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# Geochemical Analysis of Obsidian and the Reconstruction of Trade Mechanisms in the Early Neolithic of the Western Mediterranean

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Geochemical fingerprinting of obsidian sources was first applied in the Mediterranean region nearly four decades ago. Since then, a number of analytical methods have proven successful in distinguishing the western Mediterranean island sources of Lipari, Palmarola, Pantelleria, and Sardinia. The existence of multiple flows in the Monte Arci region of Sardinia and on some of the other islands, however, has enabled the study of specific patterns of source exploitation and the trade mechanisms which resulted in the distribution of obsidian hundreds of kilometers away during the neolithic period (ca. 6000-3000 BC). Results are presented here from the chemical analysis of significant numbers of artifacts from several Early Neolithic sites in Sardinia, Corsica, and northern Italy as part of the largest and most comprehensive study of obsidian sources and trade in this region. The patterns of source exploitation revealed by this study specifically support a down-the-line model of obsidian trade during this period.

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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 and finished tools, use and eventual disposal. The identification of the geological source establishes the beginning of this *chaîne opératoire*, while the analysis of geographic and chronological patterns of obsidian source exploitation complements lithic reduction and use-wear studies in elucidating the intervening behavioral links. Obsidian is perhaps the most visible indicator of interactions during the Neolithic period (ca. 6000-3000 BC), and as such is important not only to our understanding of long-distance exchange networks and craft specialization, but also of the earliest settlement of the Mediterranean islands and the transition from hunting and gathering to an agricultural way of life.

## The Early Neolithic in the Western Mediterranean

The Early Neolithic in the western Mediterranean is defined by the first appearance of ceramics along with domesticated plants and animals. This transition went hand in hand with an accelerated involvement of Sardinia and Corsica in Mediterranean interrelations (*1*). Several dozen Early Neolithic sites have been identified on these islands, including caves and rockshelters concentrated in the less mountainous parts of the islands or near the coasts, but also including open-air sites. Some are located well in the interior of the islands, away from fluvial systems. Radiocarbon dates place the Cardial phase of the Early Neolithic in Sardinia and Corsica at 5700-5300 cal BC (*2*).

Early Neolithic pottery decorated with impressions of *Cardium edule* shells is found not only in Sardinia and Corsica, but also in other areas of the western Mediterranean. At Filiestru Cave in Sardinia, for example, Cardial impressed bowls, plates, and jars comprise 7% of the ceramic assemblage (*3*). Provenance studies of these wares indicates the existence of intra-regional, multi-directional interaction networks, with vessels found up to 50-70 km from their production area (*4*). Overall, we may interpret the Cardial phenomenon as suggesting a common cultural base over much of the western Mediterranean, with broad inter-group interaction evidenced not only by the ceramics (*5, 6, 7*), but also by inter-regional movement of ground and chipped stone artifacts including obsidian (Figure 1).

Lithic assemblages are typically composed of geometric microliths, including rectangles, trapezes, lunates, triangles, and larger implements including scrapers, burins, and transverse tranchet arrowheads (*8, 9, 10*). These tools were fashioned from flint, quartz, rhyolite, and above all obsidian. In Corsica, obsidian is rare or non-existent in the earliest Cardial I phase, although the flint from which most tools were made was imported from the Perfugas area in Sardinia (*11, 12*). In Sardinia,

*Figure 1. Obsidian sources in the Central Mediterranean and archaeological sites with more than 10 analyzed obsidian artifacts.*

obsidian is found at all Early Neolithic sites, and accounts for 17% of the Cardial I lithic assemblage at Filiestru (*3*). In Cardial II, obsidian becomes abundant at Corsican sites, although obsidian cores are small and rare, and arrowheads are infrequently made of obsidian.

## Geological Sources of Obsidian

The existence of obsidian sources on the Italian islands of Sardinia, Lipari, Palmarola and Pantelleria has been well documented, and early provenance studies identified them as the source of virtually all obsidian artifacts found at archaeological sites in the western Mediterranean (*13, 14*). Resolution has become one of the most important considerations in the characterization of western Mediterranean obsidian sources, since obsidian may be found in more than one locality on each island (*15*). While the geological age of obsidian formation on each island is sufficiently different for fission-track dating to have been widely used as a provenance technique (*16*), it is generally insufficient to separate the more closely related volcanic events on each island. Since there is considerable variation in the quantity, quality, and accessibility of specific obsidian sources, this knowledge is essential to a complete understanding of obsidian exploitation in this region (*17*).

