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ORIGINAL PAPER

Lithic technology and obsidian exchange networks in Bronze Age Nuragic Sardinia (Italy)

Kyle P. Freund · Robert H. Tykot

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Abstract The study of the Sardinian Bronze Age (Nuragic period) and the factors which created and maintained an island-wide identity as seen through the presence of its distinctive *nuraghi* has received considerable attention; however, the amount of research directly related to the stone tools of the era has been relatively limited despite the wealth of knowledge it is capable of yielding. This research hopes to contribute to Sardinian archaeology through the study of ancient technology, specifically obsidian lithic technology, by combining typological information with source data gleaned from the use of portable X-ray fluorescence spectroscopy. This research also explores temporal changes in the acquisition of obsidian raw materials and the corresponding changes in how the obsidian was used. The results provide precedence for future work in Sardinia and create a model for integrating two types of analyses, sourcing and typological. By combining these results, it is possible to investigate ancient economies, exchange networks, and cultural values.

Keywords Sardinia · Italy · Nuragic culture · Obsidian · Typologies · X-ray fluorescence (XRF)

K. P. Freund (✉)
Department of Anthropology, McMaster University,
Chester New Hall Rm. 524 1280 Main Street West,
Hamilton, Ontario L8S 4L9, Canada
e-mail: freundkp@mcmaster.ca

R. H. Tykot
Department of Anthropology, University of South Florida,
4202 E. Fowler Ave., SOC107,
Tampa, FL 33620, USA
e-mail: rtykot@usf.edu

Introduction

Sardinia is located in the Mediterranean Sea off the west coast of Italy and occupies an area of approximately 24,000 km^2 (Fig. 1). The Sardinian Bronze Age Nuragic period (ca. 1700–900 BC) is named after the approximately 7,000 truncated cone-shaped residential stone structures called nuraghi which were constructed throughout the island during this period. These structures are usually corbelled domes made of different kinds of stones, mainly basalt and granite; they average approximately 12 m in diameter and originally rose to around 15–20 m high, although there is a wide range of variation (Balmuth 1984). Two types of nuraghi are present, “simple” and “complex”. These likely represent a chronological progression with an increase in complexity over time. Simple towers had low doors, interior stairways, and one or two chambers. Complex nuraghi included additional stories, chambers, and walls (Dyson and Rowland 2007).

The study of Nuragic lithic technology and the exchange networks which created and maintained an island-wide identity as seen through the presence of its distinctive nuraghi has received little attention despite the wealth of knowledge it is capable of yielding. The relative isolation of the island from outside influences compared to contemporaneous communities elsewhere in the Mediterranean provides a unique opportunity to study indigenous Sardinian cultural developments, since islands are truly fascinating places which raise issues of identity, isolation, connectivity, power, and resources (Pearson 2004).

This research provides one of the first comprehensive studies of Nuragic obsidian technology and trade by combining typological analyses with source data gleaned from the use of portable X-ray fluorescence spectrometry (pXRF). Such a combination of data is able to track the

Fig. 1 The Italian island of Sardinia

movements of ancient peoples and goods across the landscape during resource procurement, whether it be directly from the quarry site or through trade with neighboring villages through reciprocation. Lithics from six sites have been examined and will be juxtaposed against earlier assemblages. It will be shown that marked technological changes occurred through time, and possible explanations for such variation will be explored. It is undeniable that stone technology was integrated into larger systems of interaction which can be analyzed to understand cultural change.

Obsidian sources and archaeological sites

There are a number of Nuragic sites and locales which are relevant for this research and these are discussed in some detail (Fig. 2). However, before introducing the archaeological sites of the Marghine region, it is necessary to expound on Sardinian geology as it relates to obsidian.

Monte Arci

Monte Arci is a region in west-central Sardinia which contains the obsidian raw material used for stone tools from the beginning of the Neolithic period and found throughout the archaeological sites of the Nuragic era. Obsidian is a type of volcanic glass, an igneous rock which is usually black-gray in color. Earlier studies have identified four subsources located in the Monte Arci area and include SA, SB1, SB2, and SC (Tykot 1992, 1997). Secondary SC obsidian deposits have also been documented by Lugliè et al. (2006a, b) south of the main SC conglomerate. This region of Sardinia is by no means the only source of obsidian in the western Mediterranean. Additional obsidian sources are found on the islands of Lipari, Palmarola, and Pantelleria. On Sardinia, however, only the obsidian from Monte Arci is known to have been exploited (Tykot 1996).

Marghine region

The Marghine region covers approximately 400 km^2 of basaltic upland plateau and is bordered on the north by the Goceano Mountains and the south by the Abbassanta Plain. To the east lies the Tirso River valley and to the west lie the uplands of Planargia (Webster 2001). The current vegetation consists of thinly covered scrub which is conducive to modern-day pastoralism, although in the past the plateau supported extensive oak forests. During the Middle Bronze to Early Iron Age periods, this region supported one of the largest clusters of nuraghi and their associated burial tombs (Webster 2001). This entire region is separated from similar areas by a 2-km buffer zone in which there are no nuraghi. This delineation of regional boundaries may be a common feature on the island which reflects territorial confines (Webster 1991). For this research, a cluster of nuraghi in the Borore locale has been analyzed which is part of a larger regional survey carried out from 1980 to 1996. This locale is a roughly elliptical area of pasture and mixed farmland which slopes gently to the southeast.

The west-central Sardinian site of Duos Nuraghes (Fig. 3) is located in the Marghine region on a low knoll in the Borore locale at a 400-m elevation (Webster 1996). It typifies a little studied but important element of Nuragic culture, a simple Nuragic village. The main occupation at the site spanned from the Middle Bronze Age to the Carthaginian conquest (around 1700–500 BC), with two centrally located nuraghi. Tower A is a single story "simple" nuraghe, and tower B is a more complex two-story nuraghe, constructed somewhat later than tower A. Residential stone structures are located to the east and west of the nuraghi. In general, the West Village has suffered more from post-depositional erosion than the East Village perhaps due to the eastern circuit wall protecting against down-slope erosion. Therefore, the East Village was extensively excavated by digging 38 2×4 m trenches, thus revealing a cistern, circuit wall, and 14 buildings with foundations containing artifacts spanning the site's occupation (Webster 2001).

Additional sites in the Borore locale have also been included in this study and comprise nuraghi Toscono, Urpes, San Sergio, and Serbine. Of these four sites, only at Nuraghe Urpes has there been excavation conducted outside of the nuraghe.

