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Obsidian in Ethiopia: a Geoarchaeological perspective

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ABSTRACT: In Ethiopia, obsidian is mainly found in the Afar Depression and the Main Ethiopian Rift. The compositional and petrological features of these obsidians vary. Some volcanic centers show that varying volcanic eruptions from a single center may not necessarily imply variable chemistry. Obsidian has been dated using K/Ar, Ar/Ar, and fission track methods to determine the time of eruption but there are also a few dates on artifacts by hydration dating to establish the time of tool manufacture. Many of the geological sources were utilized by prehistoric populations beginning at least since the Early Stone Age but obsidian became commonly used during the Middle Stone Age. Obsidian based stone tool use for scraping in Ethiopia persisted until recent times.

Key words: Ethiopia, geochemistry, obsidian; provenance, Stone Ages

INTRODUCTION

The typical conchoidal fracture characteristics of obsidian allows the removal of predictable sharp edged flakes and makes it a high quality raw material for stone tool production. Its geochemical signature has been used to trace its transport from geological sources to archaeological sites. Although there are abundant sources of obsidian and despite its archaeological presence from the Early Stone Age (ESA) to the present, geochemical research on obsidian has generally been lacking until recent times. This manuscript presents a review of the current status and provides new insights on obsidian studies in Ethiopia from a geoarchaeological perspective.

Geology and geochemistry

Obsidian is amply found in the Main Ethiopian Rift (MER) and Afar Rift, although rare occurrences are also found in the highlands outside the rift system (Fig. 1). The Afar Rift and the MER are characterized by volcanism that produced a number of obsidian domes, dating from the Miocene to the recent times, indicating their availability for utilization by successive prehistoric populations beginning from the ESA. Obsidian is found in the form of massive lava flows (e.g. those found at Birenti or Kone), domes (e.g., as at Aluto), fiamme (e.g., as at Assebot), superficial lapilli, boulders and gravels, some containing vesicles (often filled with secondary materials) or showing lamination of lava flow such as those found in many parts of the Afar Rift (Agazi Negash *et al*., 2020).

The MER is divided in to the southern, central and the northern sectors, and it widens northwards to the Afar Rift. There is as yet no report on the presence of obsidian in the southern sector. The southernmost obsidian dome so far studied is Bantu, located in the southern end of the central sector of the MER. These obsidians are situated in two adjacent hills, in the Hobitcha caldera, the inner wall of which is dated at 1.57 Ma on a rhyolite (Chernet 2011). The obsidians are massive (although some of them show flow lamination) found exposed with trachytic/rhyolitic boulders and fragments. They generally have a higher Fe content. They contain microscopic inclusions but 90-95% of the groundmass is glassy (Agazi Negash 2022). Most of the obsidians in this sector are massive (e.g. Aluto), but rare pitchstones also occur (such as in Barichia). At Aluto the obsidians occur in the form of flows of 3-5 m thickness. Aluto's obsidian has been dated at 0.4 ± 0.01 Ma (Wode Gabriel *et al*., 1990) and at 10-20 ka by Hutchison *et al*. (2016a, b). The obsidian in this area is characterized by a relatively high Fe content, with 83-88% glassy groundmass but with variable amounts of sanidine (8-10%) and even rare plagioclase. Among the studied obsidian sources in the central sector of the MER Barichia presents rare non-vitreous pitchstones, showing in some cases, occurrences of flow banding. It is interesting to note that unlike the obsidian sources in the region (e.g., Worja, Bora, Aluto) the obsidian at Barichia are stiff pitchstones but still characterized by conchoidal fracture. Also unlike the other sources the obsidian here is trachytic, with modal composition ranging from 55-60% glass, 37-40% sanidine, 3% hornblende, and even 2% pyroxene in one of the samples (Fig. 2a).

