JOURNAL OF ROMAN ARCHAEOLOGY

SUPPLEMENTARY SERIES NUMBER 39

This volume is published with the support of Shelby White and Leon Levy

ISBN 1-887829-97-0
ISSN 1063-4304 (for the supplementary series)

This and other supplements to the *Journal of Roman Archaeology*® may be ordered from:
JRA®, 95 Peleg Road, Portsmouth, Rhode Island 02871, U.S.A.
telephone (USA code+) 401 683 1955
telefax (USA code+) 401 683 1975 (fax only)
e-mail: jra@JournalofRomanArch.com
or via our Web site at: www.JournalofRomanArch.com

AN INTERNATIONAL JOURNAL

FROM THE PARTS TO THE WHOLE

VOLUME 2

Acta of the 13th International Bronze Congress,
held at Cambridge, Massachusetts,
May 28 - June 1, 1996

edited by

Carol C. Mattusch, Amy Brauer,
and Sandra E. Knudsen

Portsmouth, Rhode Island
2002

Recipes for Sardinian bronzes

Miriam S. Balmuth and Robert H. Tykot

Sardinia is well known for its indigenous Nuragic culture, *c.* 1800-500 B.C., characterized by the remains of some 7,000 monumental stone towers on an island roughly the size of the state of Massachusetts.[1] The Nuragic culture is also well known for its *bronzetti*, small human, animal, and other figures often found in votive contexts at temples and sacred wells. At the sanctuary of Su Tempiesu in the mountainous Nuorese region, for example, they were found as part of a hoard at a sacred well surrounded by a broad flat pavement that would have been suitable for their display.[2] In their economy of execution some *bronzetti* have an appeal to the modern eye similar to that given by Cycladic marble figurines. More than 500 examples are housed in Sardinian museums, and public and private collections all over the world house a larger number.[3]

What is less well known is that Sardinia is itself rich in copper and other ores and that it has its own metallurgical tradition dating from the 4th millennium B.C.[4] The ore deposits that were worked in historic times are located in the Iglesiente region in the SW part of the island (e.g., Monte Rosas); in the mountainous Barbagia region of east-central Sardinia (e.g., Funtana Raminosa); and near Alghero in the northwest (e.g., Calabona). Recently a Nuragic metal workshop has been excavated at Santa Barbara (Bauladu, Oristano) and supports the evidence for indigenous Nuragic metallurgical activity, which previously had depended on the many finds of stone molds, copper bun ingots, and bronze artifacts in archaeological contexts.[5]

Excavations led by L. Gallin, under the auspices of the Soprintendenza Archeologica per le Provincie di Cagliari e Oristano, focused on the village area adjacent to a multi-towered nuraghe.[6] A number of separate rooms surrounding a central paved courtyard were uncovered and dated to the Italian Late Bronze and Early Iron Ages, from about the 12th to the 8th c. B.C. The SW part of the site contained abundant evidence of metalworking: scrap metal, smithing slag, ceramic crucibles with copper metal residues still attached, ceramic cores used for hollow casting of spearheads, Y-shaped ceramic gates for channeling molten metal into molds and that sometimes formed bases for figurines, and even pieces of the clay molds for the figurines themselves, broken open to release the cast bronzes.[7]

---

1 See most recently G. Webster, *A prehistory of Sardinia 2300-500* B.C. (Sheffield 1996). Other important sources include M. S. Balmuth and R. J. Rowland, Jr. (edd.), *Studies in Sardinian archaeology* (Ann Arbor, MI 1984) 23-52; M. S. Balmuth (ed.), *Studies in Sardinian archaeology* 2: *Sardinia in the Mediterranean* (Ann Arbor, MI 1986); ead. (ed.), *Studies in Sardinian archaeology* 3: *Nuragic Sardinia and the Mycenaean world* (Oxford 1987); G. Lilliu, *La civiltà dei Sardi dal Paleolitico all'età dei nuraghi* (Turin 1988); id., *La civiltà nuragica* (Milano 1990); M. S. Balmuth, "Archaeology in Sardinia," *AJA* 96 (1992) 663-97; R. H. Tykot and T. K. Andrews (edd.), *Sardinia in the Mediterranean: a footprint in the sea: studies in Sardinian archaeology presented to Miriam S. Balmuth* (Sheffield 1992); E. Contu, *La Sardegna preistorica e nuragica* (Sassari 1997); and M. S. Balmuth and R. H. Tykot (edd.), *Sardinia and Aegean chronology: towards the resolution of relative and absolute dating in the Mediterranean* (Oxford 1998).

2 M. A. Fadda, "Il tempio a pozzo di Su Tempiesu (Orune, Nuoro)," *Rivista di Scienze Preistoriche* 37 (1982) 284 ff.; id., *La fonte sacra di Su Tempiesu* (Sassari 1988); id., "Antichi Sardi purificati," *Archeologia Viva* 15 (maggio/giugno 1996) 78-83.

3 G. Lilliu, *Le sculture della Sardegna nuragica* (Cagliari 1966) is the most comprehensive catalogue available of the Sardinian *bronzetti*.

