NEOLITHIC EXPLOITATION AND TRADE OF OBSIDIAN IN THE CENTRAL MEDITERRANEAN: NEW RESULTS AND IMPLICATIONS FOR CULTURAL INTERACTION

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Résumé : Les objets fabriqués de l'obsidienne ont été trouvés à beaucoup sites préhistoriques dans le central Méditerranéen, jusqu'à centaines de kilomètres de leurs sources géologiques sur les îles de Lipari, Palmarola, Pantelleria, et Sardaigne. Nouvelles études de ces sources ont eu de l'emplacement plus précis et documentation de chaque courant de l'obsidienne ou affleurement pour résultat, et autorise la considération des facteurs tel qu'accès (par exemple topographie, distance de côte), dimension et fréquence des nodules, et mécanique et propriétés visuelles, dans leur exploitation. Physique et le chimique analyse de nombres grands des spécimens géologiques démontre l'utilité des méthodes pour identifier des sources, par exemple mesure précise de densité, et analyse d'élémentaire et de la composition isotopique. Analyses de nombres grands des objets fabriqués démontrent l'usage différentiel de subsources de la île, et suggère des motifs particuliers et des mécanismes pour leur exploitation. Les modèles spatiaux et chronologiques de distribution de l'obsidienne peuvent être utilisés pour adresser tel public comme la colonisation des îles; la présentation des économies du Néolithique; et la complexité sociale croissante des Néolithiques et les sociétés de l'âge du bronze dans le central Méditerranéen.

Abstract: Obsidian artifacts have been found at many prehistoric sites throughout the central Mediterranean, many of them up to hundreds of kilometers from their geological sources on the islands of Lipari, Palmarola, Pantelleria, and Sardinia. New geoarchaeological surveys of these sources have resulted in the more precise location and documentation of each obsidian flow or outcrop, and allow the consideration of factors such as access (e.g. topography, distance from coast), size and frequency of nodules, and mechanical and visual properties, in their exploitation. Physical and chemical analyses of large numbers of geological specimens demonstrates the utility of methods such as high precision density measurement, as well as elemental and isotopic fingerprinting, in identifying sources. Analyses of large numbers of artifacts demonstrate the differential use of island subsources, and suggest particular motives and mechanisms for their exploitation. The spatial and chronological patterns of obsidian distribution may be used to address such issues as the colonization of the islands; the introduction of Neolithic economies; and the increasing social complexity of Neolithic and Bronze Age societies in the central Mediterranean.

INTRODUCTION

Obsidian sourcing has been a major aspect of archaeological research for more than a quarter-century (Cann & Renfrew 1964; Williams-Thorpe 1995; Tykot 2002a), yet until recently the central Mediterranean sources were not all fully documented (Fig. 1). Furthermore, while many studies (e.g. Hallam *et al.* 1976; Williams-Thorpe *et al.* 1979; 1984; Crisci *et al.* 1994; Bigazzi & Radi 1996) have contributed to a general picture of obsidian distribution, the source analysis of artifacts mostly has been limited to small numbers from any one site, limiting the determination of regional and chronological patterns of obsidian use (Tykot & Ammerman 1997).

Our current NSF-funded geoarchaeological survey of obsidian sources on Lipari, Palmarola and Pantelleria has employed a systematic approach to the documentation of the multiple localities where obsidian may be found, and complements previous work done on the Monte Arci sources in Sardinia (Tykot 1997; 1998). The analysis of over 1200 artifacts from dated archaeological contexts will allow geographic and chronological patterns of specific source exploitation to be recognized (for results on Sardinian obsidian, see Tykot 1996; 2001; 2002b; 2002c). These data will be used to test models of maritime capabilities, identify interconnections between island and mainland populations, and to reconstruct the economic and sociopolitical role of obsidian and other raw materials in prehistoric Mediterranean societies.

OBSIDIAN IN THE CENTRAL MEDITERRANEAN

Obsidian was used in the central Mediterranean primarily during the Neolithic period (ca. 6000-3000 BC) for blade and flake tool technologies. The sources on Lipari, Pantelleria and Palmarola are widely thought to have been a major factor in the initial settlement of these islands. Although Sardinia was settled earlier, the exploitation of its obsidian sources only began in the Neolithic. The detailed analysis of obsidian sources and mechanisms of exploitation, along with typological and use wear studies promise to provide important insights into the socioeconomic structures of Neolithic societies in this region (Tykot 1999).

Previous research on the multiple obsidian sources in the Monte Arci region of Sardinia has revealed differential patterns of exploitation which may be attributed to chronological and cultural change, as well as geographic variation and the availability of alternative lithic raw materials. These patterns were only revealed through the systematic characterization of each obsidian source locality and the analysis of large numbers of archaeological artifacts. Distinctly different patterns of utilization of Sardinian obsidian existed at archaeological sites in France, where type SA accounts for more than 90% of the Sardinia obsidian, compared to Sardinia, Corsica and northern Italy, where it accounts for less than 50% (Tykot 1996; 2002b; 2002c; Williams-Thorpe *et al.* 1979; 1984; Crisci *et al.* 1994; Ammerman & Polglase 1997; Poupeau *et al.* 2000; de

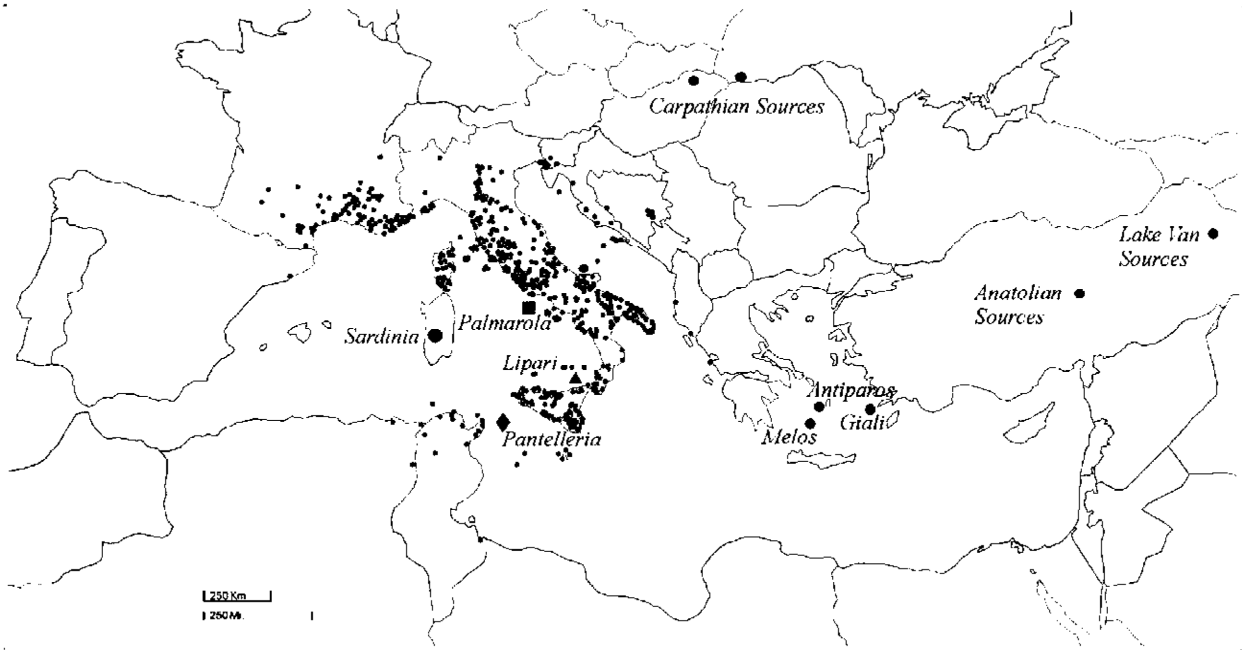

Figure 1. Obsidian sources in the Mediterranean area, and archaeological sites where obsidian has been found in the central Mediterranean. Sites in Sardinia not shown.

