Investigating the provenance of Italian archaeological obsidian tools based on their magnetic properties

(Article begins on next page)

Archaeological and Anthropological Sciences

Investigating the provenance of Italian archaeological obsidian tools based on their magnetic properties

--Manuscript Draft--

Manuscript Number:	AASC-D-18-00180R1
Full Title:	Investigating the provenance of Italian archaeological obsidian tools based on their magnetic properties
Article Type:	Original Paper
Corresponding Author:	Enzo FERRARA Istituto Nazionale di Ricerca Metrologica Torino, Piemonte ITALY
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Istituto Nazionale di Ricerca Metrologica
Corresponding Author's Secondary Institution:	
First Author:	Enzo FERRARA
First Author Secondary Information:	
Order of Authors:	Enzo FERRARA
	Evdokia Tema
	Elena Zanella
	Cinzia Beatrice
	Francesca Miola
	Elena Pavesio
	Andrea Perino
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Reconstructing the distribution of ancient obsidian tools is one of the few ways to trace ancient trade routes during the Neolithic. The use of magnetic properties for obsidian provenance studies has already been applied as a useful inexpensive and non-destructive tool. It is mainly based on the variation of the type, concentration, and grain size of the magnetic particles within the vitreous matrix coming from different sources. In this study, we present the results of a rock magnetic investigation carried out on archaeological obsidian tools collected from six Neolithic sites situated in Northern Italy (Castello d'Annone, Brignano Frascata, Cascina Chiappona, Casalnoceto, Garbagna, and Parma). A total of 57 archaeological samples were analyzed by measuring several magnetic parameters such as: low field and anhysteretic susceptibility, saturation isothermal remanent magnetization at room and liquid nitrogen temperature, remanence and saturation magnetization from hysteresis cycles, and anisotropy of low field susceptibility. The obtained results were compared with the magnetic properties of geological samples from five Mediterranean islands (Lipari, Sardinia, Palmarola, Pantelleria, and Melos). Cluster analysis was applied to the whole set of parameters, allowing the correlation of the pertinent group of artefacts and geological obsidians. Such analysis shows that most of the studied archaeological tools come from Lipari, with few exceptions consisting of samples coming from Pantelleria and Sardinia. Our results are in good agreement with other studies based on chemical analyses that also show that Lipari is the most common Neolithic obsidian source in Northern Italy, despite its longer distance in respect to other obsidian sources.
Response to Reviewers:	Torino, November 9th 2018

Investigating the provenance of Italian archaeological obsidian tools based on their magnetic properties

Enzo Ferrara[1,*], Evdokia Tema [2,3], Elena Zanella[2,3], Cinzia Beatrice[1], Francesca Miola[1], Elena Pavesio[1], Andrea Perino[1]

[1]*Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Torino, Italy*

[2]*Dipartimento di Scienze della Terra, Università degli studi di Torino, via Valperga Caluso 35, 10125 Torino, Italy*

[3]*CIMaN-ALP Palaeomagnetic Laboratory, via G. U. Luigi Massa 6, 12016 Peveragno, Italy*

*Corresponding author: Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Torino, Italy. Tel.: +39 011 3919837, E-mail address: e.ferrara@inrim.it

Abstract

Reconstructing the distribution of ancient obsidian tools is one of the few ways to trace ancient trade routes during the Neolithic. The use of magnetic properties for obsidian provenance studies has already been applied as a useful inexpensive and non-destructive tool. It is mainly based on the variation of the type, concentration, and grain size of the magnetic particles within the vitreous matrix coming from different sources. In this study, we present the results of a rock magnetic investigation carried out on archaeological obsidian tools collected from six Neolithic sites situated in Northern Italy (Castello d'Annone, Brignano Frascata, Cascina Chiappona, Casalnoceto, Garbagna, and Parma). A total of 57 archaeological samples were analyzed by measuring several magnetic parameters such as: low field and anhysteretic susceptibility, saturation isothermal remanent magnetization at room and liquid nitrogen temperature, remanence and saturation magnetization from hysteresis cycles, and anisotropy of low field susceptibility. The obtained results were compared with the magnetic properties of geological samples from five Mediterranean islands (Lipari, Sardinia, Palmarola, Pantelleria, and Melos). Cluster analysis was applied to the whole set of parameters, allowing the correlation of the pertinent group of artefacts and geological obsidians. Such analysis shows that most of the studied archaeological tools come from Lipari, with few exceptions consisting of samples coming from Pantelleria and Sardinia. Our results are in good agreement with other studies based on chemical analyses that also show that Lipari is the most common Neolithic obsidian source in Northern Italy, despite its longer distance in respect to other obsidian sources.

Keywords: Obsidian; Provenance; Magnetic properties; Neolithic; Italy

1. Introduction

In Central Europe, obsidian tools were abundantly used as cutting utensils during the prehistoric period, before the employment of metallic alloys, and they remain the ancient trading artifacts most used to reconstruct trade routes in the Neolithic (Cann and Renfrew 1964; Renfrew et al. 1965; Freund 2018). In the Mediterranean area, a few obsidian sources are available, located at the volcanic islands of Lipari, Palmarola, Pantelleria and Sardinia in Italy, and at Melos and Gyali in Greece (Fig. 1). Obsidians from these sources have distinctive chemical compositions, which have been considered as a fingerprint and used for provenance investigations of Neolithic artefacts found in the archaeological sites of Central Europe (Scorzelli et al. 2001; Poupeau et al. 2007; Weaver et al. 2009).