4 F. Lo Schiavo, "Sardinian metallurgy: the archaeological background," in Balmuth 1986 (supra n.1) 231-50; "Early metallurgy in Sardinia," in R. Maddin (ed.), *The beginning of the use of metals and alloys, Zhengzhou, China, 1986* (Cambridge, MA 1988) 92-103.

5 E.g., M. J. Becker, "Sardinian stone moulds: an indirect means of evaluating Bronze Age metallurgical technology," in Balmuth and Rowland (supra n.1) 163-208.

6 L. J. Gallin and S. Sebis, "Bauladu (Oristano) — villaggio nuragico di S. Barbara: lo scavo: i materiali di età nuragica," *Nuovo Bullettino Archeologico Sardo* 2 (1985) 271-75.

7 C. Atzeni *et al.*, "Bronze metalworking at the Nuragic site of Santa Barbara, Sardinia, Italy," *Historical*

There was also abundant use of metallic lead in Nuragic Sardinia, especially for ceramic repairs.[8] Analysis by R. H. Tykot of the metal residue in a crucible from Nuraghe Santa Barbara indicates that it is composed of *c.* 76% copper, 21% lead, and 3.5% tin. However, of the handful of bronze artifacts from Santa Barbara that has been analyzed, not one contains more than 1% lead. It is possible that the crucible residue is the result of multiple uses with different pure and alloyed metals.

Metallurgical investigation of the Nuragic *bronzetti* themselves was initiated in 1978 by M. Balmuth with the analysis and publication of 4 figurines from American museums.[9] The *bronzetti* were analyzed by L. Stodulski, Center for Conservation and Technical Studies, Fogg Art Museum, Harvard University, under the supervision of A. Beale, and were part of a larger scheme to examine multiple aspects of Sardinian metal production, namely metal sources, manufacturing methods, and chronology.[10] Since that time, collections in the British Museum and the Cagliari National Museum have been examined, as were the figurines in a major exhibition of 1980, *Kunst und Kultur Sardiniens vom Neolithikum bis zum Ende der Nuraghenzeit*.[11] Considerable effort has also been expended on the characterization of Sardinian and other Mediterranean copper sources using lead isotope analysis, which indicates that all of the analyzed Nuragic copper-based ingots and artifacts are consistent with having come from Sardinian ore sources, while all of the ox-hide ingots of Eastern Mediterranean style found in Sardinia are consistent with a Cypriot origin.[12]

We report here on the analysis of an additional 4 *bronzetti* in American collections; they have been prepared for publication by M. S. Balmuth along with two more, as a sequel to her 1978 publication.[13] All had been assigned the standard dates of 9th to 7th c. B.C. without explanation. The controversy concerning the chronology and original introduction of the figure type to Sardinia is still unresolved, the existence of Cypriot iconographic parallels from the

---

Metallurgy 26 (1992) 31-35; L. J. Gallin and R. H. Tykot, "Metallurgical activity at the Nuragic village of Santa Barbara (Bauladu), Sardinia, Italy," *JFA* 20 (1993) 335-45; L. J. Gallin *et al.*, "Attività metallurgica al Nuraghe Santa Barbara Bauladu (OR)," *Quaderni della Soprintendenza archeologica per le provincie di Cagliari e Oristano* 11 (1995) 141-53.

8 C. Atzeni *et al.*, "Notes on lead metallurgy in Sardinia during the Nuragic period," *Historical Metallurgy* 24 (1991) 97-105.

9 M. S. Balmuth, "Sardinian *bronzetti* in American museums," *StSard* 24 (1974 [1978]) 145-56.

10 M. S. Balmuth and R. F. Tylecote, "Ancient copper and bronze in Sardinia: excavation and analysis," *JFA* 3 (1976) 195-201; R. F. Tylecote, M. S. Balmuth, and R. Massoli-Novelli, "Copper and Bronze Age metallurgy in Sardinia," in Balmuth and Rowland (supra n.1) 115-62.

11 J. Riederer, "Metallanalysen sardischer Bronzen," in J. Thimme (ed.), *Kunst und Kultur Sardiniens vom Neolithikum bis zum Ende der Nuraghenzeit* (Exhib. cat., Badisches Landesmuseum Karlsruhe 1980) 156-60; P. T. Craddock, "The metallurgy of Italic and Sardinian bronzes," in J. Swaddling (ed.), *Italian Iron Age artefacts in the British Museum* (London 1986) 143-49; C. Atzeni *et al.*, "Struttura e composizione dei 'bronzetti nuragici' del Museo Archeologico Nazionale di Cagliari," *La metallurgia italiana* 83 (1991) 583-90; C. Atzeni *et al.*, "Some metallurgical remarks on Sardinian bronzetti," in Tykot and Andrews (supra n.1) 347-54.

