

# Metallurgy at Nuraghe Santa Barbara (Bauladu), Sardinia

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*Excavations at Nuraghe Santa Barbara, Bauladu, western Sardinia have filled gaps in the poorly documented history of bronze casting in ancient Sardinia. The western section of the 12th–8th century B.C. village surrounding this five-towered nuraghe has yielded clear signs of metallurgical activity. The technological assessment of these remains, based on elemental and microscopic analyses, is described.*

## Introduction

The Nuragic culture of Bronze Age/Iron Age Sardinia is noted for achievements in monumental architecture and for prolific metallurgical activities. Over 7000 stone towers (*nuraghi*), the majority with skillfully-engineered corbelled domes and involving sophisticated geometrical conceptions, were built over a 1000-year period beginning around 1800 B.C. (Gallin 1989: 50). Associated with the towers and surrounding villages are tools, weapons, ingots, and decorative and utilitarian objects of copper, bronze, lead, and iron. Miniature bronze figurines (*bronzettini*), often found in votive contexts, depict Nuragic chiefs, warriors, nuraghi towers, animals, and boats.

Both Nuragic architecture and metallurgy have been inadequately documented and are poorly understood, primarily due to lack of scientific excavations and a verifiable database. Despite the richness of the archaeological remains of this period, Sardinia continued to be considered a relatively insignificant backwater in the otherwise prospering world of the ancient Mediterranean. This interpretation is changing. Advances in Sardinian archaeology over the last several decades confirm the local origin of architectural developments previously thought to have been inspired by eastern counterparts (Gallin 1989), and suggest how rich sources of native metals and a growing and diversified metallurgical industry may have propelled the island into a key position in trans-Mediterranean trade and commerce (Balmuth and Tylecote 1976; Zwicker, Viridis, and Ceruti 1980; Tylecote, Balmuth, and Massoli-Novelli 1984; Lo Schiavo 1981, 1986, 1988b; Gale and Stos-Gale 1987; Lo Schiavo et al. 1990).

While the broad outlines of prehistoric Sardinian culture are being redefined, still lacking are details of the socioeconomic nature of Nuragic society. Comprehensive exploration of Nuragic sites has been limited, and interpretation of their contents is complicated by successive reoccupations. The function of the nuraghi and their subsidiary towers and walls is not well understood, although there is some evidence for residential activities in the early occupation phases of the central bastions (Webster 1988). The surrounding villages thus far explored, rather than the nuraghi themselves, have yielded promising information about Nuragic economic organization (Webster and Michels 1986; Michels and Webster 1987). Questions regarding evolving technology, site utilization and hierarchy, settlement patterns, and regional organization and exchange during the Nuragic period are beginning to be addressed by expanded archaeological exploration and the synthesis of newly emerging data.

Recent excavations (directed by Lenore J. Gallin, 1986–1989) at Nuraghe Santa Barbara, Bauladu (FIG. 1), under the auspices of the Sardinian Superintendent of Archaeology for the Provinces of Cagliari and Oristano, provide important information on the economy of Late Bronze Age/Early Iron Age Nuragic society, especially in the area of metalworking. Until now, there have been few, if any, confirmed finds of metalworking facilities on Sardinia.

While only a small portion of the site has been excavated, the information so far retrieved presents a preliminary picture of the metallurgical activity at Santa Barbara and reveals new evidence on the nature of bronze casting. Metal slag, terra cotta crucibles with residues of molten

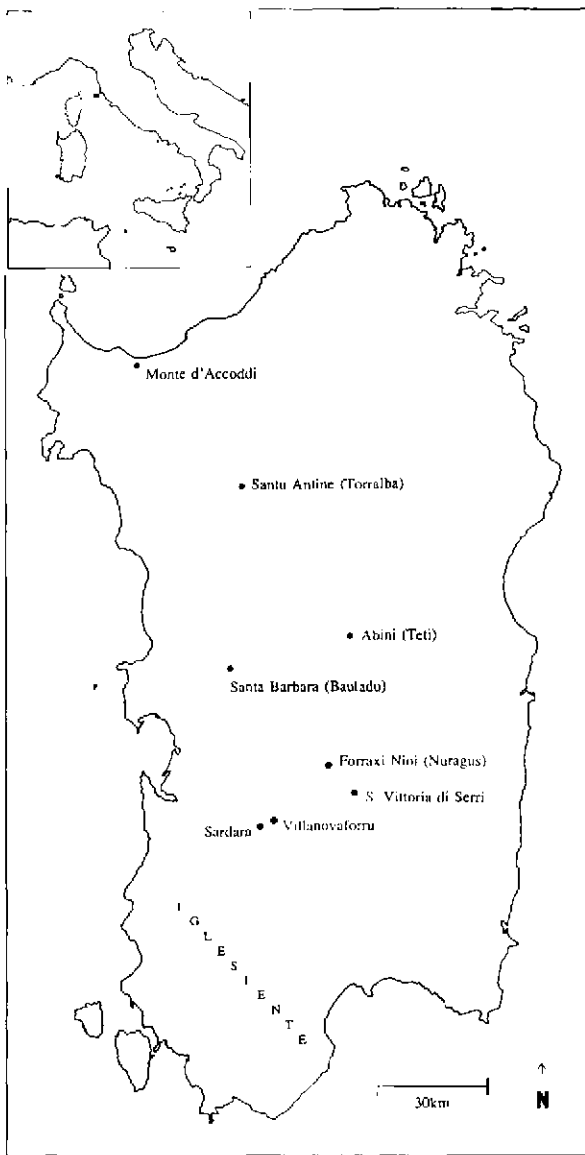


Figure 1. Map of Sardinia showing sites mentioned in the text.

