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GEOCHEMICAL PROVENANCE OF OBSIDIAN ARTEFACTS FROM THE MSA SITE OF PORC EPIC, ETHIOPIA*

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Obsidian geochemical analysis has become an indispensable tool in archaeological research and has wide applications. However, in spite of the abundance of geological and archaeological obsidian, there has been virtually no such investigation in Ethiopia. Recent instrumental characterization of 31 obsidian artefacts from the Middle Stone Age site of Porc Epic and numerous obsidian geological sources show that artefacts were being transported from as far as 250 km away. We believe this has relevance to the understanding of the emergence of modern human behaviour.

KEYWORDS: ETHIOPIA, OBSIDIAN, GEOCHEMISTRY, MIDDLE STONE AGE, MODERN HUMAN BEHAVIOUR, XRF

INTRODUCTION

Obsidian geochemical studies have been used to address a number of archaeological issues in many parts of the world. Such investigations have provided evidence, among others, for long-distance trade, contacts and resource utilization in eastern Africa (Merrick and Brown 1984; Merrick *et al*. 1994), Mesoamerica (e.g., Fralick *et al*. 1998; Glascock *et al*. 1999), Oceania (e.g., Bird *et al*. 1997; White and Harris 1997; Weisler and Clague 1998), South America (e.g., Bellot-Gurlet *et al*. 1999; Burger *et al*. 2000; Vasquez *et al*. 2001); North America (e.g., Shackley 1992, 1995, 1998a–c; Glascock *et al*. 1999; Ambroz *et al*. 2001), and the circum-Mediterranean region, including the Middle East (e.g., Cann and Renfrew 1964; Renfrew *et al*. 1966, 1968; Francaviglia 1984; Torrence 1986; Randle *et al*. 1993; Tykot 1997, 1998; Gratuze 1999), where it has been acclaimed as a ‘success story’ (Williams-Thorpe 1995).

Ethiopia, however, lacks obsidian sourcing investigations (save for the preliminary works of Muir and Hivernel [1976] and Brown [in Agazi 2001]) in spite of the fact that there are abundant known obsidian geological sources and obsidian artefacts recovered from sites ranging from the Early Stone Age (ESA) to the Neolithic. Although archaeologists have recognized a

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number of obsidian sources through archaeological surveys, there has been no attempt to generate a serious systematic programme of sampling at these sources. For example, the Middle Stone Age (MSA) sites of Gademota and Kulkuleti (Wendorf and Schild 1974) are situated close to obsidian domes and although the makers of the MSA artefacts are supposed to have utilized these sources, no geochemical analysis of either the sources or the artefacts has been provided. At the site of Kone, although investigators note the macroscopic homogeneity of the obsidian outcrops close to the site and the undertaking of X-ray fluorescence analyses on some of the obsidian (Kurashina 1978, 587), there is no report of the elemental composition of the artefacts.

The situation is even bleaker for other MSA sites of Ethiopia, where very little is as yet known and an in-depth investigation has long been overdue (Clark 1988). The only 'exception' in terms of obsidian chemical investigation for the MSA in Ethiopia is Porc Epic cave, where six archaeological specimens from the 1930s excavations were instrumentally characterized as part of an obsidian hydration dating study. They show three distinct geological sources (table 5 in Michels and Marean 1984, 64). One of these specimens matches a single sample from Mojjo, situated over 300 km to the west of Porc Epic (Michels and Marean 1984, 64), which was analysed for geological purposes (Mohr 1971). However, due to the absence of archaeologically oriented geochemical research, the two remaining sources were not identified, nor was the source provenance of the remaining obsidian artefacts, which comprise 5.5% of the total lithic assemblage of the 1974 excavations, analysed (Clark and Williamson 1984; Clark 1988).

Therefore, even though obsidian tools are known from many of the MSA sites (Wendorf and Schild 1974; Kurashina 1978; Chavaillon *et al.* 1979; Clark and Williamson 1984; Brandt 1986; Clark 1988), the source provenance of these tools still remains unknown. Thus, there is a similar lack of evidence for the movement of obsidian from its source to these sites and the concomitant scale and complexity of exchange, contact and/or interaction that may have existed during its transport.