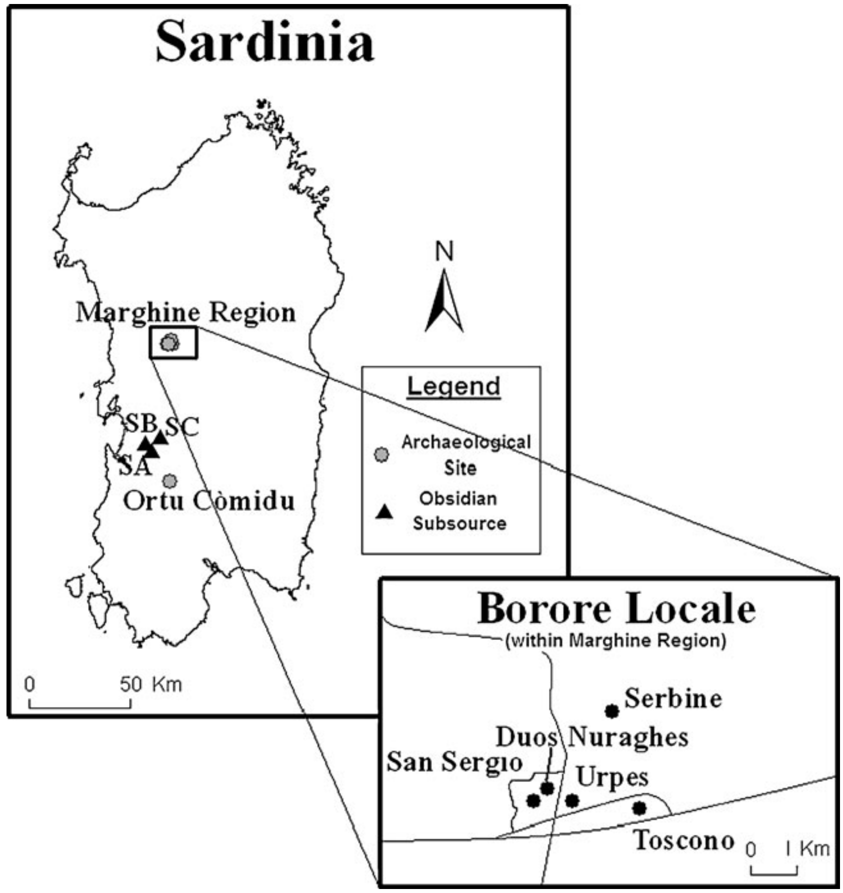

Fig. 2 Map of all relevant sites

Nuraghe Ortu Còmidu (Sardara)

The excavation of Ortu Còmidu, located near the Pixina River, south of Monte Arci in the province of Cagliari, took place in 1975, 1976, and 1978 as part of a project which explored early Sardinian metal working (Balmuth and Phillips 1986) and followed earlier work done at this site by Taramelli (1918). Ortu Còmidu initially dates to the earlier phases of the Nuragic period (around 1700 BC) and is a "complex" nuraghe 12 m in diameter. Figure 4 shows that it has a central tower, a courtyard with a well, and at least three subsidiary towers attached to the central one. The recovered artifacts come from both in and outside of the nuraghe. The excavators divided the site into 5×5 m grid units and excavated following 10 cm levels. Most of the nuraghe as well as the surrounding area were uncovered.

Artifact description

Three types of raw material were continually used for chipped stone production in Sardinia during the Bronze Age: chert, quartz, and obsidian. For this study, only the obsidian will be considered. While the lithic assemblages from the aforementioned sites were composed of other raw materials such as chert and quartz, the majority of lithic material was obsidian.

Sourcing methods

To identify the source of obsidian artifacts, several methods are available. The most cost-efficient method is visual inspection. Some obsidian sources can be distinguished based on an artifact's color, transparency, and presence of phenocrystic inclusions. Additional methods include calculating the artifact's density and comparing it with known measurements. The third option is elemental analysis. This method is the most precise and accurate, but several assumptions must be tested. One or more of the elements tested must be homogenous within the source as well as statistically different from any other source (Tykot 2003). If these prerequisites are met, then a choice must be made as to the appropriate type of analysis to be used. Factors such as time, cost, size of the artifact, and destructiveness of the analysis must be considered. A variety of elemental analysis options have proven successful in differentiating obsidian sources, including instrumental neutron activation analysis, proton-induced X-ray/gamma ray emission, inductively coupled plasma spectroscopy, ICP mass spectrometry,

