Archaeological Obsidian Studies

Method and Theory

Edited by

M. STEVEN SHACKLEY

University of California
Berkeley, California

Published in cooperation with the
Society for Archaeological Sciences

PLENUM PRESS • NEW YORK AND LONDON

Chapter 3

Mediterranean Islands and Multiple Flows

The Sources and Exploitation of Sardinian Obsidian

Robert H. Tykot

ABSTRACT

Obsidian tools found at prehistoric sites in the Mediterranean are evidence of a complex series of activities including procurement and transport of the raw material from island sources, production and distribution of cores or finished tools, and consumption and eventual disposal. Recent developments in the study of the western Mediterranean sources include the localization and characterization of five Monte Arci (Sardinia) sources used in antiquity; more detailed survey and characterization of the Lipari, Pantelleria, and Palmarola sources; and the provenance determination by ICP-mass spectrometry and electron probe microanalysis of more than 700 tools from sites in Italy and France doubles the provenance data previously available for reconstructing western Mediterranean exchange systems and provides a framework for interpreting the specific cultural context in which their acquisition was embedded. Furthermore, the analysis of samples from each stratigraphic level of multi-component sites such as Grotta Filiestru in Sardinia and Basi in Corsica allows for temporal control over three millennia. While differential use of the various

---

ROBERT H. TYKOT • Department of Anthropology, University of South Florida, Tampa, Florida.

Archaeological Obsidian Studies, edited by Shackley.
Plenum Press, New York, 1998.

obsidian sources has been recognized in peninsular Italy, it is apparent now that distribution patterns vary both geographically and chronologically, and in ways not explained by differences in accessibility or functional suitability between sources.

INTRODUCTION

The volume *Advances in Obsidian Glass Studies* (Taylor 1976) included a detailed assessment of the state of obsidian characterization studies in the Mediterranean at that time (Dixon 1976). By then, the first successful application of trace-element sourcing (Cann and Renfrew 1964) had spawned a number of more in-depth studies focusing on particular source regions (e.g. Hallam *et al.* 1976; Renfrew and Dixon 1976). In the western Mediterranean, the island sources of Lipari (Li), Palmarola (Pl), Pantelleria (Pa), and Sardinia (SA, SB, SC) could be differentiated from one another, and from the eastern Mediterranean sources of Melos (Sta Nychia and Demenegaki) and Giali (Fig. 3.1).

Dixon (1976: 289) identified four stages of increasing sophistication of obsidian characterization studies, which remains a useful measure for archaeologists interested in interpreting obsidian source data. At that time, provenance studies in the western Mediterranean region had not yet reached the routine stage where definitive results are produced, since the "source and sample data sets [for Sardinia] contained more diversity than is consistent with their relating to a single flow." Differentiating the Sardinian flows is important because it is a very large island (24,000 km^2) and, unlike the other Mediterranean source islands, was inhabited by an indigenous culture predating the earliest obsidian exploitation.

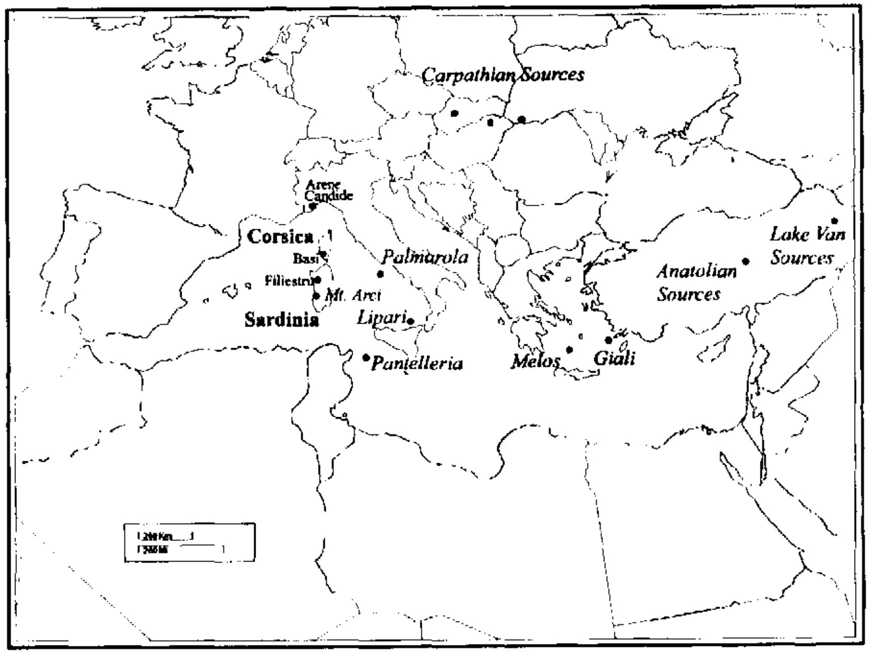

Figure 3.1. Obsidian sources in the Mediterranean region, with important sites mentioned in the text.

Obsidian has been identified at some 1000 western Mediterranean sites (Pollmann 1993), but none are demonstrably earlier than the Neolithic (ca. 6000–3000 BC). Obsidian is not even found in the pre-neolithic levels at sites in Sardinia and Corsica, where sea voyages would not have been an issue. It is thus apparent that obsidian served a social as well as functional role, perhaps as an ethnic identifier for populations culturally diversifying due to increased sedentism (Tykot 1996). This hypothesis is supported by the closed nature of the western Mediterranean obsidian exchange system, with only two pieces of Carpathian obsidian identified at north Adriatic sites near Trieste (Randle *et al.* 1993), and the only sure pieces of Melos obsidian from undatable contexts at Grotta del Leone near Pisa (Bigazzi *et al.* 1992b; 1986; Bigazzi and Radi 1981).