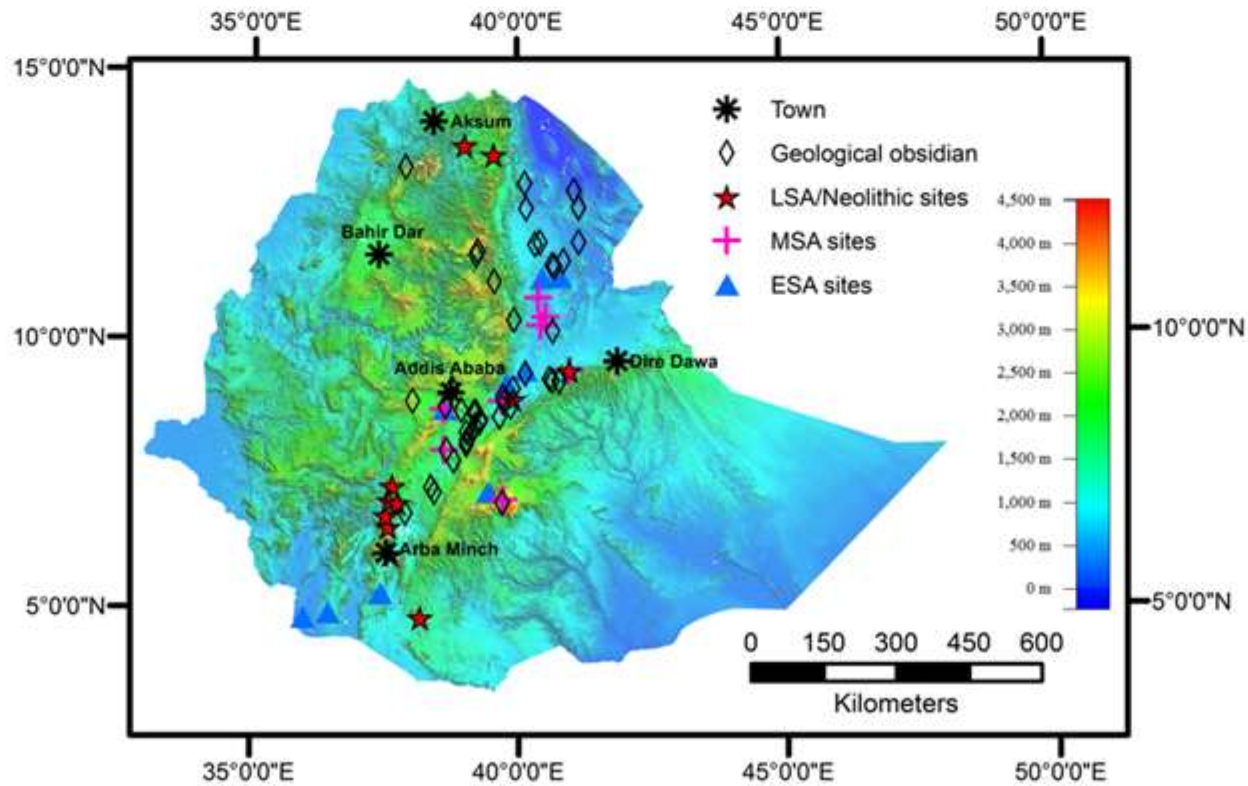

Figure 1:- Location of geological obsidian sources (from Agazi Negash *et al.*, 2020) and archaeological sites containing obsidian artifacts (from multiple sources mentioned in the text).

The obsidians from the northern sector of the MER present a different scenario based both on elemental composition and modal mineralogical content. The most variable obsidian, in terms of composition and petrology, are found in this sector of the MER, particularly those that are found in the transition zone to the Afar Rift. It must be noted that it is around Dofen (also spelled Dofan) where the northern sector of the MER begins to bifurcate into a triangular form of the Afar Rift. Here Fe content ranges from 5.2 wt% in Dofen to 11.69 wt% in Fentale (Agazi Negash *et al.*, 2021). Dofen, in particular contains different sets of obsidian ranging in Fe content from 5.2 wt% to 10.2 wt%. It also contains the only comendite obsidians of this region (Agazi Negash *et al.*, 2021). Fe begins to decrease northwards in the volcanic complexes in the Afar.

The petrology of obsidians in the localities in this sector have discrete characteristics, and with the exception of Barichia, which is located in the central sector of the MER, trachytic obsidians with sometimes more mineral content than the glass groundmass are found here. The obsidians on the eastern side of Mount Fentale have very minimal mineral inclusions and are trachyte/trachydacite in composition (Agazi Negash *et al.*, 2020) but the western flanks contain trachytic obsidians with volcanic glass and minerals having almost comparable modal content (Fig. 2b), indicating not just elemental differences but also different mineralogical abundances. Fentale and Dofen sources are mostly of a trachytic affinity. In contrast, Birenti and Kone, volcanic centers situated close to Fentale and Dofen, each contain obsidian of uniform composition (Agazi Negash *et al*., 2021).