At the Laboratory for Human Evolutionary Studies (LHES) and the Archaeological XRF Laboratory at the University of California at Berkeley, and the Max Planck Institute for Evolutionary Anthopology, Leipzig, Germany, we have initiated an ongoing long-term effort to characterize archaeological obsidian artefacts and obsidian geological sources in Ethiopia collected by one of us (A.N.). So far, we have analysed archaeological artefacts from eight sites ranging in age from the Early Stone Age to the Neolithic and obsidians from not less than 25 primary sources. Here, we present the results of the analysis of artefacts from the MSA site of Porc Epic and attempt to trace their sources.

BACKGROUND

Porc Epic is a cave situated very close to the town of Dire Dawa, in eastern Ethiopia (Fig. 1), containing predominantly points and scrapers dating to the MSA. It was excavated twice in the first half of the 20th century, but the materials available to us are from the excavations in the 1970s by J. Desmond Clark and colleagues (Clark and Williams 1978; Clark and Williamson 1984). The 1974 excavations unearthed a total of 5146 artefacts. Although the dominant raw material is chert (80%), obsidian artefacts comprise 5.5% of the total lithic assemblage. Since there was no obsidian outcrop in the immediate vicinity of the site, the excavators hypothesized that the artefacts must have been derived from sources in southern Afar (Clark and Williamson 1984, 49), where there are a number of rhyolite flows. On the basis of the fauna found

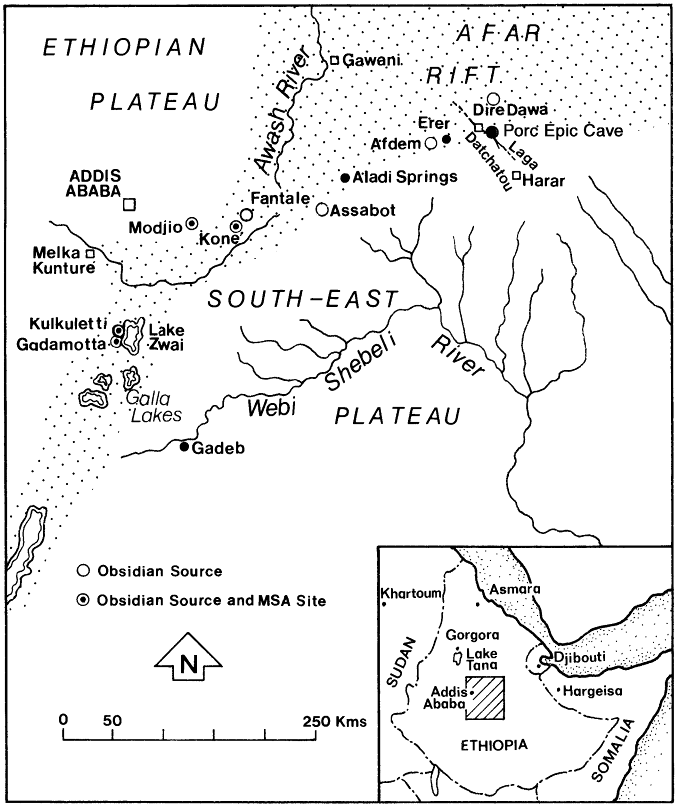

Figure 1 *A map showing the location of Porc Epic and some relevant obsidian sources (after Clark and Williamson 1984).*

together with the lithic assemblage, the excavators of the site infer that Porc Epic was a seasonal hunting camp that was occupied during fall and/or spring. Obsidian hydration dates bracket the occupation of the site between 61 000 and 77 500 years BP (Michels and Marean 1984).

Thanks to the permission given to us from the ARCCH, the Ethiopian government agency that oversees palaeontological/archaeological investigations, we characterized 31 obsidian artefacts from the site that were stored at the National Museums of Ethiopia. We have also analysed samples from obsidian geological sources from as far north as the Afar Rift to as far south as the southern edge of the Main Ethiopian Rift Valley. This has allowed the identification of numerous obsidian sources that, to our knowledge, were previously unknown archaeologically.

The obsidian sources from which samples were collected range in age from as early as 5.6 mya (e.g., Assebot; Tadiwos *et al.* 1998) to as recent as 25 kya (e.g., Korbetti; Giday *et al.* 1992), indicating the availability of these sources for utilization by populations from ancient times to the very recent past. The sources were either in the form of lapilli (e.g., the source of Guddo), silicic lava flows (e.g., Aluto, Bede Gebabe, etc.) or found as obsidian fiamme as embedded marekanites in a rhyolite ash flow tuff, such as those found at Sodoma Misra.

