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PROVENANCE OF MIDDLE STONE AGE OBSIDIAN ARTEFACTS FROM THE CENTRAL SECTOR OF THE MAIN ETHIOPIAN RIFT VALLEY

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ABSTRACT: The Gademotta/Kulkuletti sites, located in the central part of the Main Ethiopian Rift Valley, represent the earliest Middle Stone Age (MSA) sequences in the country. Here we present the geochemical provenance of obsidian archaeological artefact recovered through excavation at the site. The artefacts and source materials were characterized by EDXRF and electron microprobe. Results show that the artefacts were procured from two sources, one local, and one presumably more distant, implying that despite the local availability of good quality raw material, not all obsidians were procured from a nearby source.

Key words/phrases: Gademotta, Kulkuletti, Middle Stone Age, obsidian, provenance

INTRODUCTION

The Middle Stone Age (MSA), a period extending from about 300 to 50 ka ago, is critical to understanding the emergence of anatomically modern humans. Regardless of one's propensity to any of the hypotheses constructed about the origins of anatomically modern humans, there is general agreement among investigators that long distance contact or interaction and/or transport of lithic raw materials is one of the key aspects of the emergence of modern behaviour [see McBrearty and Brooks (2000) for a review].

One way of investigating such aspects of behaviour is through elemental analysis of obsidian from geological sources and from archaeological artefacts. In most cases obsidian from an individual eruptive event has an elemental composition that is distinct from obsidian erupted during another event, so that artefacts can be attributed to a specific source on the basis of their composition (Glascock *et al.*, 1998, Agazi Negash *et al.*, 2006). In this way it has been possible to identify the procurement and transport of obsidian from the source to habitation sites.

However, the geological provenance of many MSA artefacts in Ethiopia remains unknown because there is no comprehensive inventory of analyses from sources, and also because many artefacts have not been analyzed. A comprehensive program of investigating the composition of obsidian sources and archaeological obsidian at MSA sites will take many years of intensive research. This paper is but a beginning toward characterization of obsidian artefacts from MSA sites in the central part of the Ethiopian Rift. The analyses were made on artefacts that are stored in the National Museum of Ethiopia, and also on geological source obsidians collected for purposes of comparison.

The archaeological sites

The Middle Stone Age archaeological sites of Gademotta and Kulkuletti are situated in the lakes region in the central sector of the Main Ethiopian Rift Valley. They lay very close to the western edge of Lake Ziway, on the upper slopes of Gademotta ridge, a prominence that rises a few hundred meters above the surface of Lake Ziway and a few km from the town of the same name (Fig. 1). The region in which these sites are found is well known for paleoclimatic and paleoenvironmental studies and includes one of the best dated Pleistocene stratigraphic sequences in the world, as recently reviewed by Le Turdu *et al.* (1999), Benvenuti *et al.* (2002), and Morgan and Renne (2008), although archaeological investigations in the region are still sparse.