In the past twenty years, considerable effort has been expended to clarify the Sardinian source situation, and to find an optimal range of techniques for determining the provenance of archaeological artifacts. In this time, some 60 papers reporting analyses of geological and archaeological samples of western Mediterranean obsidian have been written (references in Tykot 1995). Much recent work has also been done in central Europe (Bigazzi *et al.* 1990; Williams Thorpe *et al.* 1984), the eastern Mediterranean (Torrence 1986), and the Near East (Keller and Seifried 1990), with the latest results presented in no less than 12 papers and posters at the 1994 International Archaeometry Symposium in Ankara, Turkey (cf. Phillips 1992 and most recently Williams-Thorpe 1995 for a review of European and Near Eastern obsidian provenance studies).

For the western Mediterranean, recent developments include: (1) the localization and characterization of five Monte Arci (Sardinia) sources used in antiquity (Tykot 1996; 1995; 1992; Herold 1986; Francaviglia 1984; Mackey and Warren 1983); (2) more detailed survey and characterization of the Lipari (Cortese *et al.* 1986; Pichler 1980), Pantelleria (Francaviglia 1988; Mahood and Hildreth 1986) and Palmarola (Herold 1986) volcanic sources; (3) the ability to differentiate all of the Mediterranean island sources, including 4 of 5 Sardinian subsources, using major/minor element composition; and (4) significant numbers of chemical analyses of western Mediterranean archaeological artifacts (Tykot 1996; 1995; Ammerman and Polglase 1996; 1993; Crisci *et al.* 1994; Randle *et al.* 1993; Bigazzi *et al.* 1992b; Ammerman *et al.* 1990; Francaviglia 1988; Francaviglia and Piperno 1987; Crummett and Warren 1985;

Michels *et al.* 1984; Williams Thorpe *et al.* 1984; 1979; Mackey and Warren 1983). These data permit not only the reconstruction of prehistoric exchange networks but also more accurate obsidian hydration rate measurements for refining cultural chronologies (Dyson *et al.* 1990; Michels 1987).

MULTIPLE METHODS

Archaeological interest in source tracing has fueled many experimental efforts at finding analytical methods appropriate for obsidian artifacts. Analysis of archaeological materials must always take into account the size of the artifact, whether a sample may be removed, and any factors which might affect the interpretation of analyses of ancient samples against a database of modern geological specimens. In addition, the cost and time of analyses should not dilute a provenance study to the point where insufficient data are produced to answer particular archaeological questions.

Neutron activation analysis and X-ray fluorescence are by far the most common—and successful—geochemical techniques used to source obsidian, relying on inter-source variation in trace element content being greater than intra-source heterogeneity. Attempts at using Mössbauer spectroscopy (Aramu *et al.* 1983; Longworth and Warren 1979), magnetic parameters (McDougall *et al.* 1983) and electron spin resonance (Mello 1983) have proven unsuccessful at differentiating all four island sources; refractive index, density, thermoluminescence, and optical transmission cannot differentiate all of the Monte Arci flows (Herold 1986). Strontium isotope ratios, in combination with rubidium and strontium concentrations, appear effective (Gale 1981), but this approach is too costly and time-consuming for the routine analysis of artifacts. Fission-track dating has also been widely used to source western Mediterranean obsidian artifacts on the basis of their differing geological ages (Bigazzi *et al.* 1992a; Arias *et al.* 1986; 1984; Bigazzi and Radi 1981; Arias-Radi *et al.* 1972); the multiple Sardinian sources cannot be resolved, however, by this method since they all appear to be about 5 million years old (see also the potassium-argon determinations by Belluomini *et al.* 1970; Bigazzi *et al.* 1976; and di Paola *et al.* 1975). As we will see, chronological and geographic differences in the exploitation of the Sardinian sources existed, and raise important questions about neolithic exchange mechanisms in northern Italy where multiple island sources were used simultaneously.

MULTIPLE FLOWS: THE MONTE ARCI SOURCES

The presence of multiple obsidian flows in the Monte Arci region of Sardinia was suggested long before Cann and Renfrew's (1964) analyses of four

artifacts fell into two distinct groups. De la Marmora (1839–40) mentions several places on Monte Arci where obsidian could be found *in situ*; both translucent and opaque types of obsidian were explicitly recognized at the archaeological site of Monte Urpinu (Loddo 1903: 47); and Puxeddu (1958) identified 4 sources, 11 collection centers, 74 workshops, and 157 additional sites with obsidian scatters in his survey of the Monte Arci region. Three chemical subgroups (SA, SB, SC) were later confirmed by Hallam's (1976; Hallam *et al.* 1976) analysis of western Mediterranean obsidian artifacts for his Master's thesis at Bradford University, although geological material from only one source (SA) was analyzed. Four independent studies have since been done to locate and characterize the different Sardinian sources represented in the archaeological record.

Mackey did a detailed survey of obsidian sources on Monte Arci for her doctoral dissertation in geology at the University of Nottingham, but in the end her thesis was not accepted. The only available data come from a brief conference paper in which three chemical subgroups, determined by X-ray fluorescence analyses, are associated with specific source areas on Monte Arci (SA = Conca Cannas, SB = Santa Maria Zuarbara, SC = Perdas Urias) although *in situ* material was not located at Perdas Urias (Mackey and Warren 1983). The main chemical subgroups thus correspond to the geographical source locations identified by Puxeddu. The SB source was also found to consist of at least two chemically differentiable outcrops (Mt. Sparau, Cucru Is Abis), both represented among the 51 archaeological artifacts analyzed in Mackey and Warren's (1983) study. Data for individual analyses are not given, however, and the number of geological samples tested remains unknown.

Francaviglia (1984) analyzed a total of 172 geological specimens from 5 source locations in Sardinia, but gave little information about the deposits themselves, and did not publish individual sample data either. Only one of the SB outcrops was tested, and two of the chemical source groups (both found in a detrital deposit at Cave della Ceca) represent obsidian nodules too small to have been utilized for artifacts. Francaviglia's main contribution was the identification of two SC subgroups, neither found *in situ*, and the demonstration that all of the main Mediterranean obsidian sources (SA, SB, SC, Li, Pa, Pl, Melos, Giali) could be chemically differentiated on the basis of major/minor elements alone.