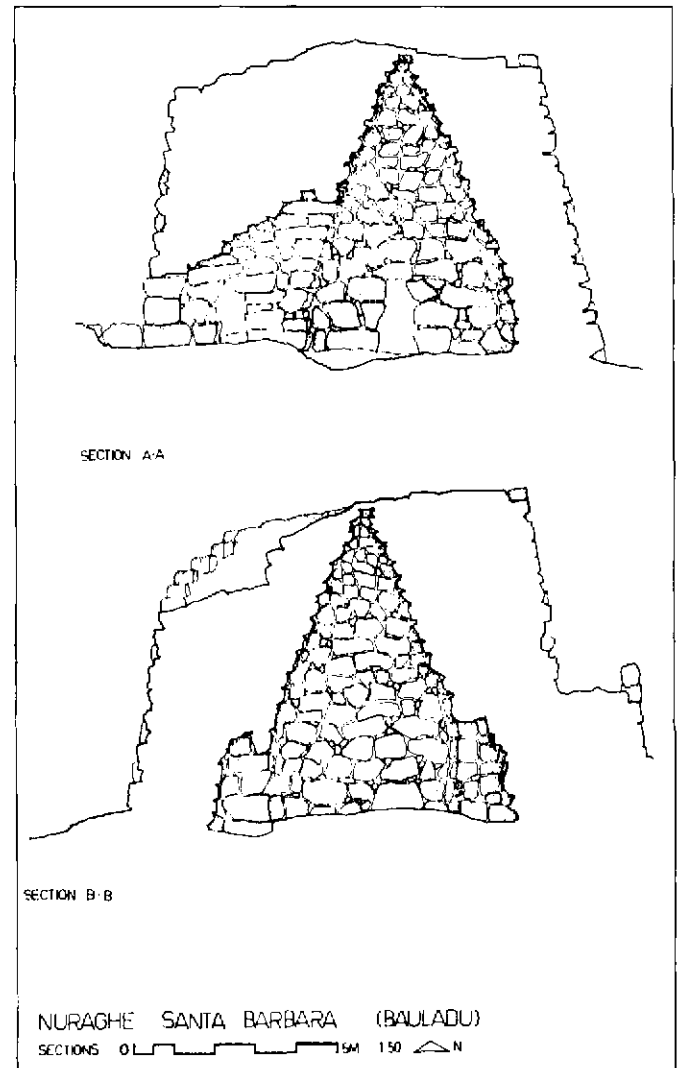
metal, a lead ingot, large quantities of lead scrap, and over 200 copper-based artifacts have been found at Nuraghe Santa Barbara. The most important finds are hundreds of fragments of fire-blackened clay moulds and cores thought to have been used to make ornate bronze objects through lost-wax investment casting. It has been assumed that the Sardinian bronzetti were produced by this method, but until now no direct evidence of their manufacture has been found. Since the one-piece moulds were broken to release the casting, only a few forms are readily identifiable from the fragments. Characteristics such as decorative relief on the inner surface of the mould, however, and different

sized openings that correspond to core sizes and the hollow shafts of spearheads, permit identification of a number of forms, including pestles, hammers, picks, sword handles, votive objects, and a sprue through which molten metal was poured into the mould. Analysis of this material reveals techniques by which Nuragic metalworkers refined their production, e.g., adding lead to bronze to improve casting properties, and making moulds with layers of two different clays to assure the smooth surfaces of casted objects.

### Nuraghe Santa Barbara

Nuraghe Santa Barbara occupies a low basalt hill that dominates the fertile coastal plain of western Sardinia. The Nuragic complex consists of a central tower with one floor

Figure 2. Nuraghe Santa Barbara: architectural section of central tower.