For Sardinia, the exploitation of multiple sources was noted prior to the actual identification and characterization of each outcrop. The obsidian sources in the Monte Arci region of Sardinia have now been thoroughly documented and geochemically characterized (*18, 19*), while the results of recent fieldwork by this author on the other islands are expected to add significantly to earlier studies on Lipari (*20*), Palmarola (*21, 22*), and Pantelleria (*23, 24*). The western Mediterranean sources are briefly described here:

- Sardinian A. Type SA obsidian is black, glassy, and highly translucent. Abundant nodules up to 40 cm are typically found in soft perlitic matrices at Conca Cannas and Su Paris de Monte Bingias in the southwestern part of Monte Arci. Individual microlite crystals are visible in transmitted light, often with some flow orientation.
- Sardinian B1. Type SB1 is also black, but less glassy and usually opaque. It may be found as smaller nodules in harder matrices along the upper western flanks of Monte Arci at Punta Su Zippiri and Monte Sparau North, and as pyroclastic bombs up to 30cm in length on the slopes of Cuccuru Porcufurau.
- Sardinian B2. Type SB2 is black but ranges from virtually transparent to nearly opaque, and from very glassy to including many white phenocrysts up to 2mm in diameter. It also occurs along the western flanks of Monte Arci, but at lower elevations near Cucru Is Abis, Seddai, Conca S'Ollastu, and Bruncu Perda Crobina, occasionally in very large blocks.
- Sardinian C1. Type SC1 is black but frequently has well-defined external gray bands, and is less glassy and totally opaque. Rare pieces have red streaks or are partially transparent but tinted brown. This type may be found along the high ridge from Punta Pizzighinu to Perdas Urias on the northeastern side of Monte Arci, in blocks up to 20cm in length.
- Sardinian C2. Type SC2 is visually indistinguishable from SC1. It is commonly found as large blocks in secondary deposits between Perdas Urias and Santa Pinta. Since it is found mixed with material of SC1 type and differs chemically only in its trace concentrations of a few elements, the characterization of material as simply SC is probably sufficient for archaeological purposes.

- Lipari. Obsidian from Lipari is either glassy and very highly transparent, with a black to gray tint, or not very transparent due to the presence of many small phenocrysts which give it a gray streaky appearance. Historic-era volcanism has covered much of the island, but prehistorically available obsidian is still present in the Gabellotto gorge and along the northern and eastern coasts. There is no evidence that an earlier flow at Monte della Guardia was exploited in antiquity.
- Palmarola. Obsidian from Palmarola is almost always black and opaque, without any phenocrysts present. It is found primarily as secondary deposits along the southwestern coast of Monte Tramontana, typically in small nodules, and near Punta Vardella at the southeastern tip of the island, frequently in much larger blocks.
- Pantelleria - Balata dei Turchi. Nearly opaque dark-green obsidian is abundantly present in large blocks along the southern end of Pantelleria, with principal exposures at Balata dei Turchi and Salta La Vecchia. At least three chemically distinct volcanic layers have been identified.
- Pantelleria - Lago di Venere. Similar appearing obsidian of a slightly different composition occurs as smaller and infrequent nodules within perlitic matrices in the slopes above a natural hot spring in northeastern Pantelleria.
- Pantelleria - Gelkhamar. Obsidian is also thought to occur in western Pantelleria, based on the presence of a 5th chemical group among artifacts in this area. No geological material has been identified there, however, suggesting perhaps that it was available only as bombs in scattered secondary deposits which were mostly exhausted.

## Chemical Characterization of Obsidian Sources

Obsidians, by definition, have relatively limited ranges in their bulk element composition. For this reason, many Mediterranean and Near Eastern provenance studies have focused on trace element characterization of both geological samples and archaeological artifacts, primarily using x-ray fluorescence (*21*, *23*, *24*, *25*, *26*, *27*) or instrumental neutron activation analysis (*14*, *28*, *29*, *30*, *31*, *32*, *33*, *34*), although laser ablation ICP-MS is expected to become the technique of choice (*35*, *36*, *37*). Nevertheless, quantitative analysis of the major and minor elements is sufficient to differentiate not only the different island sources (Sardinia, Lipari, Palmarola, and Pantelleria, as well as Melos and Giali in the Aegean) but even several sub-sources on Sardinia, Pantelleria and Melos, so that at least in the Mediterranean all currently known and useful source distinctions can be made without resorting to trace element techniques.

