeking to reconstruct movements of MP hominins throughout the local landscape. Our solution was to develop a novel approach, based on the magnetic properties of obsidian that vary within an individual source, to investigate more precisely how the LKT1 occupants procured GVC obsidian during specific time intervals (Frahm and Feinberg, 2013; Frahm et al., 2014b). Besides our own pilot work, this is the largest archaeological study of obsidian magnetism to our knowledge (Frahm and Feinberg, 2013: Table 1). The GVC has been magnetically studied much more thoroughly than any other obsidian source in the world (i.e., 244 subsamples measured for Frahm et al., [2014b] plus 359 new subsample measurements), and our interpretations are based on more obsidian artifacts ($n = 286$) than tested magnetically in all earlier studies combined ($n \sim 242$). In addition, no past study has used obsidian magnetic measurements to reveal otherwise invisible hominin behaviors encoded in their artifacts.

Whereas other studies have focused on maximal transport distances of toolstone during the MP (e.g., Féblot-Augustins, 1997a,b, 2008; Moutsiou, 2012), our focus here is local. The hypotheses we consider in this study do not focus explicitly on the linear distances between the outcrops and site. Instead, our hypotheses consider the behaviors of MP hominins to stay adequately supplied with obsidian while occupying LKT1. That is, we seek a better understanding of how these hominins used and moved through the local landscape. If we can show, for example, that obsidian was procured from either favored outcrops or varied exposures randomly scattered throughout the Hrazdan River valley, we may further our understanding of behaviors linked to their subsistence and settlement strategies and their organization of lithic technology. We anticipate that toolstone acquisition by MP hominins was affected by a diverse set of variables throughout Eurasia, especially the local environment, so the study at hand is a component of our broader research program to develop an understanding of local factors that shaped hominin lifeways in the region.

As we report here, it is not the case that one particular obsidian outcrop or deposit attracted the LKT1 residents during the studied time intervals. Nor did they acquire obsidian across the entire volcanic landscape. Instead, our data support the hypothesis that they collected obsidian from various outcrops and exposures throughout the Hrazdan River valley, likely in conjunction with other subsistence activities, which, in turn, reflects the scale of their daily foraging activities. That is, their obsidian procurement taskscape (sensu Ingold, 1993) appears to coincide with the valley landscape. Our results are generally consistent with extant notions of MP toolstone procurement and subsistence. For example, Gamble (1986, 1999) argued that dependence on local resources — toolstone, flora, fauna and their migration routes, shelter, and so on — is a common characteristic of the MP. No previous study, however, has generated these kinds of data, which can be used to test such hypotheses and clarify procurement activities across the local landscape. The coincidence of toolstone procurement and foraging behaviors in the valley suggests the efficient exploitation of a rich, diverse biome at a time immediately preceding the Middle to Upper Palaeolithic "transition," the nature and timing of which has yet to be determined for the region.

2. Background: site and context

The focus of this study is an Armenian MP cave site with well-preserved, stratified, and in situ obsidian artifacts, while its

Table 1
Summary statistics for the magnetic measurements for the five hypothesized models.[a]

		M_s (Am/kg)	M_r (Am/kg)	M_r/M_s	B_c (mT)	B_{cr} (mT)	B_{cr}/B_c
Geological models:							
Entire GVC	Maximum:	0.5075	0.0936	0.2314	28.81	70.53	6.01
	Minimum:	0.0067	0.0007	0.0467	6.62	23.63	1.66
	Range:	0.5008	0.0930	0.1848	22.20	46.89	4.35
	Median:	0.1527	0.0180	0.1109	16.04	45.12	2.85
	Mean:	0.1644	0.0215	0.1210	16.22	45.99	2.97
	St Deviation:	0.1288	0.0207	0.0394	4.35	9.66	0.75
Hrazdan valley	Maximum:	0.5218	0.1031	0.2289	28.58	73.07	6.26
	Minimum:	0.0023	0.0003	0.0497	5.73	24.84	1.71
	Range:	0.5196	0.1028	0.1791	22.85	48.23	4.54
	Median:	0.1516	0.0225	0.1452	17.93	43.07	2.33
	Mean:	0.1995	0.0315	0.1481	18.18	43.60	2.45
	St Deviation:	0.1701	0.0288	0.0294	3.94	9.35	0.51
Alluvial deposit	Maximum:	0.4890	0.0990	0.2520	27.26	52.09	4.74
	Minimum:	0.0100	0.0010	0.0590	7.77	29.62	1.87
	Range:	0.4790	0.0980	0.1930	19.49	22.47	2.86
	Median:	0.4140	0.0520	0.1310	15.60	39.86	2.35
	Mean:	0.2814	0.0414	0.1387	16.53	40.22	2.54
	St Deviation:	0.1861	0.0293	0.0402	4.28	6.73	0.61
Quarry area	Maximum:	0.1498	0.0249	0.2043	26.68	53.51	3.22
	Minimum:	0.0167	0.0023	0.0957	13.42	37.09	1.87
	Range:	0.1331	0.0226	0.1086	13.26	16.42	1.35
	Median:	0.0698	0.0087	0.1400	18.61	47.11	2.56
	Mean:	0.0704	0.0106	0.1442	18.83	46.86	2.55
	St Deviation:	0.0380	0.0068	0.0280	3.38	3.73	0.38
Outcrop A	Maximum:	0.3244	0.0436	0.1607	23.01	56.16	2.81
	Minimum:	0.1192	0.0149	0.1152	16.16	41.59	2.15
	Range:	0.2052	0.0288	0.0455	6.85	14.56	0.66
	Median:	0.1797	0.0239	0.1319	18.85	49.36	2.56
	Mean:	0.1852	0.0246	0.1334	19.17	48.65	2.54
	St Deviation:	0.0495	0.0063	0.0093	1.69	4.19	0.13
Outcrop B	Maximum:	0.0672	0.0076	0.1470	18.16	59.56	3.86
	Minimum:	0.0065	0.0007	0.0665	7.77	28.95	2.46
	Range:	0.0607	0.0069	0.0805	10.39	30.61	1.40
	Median:	0.0300	0.0035	0.0976	11.84	39.32	3.18
	Mean:	0.0373	0.0036	0.0997	12.83	40.52	3.21
	St Deviation:	0.0188	0.0017	0.0230	2.48	5.89	0.37
Archaeological samples:							
F05-1933	Maximum:	0.6582	0.1031	0.2234	29.85	59.97	6.14
	Minimum:	0.0085	0.0004	0.0466	7.93	28.75	1.84
	Range:	0.6496	0.1027	0.1767	21.92	31.21	4.30
	Median:	0.2885	0.0432	0.1468	16.65	40.35	2.31
	Mean:	0.2717	0.0414	0.1438	17.12	41.76	2.53
	St Deviation:	0.1654	0.0265	0.0332	3.64	7.66	0.71
F05-2287	Maximum:	0.6089	0.1206	0.2195	28.40	61.85	7.20
	Minimum:	0.0147	0.0009	0.0522	8.41	28.14	1.85
	Range:	0.5941	0.1197	0.1673	19.99	33.71	5.35
	Median:	0.3746	0.0535	0.1465	17.87	42.71	2.33
	Mean:	0.3281	0.0486	0.1451	18.37	43.92	2.44
	St Deviation:	0.1721	0.0264	0.0283	3.34	8.02	0.64
F05-2397	Maximum:	0.6005	0.1182	0.2690	29.45	62.27	4.09
	Minimum:	0.0148	0.0019	0.0845	10.91	32.74	1.59
	Range:	0.5857	0.1164	0.1845	18.54	29.52	2.49
	Median:	0.2981	0.0508	0.1594	19.15	45.39	2.28
	Mean:	0.2924	0.0483	0.1611	19.92	45.78	2.35
	St Deviation:	0.1559	0.0271	0.0333	3.52	6.31	0.42

[a] The columns are saturation magnetization (M_s), saturation remanence (M_r), remanence ratio (M_r/M_s), coercivity (B_c), coercivity of remanence (B_{cr}), and coercivity ratio (B_{cr}/B_c).

location, along a river valley, is immediately adjacent to one of the most archaeologically important obsidian sources in the Southern Caucasus.

2.1. Lusakert Cave 1

Lusakert Cave 1 (LKT1; Figs. 1b and 2b; 40.371753° N, 44.597243° E) is an exogene cave (i.e., a rockshelter; ~85 m^2 in area, ~5 m into the cliff face, ~12 m across, ~4 m from the cave roof to bedrock) in a basalt cliff along a cut-off meander of the Hrazdan River. Indeed the river flowed past the cave while it was occupied by MP hominins, before adopting its current course ~300 m to the east (Adler et al., 2012). The first excavations during the 1970s and 1980s, led by one of us (BY) yielded a small faunal assemblage and more than 200,000 lithic artifacts, all obsidian (Yeritsyan, 1975; Yeritsyan and Korobkov, 1979). A lack of absolute dates restricted

Figure 2. (a) The Hrazdan River valley near LKT1 today. (b) LKT1 during the HGPP excavations in 2011. (c) View from inside LKT1 looking east at an obsidian outcrop (white arrow) and the peak of Gutansar volcano (black arrow). (d) View from the obsidian outcrops looking west to LKT1 (white arrow). The steep gorge sides cut into basalt are a product of tectonic uplift and river downcutting that postdate the MP occupation of LKT1.

the impact of this work. Nevertheless, LKT1 became known in the Soviet and, subsequently, Western literature as one of the most significant MP sites in the Southern Caucasus (Lyubin, 1977, 1989). During the 1990s, an Armenian-French team carried out a limited re-excavation of deposits outside the cave and recovered relatively small lithic and faunal assemblages (Fourloubey et al., 2003). Importantly, their research yielded a radiometric date. An equid tooth from Yeritsyan's Unit C (MP Mousterian) was AMS radiocarbon dated to 26,920 ± 220 ^{14}C BP (GRA 14949/Lyon 1006), which corresponds to 31,692 ± 190 cal ^{14}C BP$_{\mathrm{Hulu}}$ (CalPal calibration 2011; Adler et al., 2012).

Our team, an international collaboration constituting the Hrazdan Gorge Palaeolithic Project (HGPP; Adler et al., 2012), began investigations at LKT1 in 2007. New dates from Unit C indicate an age ~36 ka BP$_{\mathrm{OSL}}$, slightly earlier than suggested by Fourloubey et al. (2003). The interior deposits, excavated from 2009 to 2011, consist of stratified layers with in situ lithic artifacts (including refits), fauna, features, and hearth features. Only the topmost stratum (Unit 1) has been notably disturbed by weathering, trampling, and percolating water. While micromorphological evidence indicates recurrent wetting-drying and freeze-thaw, the LKT1 cave interior (Unit 2 and below) contains intact strata and in situ artifacts. The stratum of interest (Unit 6) is preliminarily dated to MIS 4 to MIS 3, and ongoing geochronological studies (i.e., IRSL, ^{40}Ar/^{39}Ar) will refine this.

After four HGPP excavation seasons (2008–2011), 13,970 lithic artifacts (>25 mm) — each individually spatially recorded by total stations and all obsidian — were excavated from ~11.9 m^3 of sediment. Tens of thousands of obsidian fragments (≤25 mm) were also recovered from water-screened sediment samples. Ongoing techno-typological analysis of the lithics will be elaborated in a future paper, but initial observations can be summarized here. The assemblage is Levallois (both flake and blade) with facetted and plain platforms, a moderate abundance of formal tools (e.g., side-scrapers, burins, end scrapers; see figures in Adler et al., [2012] and Gasparyan et al., [2014]), few cores, and very rare cortical surfaces. Kombewa flaking also occurs.

