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The provenance of obsidian artefacts from the Middle Kingdom harbour of Mersa/Wadi Gawasis, Egypt, and its implications for Red Sea trade routes in the 2nd millennium BC

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ABSTRACT

This paper presents the results of the geochemical analysis carried out on the obsidian artefacts discovered at the archaeological site of Mersa/Wadi Gawasis, located along the Egyptian Red Sea coast, in between the modern cities of Safaja and Quseir. During the 12th and 13th Dynasties of Egypt the site hosted a port city from where the Egyptian expeditions set sail directed to the south, on both edges of the Red Sea. Six obsidian artefacts collected during the 1970s' research carried out at the site by A. Sayed, were geochemically analysed, together with five geological samples from the obsidian Kusrale source in Eritrea. The major element concentrations were determined by SEM-EDS analysis and the trace element concentrations were obtained by LA-ICP-MS method, a micro-destructive technique, capable of chemically characterizing the volcanic glass. A comparison of geochemical results obtained on the archaeological artefacts and geologic samples, together with the literature data on different geological obsidian outcrops from the Horn of Africa and the southwestern Arabian peninsula, allowed us to determine the provenance of the Mersa/Wadi Gawasis obsidian artefacts in both the Kusrale source of Eritrea, and the volcanic area of Dhamar Reda in Yemen. These results can provide further insights on ancient trade routes along the Red Sea during the early second millennium BC.

1. Introduction

Obsidian from southern Red Sea outcrops was imported into Egypt from the early 4th millennium BC onwards, as evidenced by its presence in the Naqada I (ca. 4000–3500 BC) and Naqada II burials (ca. 3500–3200 BC) (Zarins, 1989, 1990, 1996). Since each obsidian source has a distinct chemical fingerprint and the artefacts are chemically stable on an archaeological time-scale, the chemical characterisation of obsidian finds is central to studies of long-distance trade and the development of trade routes (e.g. Williams-Thorpe, 1995). The analysis of the few obsidian artefacts discovered at the pharaonic harbour of Mersa/Wadi Gawasis can thus shed new light on where this material was procured, in regions located further south, both in the Arabian peninsula and in the Horn of Africa.

Mersa Gawasis is located ca. 23 km south of Safaja and 50 km north of Quseir, on a fossil coral terrace 2 km south of the mouth of Wadi Gasus (Figs. 1–3). Its overall area covers 14 ha (550 × 250 m) and it is bordered to the east by the seacoast, and to the south and west by Wadi Gawasis. The site is one of three known pharaonic harbours along the Red Sea coast, which were in use during the Old and/or Middle Kingdom times, together with Ayn Soukhna and Wadi Al-Jarf (Tallet, 2015).

The site was first investigated in 1976 and 1977 by Abdel Monem A.H. Sayed (University of Alexandria). Thanks to the inscribed stelae he found, Sayed could identify the site as the harbour of *Saww*, which was in use during the 12th Dynasty. In 2001, the Italian-American Joint Archaeological Expedition (hereafter IAJAE), previously directed by Rodolfo Fattovich (University of Naples L'Orientale and ISMEO) and Kathryn Bard (Boston University), and more recently by the same Kathryn Bard and Andrea Manzo (University of Naples L'Orientale and ISMEO), started a new cycle of research at the site.

From absolute chronology and pottery types the main phase of use of Mersa/Wadi Gawasis can be set in both the early and late 12th Dynasty, and in the early 13th Dynasty (ca. 1985–1650 BC) (Bard and Fattovich, 2018: 31). Few excavated potsherds also hint to a possible

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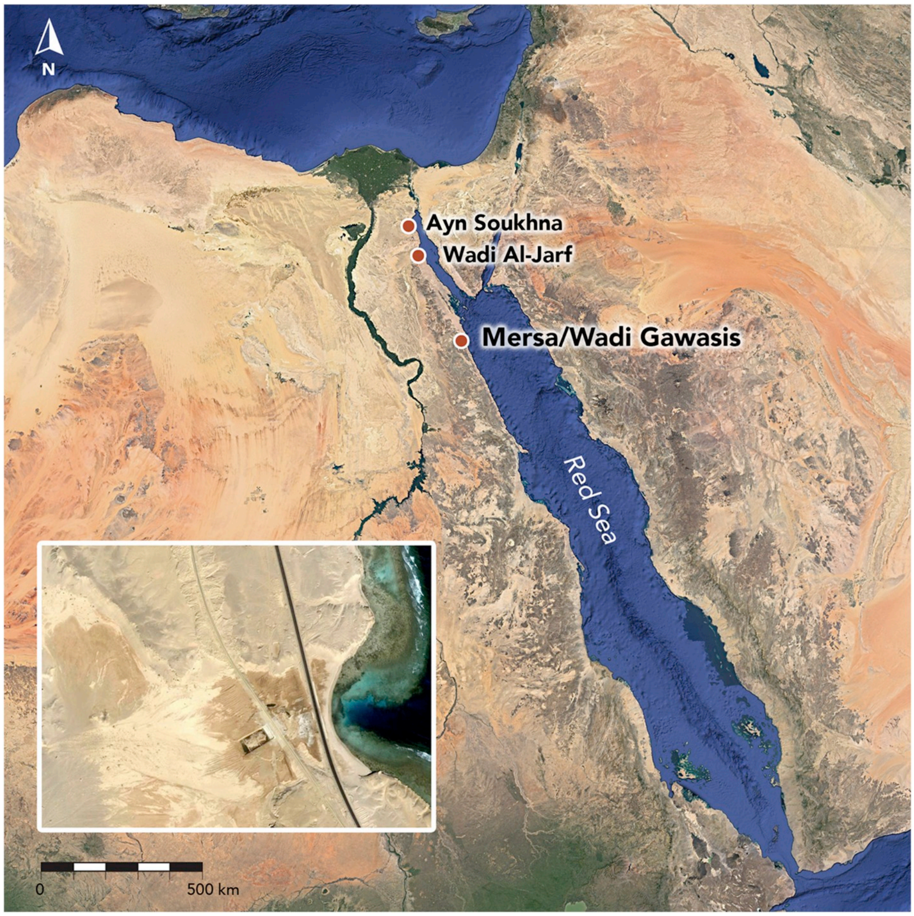

Fig. 1. Map of Egypt showing the location of the three Dynastic harbours of Mersa/Wadi Gawasis, Ayn Soukhna and Wadi Al-Jarf, and inset with the satellite image of Wadi Gawasis.

Fig. 2. Wadi Gawasis. View of the site (photo: E. Selby, IAJAE Archive).

use of the site during the late Old Kingdom/First Intermediate Period and late Second Intermediate Period/early New Kingdom (Manzo and Perlingieri, 2007: 110, 114–115).

The finding of several carved, round-topped stones, interpreted as anchors and fragments of cedar timbers belonging to ships, are clear evidence of the use of the site as a harbour for seafaring expeditions (Bard and Fattovich, 2007: 23). According to the textual evidence on stelae, cargo boxes, sealings and ostraca found at the site, Egyptian expeditions set sail from Mersa/Wadi Gawasis towards the legendary land of *Pwnt* and/or *Bi3 Pwnt* (the "mine/s" of Punt) and returned there at the end of their journey (Bard and Fattovich, 2018: 62). Investigations carried out at Mersa/Wadi Gawasis have shed new light not only on how the expeditions to *Pwnt/Bi3 Pwnt* were organized in the early second millennium BC, along with the exploitation of both the Red Sea coast and regions of the Eastern Desert, but also on their economic, ideological and social implications.