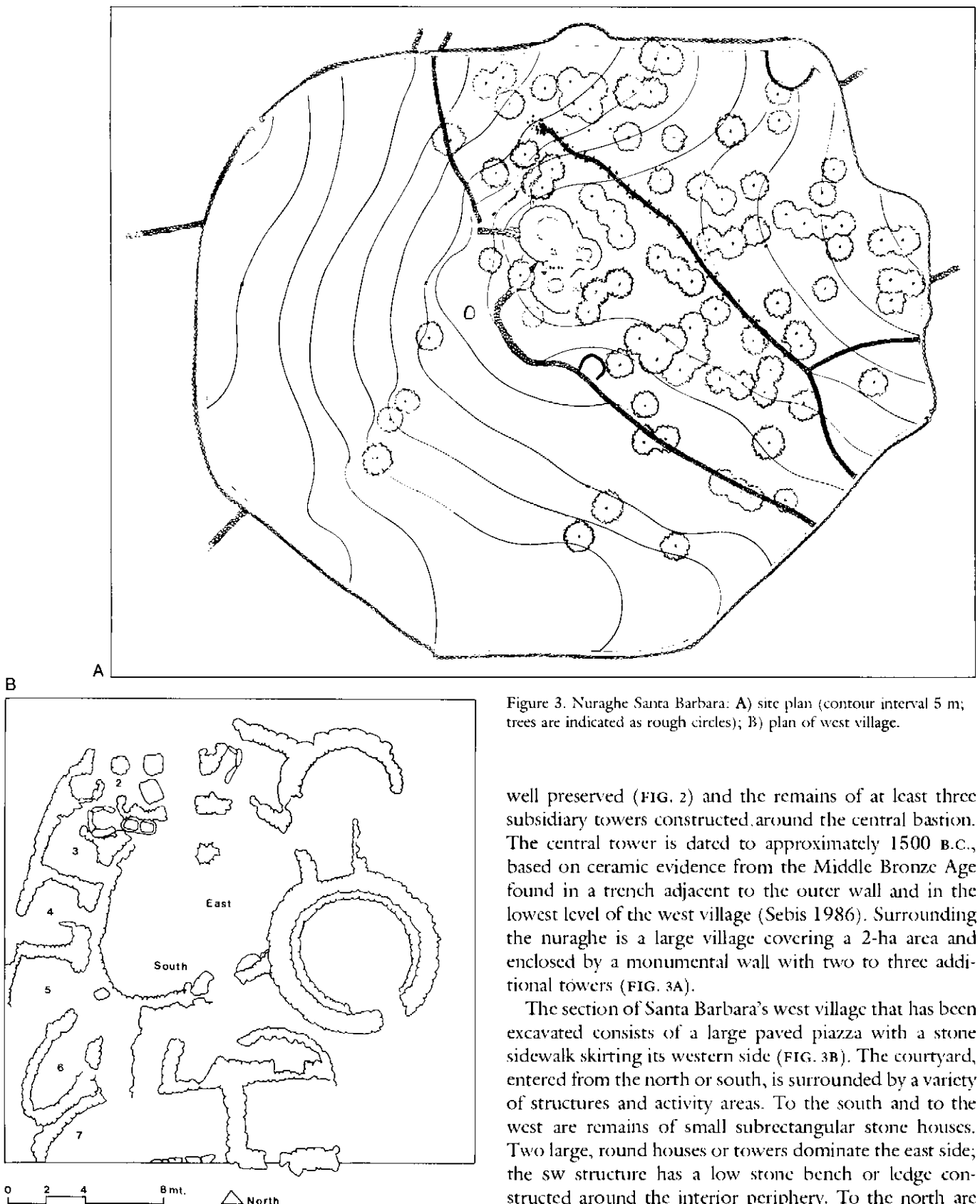


Figure 3. Nuraghe Santa Barbara: A) site plan (contour interval 5 m; trees are indicated as rough circles); B) plan of west village.

well preserved (FIG. 2) and the remains of at least three subsidiary towers constructed around the central bastion. The central tower is dated to approximately 1500 B.C., based on ceramic evidence from the Middle Bronze Age found in a trench adjacent to the outer wall and in the lowest level of the west village (Sebis 1986). Surrounding the nuraghe is a large village covering a 2-ha area and enclosed by a monumental wall with two to three additional towers (FIG. 3A).

The section of Santa Barbara's west village that has been excavated consists of a large paved piazza with a stone sidewalk skirting its western side (FIG. 3B). The courtyard, entered from the north or south, is surrounded by a variety of structures and activity areas. To the south and to the west are remains of small subrectangular stone houses. Two large, round houses or towers dominate the east side; the sw structure has a low stone bench or ledge constructed around the interior periphery. To the north are