We have also collected samples from the geological sources of obsidian that have previously been described in the petrological literature, because these investigations contained very few obsidian geochemical data and do not state the quality of the obsidian. Because of concern about intra-source elemental variability (Hughes 1994, 1998; Shackley 1998c; Ericson and Glascock 2004), samples from each source were collected from different localities within the source. We also examined the quality of the stone for tool production, as some of the sources contained non-artefact quality material, and those with the best flaking properties were collected for analysis. Attention was also paid to colour during collection as, in some cases, this is a useful indicator of provenance (e.g., Bettinger *et al*. 1984; Tykot 1998). However, 'colour provenancing' is useful in circumstances where there are few sources. Moreover, different-coloured obsidians may sometimes have identical elemental compositions (Darling and Hayashida 1995; Tenorio *et al*. 1998). This, coupled with the abundance of obsidian sources in Ethiopia with similar colours, makes 'visual provenancing' of limited utility. In this case, undertaking elemental compositional analysis becomes imperative, as this is a very effective means of sourcing archaeological artefacts. Therefore, we instrumentally characterized 31 MSA artefacts from the site of Porc Epic and geological sources that form the basis of this discussion.

ANALYTICAL PROCEDURE

Instrumental characterization of artefacts and sources was undertaken using EDXRF (for both artefacts and sources) and WDXRF (for some sources).

All archaeological samples were analysed whole. The results presented here are quantitative in that they are derived from 'filtered' intensity values ratioed to the appropriate X-ray continuum regions through a least-squares fitting formula, rather than plotting the proportions of the net intensities in a ternary system (Schamber 1977; McCarthy and Schamber 1981). Or more essentially, these data, through the analysis of international rock standards, allow for inter-instrument comparison with a predictable degree of certainty (Hampel 1984).

The trace element analyses were performed in the Archaeological XRF Laboratory, Department of Earth and Planetary Sciences, University of California at Berkeley, using a Spectrace/ThermoNoran™ QuanX energy-dispersive X-ray fluorescence spectrometer. The spectrometer is equipped with an air-cooled Cu X-ray target with a 125 μm Be window, an X-ray generator that operates in the range 4–50 kV/0.02–2.0 mA at 0.02 increments, using an IBM PC based microprocessor and WinTrace™ reduction software. The X-ray tube is operated at 30 kV/0.14 mA, using a 0.05 mm (medium) Pd primary beam filter in an air path at 200 s livetime to generate X-ray intensity Kα-line data for the elements titanium (TiO_2), manganese (MnO) and iron (as $Fe_2O_3^T$) and, using the Lα line, rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr) and niobium (Nb). Major and trace element intensities were converted to concentration estimates by employing a least-squares calibration line established for each element from the analysis of international rock standards certified by the National Institute of Standards and Technology (NIST), the United States Geological Survey (USGS), the Canadian Centre for Mineral and Energy Technology and the Centre de Recherches Pétrographiques et Géochimiques in France (Govindaraju 1994). Line fitting is linear (XML) for all elements except Fe, where a derivative fitting is used to improve the fit for the high concentrations of iron and thus for all the other elements. Further details concerning the petrological choice of these elements in obsidian are available in Shackley (1992, 1995, 1998a); see also Mahood and Stimac (1990) and Hughes and Smith (1993). Specific standards used for the best fit regression calibration for elements Ti through Nb include G-2 (basalt), AGV-1 (andesite), GSP-1 and SY-2 (syenite), BHVO-1 (hawaiite), STM-1 (syenite), QLO-1 (quartz latite), RGM-1 (obsidian), W-2 (diabase), BIR-1 (basalt), SDC-1 (mica schist), TLM-1 (tonalite), SCO-1 (shale)—all US Geological Survey standards—BR-N (basalt) from the Centre de Recherches Pétrographiques et Géochimiques in France, and JR-1 and JR-2 (obsidian) from the Geological Survey of Japan (Govindaraju 1994).