The most complete characterizations currently available for the western Mediterranean obsidian sources have been accomplished using XRF and the electron microprobe (Table 1). Comparison of the average major/minor element values for the western Mediterranean sources reveals that $K_2O$ concentration alone can often distinguish SA from SB from SC (5.24 ± 0.12; 5.48 ± 0.17; and 5.89 ± 0.34 %, respectively); SB1 has 1.2% lower $SiO_2$ and 0.7% higher $Al_2O_3$ than SB2; and type SC obsidian is distinguished from all other western Mediterranean obsidians by its high $Al_2O_3$ (13.9%), MnO (0.14%), and BaO (0.11%). All four of these types are easily distinguished from Lipari and Palmarola obsidian by their $Na_2O$ concentrations (<3.5 vs. >4%), while the peralkaline obsidian from Pantelleria is easily distinguished by its extremely low $SiO_2$, $Al_2O_3$, and CaO, and its extremely high $Fe_2O_3$ and $Na_2O$ concentrations (Figure 2).

## Early Neolithic Obsidian Artifacts

Sixty-one obsidian artifacts from four Early Neolithic sites were selected for chemical analysis. The analysis of significant-sized assemblages from single cultural periods allows direct comparison between contemporary sites in different geographic locations. Many early provenance studies, however, relied on very few artifacts from individual sites so that such patterns in the exploitation of specific obsidian sources could not be determined (*15*).

**Table I. Electron microprobe data for Sardinian obsidian**

| *Type* | *$SiO_2$* | *$Al_2O_3$* | *$TiO_2$* | *$Fe_2O_3$* | *MgO* | *CaO* | *$Na_2O$* | *$K_2O$* | *MnO* | *$P_2O_5$* | *BaO* | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sardinia A* | | | | | | | | | | | | |
| 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 | |
| *Sardinia B1* | | | | | | | | | | | | |
| 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 | |
| *Sardinia B2* | | | | | | | | | | | | |
| 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 | |
| *Sardinia C* | | | | | | | | | | | | |
| 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 | |

NOTE: Mean and standard deviation in percent. Values standardized to a total of 99% allowing 1% for water and trace elements.