Apart from differences in the chemical composition of obsidians, variations of the size, distribution, and structure of the ferrous grains in the amorphous matrix may occur in both outcrop and sample scale, depending on the geochemistry of the lava and the conditions under which the volcanic eruption and subsequent cooling of the magma took place. Such important variants may be detected as changes in the magnetic properties of obsidians from different geological sources. Magnetic measurements can therefore offer an alternative approach of non-destructive and cheap laboratory methods to investigate obsidian provenance, in comparison with the conventional trace element analysis or to the examination of physical-chemical properties such as the thickness of the hydrated layer (Liritzis and Laskaris, 2011), and the extent of geochronological fission tracks (Bigazzi et al. 1990).

Several decades ago, McDougall et al. (1983) first examined the potential of magnetic measurements to investigate the provenance of obsidian artifacts by studying samples from Mediterranean and Near Eastern sources. Since then, several other studies focused on the use of magnetic properties in sourcing archaeological obsidians, often introducing new parameters to obtain clearer provenance correlations and/or integrating them to other analyses e.g. geochemical measurements, ^{57}Fe Mossbauer spectroscopy, and X-ray fluorescence (XRF) (Urrutia Fucugauchi 1999; Vasquez et al. 2001; Tykot 2002; Stewart et al. 2003; Zanella et al. 2012; Frahm et al. 2014; Mameli et al. 2016). However, magnetic approaches have often shown variable success, probably because of the complex magnetic and microstructural features of the obsidians, which can result in unclear source determination (Vasquez et al. 2001). Frahm and Feinberg (2013) investigated a large number of geological and archaeological obsidians, observing important magnetic variability across an individual flow. They thus suggested the use of magnetic properties to identify quarrying locations within a flow, rather than using them to source artifacts to an obsidian flow. Frahm et al. (2014) further explored the potential of magnetic properties in sourcing obsidians from Armenia, concluding that the measurement of few basic magnetic parameters could contribute to distinguish geochemically identical obsidians from different eruptive centers.

In this study, we further investigate the use of magnetic analyses for archaeological obsidian sourcing by presenting new magnetic data from obsidian bladelets and nodules collected from six Neolithic sites (Castello d'Annone, Brignano Frascata, Cascina Chiappona, Casalnoceto, Garbagna, and Parma) situated in Northern Italy. The new data are compared with the magnetic properties previously determined (Zanella et al., 2012) on geological samples from the main Central Mediterranean obsidian sources (Lipari, Sardinia, Palmarola, Sardinia Monte Arci, Pantelleria, and Melos). In addition to the magnetic parameters proposed in Zanella et al. (2012), we consider here also the anisotropy of low field susceptibility, P, as a useful additional indicator to discriminate samples from the sources of Lipari and Sardinia SA, both characterized by large content of superparamagnetic grains and thus undistinguishable using other magnetic parameters. Cluster analysis is finally applied on the resulting dataset, as a suitable representation of the different groups used to identify and correlate geological and archaeological obsidians.

2. Material and methods

2.1 Archaeological samples

A collection of 57 archaeological obsidians has been studied. The samples come from six archaeological sites found in Northern Italy, five of them situated in Piedmont and one at Parma (Fig. 1). Specifically, the samples from the prehistoric settlements in Piedmont are: 22 samples from Castello d'Annone (CDA), 1 sample from Garbagna (Ossi 6), 3 samples from Cascina Chiappona (Ossi 7-9), 3 samples from Brignano Frascata (Ossi 10-12), and 8 samples from Casalnoceto (Ossi 13-20). Almost all samples are obsidian bladelets, with only exception two samples from Castello d'Annone (CDA I and II), two samples from Casalnoceto (Ossi 19 and 20) and one sample from Brignano Frascata (Ossi 12) that are obsidian nodules.

The obsidians from Piedmont were collected during excavations in the 80's and 90's and they were catalogued and stored at the Museum of Antiquity of Torino (Venturino Gambari 2004). Even though from some sites the number of available archaeological tools is very limited (e.g. only one sample from the Garbagna site), the Piedmont sites of Garbagna, Cascina Chiappona, Brignano Frascata and Casalnoceto are located in the same area (Fig. 1), and can therefore be considered altogether for investigating the provenance of obsidian tools in this area of Northern Italy. The obsidians from Parma consist of 20 samples (GUI) and come from a settlement found in the urban habitat of the city, in the modern via Guidorossi (Bernabò Brea et al. 1988; Quero 2014). According to archaeological evidence, all the studied sites were inhabited in the mid-late Neolithic period (Venturino Gambari 1988, 1993), even though detailed information on their precise dating is not available.

The dimensions of the studied archaeological bladelets and nodules are generally small, ranging from 3-4 mm to 20 mm (Fig. 2). Their masses vary from 0.08 g to 4 g. With the only exception of a larger bladelet from Castello d'Annone (CDA I), all samples were sufficiently small to be placed in plastic sample holders that made possible the performance of the magnetic measurements without cutting or harming them, confirming the non-destructive character of such analyses.

2.2 Magnetic measurements

The magnetic granulometry of the obsidian artefacts was investigated by the measurement of: low field susceptibility (χ), anhysteretic susceptibility (χ_{α}), saturation of isothermal remanent magnetization at room temperature ($SIRM_{293}$) and in liquid nitrogen ($SIRM_{77}$), and anisotropy of magnetic susceptibility (P). Furthermore, the susceptibility ratio (Q_a), the $SIRM_{77}/SIRM_{293}$ ratio (S_T), and the ratio of remanence and saturation magnetization (M_R/M_S), as evidenced through hysteresis cycles, were calculated.

2.2.1 Low-field and anhysteretic susceptibility

The low field susceptibility was first measured on all samples using a KLY-3 Kappabridge (Agico). An accurate evaluation and subtraction of the diamagnetic contribution due to the plastic container and sample holder was applied, particularly for samples with mass lower than 0.2 g (in such very small samples the diamagnetic contribution of the plastic holder may be very important). In order to avoid the directional bias due to the large magnetic anisotropy of obsidians (Lanci and Zanella 2016), the anisotropy of the magnetic susceptibility (AMS) was also measured and the AMS anisotropy degree, P = K1/K3, defined as the ratio of the maximum susceptibility axis (K1) and the minimum susceptibility axis (K3), was calculated (Tarling and Hrouda 1993).

