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Petrographic characterisation of polished stone axes from Neolithic Sardinia: archaeological implications

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ABSTRACT. — In Sardinia, polished stone axes appear in early Neolithic communities (VI millennium B.C.) and are found up to the beginning of the Copper Age.

Classification of polished axes from western central Sardinia has been redefined archaeometrically in a preliminary sampling of specimens found in open-air settlements. In the studied Neolithic sites, «nephrites» make up 95% of all examined lithologies. Two main groups may be distinguished, characterised respectively by the presence or absence of epidote. «Nephrites» are made up of actinolite or tremolite, chlorite, ±epidote, and Fe-oxide. The other stone axes are composed of glaucophane schist, metadiabase, andalusite hornfels, and phonolite.

The extensive occurrence of lithotypes from outside Sardinia, mainly «nephrite», which was commonly used to produce the mainland axes, chiefly in the Neolithic villages of northern Italy, is confirmed. Axes made of jadeitite or eclogite seem to be absent or very rare. Conversely, semi-finished samples found in Sardinia bear witness to raw materials or rough-casts acquired from the mainland. One axe made of volcanic rock from Montiferro is of particular interest, since it may also document local production of stone axes.

RIASSUNTO. — Asce in pietra levigata sono ampiamente note nella Sardegna preistorica. Esse fanno la loro comparsa nelle prime comunità neolitiche (VI millennio a.C.) e perdurano fino all'età dei primi metalli. Questa ricerca sulla definizione tipologica delle asce in pietra levigata della Sardegna è basata su determinazioni archeometriche effettuate su un campionamento preliminare di manufatti provenienti da alcuni insediamenti all'aperto della Sardegna centro-occidentale.

Nei siti neolitici studiati il 95% dei litotipi delle asce in pietra levigata è costituito da «nephriti». Le «nephriti» possono essere suddivise in due gruppi a seconda che contengano o siano prive di epidoto. L'associazione mineralogica è costituita da actinolite e tremolite, clorite, ±epidoto e ossido di ferro. Le altre litologie trovate sono: uno scisto a glaucofane, un metadiabase, una cornubianite ad andalusite e una fonolite.

Questi dati confermano una massiccia presenza di litotipi di origine esotica, che sono simili a quelli frequentemente impiegati nella produzione di manufatti continentali, soprattutto nei centri neolitici dell'Italia settentrionale.

Sembrano invece mancare, o essere molto rare, asce in giadeitite e in eclogite.

Il ritrovamento in Sardegna di esemplari non finiti, costituiti da litotipi di provenienza continentale, suggerisce una parziale lavorazione in loco del materiale grezzo.

La presenza di un'ascia in fonolite del Montiferro attesta anche una produzione locale dei manufatti in pietra levigata finora non documentata.

KEY WORDS: *Neolithic polished axes; nephrite; mineralogy; mineral chemistry; bulk rock chemistry; Sardinia.*

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INTRODUCTION

Polished stone axes are an important component in Neolithic manufacts. Petrographic studies of Neolithic stone axes, carried out in past decades over large areas of continental Europe, identify source areas of raw materials and allow us to draw patterns of the form and directions of tool distribution (Compagnoni and Ricq-de-Bouard, 1993; D'Amico *et al.*, 1995; Barfield, 1996; Ricq-de-Bouard, 1996; etc.).

Although the study of obsidian tools in the western Mediterranean has highlighted the increasing importance of trade in Sardinia starting from the early Neolithic, petrographic examination of polished stone axes has been neglected, especially when considering their close connection with the Monte Arci obsidian implements (Tykot, 1999).

Despite the pioneering work of Lovisato (1886, 1888), analytical studies on the stone artefacts of Sardinian prehistory, classification of evidence, definition of cultural and chronological indicators are still lacking.

A further problem is the lack of data from reliable stratigraphical contexts, since even the most recent publications are mainly based on archaeological surveys. It is therefore necessary to create a database of all stone axes in museums and private collections containing morphological, morphometrical and petrographical data on each tool.

This paper deals with the petrological characterisation of Neolithic polished stone axes found in several archaeological sites in central Sardinia. A petrographical description is given for all lithologies encountered, and bulk rock chemical analyses and mineral chemistry of minerals from 12 representative samples are given, with the purpose of determining the origin of the raw materials.