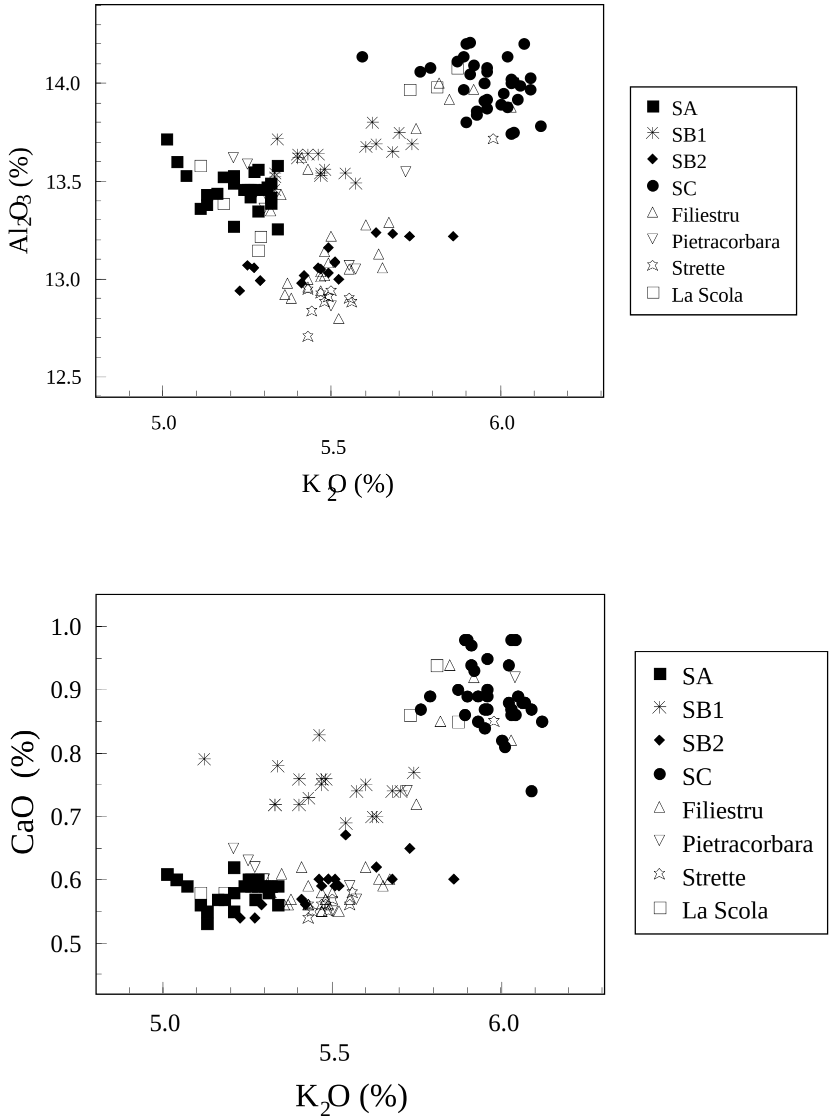

*Figure 2. Bivariate plots of major element oxides for Sardinian obsidian sources and artifacts analyzed in this study.*
*CaO vs.* $K_2O$ (top); $Al_2O_3$ *vs.* $K_2O$ (bottom)

Obsidian accounts for 17% of the over 400 Cardial Early Neolithic stone tools excavated at Filiestru Cave in northwestern Sardinia (*3, 38*). Twenty-seven obsidian artifacts were selected from these levels in trenches B (B10; B11 t.2 and t.3) and D (stratigraphic column) for chemical analysis. An additional 45 obsidian artifacts from the same contexts were also visually analyzed, while obsidian artifacts from a later Early Neolithic (Filiestru culture) level as well as Middle and Late Neolithic contexts were also analyzed by chemical and visual means (*17*).

Ten obsidian artifacts each were also selected from two sites in northern Corsica. The Cardial Early Neolithic levels at Strette included over 1000 lithic artifacts, with over 11% in obsidian; the ten artifacts selected came from level XIV of Strette 1 (*39, 40*). The 24 obsidian artifacts excavated in level VI at Pietracorbara, however, comprised only about 6% of the lithic assemblage there (*41*).

Fourteen obsidian artifacts from the small islet of La Scola near Pianosa in the Tuscan Archipelago were also analyzed. About 20% of the 1500 lithics recovered are in obsidian, and they are predominantly microliths with no retouch and showing only the faintest traces of use (*42, 43*). The analyzed obsidian was recovered from units BC 11-12 I/3; A12 tg3 (I3); and A8-9-10 B12, all associated with Cardial ceramics.

## Chemical Analyis of Obsidian Artifacts

Electron probe microanalysis using wavelength dispersive x-ray spectrometers was selected as the method of choice for analyzing large numbers of archaeological artifacts since only a tiny 1-2mm sample needs to be removed, sample preparation is minimal, and fully quantitative measurement of all major and minor elements is possible at a very low per-sample cost. Although recent studies indicate that energy dispersive spectrometry can also produce excellent quantitative results for ancient glassy materials (*44, 45*), $TiO_2$, MgO, MnO, $P_2O_5$, and BaO are below the minimum detection limits of SEM-EDS systems, and at least $TiO_2$, MgO, and BaO are important discriminators among western Mediterranean obsidian sources (*19*).

Cylinders one inch in diameter were made using Epotek two-part epoxy, and up to 18 holes 2mm in diameter and 3mm in depth were drilled in the flat surface of the hardened disk. Fresh epoxy and obsidian samples, cut earlier with a fast-speed diamond saw if necessary, were inserted in the holes and allowed to harden for 48 hours before grinding and polishing to a 1-micron finish. Sample disks were carbon-coated prior to analysis to minimize local surface charging under the electron beam.

Samples were analyzed using a Cameca MBX electron microprobe equipped with a Tracor Northern computer control system, and quantitative wavelength dispersive analysis was performed using a modified version of Sandia TASK8.

Samples were excited by a wide 40 micron electron beam at 15 KeV in order to minimize the influence of tiny microlite inclusions (typically high in iron) on the overall composition of the sample, as well as to prevent the heat-induced decomposition of alkali elements during analysis. Two to three points on each sample were analyzed to further reduce any heterogeneity in the results. The X-radiation produced was measured by wavelength dispersive spectrometry (WDS) using TAP (thallium acid phthalate), PET (penta-erythritol) and LiF (lithium fluoride) crystals, with counting times of 10-80 seconds per element. All samples were analyzed for $SiO_2$, $Al_2O_3$, $TiO_2$, $Fe_2O_3$, MgO, CaO, $Na_2O$, $K_2O$ and BaO; MnO, $P_2O_5$ were also measured for some samples. The measured X-ray intensities were corrected for matrix effects, absorption, and secondary fluorescence by the Bence-Albee correction program. Results were internally calibrated against international standards, and a laboratory reference material (hornblende) was repeatedly measured to insure consistency between analytical sessions. The results for each point analysis were normalized to total 99.00% (allowing 1% for water and trace elements) and then the average calculated for each sample (Table 2).