The anisotropy of the anhysteretic remanent magnetization (J_{ARM}) was measured using a D-2000 ASC equipment and a JR-6 spinner magnetometer. Each sample was initially tumbling demagnetized with an alternating field (AF) of 200 mT to erase as much as possible of the original hard natural remanent magnetization (NRM) component. Then the ARM was evaluated imposing a steady field H_{DC} = 100 μT (i.e. within the Rayleigh region) in the presence of an AF field of 100 mT. Following, the remanent magnetization J_{ARM} was measured. The procedure was repeated in six different orientations with respect to the applied direct field (H_{DC}) and in two opposite senses for each position to cancel out any unwanted contribution by unerased NRM (12 positions in total). Finally, the anhysteretic susceptibility, $\chi_a = J_{ARM}/H$, was calculated. The ratio Q_a is then defined as $Q_a = \chi_{a/}\ \chi$ (Zanella et al. 2012).

2.2.2 Isothermal Remanent Magnetization

Stepwise acquisition of the isothermal remanent magnetization (IRM) was measured up to 2T IRM curves were obtained at two temperatures: 293 K and 77 K. Each sample was blocked with plastiline in a small plastic open box, and a stepwise increasing direct field was applied with an ASC pulse magnetizer. After each step, the IRM was measured with a 2G Enterprises cryogenic magnetometer. For the acquisition of IRM at low temperature, the same field sequence was followed but before each step the open box container with the sample was bathed in liquid nitrogen and let cool down until 77 K. The IRM saturation values obtained at 293 K ($SIRM_{293}$) and at 77 K ($SIRM_{77}$) were then used to calculate the S_T ratio, defined as $S_T=SIRM_{77}/SIRM_{293}$.

2.2.3 Hysteresis loops and magnetization values

Remanence (MR) and saturation magnetization (MS) at room temperature where obtained from the hysteresis cycles whose shape variation with temperature can provide information on the magnetic granulometry (Zanella et al. 2012). Each archaeological sample was measured with a Vibrating Sample Magnetometer (VSM – Lake Shore 7400) or, for larger obsidians, with a Cryogenic Magnetometer (Oxford Instrument Cryomagnet), with a maximum applied field B = ±1 T. Samples were tightly clamped on the holder using diamagnetic tape. Such measurements were furthermore repeated at two temperatures, 293 K and 77 K, for all the samples, in the latter case maintaining obsidians in liquid nitrogen during the analysis. M_S values were interpolated through subtraction from the loop of the linear paramagnetic contribute emergent at high magnetizing fields.

2.2.4 Cluster Analysis

As former studies have shown, overlaps may occur in the confidence intervals of the various magnetic parameters obtained from the different obsidian sources. To overcome this limitation, multi-variate analysis was applied using Cluster 3.0 software. The results were graphically represented using Java Treeview, an open-source software platform that can handle very large datasets allowing the visualization and comparison of the data.

3. Results

The results of the magnetic parameters measured for all the archaeological obsidian samples are analytically reported in Table 1. These parameters are similar to those used by Zanella et al. (2012) on geological samples from Lipari (Canneto, Diana, and Piano Conte), Palmarola, Pantelleria, Sardinia (SA, SB1, SB2, and SC), and Melos. However, to allow the direct comparison between the archaeological and geological samples, avoiding discrepancies due to possible different ways of calculating the various parameters, the previously published magnetic results from the Mediterranean geological obsidians (Zanella et al. 2012) are reported in Table 2, using the same calculations, parameters, ratios and format as those used for the archaeological samples in this study (Table 1).

The IRM curves obtained for representative archaeological samples (GUI 38, CDA 04, CDA 08) at 293 K and 77 K are plotted in Fig. 3, together with the same plots from typical geological samples from Lipari, Sardinia (SB) and Melos. Such curves indicate that most of the archaeological obsidians show large changes in IRM while passing from room temperature to liquid nitrogen temperature, resembling the behavior shown by the geological obsidians from Lipari (Fig. 3). These data are also confirmed by the hysteresis loops obtained at 293 K and 77 K (Fig. 4). In almost all cases the loops obtained at 77 K have larger magnetic moment than those obtained at 293 K, while an important paramagnetic contribution is clearly seen, with linear increase of the magnetic moment at high fields, accompanied by a large increase of the coercive force (e.g. Fig. 4 g, j, k). These samples have a similar behavior to that obtained from geological samples from Lipari (Fig. 4a), which contain a large amount of superparamagnetic (SP) grains whose magnetization is not stable at room temperature (Zanella et al. 2012). In other cases, the increase of magnetization and coercive field when measured at low temperature (77K) is not as large as in the previous samples (e.g. Fig. 4 f, i). Finally, there are also few samples showing a very important change of magnetic moment between room and liquid nitrogen temperature, characterized by an almost linear behavior of the magnetic moment versus field, with a faint ferrimagnetic content and a large paramagnetic contribution (e.g. Fig. 4 e, h).