Herold (1986) conducted an extremely thorough survey and analysis of the Sardinian (and Palmarola) sources for his doctoral dissertation in geological science at the University of Karlsruhe, but these data also have not been formally published. For Monte Arci, he identified 4 chemical subgroups among numerous localities with small unworkable nodules, in addition to the 4 usable sources identified by Mackey and Warren (1983).

Finally, this author (Tykot 1992; 1995; 1996) has also completed an

Erratum. The first line on this page should read:

...confirming the archaeological use of 5 distinct chemical sources and the existence of others of unworkable size or quality.

confirming the archaeological use off others of unworkable size or quality. Importantly, the SC source was finally located *in situ*. In contrast to the preceding studies, this research was designed to demonstrate the utility of low-cost, major-element analysis for determining the provenance of hundreds of artifacts from stratigraphically excavated archaeological sites. It was also discovered that obsidian artifacts from the western Mediterranean could be visually assigned a provenance with a high degree of accuracy. In a blind test, visual determination of provenance was recorded prior to chemical analysis for nearly 600 artifacts. No errors were made distinguishing between Lipari, Sardinia, and Pantelleria obsidian (no Palmarola obsidian was present); the only erroneous attributions were among the Sardinian sources, for which 68% were correctly identified to a specific Monte Arci source, 16% were correctly narrowed down to one of two specific sources, and 16% were incorrectly attributed (Tykot 1995). Since many of the incorrect attributions were bi-directional between types SA and SB, the frequency of each source represented in an entire lithic assemblage could be estimated with the same degree of confidence associated with the chemical analysis of a selected sample of artifacts.

ANALYSIS OF GEOLOGICAL AND ARCHAEOLOGICAL MATERIAL

A complete account of the geological survey has been given elsewhere (Tykot 1992; 1995). Hundreds of hand samples were collected from the localities shown in Fig. 3.2, visually examined, and a subset selected for chemical analysis. At first, 186 geological specimens and 33 archaeological artifacts were analyzed for 38 major and trace elements by inductively coupled plasma-mass spectrometry to explore whether additional subgroups could be chemically distinguished. For archaeologists, ICP-MS has several important advantages over neutron activation and X-ray fluorescence analysis: 1) only a tiny powdered sample is required, so the technique is minimally destructive to valuable artifacts; 2) the large number of elements that can be accurately and precisely analyzed is particularly important for characterization and provenience studies; 3) isotope ratio measurements to 3 significant figures are possible without extensive sample preparation; and 4) the combination of small sample size and low per-sample cost allows assemblages of artifacts rather than individual objects to be studied (Tykot and Young 1996). The number of elements that can be accurately and precisely analyzed is unmatched by any other single technique, since the problem of mass spectral overlap is minimal, in contrast to the overlapping energy or wavelength spectra produced by other techniques, including ICP-atomic emission spectroscopy. Like ICP-AES and other solution-based methods, the obsidian sample must be pulverized and dissolved by hydrofluoric acid digestion or by fusion with a lithium metaborate flux. No sample preparation at all is necessary if a laser ablation device is used, at least for artifacts small enough to fit into the sample chamber.

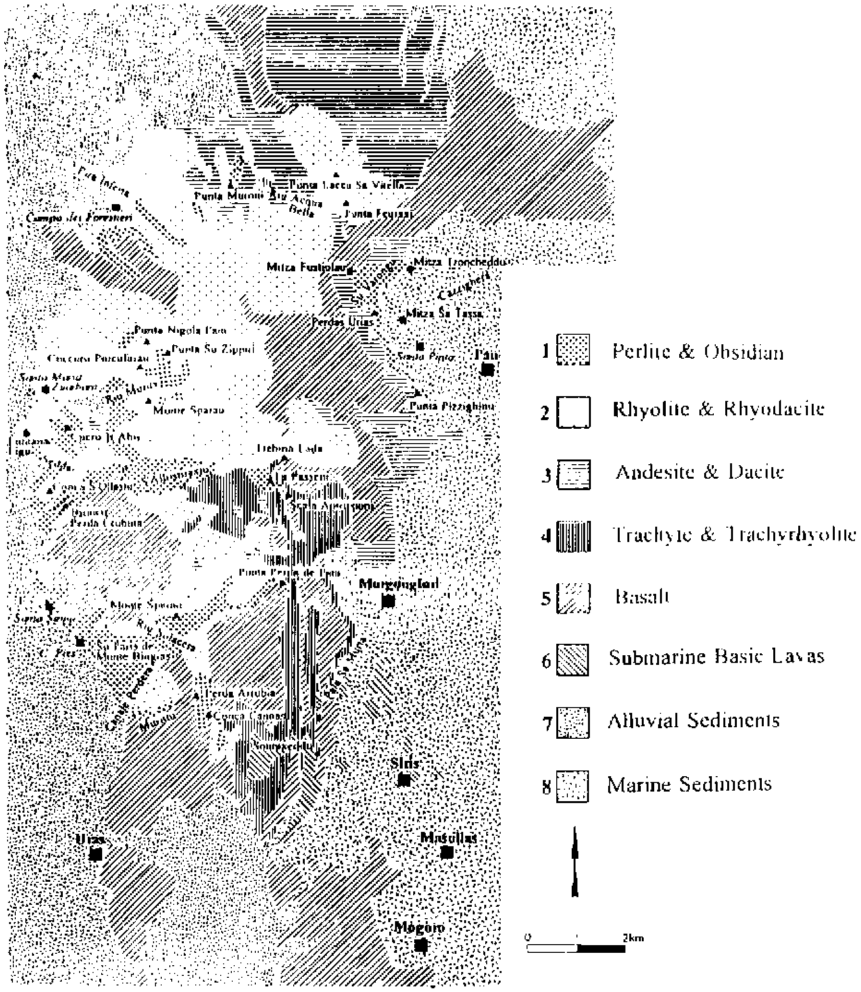

Figure 3.2. Geological map of the Monte Arci region of Sardinia, showing locations mentioned in the text.