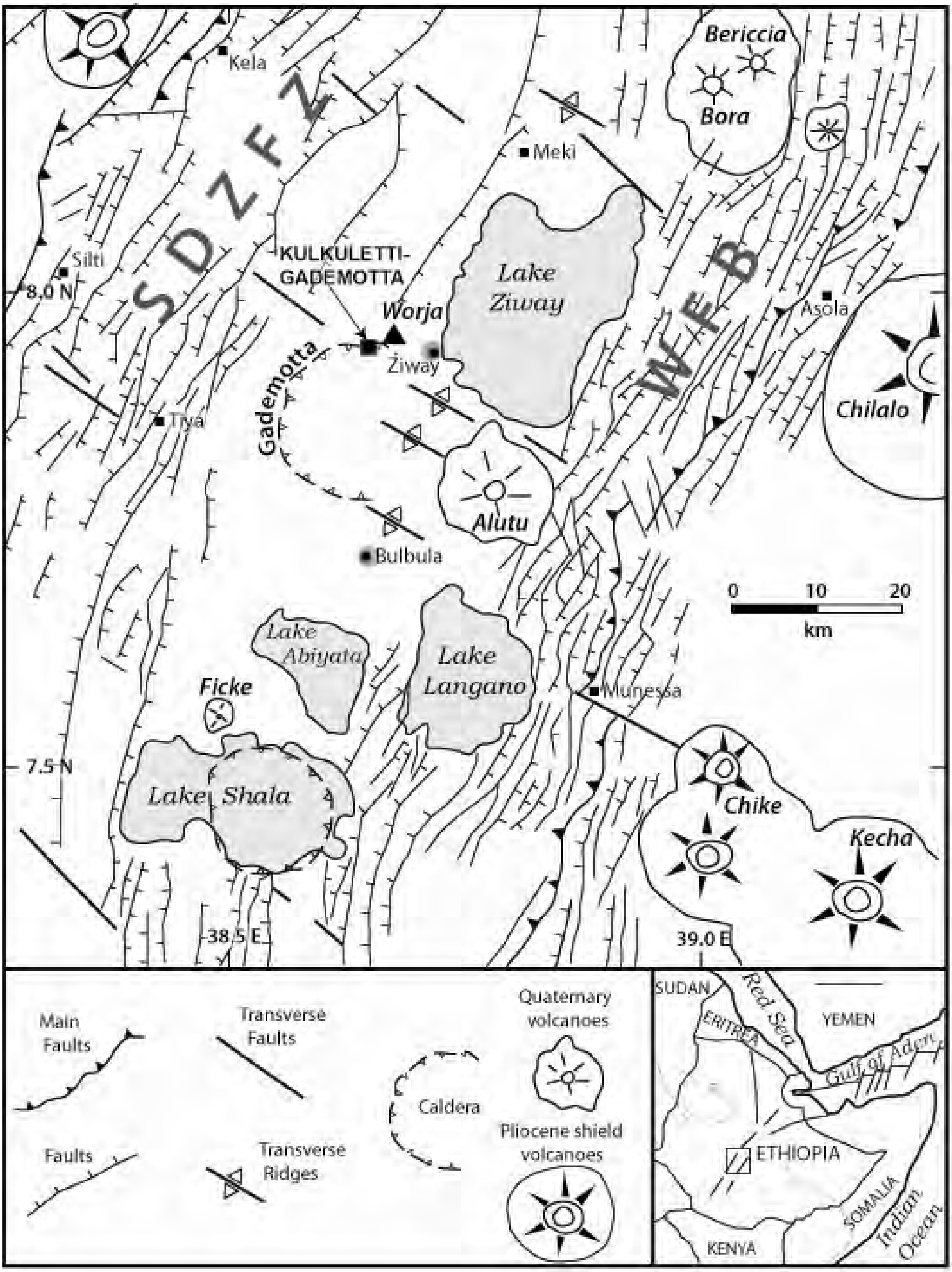

Fig. 1. Map showing the volcano-structural features of the central part of the Main Ethiopian Rift (MER) and the location of the archaeological sites and geological sources discussed in the text. WFB, Wonji Fault Belt; SDZFZ, Silti-Debre Zeit Fault Zone (modified from Benvenuti *et al.*, 2002). Note the alignment of the Alutu and Bericcia Quaternary volcanoes along the tectonically active NNE-trending WFB within the MER.

Excavated in the early 1970's by Wendorf and colleagues (*e.g.*, Wendorf and Schild, 1974), the sites of Gademotta and Kulkuletti have yielded the earliest MSA artefacts in Ethiopia, and perhaps in the world. The artefacts were excavated from the Gademotta Formation, a sequence of volcanogenic stratified clastic sediments that lie unconformably on the Kulkuletti volcanics that form much of the base of the Gademotta ridge. Although the Gademotta Formation varies in thickness from <1 m to 40 m, it is 20 m thick in the type area (Laury and Albritton, 1975) with archaeological materials restricted to the upper 10 m of the section (Wendorf *et al.*, 1994). Laury and Albritton (1975) subdivide the Gademotta Formation into two parts, a lower part (their Units 1–8) that lacks artefacts and an upper section with abundant artefacts (beginning at Unit 9). Early K/Ar dates of 235±5 ka, and 181±6 ka on Unit 10, and 149±13 ka on unit D (Laury and Albritton, 1975; Wendorf *et al.*, 1994) in the upper part of the section have been supplemented by new determinations of Morgan and Renne (2008). The careful study of the latter authors reports $^{40}Ar/^{39}Ar$ ages of 280±8 ka, and 276±4 ka for Unit 10 at the Kulkuletti and Gademotta sites, respectively, and of 183±10 ka on unit D. Further, Morgan and Renne (2008) correlate Unit 10 between the two sites on the basis of similarity in composition of volcanic glass. These ages make the sites of Gademotta and Kulkuletti the earliest dated MSA sites in the Horn of Africa, and as old as those reported from the Kapthurin Formation in Kenya (Deino and McBrearty, 2002).