In the present study, we geochemically characterised six obsidian artefacts recovered at Mersa/Wadi Gawasis and five obsidian geological samples from the Kusrale source, Eritrea, and compared the results with those from the data available in the literature on samples from various regions of the Horn of Africa and the Arabian Peninsula. Although the major-element composition of obsidian from different origins may present some variability that could help to identify their geological provenance, trace element concentrations, which vary strongly from source to source, allow a sound discrimination of sources and identification of obsidian raw material used for artefact manufacturing (Barca et al., 2019a). In particular, LA-ICP-MS analysis allows a complete geochemical characterisation of the specimens in terms of trace (including rare earth) elements, highlighting different chemical behaviours and fingerprints among the samples (Barca et al., 2007, 2019b).

Our investigation on the provenance of the obsidian artefacts from Mersa/Wadi Gawasis is important also for the implication it has to better understand the trade routes along the Red Sea coasts during the early second millennium BC, and for the contribution it can yield in the still-ongoing debate about the location of the land of Punt, the legendary region from which a number of exotic materials and resources where imported. Several hypotheses about the exact geographical location of the land of Punt have been proposed over the years, and the most plausible candidates seem to be the regions of eastern Sudan, northern Ethiopia, Eritrea, and southern Arabia (Fattovich, 1996; Kitchen, 1993, 2004; Meeks, 2003).

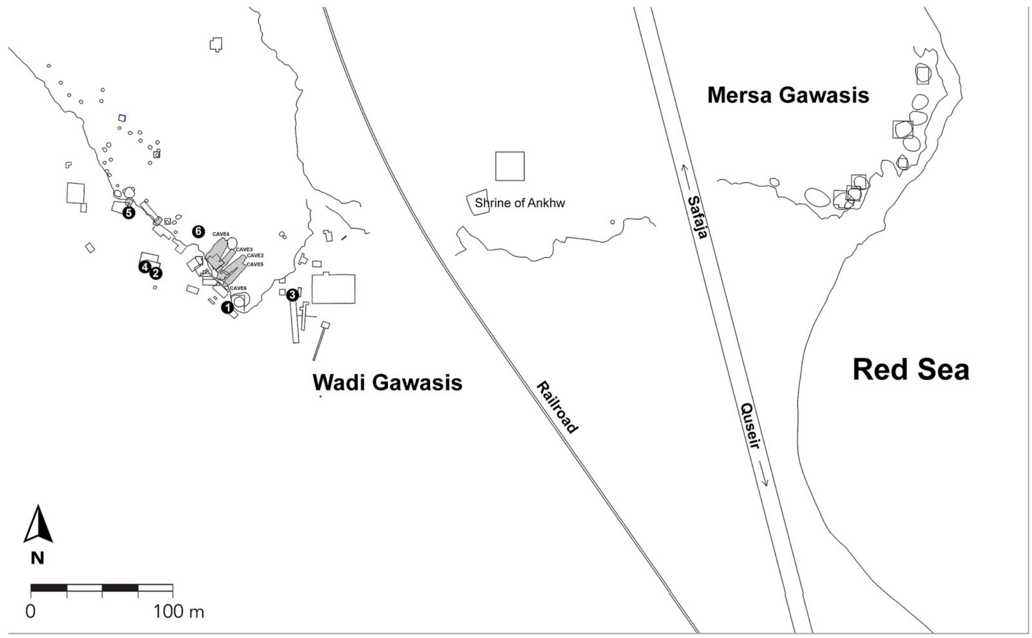

Fig. 3. Mersa/Wadi Gawasis. Topographic map of the site showing the location where the six obsidian artefacts were discovered (IAJAE Archive).

2. Materials

Although the team of the University of Alexandria firstly noted the presence of lithic artefacts at Mersa/Wadi Gawasis, the first systematic study of the stone tool assemblage from the site took place in the framework of the IAJAE research (Lucarini, 2007a, 2007b, 2008). The lithic complex comprises ca. 3500 artefacts mostly made of chert, a material widely available in the form of pebbles at the bottom of the Wadi Gawasis. The remaining items are manufactured in quartz and, in much lower numbers, obsidian.

The first significant group of artefacts comes from the western margin of the coral terrace, which is also the core area of the site: an area in which eight human-made caves/galleries were excavated and used for storage (Bard and Fattovich, 2018). On the narrow beach below these caves and next to the palaeo-bay, the “production area” was excavated (in trenches WG 19/25/26/27/44). This was where production activities took place, especially baking bread in cylindrical moulds, as can be inferred by the associated waste and analysis of the ceramic artefacts found there (Arpin et al., 2007: 73–77). The production area was used in five different phases: Phase 1 dates to the early 12th Dynasty, while the other phases of use all date to late 12th to early 13th Dynasties (Arpin et al., 2007: 75–77).

The lithic assemblages coming from this area are almost uniquely marked by the presence of *debitage* elements, including flakes, which are the most numerous class; laminar products are instead rather low in number. The presence of a number of core trimmings, together with a large quantity of knapping debris, provides a clear indication of the prolonged core exploitation in some knapping areas, also confirmed by the presence of a few hammerstones (Lucarini, 2007a, 2007b, 2008).

The assemblage comprises well finished tools coming from the upper layers of the stratigraphic sequence together with less standardized, i.e., worse manufactured, ones. The first group includes drills on flakes, bifacial knives and other tools characterized by continuous retouch, often produced on large laminar blanks. The second group consists instead of opportunistic tools, such as different sorts of scrapers, possibly related to the processing and salvaging of wood (Lucarini, 2007a: 211). The high quantity of processing waste from wood found in trench WG 55 (above the production area, on the coral terrace slope and outside the entrance to Cave 7), the same one from which the largest number of lithic artefacts comes from, may corroborate the hypothesis that such scrapers were only roughly knapped and then utilized for scraping and cleaning ship timbers. Barnacle shells with wood impressions were also excavated in this unit (Carannante et al., 2014: 129). Artefacts at Mersa/Wadi Gawasis showing a higher manufacturing standard, such as bifacial knives and blades with continuous retouch, may instead have been used as multipurpose tools, mainly for cutting and scraping activities. should be corrected like this: Artefacts at Mersa/Wadi Gawasis showing a higher manufacturing standard, such as bifacial knives and blades with continuous retouch, may instead have been used as multipurpose tools, mainly for cutting and harvesting activities (Lucarini, 2008).

The southern slope of the fossil coral terrace, in WG 18, has yielded the second richest lithic assemblage, also associated with ceramics of the Middle Kingdom (Lucarini, 2007a: 211). However, technological and typological traits that characterise these lithics differ greatly from those belonging to the previous group. In this case, the microlithic index is preponderant as is the presence of types that can be associated with the exploitation of fish resources. In the lower layers of WG 18, a group of microlithic drills unearthed together with fish bones and shells (some of which were pierced) seems to suggest that these tools were used to manufacture bead items (Lucarini, 2007a: 211).

The same layers of the sequence have also yielded fragments of grinding stones associated with a concentration of shells and fish remains (Lucarini, 2007a: 211–212), pointing to a likely use of such tools in the processing of fish resources. This hypothesis may also be corroborated by Greek historian Agatharchides of Cnidus, who, in his treatise *On the Erythraean Sea* (Diodorus, III, 7), describes how some groups which settled along the Red Sea coasts during the Hellenistic period, the so-called “fish eaters” (*Ἰχθυοφάγοι*), used to grind dried fish together with seeds (Burstein, 1989: 68–89).