Cluster analysis of the ICP-MS obsidian data did not suggest the existence of additional, useful subdivisions beyond those already established by Mackey and Warren (1983) and Francaviglia (1984), while stepwise discriminant analysis provides clear separation of the five groups represented by both geological and archaeological samples (Fig. 3.3). A description of each type and its geological source follows:

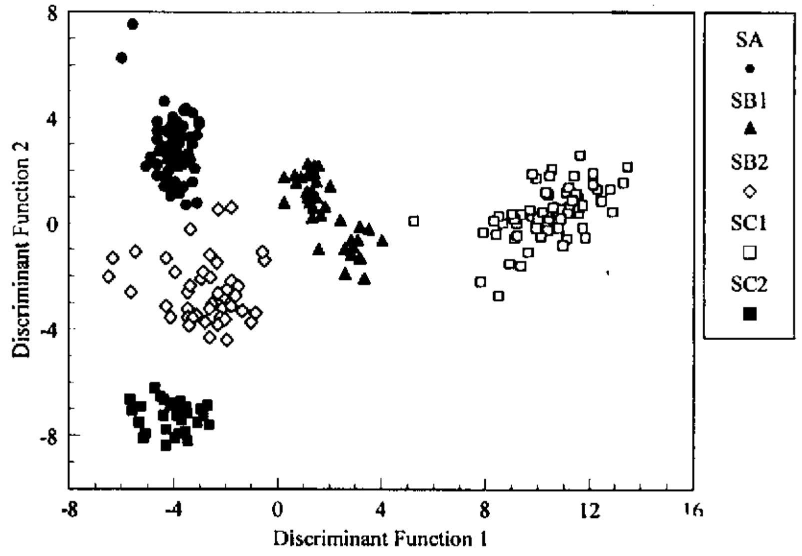

Figure 3.3. Plot of first two discriminant functions for ICP-MS analyses of Monte Arci (Sardinia) obsidian.

1. SA. Type SA obsidian is very glassy, black in color but highly translucent, with nodules up to 40 cm found *in situ* within perlite beds near Conca Cannas and Su Paris de Monte Bingias. Individual microlite crystals are visible in transmitted light, often with some flow orientation.
2. SB1. Type SB1 is less glassy and black, but usually opaque; it is found *in situ*, also in a perlite matrix, at the higher elevations of Punta Su Zippiri and Monte Sparau North, and in the form of bombs up to 30cm in length on the slopes of Cuccuru Porcufurau.
3. SB2. Type SB2 is often very glassy, but ranges from virtually transparent to nearly opaque; it is sometimes characterized by the frequent presence of white phenocrysts up to 2mm in diameter. Microlites are usually not present in the transparent variety. Type SB2 occurs in large blocks (occasionally up to 1 meter in length) within a perlite matrix near Cucru Is Abis, Seddai, Conca S'Ollastu, and Bruncu Perda Crobina.
4. SC1. Type SC1 is less glassy, black but frequently with well-defined external gray bands, and totally opaque. Rare pieces have red streaks or are partially transparent but tinted brown. This type can be found *in situ* in a perlite seam along the ridge from Punta Pizzighinu to Perdas Urias on the northeastern side of Monte Arci, in blocks up to 20cm in length.

5. SC2. Type SC2 is visually indistinguishable from SC1, and differs chemically only in its trace concentrations of strontium and a few other elements. It has only been found in detrital deposits between Perdas Urias and Santa Pinta, mixed with material of SC1 type. For these reasons, I consider the characterization of material as simply SC sufficient for archaeological purposes, since it is extremely unlikely that one type could have been selected over the other for making lithic artifacts.

Since all useful Mediterranean source distinctions could be made on the basis of major/minor element concentrations, electron probe microanalysis using wavelength dispersive X-ray spectrometers was selected as the method of choice for analyzing large numbers of archaeological artifacts since the precision of the microprobe is superior to laser ablation ICP-MS, only a tiny 1–2mm sample needs to be removed, sample preparation is minimal, and the per-sample cost is equally low—a fraction of the price of XRF or NAA (see Merrick and Brown 1984 for another example). Up to 18 samples were mounted in one-inch epoxy disks, polished flat, and analyzed for 11 major/minor elements using a beam diameter of 40 microns and counting times of 10 to 80 seconds per element. Typically, three points on each sample were analyzed to account for any heterogeneity. Table 3.1 shows the average concentrations for each source, for nearly 2000 analyses of over 700 specimens. Discriminant analysis of major/minor element data provides highly confident attribution of obsidian artifacts to the four main Sardinian sources (SA, SB1, SB2, SC) as well as to all of the other Mediterranean island sources, including two subgroups for Melos (Sta Nychia and Demenegaki) and three for Pantelleria (Balate dei Turchi, Lago di Venere, and Gelkhamar).

Table 3.1. Average Major Element Concentrations of Monte Arci Obsidian Sources, Based on Nearly 2000 Electron Probe Microanalyses