Of all the northern MER obsidian localities, Dofen and Fentale present the most mineralogically variable obsidian. In fact, at Dofen sanidine makes 50% while glass is only 41 % with other minerals making the balance (Fig. 2c), even though there are no visible phenocrysts in hand specimen. This is paralleled by only Barichia (located in the central sector) from the rest of the MER obsidians. Kone and Birenti on the other hand contain minimal inclusions, with their obsidian composed almost entirely of glass (Fig. 2d). Furthermore, unlike Fentale and Dofen, which have variable compositions, Birenti and Kone, although they have erupted several times, each has distinct composition with their obsidians having almost no mineral inclusion, at least in the samples currently analyzed. At Birenti, although seventeen samples from five sections were analyzed they are compositionally indistinguishable from one another as are those of Kone (Agazi Negash *et al*., 2021). This is analogous to Chebe, a volcanic complex located some 250 km south of Birenti, whose obsidians are elementally homogeneous despite the center erupting from several vents (MacDonald and Gibson 1969; Rapprich *et al*., 2016; Agazi Negash 2022). These localities present exceptions to the widely held assumption of every eruptive episode with unique chemistry, although the archaeological significance of this is yet to be determined.

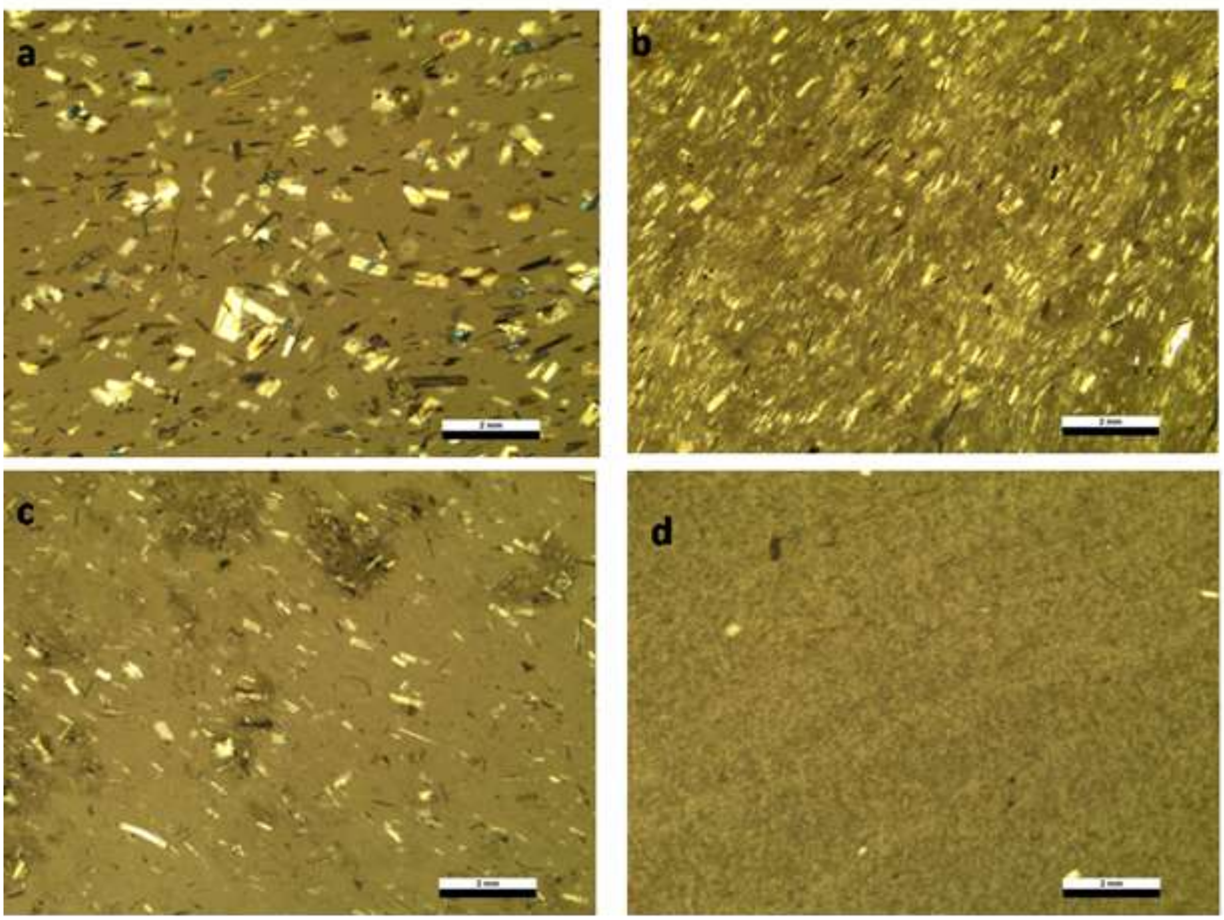

Figure 2. Petrography of obsidian from selected sites. Notes:- (a) a volcanic glass, sanidine and hornblende; (b) volcanic glass, sanidine and hornblende; (c) volcanic glass, sanidine, plagioclase and opaque mineral (Fe-oxide) grains; and (d) mainly composed of volcanic glass.

The most northerly obsidians are in the Afar Rift. Here, obsidians are found in several areas along the Gayderu mountain chains. These sources are situated not very far from the famous paleoanthropological and/or archaeological sites of Gona, Hadar, and Woranso Mille. Also in the northern Afar Rift there are other obsidian centers along the long stretch of massifs between Serdo and Lake Afdera. This stretch contains a number of volcanic centers containing typical obsidian intercalated with rhyolite lavas and the Afar Stratoid series basalts. At a locality called Silsa there are vesicular obsidians, something that is not readily found everywhere. There are also obsidians in other places in the Afar Rift but these are porphyritic and/or perlitic with onion skin like fracture and therefore not useful for artifact manufacture.