Seven of the artifacts from the La Scola site were analyzed by ICP-MS. Samples were ultrasonically cleaned and dried, and then pulverized at liquid nitrogen temperatures using a SPEX 6700 freezer mill. 100 mg of the powdered sample were mixed with 0.2 mL aqua regia and 2.5 mL hydrofluoric acid and dissolved in a Parr acid digestion bomb at 120 $^{o}$C for 2 hours. Samples were then diluted to a total volume of 250 ml so that elements of interest would be present at concentrations of 500 ppb or less.

Immediately prior to analysis, 100 μL of a 10 ppm $^{115}$In solution were added to a 10 mL aliquot of each sample as an internal spike to correct for instrument drift. Analyses were performed on a Fisons PQ 2 Plus quadrupole ICP mass spectrometer. Rather than produce calibration curves for each of the 41 elements analyzed, simple blank subtraction was used and the results for the artifacts were compared directly against geological source samples prepared and analyzed in the same way (*35*).

## Results and Discussion

Source attributions were initially made using bivariate element plots, and were confirmed by applying multivariate discriminant functions determined for the geological samples to the artifact samples using the jackknife option of the software program BMDP 7M. The specific geological source of all 61 artifacts analyzed was identified with greater than 95% statistical probability (Table 3). Not surprisingly, all of the artifacts from all four sites come from the Monte Arci sources in Sardinia. To date, no obsidian from any of the other island sources has been found on Corsica or Sardinia. Obsidian from both Lipari and Palmarola,

**Table III. Source Attributions of Archaeological Artifacts**

| *Site* | *SA* | *SB1* | *SB2* | *SC* | *Total* |
|---|---|---|---|---|---|
| La Scola | 3 | 0 | 5 | 6 | 14 |
| Filiestru | 4 | 1 | 18 | 4 | 27 |
| Pietracorbara | 5 | 1 | 3 | 1 | 10 |
| Strette | 0 | 0 | 9 | 1 | 10 |
| *total* | 12 | 2 | 35 | 12 | 61 |

however, have been identified at the Early Neolithic site of Cala Giovanna on Pianosa, in sight of and presumably contemporary with La Scola, although Sardinian obsidian does account for more than 90% of the obsidian found there (*27*, *46*).

The relative proportions of each Sardinian source are also significant. Types SA and SC each represent about 20% of the artifacts tested, but are not consistently present in quantity at all four sites, type SA being absent at Strette and type SC accounting for only two artifacts total at the two Corsican sites. Type SB1 is represented by just two artifacts, but notably at two different sites, while type SB2 is consistently well represented at all four sites, accounting for nearly 60% of all the artifacts tested.

This pattern is consistent with that observed at other Early Neolithic sites in Corsica (*27*), Tuscany (*47*), and Liguria (*34*), but contrasts sharply with southern France (*26, 29*) where type SA accounts for the vast majority of obsidian found there (Figure 3). These patterns would not have been observable without the level of resolution enabled by the analytical methodology used here, and allow us to make interpretations that were not possible using more basic distributional data (*48*, *49*). Down-the-line trade (*50*), characteristic of societies without marked social hierarchies, is widely considered to be a common exchange mechanism during the Neolithic period. Settlements close to an obsidian source would have direct access and an abundant supply. They would have exchanged some of their obsidian with neighboring villages further from this supply zone, and these villages would have done the same with others even further away, so that the frequency of obsidian would decrease with distance from the source. The presence, in all but one case, of three Monte Arci obsidian types, with a high importance of type SB2 in all cases, at Filiestru, Strette, Pietracorbara, Lumaca, La Scola, Cala Giovanna, Paduletto di Castagneto, Querciolaia, and Arene Candide, is consistent with such a model for the