Artefacts manufactured on obsidian are scanty; only 12 artefacts were found at Mersa/Wadi Gawasis (six were found by the IAJAE, and another six artefacts were discovered during the fieldwork conducted by A. Sayed). Considering the low number of artefacts found at the site, and that obsidian was a highly desired raw material in Egypt, it can be assumed that the obsidian blocks or preliminarily shaped cores arriving, via sea, to Mersa/Wadi Gawasis were destined for use in the Nile Valley. Nevertheless, the finding of these 12 small items, which resulted mainly from knapping activities and core reduction stages, confirms that obsidian was also used to a small extent at the site; as presented above, the large lithic assemblages found in all the excavation trenches confirm that the inhabitants of the region were used to exploiting different types of stones for manufacturing tools to be used in different production activities. Due to the exportation ban on artefacts imposed by the Egyptian authorities, only the six items discovered by A. Sayed, which were already stored at the University of Naples L'Orientale, were analysed, and are therefore the focus of this study. These obsidian artefacts were the only lithics collected at the site by A. Sayed in the 1970s. With the hope of getting more precise information about their provenance, and being aware that R. Fattovich and other colleagues in Naples were involved in fieldwork activities in different regions of the southern Red Sea, where several obsidian sources are located, A. Sayed brought the artefacts to Naples in 1981 when he was invited to give a lecture about his excavations at Mersa/Wadi Gawasis. Since then, the six obsidian items have been stored in the Laboratory of African Archaeology, and more recently in the storerooms of the University Museum "Umberto Scerrato". A. Sayed provided a sketch map and field notes, which specified the circumstances relating to and the exact areas of the discovery (Fig. 3).

The techno-typological description and exact provenance of these six items is reported here:

- **Artefact 1:** Chunk. *Provenance:* mid-slope terrace corresponding to the location of the stela of Antefoker (Fig. 4a).
- **Artefact 2:** Sidescraper on a tertiary flake from a multiple platform core. Obverse, flat, and marginal retouch occurring on the left distal end. Measurements: 30 × 27 × 6 mm. Weight: 6.40 g. *Provenance:* wadi, area with burned spots, northwest of the Antefoker stela. This corresponds to the area where units WG 19/25/26/27 were excavated by the IAJAE (see Arpin et al., 2007: 73–76) (Fig. 4b).
- **Artefact 3:** Tertiary flake fragment from a multiple platform core. Unidentifiable platform; the bulb is diffuse. Measurements: 17 × 21 × 4 mm. Weight: 1.00 g. *Provenance:* base of the southern slope of the coral terrace, southwest of the Ankhu shrine, and associated with a concentration of shells in a deeply eroded gulley. This location corresponds to the shell concentrations recorded by the IAJAE in excavation unit WG 18 (see Arpin et al., 2007: 52–53) (Fig. 4c).
- **Artefact 4:** Multiple platform core fragment. Unidentifiable percussion platforms; the core is highly exploited. Measurements: 22 × 23 × 12 mm. Weight: 4.80 g. *Provenance:* wadi, area with burned spots northwest of the Antefoker stela. This location corresponds to the area where excavation units WG 19/25/26/27 were excavated by the IAJAE (see Arpin et al., 2007: 73–76) (Fig. 4d).
- **Artefact 5:** Tertiary blade from a single platform core. The platform type is unfaceted and shape is lenticular; bulb is diffuse. Both sides show use retouch. Measurements: 42 × 13 × 5 mm. Weight: 3.50 g. *Provenance:* mid-slope terrace northwest of the Antefoker stela (Fig. 4e).
- **Artefact 6:** Core side from a single platform core. The platform is unfaceted and irregular in shape; bulb is flaked. Measurements: 26 × 44 × 12 mm. Weight: 10.10 g. *Provenance:* coral terrace, surface collection.

If we consider the area where the obsidian artefacts were collected in light of the more recent investigations conducted at the site by the IAJAE, we can confirm that all the artefacts are likely to be related to the Middle Kingdom phase of use of the site, given that a possible assemblage dating to the late Old Kingdom/First Intermediate Period was found only inside Cave 1 (Manzo and Perlingieri, 2007: 121), while evidence from the early New Kingdom is limited to a few spots close to the entrance of the cave complex, on a mid-slope terrace on the western side of the coral terrace (Manzo and Perlingieri, 2007: 121).

In addition to the six archaeological finds, we also present the results of the analysis carried out on five geological samples (Kus1-5), which come from the Kusrale obsidian outcrops in Eritrea (Fig. 5).

3. Analytical methods

The geochemical analyses of the archaeological finds were conducted in the laboratories of the Department of Biology, Ecology and Earth Sciences, University of Calabria, using a Scanning Electron microscope FEG (field emission gun) Quanta 200 F (FEI/Philips) equipped with an EDS system (EDAX GENESIS 4000 with Si/Li detector) to determine the major element composition. SEM/EDS analyses were carried out using a defocused beam in order to minimize loss of alkali and an accelerating voltage of 20 kV. Quantitative analyses were obtained through the internal correction system. Precision was better than 1%. Trace element composition was determined by Inductively Coupled Plasma Mass Spectrometry with Laser Ablation (LA-ICP-MS). The LA-ICP-MS equipment is an Elan DRCe (PerkinElmer/SCIEX), connected to a New Wave UP213 solid-state Nd-YAG laser probe (213 nm). Samples were ablated by laser beam in a cell, and the vaporised material was then flushed (Gunther and Heinrich, 1999) to the ICP, where it was quantified. Each ablation crater was generally 50 μm in diameter and nearly invisible to the naked eye. The procedures for data acquisition were those normally used in the Mass Spectroscopy Laboratory of the Department of Biology, Ecology and Earth Sciences, University of Calabria (Barca et al., 2007, 2008, 2012). Three-point analyses were only carried out on the portions of archaeological fragments showing no roughnesses or alterations, and were sufficient to assign provenance. In order to remove any traces of soil, each find was cleaned by ultrasound in Millipore water. Calibration was performed on glass reference material SRM 612–50 ppm by NIST (National Institute of Standards and Technology) in conjunction with internal standardisation, applying SiO_2 concentrations (Fryer et al., 1995) from SEM-EDS analyses. In order to evaluate possible errors within each analytical sequence, determinations were also made on the SRM 610–500 ppm by NIST and on BCR 2G by USGS glass reference materials as unknown samples, and element concentrations were compared with reference values from the

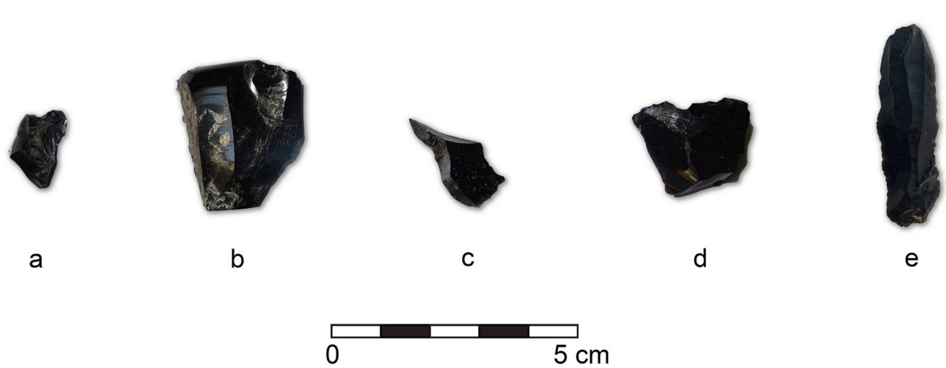

Fig. 4. Wadi Gawasis. Obsidian artefacts from the 1976–77 excavations (a: Artefact 1 - chunk; b: Artefact 2 - Sidescraper on flake; c: Artefact 3 - Flake from a multiple platform core; d: Artefact 4 - Fragment of a multiple platform core; e: Artefact 5 - Blade from a single platform core) (photo: G. Lucarini, IAJAE Archive).