The obsidian artifacts at LKT1 are predominantly, though not exclusively, derived from local sources. Analyzing 1401 artifacts in our field laboratory using pXRF (Frahm, 2014; Frahm et al., 2014a) revealed 92.3% ($n = 1293$) originated from the adjacent GVC (Fig. 1a and b). The remainder derived from a variety of local (Hatis, 4.2%,

~12 km SE of LKT1), intermediate (three Tsaghkunyats sources, 1.9%, ~25 km N and Geghasar, 0.50%, ~40 km SE), and distant sources (Pokr Arteni, 1.0%, and Mets Arteni, 0.14%, ~70 km W).

2.2. The Hrazdan River valley and GVC

LKT1 lies on the flank of the central Hrazdan valley (Fig. 2a and d), a tectonic trough in the middle of the Gegham highlands, occupied by the Hrazdan River, which connects Lake Sevan to the Araxes River (Fig. 1a). Regional tectonism has resulted in downcutting by the Hrazdan River, revealing a series of lava flows in cross-section in the valley walls. The flows are principally Quaternary basalts and Miocene-Pliocene andesites derived from Gegham volcanoes to the east. LKT1 occurs in the final basalt flow, which has been $^{40}Ar/^{39}Ar$ dated at nearby Nor Geghi 1 to 197 ± 7 ka (Adler et al., 2014).

The GVC (Figs. 1b and 2c), lies immediately east of the Hrazdan valley and was one of the most extensively utilized obsidian sources in Armenia (Badalyan et al., 2004). The GVC is also unusually large as a primary source of obsidian. Elsewhere, lava flows and domes bearing high-quality obsidian rarely cover more than 10 km^2 (Walker, 1973; Hughes and Smith, 1993; Fink and Anderson, 2000). Obsidian-bearing features of the GVC, however, cover an area at least seven times that (although portions are covered by later basalts and alluvium). Various named localities for GVC obsidians can be found in the literature, but obsidian is elementally indistinguishable across the area (e.g., Keller and Seifried, 1990; Keller et al., 1996; Chataigner and Gratuze, 2014; Frahm et al., 2014b). For example, the elemental composition of obsidian from the eastern portions of the GVC cannot be discerned from obsidian from its western portions. In addition, obsidian throughout the GVC appears to have formed contemporaneously, although, due to inconsistencies between fission track (FT) and radiometric (i.e., $^{40}K/^{40}Ar$, $^{40}Ar/^{39}Ar$) methods, the precise date remains unclear (e.g., Karapetyan, 1972; Komarov et al., 1972; Badalian et al., 2001; Arutyunyan et al., 2007; Lebedev et al., 2013; Adler et al., 2014). We provisionally interpret the findings from previous studies as evidence that GVC obsidian formed at some point between ~750 and ~550 ka.

2.3. GVC obsidian and the landscape

Typically, across much of an obsidian-bearing flow or dome, glassy obsidian is buried beneath a pumiceous carapace, its weathered matrix, or later lava flows. Obsidian also occurs in dikes that intrude into a fractured rock body or porous strata around a volcano. Due to these formation processes (and a few rarer ones; Hughes and Smith, 1993), obsidian tends to be accessible only where it protrudes at the surface or has been exposed via erosion, slope processes, faulting, tectonics, and/or emplacement forces. The GVC is no different from other obsidian sources in this regard. Obsidian is accessible at the surface only where exposed by natural (e.g., gully erosion, river downcutting) and anthropogenic (e.g., road and pipeline cuts, modern quarrying) processes. Natural obsidian outcrops occur along a ~1.4-km stretch of the Hrazdan valley almost perfectly centered around LKT1 (Figs. 1b and 2c) and in scattered locations (Fig. 3a and b) throughout the complex. Modern quarries across the GVC (Fig. 3c) reveal the true extent and scale of this obsidian, mostly hidden beneath agricultural fields and alpine meadows. Sedimentary strata exposed in the valley escarpment downstream from the GVC occasionally contain alluvial secondary deposits of obsidian (Fig. 3d), but the nodules have often been heavily damaged and cracked by river transport and frost fracturing, sometimes even shattering in one's bare hands. Additionally, known alluvial deposits in Pleistocene river terraces have since been covered by subsequent basalt flows. Across much of the complex, large blocks of excellent obsidian can be found in the nearest gully, where erosive forces have cut into and exposed the primary deposits. Consequently, while the magnetic properties of GVC obsidian may exhibit continuous ranges throughout the entire volcanic complex, geomorphology and human behaviors combine (i.e., collecting obsidian only where it is exposed at or near the surface) to yield ostensible clusters in the magnetic data of the artifacts.

Uplift of the Gegham highlands and downcutting of the Hrazdan River has produced a valley more deeply incised (~15 m) than when LKT1 was occupied. It also seems probable that modern anthropogenic processes contributed to the current abundance of obsidian exposures. For example, some slopes on the east bank exhibit remnants of Soviet-era agricultural terraces and the ditches needed to irrigate them, thereby altering the slope angles and vegetation cover. However, given the extent of obsidian facies in nearby anthropogenic exposures (e.g., a large quarry near Charentsavan, a landslide near the Argel hydroelectric plant), it is equally likely that multiple obsidian outcrops have frequently been present along the valley, especially during interglacials. Even without river downcutting since the LKT1 was occupied and other geomorphological changes, obsidian outcrops on the eastern bank of the valley, opposite the cave, would likely have been visible to its occupants, much as they are today (Fig. 3a), even if the same outcrops exposed today were not those accessible at the time. Indeed, our focus here is not the specific identification of the exact outcrops or deposits used by the LKT1 occupants. Change in the landscape, both natural and anthropogenic, has almost certainly made such specificity unattainable. Instead, we examine the overall patterns of magnetic signals that are expressed in the LKT1 artifacts and their links to hominin behavior.

3. Hypotheses regarding lithic procurement

A series of five hypotheses describe how LKT1 occupants may have procured local toolstone (i.e., GVC obsidian). Each hypothesis focuses on the geographic locations of hominin behaviors that were used to remain adequately supplied with obsidian in this landscape. "Embedded" and "special purpose" procurement strategies are not binary, but instead lie on a continuum. Hunter-gatherers are known to combine strategies in response to varying environments, seasons, and other conditions, and occasional toolstone excursions may occur alongside largely embedded lithic procurement strategies. We do not assume that the LKT1 residents relied exclusively on a single strategy for toolstone provisioning. Any dominant strategy at LKT1 may not have been used at other sites in their territory, reflecting flexibility as they moved or as seasons and other conditions changed. By analyzing artifacts from three time intervals in Unit 6 at LKT1, there will be certain constant geographic variables, including, presumably, the locations of obsidian exposures. The relative importance of each procurement strategy, however, remains free to vary. This set of hypothesized strategies is represented diagrammatically in Fig. 4.

Hypothesis #1. *Procurement occurred on the same scale as extended hunting-gathering carried out from the cave, assumed to be ~10 km, resulting in obsidian collection from various outcrops and exposures scattered across the full GVC.*

This hypothesis is consistent with the occupants as foragers (sensu Binford, 1980) who practiced high logistical and low residential mobility, moving groups to residential camps to exploit resource-rich areas. Ethnographic studies and energetic analyses of modern humans often note maximum daily foraging radii of 15 km or more (e.g., Kelly, 1995; Binford, 2001; Layton et al., 2012). These

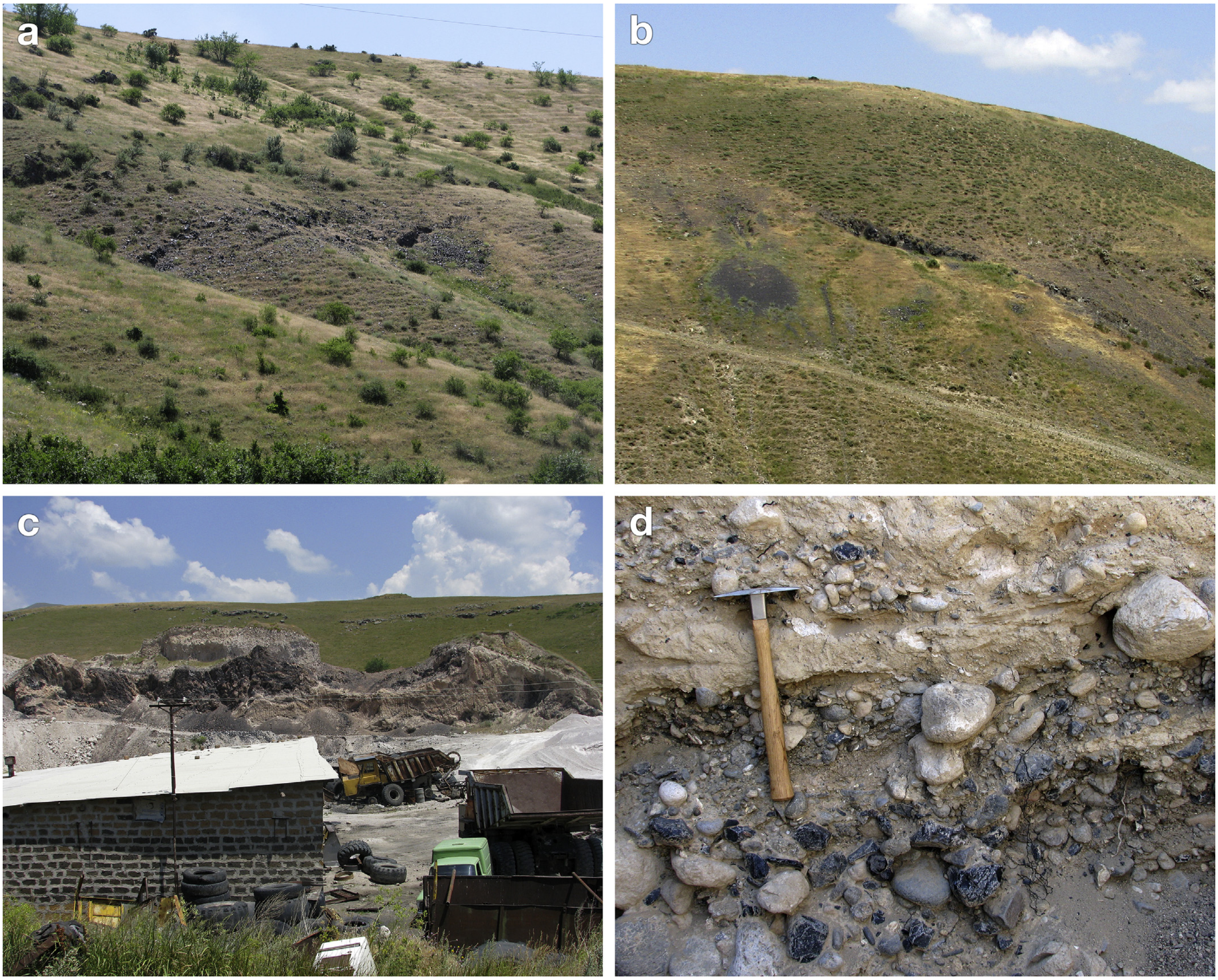

Figure 3. (a) and (b) Examples of obsidian outcrops scattered around the GVC. (c) A 80-m exposure of near-surface obsidian in a pumice/perlite quarry, which was sampled to replicate extraction pits following a specific geological facies. (d) An alluvial deposit along the Hrazdan valley, downstream from LKT1. The Ingalls patiche in the photograph is 31-cm long.

distances, however, vary greatly by ecological context, and they would differ as well due to the energetic requirements of MP hominins (e.g., Sorensen and Leonard, 2001; Churchill, 2006; Verpoorte, 2006). This hypothesis ostensibly correlates with exploitation of the greatest resource diversity as it implies the largest foraging area, but it also necessitates travel across the largest distances, including climbing out of the valley.