Source		SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	BaO	Total
SA	ave	74.72	13.40	0.09	1.25	0.08	0.59	3.44	5.26	0.08	0.06	0.02	99.00
	sd	0.26	0.15	0.01	0.09	0.01	0.04	0.16	0.22	0.01	0.01	0.02	
	n	207	207	207	207	207	207	207	207	60	60	202	
SB1	ave	73.87	13.63	0.17	1.33	0.12	0.75	3.38	5.55	0.10	0.04	0.05	99.00
	sd	0.35	0.10	0.03	0.20	0.04	0.06	0.10	0.20	0.02	0.01	0.02	
	n	26	26	26	26	26	26	26	26	21	21	26	
SB2	ave	75.05	12.97	0.13	1.17	0.11	0.57	3.34	5.51	0.08	0.04	0.02	99.00
	sd	0.33	0.15	0.02	0.17	0.02	0.02	0.22	0.35	0.01	0.01	0.02	
	n	130	130	130	130	130	130	130	130	81	81	130	
SC	ave	72.71	13.92	0.27	1.53	0.21	0.88	3.30	5.90	0.14	0.03	0.11	99.00
	sd	0.37	0.19	0.03	0.21	0.07	0.10	0.20	0.30	0.01	0.01	0.03	
	n	341	342	342	339	339	342	342	342	120	120	340	

n = number of individual specimens tested

THE DISTRIBUTION OF SARDINIAN OBSIDIAN

Obsidian artifacts from more than 50 archaeological sites in Sardinia, Corsica, and northern Italy have been chemically and/or visually analyzed by this author, and add to the existing body of data (compiled in Tykot 1995, appendices A and B) produced primarily by neutron activation at Bradford (Hallam *et al.* 1976; Williams Thorpe *et al.* 1979; 1984; Mackey and Warren 1983), Milan (Ammerman *et al.* 1990; Ammerman and Polglase 1993; 1995), Pavia (Bigazzi *et al.* 1992b; 1986) and Birmingham (Randle *et al.* 1993), and elsewhere by atomic absorption spectroscopy (Michels *et al.* 1984), X-ray fluorescence (Dyson *et al.* 1990; Crisci *et al.* 1994), and fission-track dating (Arias *et al.* 1986; 1984; Bigazzi and Radi 1982; Arias-Radi *et al.* 1972).

The most significant results are obtained through comparison of the relative importance of each Sardinian source at different sites and in different cultural phases, and in the type of artifacts and/or lithic reduction debris represented. It has been suggested that in the Early Neolithic (ca. 6000–5000 BC), less-organized selection of source material would result in the presence of obsidian flakes from multiple sources, and in its relatively inefficient use; by the Late Neolithic (ca. 4000–3000 BC), procurement would have been better organized, focusing on the higher quality SA obsidian, and featuring more efficient reduction technology in the production of cores and blades (Hurcombe and Phillips 1995). Such a shift is observed at Arene Candide, where less-intensive, on-site production of tools from multiple obsidian sources (SA, SB, SC, Pl) in the Early Neolithic is followed by nearly exclusive importation of blades of high-quality Lipari obsidian in the Late Neolithic (Ammerman and Polglase 1993; 1996).

This pattern is not paralleled in Sardinia and Corsica. Type SB1 obsidian was not used often, but nevertheless is present in archaeological assemblages. Type SA, SB2, or SC may be the most frequent at any one site in a given chronological period. Here, I focus on two of the most important stratigraphically excavated sites, Grotta Filiestru (Mara) in Sardinia (Trump 1983) and Basi (Serra-di-Ferro) in Corsica (Bailloud 1969a; 1969b), from which 300 pieces of obsidian have been analyzed. At Grotta Filiestru, the use of clear, glassy type SB2 obsidian from the western flanks of Monte Arci decreases over 4 Neolithic cultural periods, while the use of opaque, less-glassy type SC obsidian from the northeastern part of Monte Arci increases (Fig. 3.4); type SA is never more than 20% of the assemblage. In contrast, type SA accounts for an average of 40% of the assemblage at Basi, both SB varieties are never important, and this pattern does not change for 8 stratigraphic levels including the Early (Cardial) and Late (Basien) Neolithic (Fig. 3.5), a span of approximately 2000 years. This finding is contrary to the suggestion, based on a limited number of analyses (Hallam *et al.* 1976), that type SB was the most frequently used obsidian source in Corsica. Type SB obsidian is also

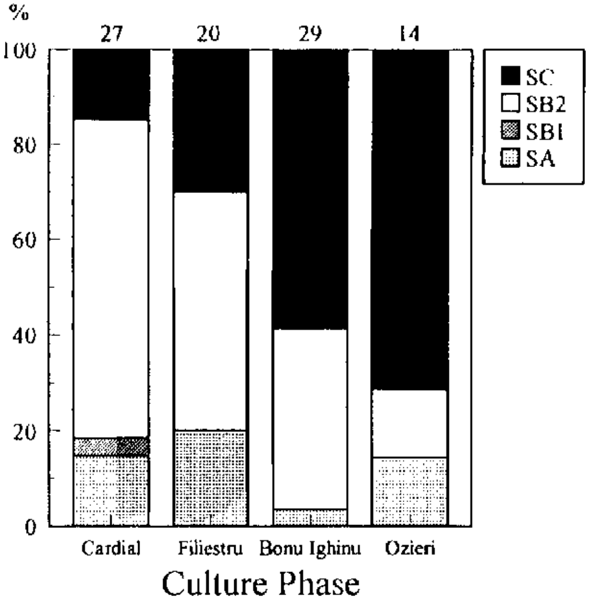

Figure 3.4. Neolithic obsidian use in 4 culture phases at Grotta Filiestru (Mara, Sardinia). Cardial and Filiestru are Early Neolithic, Bonu Ighinu is Middle Neolithic, and Ozieri is Late Neolithic. Number at top of each bar is number of pieces analyzed.

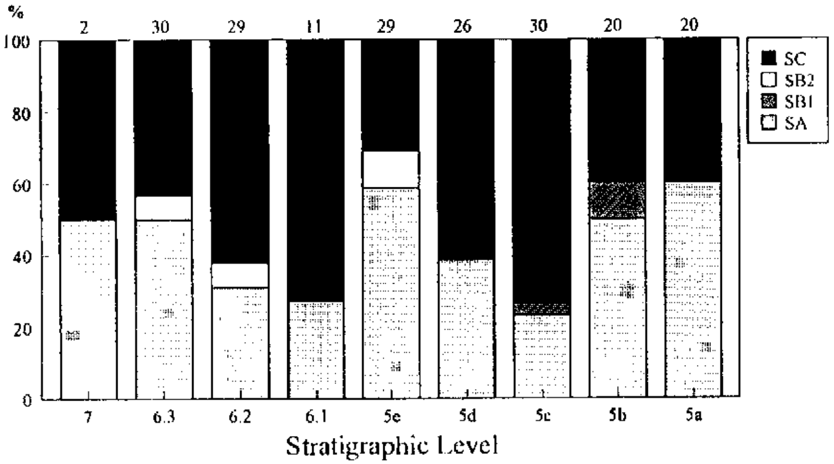

Figure 3.5. Neolithic obsidian use in 9 stratigraphic levels at Basi (Serra-di-Ferro, Corsica). Levels 7 and 6 are Early Neolithic; level 5 is Late Neolithic. Number at top of each bar is number of pieces analyzed.