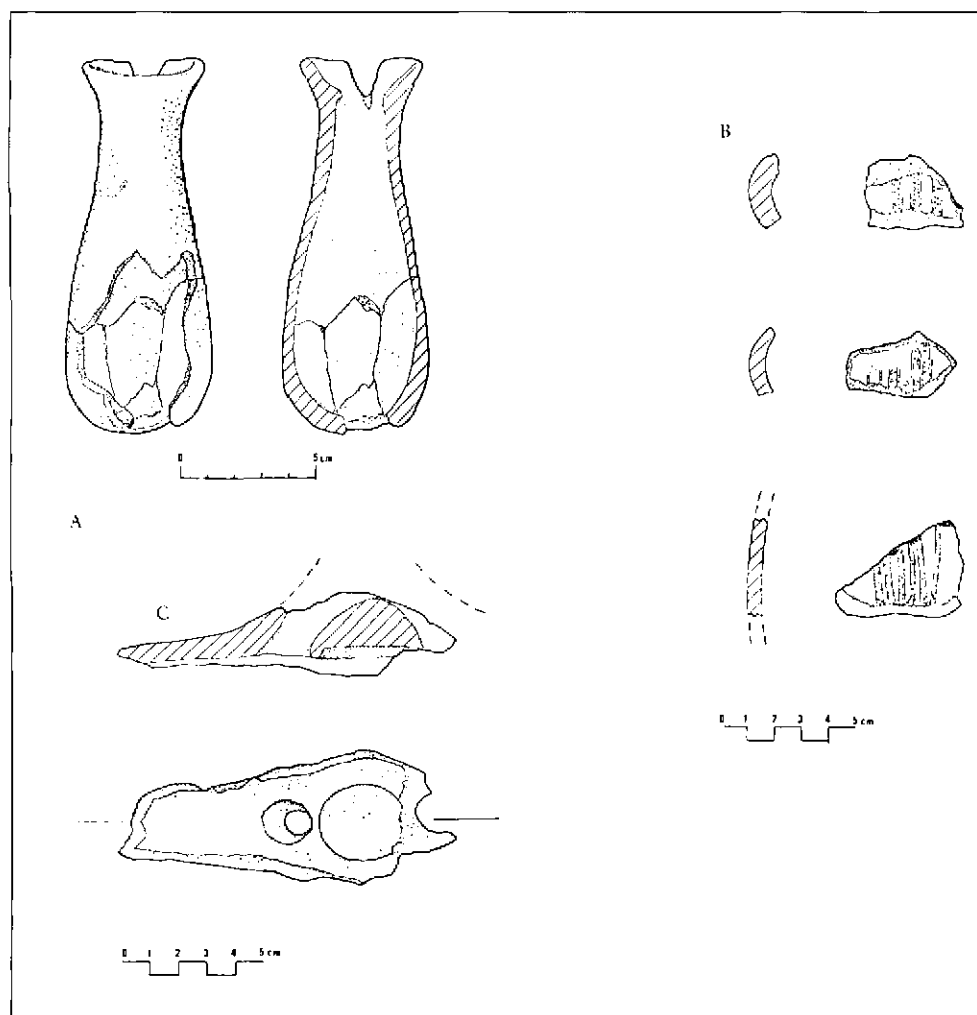


Figure 4. A) Ceramic mould for a pestle; B) ceramic moulds with incised decoration; C) ceramic mould for a hammer or pick.

several areas with specialized features. One of the most interesting is a structure enclosing a circular stone bench with drain holes cut in the lower portions of the blocks and a large basin at its center; similar structures are known at Su Nuraxi-Barumini. Adjacent to this structure is a large double basin cut from one piece of stone; two ovens; two huge stone slabs now lying on their sides; and a stone pedestal-platform on which a poorly-preserved stone model of a nuraghe, found nearby, is believed to have stood.

The occupation phase represented by the village structures, dated by ceramic evidence to the Late Bronze Age/Early Iron Age (12th to 8th centuries B.C.) (Badas 1987), appears to have followed the initial abandonment and partial destruction of the nuraghe. Complicating the investigation of the village is the fact that, by the end of the Early Iron Age, it apparently was abandoned peacefully,

with most items carried away by the former inhabitants. Those artifacts and structures which remain are not well preserved, having been disturbed by successive occupations in the Punic, Roman, and Medieval periods. During the last century, the hillside was extensively plowed, in many cases probably damaging the walls of structures still intact. Nevertheless, abundant ceramic, lithic, faunal, and metallurgical remains document a range of activities, including cooking, baking, butchery, spinning, weaving, pottery repair, and metallurgy.

### Metallurgical Activity

The manufacture of metal artifacts, and the technology of production, are usually documented only indirectly from analysis of the artifacts themselves, and from comparison with the practices of related cultures. The raw

materials (ores, flux, fuel), equipment (moulds, crucibles, furnaces), and byproducts (slag, scrap metal) used at metal production sites are only rarely found in archaeological context, and Sardinia is no exception. Sites are frequently identified as foundries simply because of the large quantity of metal found there, and/or by the presence of stone moulds or of some slag (Lo Schiavo 1986: 242–245).

Small quantities of Nuragic slags have been identified at Forraxi Nioi (Tylecote, Balmuth, and Massoli-Novelli 1984: 135–138), the Nieddu site in Nurallo (Zwicker, Virdis, and Ferrarese Ceruti 1980: 138, 141), Nuraghe Genna Maria in Villanovaforru (Atzeni et al. 1987: 150), and Sa Sedda 'e Sos Carros in Oliena (Lo Schiavo 1976, 1978); the last was identified as a foundry on the basis of the large number of bronzes, including plano-convex copper ingots found there, a situation actually quite typical of Late Bronze Age scrap metal hoards (Tylecote, Balmuth, and Massoli-Novelli 1984: 140). The discovery at Nuraghe Santa Barbara of ceramic moulds, cores, crucibles, and slag, along with fragments of bronze, copper, and lead, provides the best documented evidence yet found of a Nuragic metal workshop.

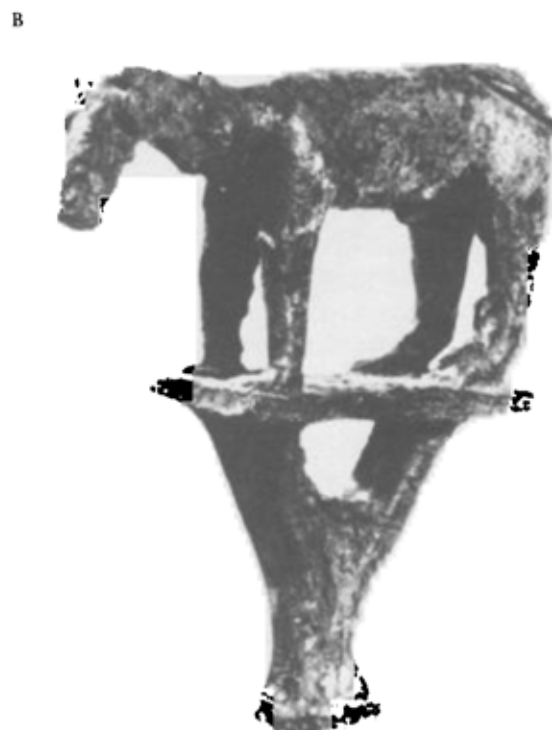
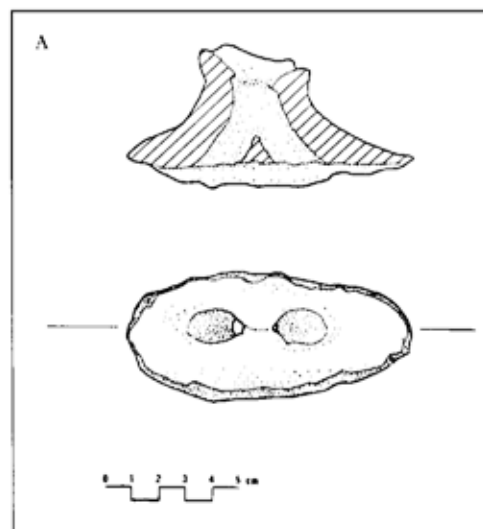
#### *Ceramic Moulds, Cores, and Crucibles*