Hypothesis #2. *Procurement occurred in the Hrazdan valley, resulting in collection of obsidian from numerous outcrops and exposures along the river.*

This hypothesis is consistent with procuring obsidian during subsistence activities throughout the river valley, which would have served as a rich and diverse biome where water and a diversity of faunal and floral resources would have been readily available to the cave's occupants without the energetic penalty of leaving the steep-sided valley. It is equally compatible, though, with forays throughout the valley specifically to collect raw toolstone when needed. Like Hypothesis #1, it is consistent with foragers who moved residential camps to resource-rich areas, as we might anticipate given the location of LKT1 immediately adjacent to the GVC for toolstone and the Hrazdan River for other natural resources.

Hypothesis #3. *Procurement was targeted and focused on a select outcrop or two, perhaps non-immediate to LKT1.*

In contrast to Binford's (1980) ethnographic research, there are accounts of toolstone procurement from a specific source, sometimes related to material quality (Gould, 1978; Gould and Saggers, 1985). Small task-focused groups were sent on short-term excursions to obtain toolstone, closer to Binford's (1980) definition of collectors. This hypothesis, though, is not inconsistent with embedded procurement. A specific outcrop might have been targeted in the sense that subsistence activities in the vicinity were planned to coincide with toolstone needs.

Hypothesis #4. *Procurement was targeted and involved "industrial" quarrying (e.g., digging a series of pits) over a restricted area to access high-quality obsidian where abundant deposits lie at or near the surface.*

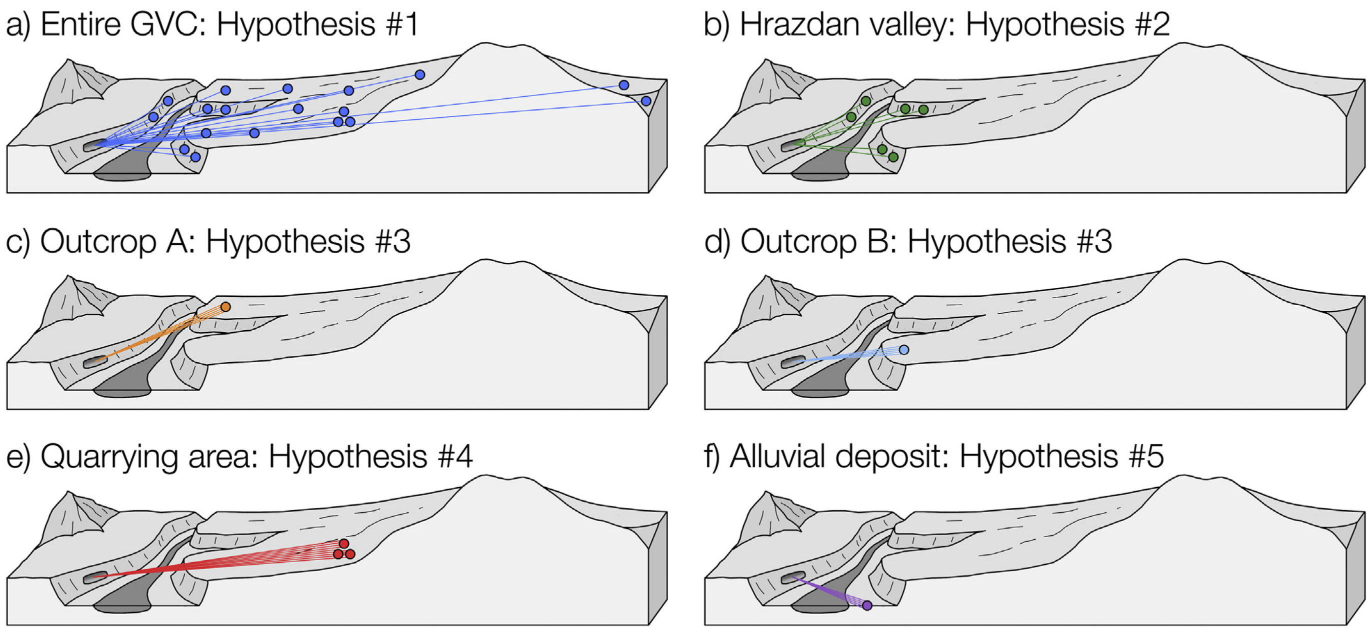

Figure 4. Simplified cartoons of the Hrazdan valley and GVC to illustrate the different procurement strategies that we hypothesize the LKT1 occupants may have used. The straight lines that connect the cave to obsidian outcrops and deposits are not literal paths and are not intended to imply direct, "special purpose" excursions. The colors for each model are consistent with Figs. 8–10. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Away from the valley, there are locations scattered across the GVC where massive obsidian-bearing facies reach or nearly reach the surface, providing a context for intensive quarrying similar to that reported in the Levant (e.g., Barkai et al., 2006; Barkai and Gopher, 2009; Gopher and Barkai, 2014). The Mount Pua quarry complex, for example, consists of hundreds of extraction pits over an area of ~90 ha, following a chert formation (Gopher and Barkai, 2014). This hypothesis is likely the one most consistent with the existence of specialized quarrying sites, whereby large-scale toolstone extraction and initial working occurred prior to its transport.

Hypothesis #5. *Procurement involved exploiting obsidian cobbles in an alluvial deposit along the river.*

There are abundant opportunities to collect obsidian from outcrops and other exposures (Fig. 3a–b) throughout the GVC. Obsidian is also accessible in alluvial secondary deposits in the valley, where small cobbles have been transported and rounded by the Hrazdan River (although the same forces have often introduced fractures that limit the utility of the cobbles). This hypothesis is consistent with exploitation of chert cobbles from alluvial deposits at Palaeolithic sites in France (e.g., Las Pelenos [Turq, 1988a] and La Chapelle-aux-Saints [Demars, 1990b]) and elsewhere (e.g., Egypt [Vermeersch et al., 1990, 1995; Vermeersch and Paulissen, 1993; Vermeersch, 2002]).

4. Principles of obsidian magnetic characterization

Our approach to magnetic characterization of obsidian is a significant departure from past studies (see Table 1 in Frahm and Feinberg, 2013). Since the 1980s, researchers have occasionally suggested using the magnetic properties of obsidian, imparted by microscopic iron oxide grains, as a potential tool for matching artifacts to their volcanic source and as an alternative to conventional geochemical sourcing techniques. Such an approach had mixed success. The pioneering work of McDougall et al. (1983) used three basic magnetic parameters, which were only partially effective for discerning sources. For instance, the two Melos obsidian sources were differentiated, but one of them overlapped with other Aegean sources. Subsequent research also noted overlapping sources and high intra-flow variability, limiting the utility of magnetic parameters for discerning obsidian sources (Urrutia-Fucugauchi, 1999; Vásquez et al., 2001; Zanella et al., 2012). For differentiating among obsidian-bearing flows, the reported intra-flow variability was detrimental. In contrast, for our purposes — identifying differences in locations within a specific flow — spatial variability in magnetic properties becomes favorable. The same processes that complicate inter-flow magnetic differentiation, we argue, make intra-flow spatial distinctions possible.

Magnetic analyses measure the properties of sub-millimeter-sized mineral grains that occur in all obsidians. Even the glassiest obsidians contain a volumetrically tiny fraction of microscopic mineral inclusions. For example, the black color of most obsidians is, in part, a result of magnetite (Fe_3O_4), while the red in some obsidians is due to hematite (Fe_2O_3) grains. We have demonstrated that these magnetic minerals can serve as sensitive recorders of localized eruptive and emplacement conditions that varied throughout a particular obsidian flow (Frahm and Feinberg, 2013). Obsidian cools differently throughout the flow and experiences different temperatures, viscosities, oxidation conditions, deformation forces, and so forth. These circumstances affect the amounts, compositions, shapes, size distributions, and arrangements of magnetic mineral grains in obsidian and, as a result, its magnetic properties. In short, spatially variable petrogenetic conditions within an obsidian flow yield differences in its magnetic mineral assemblage, and, thus, measuring the magnetic properties of obsidian can be used to infer artifacts' geospatial origins within a flow.

A central premise of our approach is that the magnetic properties of obsidian are similar on small spatial scales (e.g., outcrops) and exhibit increasing diversity as scale increases (e.g., a flank of the volcano, across an entire obsidian flow). This occurs for all magnetic parameters that we have evaluated. In short, obsidian magnetic properties exhibit a consistency at the centimeter and meter scales that is absent at larger scales (Frahm and Feinberg, 2013). Magnetic variability, however, does not necessarily increase linearly with spatial scale – that is, it is not so simple a relationship that an area ten times greater yields ten times the magnetic variability. In fact, our pilot research suggests that the precise relationship will vary source-to-source (Frahm and Feinberg, 2013; Frahm et al., 2014b), depending on flow size and the nature of its eruptive conditions.

Given that the emplacement and cooling conditions (e.g., temperature, viscosity) would be largely continuous throughout a flow, magnetic properties of the resulting obsidian would tend to exhibit continuous ranges. Only the combination of hominin behavior and landscape (i.e., procuring obsidian only where it has been exposed at the surface by erosion, faulting, and similar forces) together yield clusters within artifacts' magnetic data. Magnetic characterization can also offer insights regarding the origins of alluvial secondary deposits because individual obsidian cobbles retain the magnetic signatures of the outcrops from which they came (Frahm and Feinberg, 2013).

It is worth emphasizing that the outcrop-to-outcrop magnetic variability is not necessarily so distinct that it is always possible to match an individual artifact to a precise quarrying location. Different parts of a flow might have experienced emplacement and cooling histories that yielded a similar combination of magnetic properties. Additionally, as previously mentioned, the landscape has changed since the MP occupation of LKT1, likely yielding differences in the precise locations of obsidian outcrops accessible then and now. Consequently, we focus here on how overall behavioral patterns on the landscape are magnetically reflected in a corpus of artifacts as a whole.

5. Methods and materials

This section discusses the collection, selection, and preparation of the artifacts and geological specimens for this study as well as their geochemical and magnetic analyses.

5.1. Excavations at LKT1

The obsidian artifacts in this study were excavated by the HGPP in 2011. All originated from one 1 × 1 m square (F05), part of a deep 2 × 2 m "sondage" inside the cave that was excavated down to bedrock (Fig. 5). In addition to all larger obsidian artifacts (>25 mm), sediment samples for wet sieving, stratigraphic boundaries, and samples for ongoing geochronological and geoarchaeological studies were recorded in three dimensions using two Leica total stations. The excavated sediment was spatially recorded as samples ~15–20 L (which, depending on the excavator, corresponds to a slice of 1.5–2 cm across a 1 × 1 m square or 6–8 cm across a quadrant). The three sediment samples in this study originated from Unit 6 (Fig. 6). Vertically they were separated by 10.6 cm (F05-1933 to F05-2287) and 2.1 cm (F05-2287 to F05-2397). All sediment samples were wet-sieved through a 1.6-mm mesh, dried, and picked to extract material, which was sorted by size, counted, and massed. All artifacts measured for this study fall into the category of small debris (≤25 mm). Specifically, the studied artifacts are 5–15 mm with masses of 67–725 mg.

5.2. Unit 6 of LKT1

Units 6 and 7 lie atop Unit 10, which is composed largely of sandy sediment (likely deposited by the palaeo-Hrazdan River) and basalt clasts (dropped from the cave roof) and contains relatively few obsidian artifacts. Such artifacts are much more abundant in Units 6 and 7, implying increased occupations of the cave after a depositional unconformity between them and Unit 10. Unit 6 (Fig. 6) consists of thin ash spreads (remnants of combustion, most likely hearths) and horizontally-bedded silty-clay sediments that contain abundant debris from MP hominin activities, including thousands of in situ obsidian artifacts. Initial sedimentological and micromorphological findings indicate the deposition of Units 6, 7, and 10 occurred during a cold climate episode that is provisionally dated to MIS 4 to MIS 3 (Adler et al., 2012).