The anhysteretic and low-field magnetic susceptibilities measured from both archaeological and geological samples have been plotted in a King plot (King et al. 1982) in Fig. 5. It can be noticed that most of the archaeological samples coincide with low values in the χ_a vs. χ plot, similar to the geological samples from Lipari, with the exception of some samples mainly coming from Piedmont. However, as already pointed out by Zanella et al. (2012), the King plot does not succeed to entirely discriminate the different geological sources, particularly between samples from Lipari and Sardinia SA and samples from Palmarola and Melos, which are generally characterized by similar χ_a vs. χ values. For this reason, the ratio $Q_a = \chi_a / \chi$ and the ratio $S_T = SIRM_{77}/SIRM_{293}$, proposed by Zanella et al. (2012), have been calculated and plotted in Fig. 6 introducing also the anisotropy of susceptibility P, graphically represented as three-dimensional plots (Fig. 6). These plots seem to be more effective in separating the different obsidian groups, in particular the geological obsidians from Sardinia SA and those from Lipari (Fig. 6 a), confirming that the use of the parameter P can be essential for separating the different sources. The three-dimensional representations are also effective to distinguish the provenance of most archaeological samples. The samples from Parma clearly group with the geological samples from Lipari (Fig. 6 a) as most of the samples from Piedmont, which also distribute preferentially around the geological obsidians from Lipari (Fig. 6b), with some exceptions mainly for the samples from Casalnoceto and Castello d'Annone that show scattered values, probably indicating various possible sources (Fig. 6 b, c).

Finally, the normalized quantities χ, χ_a, Q_a, $SIRM_{293}$, $SIRM_{77}$, S_T, M_R/M_S, and P were elaborated using cluster analysis and the obtained results are plotted in the form of dendrograms (Fig. 7). The multivariate analysis has been conducted on the normalized magnetic parameters, so it is not possible to quantify definitely the distances among different obsidian groups. However, such analysis can offer a qualitative interpretation based on the relative distances among the groups, which can be appreciated through the ordinate value reported in the graphs, or the height of the line connecting the different clusters. Compound clusters are in fact formed by joining individual obsidians having the shorter distance in the multivariate space, with the join point referred to as a node. Numerical correlations among different objects and groups in the dendrogram are thus proportional to their Euclidean distance that corresponds to the value of the vertical axis and refers to the measure between adjacent individual objects or compound clusters. As we move up in the dendrogram, the compound clusters get bigger and the distance between adjacent clusters increases. Indeed, the cluster analysis applied on the geological samples shows that all the geological sources, including Sardinia SA, clearly separate (Fig. 7 a). Samples from Sardinia SB1 and SC, having lower SP and larger single domain (SD) grains, differentiate neatly from all the other sources and constitute a separate group. Samples from Pantelleria also group separately as well as samples from Lipari that are well grouped and form a distinct cluster.

The same dendrograms have been used to identify the provenance of the archaeological samples studied here, based on their magnetic affinity to the geological groups. Although introducing the archaeological obsidians in the multivariate analysis slightly modifies the relative distances of the dendrograms, yet it seems that such analysis can successfully separate the different groups. For the samples from Parma, the cluster analysis (Fig. 7b) clearly associates all of them to Lipari. For the sites of Garbagna, Casalnoceto, and Cascina Chiappona the dendrogram confirms Lipari as a source of 7 samples (Fig. 7c). From Casalnoceto, two samples (Ossi 14 and Ossi 20) seem to group with samples from Palmarola, as already indicated by the hysteresis loops and the King Plot (Fig. 5). Few other samples from Piedmont are grouped with samples from Sardinia SA, mainly due to their high values of P and Q_a. All samples from Brignano Frascata are also clustered close to Sardinia geological obsidians (Fig. 7c). Among the 22 obsidians from Castello d’Annone, 9 samples group directly with Lipari and 11 have Palmarola as the only possible alternative to Lipari; CDA17 is probably an outlier, although it groups with Sardinia SB1 but at a large distance (Fig. 7d).

4. Discussion and conclusions

Even though obsidian is a complex volcanic material, which can contain different magnetic phases that may influence its magnetic properties, depending on the concentration, shape and grain-size of the ferromagnetic grains, yet this study shows that the investigation of several magnetic parameters and their combinations can be a useful tool for obsidian sourcing studies. Criticisms persists on the possibility to apply magnetic granulometry for obsidian provenance in regions where outcrops of volcanic glasses show inhomogeneous magnetic features (Frahm et al. 2012; 2014; 2016; Rochette et al. 2015); nevertheless this technique is available in addition to compositional and geochronological analysis for matching artifacts to a specific obsidian source among Mediterranean outcrops. For this purpose, we suggest the use of seven simple and easily measured magnetic parameters (low field and anhysteretic susceptibilities, saturation isothermal remanent magnetizations at room, 293 K, and liquid nitrogen, 77 K, temperature, saturation and remanent magnetizations, and anisotropy of low field susceptibility), as a reference dataset for comparison between archaeological and geological obsidian magnetic behavior. In respect to the previously proposed parameters, we introduce here the use of P that seems to be effective on distinguishing obsidians with similar Q_a and S_T values.

We have applied this approach to obsidian archaeological samples from six Neolithic sites in Northern Italy, comparing them with the magnetic properties of geological obsidians from the five major volcanic islands of the Mediterranean (Lipari, Sardinia, Palmarola, Pantelleria, and Melos). Our results show that the combined use of the King plot and Q_a vs. S_T plots, introducing also the degree of anisotropy, P, in three-dimensional representations, can effectively discriminate the origin of the archaeological obsidian tools. The applied multivariate analysis on the dataset, based on combined parameters as vectors in a multidimensional space, further contributes to provenance studies allowing the correlation with the volcanic sources when geological and archaeological samples fall in the same cluster.

According to our results, most of the archaeological obsidians from Northern Italy investigated in this study come from Lipari, with some other sources being also present. Indeed, cluster analysis shows that all the archaeological samples from Parma are well grouped with the geological samples from Lipari and most of the samples from Casalnoceto and Cascina Chiappona also gather with Lipari geological obsidians. Samples from Castello d'Annone show a more varied origin with some samples coming from Lipari and other clustering with geological samples from Palmarola and Pantelleria. All three studied samples from Brignano Frascata seem to come from Sardinia. We haven't observed any systematic correlation between the provenance of the obsidians and their use (e.g. bladelets and nodules). That's probably because most of the investigated samples were bladelets and only five nodules were included in our archaeological obsidian collection, so that it is not possible to drive clear conclusions on such a possible correlation.