We also analysed a few samples from each source using a Philips PW2400 sequential wavelength-dispersive X-ray spectrometer, also in the Department of Planetary and Earth Sciences, University of California at Berkeley, for source standard obsidian and minor and trace elements for some archaeological and source specimens. This crystal spectrometer uses specific software written by Philips (SuperQ/quantitative) for the elements of interest. Sample selection is automated and controlled by the Philips software. We used this instrument to check instrumental variation, but as the results from this spectrometer agree with those of EDXRF, we report here the results from the latter. Further discussion of the Phillips instrumental setting is available in Shackley (1998a).

The data from the WinTrace software were translated directly into Excel for Windows for manipulation and then on into SPSS for Windows for statistical analyses. In order to evaluate these quantitative determinations, machine data were compared to measurements of known standards during each run. RGM-1 was analysed during each sample run for obsidian artefacts and sources to check the machine calibration, and is included in Table 1.

RESULTS AND DISCUSSION

Ten elements were measured using these instruments and are here expressed both as wt% (TiO_2, MnO and total iron as $Fe_2O_3^T$) and as ppm (Zn, Ga, Rb, Sr, Y, Zr and Nb). The elemental compositions of both the artefacts and probable sources are presented in Table 1 and plotted in Figures 2–4.

Table 1 shows results of EDXRF characterization of archaeological samples from Porc Epic and source compositions from Ayelu, Assebot and Kone. The data in the table and Figures 2–4

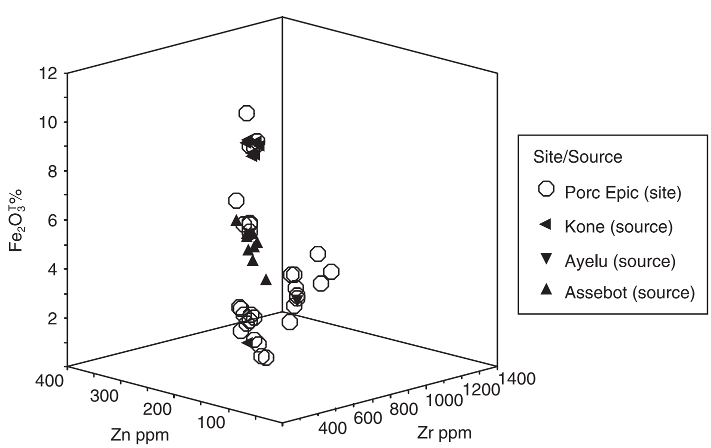

Figure 2 *The $Fe_2O_3^T$, Zn and Zr three-dimensional plot for the Porc Epic artefacts and the geological sources.*

Table 1 *The elemental composition of Porc Epic and the geological sources of Ayelu, Kone, and Assebot*