Fig. 5. Map with location of Kusrale (Eritrea) and all the others obsidian outcrops in the Horn of Africa and southern Arabian peninsula, which are mentioned in the text.

literature (Gao et al., 2002). Accuracy, as the relative difference from reference values, was always better than 10%, and most elements plotted in the range ± 5% (see Table 1).

4. Results and discussion

Table 2 lists the major element composition, determined by SEM-EDS, for the archaeological specimens studied; each quantity in the table represents the mean value of three analyses.

The major element concentrations show little differences among the six archaeological artefacts. Five show a typical rhyolitic composition (Le Bas et al., 1986) with a SiO_2 content ranging from 73.42 wt% to 75.26 wt%; only artefact 2 shows a lower silica content (68.76 wt%).

Although the major element content of obsidian from different localities may show some variability and generally could help distinguish between different geological sources, trace element analysis is widely used to discriminate between the sources and usually allows the identification of the geological provenance of archaeological finds (Barca et al., 2007, 2008).

Table 3 lists the composition of rare earth and other trace elements, determined by LA-ICP-MS, for the archaeological finds; each trace element quantity in the table represents the mean value of three analyses.

The main potential sources for obsidian found in Egypt can be traced to two different major volcanic systems: obsidian from the Near East (including Cappadocia, Taurus and Armenia), which erupted in a collisional tectonic setting; and East African obsidian produced by an intraplate volcanism (Bavay et al., 2000). The different tectonic settings determine different geochemical features of the two groups of obsidian and the Th/Ta ratio was proposed by Bavay et al. (2000) as the discriminating parameter to distinguish between intraplate and subduction derived obsidian. In a first approach, the limit value to separate these two systems was set at Th/Ta = 5.

All archaeological artefacts recovered at Mersa/Wadi Gawasis show Th/Ta ratios less than 5, suggesting a possible provenance from the Ethiopian, Eritrean, Yemeni or southwestern Saudi Arabia obsidian sources (Fig. 5).

In recent years information about Ethiopian and Yemeni geological sources of obsidian has increased significantly (Barca et al., 2012; Khalidi et al., 2010; Negash and Shackley, 2006; Negash et al., 2006, 2011; Poupeau et al., 2004). Information about Eritrean obsidian sources, however, is limited (Beyin, 2009; Giménez, 2014).

The study by Khalidi et al. (2010), after the pioneering work of Francaviglia (1990), provides a detailed reconstruction of the volcanological history of the Red Sea region together with the geochemical characterisation of the major obsidian sources in the Yemeni highlands and of the Afar1 Ethiopian source. In the studies by Khalidi et al. (2010) and Barca et al. (2012) the different Yemeni obsidian sources were chemically characterised by using LA-ICP-MS; the data represent a key database of reference for assigning the provenance of obsidian from

Table 1
Analyses by LA-ICP-MS of BCR-2G and NIST SRM 610 standard glass (in ppm); 1s: standard deviation. Comparison between literature data (Gao et al., 2002) and results from the present study.

	BCR-2G					NIST-SRM610				
	Gao et al. (2002)		This study[a]		Accuracies[b]	Gao et al. (2002)		This study[a]		Accuracies[b]
	Concentrations	1s	Concentrations	1s		Concentrations	1s	Concentrations	1s	
Rb	51	3	49	0.6	3.82	431	6	427	21	0.81
Sr	321	6	333	4.9	−3.78	497	5	519	7	−4.43
Y	31	2	30	1.2	3.34	450	7	479	10	−6.44
Zr	167	8	165	6.8	1.23	439	7	434	16	1.13
Nb	10.9	0.6	11	0.9	2.20	420	5	443	6	−5.48
Ba	641	14	635	12.5	0.91	425	6	445	13	−4.74
La	25	1	23.8	2.2	4.83	457	6	477	18	−4.27
Ce	52	2	52.2	2.3	−0.31	448	6	457	19	−2.05
Pr	6.3	0.4	6.2	0.6	1.16	430	5	448	22	−4.24
Nd	27	1	25.8	1.0	4.32	430	5	447	18	−3.98
Sm	6.3	0.5	6.4	0.4	−2.28	449	10	454	22	−1.11
Eu	1.91	0.09	1.9	0.05	−1.59	460	5	473	28	−2.78
Gd	6.5	0.6	6.8	0.4	−4.15	420	6	436	23	−3.90
Tb	0.95	0.07	0.99	0.1	−4.49	442	6	435	26	1.58
Dy	6	0.4	6.2	0.1	−4.11	426	7	466	21	−9.39
Ho	1.2	0.07	1.2	0.03	−2.39	448	8	453	19	−1.12
Er	3.3	0.2	3.5	0.09	−7.07	426	7	444	24	−4.24
Tm	0.46	0.04	0.48	0.02	−5.00	420	8	452	19	−7.60
Yb	3.2	0.3	3.1	0.21	2.29	460	9	493	24	−7.17
Lu	0.47	0.04	0.47	0.03	−0.28	435	9	456	16	−4.77
Hf	4.5	0.4	4.3	0.18	3.78	418	9	429	17	−2.63
Ta	0.63	0.06	0.61	0.04	3.17	376	8	408	12	−8.51
Pb	10.9	0.5	11.3	0.16	−3.36	413	7	442	19	−7.02
Th	5.5	0.2	5.8	0.22	−4.73	451	7	465	14	−3.03

[a] Values determined by LA-ICP-MS. Mean values of 15 determinations.
[b] Accuracies were calculated on data from Gao et al. (2002).

archaeological contexts. Similarly, the works of Negash and Shackley (2006), Negash et al. (2006, 2011), and Poupeau et al. (2004) provide geochemical information on Ethiopian obsidian.

Negash and Shackley (2006) characterized the 31 obsidian artefacts recovered in the Porc Epic cave in eastern Ethiopia, and which are now stored at the National Museum of Ethiopia. They compared these archaeological artefacts with samples from geological sources of obsidian from as far north as the Afar Rift and as far south as the southern edge of the Main Ethiopian Rift Valley. In particular, the geological sources analysed are those of Ayelu, Kone and Assebot. The various samples show a general elemental homogeneity, with the exception of sample KO-2 (Kone source), which is clearly an outlier and could be representative of a distinct geochemical variety of the Kone source area. The data in Negash and Shackley (2006) were obtained using energy dispersive X-ray fluorescence (EDXRF) and wavelength dispersive X-ray fluorescence (WDXRF) and the trace elements analysed are Zn, Ga, Rb, Sr, Y, Zr and Nb.

Poupeau et al. (2004) and Negash et al. (2006) studied the obsidian

Table 2
Major element concentrations of archaeological artefacts and geological samples determined by SEM-EDS.

The concentrations are in *wt%*.