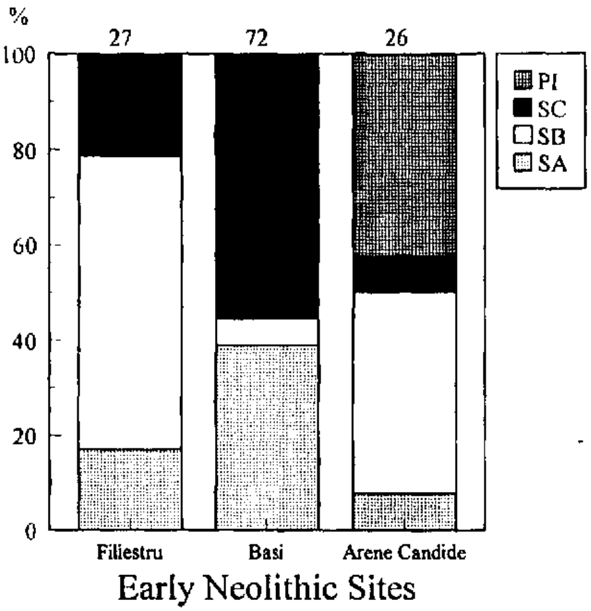

Figure 3.6. Early Neolithic obsidian use at Grotta Filiestru, Basi, and Arene Candide. Number at top of each bar is number of pieces analyzed. Arene Candide data from Ammerman and Polglase (1993; 1996).

infrequent at sites in southern Sardinia, and even at sites near the Monte Arci source zone.

Comparison of obsidian source frequencies in the Early Neolithic between Grotta Filiestru, Basi, and Arene Candide (Liguria) suggest that different obsidian use patterns existed in different geographic regions by contemporary Cardial Impressed Ware culture groups (Fig. 3.6). The importance of type SB obsidian at Arene Candide, but its low frequency at Basi, implies that obsidian may not have always been dispersed through simple down-the-line transactions from the source zone (see Tykot 1996). It is also possible that maritime contacts between Sardinia and the mainland were not necessarily routed across the shortest open-water crossings (from Sardinia to Corsica to Elba to Piombino and then up the Ligurian coast).

CONCLUSIONS

As Ammerman and Polglase (1993; 1996) have already noted, a new generation of theoretical models are necessary to explain prehistoric obsidian exchange mechanisms. These models should take into account more than just the procurement and movement of raw materials, but also the transformation of the raw material into a finished product, how and why it was used and re-used, and finally its discardment. For areas outside obsidian source zones, these multiple stages probably represent activities by at least two parties, and perhaps four or five. Technological studies of the sort carried out by Hurcombe and Phillips (1995) and Polglase (1990; Ammerman *et al.* 1990; Ammerman and Polglase 1993) enlighten our understanding of where obsidian reduction occurred (at quarry, workshop, or domestic sites), while microscopic use-wear studies (Hurcombe 1992a; 1992b) are narrowing down the functions these tools served. Finally, the combination of visual and low-cost chemical analysis allows comprehensive sourcing of entire obsidian assemblages and the effective statistical comparison of spatially and temporally dynamic obsidian source exploitation patterns. The integration of all these data categories will ultimately provide insight into the social significance of obsidian.

REFERENCES

Ammerman, A., Cesana, A., Polglase, C. and Terrani, M. 1990 Neutron activation analysis of obsidian from two neolithic sites in Italy. *Journal of Archaeological Science* 17(2): 209–220.

Ammerman, A. and Polglase, C. 1993 The exchange of obsidian at Neolithic sites in Italy. *In* Healy, F. and Scarre, C., eds., *Trade and Exchange in European Prehistory.* Oxbow Monograph 33. Oxford, Oxbow Books: 101–107.

Ammerman, A. and Polglase, C. 1996 Analyses and descriptions of the obsidian collections from Arene Candide. *Quaternaria Nova.*

Aramu, F., Maxia, V., Serci, S. and Uras, I. 1983 Mössbauer study of Mount Arci (Sardinia) obsidian. *Lettere al Nuovo Cimento* 36(5): 102–104.

Arias, C., Bigazzi, G., Bonadonna, F.P., Cipolloni, M., Hadler, J.C., Lattes, C.M.G. and Radi, G. 1984 Fission track dating in archeology. A useful application. *In* Parrini, P.L., ed., *Scientific Methodologies Applied to Works of Arts.* Montedison Progetto Cultura: 151–159.

Arias, C., Bernardes, C., Bigazzi, G., Bonadonna, F.P., Cesar, M.F., Hadler Neto, J.C., Lattes, C.M.G., Oliveira, J.X., Osorio Araya, A.M. and Radi, G. 1986 Identificaçao da proveniência de manulaturados de obsidiana através da dataço com o método do traço de fisso. *Ciência e Cultura* 38(2): 285–308.

Arias-Radi, G., Bigazzi, G. and Bonadonna, F.P. 1972 Le tracce di fissione. Un metodo per lo studio delle vie di commercio dell'ossidiana. *Origini. Preistoria e Protostoria delle Civiltà Antiche* 6: 155–169.

Bailloud, G. 1969a Fouilles de Basi (Serra-di-Ferro, Corse). Campagne de 1968. *Corse Historique* 9(33): 49–64.