Sample number	*Location*	*TiO_2*	*MnO*	*$Fe_2O_3^T$*	*Zn*	*Ga*	*Rb*	*Sr*	*Y*	*Zr*	*Nb*
PE-1	Porc Epic	0.50	0.33	8.61	256	30	140	20	107	813	134
PE-2	Porc Epic	0.54	0.38	9.72	287	28	151	15	113	866	152
PE-3	Porc Epic	0.21	0.04	2.34	239	24	185	16	171	687	178
PE-4	Porc Epic	0.19	0.04	1.99	215	29	167	18	159	643	155
PE-5	Porc Epic	0.52	0.33	8.63	266	31	142	17	106	820	148
PE-6	Porc Epic	0.28	0.04	2.16	112	26	157	36	95	404	105
PE-7	Porc Epic	0.24	0.10	3.01	146	24	97	36	89	702	97
PE-8	Porc Epic	0.25	0.08	3.54	260	26	172	16	113	1180	94
PE-9	Porc Epic	0.22	0.10	3.18	150	25	108	36	91	735	110
PE-10	Porc Epic	0.16	0.04	2.13	215	29	163	9	162	691	172
PE-A	Porc Epic	0.22	0.05	2.96	203	22	149	12	99	1025	103
PE-B	Porc Epic	0.30	0.22	5.43	269	31	128	15	115	823	144
PE-C	Porc Epic	0.17	0.04	2.12	235	30	168	12	163	690	165
PE-D	Porc Epic	0.19	0.05	2.05	67	23	162	28	54	308	39
PE-E	Porc Epic	0.19	0.04	2.42	243	32	178	12	165	689	165
PE-F	Porc Epic	0.26	0.09	3.01	87	24	129	64	56	505	75
PE-G	Porc Epic	0.16	0.03	2.07	186	29	161	15	140	523	155
PE-H	Porc Epic	0.31	0.24	6.08	302	30	135	13	120	852	138
PE-I	Porc Epic	0.30	0.22	5.47	263	30	123	18	123	805	132
PE-J	Porc Epic	0.17	0.05	2.23	220	28	169	9	169	683	163
PE-K	Porc Epic	0.23	0.06	3.23	211	27	155	17	105	1108	104
PE-L	Porc Epic	0.29	0.20	5.33	278	25	133	16	112	823	126
PE-M	Porc Epic	0.21	0.05	2.21	126	27	155	28	90	425	105
PE-N	Porc Epic	0.47	0.34	8.87	253	31	137	9	100	819	150
PE-O	Porc Epic	0.27	0.11	3.58	157	25	111	29	96	749	101
PE-P	Porc Epic	0.24	0.10	3.33	152	26	105	29	96	739	105
PE-Q	Porc Epic	0.24	0.09	3.60	202	29	122	11	104	870	125
PE-R	Porc Epic	0.24	0.12	3.57	208	30	127	11	105	874	122
PE-S	Porc Epic	0.31	0.19	5.13	263	29	125	16	117	811	138
PE-T	Porc Epic	0.20	0.05	2.09	75	21	167	33	53	310	42
PE-U	Porc Epic	0.16	0.04	2.03	220	31	171	10	161	675	180
2C78-78*	Ayelu	0.19	0.09	3.14	150	N/A	110	25	89	729	97
KO-1	Kone	0.48	0.40	8.87	253	30	132	10	112	816	136
KO-2	Kone	0.24	0.06	2.42	103	24	35	12	40	321	30
KO-3	Kone	0.48	0.33	8.79	256	28	143	10	97	821	124
KO-4	Kone	0.48	0.32	8.36	257	25	133	20	101	809	131
KO-5	Kone	0.49	0.33	8.68	250	26	135	16	99	826	130
KO-6	Kone	0.52	0.35	8.90	263	29	130	9	99	796	147
KO-7	Kone	0.49	0.30	8.39	256	30	141	16	103	802	139
KO-8	Kone	0.48	0.31	8.29	257	28	140	15	100	804	140
KO-9	Kone	0.49	0.32	8.82	264	27	134	20	102	794	139
KO-10	Kone	0.50	0.30	8.34	254	28	132	25	103	813	127
ASEB-1	Assebot	0.26	0.17	4.65	244	29	122	11	115	775	126
ASEB-2	Assebot	0.31	0.20	5.36	292	29	134	8	119	822	137
AS-3	Assebot	0.30	0.18	5.10	254	29	139	20	117	793	134
ASEB-4	Assebot	0.25	0.14	3.65	202	26	114	7	99	718	127
ASEB-5	Assebot	0.30	0.18	4.49	252	26	118	11	104	767	115
AS-6	Assebot	0.33	0.19	5.06	257	28	139	14	109	794	125
ASEB-7	Assebot	0.29	0.18	4.95	264	32	132	14	109	792	128
AS-8	Assebot	0.30	0.19	4.98	271	26	133	18	113	815	128
ASEB-9	Assebot	0.29	0.19	4.82	245	28	125	12	117	793	126
ASEB-X	Assebot	0.30	0.16	4.24	235	30	115	16	112	742	122
RGM1-H1		28 ± 0.02	0.04 ± 0.00	2 ± 0.08	39 ± 2	20 ± 1	154 ± 3	113 ± 2	22 ± 4	224 ± 2	8 ± 3

* From Tadiwos (1995); values for Ga not available in the original report.