	Item	SiO_2	Al_2O_3	FeO	MgO	Cl_2O	CaO	Na_2O	K_2O
Archaeological artefacts	1	73.42	11.85	3.49	0.32	0.48	1.06	4.76	4.62
	std	*0.52*	*0.13*	*0.04*	*0.008*	*0.01*	*0.02*	*0.06*	*0.05*
	2	68.76	14.12	1.86	4.33	1.70	0.70	5.08	3.45
	std	*0.64*	*0.16*	*0.03*	*0.15*	*0.06*	*0.01*	*0.05*	*0.21*
	3	74.35	12.11	3.06	0.24	0.32	0.27	5.42	4.23
	std	*0.55*	*0.14*	*0.02*	*0.01*	*0.01*	*0.01*	*0.41*	*0.28*
	4	75.26	10.69	3.96	0.38	0.22	0.32	4.89	4.28
	std	*0.67*	*0.22*	*0.04*	*0.02*	*0.01*	*0.02*	*0.16*	*0.27*
	5	74.24	11.67	3.50	0.44	n.d.	0.40	5.22	4.53
	std	*0.59*	*0.16*	*0.13*	*0.02*	-	*0.02*	*0.31*	*0.21*
	6	73.67	12.40	3.34	0.33	0.30	0.23	5.34	4.39
	std	*0.46*	*0.21*	*0.04*	*0.01*	*0.01*	*0.01*	*0.24*	*0.18*
Geological samples	Kus1	72.05	12.90	2.26	0.50	0.59	0.28	6.79	4.63
	std	*0.87*	*0.38*	*0.04*	*0.01*	*0.01*	*0.01*	*0.46*	*0.32*
	Kus2	73.85	11.58	3.81	0.43	0.60	0.32	3.85	5.56
	std	*0.74*	*0.25*	*0.03*	*0.006*	*0.007*	*0.005*	*0.025*	*0.31*
	Kus3	72.39	12.40	2.54	0.58	0.64	0.25	6.32	4.88
	std	*1.08*	*0.28*	*0.03*	*0.04*	*0.01*	*0.006*	*0.28*	*0.33*
	Kus4	72.94	12.61	2.66	0.53	0.43	0.33	6.18	4.32
	std	*0.76*	*0.32*	*0.04*	*0.03*	*0.01*	*0.01*	*0.35*	*0.25*
	Kus5	71.72	13.02	3.24	0.52	0.49	0.25	6.23	4.53
	std	*1.12*	*0.52*	*0.05*	*0.00*	*0.01*	*0.01*	*0.42*	*0.27*

Table 3
Trace element concentrations of archaeological artefacts and geological samples. Data obtained by LA-ICP-MS.

The values are in ppm. *std* = standard deviation.

	Archaeological artefacts						Geological samples				
	1	2	3	4	5	6	Kus1	Kus2	Kus3	Kus4	Kus5
Rb	119	115	132	198	136	122	140	127	139	131	110
std	*5.42*	*7.23*	*11.63*	*9.12*	*7.34*	*10.06*	*13.5*	*8.08*	*12.41*	*11.2*	*9.18*
Sr	2.23	37.4	3.13	0.28	2.22	1.77	0.69	6.99	0.87	0.52	3.49
std	*0.18*	*3.03*	*0.24*	*0.02*	*0.34*	*0.35*	*0.04*	*0.17*	*0.10*	*0.02*	*0.33*
Y	61.6	61.7	68.1	0.10	69.2	66.7	73.8	79.1	73.9	50.1	70
std	*1.98*	*4.38*	*2.88*	*0.01*	*2.72*	*4.62*	*6.13*	*4.04*	*4.06*	*7.81*	*4.62*
Zr	404	348	450	1711	462	437	548	551	548	356	460
std	*11.98*	*10.38*	*15.88*	*64.23*	*13.72*	*21.62*	*24.13*	*30.06*	*25.18*	*19.81*	*22.62*
Nb	136	101	149	301	158	148	167	173	163	136	158
std	*4.28*	*6.15*	*8.03*	*13.71*	*8.21*	*6.14*	*4.76*	*5.68*	*4.93*	*9.32*	*5.31*
Ba	7.99	847	11.36	2.15	9.47	7.82	11.06	514	12.16	10.36	107
std	*1.22*	*35*	*1.16*	*0.51*	*1.63*	*1.12*	*1.12*	*32*	*1.51*	*0.86*	*11*
La	84	63	97	138	95	87	108	106	100	84	93
std	*4.27*	*4.27*	*6.18*	*11.73*	*7.34*	*8.12*	*9.13*	*9.75*	*8.44*	*7.36*	*8.92*
Ce	157	125	182	289	177	159	187	175	180	162	168
std	*10.74*	*9.65*	*12.79*	*21.25*	*9.53*	*13.18*	*12.76*	*14.83*	*15.08*	*13.82*	*11.58*
Pr	17.1	13.3	19.7	34.7	18.4	17.1	19.3	19.2	19.2	16.5	18
std	*1.88*	*1.71*	*1.12*	*2.46*	*1.85*	*1.76*	*2.33*	*1.43*	*1.83*	*2.76*	*1.17*
Nd	63.3	49.5	73.2	122	67	63.5	69.3	71	71.4	56.9	65
std	*5.37*	*3.27*	*8.17*	*13.76*	*7.18*	*6.24*	*5.74*	*8.21*	*6.38*	*4.26*	*7.32*
Sm	11.5	9.23	11.5	26.1	11.9	12.7	12.7	15	13.4	8.59	12.3
std	*2.15*	*1.33*	*0.97*	*2.52*	*1.57*	*1.16*	*1.42*	*1.43*	*1.74*	*0.75*	*1.53*
Eu	0.61	1.09	0.24	0.99	0.72	0.17	0.83	1.33	0.77	0.71	1.16
std	*0.05*	*0.08*	*0.02*	*0.08*	*0.08*	*0.01*	*0.09*	*0.12*	*0.06*	*0.08*	*0.12*
Gd	11.5	9.32	12.8	24.1	11.9	9.42	11.4	11.8	11.4	8.35	12.7
std	*1.36*	*1.13*	*1.43*	*2.68*	*1.51*	*1.02*	*1.08*	*1.57*	*1.26*	*0.92*	*1.11*
Tb	1.74	1.47	2.29	4.28	1.67	1.66	2.05	2.08	2	1.44	1.97
std	*0.16*	*0.09*	*0.26*	*0.52*	*0.21*	*0.19*	*0.22*	*0.18*	*0.18*	*0.17*	*0.17*
Dy	12	10.6	12.6	26.8	11.1	12.5	10.83	11.8	12.8	8.97	11.9
std	*1.27*	*1.22*	*1.20*	*2.08*	*1.17*	*1.21*	*1.18*	*1.22*	*1.19*	*0.97*	*1.31*
Ho	2.42	2.16	2.94	5.42	2.48	2.34	2.16	2.84	2.62	1.94	2.28
std	*0.27*	*0.18*	*0.21*	*0.39*	*0.16*	*0.23*	*0.19*	*0.26*	*0.25*	*0.16*	*0.21*
Er	7.80	6.88	12.11	15.58	6.98	7.48	5.96	7.98	8.33	6.24	8.18
std	*0.67*	*0.96*	*1.42*	*1.57*	*0.71*	*1.11*	*0.62*	*0.74*	*0.85*	*0.42*	*0.78*
Tm	1.17	1.16	1.29	2.21	1.20	1.38	1.17	1.52	1.26	0.78	1.20
std	*0.14*	*0.09*	*0.13*	*0.18*	*0.11*	*0.14*	*0.14*	*0.13*	*0.14*	*0.08*	*0.11*
Yb	7.99	7.91	9.13	14.04	8.37	8.58	9.20	8.95	8.04	6.48	8.66
std	*0.71*	*0.73*	*1.04*	*2.07*	*0.76*	*0.83*	*0.87*	*0.81*	*0.75*	*0.77*	*0.85*
Lu	1.23	1.29	0.99	1.87	1.31	1.10	1.38	1.63	1.31	0.93	1.07
std	*0.12*	*0.13*	*0.09*	*0.14*	*0.14*	*0.12*	*0.12*	*0.15*	*0.12*	*0.09*	*0.09*
Hf	10.79	9.72	13.52	42	10.38	10.29	12.80	13.78	13.88	7.65	11.21
std	*1.15*	*1.05*	*1.23*	*2.74*	*1.07*	*1.05*	*1.41*	*1.26*	*1.28*	*1.02*	*1.02*
Ta	9.01	6.05	9.77	21.74	9.32	9.38	10.48	11.68	10.72	7.67	9.91
std	*0.87*	*0.57*	*0.88*	*1.97*	*0.87*	*0.74*	*1.21*	*1.42*	*1.07*	*0.62*	*0.89*
Pb	12.4	9.8	16.8	24	12.5	11.8	10.7	9.93	12.1	11.6	8.6
std	*1.15*	*0.78*	*1.73*	*2.08*	*1.17*	*1.16*	*1.08*	*0.87*	*1.17*	*1.17*	*0.87*
Th	15	11.3	18.4	36.4	16	15.9	17.5	18.0	17.9	11.9	16.0
std	*1.47*	*1.15*	*1.76*	*2.48*	*1.57*	*1.48*	*1.53*	*1.73*	*1.74*	*1.28*	*1.48*
Ratio Th/Ta	1.66	1.87	1.88	1.68	1.72	1.70	1.67	1.54	1.67	1.55	1.62