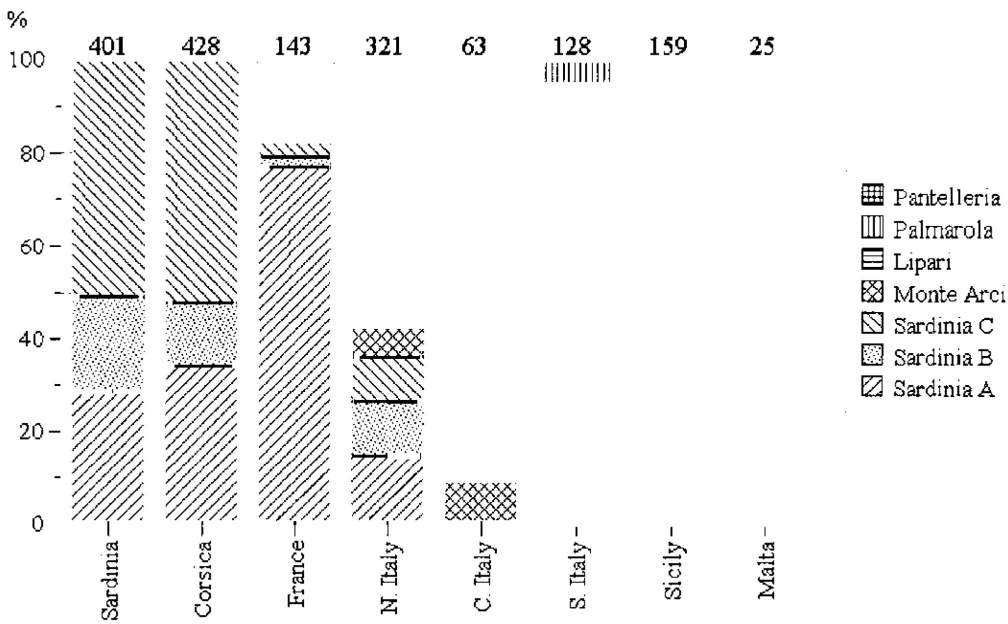

Figure 2. Regional frequencies of obsidian source usage in the central Mediterranean. Data from published sources cited in the text. Most fission track analyses attribute obsidian to Monte Arci (Sardinia) without differentiating between subsources. The number of artifacts analyzed is shown at the top of each bar.

Francesco & Crisci 2000) (Fig. 2). This could be explained by different trade and transport mechanisms, the availability of other lithic raw materials, particular obsidian use functions, and/or selection for certain visual and physical properties.

In other areas of the central Mediterranean, obsidian from Lipari, Palmarola, and Pantelleria was used more frequently. While obsidian from Lipari clearly has the widest distribution, Palmarola obsidian is quite common in archaeological assemblages in central Italy, and Pantelleria contributes a significant percentage at sites in Sicily, Malta, and Tunisia (Bigazzi & Radi 1996; Francaviglia & Piperno 1987; Nicoletti 1997). This project is proceding to characterize these other island sources using the same detailed and comprehensive approach, with the expectation that previously unknown patterns of exploitation and distribution will be revealed. Geoarchaeological fieldwork was conducted in 2000 and 2001 to fully document each source and obtain samples for physical and chemical characterization studies. The preliminary results of this research are reported here.

LIPARI

On Lipari, eruptions during the historic period have significantly changed the island's landscape and obscured most of the obsidian outcrops available during the Neolithic (Buchner 1949; Pichler 1980). Settlements on Lipari dating to the Neolithic have been identified, however, as have large workshops in nearby western Calabria (Ammerman 1985). Earlier geochemical studies by Francaviglia (1986) and others were unable to distinguish more than one source on Lipari, and fission-track dates on 66 artifacts of Lipari obsidian from archaeological sites in Italy include only one determination older than 12,500 BP (Bigazzi & Radi 1996), suggesting that most if not all of the obsidian used in antiquity was the result of a single geological episode.

In our survey, more than 1200 geological samples were collected from over 40 localities, each precisely marked using a hand-held global positioning system unit (Fig. 3). Workable obsidian was found along the eastern and northern coasts (perhaps a mixture of prehistoric and recent flows), as well as inland at Gabellotto and above Canneto, Papesca, and Acquacalda. The *in situ* obsidian located on Monte della Guardia appears to be mostly of unworkable quality. Detailed examination of both these geological samples and prehistoric artifact assemblages has revealed at least two visual types of Lipari obsidian, one black and highly transparent, the other gray-banded, often with many spherulites present. Dating of each deposit will confirm its age, and chemical analyses will reveal whether more than a single 'island' fingerprint exists.

PALMAROLA

Palmarola is a tiny island with no evidence of prehistoric settlement, and until recently its geological history has not been widely studied (Barberi *et al.* 1967; Tethys srl 2000). In the Neolithic, obsidian was likely obtained by seasonal fishermen coming from the mainland or the nearby island of Ponza. Obsidian on Palmarola is primarily to be found along its southeastern and northwestern shores, near Punta Vardella and Monte Tramontana, respectively. A geochemical investigation by Herold (1986) failed to reveal any differences among the deposits on the island, although fission track dates on artifacts (Bigazzi & Radi 1996) suggests a range in their age of formation.

In the current study, over 300 geological samples were collected from 10 localities (Fig. 4). At least two visually distinguishable types of workable obsidian have been identified, including some specimens from the northern part of Punta Vardella that are quite transparent and visually similar to the most commonly used type of obsidian from Lipari, although the size and quantity of workable nodules is much more limited on Palmarola. The obsidian recovered from the southern part of Punta Vardella and from Monte Tramontana, however, is grey to black and nearly opaque (and difficult to visually distinguish from opaque Sardinian obsidian). Only devitrified obsidian of unworkable quality was found *in situ* anywhere else on the island. Preliminary results from elemental analysis of the geological specimens from Palmarola indicate that these three source localities are chemically distinguishable so it will be possible to determine whether obsidian for artifacts was selected from one or more of them.

PANTELLERIA

Pantelleria is located ca. 120 km from Sicily and ca. 90 km from Tunisia, making it the most remote obsidian source in the Mediterranean. Nevertheless, obsidian from Pantelleria is regularly found at Neolithic sites in Sicily and Malta, and may even have been settled itself in the Neolithic. Five chemical groups of Pantellerian obsidian had been described by Francaviglia (1988), but were not all based on the analysis of geological samples. While it is generally thought that most artifacts of Pantellerian obsidian probably come from the Balata dei Turchi sources at the southern end of the island, chemical analysis of Bronze Age artifacts from sites on Pantelleria (Francaviglia 1988), in Sicily (Francaviglia & Piperno 1987), and on Ustica (Tykot 1995) shows that obsidian from near Lago di Venere and Gelkhamar was also used. Furthermore, fission-track dates on archaeological artifacts from other sites have a range of nearly 100,000 years, suggesting the use of multiple source flows (Bigazzi & Radi 1996).