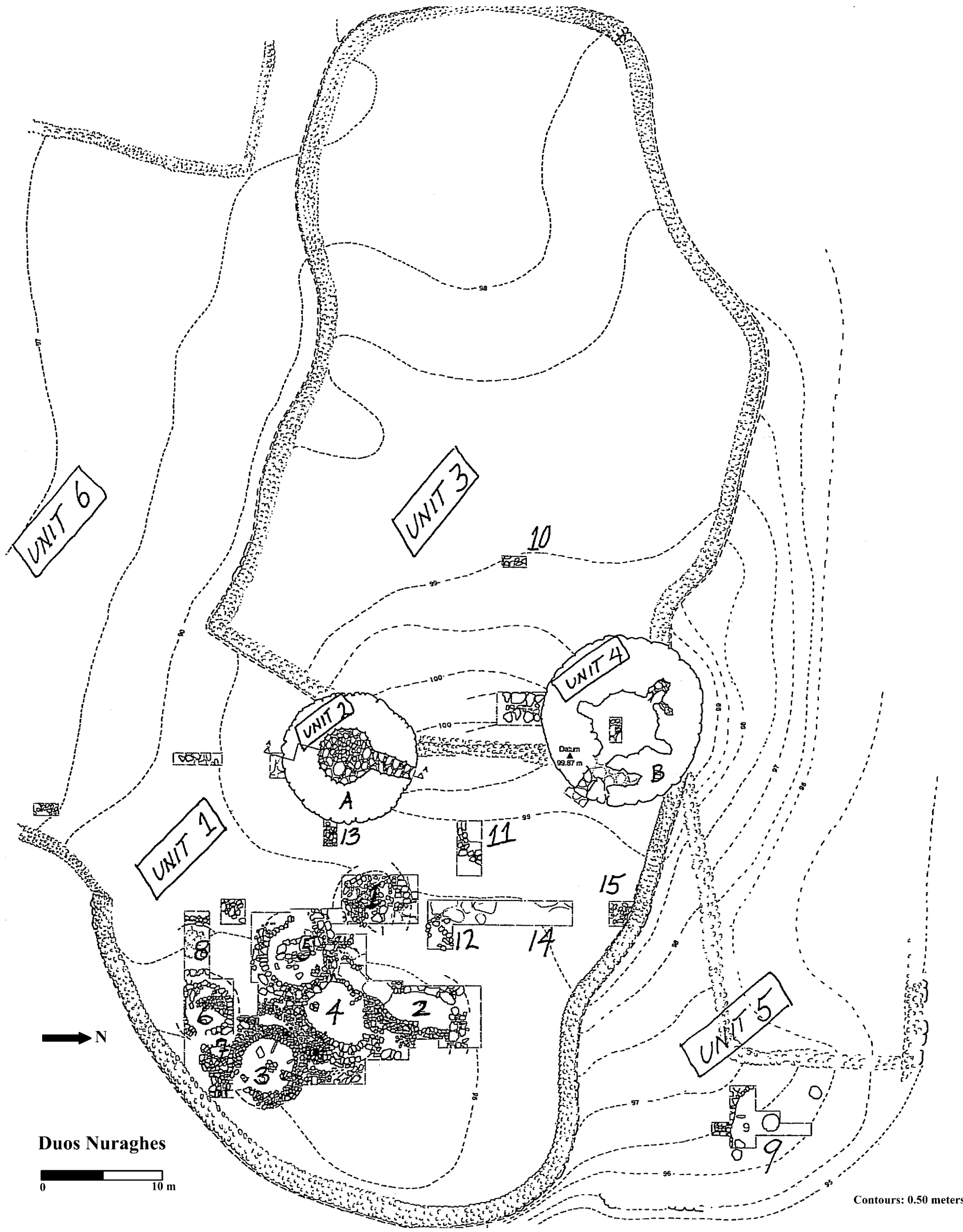

Fig. 3 Plan of Duos Nuraghes (Webster 2001: 7)

scanning electron microscope with energy dispersive spectrometry, electron microprobe with wavelength dispersive spectrometry, and a variety of XRF instruments.

X-ray fluorescence

At the heart of XRF technology is the principle that primary X-rays shot at a sample create vacancies in the atoms on the surface of the material which produce secondary, or fluorescent, X-rays which are characteristic of the elements of which it is composed (Pollard et al. 2007). XRF is capable of recognizing major and trace elements, both of which have been shown to be successful in distinguishing the Sardinian obsidian subsources (Tykot 2002; Le Bourdonnec et al. 2010). XRF is by no means limited to obsidian sourcing; it is also useful in the study of metals, glass, and ceramics. Since it can be non-destructive, it is especially useful for archaeologists, as is indicated by the increased use of portable XRF instruments for obsidian studies in recent years (e.g., Tykot 2010; Nazaroff et al. 2010; Phillips and Speakman 2009; Cecil et al. 2007).

For this study, a Bruker Tracer III–V portable XRF machine was used to source 347 artifacts from the Marghine region: 242 from Duos Nuraghes and 105 from nuraghi Toscono, San Sergio, Serbine, and Urpes. An additional 144 artifacts from Ortu Còmidu were also sourced. Figure 5 displays some examples of the analyzed artifacts. A filter was placed directly into the machine

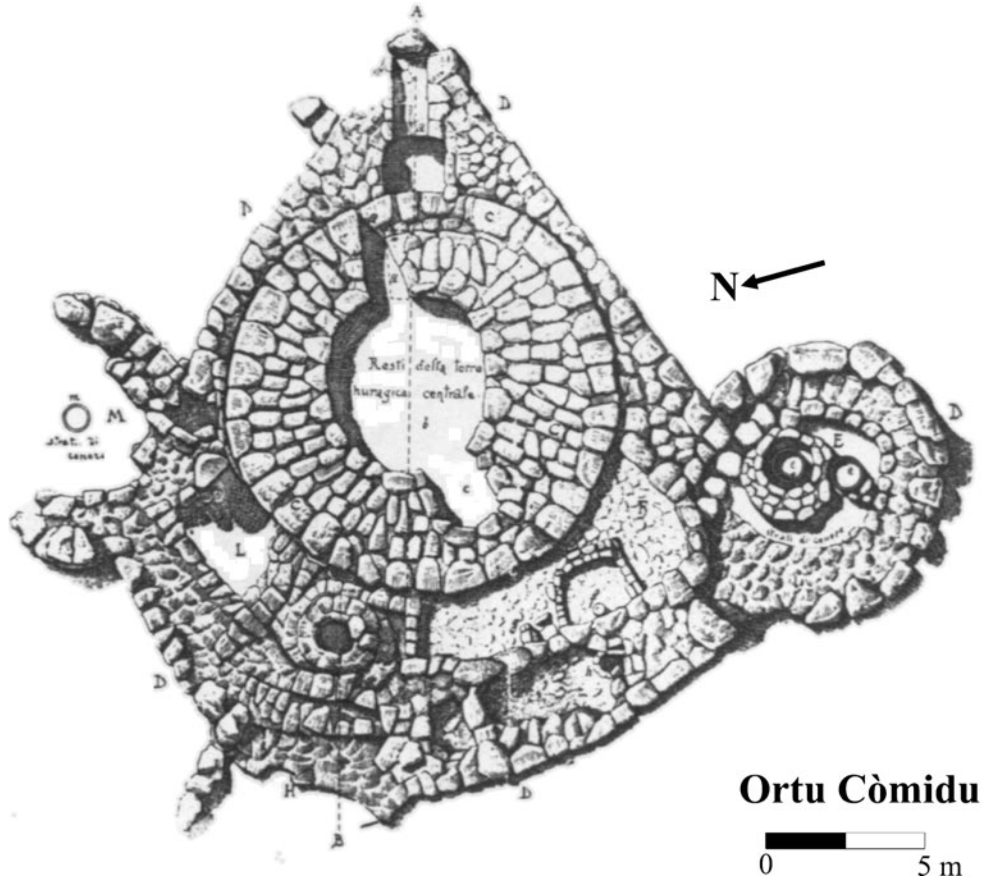

Fig. 4 Plan of Nuraghe Ortu Còmidu (Balmuth and Phillips 1986: 356)

which enhanced results for certain trace elements (Rb, Sr, Y, Zr, Nb) already shown to be successful for Mediterranean obsidian sourcing. The artifacts were placed on the top of the machine and analyzed for a period of 3 min. While the immediate display on the computer screen showed obvious differences between samples, the raw analytical data were calibrated against standard reference materials to come up with actual concentrations. The results were ultimately compared with known geological samples using a graph of the element ratios of rubidium and strontium to niobium (Fig. 6). Attributions of artifacts to a specific Monte Arci subsource were double-checked with other elemental data as well as their visual appearance and density (Tykot 1997).