massif of Balchit of the Wachacha Formation, located on the western border of the Main Ethiopian Rift, in the Addis Ababa Rift Embayment. By using ICP-MS and considering the different trace element concentrations, Poupeau et al. (2004) identified four compositional groups.

Geochemical data on the geological obsidian of the Kusrale volcano outcropping on the coast of Eritrea are limited. Beyin (2009) and Giménez (2014) analysed only a few obsidian samples collected in the area of Kusrale. Giménez et al. (2015) demonstrate the geochemical similarity between Eritrean and Yemeni obsidian.

In the present study we have had the opportunity to analyse five geological samples collected in the outcrops of the Kusrale source. The major and trace element compositions, determined by SEM-EDS and LA-ICP-MS, are listed in Tables 2 and 3, respectively.

It is clear that a systematic study and a geochemical characterisation of all obsidian geological sources outcropping in these areas is necessary, but in recent years it has been difficult to work in Eritrea, and the current unstable political situation in Yemen has made field investigations there impossible.

The results of the analysis on the lithic artefacts from Mersa/Wadi Gawasis were compared with the geological data from the Yemeni and Ethiopian sources (Barca et al., 2012; Khalidi et al., 2010; Negash and Shackley, 2006; Negash et al., 2006; Poupeau et al., 2004), and with new Eritrean geological data. In the Sr *vs* Zr diagram (Fig. 6a), artefact 4 plots undoubtedly in the area of the Isbil volcano, indicating a definite Yemeni provenance. The remaining five obsidian finds can be separated into a group formed by artefacts 1, 3, 5 and 6 showing low contents of Sr (from 1.77 to 3.13 ppm), while artefact 2 shows higher concentrations of Sr (37.4 ppm).

In addition, the group formed by four obsidian artefacts (1, 3, 5 and 6) shows geochemical affinities with the Egyptian finds studied by Bavay et al. (2000), with the exception of sample MRAH E4833e (a rim fragment of a small obsidian vessel from Abydos), which displays

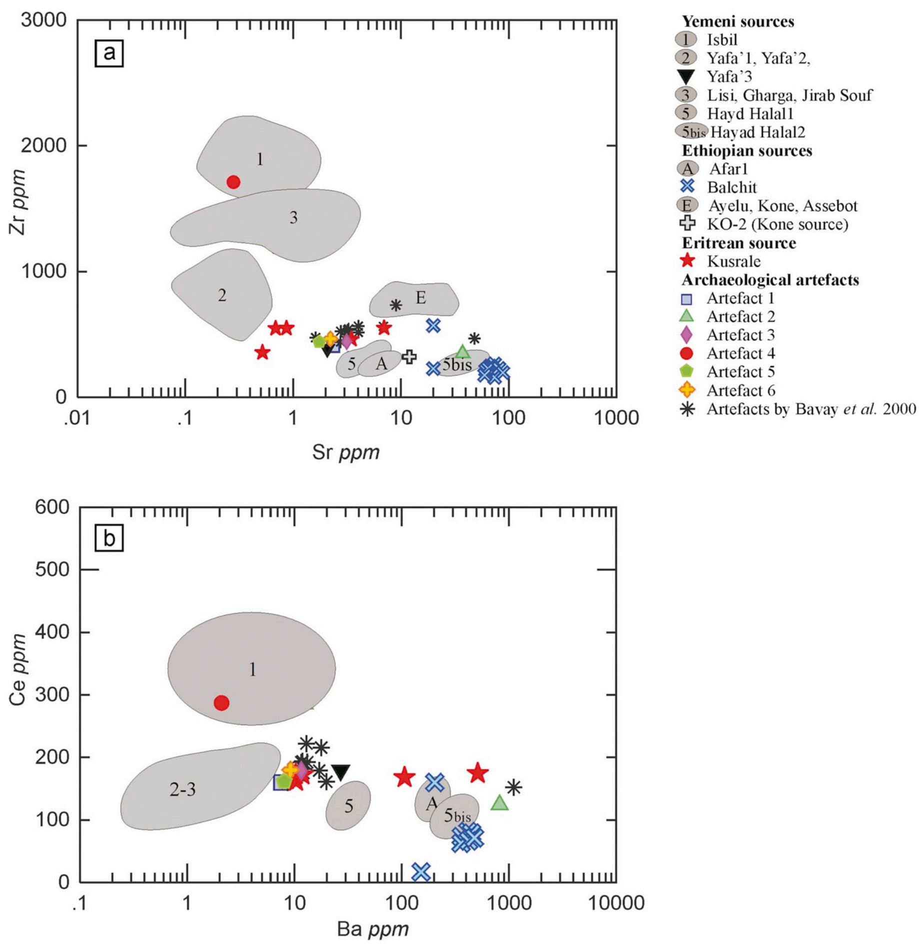

Fig. 6. a: Sr *vs* Zr; **b:** Ba *vs* Ce diagrams for the analysed archaeological artefacts compared with the Eritrean geological obsidian of Kusrale and with the dataset published in Barca et al. (2012), Khalidi et al. (2010), Negash and Shackley (2006), Negash et al. (2006), and Poupeau et al. (2004). The Egyptian artefacts presented in Bavay et al. (2000) are also plotted in the diagrams.

geochemical affinity with artefact 2. The diagram presented in Fig. 6a also shows that the group of four artefacts plots very near the geological sources of Yafa'3, Yemen (Khalidi et al., 2010) and Kusrale, Eritrea. On the other hand, artefact 2 overlaps with the area of Hayd Halal2, Yemen (Khalidi et al., 2010). The Sr *vs* Zr diagram (Fig. 6a) highlights the presence of clearly differentiated geological sources in Ethiopia; indeed, the Ayelu, Kone and Assebot obsidians show very different concentrations of zirconium compared to the Afar1 (Khalidi et al., 2010) and Balchit sources (Negash et al., 2006; Poupeau et al., 2004). The KO-2 sample, collected in the Kone geological area (Negash and Shackley, 2006) and two Balchit samples (type C and D by Poupeau et al., 2004) display different concentrations in relation to their groups.