MSA artefacts from Gademotta and Kulkuletti include Levallois points and cores. Wendorf and Schild (1974) suggest that these probably represent habitation sites or base camps with obsidian workshops. There are obsidian sources close to the Gademotta and Kulkuletti sites, and it has been hitherto thought that these provided all the raw materials utilized by the prehistoric inhabitants of the sites. To test this notion, we analyzed 13 archaeological debitage samples as well as geological samples from other sources in the region that form the basis for this work. The artefacts were randomly selected from the excavated materials stored at the National Museum of Ethiopia. The analyzed source materials are artefact quality obsidian samples taken from many different parts of each source due to concern about intra-source elemental variability (Hughes, 1994, 1998; Ericson and Glascock, 2004).

The potential geological sources

As part of a project of documenting Ethiopian obsidians, we surveyed the region around the Gademotta area for potential obsidian sources. We identified three volcanic source areas with artefact quality obsidians (Worja, Alutu, and Bericcia) and one (Butajira) with porphyritic obsidians unsuitable for artefact manufacture. The latter source is, therefore, not discussed here.

The Worja source area (average location 7.9411° N, 38.6557° E) forms part of the Gademotta caldera, located along the tectonically active Wonji Fault Belt (WFB) in the Main Ethiopian Rift on the Ziway-Langano-Abiata rift floor. It is adjacent to the Guraghe escarpment where there is an active western marginal graben called the 'Silti-Debre Zeit Fault Zone' (Giday WoldeGabriel *et al.*, 1990; Fig. 1). The western rim of the Gademotta caldera forms an arcuate structure of pantellerite ridges and domes whereas younger deposits largely cover the eastern rim. In some sections of the eastern rim of the caldera, outcrops of rhyolite/pantellerite containing thin, fragmented obsidian layers are exposed, and obsidian pebbles and boulders are abundant (Fig. 2). In other places, intact steeply dipping obsidian layers intercalate with the rhyolite/pantellerite flows. This section, known as the Kulkuletti volcanics, attains a maximum thickness of 100 m, and has yielded a K/Ar age of 1.048 ± 0.025 Ma (Laury and Albritton, 1975). Giday WoldeGabriel *et al.* (1990) report a K/Ar age of 1.3 Ma on a rhyolite from this section, which is confirmed by some of the ages measured by Vogel *et al.* (2006) and substantiated by reanalysis of Vogel's data by Brown *et al.* (2009) and Morgan *et al.* (2009). Obsidian samples from the Worja locality in Gademotta are black to dark green, with flow banding, patches of oxidized material, and typical conchoidal fracture. In this area obsidian occurs as thin, highly fragmented flow layers, so abundant gravels and boulders are very common.

Fig. 2. Obsidian pebbles from Worja locality.

A second potential obsidian source which we sampled is Bericcia volcano (8.0444° N, 39.0178° E), near the small town of Ogolcho. Volcanism in the Bericcia area is part of the Main Ethiopian Rift volcanic complex along the Langano-Ziway segment of the WFB and, as at Alutu (see below), is characterized by rhyolitic lava flows, domes and pyroclastic rocks including pumice, tuff, obsidian and pitchstone. Patches of obsidian/-pitchstone are common within one rhyolitic flow unit in the Ogolcho-Bericcia area. The obsidian (pitchstone) is generally non-vitreous, black, and found intercalated within rhyolitic ignimbrites that are generally light grey, vesicular, and in some cases flow banded.

Like Bericcia, Alutu volcano (7.7381°N, 38.7914°E) lies along the Langano-Ziway segment of the WFB (Fig. 1). It has rhyolitic lava flows and domes associated with the rift floor ignimbrites. It has been dated at 1.3±0.1 Ma on rhyolite lava and 0.04±0.01 Ma on obsidian (Giday WoldeGabriel *et al.*, 1990). On the slopes of Alutu volcano, exposures of a mass of obsidian up to 3 to 5 m thick are common (Fig. 3). On the lower slopes, obsidian flows intercalate with a rhyolitic lava flow whereas in the upper part the obsidian is interlayered with an oxidized and weathered friable unit. The obsidian is black, vitreous, and has a characteristic conchoidal fracture and flow structure, with folded flow bands.