In 2000-2001, over 900 samples were collected from some 35 localities on Pantelleria (Fig. 5). Three vertically distinct obsidian flow layers were confirmed at both Balata dei Turchi and at Salta La Vecchia, apparently representing different eruptive cycles. Much smaller quantities of obsidian were found *in situ* within pumice deposits near Lago di Venere, but only surface finds of workable quality were observed near Gelkhamar, perhaps the product of airborn distribution or of erosion from a mostly buried deposit. Two extensive workshop areas were also located near Balata dei Turchi. Pantellerian obsidian may be easily distinguished from the other Mediterranean sources by its dark green color in transmitted light, and at least two visual types have been identified; preliminary results from elemental analysis confirm the existence of at least five chemical groups to which artifacts can be specifically attributed.

MONTE ARCI, SARDINIA

On Sardinia, all of the obsidian exploited in antiquity comes from the Monte Arci region in the west central part of the island. The existence of two or three chemical groups was

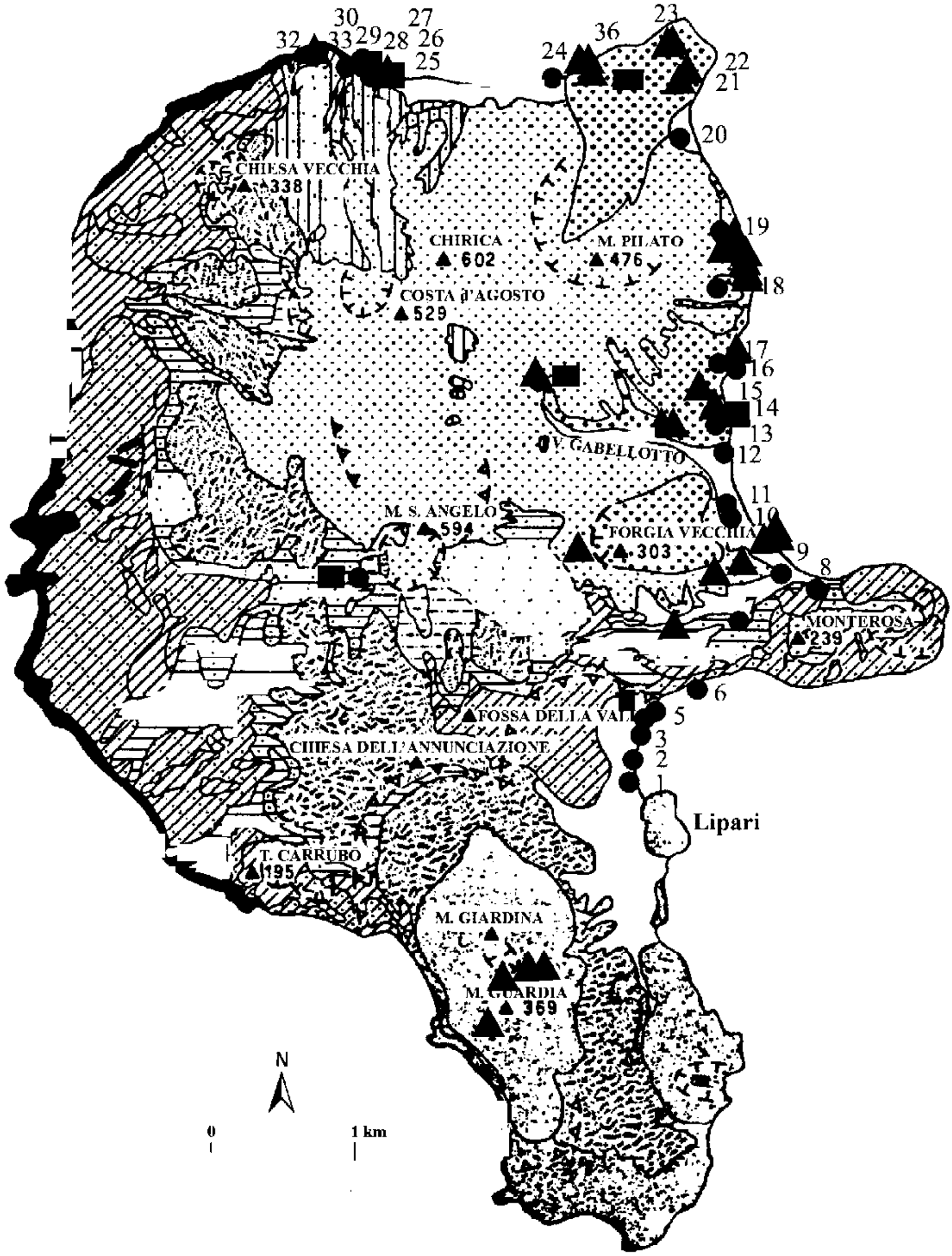

Figure 3. Map of Lipari showing localities where geological samples of obsidian were collected in this study.

revealed from early analyses of central Mediterranean artifacts (Cann & Renfrew 1964; Hallam *et al.* 1976), although it was not until later that the geological sources themselves were identified and fully characterized (Mackey & Warren 1983; Francaviglia 1986; Herold 1986; Tykot 1997; 1998) (Fig. 6). Best known is type SA from the Conca Cannas area, very glassy and highly translucent; the SC1 and SC2 chemical groups, represented by large blocks found between Punta Pizzighinu and Perdas Urias on the northeast side of Monte Arci, are less glassy and mostly opaque. Type SB2, which ranges from highly transparent to nearly opaque and with phenocrysts, also occurs in large natural blocks but apparently less frequently, on the western slopes of Monte Arci near Cucru Is Abis, Seddai, and Conca S'Ollastu. Type