Fig. 5 Some examples of Nuragic obsidian artifacts from Duos Nuraghes (note sections missing as a result of obsidian hydration dating (Stevenson and Ellis 1998))

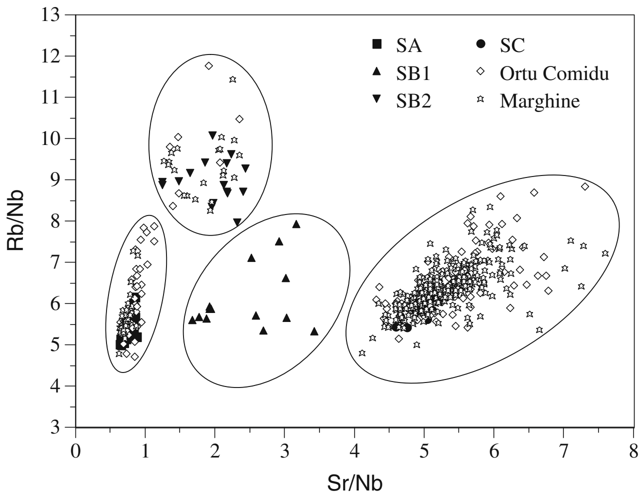

Fig. 6 pXRF data distinguishes the Monte Arci subsources in this graph of Sr/Nb vs. Rb/Nb for geological and archaeological samples

Typological methods

This section introduces the methods which were utilized to classify and analyze the same artifacts which were sourced using XRF. The measured attributes are capable of determining the reduction strategies employed on the artifacts. In this way, it is possible to correlate an artifact's provenance with how it was knapped, a scheme which has already been shown to be useful in Anatolian and Mediterranean obsidian studies (Carter et al. 2006; Lugliè et al. 2008).

For this study, a total of 413 obsidian artifacts were typologically analyzed. This included 228 artifacts from Duos Nuraghes and 71 from the other sites in the Marghine region. An additional 114 artifacts were analyzed from Ortu Còmidu. It must be pointed out that the number of artifacts which were chemically sourced is larger than the number of artifacts being typologically analyzed. This is due to the fact that some artifacts were too destroyed to be properly measured. Many of the artifacts had undergone obsidian hydration dating, a destructive technique capable of yielding chronologies on obsidian artifacts. This destruction may have prohibited a typological analysis, but it did not preclude analysis using XRF.

Artifact classification is a necessary component of archaeological investigation. In lithic studies, it has usually taken the form of typology creation. Dibble (2008: 86) defines a typology as "a classification of lithic objects according to various criteria, most often morphological ones." Morphological classification schemes are easy to create and are based on the recognition of certain attributes common to all forms. The choice of attributes can be related to the perceived function of the artifact or they can be value-free measurements predicated on the recognition of certain features. Lithic assemblages are typically composed of two material types: tools which display some sort of intentional retouch and the debitage fashioned during the process of knapping. The sites for this study offer an exceptional opportunity to examine Nuragic lithic assemblages with suitable provenience, thus making it possible to use debitage analysis to explore a myriad of issues. For purposes of this survey, only the obsidian artifacts have been analyzed because of the ability to correlate morphological attributes with source data gleaned from the use of XRF technology.

Relevant typology

The process of debitage analysis described in Sullivan and Rozen's (1985) article has been utilized to reconstruct ancient residential patterns and socio-political organization and to identify typological changes through time and space. These data have been subsequently incorporated into the broader understanding of cultural, social, and political aspects of Nuragic culture. The crucial conceptual power of this typology is the ability to distinguish between core reduction and tool production based on the varying proportions of debitage categories, thus allowing comparisons to be formulated. Tool production refers to the manufacture of tools through flaking, while core reduction refers to the process of flake removal for the purpose of the acquisition of the detached pieces (Andrefsky 2009). Tool production is recognized archaeologically by the presence of a large percentage of broken flakes and flake fragments compared to the number of cores and complete flakes. The inverse is true of core reduction (Sullivan and Rozen 1985). Assemblages were divided into several categories: retouched tools, proximal flakes, medial flakes, distal flakes, and angular waste. Retouched tools were further subdivided into shaped and unshaped tools, backed tools, and blades. Unshaped tools were distinguished from shaped tools by the recognition of a striking platform as well as by evidence of the original shape of the flake from which it came. The shape of a flake becomes indistinguishable when there is a significant amount of retouch and, thus, a significant energy output into the fashioning of a tool. One will note that the debitage categories are slightly different than those outlined by Sullivan and Rozen (1985) and further classify flake fragments into medial and distal categories. Broken flakes are classified as proximal flakes, thus allowing for the possibility of additional analyses which can account for post-depositional processes such as flake breakage as a result of trampling.

Sourcing results and discussion

This section presents the results obtained from pXRF analysis and integrates these data within the larger picture of Sardinian prehistory. It also expands on previous

Nuragic obsidian sourcing by Michels et al. (1984). It will be shown that Nuragic obsidian exploitation differs from that of earlier time periods, a conclusion which has broader economic and social implications.

Nuragic results

Overall, the pattern of obsidian acquisition is roughly similar at all of the observed sites and between the different chronological and spatial contexts at individual sites. Figure 6 shows that at Duos Nuraghes, type SA obsidian accounts for 14.5% of the assemblage, type SB1 is represented by just 1 artifact (0.4%), type SB2 7.9%, while type SC dominates at 77.2%. This pattern is the same at the other sites in the Marghine region, with type SA accounting for 13.3% of the assemblage, type SB2 is represented by 10 artifacts (9.5%), while type SC dominates at 77.2%. In comparison, at Ortu Còmidu, type SA accounts for much more of the overall assemblage at 33.1%, type SB2 is represented by just one artifact (0.7%), while type SC dominates at 66.2%. One must note Ortu Còmidu's close proximity to the SA subsource which could explain its larger abundance. Moreover, secondary SC obsidian deposits identified by Lugliè et al. (2006a, b) are in close proximity to Ortu Còmidu. However, it is difficult to assume that the SC subsource dominates the assemblage only because of its location, not when all other Nuragic sites in this study display similar patterns.

In general, type SC obsidian overshadows other subsources in the composition of these Nuragic assemblages. Type SB1 and SB2 were not a significant source of raw material while type SA is the second most common, comprising as much as one-third of an entire assemblage. Similar studies at other Nuragic sites carried out by Michels et al. (1984) support these findings, but one must note the low number of artifacts sourced at these other sites (Fig. 7).