Although open and bivalve moulds of steatite and chlorite are quite common in Sardinia (Becker 1984; Tylecote 1987: 212–218), ceramic moulds were until recently unknown on the island (Lo Schiavo 1986: 244). It has been assumed, however, that lost-wax investment casting was the process used in the manufacture of the Sardinian bronzetti (Giardino 1987: 203; Lo Schiavo 1988b: 101). At Sant'Anastasia, several small ceramic moulds, including two for producing nails, were found in Iron Age I contexts (Ugas and Usai 1987: 202–203, tav. XIV; Paderi and Ugas 1988: 201, fig. 4). These are the only other ceramic moulds ever found in Sardinia. Fifteen lead ingots, weighing up to 29 kg each, and more than a dozen fragments of oxhide ingots were also found at that site.

At Santa Barbara, more than 75% of the 92 mould and 44 core fragments come from undisturbed Nuragic contexts in the sw part of the village. Moulds used for lost-wax must be broken to release the casting, so it is not surprising that it is difficult to identify the form of these castings from the shattered mould fragments. Nevertheless, one mould would have been suitable for producing a pestle (FIG. 4A). This specimen also exhibits signs of thermal alteration near its neck, and in places the clay is vitrified. Chemical analysis shows that the copper content of the interior surface (0.2%) is greater than that of the external surface (0.05%), a result in all likelihood of the presence of molten copper inside the mould.

Several mould fragments with incised decorations suggest that some moulds were used to produce small decorative items, for example, votive objects or ornate sword handles (FIG. 4B). Utilitarian objects such as hammers and picks were also cast (FIG. 4C). One mould fragment is actually the mouth or sprue through which molten metal was poured to reach the mould proper (FIG. 5A). The

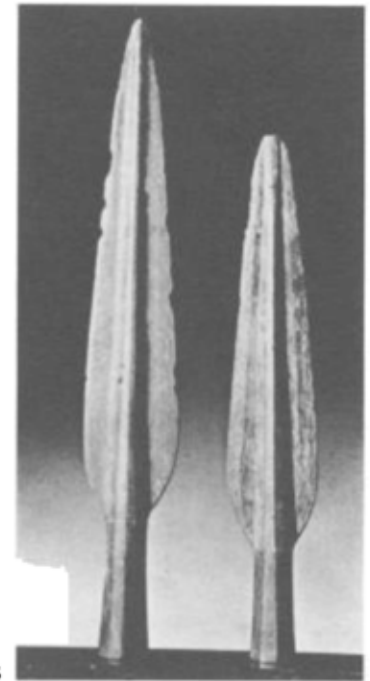
Figure 5. A) Y-shaped ceramic mould or sprue; B) animal figurine with Y-shaped base (Cagliari Museum). Figurine is 10 cm in height.





A

Figure 6. A) Ceramic cores for hollow castings; B) bronze spearheads with hollow shafts (Cagliari Museum). The spearhead on the right is 25 cm in length.



B

casting channels in this case are in the form of a “Y,” and several examples are known in which the metal jet which forms in the sprue was retained as a base for the cast objects, especially animal figurines (Lilliu 1966: 320, no. 197; 329, no. 207; 334, no. 216; 339, no. 221) (FIG. 5B).

A group of metallurgists at the University of Cagliari (C. Atzeni, L. Massidda, U. Sanna, and P. Viridis) have noted that the mould surfaces meant to come into contact with molten metal are well polished, whereas the mould matrices retain high levels of porosity. Such porosity is technically important in that gasses produced during solidification must be released in order to eliminate rough or “blistered” surfaces on the cast object. It appears that moulds were made by layering two different clays around a wax model, a technique documented at Sant’Anastasia di Sardara (Ugas and Usai 1987: 203) and elsewhere in Europe (Tylecote 1987: 187–188, 1962: 118).

All of the 44 core fragments are conical (or truncated) in shape, and some can be refitted in pieces up to 20 cm in length (FIG. 6A). These cores may have been used to make hollow shafts of spearheads, such as those from Teti-Abini (Nuoro) (Lilliu 1982: 120, fig. 133) (FIG. 6B). Several of the stone moulds are also in the form of this type of spearhead (Tylecote 1987: 217, fig. 6.24; Becker 1984: figs. 7.4, 7.8), and must have been held in a vertical position during casting. Typically, the bottom of a mould would have a well with a diameter somewhat narrower than that of the object to be cast, and into which the plug or core would fit. Chaplets of wood or scrap metal could also be used to center the core within the mould during casting. The mould in Figure 4C (top) has such a well into which several cores fit perfectly.