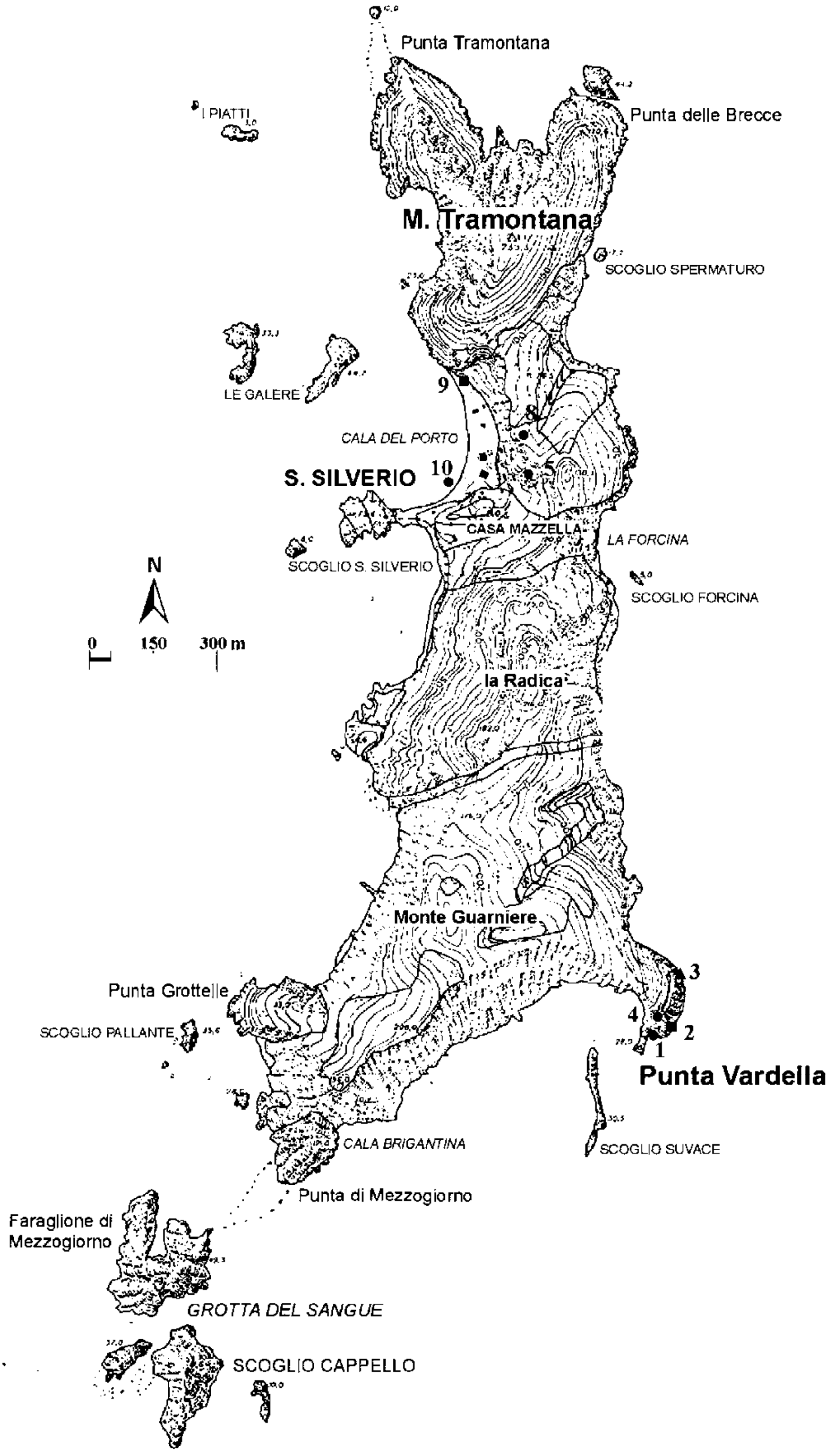

Figure 4. Map of Palmarola showing localities where geological samples of obsidian were collected in this study.

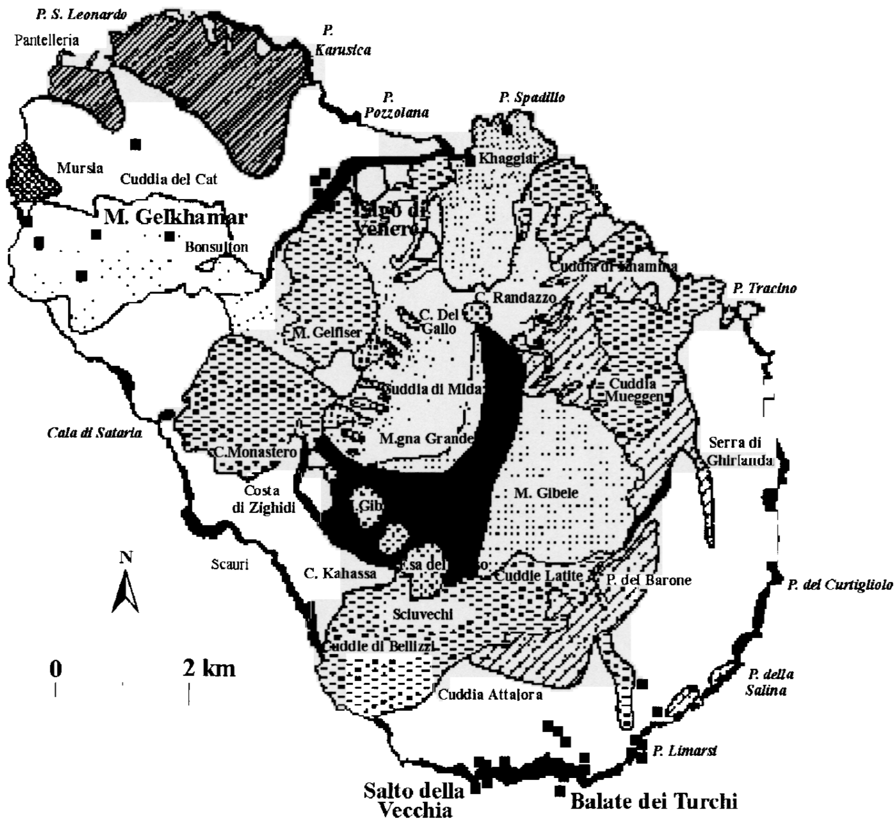

Figure 5. Map of Pantelleria showing localities where geological samples of obsidian were collected in this study.

SB1, not nearly as well represented among artifacts, actually represents three chemically distinct source localities at high elevations east of Santa Maria Zuarbara (Tykot 2001). Survey of the Monte Arci region by Puxeddu (1958) revealed over 200 archaeological sites and several workshops, including the major production center of Mitza Sa Tassa near Perdas Urias where additional fieldwork to document this site has recently begun.

VISUAL ANALYSIS

Most provenance studies of obsidian have depended on chemical analyses which take advantage of the homogeneous elemental composition of most sources and the significant differences between each of them., although visual and physical characteristics are also useful in many cases (Tykot 2002a). Since the latter are inexpensive and non-destructive techniques, the ability to use them on very large numbers of artifacts, even if not 100% accurate, may counter-balance the statistical limitations of small numbers of chemically-sources artifacts (even if 100% accurate), and therefore should be investigated first (Tykot & Ammerman 1997). In our studies, physical attributes including workability, color, transparency, luster, and the presence and orientation of microlite crystals, larger phenocrysts, and banding are recorded for all samples. Lipari obsidian is black-grey and either very transparent or streaked with microlites and phenocrysts. Palmarola obsidian is black but opaque, although some transparent obsidian was found near Punta Vardella. Pantellerian obsidian is nearly opaque but its green color can be seen in thin edges. The color and translucency of the Pantellerian sources appears to have some systematic variation. Were it not for the several Sardinian obsidian sources, which appear similar to Lipari (SA, SB2) and to Palmarola (SB1, SB2, SC), it would be possible to reliably attribute artifacts found at Neolithic central Mediterranean sites at least to its source island based on visual means. By starting with visual assessments on artifacts from many Neolithic sites, some may be attributed without further analysis, allowing physical and chemical methods to be used as necessary on those still questionable. It must be remembered, however, that significant Neolithic usage patterns and differences have only been revealed through specific intra-island source attribution and visual analysis alone will rarely be sufficient for this purpose.