METHOD

Samples were analyzed using two instruments: energy dispersive x-ray fluorescence (EDXRF) for trace elements and electron microprobe for major and minor elements. Trace elements were analysed at the Archaeological XRF laboratory of the Department of Anthropology, University of California, Bereley.

We did not measure the major/minor elements for the artefacts because they were destroyed as they were irradiated for Ar/Ar age determination (Vogel *et al*., 2006) and therefore only their trace element concentrations (analyzed before irradiation) are reported here. It should be noted that samples labelled GADT-1 through GADT-13 correspond to samples Kulkuletti-1 through Kulkuletti-13 of Vogel *et al*. (2006), and in addition, the sample labelled Worja-3 in Vogel *et al.* (2006) is labelled Worja-A here.

Analytical details for EDXRF obsidian characterization have been described elsewhere (Shackley, 1998; Agazi Negash and Shackley, 2006; Agazi Negash *et al*., 2007). Details of the method used for analysis by electron microprobe are provided in Nash (1992), and Brown *et al*. (2006) give standards used and analytical conditions for each element as a supplementary table.

Fig. 3. Obsidian flow from Alutu volcano.

RESULTS AND DISCUSSION

Compositional results are presented in Table 1 (for major and minor elements) and Table 2 (for trace elements) and plotted in Figure 4. Simple discrimination of the sources can be made on the basis of Fe, Al, Mn, and Ca. For instance, the Worja source samples can be separated from the rest by their lower Fe content (Fig. 4). Of the three clusters, obsidian from Alutu has the highest concentration of Fe and Mn while Bericcia has a higher concentration of alumina (in excess of 11.7 wt %, Fig.4) and also a higher Ca concentration (Table 1).

The artefacts can easily be grouped into two distinct compositional clusters on the basis of Zr. Most of the artefacts correspond compositionally to source obsidian from Worja, located close to the archaeological sites. However, two of the artefacts (GADT-9 and -10) are compositionally distinct, with Zr content some 300 ppm lower than the main group of artefacts. These come from a source that we have not yet located. In many respects these two artefacts are compositionally similar to the obsidians from Bericcia, but are distinct in their higher Nb content and lower Sr content (Table 2). This leaves only Alutu as a possible source for which we have compositional data.

Analyses of source samples from Alutu located some thirty km southeast of the sites (Fig. 1), suggest that at least two and possibly three compositional types are present on that volcano. The principal group of seven samples (Alutu F-1, F-2, F-3, F-A, S-4, S-5, and S-6) is well defined, and is most similar to the artefact compositions in trace element contents. Source samples Alutu S-1 and S-2 are clearly distinct from the main group of samples from Alutu in having higher Zn, Rb, Y, Zn, Zr, Nb and Cl, and also in having lower contents of CaO, TiO_2, Al_2O_3 and Fe_2O_3. Sample Alutu S-3 has trace element contents similar to the principal group, but has Fe content similar to that of Alutu S-1 and S-2; on the basis of the data available, we treat it as compositionally distinct from both.

That two artefacts are clearly not derived from obsidian from Worja, but from another source demonstrates that the people who made the tools sometimes used material from other localities, even though good material was available nearby (Merrick *et al*., 1994). Although contact, exchange, and even curated transport have been invoked to explain the presence of non-local raw materials at an archaeological site, such explanations require prior extensive regional archaeological evidence. The scarcity of archaeological investigations in the central part of the Ethiopian Rift precludes determining of how obsidians of Gademotta from an unknown source were procured.

Table 1. Major and minor element abundances of obsidian samples (expressed in wt %) from Worja, Alutu and Bericcia.