Bailloud, G. 1969b Fouille d'un habitat néolithique et torréen à Basi (Corse). *Bulletin de la Societe Préhistoire Française* 66: 367–384.

Belluomini, G., Discendenti, A., Malpieri, L and Nicoletti, M. 1970 Studi sulle ossidiane italiane. II. - Contenuto in ^{40}Ar radiogenico e possibilità di datazione. *Periodico di Mineralogia* 39: 469–479.

Bigazzi, G., Bonadonna, F.P., Maccioni, L. and Pecorini, G. 1976 Research on Monte Arci (Sardinia) subaerial volcanic complex using the fission-track method. *Bolletino della Società Geologica Italiana* 95: 1555–1570

Bigazzi, G., Marton, P., Norelli, P. and Rozloznik, L. 1990 Fission track dating of Carpathian obsidians and provenance identification. *Nuclear Tracks and Radiation Measurements* 17: 391–396.

Bigazzi, G., Meloni, S., Oddone, M. and Radi, G. 1986 Provenance studies of obsidian artifacts: trace elements and data reduction. *Journal of Radioanalytical and Nuclear Chemistry, Articles* 98(2): 353–363.

Bigazzi, G., Meloni, S., Oddone, M. and Radi, G. 1992a Nuovi dati sulla diffusione dell'ossidiana negli insediamenti preistorici italiani. *In* Herring, E., Whitehouse, R. and Wilkins, J., eds., *Papers of the Fourth Conference of Italian Archaeology 3. New Developments in Italian Archaeology Part 1*. London, Accordia Research Centre: 9–18.

Bigazzi, G., Meloni, S., Oddone, M. and Radi, G. 1992b Study on the diffusion of Italian obsidian in the neolithic settlements. *Atti del VIII Convegno Nazionale sulla Attività di Ricerca nei Settori della Radiochimica e della Chimica Nucleare, delle Radiazioni e dei Radioelementi, Torino, 16–19 Giugno 1992*. CNR and Università degli Studi di Torino: 243–247.

Bigazzi, G. and Radi, G. 1981 Datazione con le tracce di fissione per l'identificazione della provenienza dei manufatti di ossidiana. *Rivista di Scienze Preistoriche* 36(1–2): 223–250.

Cann, J.R. and Renfrew, A.C. 1964 The characterization of obsidian and its application to the Mediterranean region. *Proceedings of the Prehistoric Society* 30: 111–133.

Cortese, M.; Frazzetta, G. and La Volpe, L. 1986 Volcanic history of Lipari (Aeolian Islands, Italy) during the last 10,000 years. *Journal of Volcanology and Geothermal Research* 27: 117–133.

Crisci, G.M., Ricq-de Bouard, M., Lanzafame, U. and 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: 299–309.

Crummett, J.G. and Warren, S.E. 1985 Appendix 1. Chemical analysis of Calabrian obsidian. *In* Ammerman, A., ed., *The Acconia Survey: Neolithic Settlement and the Obsidian Trade*. Institute of Archaeology Occasional Publication 10. London, Institute of Archaeology: 107–114.

de la Marmora, A. 1839–40 *Voyage en Sardaigne*. Turin, J. Bocca.

di Paola, G.M., Puxeddu, M. and Santacroce, R. 1975 K-Ar ages of Monte Arci volcanic complex (central-western Sardinia). *Rendiconti della Società Italiana di Mineralogia e Petrologia* 31: 181–190.

Dixon, J.E. 1976 Obsidian characterization studies in the Mediterranean and Near East. *In* Taylor, R.E., ed., *Advances in Obsidian Glass Studies*. Park Ridge, NJ, Noyes Press: 288–333.

Dyson, S.L.; Gallin, L.; Klimkiewicz, M.; Rowland, R.J., Jr. and Stevenson, C.M. 1990 Notes on some obsidian hydration dates in Sardinia. *Quaderni della Soprintendenza Archeologica per le Province di Cagliari e Oristano* 7: 25–42.

Francaviglia, V. 1984 Characterization of Mediterranean obsidian sources by classical petrochemical methods. *Preistoria Alpina* 20: 311–332.

Francaviglia, V. 1988 Ancient obsidian sources on Pantelleria (Italy). *Journal of Archaeological Science* 15: 109–122.

Francaviglia, V. and 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: 31–39.

Gale, N.H. 1981 Mediterranean obsidian source characterisation by strontium isotope analysis. *Archaeometry* 23(1): 41–51.

Hallam, B.R. 1976 *Neutron Activation Analysis of Western Mediterranean Obsidians*. Unpublished Master's Thesis, Bradford University.

Hallam, B.R., Warren, S.E. and Renfrew, A.C. 1976 Obsidian in the western Mediterranean: Characterisation by neutron activation analysis and optical emission spectroscopy. *Proceedings of the Prehistoric Society* 42: 85–110.

Herold, G. 1986 *Mineralogische, chemische und physikalische Untersuchungen an den Obsidianen Sardiniens und Palmarolas. Grundlagen zur Rekonstruktion Prähistorischer Handelswege im Mittelmeerraum*. Unpublished PhD dissertation, Universität (TH) Fridericiana Karlsruhe.

Hurcombe, L.H. 1992a New contributions to the study of the function of Sardinian obsidian artifacts. *In* Tykot, R.H. and Andrews, T.K., eds., *Sardinia in the Mediterranean: A Footprint in the Sea*. Sheffield, Sheffield Academic Press: 83–97.

Hurcombe, L.H. 1992b *Use Wear Analysis and Obsidian: Theory, Experiments and Results*. Sheffield, Sheffield Archaeological Monographs 4.

Hurcombe, L.H. and Phillips, P. Chronology and artifact function at the Grotta Filiestru. Paper presented at the international conference "Sardinian Stratigraphy and Mediterranean Chronology," Tufts University, Medford, Massachusetts, March 17–19, 1995. Proceedings forthcoming.