The results obtained here are in good agreement with other studies investigating the distribution of archaeological obsidians in Northern Italy based on chemical analysis. Even though finds of obsidians are comparatively rare in Northern Italy, early provenance studies have identified obsidians from more than one source, mainly coming from Sardinia and Lipari, with more sites shown to use Liparian obsidian rather than Sardinian one (Thorpe et al. 1979). Tykot (1996) reports that at the Italian Middle Neolithic site of Gaione-Parma, obsidian from Sardinia, Palmarola and Lipari is present, with a strong tendency towards blades being of Lipari obsidian and cores and trim of Sardinian obsidian. Analyses from several Neolithic stratigraphic contexts from the archaeological site of Arene Candite-Savona show that lithic assemblage from Early Neolithic comes equally from Sardinia and Palmarola. However, in the Middle Neolithic, obsidian from Lipari replaces much of the Sardinian SA and SB contribution while by the Late Neolithic nearly all obsidian artefacts are finished blades of obsidian from Lipari (Ammerman and Polglase 1998; Costa 2007). According to these authors, Lipari, notwithstanding its greater distance in comparison with Sardinia and Palmarola, come to play an ever-increasing role in the exchange of obsidian in Northern Italy, probably because of its high quality and its circulation as a prestige item in later Neolithic times, characterized by greater demand. Our results further support such hypothesis, confirming Lipari as the main obsidian source in Northern Italy. They also confirm that most of the studied archaeological sites belong to the

Middle – Late Neolithic, while for the sites were various obsidian sources were identified, an older age cannot be excluded.

Acknowledgement

Marica Venturino (Soprintendenza per i Beni Archeologici del Piemonte e del Museo Antichità Egizie) and Maria Bernabò Brea (Soprintendenza Archeologica dell'Emila Romagna and Museo Archeologico Nazionale di Parma) are warmly acknowledged for providing the archaeological obsidian samples and for their precious collaboration and discussion. The Editor and two anonymous reviewers are also acknowledged for their useful and constructive comments.

References

Ammerman A.G, Polglase C. (1998). Obsidian at Neolithic sites in Northern Italy. Preistoria Alpina, 34, 291-296.

Bernabò Brea M., Ghiretti A., Polglase C., Visconti V. (1988). I siti neolitici lungo il torrente Cinghio (Parma). Preistoria Alpina – Museo Tridentino di Scienze Naturali, 24, 103-164.

Bigazzi G., Marton P., Norelli P., Rozloznik L. (1990). Fission track dating of Carpathian obsidians and provenance identification. Nuclear Tracks and Radiation Measurements 17(3), 391-396.

Cann J. R., Renfrew C. (1964). The Characterization of Obsidian and Its Application to the Mediterranean. Region. Proc. Prehistoric Soc. (30), 111–133.

Costa L. J. (2007). L'obsidienne. Un témoignage d'échanges en Méditerranée préhistorique. Editions Errance, Paris.

Frahm E., Feinberg J. M. (2013). From flow to quarry: magnetic properties of obsidian and changing the scale of archaeological sourcing. Journal of Archaeological Science, 40 (10), 3706–3721. http://dx.doi.org/10.1016/j.jas.2013.04.029

Frahm E., Feinberg J. M., Schmidt-Magee B., Wilkinson K., Gasparyan B., Yeritsyan B., Karapetian S., Meliksetian K., Muth M. J., Adler D. S. (2014). Sourcing Geochemically Identical Obsidian: Multiscalar Magnetic Variations in the Gutansar Volcanic Complex and Implications for Palaeolithic

Research in Armenia. Journal of Archaeological Science 47, 164-178. http://dx.doi.org/10.1016/j.jas.2014.04.015

Frahm E., Feinberg J. M., Schmidt-Magee B.A., Wilkinson K. N., Gasparyan B., Yeritsyan B., Adler D.S. (2016). Middle Palaeolithic toolstone procurement behaviors at Lusakert Cave 1, Hrazdan valley, Armenia. Journal of Human Evolution, 91, 73-92.

Freund K.P. (2018). A long-term perspective on the exploitation of Lipari obsidian in central Mediterranean prehistory. Quaternary International 468, 109-120.

King J., Banerjee S. K., Marvin J., Ozdemir Ö. (1982). A comparison of different magnetic methods for determining the relative grain size of magnetite in natural materials: Some results from lake sediments, Earth Planet. Sci. Lett., 59, 404–419. Doi:10.1016/0012-821X(82)90142-X

Lanci L., Zanella E. (2016). The anisotropy of magnetic susceptibility of uniaxial superparamagnetic particles: Consequences for its interpretation in magnetite and maghemite bearing rocks Journal of Geophysical Research, 121 (1), pp. 27–37. Doi:10.1002/2015JB012255

Liritzis I., Laskaris N. (2011). Fifty years of obsidian hydration dating in archaeology. Journal of Non-Crystalline Solids 357 (10), 2011-2023.

McDougall J. M., Tarling D. H., Warren S. E. (1983). The magnetic sourcing of obsidian samples from Mediterranean and near Eastern sources. Journal of Archaeological Science 10, 441-452.

Mameli V., Musinu A., Niznansky D., Peddis D., Ennas G., Ardu A., Luglià C., Cannas C. (2016). Much More than a Glass: The Complex Magnetic and Microstructural Properties of Obsidian, Journal of Physical Chemistry C, 120 (48), 27635-27645. doi:10.1021/acs.jpcc.6b08387

Poupeau G., Le Bourdonnec F. X., Dubernet S., Scorzelli R. B., Duttine M., Carter T. (2007). Tendances actuelles dans la caractérisation des obsidiennes pour les études de provenance, ArchéoSciences, 31, 79-86.