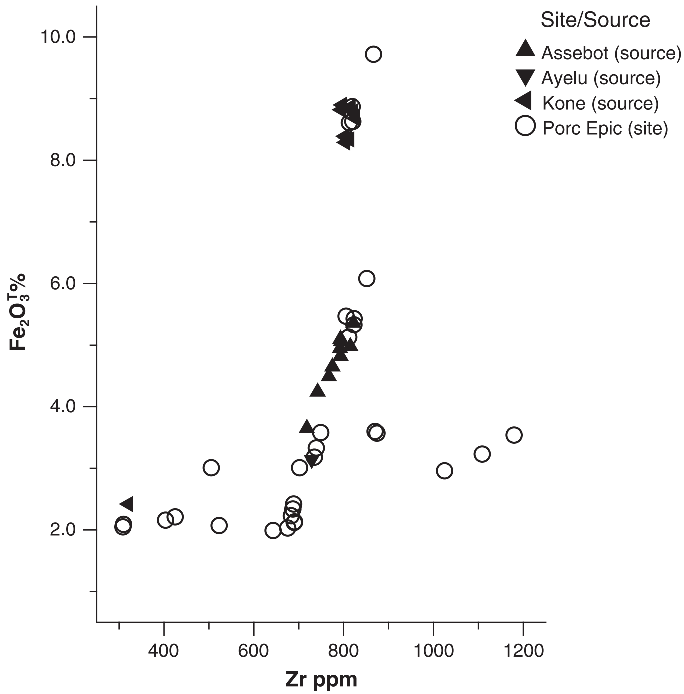

Figure 3 *The $Fe_2O_3^T$ and Zr two-dimensional plot for the Porc Epic artefacts and geological sources.*

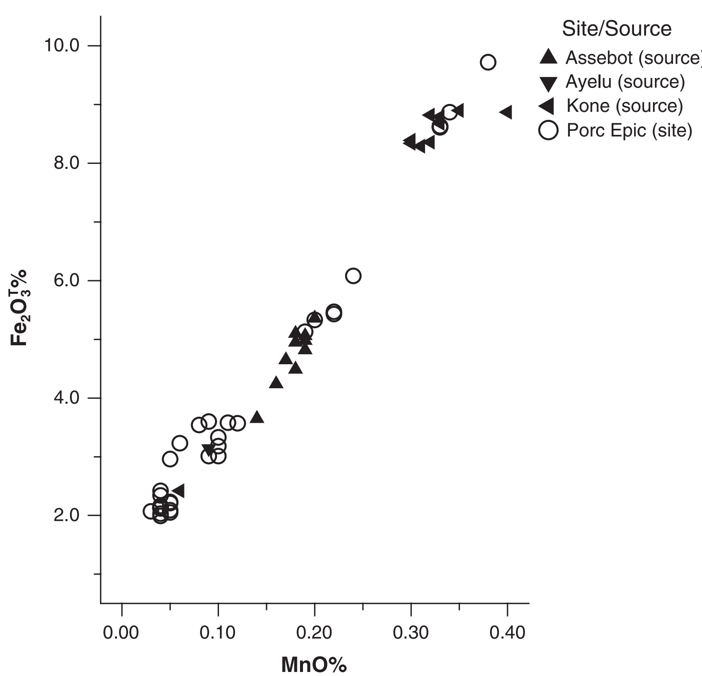

Figure 4 *The $Fe_2O_3^T$ and MnO two-dimensional plot for the Porc Epic artefacts and geological sources.*

clearly show that Porc Epic's artefacts had several sources of obsidian. We have identified three of these sources: Ayelu, Assebot and Kone (Fig. 1). The former is a silicic centre situated near the modern town of Gewane, some 150 km to the north-west of Porc Epic, a distance similar to that of Assebot, while Kone is situated some 250 km to the west.

Ayelu, a stratovolcano located at 10°08′N and 40°38′E, the summit of which is at 2145 m, belongs to the Wonji Group of the Quaternary Axial silicic volcanics of the Ethiopian Rift. Due to logistical and time constraints, we did not analyse samples from this source. However, our research in the petrological literature yielded an analysis of one obsidian sample (sample # 2C78-78, Table 1) as part of a Ph.D. dissertation (Tadiwos 1995). Its composition clearly matches those of some of the artefacts from Porc Epic. We plan on undertaking analysis of obsidians from this source in the near future.

Assebot, a source somewhat similar in distance to Ayelu, but located at 9°13′N and 40°46′E, is also another source for some of the artefacts of Porc Epic. It is part of the Mio-Pliocene volcanics that are aligned along the southern margin of the Afar Rift, with its obsidians dated to 5.6 mya by Tadiwos *et al.* (1998) and to 5.23 mya by Giday *et al.* (1992). Other obsidian sources that are even closer to Porc Epic, such as Meiso and Sodoma Misra Goro, have a totally different (peralkaline) chemical composition with extremely high values of Zr (≥ 2500), Y (≥ 274), Nb (≥ 367) and Zn (≥ 500), and can be eliminated from being potential sources.