SITES: GEOMORPHOLOGIC FEATURES AND CULTURAL COMPLEXES

The polished stone tools examined here were found in eight sites in the Oristano district, central Sardinia (fig. 1): Conca Illonis, Cuccuru is Arrius, Su Pranu Mannu (near Cabras), Gribaia (near Nurachi), Interacquas (near S. Giusta), S. Ciriaco, S. Giovanni (near Terralba), and Serra sa Furca (near Mogoro) (fig. 1). All sites lie on the edge of more or less neighbouring marshy lands, or along important rivers. The landscape is typically a plain or a gently undulating low alluvial terrace.

Conca Illonis is a typical large long-term settlement, lying west of the Cabras lagoon near Oristano on a coastal plain sloping slightly from the Sinis basaltic plateau. Prehistoric dwellings have been documented by findings of dark anthropogenic soils filled with food remnants, lithics and potsherds (Atzeni, 1962). In the past few decades, most archaeological layers have been mixed by agricultural ploughing and levelling. On the basis of findings of chiefly pottery (cultural facies of Bonu Ighinu, S. Ciriaco, Ozieri, Subozieri and Monte Claro), it is hypothesized that a settlement probably existed continuously from the Middle Neolithic to the late Copper Age, and that another one was established in the late Middle Bronze Age, with the building of a single-tower Nuraghe, now totally destroyed (Sebis, 1998).

The habitat of *Cuccuru is Arrius* was very similar to that of *Conca Illonis*. The settlement of *Cuccuru is Arrius* lies on a stabilised low dune along the south coast of the Cabras Lagoon, a site well-known in archaeological literature since the end of the nineteenth century (Zanardelli, 1899). In the late 1970s, the dune was drained to create a channel from the lagoon to the sea. During this digging, extensive excavations were made in the settlement area, and a complex of partially underground dwellings, waste accumulation and food storage areas was found. A few burials, below or above ground, were also found. Stratigraphic data revealed a long-term settlement, lasting from the Middle Neolithic to the early Copper Age (Santoni, 1982) but also, partially, during the Nuragic and Carthaginian-Roman civilisations.

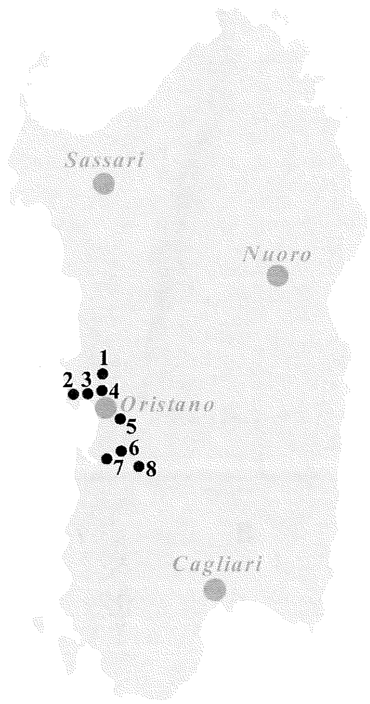

Fig. 1 - Location of archaeological sites of origin of studied polished stone axes. 1: Gribaia; 2: Conca Illonis; 3: Cuccuru is Arrius; 4: Su Pranu Mannu; 5: Interacquas; 6: San Ciriaco; 7: San Giovanni; 8: Serra sa Furca.

The third settlement is that of *Su Pranu Mannu* region near Cabras, a few kilometres north-east of *Cuccuru is Arrius*. It was found during non-systematic archaeological surveys and is located on a low alluvial terrace along the large Nurechi lagoon, now drained. Published archaeological findings testify to the continuous presence of humans during the Late and Final Neolithic Ages, with the S. Ciriaco facies and the Ozieri culture (Baiocchi, 1996). A larger settlement area is documented in the subsequent Chalcolithic Subozieri facies. The same cultural levels and a later Middle Bronze Age settlement are found at *Gribaia* (Nurachi) five kilometres to the north (Lugliè, 1998).

The settlement of *Interacquas* was found in the southern part of this area, close to the eastern coast of the Pauli Maiori marsh, along the boundary between S. Giusta and Palmas Arborea. A few remains were found during archaeological surveys, indicatingt an Early Neolithic settlement that was continuous until the Late Neolithic (Lugliè, 2002).