Sample	Locality	SiO_2	TiO_2	ZrO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	BaO	Na_2O	K_2O	F	Cl	Sum
WO-1	Worja	72.67	0.27	0.23	9.59	4.40	0.14	0.00	0.19	0.01	5.14	4.52	0.36	0.10	97.63
WOR-11	Worja	72.67	0.25	0.18	9.70	4.34	0.14	0.00	0.21	0.01	5.14	4.45	0.34	0.10	97.54
WOR-12	Worja	72.61	0.25	0.21	9.71	4.38	0.15	0.00	0.20	0.00	5.16	4.47	0.35	0.09	97.58
WOR-13	Worja	71.99	0.28	0.21	9.63	4.28	0.14	0.01	0.20	0.02	5.09	4.44	0.35	0.10	96.74
WOR-14	Worja	72.88	0.25	0.19	9.61	4.33	0.16	0.00	0.18	0.01	5.14	4.49	0.34	0.10	97.68
WOR-15	Worja	73.07	0.27	0.20	9.73	4.33	0.16	0.00	0.19	0.01	5.04	4.47	0.35	0.10	97.91
WOR-16	Worja	72.91	0.27	0.18	9.75	4.31	0.15	0.01	0.20	0.02	5.17	4.43	0.34	0.10	97.85
WO-2	Worja	72.68	0.27	0.21	9.68	4.37	0.15	0.00	0.19	0.02	5.08	4.48	0.37	0.10	97.59
WO-A	Worja	73.35	0.27	0.20	9.77	4.32	0.15	0.01	0.21	0.00	5.13	4.49	0.35	0.10	98.36
ALU-F-A	Alutu	71.28	0.38	0.16	9.87	6.46	0.30	0.01	0.29	0.00	6.12	4.51	0.36	0.14	99.88
ALU-F-1	Alutu	71.41	0.37	0.12	9.89	6.53	0.30	0.02	0.29	0.00	6.21	4.49	0.37	0.14	100.15
ALU-F-2	Alutu	71.07	0.37	0.18	9.79	6.48	0.28	0.02	0.29	0.00	5.95	4.58	0.32	0.14	99.48
ALU-S-4	Alutu	71.37	0.34	0.14	10.00	6.50	0.29	0.02	0.28	0.00	6.09	4.58	0.37	0.14	100.11
ALU-S-5	Alutu	71.51	0.34	0.18	9.75	6.47	0.30	0.01	0.27	0.00	6.11	4.56	0.39	0.13	100.03
ALU-S-6	Alutu	71.63	0.36	0.14	9.91	6.51	0.30	0.02	0.28	0.00	6.08	4.53	0.34	0.13	100.23
ALU-S-1	Alutu	71.63	0.24	0.20	9.21	5.93	0.25	0.02	0.20	0.01	5.77	4.51	0.44	0.19	101.23
ALU-S-2	Alutu	74.27	0.23	0.23	9.21	5.95	0.24	0.01	0.20	0.00	5.77	4.47	0.45	0.19	101.34
ALU-S-3	Alutu	74.38	0.31	0.19	10.10	5.91	0.24	0.01	0.27	0.00	5.88	4.57	0.37	0.16	101.36
ALU-F-3	Alutu	73.35	0.36	0.20	10.07	6.62	0.30	0.03	0.29	0.00	6.20	4.58	0.37	0.14	101.70
Alu-1	Alutu	72.54	0.36	0.11	9.82	6.60	0.31	0.02	0.30	0.01	5.64	4.39	0.36	0.14	99.49
Alu-2	Alutu	71.43	0.40	0.13	9.89	6.67	0.31	0.02	0.32	0.00	5.64	4.57	0.36	0.14	100.13
Alu-3	Alutu	71.67	0.40	0.10	9.91	6.66	0.32	0.01	0.32	0.00	5.72	4.56	0.36	0.15	100.24
BAR-1	Bericca	71.73	0.37	0.17	11.74	5.38	0.22	0.01	0.42	0.04	6.17	4.01	0.26	0.11	101.58
BAR-3	Bericca	72.67	0.40	0.16	11.89	5.32	0.24	0.01	0.41	0.06	6.25	4.07	0.28	0.11	101.89
BAR-4	Bericca	72.69	0.35	0.14	11.91	5.24	0.23	0.01	0.34	0.06	6.35	4.04	0.23	0.11	102.07
BAR-5	Bericca	73.04	0.40	0.18	11.87	5.22	0.22	0.01	0.39	0.06	6.29	4.02	0.26	0.11	101.73
BAR-6	Bericca	72.70	0.35	0.14	11.88	5.34	0.23	0.02	0.36	0.07	6.32	4.03	0.25	0.11	101.79
BAR-7	Bericca	72.70	0.35	0.14	11.83	5.45	0.24	0.02	0.47	0.06	6.28	4.00	0.25	0.11	101.81
BAR-8	Bericca	72.60	0.35	0.16	11.85	5.31	0.22	0.01	0.35	0.07	6.25	4.04	0.29	0.11	101.84
BAR-9	Bericca	72.81	0.36	0.14	11.82	5.36	0.23	0.01	0.37	0.07	6.32	4.06	0.30	0.11	102.38
BAR-10	Bericca	73.21	0.36	0.17	11.89	5.39	0.22	0.01	0.36	0.06	6.30	4.06	0.31	0.12	102.39

Table 2. Trace element composition (in ppm) of the Gademotta artefacts and from the sources of Worja, Alutu and Bericcia.