12 Z. A. Stos-Gale and N. H. Gale, "New light on the provenience of the copper oxhide ingots found on Sardinia," in Tykot and Andrews (supra n.1) 317-46; Z. A. Stos-Gale *et al.*, "Lead isotope characteristics of the Cyprus copper ore deposits applied to provenance studies of copper oxhide ingots," *Archaeometry* 39 (1997) 83-123; E. Angelini *et al.*, "Lead isotope analysis of Nuragic bronzes and copper ores by ICP-MS," in G. Holland and A. N. Eaton (edd.), *Applications of plasma source mass spectrometry* 2 (Cambridge 1993) 165-74. The Gales's conclusions have been challenged because of the possibility that ores from multiple sources may have been mixed, because some sources have not yet been well characterized, and because of the statistical methods employed. Nevertheless, we still find their results convincing in light of present evidence. See P. Budd *et al.*, "Oxhide ingots, recycling and the Mediterranean metals trade," and the comments by the Gales and others in the same issue, *JMA* 8 (1995) 1-75.

13 M. S. Balmuth, "More Nuragic bronzetti in American museums," in A. Moravetti (ed.), *Studi in onore di G. Lilliu per il suo ottantesimo compleanno* (Sassari 2001).

Fig. 1. Warrior. Sardinia. Bronze, h. *c.*11.0 cm. Medford, MA, Tufts University Art Collection 1985.9.3. (Photo: M. S. Balmuth)

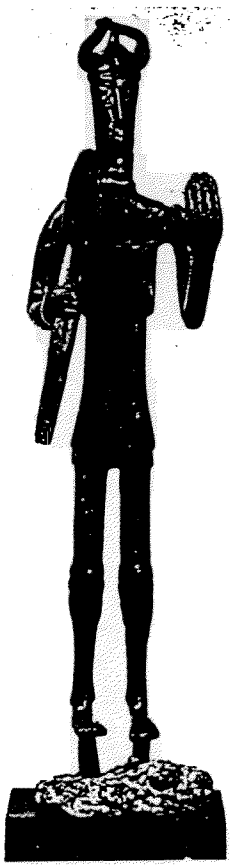

Fig. 2. Warrior. Sardinia. Bronze, h. *c.*24.5 cm. Los Angeles, The J. Paul Getty Museum 75.AK.110. (Photo: courtesy The J. Paul Getty Museum)

Fig. 3. Kneeling shepherd. Sardinia. Bronze, h. 12.7 cm. Cambridge, MA, Arthur M. Sackler Museum, Gift of Mr. and Mrs. Samuel Lindenbaum 1984.798. (Photo: courtesy Harvard University Art Museums)

11th c. B.C. contrasting with the presence of *bronzetti* in Etruscan tomb contexts of the late 9th through the 7th or 6th c. B.C.[14] Authentication presents another problem and should be dealt with elsewhere.

1. From the Tufts University Art Collection (1985.9.3) comes a warrior figure, carrying a large spear over his left shoulder and a shield strapped to his back, while his right hand is extended slightly upward but with the palm facing down (fig. 1). About 11 cm in height, the figure is wearing a short straight skirt and perhaps a short-sleeved shirt. A plumed helmet on the head and a sheathed dagger at the waist complete the visible accessories. Analysis by Tykot using inductively coupled plasma mass spectrometry (ICP-MS) indicates a composition of 89.4% copper, 8.4% tin, and 1.9% lead (Table 1).[15] No other elements were present in more than trace quantities.
2. The second *bronzetto* is a warrior from the J. Paul Getty Museum (75.AK.110), *c.* 24.5 cm in height (fig. 2). He wears a short skirt, greaves on his legs, and a helmet with curved horns on his head. In his right hand he carries a bow, while his left arm is raised with the palm of the hand facing outward. Analyses by D. Scott of the Getty Conservation Institute using inductively coupled plasma mass spectrometry (ICP-MS)

14 F. Barreca, "Phoenicians in Sardinia: the bronze figurines," in Balmuth 1986 (supra n.1) 131-43; A. M. Bisi, "Bronzi vicino-orientali in Sardegna: importazioni ed influssi," in Balmuth 1987 (supra n.1) 225-46; F. R. Serra Ridgway, "Nuragic bronzes in the British Museum," in Balmuth 1986 (supra n.1) 85-101.

15 The ICP-MS technique has been described in detail elsewhere: R. H. Tykot and S. M. M. Young, "Archaeological applications of inductively coupled plasma-mass spectrometry," in M. V. Orna (ed.), *Archaeological chemistry: organic, inorganic, and biochemical analysis* (Washington, D.C. 1996) 116-30.

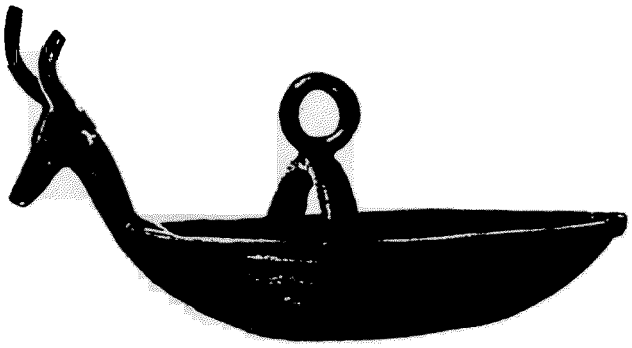

Fig. 4. Boat. Sardinia. Bronze. l. *c.*16.5 cm. Boston, Museum of Fine Arts, J. W. and J. M. Elliot Fund 1976.67. (Photo: courtesy Museum of Fine Arts)

and x-ray fluorescence (XRF) indicate a composition of 81.5% copper, 5.5% tin, 8.9% lead, 2.5% zinc, 0.3% nickel, 0.14% iron, and 0.13% antimony. The exceptionally high zinc content raised significant doubts about the authenticity of this figure, since no previously published example contains more than 1% zinc. Lead isotope analysis using ICP-MS, however, indicates consistency with a Sardinian ore source, and metallographic examination suggests that the corrosion patina displays all of the features anticipated for a genuine ancient bronze.[16]