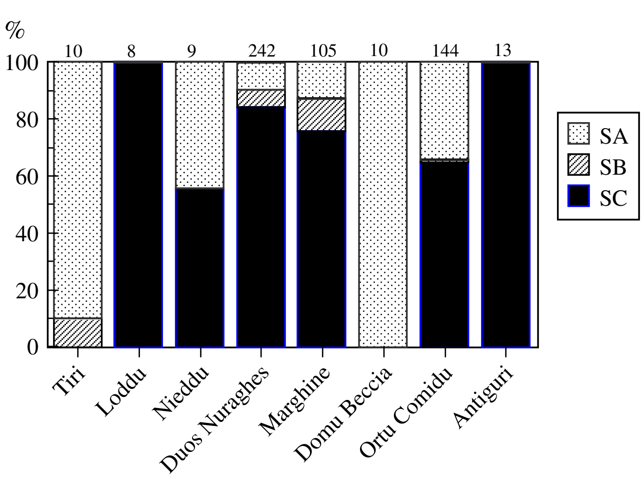

Fig. 7 Obsidian source distribution at Nuragic sites

Pre-Nuragic obsidian exploitation

To properly contextualize the results, these data must be situated within a wider temporal scheme. This will allow comparisons to be made to earlier time periods. During the Neolithic, trade of Sardinian obsidian extended throughout the central-western Mediterranean and was an important part of the ancient economy (Tykot 2002). The degree to which obsidian exportation was controlled by Sardinian residents is open for debate. It can reasonably be expected that residents in the vicinity of Monte Arci were those mainly responsible for acquisition and primary reduction of the obsidian, followed by transport and exchange outside of the Monte Arci region. There is also no evidence that trade with the mainland was frequent enough to significantly affect local economies. What is curious is that these external obsidian trade networks did not continue into the Bronze Age. Regardless, the general pattern of Early to Middle Neolithic obsidian exploitation on Sardinia, and the nearby island of Corsica, demonstrates a larger variety of obsidian sources being used than during the Chalcolithic and Nuragic. In particular, the SB subsources were utilized in much greater abundance, while type SA was also much more common (Tykot 2002). By the Late Neolithic, type SC obsidian begins to predominate at many archaeological sites, although it is not until Chalcolithic and Nuragic times that the SC subsource shows up in statistically higher quantities. Possible explanations for these changes in source distribution in the archaeological record can be addressed through an evaluation of the exchange systems which were in place during the Neolithic through Bronze Ages.

Exchange networks

It has been argued that down-the-line obsidian trade was the dominant mode of raw material acquisition for Neolithic peoples in Sardinia because of the broad geographic similarity in the purposes of obsidian usage and in the socio-economic circumstances in which it occurred (Tykot 1996, 2003; Tykot et al. 2008). Down-the-line trade is defined as a mode of exchange in which residents close to a raw material source traded goods with those within their immediate contact zone, thus passing these goods through several hands before eventually being discarded (Renfrew 1969; Smith 1987). We would argue strongly that the exchange of obsidian was a unifying mechanism which maintained an insular cohesiveness embedded in reciprocal trade. This does not mean that residents of a particular village had any knowledge of people elsewhere on the island or even a knowledge of where the obsidian quarry was located. It is just that those residents close to the quarry, who were responsible for primary reduction, were engaged in activities which resulted in the pattering of the archaeological record. There appears to be no evidence that this model of obsidian acquisition changed from Neolithic to Nuragic times. There is, however, a change in the quantitative distribution of the obsidian subsources, resulting in the dominance of the SC subsource towards the end of the Neolithic and continuing into Nuragic times. This corresponds with the development of SC workshops located at the quarry which can be seen by the high levels of standardized primary reduction revealed by survey and excavation in the Sennixeddu area on the east side of Monte Arci (Tykot et al. 2006). It is therefore plausible that an increased control of access at the quarry site, as seen at Sennixeddu, could have led to a trickle-down effect into larger spheres of interaction, thus resulting in the widespread dominance of one type of obsidian.

Similar situations have been analyzed at sites such as Teotihuacan in Mexico. Santley (1980) outlines a multi-step process of increasing complexity beginning with local elites managing part-time craft specialty activities, and then increasingly limiting access to the quarry site, eventually leading to a state-managed, vertically integrated monopoly. This model addresses the issue from a formalist perspective based on capitalistic principles. While it is true that material culture relates to the rise of ideological configurations, fields of discourse, attendant and contingent upon capitalism (Foucault 1979), this model fails to account for substantivist approaches which posit that non-western societies operate under different economic principles than traditional western societies (Sahlins 1972).

Instead of arguing for any predetermined relationship between structures of power and particular contexts of action, namely controlling obsidian distribution at the end of the Neolithic and into the Nuragic, it is more appropriate to examine how the relationship between structure and context is set in motion by human action (Hodder 1989). It is plausible that elites in the vicinity of Monte Arci used obsidian exchange as a way to create, solidify, and reify their power. This could have been just one context in which these elites established power. For example, if Nuragic obsidian exchange was the only context for establishing power, then one would expect to find the most extravagant nuraghi in the proximity of Monte Arci, if it can be assumed that elites expressed their power through architecture. This is not the case; there are multiple regional cores with multiple peripheries likely with a variety of economic and social structures.

Regardless of the structure of the post-Neolithic economy, this change in source distribution could have led to changes in the reduction strategies employed throughout the island which can be quantified by typological analysis, although causal relationships may be difficult to determine. It may be better to consider this relationship as a dialectic between raw material acquisition and its ultimate reduction for use. Nevertheless, this can be studied through typological investigation.

Typological results and discussion

Integration with previous analyses

To appreciate Nuragic lithic technology, it is useful to juxtapose it against the lithic assemblages and large-scale trade networks typical of the Neolithic. Studies indicate that the Neolithic saw a shift in reduction strategies more oriented towards blade and microlith production. Arrowheads, axes, and a small number of lunates are also found (Trump 1984). Geometric retouched pieces in the form of burins and scrapers dominated the assemblages (Lugliè et al. 2006a, b, 2008). These types of artifacts were created using a tool production strategy, a subtractive process in which a core eventually becomes one tool. Although the debitage from the creation of these tools has not been analyzed, the presence of tools not created from flakes, or flake blanks, inherently makes their creation the result of a tool production strategy.