Sample	Legend	Zn	Ga	Rb	Sr	Y	Zr	Nb
GADT-1	artefact	264	26	112	15	123	1036	130
GADT-2	artefact	277	30	109	18	122	1048	140
GADT-3	artefact	262	27	104	16	127	1031	125
GADT-4	artefact	264	26	108	17	121	989	136
GADT-5	artefact	258	27	115	19	121	1012	135
GADT-6	artefact	298	31	116	15	124	1064	138
GADT-7	artefact	258	29	103	17	128	1013	139
GADT-8	artefact	275	26	109	17	128	1027	134
GADT-9	artefact	238	27	95	11	103	755	137
GADT-10	artefact	245	27	87	13	95	749	144
GADT-11	artefact	261	25	102	19	123	991	129
GADT-12	artefact	226	30	101	19	109	924	121
GADT-13	artefact	257	30	109	15	119	995	135
WO-1	Worja	269	34	104	14	116	1002	141
WO-2	Worja	264	28	115	17	117	989	123
WO-A	Worja	268	27	106	13	120	984	132
WOR-11	Worja	264	28	105	17	120	1005	132
WOR-12	Worja	247	21	97	19	116	931	123
WOR-13	Worja	276	24	112	18	124	1017	124
WOR-14	Worja	255	34	109	16	127	981	130
WOR-15	Worja	295	28	104	19	130	1062	141
WOR-16	Worja	270	26	109	16	126	1026	140
BAR-1	Bericcia	211	27	95	19	89	708	109
BAR-3	Bericcia	208	29	91	17	81	677	108
BAR-5	Bericcia	233	27	94	21	92	722	127
BAR-7	Bericcia	208	29	94	25	82	702	108
BAR-8	Bericcia	231	32	97	20	87	714	116
BAR-10	Bericcia	264	34	109	18	83	752	119
ALU-S-1	Alutu	307	30	120	16	127	1057	189
ALU-S-2	Alutu	321	28	115	18	134	1071	192
ALU-S-3	Alutu	252	27	90	16	94	855	140
ALU-S-4	Alutu	242	27	93	19	93	792	142
ALU,S-6	Alutu	248	30	98	13	86	758	142
ALU,S-5	Alutu	253	30	95	13	89	781	137
ALU,F-A	Alutu	253	33	88	20	96	774	147
ALU-F-1	Alutu	287	31	102	17	103	828	162
ALU-F-2	Alutu	272	31	96	12	99	804	133
ALU-F-3	Alutu	280	31	106	13	93	826	145