In addition to the moulds and cores, 11 fragments of ceramic crucibles have been excavated at Nuraghe Santa Barbara. Several objects in Sardinian museums (Tylecote, Balmuth, and Massoli-Novelli 1984: 142, 150), and most recently from the excavations at Monte D’Accoddi (Lo Schiavo 1988b: 93, 98, fig. 9.3), have been identified as being ceramic crucibles, but in contrast to the situation at Santa Barbara, they are isolated examples unassociated with any other direct evidence of metalworking.

Two crucibles were also examined by the Cagliari group. They appear thermally altered on their interior surfaces, with one having a thin patina of vitrified material. A sample from the unaltered exterior of each crucible was subjected to testing temperatures from 1000° to 1220°C, and X-ray diffraction was performed at each interval. Those specimens reheated to more than 1150°C showed changes in mineral composition not found in the interior surface sample, suggesting that the maximum temperature reached in the interior of the crucible was 1150°C or even a little less. Chemical analysis confirmed the presence of copper on the interior surface of the two crucibles in amounts much greater than that present in the base material (0.25% and 0.21% compared with 0.02% and 0.013% respectively).

Metallographic and X-ray analysis of the copper residue on the inside of a third crucible fragment (FIG. 7) demonstrates that lead was probably being added to bronze to improve its casting properties. Semi-quantitative energy-dispersive spectrometry analysis shows the residue to

be approximately 75.9% copper, 20.7% lead, and 3.5% tin.

### Slags and Smelting

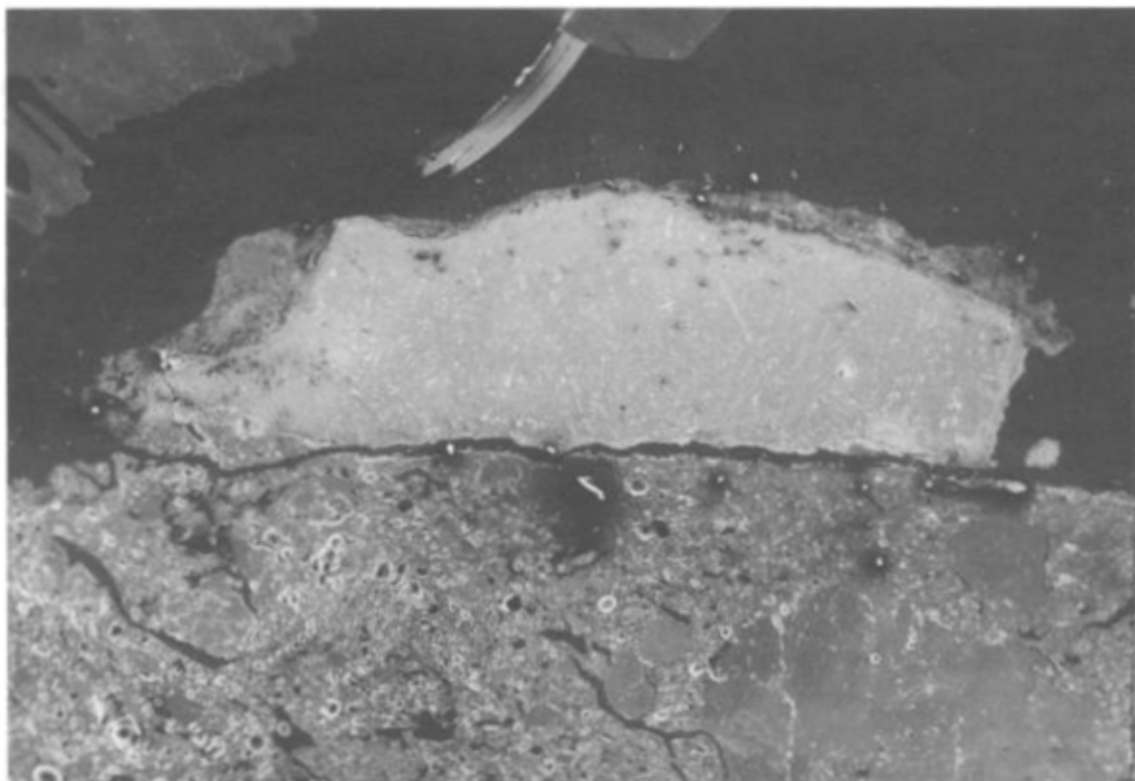
Thousands of pieces of *scoria leggera*, a vitrified siliceous material, have been found all over the site, and are indicative of high temperature operations. Although this "light slag" has not yet been analyzed, it may be tentatively identified as crucible slag, which results from the reaction of the fuel ash used with the crucible material itself and any smelting slag retained in the copper being melted (Tylecote 1976: 19, 1987: 292–293). The level of vitrification observed is unlikely to have occurred during the firing of Nuragic pottery. This slag material is especially concentrated at the southern end of the site in undisturbed Nuragic levels, including those where concentrations of moulds and cores have been found. Some pieces have smooth, convex outer surfaces and rough inner surfaces, which suggest that they were formed on the inner walls of the crucibles.

Only a few small pieces of what can be identified as slag resulting from the smelting of copper-bearing ores such as chalcopyrite, have been found at Nuraghe Santa Bar-

bara. One was in an undoubted Nuragic context. Since there is approximately a 20:1 ratio of slag to copper metal produced during a typical smelting operation (Merkel 1986: 256), these few finds do not constitute evidence that copper ores were smelted at this site. It would have been most efficient, of course, to smelt ores near their source, and transport the raw metal in ingot form to metalworking sites. Unfortunately, 19th and 20th-century exploitation of Sardinian mines has obliterated any traces of ancient mining and smelting activity to be found there.