Some Porc Epic artefacts were also being transported from Kone, located about 250 linear km away. Kone is a caldera complex characterized by cinder cones and craters, as well as abundant and stretched obsidian (mostly black, but also some green) flows along the badland eroded areas, which contain archaeological sites (Cole 1969; Kurashina 1978). Although most of the samples from Kone show elemental homogeneity, it is interesting to note that sample # KO-2 is a clear outlier (Table 1). We believe that it is a representative of a distinct geochemical variety of the Kone source area, but because it is just one sample we need to undertake further research to determine whether there is an intra-source variation.

As indicated above, the source of Kone was occupied during the MSA times. Similarities between Kone and Porc Epic artefacts have been surmised on technological and stylistic grounds (Clark and Williamson 1984; Clark 1988). Clark and Williamson (1984) also argue that Porc Epic was a seasonal hunting camp-site, hypothesizing its inhabitants to have been moving from the Afar Rift following the migration of game. We further hypothesize here that such technological similarity, coupled with the artefacts of Porc Epic being derived from Kone, can be taken as an indication that at least part of the obsidian from Porc Epic was transported by the people of Kone, assuming that the sites were contemporaneous. Alternatively, the inhabitants of Porc Epic may have transported the obsidians. Another equally possible explanation is that the obsidians from Kone reached Porc Epic through direct or intermediate trade or contact. Unfortunately, we do not have radiometric dates for Kone, and such inferences have to await further investigation of MSA sites that may be located between Kone and Porc Epic.

It is interesting to note that there are a number of obsidian sources that are located between Kone and Porc Epic that were not exploited by the inhabitants of Porc Epic. Of particular interest are the sources of Meiso and Sodoma Misra Goro, which contain good-quality material and are closer by far to Porc Epic than are the sources that we identified here. We have analysed 10 samples from each of these sources, but these were not represented in the lithic assemblage of Porc Epic, at least not in those archaeological samples that we analysed.

Porc Epic had other, as yet unidentified, sources. These 'unknown' sources are not represented in the source material that we characterized. Nor do they match those data found in the petrographic literature that are available to us. Our own characterization of geological obsidians from other sources has shown that there are obsidian sources in the Afar Rift (e.g., the sources of Asbole, Wuriandi'u and Guyah) with very close compositional similarity to some of the artefacts of Porc Epic, and it is not unreasonable to assume that some of the artefacts at Porc Epic may have been brought from this general area. Other possible sources (from which we could not sample, for reasons beyond our control) include the Mio-Pliocene silicic centres of Gara Gumbi, Gara Adi and Bora'at that lie in the northern part of the Main Ethiopian Rift Valley and the southern Afar Rift transition zone (Giday *et al.* 1992; Tadiwos *et al.* 1998). Of these, Bora'at is the closest source to Porc Epic, situated just 45 km or so away. Assuming that its obsidians are of artefact quality, its location in the proximity of Porc Epic and its date (on obsidian) of 4.53 mya (Giday *et al.* 1992) indicates its availability for exploitation by the inhabitants of the site.

CONCLUSIONS

Obsidian is an excellent raw material for stone tool production, and because of its source-specific chemistry, it is an ideal candidate for the tracing of its movement from the source to archaeological sites. Our main objective here was to chemically characterize the obsidian artefacts of Porc Epic, and we have determined that at least some of the artefacts were being transported from a distance as far as 250 linear kilometres away. This is in keeping with other previous investigations in East Africa that have demonstrated MSA movement of obsidian over similar distances from sources to archaeological sites (Merrick *et al.* 1994).

However, some other issues remain unresolved. Assuming that they were present at the time, why were the sources closer to Porc Epic not utilized? Was it because these were unknown to the inhabitants of the cave, or did certain social constraints prevent the use of these sources? Or was there some sort of control of raw material that precluded the inhabitants of Porc Epic from getting obsidian from these sources? Future studies should illuminate the development of exchange systems and spheres of interaction through the analysis of the geochemistry of sources and artefacts. We also believe that such long-distance movement of raw material, such as is the case with Porc Epic, linked to environmental records and other lines of archaeological evidence, is of relevance for the understanding of the emergence of modern human behaviour (McBrearty and Brooks 2000). An important point derived from this research is that modern *Homo sapiens* was already employing large procurement ranges, and/or extensive inter-group interactions, to procure raw material as early as, if not before, 77 000 years ago.

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