5.3. Sampling for procurement models

Obsidian specimens were collected at the GVC in ways designed to replicate our hypotheses involving toolstone procurement. Consequently, this complex has been magnetically studied much more thoroughly than any other obsidian source ($n = 244$ subsamples initially measured for Frahm et al., [2014b] plus 359 newly measured subsamples). The next-most magnetically studied obsidian sources in the world are Valle Toledo (New Mexico, United States, $n = 134$ [Gregovich et al., 2014]) and Cerro Ora (Argentina, $n = 34$ [Vásquez et al., 2001]). Therefore, we have high confidence in the obsidian sample sizes used to create our procurement models.

5.3.1. Sampling for Hypothesis #1 Procuring obsidian across the GVC was simulated by sampling outcrops and exposures up to 9 km from LKT1 (i.e., within a foraging radius of 10 km). Obsidian is accessible in certain places, typically where an erosional feature (e.g., gullies) or mass wasting (i.e., slope failure) has exposed an obsidian layer. Road cuts and quarries (for concrete production) have also exposed obsidian. The greatest possible coverage of the GVC was sought for this model. A total of 267 obsidian specimens were collected from 28 loci, each recorded by GPS (Frahm et al., 2014b). One to three subsamples per specimen were measured for this model, yielding 313 subsamples. As discussed later, hematite-rich obsidian was excluded from our analyses. Ultimately, this model involves 244 subsamples from 218 specimens from all 28 loci throughout the GVC.

5.3.2. Sampling for Hypothesis #2 Procuring obsidian throughout the valley, where diverse faunal and floral resources would have been available, was also simulated. To mimic obsidian acquisition while tracking prey, grazing cattle were followed through the Hrazdan valley for three days, and obsidian was collected whenever outcrops or exposures were encountered. If the LKT1 occupants principally collected obsidian when needed for tools to, for example, butcher and process caprids and equids moving through the valley, their procurement patterns were likely similar to ours, even if the exact same collection locations were not. A random sample of the valley-collected obsidian specimens was measured for this model. After removal of hematite-rich subsamples, this dataset includes 160 subsamples of 48 specimens from ten loci.

5.3.3. Sampling for Hypothesis #3 Preferential collection from specific outcrops was simulated by sampling two exposures of high-quality obsidian (e.g., pristine glass, few cracks or joints). The two chosen exposures both lie just outside the Hrazdan valley but still within a foraging radius of 5 km from LKT1. One is 2.2 km NE of LKT1 (locus AR.2011.39; "Outcrop A") and the other is 4.5 km SE (locus AR.2011.45; "Outcrop B"). The cave is visible, or nearly so, from both locations. A small area (~1–3 m^2) was sampled at each. For this model, 52 subsamples of ten specimens from Outcrop A and 39 subsamples of ten specimens from Outcrop B were measured. The goal is not to determine whether or not these exact outcrops were used. Indeed, it is likely that obsidian was not accessible from these precise locations when LKT1 was occupied. Instead, our focus is establishing general patterns in magnetic data due to preferentially exploiting a favored outcrop.

5.3.4. Sampling for Hypothesis #4 Procuring obsidian from a surface quarrying area, analogous to the "industrial" chert quarries

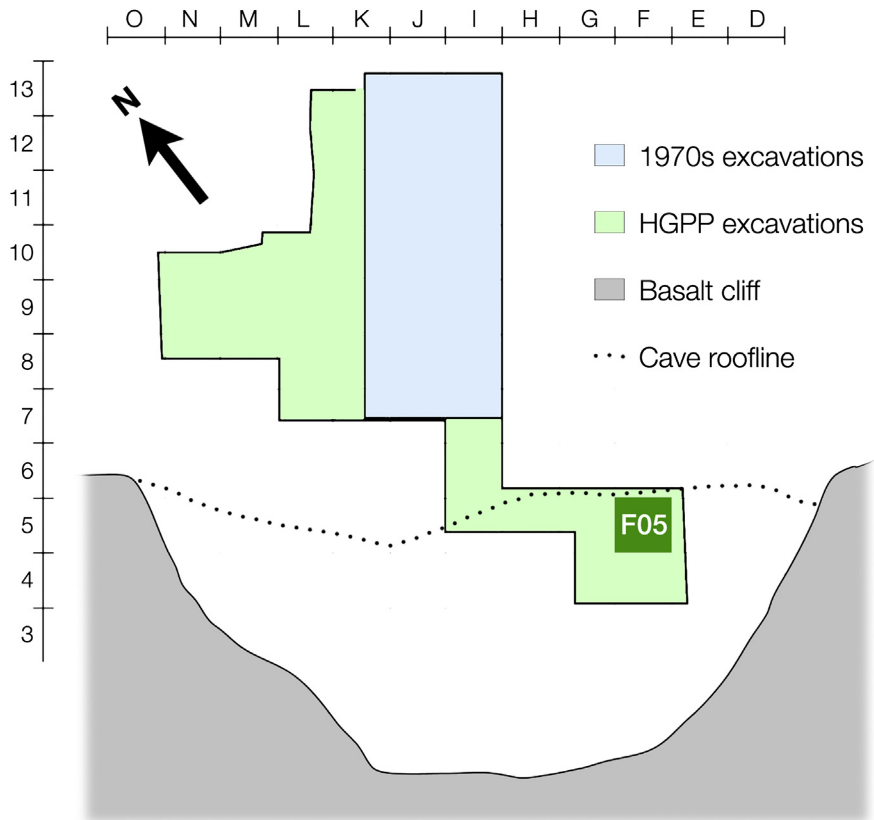

Figure 5. Plan view of the excavations at LKT (blue marks the 1970s trench; green marks the HGPP excavations), the 1 × 1 m excavation grid, and the location of square F05 inside the cave. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

documented in the Levant, was simulated using an anthropogenic exposure of near-surface obsidian in a modern quarry. In this location (AR.2011.52), ~6 km SE of LKT1, considerable amounts of obsidian reach the surface across a large area (e.g., this particular quarry is ~62 ha). Obsidian was collected along an 80-m exposure in the middle of the quarry (Fig. 3c) to replicate a set of extraction pits following a particular facies. The resulting dataset consists of 64 newly measured subsamples of ten specimens from

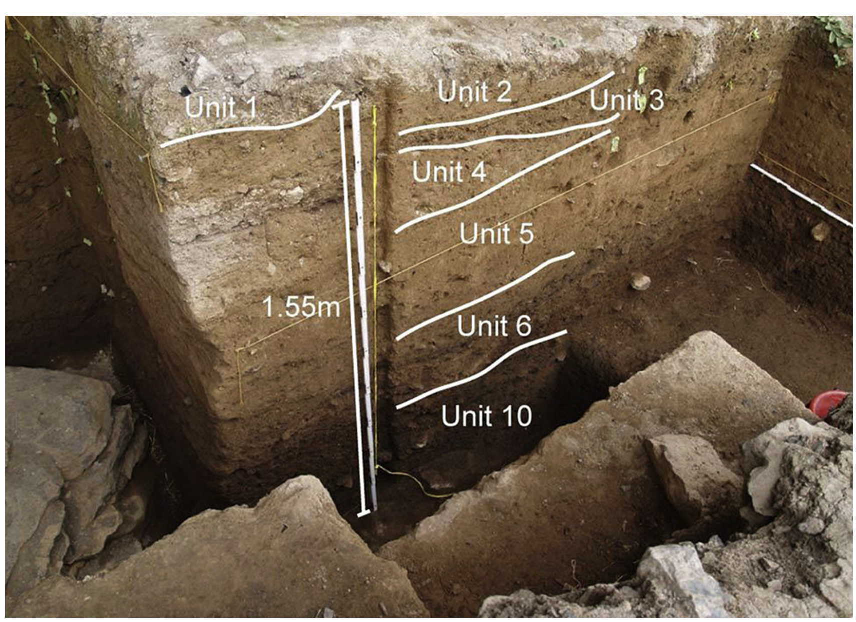

Figure 6. Profile 4 of LKT1. The three sediment samples in this study originated from Unit 6. Unit 7 is not present here, but the profile otherwise illustrates the relationship among Units 5, 6, and 10. The sediment column beside the scale bar was sampled for a suite of forthcoming geochronological and environmental analyses.

this locus. Like Hypothesis #3, the goal is not to determine if this exact area was exploited. Certainly the LKT1 occupants did not have the benefit of a large section exposed by modern quarrying equipment. Instead, our focus is identifying general patterns in magnetic data due to exploiting obsidian from a restricted area.

5.3.5. Sampling for Hypothesis #5 Obsidian procurement from an alluvial deposit along the palaeo-Hrazdan River was simulated by sampling such a deposit. Specifically, we sampled obsidian cobbles from a deposit (locus AR.2013.1; Fig. 3d) ~2.7 km downstream of LKT1. This is, to date, the only alluvial deposit in a Pleistocene river terrace that we have located along the Hrazdan. Based on its stratigraphic relationship to another site excavated by the HGPP (Nor Geghi 1 [Adler et al., 2014]), the deposit formed ~400 ka. This dataset includes 43 subsamples of ten specimens.

5.4. Selecting and preparing GVC specimens

These obsidian specimens were collected with magnetic characterization in mind, including selecting, in general, ten specimens from each locus for statistical robustness (Frahm and Feinberg, 2013). Specimens were cut into a set of cubic subsamples ~10 × 10 × 10 mm. This form fit easily into the Princeton Measurements MicroMag vibrating sample magnetometer (VSM) used in this study, facilitated measurements along three axes, and, in turn, enabled measurements to take only a few minutes each. Measuring multiple subsamples allows us to examine variability on the centimeter scale, relevant to artifacts. The number of subsamples per specimen was governed by the number of ~1-cm^3 cubes that could be readily cut from each specimen. Testing subsamples of equal size also means that each measurement reflects the magnetic properties of obsidian on the same scale, rather than different specimens reflecting properties on different scales.

5.5. Selecting and preparing LKT1 artifacts

Three sediment samples from Unit 6 in Square F05 with abundant small debris (≤25 mm) were identified, and 100 fragments were chosen from each sediment sample. Their sizes are ~5–15 mm along the maximum dimension and typically ~2–4 mm thick. Their average mass is 208 ± 94 mg (~80 ± 35 mm^3). The fragments were cleaned using an ultrasonic cleaner and tap water to remove adhered sediment. They were massed (i.e., our magnetic measurements are mass-normalized) and kept in individually numbered bags. No cuts or modifications were needed.

Artifacts within this size range are small enough to (1) easily fit inside the VSM while still large enough to (2) be quickly measured magnetically (i.e., larger specimens contain more magnetic material, and the stronger signals can be measured more quickly than the weaker signals from smaller specimens with less magnetic material) and (3) be reliably measured geochemically by pXRF. Thus, this size class allowed us to optimize for efficiency, but future work can incorporate other sizes using new VSM specimen holders and/or instrument adjustments. The VSM, however, is currently unable to accommodate artifacts larger than 4 cm. The technical requirement that, at present, we focus on small debris likely does restrict the behavior reflected in our artifact sample, albeit to some unknown degree. For example, Turq et al. (2013) stress the fragmentation of MP lithic production across the landscape, such that persistent transport of artifacts can lead to only certain lithic reduction products being left behind during any particular occupation. Ultimately, given the current technical limitations of magnetic characterization, being able to capture behaviors reflected only among cores, for example, would require them to be subsampled.