Giardino (1987: 197–199) notes, however, that several stone tool forms can be associated with mining activities, and suggests that the mallet heads known as *teste di mazza* were used for crushing and concentrating metalliferous ores. Taramelli (1923) noted the association of these stones with ores and slags at several sites in the Flumendosa Valley and in the Iglesiente, in southern Sardinia. At sites such as Nuraghe Ortu Còmidu in Sardara, however, they are not associated with any evidence of metalworking (Balmuth 1986: 383, fig. 40: 1–5; Tykot n.d.). Fourteen of these mallet heads (FIG. 8), along with 31 ground stone pestles and a stone mortar have been found at Santa Barbara, as well as a few flat grinding stones and a large

Figure 7. Photomicrograph of crucible (bottom) with copper residue (top). The copper residue is about 2 mm thick.



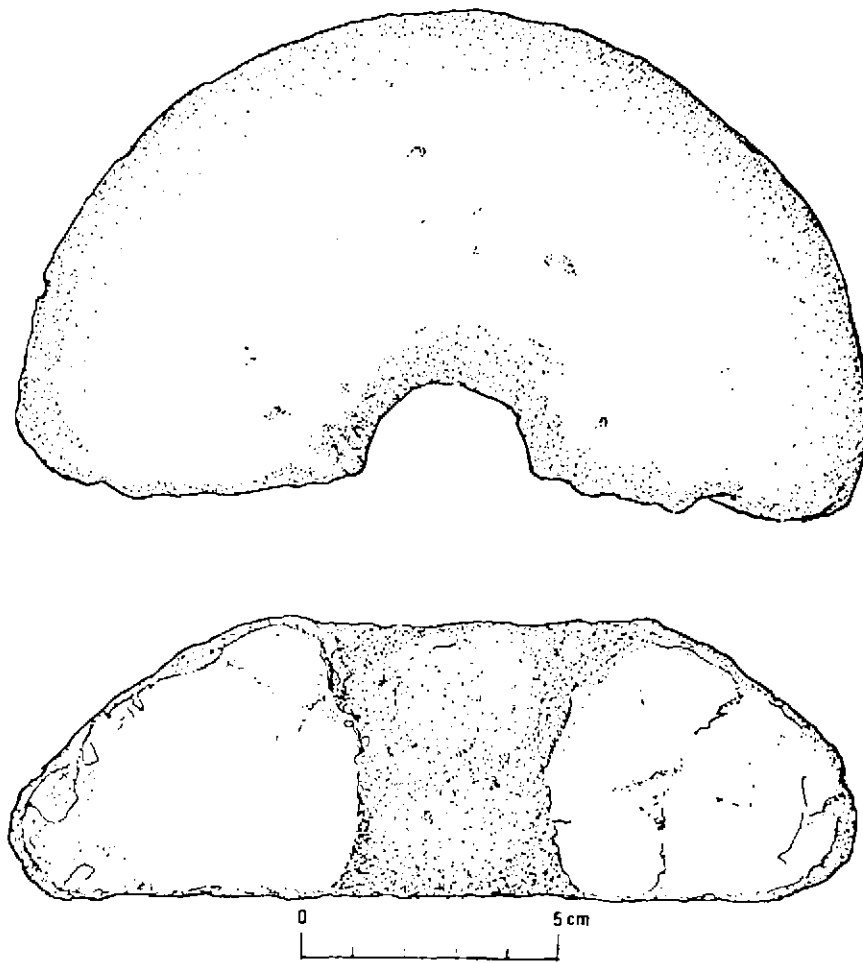


Figure 8. Broken stone mallet (*testa di mazza*).

concave grinding surface within hut 6. These artifacts could conceivably have been used for crushing metal ores or for separating copper prills (small nodules of metal) from a slag matrix produced by smelting the ores at a temperature insufficient to fully liquefy the slag; neither ores nor significant quantities of smelting slag, however, have been found at Nuraghe Santa Barbara to support such a hypothesis. The mallet heads alternatively could have been used in the shaping of tools and weapons from cast blanks, and in the work-hardening of their edges, but again there is no evidence to suggest that they were hammerstones designed for such a specific function.

#### *Copper-based Artifacts*

Over 200 copper-based artifacts have been excavated at Santa Barbara, including several fibulas, nails, fishhooks, pins or awls, pieces of knife blades and handles, straps, and buckles. While many copper artifacts were found in Nuragic contexts in and around the “meeting house” (the

large circular structure on the east side of the courtyard), very few pieces were found within the houses on the west side of the courtyard, or in the northern part of the village. The largest concentrations of copper artifacts were found in the sw corner of the courtyard, the same area where the majority of moulds and core fragments were discovered. While many of these artifacts do not come from clear Nuragic contexts, some are identifiable through comparisons with objects found at other Nuragic sites: e.g., a *spillone* (pin) similar in style to those found at Santu Antine (Torralba), Forraxi Nioi, Abini, and S. Vittoria di Serri (Lo Schiavo 1988a: 223–225, tav. XVI) (FIG. 9).