3. The third figure is a kneeling shepherd from the Arthur M. Sackler Museum, Harvard University Art Museum (1984.798), 12.7 cm in height (fig. 3). The shepherd wears a short skirt, and a tunic is evident on the upper chest and shoulders. With both hands he holds the legs of what appears to be a moufflon (horned sheep). The animal is not rendered with much detail, and the softness in modeling of the whole figure is atypical. Chemical analysis by J. Riederer of the Rathgen Research Laboratory, Berlin, indicates a composition of 78.7% copper, 2.3% tin, 2.9% lead, 15.3% zinc, 0.34% nickel, 0.37% iron, and less than 0.1% each of antimony and arsenic. The excessive presence of zinc is unique and thus problematic.
4. The fourth *bronzetto* is a votive model boat with rather simple decoration from the Museum of Fine Arts, Boston (1976.67; fig. 4). The boat is *c.* 16.5 cm in length and has a deer with antlers as its figurehead. A curved bar with a circular ring spans the middle of the boat. Electron microprobe analysis performed by R. Newman, Department of Objects Conservation and Scientific Research, Museum of Fine Arts, indicates a composition of 69.9% copper, 8.8% tin, 21% lead, and 0.26% arsenic. Zinc, nickel, iron, silver, and antimony were present in only trace amounts.

Comparison of the compositions of the 4 *bronzetti* shows that only the Tufts warrior is similar in composition to previously analyzed figures from American collections. The MFA boat and the Getty warrior contain substantially more lead, while the Sackler shepherd and to some extent the Getty warrior contain significant quantities of zinc.

Such high lead and/or zinc concentrations are in fact unknown in the corpus of analyses currently available (Table 1).[17] Analyses by P. Craddock of 20 *bronzetti* in the British Museum reveal compositionally consistent bronzes with about 9% tin and perhaps 1% lead. Similarly, most of the 80 analyses by Riederer of figurines, boats, and other votives in the 1980 Karlsruhe exhibition are compositionally consistent, with the exception of a boat that contains 5-6% silver and less than 1% tin. Recently, a second example of a high-silver Nuragic object was found among 12 *bronzetti* in the Cagliari National Museum analyzed by P. Virdis and his colleagues at the University of Cagliari. This figurine, from the Teti (Abini) hoard, is clearly genuine and suggests that a precious metal was deliberately used instead of tin, a possibility which must be considered likely in light of the cult or ritual context in which these votive figurines are found.[18] It is unlikely that the high silver content could have resulted from the indiscriminate

16 Lead isotope analysis by D. Scott of the Getty archer produced values [2.100 ($^{208}Pb/^{206}Pb$), 0.861 ($^{207}Pb/^{206}Pb$), and 17.95 ($^{206}Pb/^{204}Pb$)] very similar to lead isotope ratios for some Sardinian artifacts of known archaeological context.

17 Riederer (supra n.11); Craddock (supra n.11); C. Atzeni *et al.* 1991 (supra n.11).

18 The Teti figurine with high silver content is no. 116, figs. 277-80 in Lilliu (supra n.3) 217-19; E. Pais, "Il ripostiglio di bronzi di Abini presso Teti," *Bullettino Archeologico Sardo* n.s. I, fasc. V-XII (1884) 67-179