5.6. Geochemical sourcing of LKT1 artifacts

Magnetic properties are much less effective than geochemical techniques for discriminating obsidian flows, often yielding ambiguous source attributions (Frahm and Feinberg, 2013). Thus, all 300 LKT1 obsidian fragments were analyzed using pXRF to identify non-GVC obsidians and remove those artifacts from the final magnetic dataset. Specifically, our analyses used a Thermo Scientific Niton XL3t GOLDD instrument. Normally the X-ray beam is ~8-mm in diameter (50 mm^2), but this instrument is equipped with a small-spot collimator that can limit the beam to a 3-mm diameter (7 mm^2), yielding an analytical area ~85% smaller. Our focus was the “mid-Z” elements (e.g., Nb, Rb, Sr, Zr), which are well measured even for irregular or curved specimens (Davis et al., 1998; Forster et al., 2011). These elements are measured using the “main” (primary) X-ray filter, which is also used to measure several X-ray phenomena (e.g., Compton scattering) to adjust data for various physical effects (e.g., morphology, density). These data were further corrected using fundamental parameters (FP), which adjusts measurements for other phenomena that occur within a specimen (e.g., X-ray absorption, secondary fluorescence). Our calibration is based on a suite of 24 obsidian custom standards characterized by neutron activation analysis (NAA) and laboratory-based XRF at the University of Missouri's Research Reactor and by electron microprobe analysis (EMPA) at the University of Minnesota (see Frahm, 2014; Frahm et al., 2014b and Frahm and Feinberg, 2015 for details). This approach has been shown to yield high accuracy and sensitivity (Frahm, 2014; Frahm et al., 2014b; Frahm and Feinberg, 2015). Routine measurements of larger artifacts often take 10–40 s using our methods; however, for this study, each measurement took 60 s in order to attain suitable counting statistics using the small-spot collimator. The data for important elements for our artifacts and geological specimens are available in Supplementary Online Material [SOM] Table 1.

Fig. 7a is a scatterplot of Sr/Rb vs. Zr/Rb (i.e., Sr versus Zr normalized to Rb) for a suite of geological specimens and the LKT1 obsidian fragments. Normalization is a standard approach for minimizing issues related to XRF specimen thickness or size, enabling accurate source attributions for obsidian artifacts as small as a few millimeters in diameter and 0.5-mm thick (Davis et al., 1998; Ferguson, 2012). A second approach is to use multivariate statistics to minimize any skew in the data due to variable specimen thickness and/or size. Fig. 7b is a scatterplot of two discriminant functions based on Nb, Rb, Sr, and Zr measurements for our geological specimens. Both approaches reveal 294 of the 300 (98%) LKT1 fragments originated from the GVC. Three artifacts came from Ttvakar (one of the three Tsaghkunyats sources, ~25 km N of LKT1), two from Hatis (~12 km SE of LKT1), and one from Damlik (a second Tsaghkunyats source; Fig. 1a). These six fragments were removed from the magnetic datasets to test our GVC-based hypotheses.

5.7. Lithic analysis of LKT1 artifacts

Our study of the 100 selected fragments included lithic analysis. Each one was attributed a class (e.g., small debris, angular debris/shatter), morphology (e.g., recognizable features such as bulb/ventral/dorsal), type (e.g., retouch/resharpening, eraillure [i.e., a small flake removed incidentally from the ventral side of a flake near the striking platform]), and fragmentation (e.g., complete, medial). These results are summarized in SOM Tables 2 and 3. Two of the pieces, when examined after adhered sediment was removed, lacked evidence of modification and, in turn, were classified as ecofacts and removed from further consideration. Our findings suggest there are no significant differences in the technological activities that created the fragments in each sample.

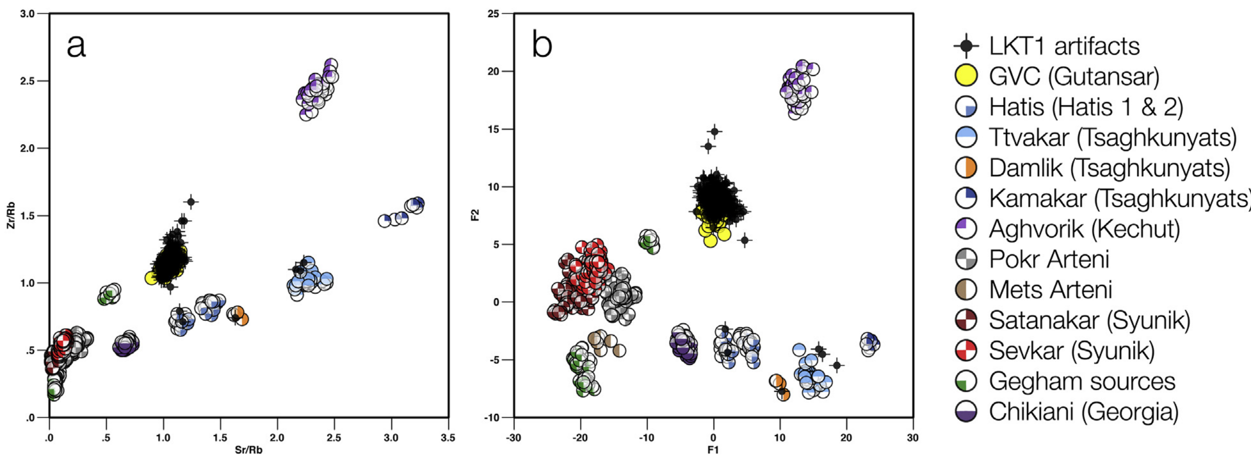

Figure 7. pXRF analyses of geological obsidian specimens and the LKT1 small debris in this study: (a) Sr/Rb versus Zr/Rb (i.e., Sr versus Zr normalized to Rb) and (b) discriminant functions based on Nb, Rb, Sr, and Zr. These two approaches to data reduction enable valid and reliable source identifications using pXRF by minimizing issues related to artifact thickness and/or size.

5.8. Magnetic characterization

This study uses rock magnetic characterization to recognize obsidian from different parts of the GVC. The parameters on which we focus reflect primarily intrinsic characteristics of obsidian's magnetite inclusions (e.g., their sizes, shapes, compositions, amounts, arrangements, orientations). Specifically, we measured four magnetic properties collectively called “hysteresis parameters”. These parameters are determined using a VSM by measuring a specimen's induced magnetization when a strong applied magnetic field varies in strength (up to 1.5 T in this study). First the applied field increases until a specimen's induced magnetization no longer increases. This is the “saturation magnetization” (M_s), which reflects the concentration of magnetic material. When the applied field is reduced, a specimen's induced magnetization decreases in response. As the field reaches zero, the induced magnetization of a specimen, which does not return to zero, reflects its maximum possible magnetic recording or its “saturation remanence” (M_r). Magnetic material concentration and mean grain size principally affect M_r, but grain alignments, interactions among grains, and other factors also affect it. “Coercivity” (B_c) is the field strength when a specimen's induced magnetization reaches zero and is inversely related to grain size. The “coercivity of remanence” (B_{cr}) is the applied field strength needed to remagnetize half of a specimen's magnetic minerals so that M_r is zero. Like B_c, B_{cr} is inversely related to mean grain size. Ratios are also useful. The remanence ratio (M_r/M_s) and coercivity ratio (B_{cr}/B_c) reflect grain size: small-grained magnetic minerals yield high M_r/M_s and low B_{cr}/B_c values. Discussions of these parameters can be found in Harrison and Feinberg (2009) and Tauxe (2010). These simple measurements can be conducted in many palaeomagnetism facilities worldwide, take only a few minutes, and are inexpensive as well as nondestructive.

5.9. Magnetic data reduction

All newly analyzed obsidian subsamples were measured along three perpendicular axes in the VSM to minimize the effects of any anisotropy (i.e., directional effects due to flow bands within obsidian). The three values were averaged to calculate the bulk mean values for each subsample, reducing any directional effects (Frahm et al., 2014b). Additionally, a remanence ratio (M_r/M_s) of 0.5 is the theoretical maximum for a population of randomly oriented, uniaxial, non-interacting magnetic grains. Higher ratios suggest the presence of strong, non-random alignments of mineral inclusions, including flow bands of aligned minerals. None of the remanence ratios in our datasets has a value above 0.5. We interpret this as evidence that, at least among these particular artifacts and geological specimens, flow banding is inconsequential.

Hysteresis data can be confounded by overlapping contributions from multiple minerals with different magnetic behaviors (e.g., specimens with magnetite but a predominance of hematite yield much higher B_c values). Our current solution is to exclude any hematite-rich subsamples from the dataset. This affects a small fraction of the artifacts (i.e., <5% of the LKT1 obsidian assemblage appears either mostly or entirely red due to hematite). Magnetite- and hematite-dominated obsidians can be discerned with a hysteresis loop shape parameter (σ_{hys}): negative values indicate magnetite-rich obsidian, and positive values indicate hematite-rich obsidian. Subsamples and artifacts with positive σ_{hys} values were excluded from datasets for this study. Detailed discussions of these data reduction procedures are found in Frahm et al. (2014b).

5.10. Artifacts summary

Of the 300 LKT1 fragments, 286 were used in the interpretation of our magnetic data. Fourteen were removed from the analysis: six were from obsidian sources other than the GVC, two were ecofacts without modification, and six were hematite-rich.

6. Results and preliminary discussion

Table 1 shows summary statistics for our magnetic measurements for the five hypothesized models, and Fig. 8 shows the measurements as box-percentile plots (Esty and Banfield, 2003). All of the magnetic measurements in these plots are available in SOM Tables 4–9.

Our models are generally consistent with the expectation that, as the scale of procurement at an obsidian source increases, the range of magnetic values increases. For the entire GVC, M_s has a range of 0.50 Am/kg, but its range is 0.21 (58% lower) and 0.06 Am/kg (88% lower) for Outcrops A and B, respectively. Similarly, the M_r range is 0.093 Am/kg for the GVC, but it is 0.029 (68% lower) and 0.007 Am/kg (92% lower) for Outcrops A and B, respectively. Hence, variability in the amount of magnetic material across the entire volcanic complex is ten times greater than that for Outcrop B. The