The diagrams Ba *vs* Ce (Fig. 6b), Nb *vs* Zr (Fig. 7a) and Ba/Rb *vs* La/Nd (Fig. 7b) confirm the geochemical similarity between artefact 4 and the Isbil source, Yemen (Barca et al., 2012; Khalidi et al., 2010); they also confirm two different provenances for the remaining analysed artefacts which again plot in two distinct areas. The group of four artefacts overlaps with the Eritrean geological obsidian of Kusrale. Artefact 2 shows an unclear provenance when it is plotted in the Ba *vs* Ce (Fig. 6b) and Ba/Rb *vs* La/Nd (Fig. 7b) diagrams, while it shows a geochemical affinity with the sources of Hayd Halal, Yemen, and Afar1, Ethiopia (Khalidi et al., 2010) when it is plotted in the Nb *vs* Zr diagram (Fig. 7a).

Considering the compositional similarity found in some cases (e.g., Kusrale, Eritrea with Yafa'3, Yemen for the group of four artefacts and Hayd Halal, Yemen and Afar1, Ethiopia for artefact 2), however, the concentration of rare earth elements (REE) could help to determine the correct provenance. The pattern of REEs normalised to the chondrites (Nakamura, 1974) shown in Fig. 8a highlights the geochemical similarity between artefact 4 and the geological source of the Isbil volcano, Yemen. In addition, Fig. 8b–c shows that the group of four archaeological artefacts has a pattern consistent with that of Eritrean obsidian, whereas the Yafa'3, Yemen source shows lower content in heavy REE.

With the aim to identify the exact provenance of archaeological artefact 2, we also drew a spider diagram comparing it with the sources of Afar1, Ethiopia and Hayd Halal, Yemen (Fig. 8d). However, considering the similarity between the REE pattern of artefact 2 and those of the two geological sources (Afar1, Ethiopia and Hayd Halal, Yemen) the provenance cannot be definitely ascertained.

5. Conclusions

The results obtained from our analysis show that an Eritrean provenance (Kusrale source) can be postulated for four archaeological artefacts (1, 3, 5 and 6). The provenance of at least one of our samples (artefact 4) is the volcanic region of Dhamar Reda, Yemen and more specifically, the area encompassing the Isbil volcano. Among the six archaeological artefacts analysed, only artefact 2 shows a dubious provenance, due to its geochemical similarity with both the Afar1, Ethiopia and Hayd Halal, Yemen sources.

The study conducted by Bavay and colleagues to identify the tectonic intraplates incorporating the regions between the two Red Sea coasts (Ethiopian highlands, Eritrean littoral, and the volcanic regions of the southwestern Arabian peninsula) fails to clearly define specific procurement areas for the obsidian artefacts dating to the Predynastic period and the 1st Dynasty (Bavay et al., 2000: 15). However, the

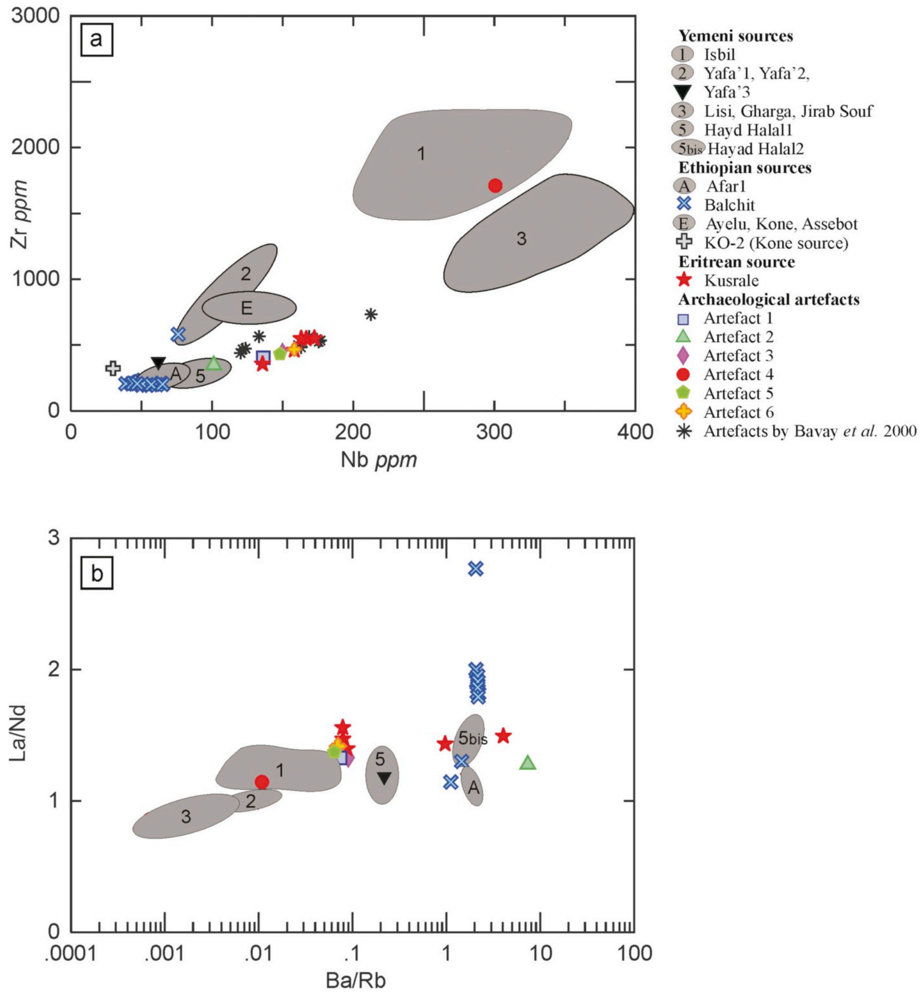

Fig. 7. a: Nb *vs* Zr; **b:** Ba/Rb *vs* La/Nd diagrams for the analysed archaeological artefacts compared with the Eritrean geological obsidian of Kusrale and with the dataset published in Barca et al. (2012), Khalidi et al. (2010), Negash and Shackley (2006), Negash et al. (2006), and Poupeau et al. (2004). The Egyptian artefacts presented in Bavay et al. (2000) are also plotted in the Nb *vs* Zr diagram.

close geochemical resemblance between these artefacts and those unearthed at Mersa/Wadi Gawasis and dating to the Middle Kingdom, provides evidence that, in Egypt, obsidian procurement areas mainly remained, over the centuries, the ones located along the two edges of the Red Sea.