DENSITY

High resolution measurement of density (specific gravity) has also revealed systematic variation among Sardinian obsidian sources, and is an important factor in the calibration of hydration dates (Stevenson & Ellis 1998). Density was

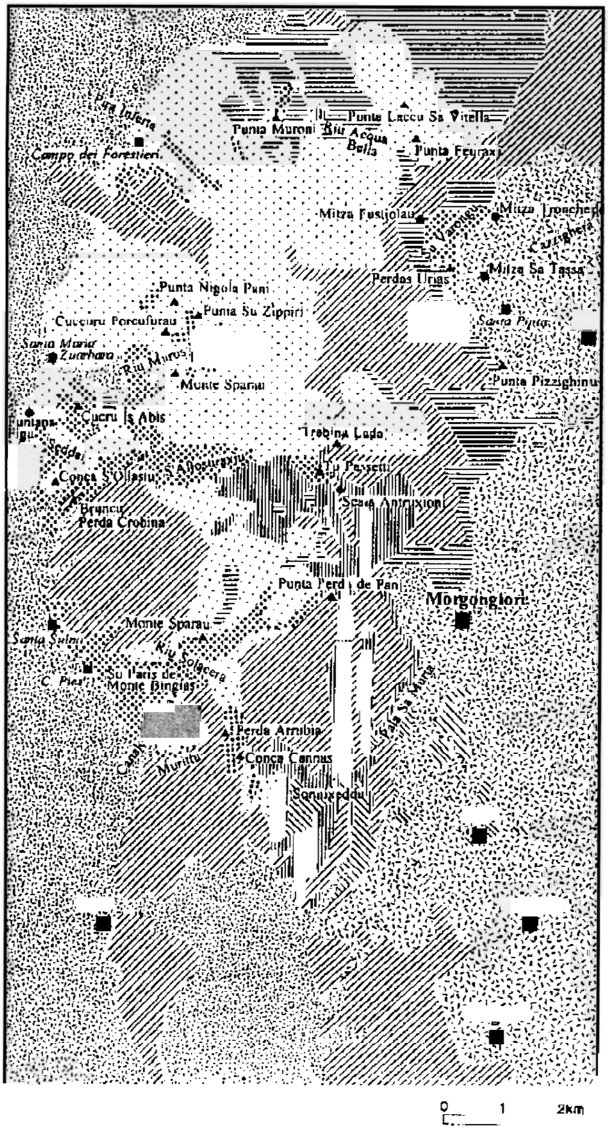

Figure 6. Map of Sardinia showing major geological source localities (after Tykot 1997).

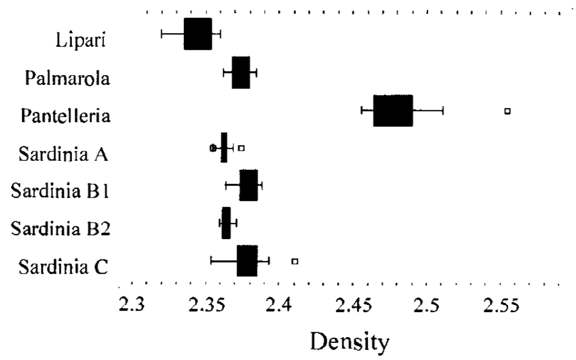

Figure 7. Box-and-whisker plot of obsidian density.

therefore also determined for geological samples collected from Lipari, Palmarola, Pantelleria, and Sardinia using a Mettler electronic balance with precision to five decimal places. Cleaned pieces of obsidian were weighed and their volume determined using the water displacement method. Results indicate that Lipari, Palmarola and Pantelleria are mostly non-overlapping, while some of the Pantellerian sources (Lago di Venere: 2.51 " 0.03; Balata dei Turchi 1: 2.46 " 0.02; Balata dei Turchi 2: 2.62 " 0.03) may also be differentiated (Fig. 7). The combination then of visual analysis and density measurement can be quite reliable for attributing artifacts to a single island, and in the case of Pantelleria some more specific source localities.

ELEMENTAL ANALYSIS

For the last quarter-century, the vast majority of provenience studies of central Mediterranean obsidian using chemical analysis relied on neutron activation analysis (e.g. Hallam *et al.* 1976; Williams-Thorpe *et al.* 1979; 1984; Crummett & Warren 1985; Bigazzi *et al.* 1986; Ammerman *et al.* 1990; Randle *et al.* 1993; Ammerman & Polglase 1997) or X-ray fluorescence (Francaviglia 1986; Francaviglia & Piperno 1987; Crisci *et al.* 1994; Giardino *et al.* 1998; De Francesco *et al.* 1998; De Francesco & Crisci 2000; Poupeau *et al.* 2000). While all were successful in attributing artifacts to an island source, some were unable to specify a particular island sub-source either because their laboratory database did not include samples from the different subsources or they were unable to calibrate their results against already published data for these subsources. Of course none attributed artifacts to the specific Palmarola subsources only recognized in the present study, but it is particularly notable for the Sardinian artifacts in some of these studies as well.

Results from the present study are now available for 320 geological samples from Lipari, Palmarola, Pantelleria, and Sardinia, comprehensively analyzed using several analytical techniques (at least 200 more are being analyzed). At the Missouri University Research Reactor Laboratories, instrumental neutron activation analysis was used to measure 27 major and trace elements, while X-ray fluorescence was used for 23 and laser ablation ICP mass spectrometry for more than 30 major and trace elements. This multi-method approach was designed to fully characterize the geological sources using the 'technique of the future' while allowing cross-referencing with previously published data on artifacts (mostly XRF and NAA) which may be reexamined and found sufficient to attribute them to specific island subsources. Abbreviated protocols for future analyses of obsidian artifacts are also being developed to maximize information about specific source exploitation while minimizing analytical costs and damage to artifacts. Laser ablation ICP-MS appears to best satisfy these requirements as it produces quantitative elemental (and even isotopic) data for the smallest of artifacts while leaving only the tiniest surface scar (Tykot & Young 1996; Gratuze 1999) (Fig. 8).

As already indicated, trace element analysis of the Sardinian samples show seven distinct groups, but the four most significant (SA, SB1, SB2, SC) are also differentiable using major element analysis (Figs. 9-10). So when it is already

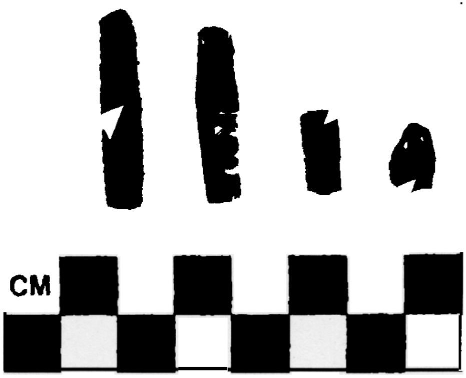

Figure 8. Barely visible laser ablation ICP-MS craters.

known that artifacts are made of Sardinian obsidian (e.g. by a combination of site location and date, visual and density analysis), other techniques such as the electron microprobe are also sufficient for source specific attribution (Tykot 1997). The preliminary results available for Lipari fall into a single chemical group, although analyses for several localities have not yet been completed, so at present there is no advantage of one elemental technique over another for artifacts made of Lipari obsidian. Obsidian from Palmarola falls into three distinct groups, while at least five groups are present among the samples analyzed from Pantelleria; in both cases trace element analysis is necessary to attribute artifacts to their specific source locality. It must be noted that certain methods which have been successfully used to attribute artifacts to a particular island, including fission track dating and elemental analysis using a scanning electron microscope (Acquafredda *et al.* 1999), cannot distinguish among the island subsources.

SOURCE TRACING OF ARTIFACTS

Obsidian is very commonly found at Neolithic sites in the central Mediterranean, although in generally decreasing frequency at greater distance from the sources. Long-standing research efforts by a few scholarly groups have revealed a general pattern of obsidian distribution in the region although, as mentioned above, the number of sites for any one cultural period and with more than a few analyzed artifacts is still quite limited (Williams-Thorpe 1995; Tykot 1996; Bigazzi & Radi 1996) (Fig. 11). Nevertheless, it is becoming clear that obsidian from Palmarola, rarely documented previously in northern Italy, is actually well represented at a few sites (Ammerman *et al.* 1990; Ammerman & Polglase 1997), while Pantellerian obsidian is continuously present in the Neolithic levels of Grotta dell'Uzzo in Sicily (Francaviglia & Piperno 1987) and common elsewhere (Nicoletti 1997), when Lipari was previously thought to be a nearly exclusive source for Sicily. Lipari appears to have been the main source, however, of obsidian distributed in the Adriatic, both along the Italian coast and across to the islands of Palagruza, Susac, Korcula, and elsewhere along the Dalmatian coast (Tykot *et al.* 2001).