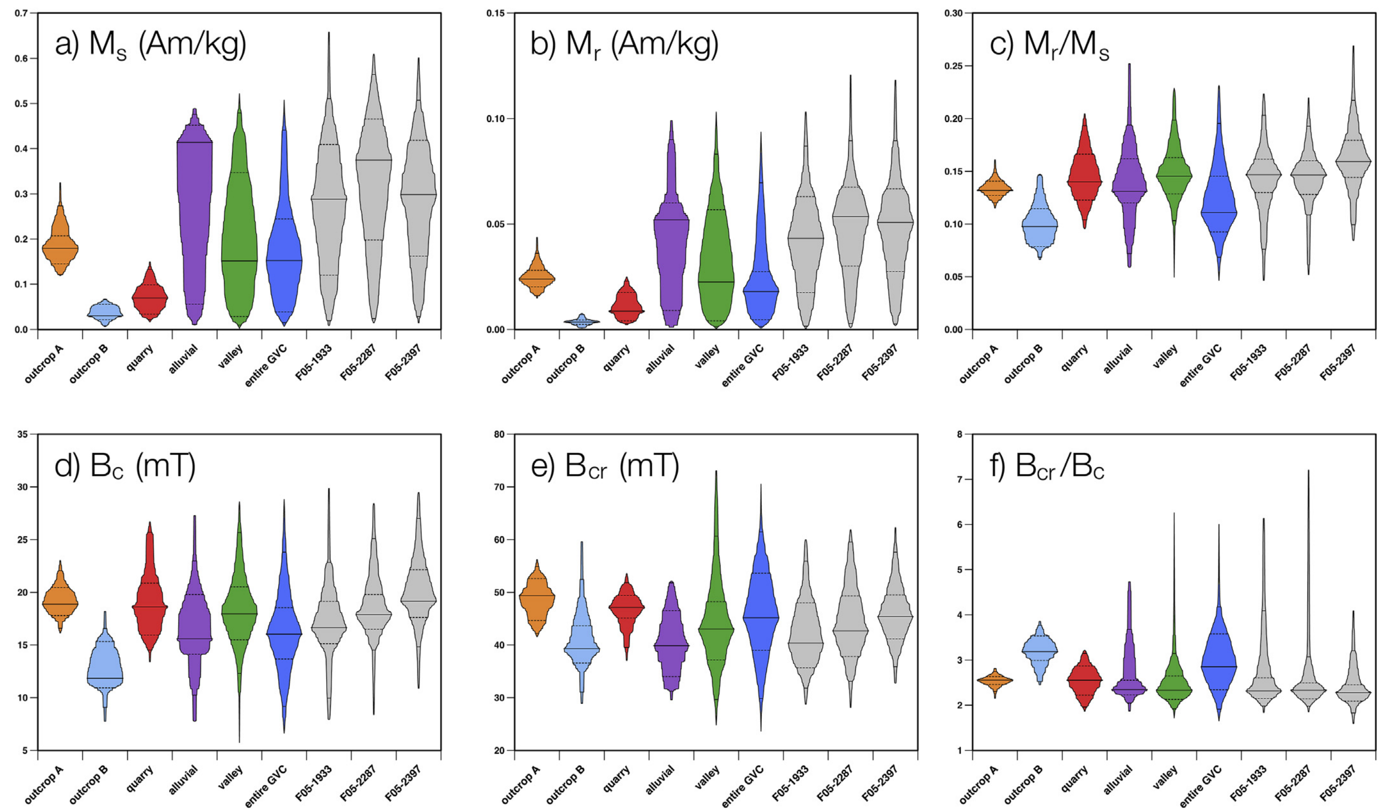

Figure 8. Box-percentile plots, as described by Esty and Banfield (2003), of our magnetic data. A variant of the conventional box-and-whisker plot, box-percentile plots illustrate the distribution of data over their entire ranges. At any given height, the width is proportional to the percentile. The median (50th percentile) is demarcated by a line at the widest point. The first and third quartiles (25th and 75th percentiles) are denoted by dashed lines that are half the width of the median, and the 5th and 95th percentiles are marked by solid lines that are one tenth of the median's width. The top and bottom points are the maxima and minima, respectively. The strength of these plots over box-and-whisker plots is an ability to reveal normal versus multi-modal or otherwise irregular measurement distributions. The colors for each model are consistent with Figs. 4, 9 and 10. The parameters are (a) saturation magnetization (M_s), (b) saturation remanence (M_r), (c) remanence ratio (M_r/M_s), (d) coercivity (B_c), (e) coercivity of remanence (B_{cr}), and (f) coercivity ratio (B_{cr}/B_c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

quarrying area exhibits similarly narrow values: M_s and M_r ranges are 0.13 (74% lower) and 0.022 (76% lower) Am/kg, respectively. Therefore, variation in the amount of magnetic inclusions across the GVC is four times greater than that in the quarrying area.

Similar trends occur for the four magnetic parameters that primarily reflect magnetic grain morphology and composition. The M_r/M_s range is 0.185 for the GVC, 0.046 (75% lower) for Outcrop A, and 0.081 (56% lower) for Outcrop B. The range for the quarrying area falls, as we would anticipate, between the GVC and two outcrops: 0.109 (41% lower). B_c exhibits the same trend. Its range is 22.2 mT across the GVC, 13.3 (40% lower) for the quarrying area, 6.9 (69% lower) for Outcrop A, and 10.4 (53% lower) for Outcrop B. B_{cr} ranges are similar: 46.9 mT for the GVC, 14.6 (69% lower) for Outcrop A, and 30.6 (35% lower) for Outcrop B. The quarrying area has a range nearly as restricted as that for Outcrop A: 16.4 mT (65% lower). Lastly, the B_{cr}/B_c range is 4.35 throughout the GVC, 1.35 (69% lower) for the quarrying area, 0.66 (85% lower) for Outcrop A, and 1.40 (68% lower) for Outcrop B.

Note that, for these six magnetic parameters, the quarrying complex exhibits the expected variability (i.e., between the GVC, on one hand, and both Outcrops A and B, on the other) in only two instances: M_r/M_s and B_c. For the other parameters, the quarrying area exhibits variability between that for Outcrops A and B. Thus it appears that, at least for the GVC, a few square meters and a few dozen square meters can yield similar scales of magnetic variability. Consequently, for this source, discerning between a favored outcrop and a quarrying complex may be difficult.

Fig. 8 shows that, even when overall measurement ranges are similar for the GVC, the Hrazdan valley, and the alluvial deposit, data distributions differ within those ranges. For example, we note the differences in M_s and M_r distributions in Fig. 8a and b among the GVC, valley, and alluvial deposit. The distributions indicate that, on average, obsidian nodules in the alluvial deposit contain more magnetic material than specimens collected from the Hrazdan valley, suggesting they are not simply a random sample from the valley. Consequently, the differences among our various models are better revealed using scatterplots.

Fig. 9 has scatterplots of the coercivity ratio (B_{cr}/B_c) versus total magnetization (the sum of the two normalized magnetization parameters, M_s and M_r) for the different procurement scenarios and our three archaeological samples. Thus, variability in magnetic grain morphology and composition is plotted horizontally, whereas variability in the amount of magnetic material is plotted vertically, so the same parameter distributions shown in Fig. 8 are also observable here. For example, the narrow range of B_{cr}/B_c for Outcrop A observed in Fig. 8f is exhibited by the restricted horizontal distribution of the Outcrop A measurements in Fig. 9d. Similarly, based on this measure of total remanence, it is evident that variability in the amount of magnetic material across the entire GVC is ten times greater than that for Outcrop B. Therefore, the mechanisms of these data distributions for each procurement scenario can be identified from these scatterplots. However, plots such as these are limited in the number of variables that can be simultaneously displayed.

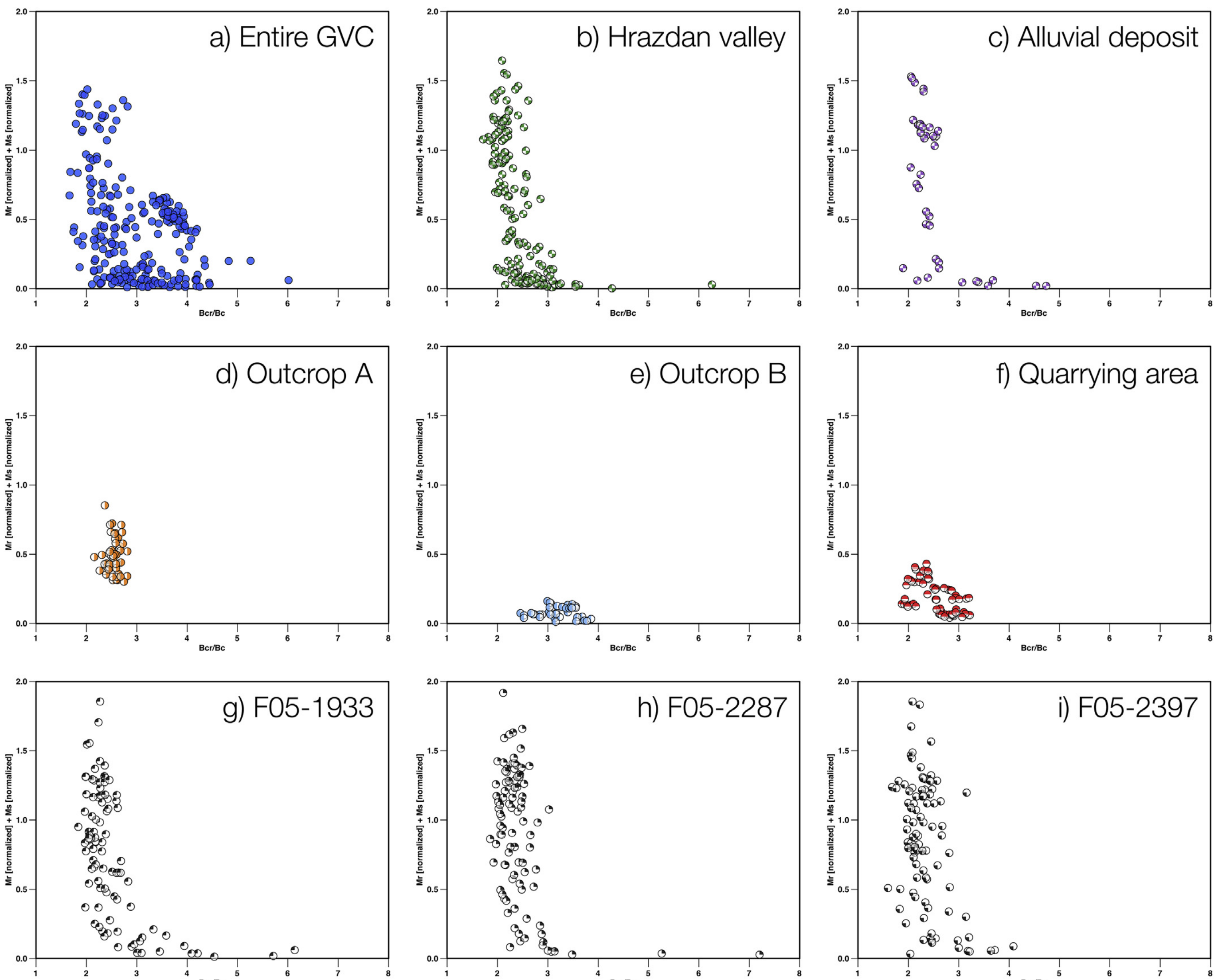

Figure 9. Scatterplots of the coercivity ratio (B_{cr}/B_c) versus total magnetization (the sum of the two normalized magnetization parameters, M_s and M_r) for the five different procurement scenarios and the three archaeological samples. The colors for each model are consistent with Figs. 4, 8 and 10. In these scatterplots, variability in magnetic grain morphology and composition is plotted horizontally, whereas variability in the amount of magnetic material is plotted vertically. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 10 shows discriminant function analysis (DFA) based on all six magnetic parameters and ratios (M_s, M_r, M_r/M_s, B_c, B_{cr}, B_{cr}/B_c) for our procurement scenarios and archaeological samples. Discriminant function analysis is a common statistical technique that creates new axes using combinations of variables that best differentiate known groups in the data. The resulting functions, based on combinations of variables, can then be applied to other observations not included in their derivation. In this case, we used the XLSTAT Pro implementation of DFA to derive functions that maximized differentiation among the subsamples from Outcrop A ($n = 52$), Outcrop B (39), and the quarrying area (64). One guideline for DFA is that the smallest group used to derive the functions should exceed the number of variables, preferably by a factor of three or more (Williams and Titus, 1988). Here there were 39 Outcrop B subsamples versus six variables (6.5 more observations than variables). Figs. 8 and 9 show that the data distributions for these three loci are largely normal and have no marked outliers, satisfying DFA guidelines. Statistical tests (Box tests, Kullback's test) reveal that the within-group covariance matrices are not equal, so the derived DFA classification functions were quadratic rather than linear. Last, the only instance of high correlation among these variables is that between M_r and M_s, suggesting collinearity of variables is low, favorable to DFA. Derived functions were, in turn, applied to the other datasets as a means to display data for all six variables on two axes.