South of the large Sassu lagoon, which was drained during the great land reclamation operations of the 1920s, several settlements have been identified in the Terralba region, on a coastal plain between the two volcanic complexes of Monte Arci and Monte Arcuentu. One, located on the S. Giovanni alluvial terrace, is formed of the old watercourses of Rio Mogoro and Rio Sitzerri near the S. Giovanni Lagoon and characterised by the unique short-term Ozieri settlement, which developed during the latest Neolithic Early Copper Age (Cossu, 1996). Instead, in the hinterland, frequent patterns of long-term settlement are found on Quaternary terraces overlooking the older Rio Mogoro. Here, the site of *S. Ciriaco* at Terralba persisted from the Middle Neolithic to the early Copper Age, and that of *Serra Sa Furca* at Mogoro from the Middle Neolithic to the Monte Claro culture of the Middle Copper Age (Atzeni, 1992). At both sites, secondary Nuragic settlements during the Late Bronze Age were probably favoured by good environmental conditions.

Study Materials

Fourteen fragments, representative of 54 polished stone tools, were selected for petrographical analysis on the basis of their macroscopic features. The samples are comparatively homogeneous and are classified as axes and hatchets; one item may be a striker. They are usually flat, symmetrical, and trapezoidal in shape; their cross-section is generally oval or lenticular, more seldom rectangular (fig. 2). Borders are rectilinear; slightly convex edges have a double inclination and are generally symmetrical. The bases are

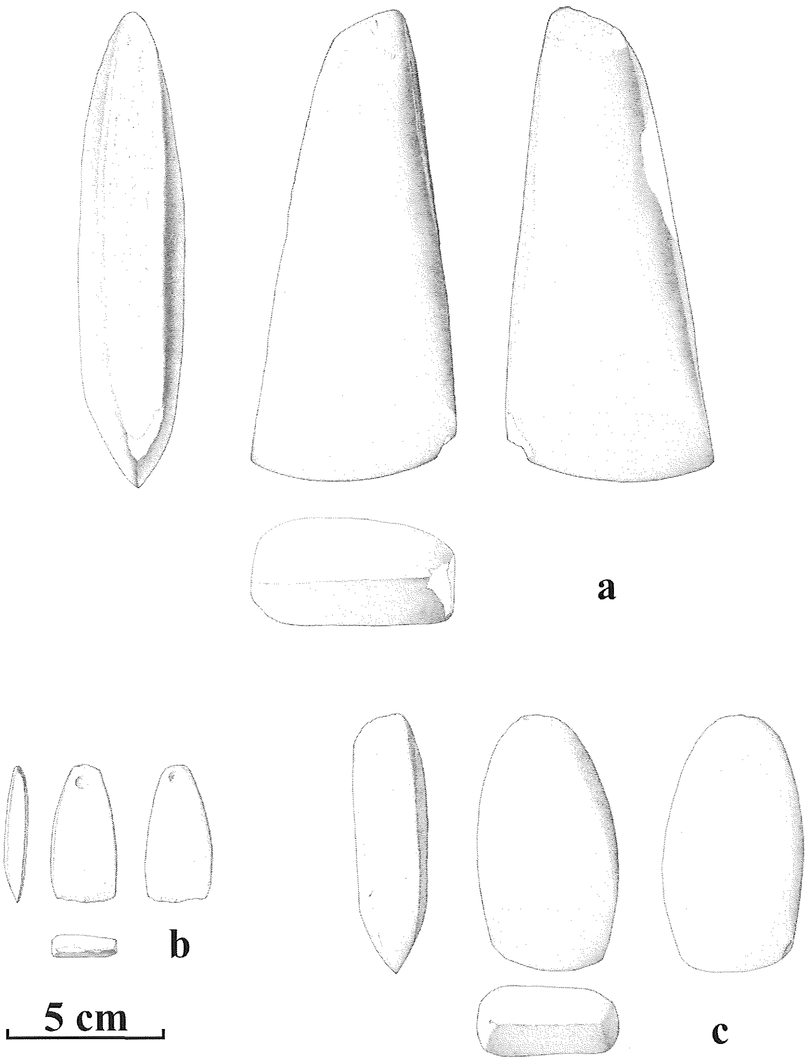

Fig. 2 – Polished stone axes (a, c) and hatchet-amulet (b) from Conca Illonis (drawing by C. Lugliè).

more frequently convex, at times strongly convex or rectilinear.