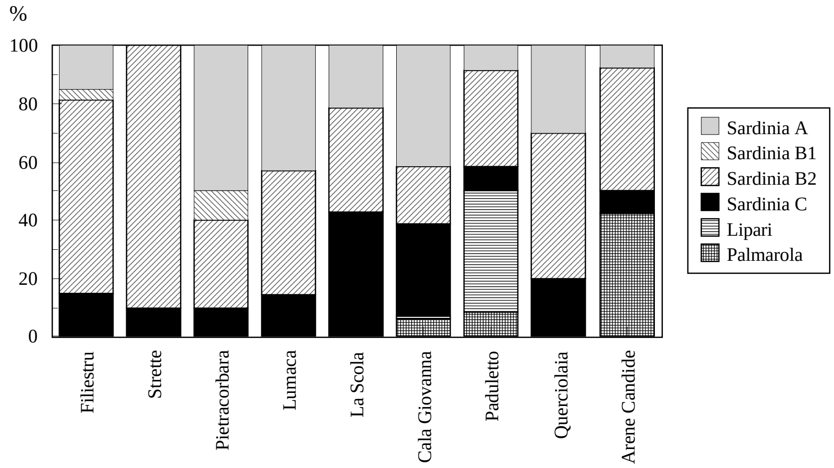

*Figure 3. Relative frequency of obsidian at Early Neolithic sites in Sardinia, Corsica, and northern Italy. Other authors have not separated any of the SB subsources, but are most likely to be SB2 as they are shown here.*

distribution of obsidian from Sardinia to Corsica to Tuscany and northwards to Liguria, perhaps in exchange for ground stone tools, pottery, and more perishable materials (*1*).

The obviously different pattern in southern France implies, however, that more than one exchange mechanism may have been in place at one time, and/or that cultural and other factors were much more complex than the heuristic explanation proposed here. Maritime contacts between Sardinia and the mainland perhaps were not necessarily routed across the shortest open-water crossings. Furthermore, there may have been significant differences in the use-function of obsidian within different groups, perhaps depending on the availability of alternative lithic resources. The integration of provenance studies with typological and use-wear analysis (*51*) shows great promise for testing these hypotheses.

In conclusion, high-resolution provenance studies of western Mediterranean obsidian artifacts produce more detailed information on Early Neolithic exchange patterns than can studies which only attribute artifacts at the island level. This was a time when an agricultural way of life was first introduced and the Mediterranean islands were first widely settled. Obsidian, as the most visible indicator in the archaeological record of intercultural contact, is a critical material for the reconstruction of this most important transition in human prehistory.

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**Table II. Electron Microprobe Data for Obsidian Artifacts**

| *No.* | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | $Fe_2O_3$ | *MgO* | *CaO* | $Na_2O$ | $K_2O$ | *MnO* | $P_2O_5$ | *BaO* | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *La Scola* | | | | | | | | | | | | |
| 292 | 74.85 | 13.58 | 0.07 | 1.19 | 0.09 | 0.58 | 3.35 | 5.11 | | | 0.03 | 98.85 |
| 293 | 72.82 | 13.97 | 0.26 | 1.55 | 0.26 | 0.86 | 3.19 | 5.73 | | | 0.15 | 98.85 |
| 294 | 73.27 | 14.08 | 0.26 | 1.10 | 0.06 | 0.85 | 3.19 | 5.87 | | | 0.14 | 98.85 |
| 295 | 74.88 | 13.39 | 0.06 | 1.17 | 0.08 | 0.58 | 3.37 | 5.18 | | | 0.01 | 98.85 |
| 296 | 75.22 | 13.15 | 0.12 | 1.17 | 0.12 | 0.59 | 3.26 | 5.28 | 0.11 | 0.07 | 0.02 | 99.00 |
| 297 | 75.21 | 13.22 | 0.11 | 0.92 | 0.09 | 0.60 | 3.36 | 5.29 | | | 0.05 | 98.85 |
| 298 | 72.96 | 13.98 | 0.32 | 1.25 | 0.11 | 0.94 | 3.20 | 5.81 | | | 0.17 | 98.85 |