The number of studies examining Chalcolithic lithic technology is especially low. This is likely due to the lack of carefully dated sites with a suitable number of Chalcolithic obsidian artifacts which would warrant a typological analysis. Based on the few descriptive analyses that have been conducted, it is known that Chalcolithic assemblages were dominated by the presence of blades and leaf-shaped arrowheads, a pattern which is not significantly different from Neolithic times (Melis 2000). However, another artifact is also prevalent. Melis (2000) does not use the term lunate, but describes a similar artifact which is elliptical in shape, with a plano-convex or trapezoidal cross section.

A study of lunate technology at Ortu Còmidu was carried out by Hurcombe (1992) and is one of the few analyses of its kind—although recent work on lunates has been conducted by Locci (2004, 2005). Morphological divisions initially separated the retouched tools into several categories including lunates (Fig. 8). Use-wear analysis on the lunates, which we refer to as backed tools, indicated that the ultimate function of these tools was the scraping of plant material. Interestingly, both the backed edges and the acutely angled edges opposite the backing also displayed traces of use-wear. This would seem to run counter to previous interpretations which suggested that these artifacts were hafted and thus indicative of the presence of composite tools. Andrefsky (2005) defines backing as the intentional dulling of an edge either by chipping, grinding, or abrading. Interestingly, 11 of the 12 backed tools at Ortu

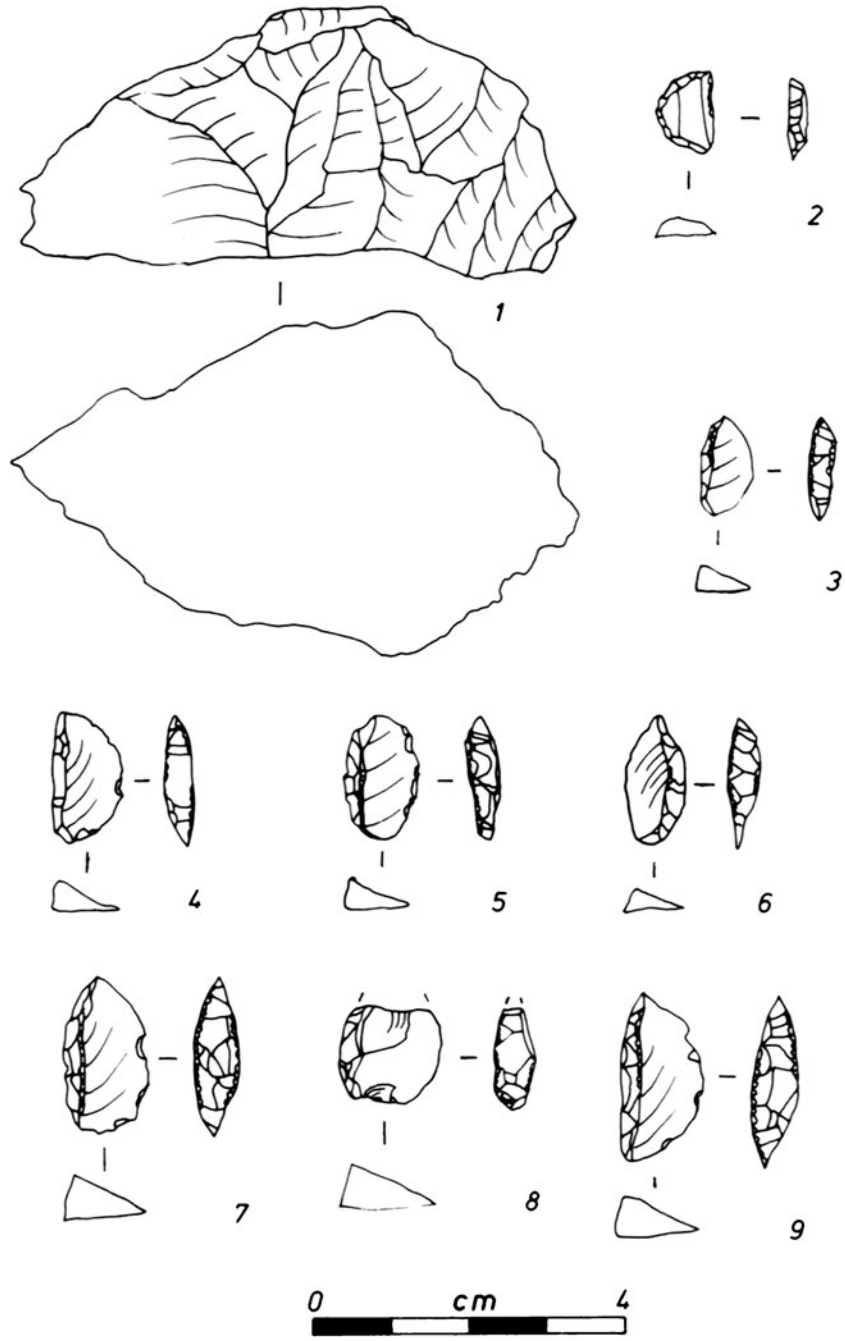

Fig. 8 Examples of obsidian lunates from Nuraghe Ortu Còmidu (Balmuth and Phillips 1986: 388)

Còmidu contain their backing on either the distal or lateral margins. This differs from sites in the Marghine region in which nearly all backed tools contain backing on the proximal end. Regardless, it is clear that this tool form was common throughout the island. All of the lithic assemblages are also similar in the lack of blades. Under the traditional definition of blade technology, an artifact's length perpendicular to the striking platform must be twice as long as its width (Bar-Yosef and Kuhn 1999). Only two retouched blades were discovered from Duos Nuraghes, one from Serbine and one from Ortu Còmidu.

At Duos Nuraghes, there is a broad distribution of backed tools. It is clear that for whatever these artifacts were used, it occurred throughout the site. Nine of the 17 structures, including the nuraghi, contain backed tools, and 14 of 17 contain unshaped tools. This would seem to negate the existence of craft specialization. Additional evidence for the lack of craft specialization is expressed by the distribution of artifacts throughout the site (Fig. 9). All of the structures display a broadly similar collection of artifacts. None of the structures contain an inordinate amount of debitage, cores, or other artifacts which would