Keller, J. and Seifried, C. 1990 The present status of obsidian source identification in Anatolia and the Near East. *In* Albore Livadie, C. and Widemann, F., eds., *Volcanologie et Archéologie. Proceedings of the European Workshop of Ravello, November 19–27, 1987 and March 30–31, 1989*. PACT 25(4): 57–87.

Loddu, R. 1903 Stazione neolitica del Monte Urpino (Cagliari). *Bullettino di Paletnologia Italiana* 29: 45–52.

Longworth, G. and Warren, S.E. 1979 Mössbauer spectroscopy and the characterisation of obsidian. *Journal of Archaeological Science* 6(2): 179–193.

Mackey, M. and Warren, S.E. 1983 The identification of obsidian sources in the Monte Arci region of Sardinia. *In* Aspinall, A. and Warren S.E., eds., *Proceedings of the 22nd Symposium on Archaeometry, University of Bradford, Bradford, U.K. March 30th–April 3rd 1982*. Bradford: 420–431.

Mahood, G.A. and Hildreth, W. 1986 Geology of the peralkaline volcano at Pantelleria, Strait of Sicily. *Bulletin of Volcanology* 48: 143–172.

McDougall, J., Tarling, D. and Warren, S.E. 1983 Magnetic sourcing of obsidian samples from the Mediterranean. *Journal of Archaeological Science* 10(5): 441–452.

Mello, E. 1983 Indagini scientifiche per l'individuazione della provenienza dei manufatti di ossidiana. In Tinè, S., Passo di Corvo e la civiltà neolitica del Tavoliere. Genova, Sagep Editrice: 122–124.

Merrick, H.V. and Brown, F.H. 1984 Rapid chemical characterization of obsidian artifacts by electron microprobe analysis. *Archaeometry* 26(2): 230–236.

Michels, J.W. 1987 Obsidian hydration dating and a proposed chronological scheme for the Marghine region. *In* Michels, J.W. and Webster, G.S., eds., *Studies in Nuragic Archaeology: Village Excavations at Nuraghe Urpes and Nuraghe Toscono in West-Central Sardinia*. BAR International Series 373. Oxford, BAR: 119–125.

Michels, J., Atzeni, E., Tsong, I.S.T. and Smith, G.A. 1984 Obsidian hydration dating in Sardinia. In Balmuth, M.S. and Rowland, R.J., Jr., eds., *Studies in Sardinian Archaeology*. Ann Arbor, University of Michigan: 83–114.

Phillips, P. 1992 Obsidian distribution and the European neolithic. *In* Tykot, R.H. and Andrews, T.K., eds., *Sardinia in the Mediterranean: A Footprint in the Sea*. Sheffield, Sheffield Academic Press: 71–82.

Pichler, H. 1980 The island of Lipari. *Rendiconti della Società Italiana della Mineralogia e Petrologia* 36(1): 415–440.

Polglase, C. 1990 Appendice 1. *In* Bernabò Brea, M.; Ghiretti, A.; Polglase, C.; Visconti, V., I siti neolitici lungo il torrente Cinghio (Parma). *Preistoria Alpina* 24: 140–155.

Pollmann, H.-O. 1993 *Obsidian im nordwestmediterranen Raum. Seine Verbreitung und Nutzung im Neolithikum und Aneolithikum*. BAR International Series 585. Oxford, Tempus Reparatum.

Puxeddu, C. 1958 Giacimenti di ossidiana del Monte Arci in Sardegna e sua irradiazione. *Studi Sardi* 14–15(1955–1957) Parte I: 10–66.

Randle, K., Barfield, L.H. and Bagolini, B. 1993 Recent Italian obsidian analyses. *Journal of Archaeological Science* 20: 503–509.

Renfrew, C. and Dixon, J.E. 1976 Obsidian in western Asia: a review. *In* Sieveking, G. de G., Longworth, I.H. and Wilson, K.E., eds., *Problems in Economic and Social Archaeology*. London, Duckworth: 137–150.

Taylor, R.E., ed. 1976 *Advances in Obsidian Glass Studies*. Park Ridge, NJ, Noyes Press.

Torrence, R. 1986 *Production and Exchange of Stone Tools: Prehistoric Obsidian in the Aegean*. Cambridge, Cambridge University Press.

Trump, D.H. 1983 *La Grotta di Filiestru a Bonu Ighinu, Mara (SS)*. Quaderni 13. Sassari, Dessì.

Tykot, R.H. 1992 The sources and distribution of Sardinian obsidian. *In* Tykot, R.H. and Andrews, T.K., eds., *Sardinia in the Mediterranean: A Footprint in the Sea*. Sheffield, Sheffield Academic Press: 57–70.

Tykot, R.H. 1995 *Prehistoric Trade in the Western Mediterranean: The Sources and Distribution of Sardinian Obsidian*. PhD dissertation, Harvard University. Ann Arbor, University Microfilms.

Tykot, R.H. 1996 Obsidian procurement and distribution in the central and western Mediterranean. *Journal of Mediterranean Archaeology* 9: 39–82.

Tykot, R.H. and Young, S.M.M. 1996 Archaeological applications of inductively coupled plasma-mass spectrometry. *In* Orna, M.V., ed., *Archaeological Chemistry V*. Washington, DC, American Chemical Society: 116–130.

Williams-Thorpe, O. 1995 Review article. Obsidian in the Mediterranean and the Near East: a provenancing success story. *Archaeometry* 37(2): 217–248.

Williams-Thorpe, O., Warren, S.E. and Barfield, L.H. 1979 The distribution and sources of archaeological obsidian from Northern Italy. *Preistoria Alpina* 15: 73–92.

Williams-Thorpe, O., Warren, S.E. and Courtin, J. 1984 Sources of archaeological obsidian from Southern France. *Journal of Archaeological Science* 11(2): 135–146.

Williams-Thorpe, O., Warren, S.E. and Nandris, J. 1984 The distribution and provenance of archaeological obsidian in Central and Eastern Europe. *Journal of Archaeological Science* 11: 183–212.