Francaviglia (1996) argues that the obsidian artefacts found in Yemeni sites dating to the Neolithic and Bronze Age do not geochemically match the major procurement sources available in the country, i.e., the volcanic area of Dhamar Reda. He therefore maintains that they should be ascribed to areas located in the Tihamah area (a region between Yemen and Saudi Arabia) and on the Eritrean coast. On the contrary, the results of the work carried out on the obsidian artefacts from the Wādī Ath-Thayyilah 3 site, Eastern Yemen Plateau (Barca et al., 2012) already confirmed that the Dhamar Reda obsidian sources were already largely in use during the Neolithic. Artefact 4 of the present study reiterates that, even if at limited scale, Yemeni sources were again in use during the early 2nd millennium BC.

The way in which obsidian was transported from the procurement areas in the southern Red Sea regions into Egypt is still object of debate. Although Late Stone Age obsidian microlithic tools from Dahlak Kebir Island may point to a certain degree of seafaring in the Red Sea since late prehistoric times (Blanc, 1955), there is no robust data confirming long-distance sea trading during the Predynastic period (Bavay et al., 2000: 18; Giménez et al., 2015). Although there is also a lack of strong archaeological evidence supporting the hypothesis of a terrestrial route across the Eastern Desert (Bavay et al., 2000: 18), it is likely that this one was the favourite one at least during the 4th millennium BC. On the contrary, archaeological evidence from the northern Horn of Africa and southern Arabia shows clear evidence of seafaring across the southern Red Sea during the 3rd and 2nd millennia BC (Bard and Fattovich, 2018: 179). The results of the analysis of the obsidian artefacts from Mersa/Wadi Gawasis reiterate that the sea was likely the preferred route for trade between Egypt, the Horn of Africa and the Arabian peninsula, from at least the Old Kingdom.

Because of the difficult terrain and impossibility of boat navigation through highland Ethiopia via the Blue Nile or Atbara River, it is also likely that obsidian did not reach Egypt via these rivers, which converge with the Nile. It is therefore proposed that land routes from highland Eritrea reached the eastern Sudanese lowlands of the Kassala region, where obsidian occurs in 3rd-2nd millennia BC assemblages (see Manzo, 2017), and this region probably should be regarded as the hinterland of Punt (Bard and Fattovich, 2018). This trade route is also confirmed by the presence of Eritrean sourced obsidian artefacts at the site of Mahal Teglinos, in the Kassala region, dated from the 4th to the 2nd millennia BC (Lucarini et al., 2018). From eastern Sudan, obsidian could have reached Egypt through routes in the Eastern Desert and Nubia, and/or the Sudanese coast and the Red Sea (Manzo, 2017). The parts of ships found in and outside of the caves/galleries at the harbour site of Mersa/Wadi Gawasis, and the cargo boxes to store goods in the ships' holds, two of which were inscribed with the text "the wonderful things of Punt" (Mahfouz, 2007), are evidence that during the Middle

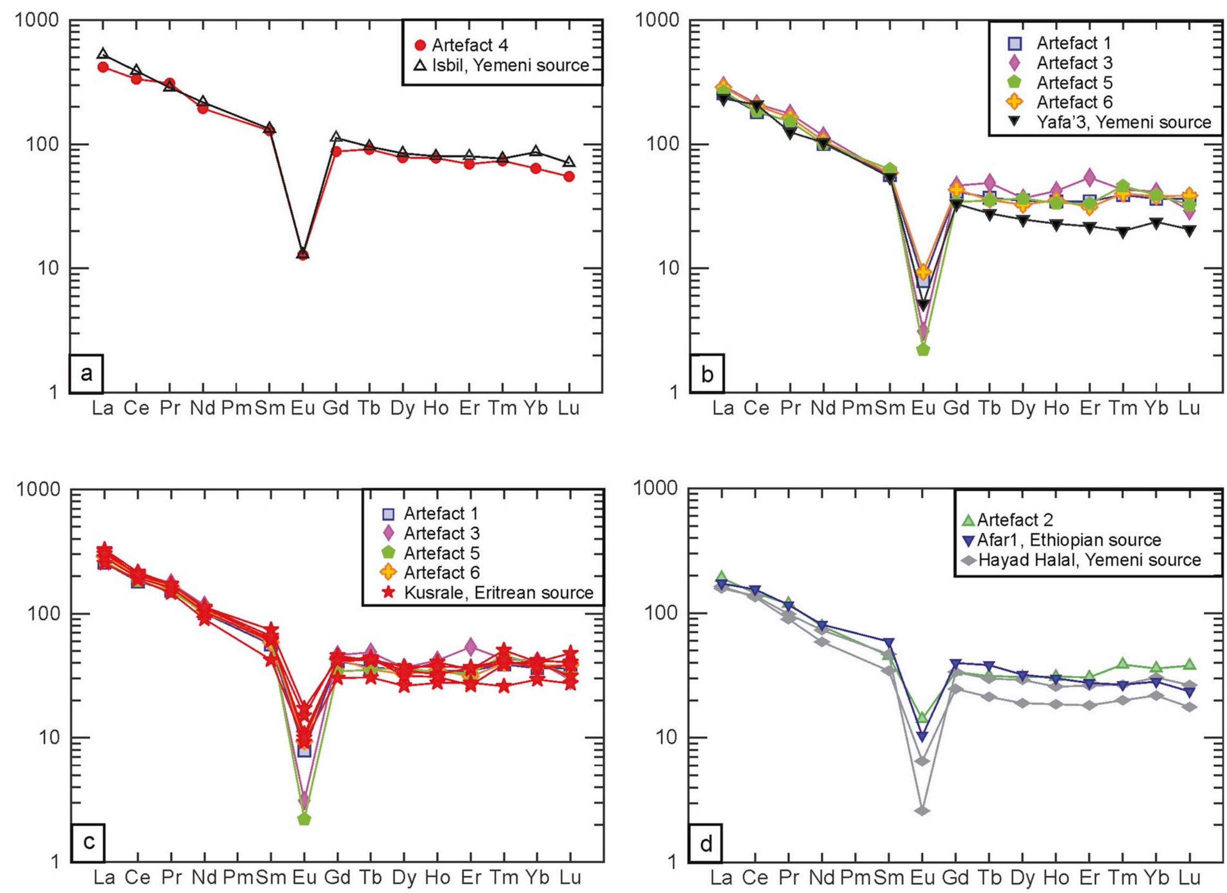

Fig. 8. Average value of REEs normalised to mantle value spider diagram (Nakamura, 1974): **a:** for archaeological artefact 4, analysed by LA-ICP-MS (data in Table 3) and compared with the dataset published in Barca et al. (2012), and Khalidi et al. (2010); **b:** for archaeological artefacts 1, 3, 5 and 6, analysed by LA-ICP-MS (data in Table 3) and compared with the data of the Yafa'3 Yemeni source (Khalidi et al., 2010); **c:** for archaeological artefacts 1, 3, 5 and 6, analysed by LA-ICP-MS and compared with the data of the Kusrale Eritrean source (data in Table 3); **d:** for archaeological artefact 2, analysed by LA-ICP-MS (data in Table 3) and compared with the dataset published in Barca et al. (2012), and Khalidi et al. (2010).

Kingdom sea routes to Punt were an important means for obtaining these goods. It is therefore very likely that the obsidian used in Egypt during the Middle Kingdom, or at least some of it, reached Egypt via this same route.

Declaration of competing interest

None.

Acknowledgements

This article is dedicated to the memory of Professor Abdel Monem A.H. Sayed, and to Professor Rodolfo Fattovich, whose untimely death is mourned by those of us who worked with him at Mersa/Wadi Gawasis. Both of them were pioneers in the study of pharaonic activities along the Red Sea.

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