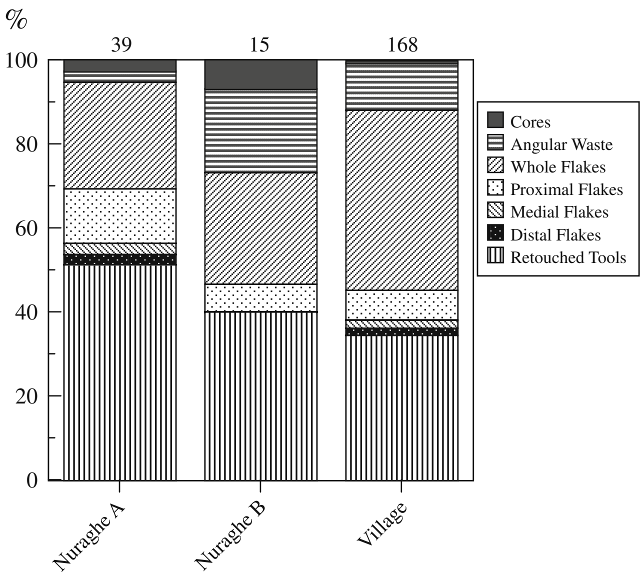

Fig. 9 Artifact type distribution within Duos Nuraghes

indicate specialization. The residents of Duos Nuraghes, including those of the nuraghi, seem to be responsible for their own lithic needs. Moreover, the reduction strategies employed throughout the sites are generally consistent (Fig. 10). Core reduction seems to be the preferred reduction strategy at all of the sites, with complete flakes making up an average of 40% of the assemblages. The relatively low number of cores may also indicate that primary reduction occurred at the quarry site or else depositional processes such as the throwing out of used cores may have affected the makeup of the assemblages.

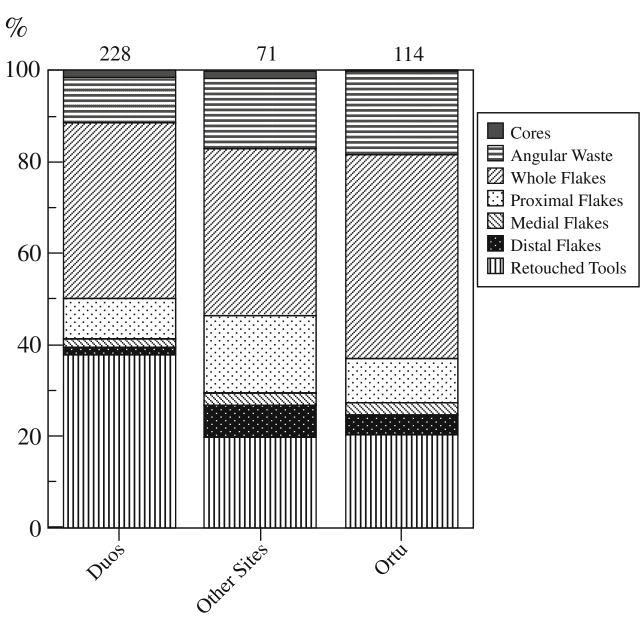

Fig. 10 Artifact type distribution at all sites in this study

Another study from Nuraghe Urpes and Nuraghe Toscono suggests that obsidian artifacts were used for a range of cutting and scraping activities (Michels 1987). Michels goes as far as to classify these artifacts into categories such as rasp-end, concave, and straight-edged scrapers. It is, however, overly simplistic to classify artifacts as concave or straight-edged when in fact many artifacts from all of the sites display retouch on multiple edges of different shapes. The diversity of morphological attributes at Duos Nuraghes does support Michels' (1987) conclusion that obsidian was used for a number of scraping and cutting activities. Figure 11 displays the frequency of different retouch locations on Duos Nuraghes artifacts. Unifacial retouch is the predominant class while parti-bifacial and bifacial classes are secondary. When combined, parti-bifacial and bifacial retouch frequency is nearly identical to the unifacial category. Platform retouch is indicative of the backed tools as discussed earlier. Retouch angles are just as diverse and range from steep to acute, likely indicating a variety of processing endeavors. This is supported by a more recent, detailed use-wear study of the obsidian assemblage from Duos Nuraghes (Setzer and Tykot 2010).

Unshaped tools comprise the bulk of the retouched category and were defined as tools in which the initial flake category was recognizable, whether that be a whole flake, medial flake, etc. For the comprehensively excavated sites, there is a larger percentage of unshaped tools at Duos Nuraghes (38%), than at Ortu Còmidu (20%). Moreover, the invasiveness of the retouch was measured in 2 mm increments from marginal to invasive and is shown in Fig. 12. The decreasing frequency of retouch invasiveness is characteristic of a reduction strategy where re-sharpening and tool maintenance was not a predominant activity. It seems that cores were expediently reduced, and the resulting debitage was retouched for the task at hand. The

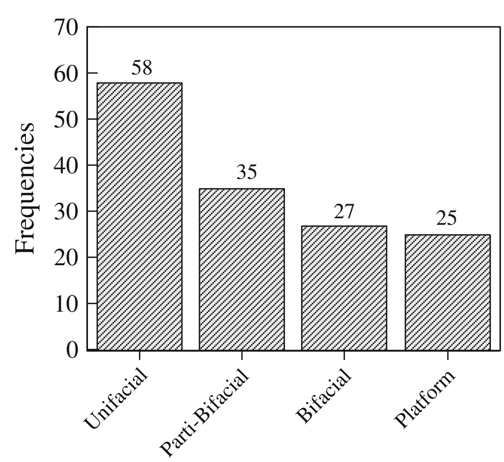

Fig. 11 Frequency of different retouch locations on Duos Nuraghes artifacts

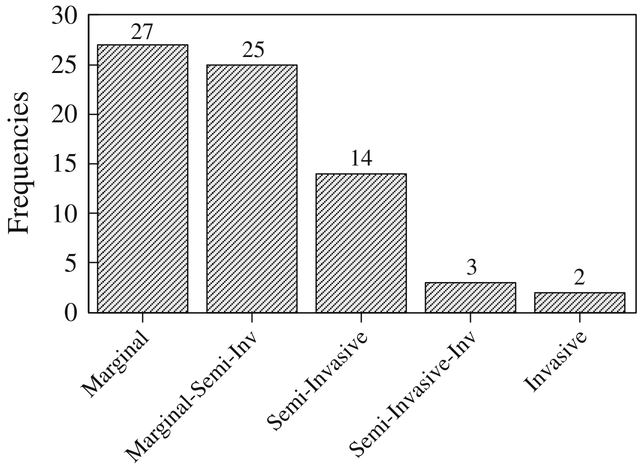

Fig. 12 Frequency of retouched tool invasiveness at Ortu Còmidu

average size and weight of the Nuragic material also supports the core reduction interpretation. Not including the cores, the average flake length to thickness ratio is 3.9, while the average weight is 1.0 g. When compared to flake length to thickness ratios of formalized assemblages from Upper Paleolithic France, which range from 4 to 8, it is clear that 3.9 is rather small (Blades 2003). The lack of cores and the relatively small size and weights of the artifacts seem to support a gradual abandonment event. There is nothing to indicate that the recovered artifacts are more than refuse; no artifacts which appear to be of social or sentimental value are present. It is possible that the cleanup of domestic areas took place which inadvertently left behind many of the smaller pieces, but the diversity of artifact types found throughout the site indicates that the lithic assemblage is a relatively complete collection of artifacts from a number of knapping and reduction events.