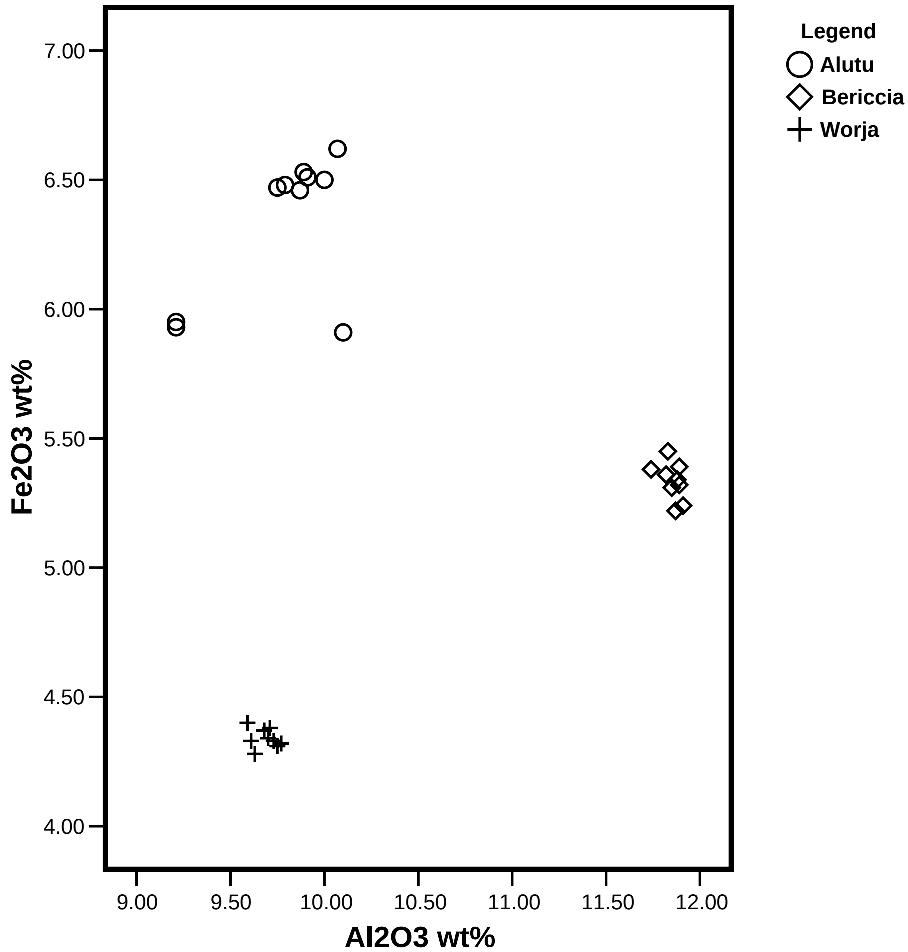

Fig. 4. $Fe_2O_3^T$- Al_2O_3 binary diagram discriminating obsidians from different sources (Alutu, Bericcia, and Worja). Note at least three clusters for the three different sources.

CONCLUSION

There is good evidence that most of the artefacts at the Gademotta sites were obtained from local raw materials, but some artefacts were made of material from sources that we have not located locally. This strongly implies that there was movement of raw material and/or artefacts from another source. This has also been demonstrated in other investigations in East Africa that showed some artefacts were being procured from non-local sources despite the presence of ample, good quality local obsidians (Merrick and Brown, 1984; Merrick *et al.*, 1994). Current archaeological evidence does not allow any inference to be made as to whether raw material was procured directly, or whether there was some sort of interaction/-exchange with other places, considered as a key aspect of the advent of modern human behaviour.