The similar relative frequencies of the Sardinian obsidian sources in Early Neolithic assemblages in northern Sardinia, Corsica, and Tuscany are supportive of a simple down-the-line trade mechanism, while the dominance of type SA obsidian in southern France must reflect specific selection for cultural preferences and/or functional reasons (Tykot 1996; 1999; 2002b; Tykot *et al.* 2002). Chronological change has also been documented at individual sites such as Arene Candide in Liguria, where it has been proposed that a shift occurred in the Late Neolithic towards the presence of

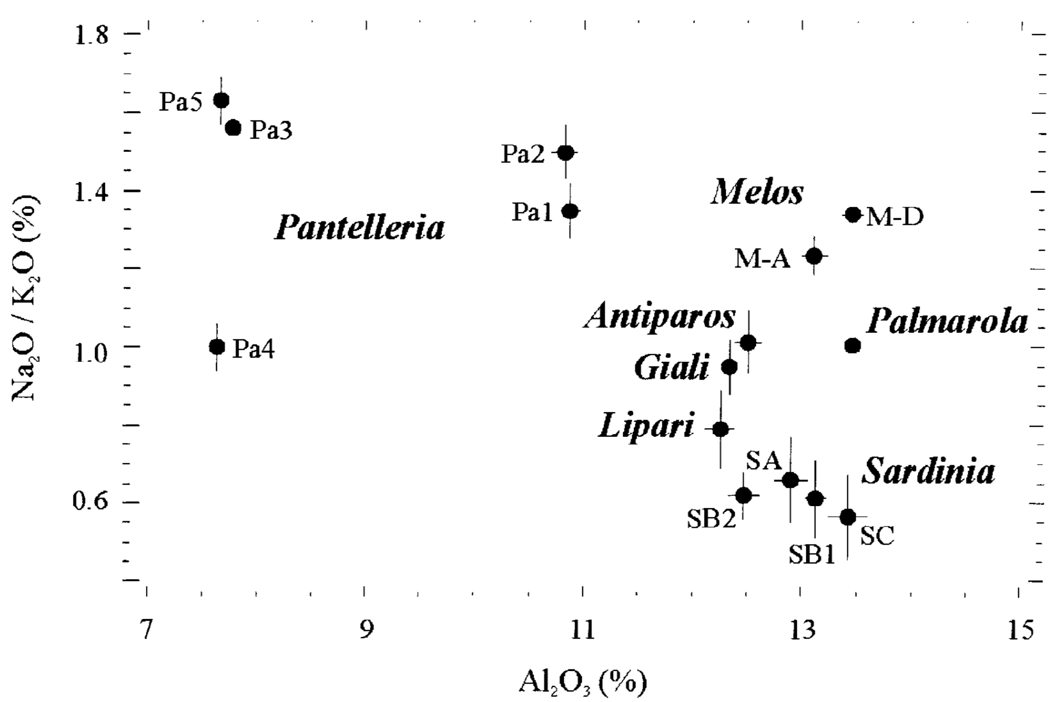

Figure 9. Major element plot of Mediterranean obsidian sources. Data from Francaviglia (1986; 1988) and Tykot (1997).

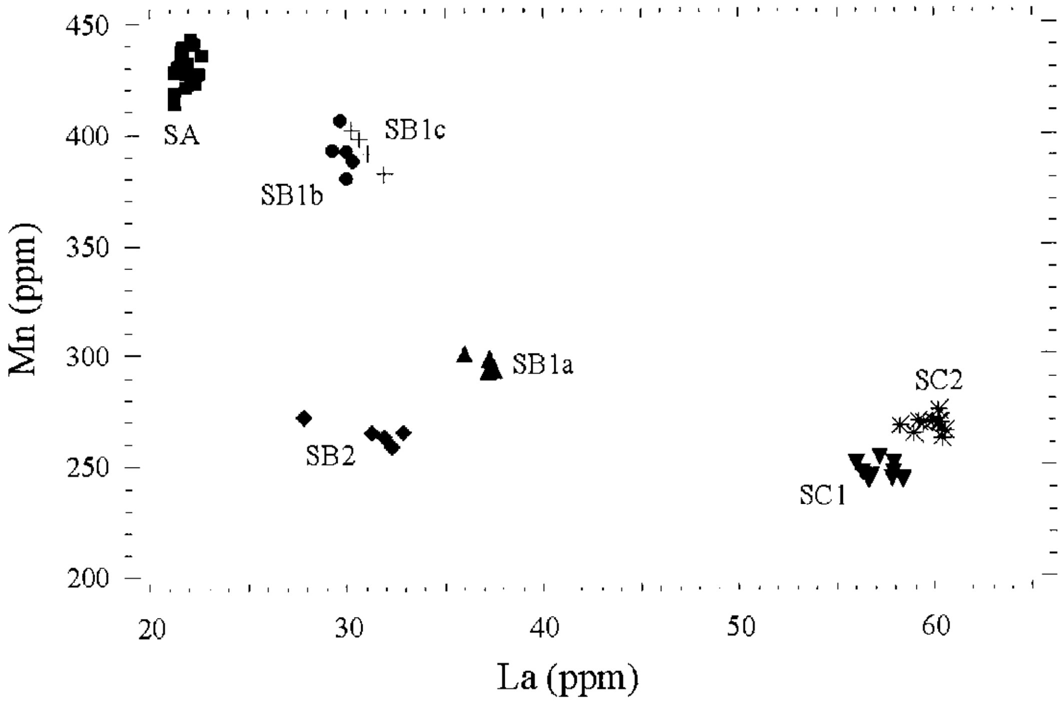

Figure 10. Trace element plot showing 7 sources on Sardinia. Similar plots show 3 sources on Palmarola and 5 on Pantelleria.