TABLE 1. CHEMICAL ANALYSES OF NURAGIC *BRONZETTI*

Ref.[1]	*Sample*[2]	*Description*	*Cu*	*Sn*	*Pb*	*Zn*	*Fe*	*Ni*	*Ag*	*Sb*	*As*	*Total*
1	Tufts 1985.9.3	Warrior	89.4	8.4	1.89	tr	tr	0.03	0.08	tr	0.26	100.0
1	MFA 1976.67	Boat	69.9	8.8	21.01	0.00	0.00	0.00	0.00	0.00	0.26	100.0
1	Sackler 1984.798	Shepherd	78.7	2.3	2.91	15.30	0.37	0.34	0.02	0.07	0.05	100.0
1	Getty 75.AK.110	Archer	82.5	5.6	9.01	2.53	0.14	0.00	0.14	0.13	0.00	100.0
2	Albright-Knox 65.22	Warrior	92.3	5.9	<0.45	0.26	0.38	<0.10	0.03	<0.06	0.46	100.0
2	RISD 55.030	Warrior	89.0	7.3	2.54	0.32	0.02	<0.11	0.03	0.13	0.51	100.0
2	DIA 49.587	Female figure	89.2	8.7	<0.6	<0.2	0.31	<0.07	0.03	<0.04	0.69	100.0
2	Fogg 1952.30	Warrior	89.3	8.5	<0.68	0.45	0.27	<0.14	0.03	<0.03	0.54	100.0
3	Cleveland 52.258	Warrior	89.3	8.8	0.69	0.37	0.39	0.01	0.03	0.05	0.39	100.0
4	BM 1856.12-23.664	Model sheath	89.1	9.9	0.45	0.03	0.01	0.12	0.07	0.25	0.10	100.0
4	BM 1914.3-18.1	Warrior	88.8	10.8	0.07		0.07	0.05	0.02		0.20	100.0
4	BM 1926.5-11.1	Jug	89.4	9.6	0.12		0.15	0.04	0.30	0.02	0.30	100.0
4	BM 1926.5-11.113	Ring	90.5	6.3	2.47	0.02	0.11	0.03	0.11	0.03	0.43	100.0
4	BM 1926.5-11.11a	Conical button	90.1	9.5	0.22	0.01	0.05	0.03	0.01	0.03	0.07	100.0
4	BM 1926.5-11.11b	Conical button	90.0	9.6	0.27	0.00	0.04	0.04	0.00	0.04	0.01	100.0
4	BM 1926.5-11.12	Stud	90.0	9.1	0.32	0.03	0.04	0.03	0.04	0.03	0.40	100.0
4	BM 1926.5-11.13	Button	88.0	10.7	0.59	0.08	0.17	0.02	0.08	0.05	0.30	100.0
4	BM 1926.5-11.136	Pendant (rod)	93.9	4.3	0.39	0.04	0.85	0.03	0.20	0.03	0.17	100.0
4	BM 1926.5-11.136	Pendant (top)	96.6	2.2	0.50	0.01	0.22	0.02	0.09	0.04	0.30	100.0
4	BM 1926.5-11.137	Rattle (top)	91.1	6.3	0.45	0.04	1.61	0.04	0.09	0.06	0.25	100.0
4	BM 1926.5-11.137	Rattle (rod)	94.3	2.8	0.80	0.04	1.70	0.03	0.07	0.02	0.22	100.0
4	BM 1926.5-11.14	Button	87.5	11.2	0.56		0.17	0.17	0.08	0.05	0.25	100.0
4	BM 1926.5-11.15	Stud	88.3	9.4	1.16	0.03	0.60	0.03	0.13	0.03	0.40	100.0
4	BM 1926.5-11.16	Stud	91.7	6.9	0.50	0.03	0.29	0.02	0.07	0.02	0.45	100.0
4	BM 1926.5-11.2	Cast tripod	91.6	7.6	0.28	0.01	0.14	0.02	0.12	0.04	0.22	100.0
4	BM 1926.5-11.22	Ring	89.8	8.8	0.71		0.03	0.03	0.12	0.04	0.45	100.0
4	BM 1926.5-11.22	Ring	82.5	16.3	0.60		0.07	0.03	0.11	0.05	0.30	100.0
4	BM 1926.5-11.26	Ring	87.5	5.4	6.10	0.02	0.24	0.02	0.15	0.03	0.55	100.0
4	BM 1926.5-11.3.1	Openwork plaque	89.2	9.5	0.61	0.02	0.12	0.03	0.06	0.03	0.42	100.0
4	BM 1926.5-11.3.2	Openwork plaque	86.2	12.8	0.18	0.01	0.08	0.03	0.16	0.02	0.49	100.0
4	BM 1926.5-11.3.3	Openwork plaque	87.5	11.8	0.03	0.00	0.03	0.03	0.02	0.02	0.65	100.0
4	BM 1926.5-11.3.4	Openwork plaque	88.0	11.2	0.21		0.03	0.03	0.09	0.03	0.41	100.0
4	BM 1926.5-11.3.5	Openwork plaque	88.1	11.2	0.02	0.01	0.06	0.03	0.08	0.02	0.41	100.0
4	BM 1926.5-11.4	Boat	85.0	13.8	0.74		0.14	0.05	0.06		0.15	100.0
4	BM 1926.5-11.41	Ring	89.8	9.1	0.46	0.00	0.04	0.02	0.12	0.08	0.37	100.0
4	BM 1926.5-11.44	Ring	89.2	9.5	0.29	0.03	0.27	0.02	0.37	0.03	0.35	100.0
4	BM 1926.5-11.47	Ring	88.7	9.4	0.55	0.03	0.78	0.02	0.06	0.03	0.39	100.0
4	BM 1926.5-11.5	Anchor pendant	86.4	11.3	1.79	0.01	0.02	0.02	0.04	0.03	0.32	100.0

1 Key to analysis references: 1 (this work); 2 (Balmuth [supra n.9]); 3 (Tylecote *et al.* [supra n.10]); 4 (Craddock [supra n.11]); 5 (Riederer [supra n.11]); 6 (Atzeni *et al.* 1991 and 1992 [supra n.11]).