Obsidians are also found out of the Rift System (Fig. 1). The farthest currently known obsidian source in the highlands is Limalimo in northwest Ethiopia but unfortunately it contains only porphyritic obsidians that are not of artifact quality. Other obsidians from outside the rift are those found in Gerado and Wegel Tena, in the northern Ethiopian massifs (Agazi Negash *et al.*, 2020) and on Dendi caldera, located along the Yerer-Tulu-Wellel volcano tectonic lineament in the central Ethiopian Plateau (Bahru 2004). The obsidians of Wegel Tena, at 2929 m above sea level, represent one of the high altitude presence of obsidians in Ethiopia after Dendi at 3065 m. asl and Wasama (at between 3939-4240 m asl), in the Bale mountains of south-eastern Ethiopia (Ossendorf *et al.*, 2019). The Dendi obsidians, with a maximum thickness of one meter are found in the northeastern and southeastern sections of the caldera carrying the same name. These obsidians are black and massive and are overlain by pyroclastic deposits (ignimbrites, some pumice and volcanic surges) but overlie rhyolites (in some cases showing columnar jointing) and trachytes (Bahru 2014).

Table 1. Al and Fe ranges in the MER and Afar Rift (data from Agazi Negash *et al.*, 2020). These elements were chosen because they show the most variability.

Element	Afar Rift	Main Ethiopian Rift
Al_2O_3 wt %	10.17-13.36	7.88-13.63
Fe_2O_3 wt%	0.81-2.91	2.45-10.75
Al Fe ratio	>4.7	<4

Finally, one must note the clear chemical differences between the Afar and MER obsidians. First, all Afar Rift samples currently analyzed are comendites, while those of the MER, with the exception of Dofen (some of whose obsidian are comendites) are pantellerites (Agazi Negash *et al.*, 2020). With the exception of one type of obsidian from Artu and Balchit all obsidians from the MER are characterized by high iron content. Conversely with the exception of one type of obsidian from Gira Ale, the northernmost obsidian source, low Fe content characterizes Afar obsidians (Agazi Negash *et al.*, 2020). It is also interesting to note that all the Afar samples have an Fe/Al ratio of >4.7 while those of the MER have a ratio of <4 (Table 1).

Geochronology

Obsidian sources currently known in Ethiopia range in age from the Miocene to recent times, indicating their availability for utilization by successive prehistoric populations. As discussed below some of these obsidian sources were the origins for archaeological artifacts in many sites. All available age determinations of obsidian (of both artifacts and sources) are presented in Table 2. A number of techniques were used to date these obsidians: Ar/Ar, K/Ar, F/Tr and hydration dating methods. The earliest obsidian is dated to the late Miocene at Assebot in the eastern margin of the MER but most MER obsidians date to the Quaternary (Table 2). The most recent dates are those of the Afar rift, although Fentale might have erupted as recently as 200 years ago (Cole 1969).