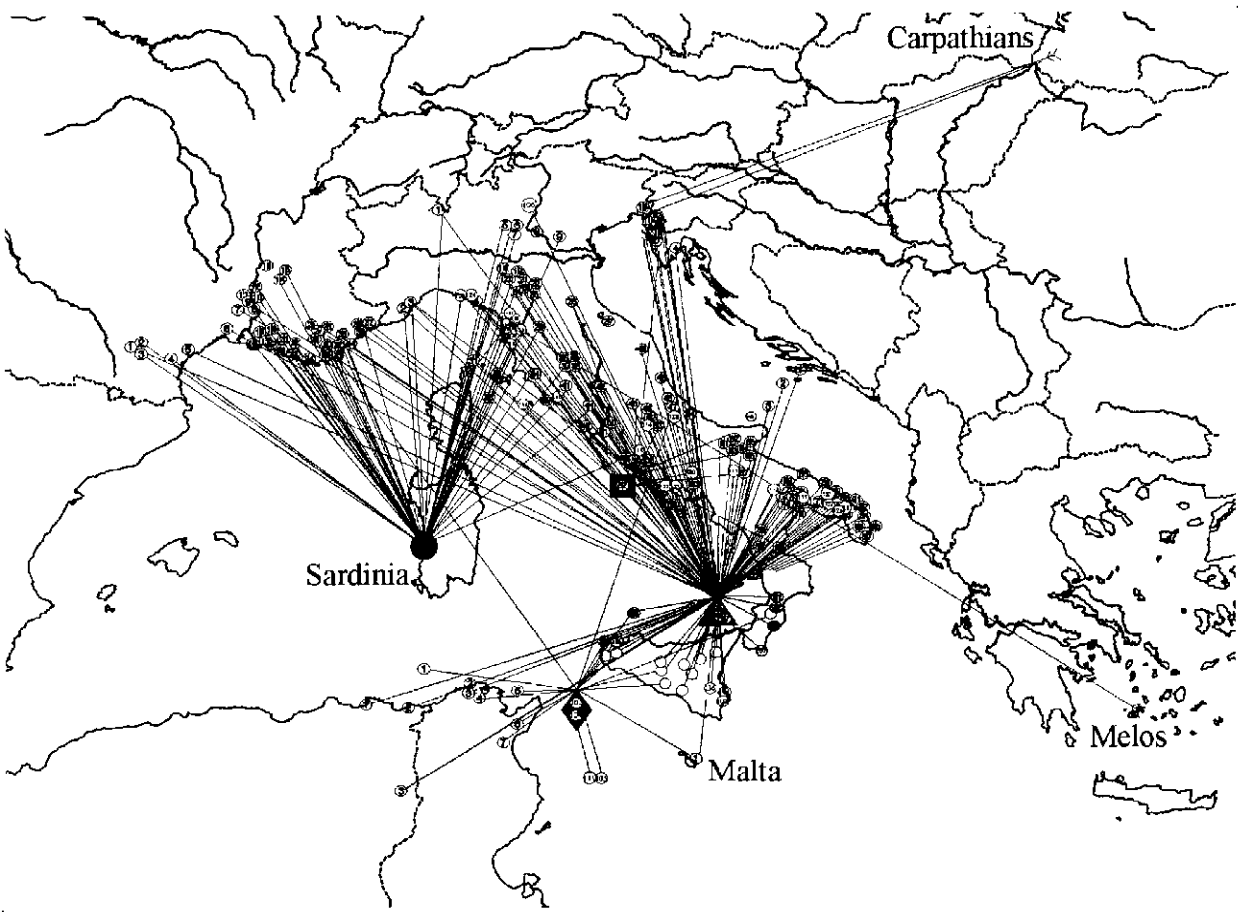

Figure 11. General distribution pattern of obsidian from central Mediterranean sources for the Neolithic period. All obsidian tested from Corsica and Sardinia (individual sites not shown) has been attributed to Monte Arci. At most sites, only a few artifacts have been tested, and the broad time span represented obscures chronological variation as well.

exclusively small blades of Lipari obsidian while Sardinian obsidian was obtained as both prepared cores and larger blades (Ammerman & Polglase 1997), and at Filiestru in Sardinia, where the decreasing frequency of types SA and SB obsidian may be explained by increasingly intense exploitation of obsidian with particular physical properties (Tykot 1996; 2002c). These patterns would not have been observed if the individual Monte Arci obsidian sources had not been documented and characterized, and perhaps provide a glimpse of the patterns which may become noticeable for the other central Mediterranean island sources and the interpretations that may be made about their exploitation.

CONCLUSION

While the characterization of the geological sources on Lipari, Palmarola and Pantelleria are still in progress, a much better understanding of the accessibility, quantity and quality of obsidian available from these islands for prehistoric exploitation already has been obtained, and the central Mediterranean island sources may be reliably distinguished based on their visual characteristics and density, both inexpensive and non-destructive techniques. Chemical analysis allows precise source attributions, and analyses of obsidian collections from significant archaeological sites are in progress which will double the number of artifacts tested for the entire region. This research will ultimately allow quantitative rather than qualitative assessment of obsidian exploitation and distribution during the Neolithic, and will be integrated with studies of typology, reduction technology and use function to reconstruct the entire *chaîne opératoire* from acquisition to tool disposal. Only in so doing can we interpret dynamic spatial and temporal behavior patterns in their functional and cultural contexts.

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Bibliography

ACQUAFREDDA, P., ANDRIANI, T., LORENZONI, S., & ZANETTIN, E., 1999, Chemical characterization of obsidians from different Mediterranean sources by non-destructive SEM-EDS Analytical Method. *Journal of Archaeological Science* 26, p. 315-325.

AMMERMAN, A.J., 1985, *The Acconia Survey: Neolithic Settlement and the Obsidian Trade*. London: Institute of Archaeology.

AMMERMAN, A. J., CESANA, A., POLGLASE, C. & TERRANI, M., 1990, Neutron activation analysis of obsidian from two Neolithic sites in Italy. *Journal of Archaeological Science* 17, p. 209-20.

AMMERMAN, A. & POLGLASE, C., 1997, Analyses and descriptions of the obsidian collections from Arene Candide. In *Arene Candide: A Functional and Environmental Assessment of the Holocene Sequence*, edited by R. Maggi. Rome: Il Calamo, p. 573-592.

BARBERI, F., BORSI, S., FERRARA, G., & INNOCENTI, F., 1967, Contributo alla conoscenza vulcanologica e magmatologica delle isole dell'arcipelago Pontino. *Memorie della Societa Geologica Italiana* 6, p. 581-606.

BIGAZZI, G., MELONI, S., ODDONE, M. & RADI, G., 1986, Provenance studies of obsidian artifacts: trace elements analysis and data reduction. *Journal of Radioanalytical and Nuclear Chemistry* 98, p. 353-63.

BIGAZZI, G. & RADI, G., 1996, Prehistoric exploitation of obsidian for tool making in the Italian peninsula: a picture from a rich fission-track data-set. In *XIII International. Congress Prehistoric and Protohistoric Sciences*, edited by C. Arias, A. Bietti, L. Castelletti & C. Peretto. Forlì: A.B.A.C.O., vol. 1, p. 149-156.

BUCHNER, G., 1949, Ricerche sui giacimenti e sulle industrie di ossidiana in Italia. I. *Rivista di Scienze Preistoriche* 4, p. 162-186.

CANN, J.R. & RENFREW, C., 1964, The characterization of obsidian and its application to the Mediterranean region. *Proceedings of the Prehistoric Society* 30, p. 111-133.

CRISCI, G.M., RICQ-DE BOUARD, M., LANZAFRAME, U., & DE FRANCESCO, A.M., 1994, Nouvelle méthode d'analyse et provenance de l'ensemble des obsidiennes néolithiques du Midi de la France. *Gallia Préhistoire* 36, p. 299-309.

CRUMMETT, J.G. & WARREN, S.E., 1985, Appendix I: Chemical analysis of Calabrian obsidian. In *The Acconia Survey: Neolithic Settlement and the Obsidian Trade*, edited by A.J. Ammerman. London: Institute of Archaeology, p. 103-114.

DE FRANCESCO, A.M. & CRISCI, G.M., 2000, Provenienza delle ossidiane dei siti archeologici di Pianosa (Arcipelago Toscano) e Lumaca (Corsica) con il metodo analitico non distruttivo in fluorescenza X. In *Il primo popolamento Olocenico dell'area corso-toscana*, edited by C. Tozzi & M.C. Weiss. Pisa: Edizioni ETS, p. 253-258.

DE FRANCESCO, A.M., CRISCI, G.M., & LANZAFAME, U., 1998, Nuovi sviluppi del metodo analitico non distruttivo in fluorescenza X per risalire all provenienza di ossidiane archeologiche. In *Le Scienze della Terra e l'Archeometria*, edited by C. D'Amico & C.A. Livadie. Napoli: Cuen, p. 141-145.

FRANCAVIGLIA, V.M., 1986, Characterization of Mediterranean obsidian sources by classical petrochemical methods. *Preistoria Alpina* 20, p. 311-332.