**Table II (continued). Electron Microprobe Data for Obsidian Artifacts**

| *No.* | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | $Fe_2O_3$ | *MgO* | *CaO* | $Na_2O$ | $K_2O$ | *MnO* | $P_2O_5$ | *BaO* | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Grotta Filiestru* | | | | | | | | | | | | |
| 1170 | 75.27 | 12.94 | 0.11 | 1.08 | 0.10 | 0.55 | 3.35 | 5.47 | 0.07 | 0.04 | 0.01 | 99.00 |
| 1171 | 74.30 | 13.56 | 0.10 | 1.33 | 0.08 | 0.59 | 3.45 | 5.43 | 0.08 | 0.07 | 0.02 | 99.00 |
| 1172 | 74.62 | 13.22 | 0.13 | 1.25 | 0.15 | 0.58 | 3.42 | 5.50 | 0.06 | 0.04 | 0.01 | 99.00 |
| 1173 | 74.42 | 13.29 | 0.14 | 1.23 | 0.14 | 0.60 | 3.42 | 5.67 | 0.07 | 0.02 | 0.01 | 99.00 |
| 1174 | 74.41 | 13.62 | 0.09 | 1.19 | 0.07 | 0.62 | 3.37 | 5.41 | 0.08 | 0.07 | 0.04 | 99.00 |
| 1175 | 75.06 | 13.04 | 0.13 | 1.12 | 0.10 | 0.55 | 3.39 | 5.47 | 0.07 | 0.03 | 0.02 | 99.00 |
| 1176 | 73.85 | 13.77 | 0.17 | 1.04 | 0.07 | 0.72 | 3.42 | 5.75 | 0.11 | 0.03 | 0.07 | 99.00 |
| 1177 | 75.06 | 13.00 | 0.12 | 1.11 | 0.11 | 0.56 | 3.42 | 5.43 | 0.08 | 0.04 | 0.00 | 99.00 |
| 1178 | 75.11 | 13.02 | 0.12 | 1.07 | 0.10 | 0.57 | 3.43 | 5.48 | 0.06 | 0.04 | 0.01 | 99.00 |
| 1179 | 75.01 | 13.05 | 0.12 | 1.13 | 0.09 | 0.57 | 3.36 | 5.55 | 0.08 | 0.04 | 0.00 | 99.00 |
| 1180 | 74.97 | 12.96 | 0.12 | 1.14 | 0.13 | 0.56 | 3.39 | 5.43 | 0.08 | 0.03 | 0.04 | 99.00 |
| 1181 | 74.96 | 13.01 | 0.12 | 1.17 | 0.11 | 0.58 | 3.45 | 5.47 | 0.08 | 0.03 | 0.02 | 99.00 |
| 1182 | 72.71 | 13.88 | 0.26 | 1.55 | 0.21 | 0.82 | 3.29 | 6.03 | 0.12 | 0.03 | 0.10 | 99.00 |
| 1183 | 74.90 | 13.08 | 0.13 | 1.15 | 0.11 | 0.56 | 3.43 | 5.49 | 0.08 | 0.04 | 0.03 | 99.00 |
| 1184 | 72.37 | 13.92 | 0.29 | 1.58 | 0.22 | 0.94 | 3.31 | 5.85 | 0.17 | 0.03 | 0.15 | 99.00 |
| 1185 | 74.35 | 13.28 | 0.15 | 1.32 | 0.14 | 0.62 | 3.41 | 5.60 | 0.08 | 0.05 | 0.00 | 99.00 |
| 1186 | 74.97 | 13.14 | 0.12 | 0.99 | 0.12 | 0.57 | 3.48 | 5.48 | 0.08 | 0.04 | 0.03 | 99.00 |
| 1227 | 75.31 | 12.92 | 0.13 | 1.18 | 0.10 | 0.56 | 3.30 | 5.36 | 0.07 | 0.05 | 0.01 | 99.00 |
| 1228 | 74.81 | 13.35 | 0.10 | 1.24 | 0.07 | 0.58 | 3.39 | 5.32 | 0.08 | 0.06 | 0.01 | 99.00 |
| 1229 | 74.71 | 13.13 | 0.16 | 1.14 | 0.14 | 0.60 | 3.34 | 5.64 | 0.08 | 0.03 | 0.03 | 99.00 |
| 1230 | 75.46 | 12.80 | 0.11 | 1.09 | 0.07 | 0.55 | 3.28 | 5.52 | 0.07 | 0.03 | 0.02 | 99.00 |
| 1231 | 72.67 | 13.97 | 0.28 | 1.60 | 0.15 | 0.92 | 3.31 | 5.92 | 0.15 | 0.02 | 0.11 | 99.00 |
| 1232 | 75.28 | 12.98 | 0.12 | 1.11 | 0.10 | 0.56 | 3.35 | 5.37 | 0.08 | 0.03 | 0.00 | 99.00 |
| 1233 | 74.61 | 13.43 | 0.09 | 1.31 | 0.09 | 0.61 | 3.40 | 5.35 | 0.06 | 0.04 | 0.00 | 99.00 |
| 1234 | 75.04 | 13.06 | 0.15 | 1.04 | 0.12 | 0.59 | 3.26 | 5.65 | 0.07 | 0.04 | 0.01 | 99.00 |
| 1235 | 72.49 | 14.00 | 0.27 | 1.43 | 0.18 | 0.85 | 3.26 | 5.82 | 0.14 | 0.03 | 0.08 | 99.00 |
| 1236 | 75.35 | 12.90 | 0.11 | 1.16 | 0.09 | 0.57 | 3.32 | 5.38 | 0.07 | 0.03 | 0.02 | 99.00 |
| *Pietracorbara* | | | | | | | | | | | | |
| 1308 | 74.61 | 13.36 | 0.09 | 1.28 | 0.09 | 0.60 | 3.53 | 5.30 | | | 0.01 | 98.85 |
| 1309 | 74.63 | 13.42 | 0.09 | 1.30 | 0.08 | 0.59 | 3.43 | 5.31 | | | 0.00 | 98.85 |
| 1310 | 75.23 | 12.86 | 0.11 | 1.11 | 0.10 | 0.55 | 3.38 | 5.50 | | | 0.00 | 98.85 |
| 1311 | 74.36 | 13.59 | 0.10 | 1.19 | 0.07 | 0.63 | 3.62 | 5.25 | | | 0.02 | 98.85 |
| 1312 | 74.14 | 13.62 | 0.09 | 1.35 | 0.07 | 0.65 | 3.71 | 5.21 | | | 0.03 | 98.85 |
| 1313 | 74.81 | 13.07 | 0.14 | 1.15 | 0.12 | 0.59 | 3.39 | 5.55 | | | 0.04 | 98.85 |
| 1314 | 72.61 | 14.00 | 0.30 | 1.31 | 0.19 | 0.92 | 3.39 | 6.04 | | | 0.08 | 98.85 |
| 1315 | 74.59 | 13.42 | 0.08 | 1.19 | 0.07 | 0.62 | 3.57 | 5.27 | | | 0.06 | 98.85 |
| 1316 | 73.44 | 13.55 | 0.18 | 1.60 | 0.18 | 0.74 | 3.43 | 5.72 | | | 0.03 | 98.85 |
| 1317 | 74.64 | 13.05 | 0.14 | 1.22 | 0.14 | 0.57 | 3.46 | 5.57 | | | 0.06 | 98.85 |