Some obsidian from Korbeti (also spelled Corbetti), Chebe (also spelled Chabbi) and the youngest flows of Aluto have also been dated at ca. 20,000 years ago (Table 2).

Table 2. Ages of natural (sources) and archaeological obsidian (artifacts). Sample numbers are from the original publications.

Sample #	General Location	Age	Technique	Reference
76-1	Gara Mariam, Tedi	3.32 ± 0.06 my	K/Ar	Morton et al 1979
76-1	Gara Mariam, Tedi	3.11 ± 0.06 my	K/Ar	Morton et al 1979
76-16	North summit, Gara Boku	0.83 ± 0.02 my	K/Ar	Morton et al 1979
76-14	Summit, Gara chisa	0.16 ± 0.01 my	K/Ar	Morton et al 1979
G15	South Pruvost complex	0.12 ± 0.05 my	K/Ar	Barberi et al 1972
G432	Sumit Gad'Elu center	0.37 ± 0.04 my	K/Ar	Barberi et al 1972
C338	Base, Gad'Elu center	0.56 ± 0.02 my	K/Ar	Barberi et al 1972
D231	Boina	10.5 ± 1.8 ky	F/track	Barberi et al 1972
D211	Boina	44 ± 7 ky	F/track	Barberi et al 1972
G432	Gad'Elu	390 ± 40 ky	F/track	Barberi et al 1972
C338	Gad'Elu	575 ± 60 ky	F/track	Barberi et al 1972
BT108	Meki river, Gurage-Mensa rift floor	1.58 ± 0.2 my	K/Ar	WoldeGabriel et al 1990
BT82	Aluto, Gurage-Mensa rift floor	0.04 ± 0.01 my	K/Ar	WoldeGabriel et al 1990
BT87B	Mensa-Asela eastern rift margin	2.95 ± 0.2 my	K/Ar	WoldeGabriel et al 1990
ET28	Wondo, Awasa eastern rift margin	0.96 ± 0.1 my	K/Ar	WoldeGabriel et al 1990
ET77	Awasa eastern rift margin	.47 ± 0.02 my	K/Ar	WoldeGabriel et al 1990
ET33	Korbeti, Awasa eastern rift margin	0.02 ± 0.01 m2	K/Ar	WoldeGabriel et al 1990
ET150	Katar river	0.38 ± 0.04 ky	K/Ar	WoldeGabriel et al 1992a
	Assebot	5.23 ± 0.024 ky	K/Ar	WoldeGabriel et al 1992a
83W-43B	Dofen	0.12 ± 0.01 ky	K/Ar	WodeGabriel et al 1992b
C712-68a	Asebot, Rift margin silicic centers	5.6 ± 0.09 my	K/Ar	Tadiwos Chernet et al 1998
2C714-14	Gedja, near Melka Konture	4.37 ± 0.07my	K/Ar	Tadiwos Chernet 1995
Ets8	NW of Mojjo	0.36 ± 0.07 my	K/Ar	Abebe et al 1998
RV 359	Gedemsa, Precaldera lava flow	0.267±0.04 my	F/T	Bigazzi et al 1993
RV 365	Gedemsa. Precaldera lava flow	0.212±0.32 my	F/T	Bigazzi et al 1993
	Bora-Bericcio complex	0.124 ± 0.014 my	F/T	Bigazzi et al 1993
	Bora-Bericcio complex	0.93 ± 0.011 my	F/T	Bigazzi et al 1993
	Bede Gebabe	0.367 ± 0.07 my		Mazzarini et al. 1999
GD4	Gedemsa, pre caldera obsidian	0.319 ± 0.02 my	K/Ar	Peccerillo et al. 2003
GD7	Gedemsa, post caldera	0.265 ± 0.02 my	K/Ar	Peccerillo et al. 2003
LA16	Tulu Moye Hate	1.3±0.3my	K/Ar	Boccaletti et al. 1999
RV 305	Bora-Bericcio complex	0.124 ± 0.014 my	F/T	Bigazzi et al 1993
RV 245	Bora-Berricio Complex	0.91± 0.011 and 0.83 ± 0.011 my	F/T	Bigazzi et al 1993
RV 226	Bora-Bericcio complex	0.092±0.012 my	F/T	Bigazzi et al 1993
182	Boset Guda	3.3±2.4 ky	Ar/Ar	Seigburg et al 2018
68	Boset Baricha	3.8±4.7 ky	Ar/Ar	Seigburg et al 2018
110	Boset Baricha	4.9±4.0 ky	Ar/Ar	Seigburg et al 2018
66	Boset Baricha	1.2±3.4 ky	Ar/Ar	Seigburg et al 2018
64	Boset Baricha	14.0±4.2 ky	Ar/Ar	Seigburg et al 2018
30-01-LNE	Aluto	19±5 ky	Ar/Ar	Hutchison et al. 2016a
18 01 08	Aluto	22±14 ky	Ar/Ar	Hutchison et al 2016a
30-01-LE	Aluto	16±14 ky	Ar/Ar	Hutchison et al. 2016b
01 02 14	Aluto	62±13 ky	Ar/Ar	Hutchison et al 2016a
Chabi-7	Chabbi	19±15 ky	Ar/Ar	Hutchison et al. 2016b
Gademota	Gademota Artifact	1.3 my	Ar/Ar	Vogel et al. 2006
Halibee	Halibee Artifact	7.1 ±1.6 to 0.093 ±0.008 my	Ar/Ar	Morgan et al. 2009
Herto	Herto Artifact	3.24 ± 0.55 to 0.11 ± 0.004 my	Ar/Ar	Morgan et al. 2009
Artifact12022	Porc Epic artifact	61,202±958	obsidian hydration	Michels and Marean 1984
Artifact12018	Porc Epic artifact	61,640±1083	obsidian hydration	Michels and Marean 1984
Artifact12020	Porc Epic artifact	77,565±1575	obsidian hydration	Michels and Marean 1984
KNM-482	Qhiha artifact	71 BC ± 107	obsidian hydration	Clark 1988