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REFERENCES

1. Agazi Negash, Mulugeta Alene, Brown, F., Nash, B. and Shackely, M.S. (2007). Geochemical Provenance of the Terminal Pleistocene/Early Holocene Obsidian Artefacts from the Site of Beseka, Central Ethiopia. *Journal of Archaeological Science* **34**:1205–1210.
2. Agazi Negash and Shackley, M.S. (2006). Geochemical provenance of obsidian artefacts from the MSA site of Porc Epic, Ethiopia. *Archaeometry* **48**:1–12.
3. Agazi Negash, Shackley, M.S. and Mulugeta Alene (2006). Source Provenance of Obsidian Artefacts from the Early Stone Age (ESA) site of Melka Konture. *Journal of Archaeological Science* **33**:1647–1650.
4. Benvenuti, M., Carnicelli, S., Belluomini, G., Dainelli, N., DiGrazia, S., Ferrari, G.A., Lasio, C., Sagri, M., Ventra, D., Balemwal Atnafu and Seifu Kebede (2002). The Ziway-Shala lake basin (main Ethiopian rift, Ethiopia): a revision of basin evolution with special reference to the Late Quaternary. *Journal of African Earth Sciences* **35**:247–269.
5. Brown, F.H., Bereket Haileab and McDougall, I. (2006). Sequence of tuffs between the KBS Tuff and the Chari Tuff in the Turkana Basin, Kenya and Ethiopia. *Journal of the Geological Society* **163**:185–204.
6. Brown, F.H., Reid, C. and Agazi Negash (2009). Possible isotopic fractionation of argon in source obsidians and archaeological artefacts from Kulkuletti, Ethiopia. *Journal of Archaeological Science* **36**:2119–2124.
7. Deino, A.L. and McBrearty, S. (2002). $^{40}Ar/^{39}Ar$ dating of the Kapthurin Formation, Baringo, Kenya. *Journal of Human Evolution* **42**:185–210.
8. Ericson, J.E. and Glascock, M.D. (2004). Sub-source characterization: obsidian utilization of sub-sources of the Coso Volcanic Field, Coso Junction, California, USA. *Geoarchaeology* **19**:779–806.
9. Giday WoldeGabriel, Aronson, J.A. and Walter, R.C. (1990). Geology, geochronology, and rift basin development in the central sector of the Main Ethiopian Rift. *Geological Society of America Bulletin* **102**:439–358.
10. Glascock, M.D., Braswell, G.E. and Cobean, R.H. (1998). A systematic approach to obsidian source characterization. **In**: *Archaeological Obsidian Studies: Method and Theory*, pp.15–66, (Shackley, M.S., ed.). Plenum Publishing Company, New York.
11. Hughes, R.E. (1994). Intrasource separation of artefact-quality obsidians from the Casa Diablo Area, California. *Journal of Archaeological Science* **21**:263–271.
12. Hughes, R.E. (1998). On reliability, validity, and scale in obsidian sourcing research. **In:** *Unit Issues in Archaeology: Measuring Time, Space, and Material*, pp. 103–114, (Ramenofsky, A.F. and Steffen, A., eds). University of Utah Press, Salt Lake City.
13. Laury, R.L. and Albritton, C.C. (1975). Geology of Middle Stone Age archaeological sites in the main Ethiopian Rift Valley. *Geological Society of America Bulletin* **86**:999–1011.
14. Le Turdu , C., Tiercelinl, J-J., Gilbert, E., Travi, Y., Lezzar, K-E., Richert, J-P., Massault, M., Gasse, F., Bonnefille, R., Decobert, M., Gensous, B., Jeudy, V., Endale Tamirat., Mohammed Umer., Martens, K., Balemwal Atnafu, Tesfaye Chernet, Williamson, D. and Taieb, M. (1999). The Ziway-Shala lake basin system, Main Ethiopian Rift: Influence of volcanism, tectonics, and climatic forcing on basin formation and sedimentation. *Palaeo-geography, Palaeoclimatology, Palaeoecology* **150**:135–177.
15. McBrearty, S. and Brooks, A. (2000). The revolution that wasn't: a new interpretation of the origin of modern human behaviour. *Journal of Human Evolution* **39**:453–563.
16. Merrick, H.V. and Brown, F.H. (1984). Obsidian sources and patterns of source utilization in Kenya and northern Tanzania: some initial findings. *African Archaeological Review* **2**:129–152.
17. Merrick, H.V., Brown, F.H. and Nash, W.P. (1994). Use and movement of obsidian in the Early and Middle Stone Ages of Kenya and northern Tanzania. **In**: *Society, Culture, and Technology in Africa*, pp. 29–44, (Childs, S.T., ed). MASCA 11.
18. Morgan, L. and Renne, P. (2008). Diachronous dawn of Africa's Middle Stone Age: New $^{40}Ar/^{39}Ar$ ages from the Ethiopian Rift. *Geology* **36**:967–970.
19. Morgan, L.E., Renne, P.R., Taylor, R.E. and Giday WoldeGabriel (2009) Archaeological age constraints from extrusion ages of obsidian: Examples from the Middle Awash, Ethiopia. *Quaternary Geochronology* **4**:193–203.
20. Nash, W.P. (1992). Analysis of oxygen with the electron microprobe: Applications to hydrated glass and minerals. *American Mineralogist* **77**:453–457.
21. Shackley, M.S. (1998). Gamma rays, X-rays, and stone tools: some recent advances in archaeological geochemistry. *Journal of Archaeological Science* **25**:259–270.

22. Vogel, N., Nomade, S., Agazi Negash and Renne, P. (2006). Forensic $^{40}Ar/^{39}Ar$ dating: a provenance study of Middle Stone Age obsidian artefacts from Ethiopia. *Journal of Archaeological Science* 33:1739–1765.
23. Wendorf, F. and Schild, R. (1974). *A Middle Stone Age Sequence from the Central Rift Valle, Ethiopia*. Polish Academy of Sciences, Warsaw.
24. Wendorf, F., Close, A.E. and Schild, R. (1994). Africa in the period of *Homo sapiens neanderthalensis* and contemporaries. **In:** *History of Humanity, Vol. 1: Prehistory and the Beginnings of Civilization,* pp. 117–135, (de Laet, S., Dani, A. and Nunoo, B., eds) Routledge and UNESCO: New York.