Figs. 9 and 10 both demonstrate that magnetic measurements for obsidian specimens collected across the GVC cover a larger area in a scatterplot (Figs. 9a and 10a) than those collected throughout the Hrazdan valley (Figs. 9b and 10b) and from the alluvial deposit (Figs. 9c and 10c). Spread on the landscape, in general, corresponds to spread in the scatterplots, and Hrazdan valley specimens reflect a subset of the magnetic properties throughout the GVC.

The overall spread of specimens from the Hrazdan valley and alluvial deposit is similar, as expected, because obsidian in the alluvial deposit is derived from outcrops along the valley. While specimens collected throughout the valley exhibit a continuous range of magnetic values (Fig. 10b), the alluvial deposit data appear to exhibit a series of clusters (Fig. 10c). At present, we interpret

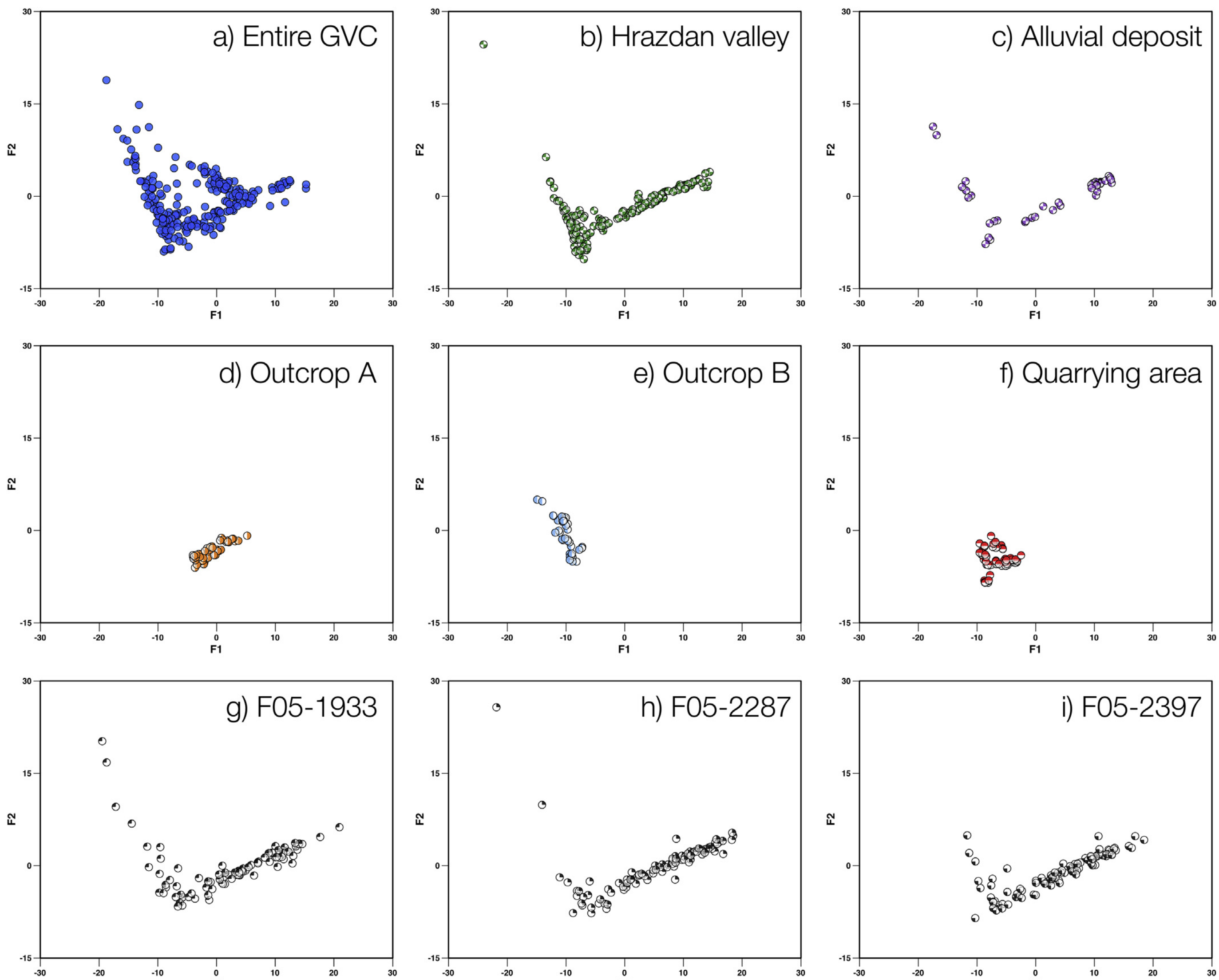

Figure 10. Discriminant function analysis based on six magnetic parameters — M_s, M_r, M_r/M_s, B_c, B_{cr}, and B_{cr}/B_c — for our different GVC procurement scenarios and the three LKT1 samples. The colors for the different models are consistent with Figs. 4, 8 and 9. Frahm et al. (2014b: Fig. 10) gives a rough example of how (b) would look if each locus had a different color and symbol. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

these clusters as evidence that, both topographically and energetically, only particular outcrops will contribute to such alluvial deposits. That is, obsidian from certain outcrops can accumulate locally (e.g., in a talus slope at the base of an outcrop, within a small depression) but, due to the immediate topography, will not fall into the Hrazdan River and contribute to an alluvial deposit. In addition, blocks shed from some outcrops may be too large for the river to transport: larger nodules require faster water. Furthermore, a given outcrop can only contribute to deposits downstream. Specimens from several outcrops (similar to Outcrops A and B) would be expected to yield clusters in the resulting magnetic dataset. Hence, we have a model that explains the mechanisms for why clustering would be observed in magnetic data for alluvial deposits, as suggested by Figs. 9c and 10c.

An alternative interpretation is that apparent clusters in the alluvial data are a result of the sample size (i.e., ten specimens, which was our field sampling protocol for each locus). In an effort to assess this interpretation, we sought to establish the likelihood of observing such clusters in the Hrazdan valley dataset with repeated random samples (i.e., plotting ten specimens at a time, chosen by a random number table, to observe the resulting patterns). The results of these trials were not unequivocal (see examples in SOM Fig. 1), leaving subjectivity in judging similarity to or difference from our alluvial dataset. We note, however, that the repeated samples tend to have smaller ranges than that of the alluvial deposit, and the M_s and M_r distributions (Fig. 8a and b) show that, on average, nodules in the alluvial deposit have more magnetic material than specimens collected throughout the valley, implying the former is not simply a random sample of the latter. In the future, it would clearly be desirable to sample alluvial deposits more intensively to resolve this issue. At present, Hypothesis #5 is best evaluated with other lines of evidence: such as the rarity of cortex at LKT1, transport damage to the alluvial nodules, and their small sizes.

To avoid judgmental determinations of whether or not obsidian fragments from a sediment sample exhibit magnetic clustering indicative of a secondary alluvial deposit, we sought to quantify the difference between Fig. 10b and c. Given that we were seeking the presence or absence of clusters in these data, our approach used cluster analysis (agglomerative hierarchical clustering with

Euclidean distance dissimilarities and Ward's agglomeration method). Specifically, when the algorithms truncated a dataset into a set number of classes (five clusters in this case), we focused on the "within-class" (intra-cluster) versus "between-class" (inter-cluster) variance with respect to the total statistical variance of the dataset. The continuous magnetic datasets (e.g., the entire GVC, Hrazdan valley) have much higher within-class variance (i.e., 16.8 ± 3.4% of the total variance) than the clustered datasets (e.g., outcrops, quarrying area; 8.1 ± 2.0% of the variance).

Artifacts from the three LKT1 sediment samples (Fig. 10g–i) exhibit magnetic distributions similar to the specimens acquired throughout the Hrazdan valley. The narrow ranges of values that characterize obsidian from individual outcrops or quarrying areas are not present, nor is the range of values encountered throughout the GVC. Instead, artifacts from each sediment sample appear to magnetically match the specimens collected in the river valley. The discrete clusters characteristic of an alluvial deposit are not apparent; however, we used the clustering analysis described above to test this observation. The three sets of LKT fragments exhibit within-class variance of 16.4 ± 3.6%, virtually identical to that of the continuous magnetic datasets (e.g., the entire GVC, Hrazdan valley; i.e., 16.8 ± 3.4%), as noted above. We interpret this as evidence for a lack of clustering. In summary, those features of the magnetic data distributions that characterize outcrops and quarrying areas (i.e., restricted ranges), the GVC (i.e., broad distributions), and an alluvial deposit (i.e., ostensible clusters) are absent in the archaeological samples, supporting valley-based collection.

We also considered the artifacts' magnetic data based on our lithic analysis, separating data for the retouch/resharpening fragments (Fig. 11b) and other small debris (Fig. 11c). In most cases, the valley-like distribution of magnetic data is present. However, the retouch/resharpening pieces from sediment sample F05-2287 might exhibit clustering, although the effect of a small sample size ($n = 18$) on the data distribution must be considered. Hence, we used a simulation approach to the cluster analysis used above as a means to compare these retouch/resharpening pieces to sets of 18 fragments randomly chosen from the sediment sample. Eighteen fragments were randomly chosen from the full F05-2287 dataset in a series of 100 trials, and within-class variance was calculated for each trial. On average, for 18 random fragments, within-class variance accounted for 8.7 ± 2.4% of the total variance. In comparison, the retouch/resharpening fragments from the three sediment samples, including F05-2287, have within-class variances of 7.4 ± 0.1%. That is, the distributions of the retouch/resharpening fragments are virtually identical among the three sediment samples. In addition, within-class variances for the retouch/resharpening fragments fall within one standard deviation of the mean of the stimulated trials (i.e., 8.7 ± 2.4%). We interpret this outcome as a lack of evidence for differences, either statistical or behavioral, among the three archaeological samples or the different fragment classes (retouch/resharpening pieces versus other small debris).

7. Discussion

The obsidian artifacts (specifically 286 small fragments) from three different LKT1 sediment samples, each corresponding to a different time interval of site occupation, exhibit magnetic properties most similar to our obsidian specimens collected throughout the Hrazdan River valley. We interpret this as support for Hypothesis #2: toolstone procurement by the occupants during these intervals largely occurred within the Hrazdan River valley, resulting in obsidian collected from a variety of outcrops and exposures inside the valley. As noted earlier, the obsidian specimens used to test this hypothesis were collected while tracking "prey" (cattle) through the river valley. If the occupants principally collected obsidian while moving through the valley, their procurement patterns were likely similar to ours. Thus, we propose that the obsidian procurement taskscape (sensu Ingold, 1993) spatially coincided with the Hrazdan River valley. The abundance of obsidian in the valley is consistent with the argument that embedded procurement (sensu Binford, 1979) can predominate in such a toolstone-rich landscape (e.g., Duke and Steele, 2010). If obsidian procurement within the valley largely reflects the geographic distribution of subsistence activities, our results suggest that the LKT1 occupants, at least during these three particular time intervals, were able to secure adequate food supplies within the river valley. The coincidence of these behaviors within the valley indicates the efficient exploitation of a rich and diverse biome. Our findings are also consistent with expectations regarding energy expenditure (i.e., hypotheses that the occupants might largely stay in the valley, as the prey animals do, and avoid climbing the valley slopes).