FRANCAVIGLIA, V.M., 1988, Ancient obsidian sources on Pantelleria (Italy). *Journal of Archaeological Science* 15, p. 109-122.

FRANCAVIGLIA, V.M. & PIPERNO, M., 1987, La repartition et la provenance de l'obsidienne archeologique de la Grotta dell'Uzzo et de Monte Cofano (Sicile). *Revue d'Archéométrie* 11, p. 31-39.

GIARDINO, C., GUIDI, G.F., MOIOLI, P. & NEGRI, P., 1998, Correlazione mediante spettrometra XRF di reperti i ossidiana provenienti da Capri con ossidiane del bacino del Mediterraneo. In Le Scienze della Terra e l'Archeometria, edited by C. D'Amico & C.A. Livadie. Napoli: Cuen, p. 295-299.

GRATUZE, B., 1999, Obsidian characterisation by laser ablation ICP-MS and its application to prehistoric trade in the Mediterranean and the Near East: Sources and distribution of obsidian within the Aegean and Anatolia. *Journal of Archaeological Science* 26, p. 869-881.

HALLAM, B.R., WARREN, S.E., & RENFREW, C., 1976, Obsidian in the western Mediterranean: characterisation by neutron activation analysis and optical emission spectroscopy. *Proceedings of the Prehistoric Society* 42, p. 85-110.

HEROLD, G., 1986, *Mineralogische, chemische und physikalische untersuchungen an den obsidianen Sardiniens und Palmarolas: Grundlagen zur Rekonstruktion prähistorischer Handelswege im Mittelmeerraum.* Unpublished Ph.D thesis, Universität (TH) Fridericiana Karlsruhe.

MACKEY, M. & WARREN, S.E., 1983, The identification of obsidian sources in the Monte Arci region of Sardinia. In *Proceedings of the 22nd Symposium on Archaeometry, University of Bradford, Bradford, U.K. March 30th - April 3rd 1982*, edited by A. Aspinall & S.E. Warren. Bradford, p. 420-431.

NICOLETTI, F., 1997, Il commercio preistorico dell'ossidiana nel Mediterraneo ed il ruolo di Lipari e Pantelleria nel più antico sistema di scambio. In *Prima Sicilia: alle origini della società siciliana.* Siracusa: Ediprint, p. 259-269.

PICHLER, H., 1980, The island of Lipari. *Rendiconti della Società Italiana della Mineralogia e Petrologia* 36, p. 415-440.

POUPEAU, G., BELLOT-GURLET, L., BRISOTTO, V., & DORIGHEL, O., 2000, Nouvelles données sur la provenance de l'obsidienne des sites néolithiques du sud-est de la France. *C.R. Acad. Sci. Paris, Sciences de la Terre et des Planètes / Earth and Planetary Sciences* 330, p. 297-303.

RANDLE, K., BARFIELD, L.H. & BAGOLINI, B., 1993, Recent Italian obsidian analysis. *Journal of Archaeological Science* 20, p. 503-9.

STEVENSON, C.M. & ELLIS, J.G., 1998, Dating Sardinian archaeological obsidian. In *Sardinian and Aegean Chronology*, edited by M.S. Balmuth & R.H. Tykot. Oxford: Oxbow, p. 17-23.

TETHYS SRL (a cura di), 2000. *Evoluzione Quaternaria dell'Isola di Palmarola. Elementi geomorfologici emersi et sommersi.* Report produced for the Soprintendenza Archeologica per il Lazio, direzione scientifica Dott.ssa Annalisa Zarattini, Rome.

TYKOT, R.H., 1995, Appendix I: Obsidian Provenance. In *Ustica I. The Results of the Excavations of the Regione Siciliana Soprintendenza ai Beni Culturali ed Ambientali Provincia di Palermo in Collaboration with Brown University in 1990 and 1991*, edited by R.R. Holloway & S.S. Lukesh. Providence and Louvain-La-Neuve: Archaeologia Transatlantica XIV, p. 87-90.

TYKOT, R.H., 1996, Obsidian procurement and distribution in the central and western Mediterranean. *Journal of Mediterranean Archaeology* 9, p. 39-82.

TYKOT, R.H., 1997, Characterization of the Monte Arci (Sardinia) obsidian sources. *Journal of Archaeological Science* 24, p. ;467-479.

TYKOT, R.H., 1998, Mediterranean islands and multiple flows: the sources and exploitation of Sardinian obsidian. In *Method and Theory in Archaeological Obsidian Studies*, edited by M.S. Shackley. New York (NY): Plenum, p. 67-82.

TYKOT, R.H., 1999, Islands in the streams: stone age cultural dynamics in Sardinia and Corsica. In *Social Dynamics of the Prehistoric Central Mediterranean*, edited by R.H. Tykot, J. Morter & J.E. Robb. London: Accordia Research Institute, p. 67-82.

TYKOT, R.H., 2001, Chemical fingerprinting and source-tracing of obsidian: the central Mediterranean trade in black gold. *Accounts of Chemical Research* 36 (2002). Published on the web (http://dx.doi.org/10.1021/ar000208p) November 2001.

TYKOT, R.H., 2002a, Determining the source of lithic artifacts and reconstructing trade in the ancient world. In *Written in Stone: The Multiple Dimensions of Lithic Analysis*, edited by P.N. Kardulias & R. Yerkes. Maryland: Lexington Books.

TYKOT, R.H., 2002b, Geochemical analysis of obsidian and the reconstruction of trade mechanisms in the Early Neolithic of the western Mediterranean. In *Archaeological Chemistry* VI, edited by K. Jakes. American Chemical Society Symposium Series.

TYKOT, R.H., 2002c, New approaches to the characterization and interpretation of obsidian from the Mediterranean island sources. *Materials Research Society Symposium Proceedings* 712.

TYKOT, R.H. & AMMERMAN, A.J., 1997, New directions in central Mediterranean obsidian studies. *Antiquity* 71(274), p. 1000-1006.

TYKOT, R.H., BASS, B. & DELLA CASA, P. 2001. Obsidian as an indicator of prehistoric trade and interaction in the Adriatic basin. Paper presented at the 66th Annual Meeting of the Society for American Archaeology, New Orleans.

TYKOT, R.H., VARGO, B.A., TOZZI, C. & AMMERMAN, A., 2002. Nuove analisi di reperti di ossidiana rinvenuti nella provincia di Livorno. In *Atti del XXXV Riunione Scientifica, Le Comunità della Preistoria Italiana. Studi e Ricerche sul Neolitico e le Età dei Metalli in memoria di Luigi Bernabò Brea.* Firenze: Istituto Italiano di Preistoria e Protostoria.

TYKOT, R.H. & YOUNG, S.M.M., 1996, Archaeological applications of inductively coupled plasma-mass spectrometry. In *Archaeological Chemistry V*, edited by M.V. Orna. American Chemical Society: Washington, DC., p. 116-130.

WILLIAMS-THORPE, O., 1995, Obsidian in the Mediterranean and the near East: a provenancing success story. *Archaeometry* 37, p. 217-248.

WILLIAMS-THORPE, O., WARREN, S.E., & BARFIELD, L.H., 1979, The sources and distribution of archaeological obsidian in northern Italy. *Preistoria Alpina* 15, p. 73-92.

WILLIAMS-THORPE, O., WARREN, S.E., & COURTIN, J., 1984, The distribution and sources of archaeological obsidian from southern France. *Journal of Archaeological Science* 11, p. 135-46.