2 Collection accession numbers are given when known; otherwise the published catalogue or laboratory numbers are used.

Ref.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As	Total
4	BM 1926.5-11.6	Votive dagger	88.8	8.8	1.31	0.03	0.81	0.04	0.05	0.03	0.12	100.0
4	BM 1926.5-11.7	Spearhead	86.8	11.0	0.80	0.03	1.10	0.03	0.05	0.02	0.15	100.0
4	BM 1926.5-11.8	Dagger	89.0	9.3	1.10		0.15	0.04	0.24	0.02	0.20	100.0
4	BM 1926.5-11.9	Spear butt	92.2	4.6	0.81	0.02	1.82	0.03	0.09	0.03	0.44	100.0
4	BM 1974.12-1.1	Warrior	88.8	10.1	1.01		0.04	0.03	0.02			100.0
4	BM 1974.12-1.2	Archer	93.6	5.0	0.40	0.20	0.42	0.04	0.07	0.25	0.10	100.0
4	BM 1974.12-1.5	Model sheath	87.8	11.7	0.38		0.09	0.01	0.02	0.01	0.03	100.0
5	Riederer 1	Votive animal	96.7		0.19	0.10	0.17	0.03	0.01	0.24	2.60	100.0
5	Thimme 194-a	Boat (bow)	91.6	0.5	2.31	0.35	0.02	0.03	5.11	0.03	0.05	100.0
5	Thimme 194-b	Boat (mast)	88.8	0.7	3.40	0.01	0.61	0.03	6.30	0.04	0.14	100.0
5	Thimme 161	Moufflon	91.1	2.2	6.31	0.05	0.01	0.05	0.12	0.07	0.08	100.0
5	Riederer 5	Male figure	95.4	2.3	1.93	0.29	0.03	0.01	0.03	0.02		100.0
5	Thimme 213	Disk ornament	94.4	3.3	1.04	<0.01	0.01	0.03	0.18	0.07	0.98	100.0
5	Thimme 256	Axe	94.5	3.5	1.71			0.04	0.06	0.06	0.16	100.0
5	Thimme 179	Boat	95.8	3.7	0.21	0.01	0.16	0.02	0.03	0.02	0.08	100.0
5	Thimme 123	Male figure	95.5	4.0	0.14	0.01	0.31	0.01	0.04	0.04	0.04	100.0
5	Thimme 182	Boat	91.3	4.2	3.95	0.06	0.23	0.03	0.14	0.02	0.15	100.0
5	Thimme 150	Bull	93.6	4.9	0.79	0.16	0.04	0.03	0.11	0.14	0.24	100.0
5	Thimme 174	Boat	87.0	5.5	6.89	0.03	0.02	0.03	0.16	0.02	0.39	100.0
5	Thimme 124	Female figure	93.8	5.5	0.39	0.18	0.03	0.01	0.02		0.09	100.0
5	Thimme 188	Boat	86.6	5.7	7.31	0.01	0.05	0.04	0.08	0.05	0.18	100.0
5	Thimme 270	Bracelet	90.0	6.3	1.68	0.04	1.76	0.04	0.03	0.01	0.19	100.0
5	Thimme 170	Hedgehog	87.7	6.4	4.48	0.01	1.23	0.03	0.03	0.01	0.09	100.0
5	Thimme 191	Boat	67.2	6.7	25.78	<0.01	0.03	0.02	0.03	0.03	0.23	100.0
5	Thimme 288	Boat	91.8	6.9	0.80	0.02	0.24	0.04	0.05	0.06	0.17	100.0
5	Thimme 152	Bull	92.5	7.0	0.08	0.05	0.03	0.03	0.12	0.02	0.16	100.0
5	Thimme 189	Boat	89.6	7.2	1.24	0.43	1.19	0.03	0.06	0.02	0.24	100.0
5	Thimme 145	Mask	89.0	7.6	1.56	0.22	0.39	0.02	0.09	0.22	0.92	100.0
5	Thimme 92	Archer	90.6	7.7	0.97	0.05	0.13	0.03	0.10	0.04	0.34	100.0
5	Thimme 121	Shepherd	90.7	7.7	0.85	0.12	0.17	0.05	0.10	0.03	0.30	100.0
5	Thimme 102	Warrior	88.0	7.8	2.78	0.14	0.10	0.13	0.10	0.25	0.74	100.0
5	Thimme 205	Scepter	91.6	7.8	0.18	<0.01	0.04	0.02	0.04	0.02	0.35	100.0
5	Thimme 120	Shepherd	90.6	7.9	0.85	0.05	0.18	0.05	0.09	0.03	0.31	100.0
5	Thimme 156	Bull	90.3	8.1	1.01	0.01	0.09	0.02	0.11	0.02	0.37	100.0
5	Thimme 262	Chisel	90.4	8.2	0.36	0.02	0.74	0.03	0.09	0.01	0.19	100.0
5	Thimme 163	Votive animal	89.6	8.2	1.50	0.30	0.02	0.02	0.02	0.04	0.33	100.0
5	Thimme 228	Lance point	90.2	8.3	0.77	0.03	0.34	0.03	0.08	0.01	0.34	100.0
5	Thimme 91	Warrior	88.6	8.3	1.86	0.03	0.83	0.03	0.08	0.02	0.31	100.0
5	Thimme 95	Archer	85.0	8.3	5.55	0.01	0.48	<0.01	0.14	<0.01	0.57	100.0
5	Thimme 141	Amphora carrier	89.8	8.6	0.96	0.05	0.16	0.03	0.02	0.04	0.30	100.0
5	Thimme 183	Boat	89.9	8.6	1.02	n.b.	0.03	0.03	0.03	0.02	0.33	100.0
5	Thimme 114	Shepherd	84.3	8.7	6.22	0.03	0.03	0.03	0.03	0.02	0.65	100.0
5	Riederer 36	Male figure	89.5	8.9	0.34	0.03	0.77	0.05	0.07	0.11	0.21	100.0
5	Thimme 173	Handle	89.8	9.1	0.25	0.02	0.44	0.03	0.06	0.02	0.35	100.0
5	Thimme 260	Chisel	90.5	9.1	0.20	0.01	0.02	0.02	0.01	0.02	0.15	100.0
5	Thimme 231	Spearpoint	86.8	9.3	3.36	0.01	0.29	0.03	0.03	0.02	0.14	100.0
5	Thimme 259	Axe	86.9	9.5	3.25	<0.01	0.01	0.02	0.05	0.02	0.27	100.0
5	Thimme 257	Axe	90.1	9.6	0.11			0.05	0.04	0.03	0.07	100.0
5	Thimme 247	Sword frag.	89.9	9.7	0.09		0.01	0.06	0.04	0.03	0.14	100.0