Explaining the causes of typological differences over time is slightly more difficult. The abundance of workable obsidian from the Monte Arci region presented ancient peoples with a choice in raw material. The art of tool production appears to have been phased out as obsidian became a secondary aspect of life, something to think about when a task needed to be completed.

The topic of causation has been addressed in a variety of ways and is central to many debates at the core of archaeological thought. While it is true that multivariate causation cannot be quantified in an absolute sense as many processualists have hoped, it should not discourage archaeologists from making inferences which are supported by the data. Renfrew (1978) provides an intriguing analysis of causation which will provide the lens through which causation will be addressed in this context. While the use of equations to quantify cultural change is premature if not outright naive, an understanding of the initial conditions under which cultural change occurs is central to any examination of causation. This analysis attempts to recognize possible initial conditions which created social and cultural discontinuity in Sardinia. They will be divided according to direct and indirect factors.

Direct causation

The first relates to the quality of raw material. It is possible that the prevalence of SC obsidian required users to adapt to different reduction strategies because of its knapping quality. However, this model tends to portray individuals as unthinking in their response to outside influences. It is perhaps more appropriate to view culture change not as an unthinking response to environmental factors, but as a dialectic between an ancient understanding of the material world, conscious human agency, and the unintended consequences of human choices (Robb 2005). It is very possible that the demand for SC obsidian increased, thus coercing those near the quarry to increase its distribution, not the other way around. The chronology does not match up either. During the Chalcolithic, lithic assemblages still contained artifacts which were very similar to those of the Neolithic. If the dominance of SC obsidian required users to adapt to different reduction strategies, then Chalcolithic assemblages should be more similar to those of the Bronze Age.

It is more plausible that an increase in plant use during the Chalcolithic and Early Bronze Age (Lai 2008) led to changes in the types of tools needed to fulfill users' needs. SC obsidian may have been preferred for the creation of plant-processing backed lunates, a tool which became prevalent in the Nuragic, and possibly earlier in similar forms. This would certainly be supported by the source data from Duos Nuraghes. Twenty-four of the 25 backed tools at Duos Nuraghes come from the SC subsource. Figure 13 displays the breakdown of retouched artifacts by source at Duos Nuraghes.

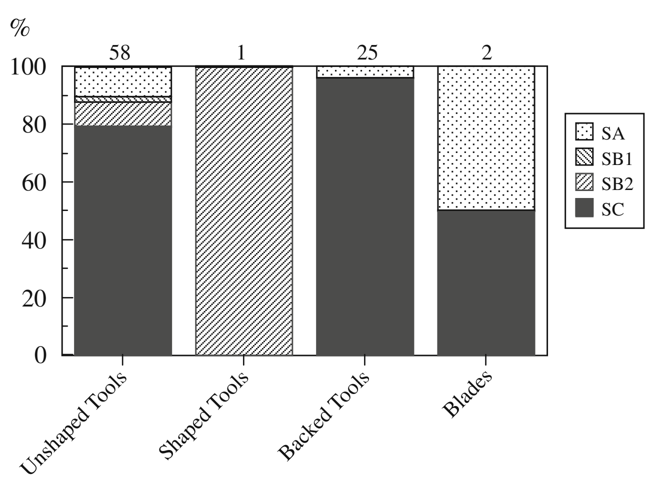

Fig. 13 Breakdown of retouched artifacts by source at Duos Nuraghes

These previous models stress the importance of materialistic conditions on the behavior of individuals and have introduced some hypothetical direct causes of lithic variation; however, indirect influences must also be addressed.

Indirect causation

It must not be forgotten that the Chalcolithic is so-named because of the introduction and proliferation of metal technology. The existence of copper deposits on Sardinia is well known; however, their history of exploitation is not. It is probably not until the later half of the third millennium that metallurgy becomes a part of the cultural landscape (Muhly 1973). Even then, extensive use of copper for utilitarian purposes is not supported by the material evidence and is highly unlikely. The introduction of bronze technology and the concomitant growth of metal foundries at sites such as Santa Barbara di Bauladu (Gallin and Tykot 1993) did affect how work was carried out. While metal was usually reserved for non-utilitarian purposes, there is evidence that bronze was used to create tools such as axe heads. Therefore, the introduction of a new tool medium could have led to changes in the social and cognitive importance of obsidian in the ancient mind. This is temporally supported by the less dramatic changes in obsidian assemblages when metal was not extensively utilized during the Chalcolithic. As metal was further integrated into daily life during the Nuragic, then obsidian assemblages began to be modified.

Conclusions

This research examined obsidian lithic artifacts from six Nuragic sites on the island of Sardinia. The geological sources of these artifacts were determined using X-ray fluorescence technology, with the results showing that the SC subsource was the dominant obsidian type which comprised all of the assemblages. This pattern of acquisition likely has its roots in the Late Neolithic and Chalcolithic time periods, when it is likely that part-time workshops began to emerge which were capable of supplying the entire island with raw materials through down-the-line exchange.

Typological analysis was used to test whether this change in the composition of lithic assemblages was accompanied with corresponding changes in how the obsidian was used. It was demonstrated that Chalcolithic assemblages were very similar to those of the Neolithic; however, they differed from earlier times in the abundance of backed lunates, a tool used for plant processing (Hurcombe 1992). During the Nuragic period, blade technology greatly diminished as assemblages became dominated by the presence of backed lunates and expediently produced unshaped tools. Core reduction strategies were utilized as cores were flaked and the resulting debitage was selected for and further reduced according to the immediate needs.

The causes for this change in obsidian usage were explored on two levels, directly and indirectly. The most plausible direct cause of this change relates to changes in diet with greater emphasis on agricultural products at the beginning of the Chalcolithic and continuing into the Nuragic. This could have led to changes in the types of tools needed to fulfill users' needs, namely lunate technology. Indirect causes relate to the introduction of metal technology which could have led to changes in the social and cognitive importance of obsidian in the ancient mind.

Further studies would benefit from an analysis of non-obsidian artifacts, not necessarily limited to lithics. Nevertheless, this study provides precedence for future work in Sardinia as well as provides a model for integrating two types of analyses, sourcing and typological. By combining these results, it is possible to investigate ancient economies, exchange networks, and cultural values.

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