The rarity of obsidian from Hatis is consistent with our findings based on the magnetic data. The volcano is only 12 km away from LKT1 and immediately southeast of the GVC (Fig. 1a and b). Its obsidian, though, is absent from two of the sediment samples, and it represents just 2% in the third sample. At least during these three time intervals, the LKT1 occupants did not routinely acquire obsidian from this volcano. The GVC obsidian outcrops most distant from LKT1 are ~9 km from the cave, and our magnetic results indicate that these and other outcrops outside the valley were rarely exploited. We interpret our geochemical results as consistent with our magnetic data and their interpretation. The site-wide average is 4.2% Hatis obsidian, which is present in certain squares and strata while absent in others. A question to address in the future is whether Hatis-obsidian-rich occupations correlate with GVC obsidian collected from farther afield.

Undoubtedly the studied sediment samples are palimpsests that reflect, at the least, multiple knapping episodes. An alternative, therefore, is to interpret our magnetic data as indicators of the amount of "behavior in a bucket" each sample reflects. A sediment sample does not correspond to the knapping debris of an individual who encountered two or three obsidian exposures that day and sat down to reduce the collected raw material. Our magnetic data are inconsistent with such an interpretation. Instead, the debris within must reflect a number of obsidian procurement episodes throughout the Hrazdan valley (although material and tools from multiple procurement episodes could have been reduced during a given knapping session). A corollary must also be kept in mind when clusters appear in the magnetic data for a certain assemblage: the reduction of obsidian from various outcrops might have differed for some reason (e.g., block size), so that the small debris left at a site does not reflect the same proportions in which the outcrops were exploited (e.g., reducing one block yields five fragments, whereas another yields fifty). Therefore, it will be important, in such instances, to consider the quantities and sizes of debitage produced by the flaking techniques used by site occupants. This is one of the reasons that we consider retouch/resharpening fragments and other small debris separately: they were likely produced in different quantities.

With excellent obsidian virtually ubiquitous on the GVC landscape, MP hominins were able to practice subsistence and other activities largely free of concerns about where and when to find toolstone. The properties of obsidian may, however, be important to other issues. Most notably, it has been argued that quarrying of chert outcrops was uncommon (Demars, 1982; Turq, 1989) because such a strategy would have been difficult and time-consuming (Bordes, 1984). Rather than attempting to extract chert from veins or nodule-bearing limestone, chert was more readily accessible, some suggest, from alluvial deposits along streams and rivers (Turq,

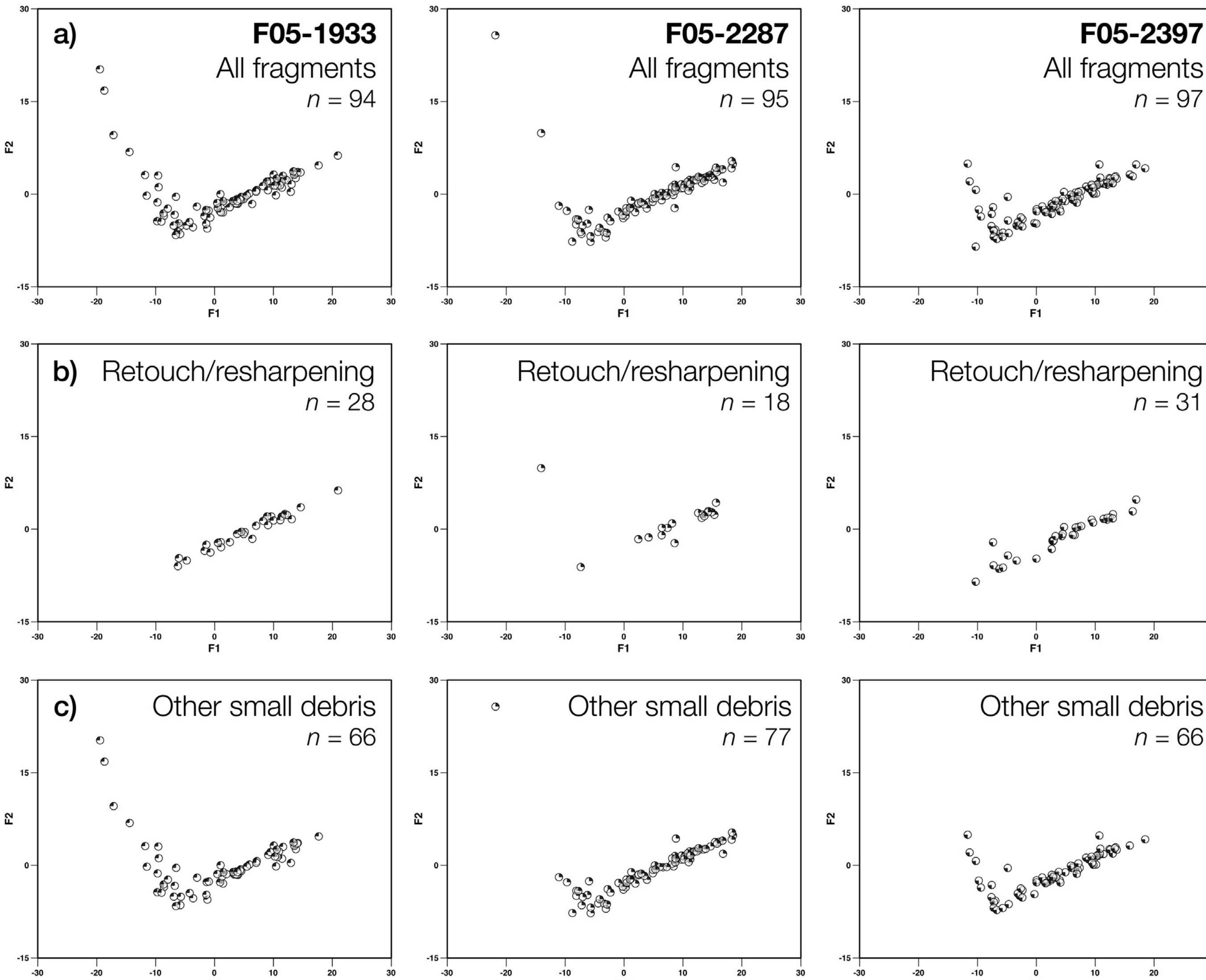

Figure 11. Magnetic data (plotted using the same discriminant functions as Figure 10) by sediment sample for (a) all 286 LKT1 artifacts, (b) only the retouch/resharpening pieces, and (c) the rest of the small debris.

1988a, 1989). Obsidian is hard but brittle, and it would have been, in general, easier to remove obsidian from the surrounding perlite in the GVC than chert from limestone. Our observations at the alluvial deposit in this study, the only Pleistocene deposit that we have located along the river, suggest the obsidian cobbles are too damaged by battering and frost action to serve as reliable sources of toolstone, and cobbles larger than 10 cm are uncommon in the deposit (and most are markedly smaller; Fig. 3d). This is consistent with our magnetic results, which we interpret as evidence that alluvial deposits were not the main sources of obsidian for the LKT1 residents. Furthermore, these multiple lines of evidence are consistent with very rare cortical flakes found at LKT1. Primary outcrops of abundant obsidian (not damaged by transport) are visible even from the cave (Fig. 2c); however, it is not the case that a particular outcrop within view was preferentially exploited.

It does seem plausible that exploiting obsidian nodules from multiple alluvial deposits, each drawing from different sets of outcrops along the palaeo-Hrazdan River, could yield an essentially continuous distribution of magnetic values very similar to the valley-collected dataset. Presumably, to draw from different outcrops, alluvial deposits would need to have different locations around the valley (due to topographic and energetic restrictions on contributing outcrops). Exploiting many alluvial deposits through the river valley, therefore, becomes a situation whereby the behaviors for Hypotheses #2 and #5 become similar: toolstone procurement in the valley results in collection of toolstone from numerous obsidian exposures – whether primary outcrops or alluvial deposits – encountered along the river. Thus, these situations may not be discernable magnetically, but they are also behaviorally similar.

Our pilot studies (Frahm and Feinberg, 2013) suggest that humans in a much later period (the Early Bronze Age) preferred low-inclusion obsidian. Based on the parameters that principally reflect the concentration of magnetic material (e.g., M_r, M_s), it seems that, for whatever reason (e.g., aesthetics, flaking predictability), they chose raw obsidian with fewer mineral inclusions for their prismatic blade technology. In contrast, there was minimal, if any, disparity between the artifacts and geological specimens with respect to magnetic parameters and ratios that primarily reflect the morphologies and compositions (e.g., B_c, B_{cr}, M_r/M_s, B_{cr}/B_c) of the inclusions. This is consistent with visual selection: one can visually recognize obsidian with less magnetic material (i.e., clearer glass), but sizes, shapes, or compositions of these microscopic grains are not readily identified by eye. In this study, there is no such effect. Fig. 8 reveals that concentration-dependent properties (i.e., M_r, M_s) for LKT1 artifacts and GVC geological specimens exhibit similar ranges. One possibility is that, when applying Levallois and Kombewa techniques, there is little motivation to select obsidian with fewer inclusions (i.e., that there is little or no perceptible effect on flaking or appearance; see Eren et al., 2011). The second possibility is that our geological specimen collection, which was collected in ways intended to replicate procurement behaviors rather than random sampling, better reflects obsidian collected by LKT1 hominins, yielding greater concordance.

8. Conclusions

At LKT1, we applied a new approach to magnetic characterization of obsidian artifacts as a means to investigate how the cave's hominin occupants procured local toolstone and utilized the surrounding landscape. Throughout Eurasia, toolstone acquisition by MP hominins was affected by diverse variables, especially the local environment, so the study at hand concerns lifeways along the Hrazdan as Unit 6 was deposited. We report here that it is not the case that one or two particular obsidian outcrops were strongly favored by the LKT1 occupants during the studied times. Nor did they appear to collect obsidian from intensive quarrying areas or from locations across the entire volcanic complex. A convergence of evidence also suggests that an alluvial deposit was not exclusively exploited either. Instead, our data best support the hypothesis that the occupants principally collected obsidian from various outcrops and exposures throughout the Hrazdan valley, likely reflecting the scale of their day-to-day foraging activities. Thus, their toolstone procurement taskscape seems to coincide with the river valley. Our findings are consistent with common notions regarding the nature of MP toolstone procurement and subsistence, namely that a dependence on local resources is a widespread and important characteristic of the MP.

Despite geographic diversification of Palaeolithic research in recent decades, many of these appraisals are predicated on the long history of research on chert procurement in western Europe, particularly southwestern France, where local (<5 km) cherts dominate the MP assemblages. How these procurement behaviors were manifested on the local landscape, however, has remained a topic of debate. The evidence was frequently equivocal whether an abundance of local toolstone reflected frequent encounters with different outcrops while foraging or whether a certain outcrop was preferred and intensively exploited. Our approach, by elucidating the locations of procurement activities on the local landscape surrounding LKT1, betters our understanding of how the cave's occupants planned for their access to adequate toolstone and/or tools and of the earliest stages of artifact movement between the source and site. Extending our analysis to other LKT1 strata and other Palaeolithic sites currently under investigation by the HGPP will further clarify the behavior of MP hominins within their specific, nuanced environmental contexts.

Our temporal and cultural perspective within the Hrazdan Basin is limited here to the MP. A site from the Upper Palaeolithic (UP) has only recently been excavated by our team. How or if the provisioning behaviors we identified at LKT1 varied over time and among populations is a major aspect of our ongoing research that we will address by applying the approach documented here to older (e.g., Nor Geghi 1), contemporaneous (MP), and younger (UP) sites within and adjacent to the river valley. The outcome of these analyses will play a central role in regional assessments of the nature and timing of the MP to UP "transition" and the relationship, if any, between procurement behaviors and presumed population dynamics during these periods.

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Supplementary Online Material

Supplementary online material related to this article can be found at http://dx.doi.org/10.1016/j.jhevol.2015.10.008.

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