Ref.	Sample	Description	Cu	Sn	Pb	Zn	Fe	Ni	Ag	Sb	As	Total
5	Thimme 118	Shepherd	89.2	9.8	0.23	0.03	0.02	0.08	0.08	0.03	0.53	100.0
5	Thimme 279	Fibula	89.2	9.8	0.41	0.01	0.08	0.16	0.08	0.06	0.17	100.0
5	Thimme 93	Archer	88.3	10.0	1.39	0.03	0.01	0.03	0.02	0.02	0.27	100.0
5	Thimme 195	Boat	88.8	10.1	0.76	0.02	0.03	0.05	0.06	0.08	0.19	100.0
5	Thimme 126	Female figure	87.6	10.3	0.85	0.01	0.97	0.06	0.07	0.13	0.06	100.0
5	Thimme 178	Boat	88.0	10.4	0.40	0.02	0.80	0.01	0.05	<0.01	0.27	100.0
5	Riederer 49	Male figure	88.1	10.9	0.51	0.01	0.04	0.02	0.09	0.02	0.36	100.0
5	Thimme 258	Axe	88.0	11.0	0.43	0.01	0.06	0.03	0.10	0.02	0.43	100.0
5	Thimme 138	Female figure	84.3	11.0	3.98	0.02	0.24	0.02	0.07	0.04	0.33	100.0
5	Thimme 261	Chisel	87.4	11.3	0.64	0.01	0.06	0.03	0.08	0.01	0.47	100.0
5	Thimme 250	Double-axe	86.2	11.4	1.18	0.02	0.80	0.03	0.05	0.01	0.25	100.0
5	Thimme 254	Hoe	87.2	11.9	0.45	<0.01	0.05	0.03	0.05	0.01	0.34	100.0
5	Thimme 132	Praying figure	87.2	12.0	0.31	0.02	0.15	0.03	0.02	0.02	0.21	100.0
5	Thimme 167	Bull protome	86.8	12.2	0.36	0.14	0.02	0.03	0.03	0.02	0.40	100.0
5	Thimme 105	Warrior	86.2	12.2	0.63	0.01	0.61	0.03	0.06	0.02	0.17	100.0
5	Thimme 122	Flute player	84.5	12.4	2.81	0.02	0.05	0.04	0.05	0.05	0.13	100.0
5	Thimme 287	Boat	85.1	12.6	1.55	n.b.	0.30	0.04	0.07	0.04	0.28	100.0
5	Thimme 157	Lid	86.0	12.7	0.47	0.03	0.62	0.02	0.07		0.11	100.0
5	Thimme 277	Bull protome	86.0	12.8	0.47	0.03	0.11	0.06	0.09	0.13	0.37	100.0
5	Thimme 149	Animal group	82.6	12.8	4.21		0.04	0.03	0.04	0.02	0.30	100.0
5	Thimme 278	Bull protome	85.0	13.5	0.98		0.04	0.06	0.03	0.07	0.32	100.0
5	Riederer 64	Votive animal	80.7	18.6	0.08	0.02	0.11	0.06	0.02	0.03	0.38	100.0
5	Thimme 240	Dagger	88.8	8.8	1.31	0.03	0.81	0.04	0.05	0.03	0.12	100.0
5	Thimme 198	Tripod side	91.6	7.6	0.28	<0.01	0.14	0.02	0.12	0.04	0.22	100.0
5	Thimme 243	Votive dagger	87.8	11.7	0.38	0.03	0.09	<0.01	0.02		0.01	100.0
5	Thimme 244	Votive weapon	89.0	9.9	0.45	0.03	0.11	0.12	0.07	0.25	0.10	100.0
5	Thimme 111	Archer	93.6	5.0	0.40	0.20	0.42	<0.04	0.07	0.25	0.10	100.0
5	Thimme 208	Jug	89.4	9.6	0.12		0.15	0.04	0.30	0.02	0.30	100.0
5	Thimme 237	Dagger blade	88.9	9.3	1.10		0.15	0.04	0.25	0.02	0.20	100.0
5	Thimme 129-a	Shepherd	91.5	6.7	0.87	<0.01	0.06	0.51	0.10	0.11	0.13	100.0
5	Thimme 129-b	Shepherd	90.0	8.0	1.20	<0.01	0.06	0.45	0.10	0.09	0.12	100.0
5	Thimme 96-a	Archer	85.3	12.0	0.93	<0.02	0.34	0.59	0.28	0.03	0.51	100.0
5	Thimme 96-b	Archer	87.0	7.4	1.00	0.03	3.50	0.47	0.20	<0.02	0.36	100.0
5	Thimme 96-c	Archer	88.7	8.7	0.87	<0.04	0.49	0.41	0.30	<0.03	0.50	100.0
5	Thimme 96-d	Archer	91.1	6.7	0.73	<0.03	0.80		0.21	0.01	0.39	100.0
5	Thimme 109	Archer	91.3	3.4	5.00	<0.10					0.31	100.0
5	Thimme 104	Warrior	92.5	5.9	<0.45	0.26	0.38	<0.10	0.03	<0.06	0.46	100.0
5	Thimme 98	Warrior frag.	89.1	7.3	2.55	0.32	0.02	<0.11	0.03	0.13	0.51	100.0
6	Lilliu 84	Warrior	88.8	10.3	0.59	0.01	0.20	0.02	0.09	<0.06		100.0
6	Lilliu 110	Warrior	89.4	9.5	0.70	0.02	0.25	0.02	0.07	<0.06		100.0
6	Lilliu 98	Warrior	89.5	9.3	0.99	0.01	0.12	0.02	0.08	<0.06		100.0
6	Lilliu 104	Warrior	90.2	9.4	0.29	0.01	0.04	0.03	0.02	<0.06		100.0
6	Lilliu 121	Female offerer	88.6	10.8	0.31	0.02	0.17	0.02	0.08	<0.06		100.0
6	Lilliu 128	Warrior	87.0	12.4	0.42	0.01	0.05	0.03	0.06	<0.06		100.0
6	Lilliu 116	Praying figure	92.8	0.3	0.29	0.10	0.01	0.04	6.50	<0.06		100.0
6	Lilliu 163	Offerer	86.5	13.1	0.14	0.00	0.23	0.03	0.01	<0.06		100.0
6	Lilliu 207	Cow	89.7	9.4	0.70	0.00	0.03	0.04	0.01	0.12		100.0
6	Lilliu 216	Yoked animal pair	81.4	12.0	6.50	0.01	0.05	0.03	0.00	<0.06		100.0
6	Lilliu 144	Female offerer	89.9	10.0	0.06	0.01	0.03	0.02	0.01	<0.06		100.0
6	Lilliu 145	Priestess	92.3	5.9	0.68	0.01	0.93	0.02	0.14	<0.06		100.0