Quero T. (2014). The early Bronze Age site of Eia (Parma). Traces in Time n. 4, 1-5.

Renfrew C., Cann J. R., Dixon J. E. (1965). Obsidian in the Aegean, Ann. British School Athens 60, 225.

Rochette P., Gattacceca J., Devouard B., Moustard F., Bezaeva N.S., Cournède C., Scaillet B. (2015). Magnetic properties of tektites and other related impact glasses. Earth and Planetary Science Letters 432, 381-390.

Scorzelli R.B., Petrick S., Rossi A.M., Poupeau G., Bigazzi G. (2001). Obsidian archaeological artefacts provenance studies in the Western Mediterranean basin: an approach by Mossbauer spectroscopy and electron paramagnetic resonance, Comptes rendus de l’académie des sciences, série ii, fascicule *a* - sciences de la terre et des planètes 332 (12), 769-77.

Stewart S.J., Cernicchiaro G., Scorzelli R.B., Poupeau G., Acquafredda P., De Francesco A. (2003). Magnetic properties and ^{57}Fe Mössbauer spectroscopy of Mediterranean prehistoric obsidians for provenance studies. Journal of Non-Crystalline Solids, 323, 188-192.

Thorpe O.W., Warren S.E., Barfield L.H. (1979). The sources and distribution of archaeological obsidian in Northern Italy. Preistoria Alpina, 15, 73-92.

Tarling D. H., Hrouda F. (1993). The Magnetic Anisotropy of Rocks. London, Glasgow, New York, Tokyo, Melbourne, Madras: Chapman & Hall.

Tykot R.H. (1996). Obsidian procurement and distribution in the Central and Western Mediterranean. Journal of Mediterranean Archaeology, 9, 39-82.

Tykot R. H. (2002). Chemical Fingerprinting and Source Tracing of Obsidian: The Central Mediterranean Trade in Black Gold. Accounts on Chemical Research 35, 618–627. doi: 10.1021/ar000208

Urrutia Fucugauchi, J. (1999). Preliminary results of a rock-magnetic study of obsidians from central Mexico. Geofisica International, 38, 83-94.

Vásquez C.A., Nami H., Rapalini A. (2001). Magnetic sourcing of obsidians in Southern South America: some successes and doubts. Journal of Archaeological Science, 28, 613-618.

Venturino Gambari M. (1988). Alessandria, loc. Cascina Chiappona. Saggio di accertamento in area di insediamento di età preistorica (tavv. XIII-XIV). Quaderni della Soprintendenza del Piemonte 7, 43-53.

Venturino Gambari M. (1993). Casalnoceto, loc. Cascina Cascinetta. Strutture di abitato del Neolitico medio (tavv. LXXXVIII – XC). Quaderni della Soprintendenza del Piemonte, 11, 195-225.

Venturino Gambari M. (2004). Alla conquista dell'Appennino: le prime comunità delle valli Curone, Grue e Ossona. Omega Edizioni, Torino.

Weaver I., Sternberg R., Tykot R. H. (2009). Magnetic fingerprinting of Central Mediterranean obsidian source groups. In AGU Spring Meeting Abstracts 1, 4.

Zanella E., Ferrara E., Bagnasco L., Ollà A., Lanza R., Beatrice C. (2012). Magnetite grain-size analysis and sourcing of Mediterranean obsidians, Journal of Archaeological Science 39 (5), 1493–1498.

Figure captions

Fig. 1. Map of Italy with the location of the obsidian samples collected from six Neolithic archaeological sites situated in Northern Italy. The main Mediterranean obsidian sources are also indicated.

Fig. 2. Obsidian archaeological tools found at the archaeological site of Parma (via Guidorossi).

Fig. 3. Isothermal acquisition curves obtained at ambient (293 K) and liquid nitrogen (77 K) temperatures for representative a-c) geological and d-f) archaeological samples.

Fig. 4. Examples of hysteresis cycles at 293 K and 77 K for geological samples from a) Lipari, b) Palmarola, c) Sardinia SC, and archaeological samples d-l) from several archaeological sites in Northern Italy.

Fig. 5. King plot, showing the anhysteretic susceptibility, χ_a, vs. low-field magnetic susceptibility, χ, from the archaeological samples studied here and the geological obsidians from several Mediterranean sources (Zanella et al., 2012).

Fig. 6. Three-dimensional graphs comparing the magnetic parameters of geological samples from volcanic islands of the Mediterranean and archaeological samples from a) Parma; b) Brignano Frascata, Cascina Chiappona, Casalnoceto and Garbagna (samples Ossi, Table 1) and c) Castello d'Annone.

Fig. 7. Dendrograms obtained after cluster analysis (Euclidean distance) of the magnetic parameters for a) the geological samples from various Mediterranean sources; b) geological obsidians and archaeological samples from Parma; c) geological obsidians and archaeological samples from Piedmont sites of Garbagna, Cascina Chiappona, Brignano Frascata, and Casalnoceto archaeological sites; d) geological obsidians and archaeological samples from Piedmont site of Castello d'Annone.

Table captions

Table 1. Magnetic data of the archaeological obsidian samples.

Columns: Name of the archaeological site; Sample code; Mass in g; χ= low-field magnetic susceptibility; χ_a = anhysteretic magnetic susceptibility; Q_a = χ_a/ χ susceptibility ratio, $SIRM_{293}$= saturation of isothermal remanence magnetization at 293K; $SIRM_{77}$= saturation of isothermal remanence magnetization at 77K, $S_{T77/293}$ = SIRM ratio; M_R/ M_S = magnetic remanence to saturation ratio; P= anisotropy degree of the magnetic susceptibility.

Table 2. Magnetic data of geological samples from several Mediterranean obsidian sources. Revised results from Zanella et al. (2012). Columns as in Table 1.