**Table II (continued). Electron Microprobe Data for Obsidian Artifacts**

| *No.* | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | $Fe_2O_3$ | *MgO* | *CaO* | $Na_2O$ | $K_2O$ | *MnO* | $P_2O_5$ | *BaO* | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Strette* | | | | | | | | | | | | |
| 1330 | 75.09 | 12.91 | 0.12 | 1.14 | 0.11 | 0.55 | 3.41 | 5.49 | | | 0.04 | 98.85 |
| 1331 | 75.01 | 12.88 | 0.14 | 1.12 | 0.12 | 0.58 | 3.39 | 5.56 | | | 0.07 | 98.85 |
| 1332 | 75.17 | 12.95 | 0.12 | 1.10 | 0.11 | 0.54 | 3.42 | 5.43 | | | 0.03 | 98.85 |
| 1333 | 75.15 | 12.88 | 0.13 | 1.13 | 0.09 | 0.56 | 3.41 | 5.48 | | | 0.03 | 98.85 |
| 1334 | 75.14 | 12.94 | 0.14 | 1.08 | 0.11 | 0.57 | 3.36 | 5.50 | | | 0.01 | 98.85 |
| 1335 | 74.79 | 12.71 | 0.13 | 1.74 | 0.09 | 0.56 | 3.39 | 5.43 | | | 0.02 | 98.85 |
| 1336 | 75.17 | 12.93 | 0.12 | 1.15 | 0.09 | 0.56 | 3.36 | 5.47 | | | 0.00 | 98.85 |
| 1337 | 75.09 | 12.90 | 0.12 | 1.09 | 0.10 | 0.56 | 3.40 | 5.55 | | | 0.05 | 98.85 |
| 1338 | 72.89 | 13.72 | 0.25 | 1.54 | 0.20 | 0.85 | 3.35 | 5.98 | | | 0.08 | 98.85 |
| 1339 | 75.32 | 12.84 | 0.11 | 1.09 | 0.11 | 0.55 | 3.40 | 5.44 | | | 0.00 | 98.85 |

NOTE: All units in percent. Values standardized to a total of 99% allowing 1% for water and trace elements, or to 98.85% when MnO and $P_2O_5$ were not determined.