mixing of recycled silver and bronze scrap metal, since the latter would have contained at least a modest amount of tin, and tin is not lost in the re-melting and casting processes. Nevertheless, recycling of bronze and other metals was probably a common occurrence, and extreme caution should be used in determining the provenance of bronze objects from lead isotope data.[19]

It is difficult to propose a specific recipe for Sardinian bronze at this time. Of the 129 objects that have been analyzed (Table 1), the 6 with high silver (Lilliu 116; Thimme 194), zinc (Sackler 1984.798; Getty 75.AK.110), or nickel (Thimme 129; Thimme 96) are atypical at best. The remaining 123 average 88.9 ± 3.9% copper, 8.8 ± 2.9% tin, 1.6 ± 3.2% lead, 0.3 ± 0.4% iron, and 0.3 ± 0.3% arsenic. Zinc, nickel, silver, and antimony all average 0.1% or less. Tin ranges from 2.2% to 18.6%, and lead ranges from 0.1% to 25.8%, however, suggesting that no single recipe was employed in all the places and at all the times that Nuragic bronzes were produced. Without archaeological provenance for most of the *bronzetti*, it is impossible to determine whether there may have been specific geographic or chronological differences in composition. The physical effects of alloying tin and copper in certain percentages was clearly understood, while the casting and working advantages of leaded bronze were only occasionally taken advantage of in the manufacture of votive objects, despite the otherwise common use of lead. We should note that, in contrast to Sardinia, much of the contemporary metal production in Etruscan Italy and Geometric Greece was in leaded bronze.[20] While this might be used to support a high dating of much of the Sardinian bronze production, it also may be due to the retention by the Nuragic people in Sardinia of a Bronze Age metallurgical tradition at the same time that increased use of metal by mainland city-states led to the debasement of copper-based objects. Authentic copper-silver alloys were occasionally employed in Sardinia, but we must remain highly sceptical of copper-zinc (brass) alloys for this time-period in Sardinia.

Department of Classics & Archaeology, Tufts University, Medford, MA 02155 (M.B.)
Department of Anthropology, University of South Florida, Tampa, FL 33620 (R.T.)

19 While bronze objects — already a mixture of ores — may be the result either of recycling or of new metal use, pure copper objects, especially ingots, are far less likely to derive from mixed ore sources.

20 Craddock (supra n.11) 146.