Archaeological obsidian materials have been dated using Ar/Ar and obsidian hydration dating methods. Unlike in Kenya (Fletcher *et al*. 1965) there is no report of fission track dating of archaeological artifacts in Ethiopia. Also unlike Kenya, where there are numerous archaeological obsidian dated using hydration dating technique (Michels *et al*. 1983), only two sites were subjected to this technique in Ethiopia. Using this technique six Middle Stone Age (MSA) artifacts from the site of Porc Epic in eastern Ethiopia yielded an age between 61,000 to 77,500 years ago (Michels and Marean 1984). These dates are considered minimum ages by the investigators. Farther north the site of Quiha yielded an obsidian hydration age of 2000 years (Clark 1988).

Other archaeological obsidian artifacts have been dated through Ar/Ar dating method (Table 2), although these are indicative of the age of the source material and not of the time of artifact manufacture. The Worja obsidian used by the MSA inhabitants of the site of Gademota is dated at 1.3 Ma (Vogel *et al*., 2006; Brown *et al*., 2009; Morgan *et al*., 2009). Other Ar/Ar dates available are for the MSA sites of Herto and Halibee. Herto artifacts range in age from 0.110 ± 0.004 My to 3.24 ± 0.55 Ma, and many in between, while numerous artifacts were dated from Halibee, with their age ranging between 0.093 ± 0.008 and 7.1 ± 1.6 Ma (Morgan *et al*., 2009).

Archaeology

The earliest mention of obsidian from Ethiopia as a trade item in literary sources is in the *Periplus of the Erythrean Sea* written some 2000 years ago (Casson 1989). By coincidence the earliest use of obsidian in archaeology seems to also be in Ethiopia at the ESA sites of Melka Konture (Chavaillon and Berthlet 2004) and Gadeb (Clark 1987). Obsidian use in archaeology became more common during the subsequent MSA and Later Stone Age (LSA)/Neolithic (e.g. Brandt 1986). Continued use of obsidian until recent times is also documented by Clark and Kurashina (1981), Brandt and Weedman (1997), Yonatan Sahle *et al*. (2012) and Yonatan Sahle and Agazi Negash (2016).