Table I

Archaeological Site	Sample	Mass (g)	χ (10^{-8} m^{3}kg^{-1})	χ_a (10^{-7} m^{3}kg^{-1})	$Q_a = \chi_a / \chi$	SIRM$_{293}$ (10^{-4} Am^{2}kg^{-1})	SIRM$_{77}$ (10^{-4} Am^{2}kg^{-1})	S_T	M_R/M_S	P
Garbagna	Ossi 6	0.266	19.75	2.70	1.37	35.64	128.95	3.60	0.17	1.19
Cascina Chiappona	Ossi 7	0.385	14.56	2.06	1.41	34.54	105.46	3.10	0.19	1.28
	Ossi 8	0.079	8.39	1.43	1.71	17.60	49.37	2.80	0.19	1.03
	Ossi 9	0.109	17.47	2.71	1.55	40.18	137.61	3.40	0.17	1.04
Brignano Frascata	Ossi 10	0.604	81.80	63.38	7.75	319.54	913.91	2.90	0.25	1.21
	Ossi 11	0.287	38.73	8.46	2.18	109.41	223.69	2.00	0.24	1.25
	Ossi 12	0.813	6.03	0.12	0.19	0.039	0.086	2.20	0.02	1.10
Casalnoceto	Ossi 13	0.277	9.26	1.45	1.57	16.86	66.24	3.90	0.18	1.06
	Ossi 14	0.235	88.11	24.11	2.74	371.49	631.91	1.70	0.28	1.06
	Ossi 15	0.159	11.66	1.98	1.67	23.71	99.06	4.20	0.18	1.07
	Ossi 16	0.114	12.00	2.15	1.79	25.26	109.65	4.30	0.17	1.04
	Ossi 17	0.217	15.50	2.41	1.55	30.28	101.38	3.30	0.17	1.14
	Ossi 18	0.219	15.11	2.84	1.88	28.90	125.11	4.30	0.18	1.06
	Ossi 19	1.953	15.43	2.88	1.87	38.50	140.30	3.60	0.25	1.03
	Ossi 20	4.150	82.16	17.99	2.19	650.53	939.66	1.44	0.36	1.06
Castello D'Annone	CDA I	0.547	14.81	==	==	==	==	==	0.19	1.12
	CDA II	0.222	63.96	18.7	2.92	139.64	340.99	2.44	0.25	1.03
	CDA III	0.299	39.80	9.3	2.33	64.88	203.68	3.14	0.29	1.03
	CDA IV	0.288	111.46	16.2	1.45	227.43	920.14	4.05	0.17	1.05
	CDA V	0.174	34.48	15.5	4.51	51.72	228.16	4.41	0.13	1.01
	CDA 1	0.384	30.74	9,30	3,02	44.54	80.75	1.81	0.12	1.01
	CDA 2	0.091	130.17	9.25	0.71	339.09	1192.30	3.52	0.16	1.02
	CDA 3	0.081	110.93	16.16	1.46	327.87	1664.00	5.08	0.15	1.03
	CDA 4	0.205	140.31	15.54	1.11	265.03	1373.87	5.18	0.13	1.02
	CDA 5	0.078	123.65	9.29	0.75	217.67	725.14	3.33	0.12	1.05
	CDA 6	0.161	118.35	44.23	3.74	267.21	984.77	3.69	0.20	1.03
	CDA 7	1.029	100.44	18.99	1.89	266.17	972.97	3.66	0.21	1.06
	CDA 8	0.136	41.20	20.43	4.96	82.77	232.50	2.81	0.22	1.06
	CDA 9	0.132	70.37	13.41	1.91	175.56	535.75	3.05	0.15	1.06
	CDA 10	0.096	159.46	23.44	1.47	334.55	1286.40	3.85	0.14	1.07
	CDA 11	0.260	60.40	18.21	3.01	151.95	500.10	3.29	0.24	1.09
	CDA 12	0.334	30.55	13.87	4.54	38.31	74.58	1.95	0.19	1.09
	CDA 13	0.128	145.77	19.34	1.33	289.18	1056.43	3.65	0.12	1.09
	CDA 14	0.021	111.00	32.16	2.90	590.25	1414.09	2.40	0.14	1.10
	CDA 15	0.140	72.86	16.35	2.24	165.71	637.14	3.84	0.16	1.08
	CDA 16	0.019	213.54	10.74	0.50	584.90	2432.29	4.16	0.11	1.09
	CDA 17	0.035	795.98	14.98	0.19	4482.76	5804.60	1.29	0.42	1.05
Parma via Guidorossa	GUI 37	0.311	13.897	1.43	1.03	57.60	139.99	2.43	0.10	1.07
	GUI 38	0367	11.559	1.25	1.08	24.09	103.81	4.31	0.15	1.04
	GUI 39	0.303	11.716	1.52	1.30	27.22	106.57	3.92	0.14	1.03
	GUI 40	0.110	8.545	0.55	0.64	23.50	57.06	2.43	0.15	1.03
	GUI 41	0.424	17.684	1.97	1.11	45.10	153.48	3.40	0.23	1.09
	GUI 43	0.123	15.528	2.01	1.29	33.64	115.91	3.45	0.13	1.03
	GUI 44	0.426	10.561	1.78	1.68	42.92	98.50	2.30	0.22	1.05
	GUI 45	0.354	7.068	1.09	1.55	25.59	53.95	2.11	0.23	1.03
	GUI 46	0.223	19.045	2.10	1.10	64.19	165.19	2.57	0.12	1.07