Some of these objects remain entirely metallic while others have become almost completely oxidized. Cupri-ferous incrustations on ceramic sherds have also been discovered. Atomic absorption analysis of five artifacts, two from pure Nuragic contexts, shows that some of the objects are in fact bronze, containing up to 7.9% tin (TABLE 1). Significantly, all five contain some copper and iron



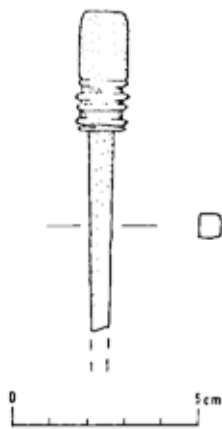


Figure 9. Copper pin (*spillone*).



Figure 10. Lead mending strips attached to Nuragic pottery.

sulfide inclusions, indicating that the metal was probably derived from chalcopyritic ores. Since only one of the pieces is of essentially pure copper, it is suggested that these particular specimens are the discarded byproducts of remelting activities.

### Lead

Lead strips and pieces of lead sheet metal are also frequently found in deep, stratified layers of purely Nuragic material. Although lead is too soft to be used for tools or weapons, its low melting point makes it an easily cast metal, particularly suitable for repairing broken ceramic vessels. The use of lead in Sardinia dates from the Abealzu-Filigosa cultures of the early 3rd millennium B.C., while the first lead mending pieces have been discovered in Monte Claro contexts (Giardino 1987: 189–191; Atzeni 1982: 336–337; Lo Schiavo 1988b: 93, 1986: 233, 238; Atzeni 1981: XLIII, fig. 22, N124). By the Nuragic period, the use of lead for repairing pottery was quite widespread, suggesting that the availability of lead was such that it was often less costly in terms of time and resources to repair a broken vessel than to obtain a new one (Atzeni et al. 1987: 150–151).

Of the more than 50 lead artifacts recovered, about half have been identified as mending pieces, including several which have Nuragic sherds still attached. The rim sherd in Figure 10 comes from a pure Nuragic context with two 10th-century B.C. obsidian hydration dates. The mending

pieces from Nuraghe Santa Barbara are virtually identical to those found at other Nuragic sites, including Nuraghe Genna Maria at Villanovaforru (Atzeni et al. 1987: tav. II:2).

In the mending process, holes are drilled on both sides of the break, and molten lead is poured across the break and filling the holes. The process is repeated on the other side of the vessel, resulting in a lead clamp riveted through the ceramic. Alternatively, lead strips may be placed between the holes on both sides of the vessel, and a small amount of molten lead added, filling the holes and joining with the lead strips.

The only other lead artifacts of interest are two pieces of "ingots," 812 and 66 g in weight, respectively; a small block, 17 mm square by 10 mm in thickness; and a cross-shaped piece 40 mm in width that could have served as a base for a figurine. Of these, only the larger "ingot" was found in undisturbed Nuragic levels. Metallographic and electron microprobe analysis demonstrates that these objects are essentially pure, with only minor inclusions of Si, Fe, Cu, S, and Zn. In this respect, the lead from Santa Barbara is again similar to that found at other Nuragic sites (Atzeni et al. 1991).

### Conclusion

While excavations at Nuraghe Santa Barbara are incomplete, present evidence confirms that bronze artifacts were being cast at this site during the Nuragic period, probably

Table 1. Atomic absorption analyses. Values are percentages.

Artifact	Sn	Pb	Ag	Zn	Fe	Ni	Cr	Co	Sb	Bi
C21-3B	0.039	0.024	0.141	0.009	0.23	0.0018	<0.004	<0.0015	0.014	<0.005
C29-2B	4.8	0.20	0.08	0.009	0.49	<0.1	<0.2	<0.07	<0.5	(no data)
C29-3B I	<0.035	0.011	0.0074	0.0025	0.25	0.0022	0.0013	<0.0015	<0.005	<0.005
C29-3B II	0.073	0.37	0.01	0.13	2.6	0.048	0.012	0.084	0.005	<0.005
C47-3A	7.9	0.21	0.14	0.009	0.06	<0.1	<0.2	<0.07	0.05	(no data)

during the 12th–8th centuries B.C. The number of clay moulds and cores found is unmatched at any other Sardinian site, and demonstrates that lost-wax casting was practiced at that time. The mould and core fragments which have been mended, and the incised decoration still visible in some moulds, indicate that both utilitarian and ornamental objects were cast. It is possible that these latter included the well-known Sardinian bronzetti.

It has been assumed that “every large nuraghe and Nuragic village seems to have had a local metallurgical activity: producing, melting, and repairing weapons, implements, and tools” (Lo Schiavo 1988b: 98). This conclusion was based not on the identification of metalworking sites, but on the numerous stone moulds, copper ingots, and bronze artifacts that have been found on the island, and the tantalizing evidence of the few crucibles and pieces of slag that are known (Balmuth and Tylecote 1976: 196; Tylecote, Balmuth, and Massoli-Novelli 1984; Tylecote 1987: 181; Lo Schiavo et al. 1985; Lo Schiavo 1986, 1988b). Recently, more direct evidence for the working of copper in Sardinia has been provided by the several clay moulds excavated at Sant’Anastasia di Sardara (Ugas and Usai 1987: 202–203, tav. XIV:1–7) and the tuyeres excavated at Nuraghe Genna Maria (Villanovaforru) (Atzeni et al. 1987: tav. II:3a–e). The existence of a true metal workshop at Nuraghe Santa Barbara provides convincing proof that the Nuragic people employed advanced metallurgical technologies in Late Bronze Age Sardinia.

### Acknowledgments

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