The first archaeological application of obsidian geochemistry is by Muir and Hivernel (1976) who determined the provenance of the artifacts of the ESA site of Melka Konture to have been Balchit. Muir and Hivernel's (1976) conclusions were later corroborated by Agazi Negash *et al*. (2006) and Piperno *et al*. (2009). Other ESA sites of Gadeb (Clark and Kurashina 1979), Kesem Kebena (WoldeGabriel *et al*., 1992) and Hugub (Gilbert *et al*., 2016) contain obsidian artifacts in both surface and excavated contexts, although the obsidian from these sites have yet to be characterized. There is also a report of rare obsidian from the ESA sites of Gona (Stout *et al*., 2005) and Hadar (Goldman-Neuman and Hovers 2012). However, a report of the presence of obsidian artifacts from other ESA sites of Ledi Geraru (Braun *et al*., 2019), Fejej (Barsky *et al*., 2011) Konso Gardula (Beyene *et al*., 2013) and Omo Shungura Formation (Maurin *et al*., 2014) is lacking.

Obsidian continued to be used during the MSA. Obsidian artifacts have been recovered from the Middle Stone Age sites of Porc Epic, Gademota, Herto, Aduma, and Halibee. Following Michels and Marean (1984) who identified three compositionally distinct groups of the artifacts of the MSA site of Porc Epic. Agazi Negash and Shackley (2006) also demonstrated that the obsidian of the site had many different origins but only a few of these are currently identified. Although located within a good quality obsidian, the MSA inhabitants of Gademota procured obsidian from as yet unknown source (Negash *et al*., 2010). The MSA sites of Herto, Aduma, and Halibee had multiple origins, but many of those are still unknown (Agazi Negash *et al*., 2011). Variable distances (as the crow flies) of the origin of some of the artifacts of these sites is presented in Table 3.

Table 3. Distance (in km) from site to source (based on Agazi Negash *et al*., 2011).

MSA site	**Source**						
	Assebot	Kone	Adokoma	Ida'ale	Asboli	Ayelu	Gira Ale
Halibee		225	78	78	89		232
Herto							289
Aduma						38	
Porc Epic	145	247				139	

There are also sizable LSA/Neolithic archaeological sites but obsidian artifacts of most of them have not yet been analyzed, the exception being Aladi Springs (Agazi Negash *et al*., 2011), Beseka (Agazi Negash *et al*., 2007), Mochena Borago (Agazi Negash 2022), and the Temben sites (Agazi Negash 2001). The denizens of Aladi Springs procured obsidian from Assebot and other places (Agazi Negash *et al*., 2011) while the sources of Kone and Fentale were used in the LSA/Neolithic site of Beseka (Agazi Negash *et al*., 2007). The inhabitants of Mochena Borago, a site in southern Ethiopia, also procured obsidian from several sources, one of which is the source of Bantu, some 20 km east of the site (Agazi Negash 2022). Bantu could also have been, at least partly, a source for the site of Mota (Arthur *et al*., 2019), a cave located some 50 km south. According to Hensel *et al*. (2021) the obsidian artifacts from Sodicho, a site situated some 60 km northwest of Bantu, may have originated from Bantu. Close to Bantu are the sites of Akirsa (Poisblaud 2002), Mome Gongolo 1 and 2 (Lesur *et al*., 2014) and Haroruna (Bachechi 2005), but their obsidian is not yet characterized. In spite of the characterization of many obsidian from the Neolithic sites in Temben, their origin is yet to be determined (Agazi Negash 2001).

There are also reports of the use of obsidian in the historical site of Aksum but the details of this are lacking. In fact, the earliest mention of obsidian as a trade item of the Aksumite empire is in the *Periplus of the Erythrean sea*, widely believed to have been written some 2000 years ago (Casson 1989). Obsidian is also being used for hide scraping in parts of southern Ethiopia (Brandt and Weedman 1997; Yonatan Sahle *et al*., 2012; Yonatan Sahle and Agazi Negash 2016).

CONCLUSION

Obsidian in the MER and Afar Rifts date from the Miocene to recent times. These obsidians vary chemically: those of the MER have high Fe content and low Fe/Al ratio while those of the Afar Rift are characterized by low iron content and high Fe/Al ratio. Furthermore, although the sources of Chebe and Birenti erupted several times they have uniform chemistry, providing exceptions to the assumption that every eruptive sequence has the same chemistry.

As indicated above, the origin of many of the obsidian artifacts from several archaeological sites in Ethiopia still remains largely unknown due to the dearth of archaeologically oriented characterization studies of artifacts and sources. Further obsidian studies that should culminate in the final mapping of obsidians containing a complete analysis of geological sources and archaeological artifacts is needed.

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