	GUI 47	0.142	10.282	1.24	1.21	29.89	101.47	3.40	0.16	1.06
	GUI 49	0.161	15.627	1.31	0.84	32.41	120.45	3.72	0.19	1.09
	GUI 50	0.219	12.466	0.86	0.69	116.94	379.98	3.25	0.11	1.06
	GUI 51	0.626	12.414	1.01	0.82	25.55	90.53	3.54	0.11	1.13
	GUI 54	0.056	43.786	6.01	1.37	150.16	358.81	2.39	0.19	1.04
	GUI 59	0.296	12.946	1.37	1.06	25.98	55.81	2.15	0.17	1.09
	GUI 61	0.049	39.755	2.44	0.61	209.31	312.94	1.50	0.24	1.02
	GUI 63	0.096	16.458	1.21	0.74	41.09	142.15	3.46	0.11	1.05
	GUI 64	1.100	23.609	2.48	1.05	66.08	193.79	2.93	0.15	1.20
	GUI 67	0.443	14.253	1.25	0.88	37.75	127.89	3.39	0.13	1.12
	GUI 68	0.148	6.486	0.64	0.98	18.24	50.13	2.75	0.13	1.04

Table II

.	Sample	Mass (g)	χ (10^{-8} m^{3}kg^{-1})	χ_a (10^{-7} m^{3}kg^{-1})	$Q_a = \chi_a / \chi$	$SIRM_{293}$ (10^{-4} Am^{2}kg^{-1})	$SIRM_{77}$ (10^{-4} Am^{2}kg^{-1})	S_T	M_R/M_S	P
Lipari Canneto	C2A1	4.38	7.70	0.85	1.10	10.90	41.98	3.85	0.08	1.04
	C2A2	2.42	20.40	2.16	1.06	45.12	108.75	2.41	0.08	1.05
	C4A1	3.33	17.60	2.26	1.28	33.19	95.83	2.89	0.06	1.03
	C4A2	2.95	20.20	2.28	1.13	18.33	71.44	3.90	0.07	1.08
Lipari Piano Conte	PC2B1	3.86	25.20	2.33	0.92	58.54	210.41	3.59	0.10	1.06
	PC2B2	3.56	47.50	5.60	1.18	117.25	321.25	2.74	0.10	1.08
	PC2B3	3.84	12.80	1.16	0.91	25.38	110.00	4.33	0.05	1.08
	PC3B1	3.27	28.00	2.87	1.03	61.19	252.86	4.13	0.07	1.06
	PC3B2	2.82	7.40	0.96	1.30	14.24	49.03	3.44	0.06	1.06
Lipari Diana	D2B1	3.28	16.40	2.29	1.40	22.48	71.98	3.20	0.06	1.05
	D2B2	2.75	15.30	4.30	2.81	53.69	116.54	2.17	0.06	1.05
	D1B1	4.35	18.90	3.99	2.11	68.71	161.43	2.35	0.15	1.01
	D1B2	3.23	30.90	3.44	1.11	59.16	143.71	2.43	0.12	1.06
	D1B3	3.04	9.00	1.23	1.37	18.32	63.30	3.46	0.09	1.07
Palmarola	Pa3B1	3.96	79.20	21.85	2.76	257.32	617.04	2.40	0.13	1.03
	Pa3B2	3.74	58.70	13.99	2.38	248.73	600.18	2.41	0.12	1.06
	Pa3B3	1.78	74.30	19.04	2.56	287.41	524.48	1.82	0.13	1.04
	Pa3B4	3.62	62.50	11.28	1.80	304.86	524.05	1.72	0.15	1.11
	Pa5B	3.40	60.70	13.96	2.30	254.64	487.62	1.91	0.18	1.04
Pantelleria	Pan1	1.95	14.50	0.60	0.41	0.93	1.28	1.37	0.01	1.01
	Pan2	2.91	14.90	0.37	0.25	0.76	1.10	1.44	0.01	1.01
	Pan3	2.73	15.90	0.54	0.34	1.54	3.16	2.04	0.01	1.01
Melos	B1A1	2.80	76.00	19.96	2.63	205.15	212.48	1.04	0.13	1.19
	B1A2	5.19	59.00	13.83	2.34	175.85	215.47	1.23	0.14	1.13
	B1A3	4.82	63.40	13.79	2.18	162.66	189.54	1.17	0.12	1.20
	B4B1	3.57	56.10	12.70	2.26	131.00	175.27	1.34	0.12	1.14
	B4B2	5.53	69.00	17.96	2.60	131.59	168.53	1.28	0.12	1.20
Mt. Arci SA	SAA1	2.34	18.50	6.21	3.36	56.31	102.77	1.83	0.08	1.15
	SAA2	2.75	24.50	5.95	2.43	74.32	173.65	2.34	0.11	1.13
	SAA3	1.36	26.80	8.26	3.08	85.74	176.38	2.06	0.09	1.17
	SAA4	3.59	15.20	4.32	2.84	41.02	92.65	2.26	0.01	1.15
Mt. Arci SB1	SB1B1	2.98	313.10	190.80	6.09	943.82	864.61	0.92	0.29	1.16
	SB1B2	2.62	403.10	254.90	6.32	1433.92	1094.51	0.76	0.29	1.17
	SB1B3	4.22	126.40	67.20	5.32	916.49	937.30	1.02	0.29	1.13
Mt. Arci SB2	SB2A1	2.98	92.60	25.50	2.75	185.73	410.60	2.21	0.09	1.11
	SB2A2	2.25	72.00	19.20	2.67	256.88	611.46	2.38	0.08	1.14

	SB2A3	3.71	72.70	17.00	2.34	155.95	377.03	2.42	0.08	1.22
Mt. Arci SC	SCB1	3.67	119.70	457.60	38.23	440.30	574.00	1.30	0.20	1.07
	SCB2	1.85	116.20	433.80	37.33	838.26	1132.83	1.35	0.20	1.03
	SCB3	3.77	122.20	269.90	22.09	595.48	666.19	1.12	0.20	1.08