All these artefacts come from archaeological surveys, generally carried out on long-term settlements dating at least as far back as the Middle Neolithic Age (4000-3250 B.C.). As regards the cultural and chronological time-scale proposed for prehistoric Sardinia, this kind of tool fits between the Early Neolithic and the early Copper Age, and seems to disappear in the middle of the third millennium B.C. during the Monte Claro culture. Detailed descriptions of the samples are given below.

Conca Illonis (Cabras)

CIC15. Mesial fragment adjacent to the edge, probably rectilinear; undetermined shape, lenticular transversal section. Remaining (rem.) max length 61 mm; rem. max width 20.5 mm; rem. max thickness 15 mm.

CIC16. Probably distal fragment of undetermined shape, from along the right rectilinear edge; asymmetrical, sub-rectangular cross-section; double-plain rectilinear edge, smoothed. Rem. max length 43.5 mm; rem. max width 46 mm; rem. max thickness 20 mm.

CIC17. Proximal fragment; probably of symmetrical, trapezoidal shape. Inclined rectilinear base; asymmetrical sub-rectangular section; repeated attempt at bi-directional drilling, as seen in the section, with probable subsequent accidental breakage (secondary polish?). Rem. max length 27.1 mm; rem. max width 32.5 mm; rem. max thickness 9 mm.

CIC18. Distal fragment, flat, probably of symmetrical trapezoidal shape; double-plain asymmetrical edge, thin, chipped, slightly convex (Convexity index = Cd 2.91: Ricq-de-Bouard, 1983); lenticular cross-section, with rectilinear symmetrical borders. Rem. max length 53.5 mm; rem. max width 48 mm; rem. max thickness 11 mm.

CIC19. Proximal fragment of symmetrical trapezoidal shape, slightly convex base. Oval cross-section, with asymmetrical borders. Rem. max length 54.5 mm; rem. max width 40 mm; rem. max thickness 12.5 mm.

Cuccuru is Arrius (Cabras)

CA4. Proximal fragment, symmetrical trapezoidal in shape, with rectilinear or slightly convex borders; rectilinear base, broken slantwise. Sub-rectangular cross-section, with asymmetrical surfaces. One surface shows traces of wear, probably produced by the haft. Rem. max length 68 mm; rem. max width 49 mm; rem. max thickness 16 mm.

CA5. Proximal fragment; probably of symmetrical shape, with rectilinear or slightly convex borders, like the base; symmetrical, oval cross-section. Rem. max length 36 mm; rem. max width 43 mm; rem. max thickness 12.5 mm.

Gribaia (Nurachi)

GRI65. Thick, probably distal fragment; undetermined shape. Rem. max length 51.5 mm; rem. max width 52.5 mm; rem. max thickness 16 mm.

GRI67. Trapezoidal asymmetrical shape with rectilinear borders; completely fragmentary base and edge; oval section with asymmetrical flat surfaces. Rem. max length 58.4 mm; rem. max width 32.3 mm; rem. max thickness 11.4 mm.

San Ciriaco (Terralba)

S.CIR30. Distal fragment; trapezoidal symmetrical shape with rectilinear borders, transversally broken; slightly convex edge (Cd 1.9), accidentally chipped, with double symmetrical plane; asymmetrical oval cross-section. One surface shows deep splintering; one border shows outlines of hammer traces. Rem. max length 55.5 mm; rem. max width 42 mm; rem. max thickness 16.1 mm.

San Giovanni (Terralba)

SG2. Distal fragment; trapezoidal in shape with rectilinear borders; double symmetrical edge contour, slightly convex (Cd 2.05) and accidentally chipped; lenticular cross-section with rectilinear asymmetrical borders. Rem. max length 38.5 mm; rem. max width 39 mm; rem. max thickness 9 mm.

SG5. Striker? Proximal fragment of flat cylindrical shape, slightly tapered; base with low convexity. Oval-circular cross-section, asymmetrical. Remaining outline hammer traces all along border and contiguous surfaces. Rem. max length 66.2 mm; rem. max width 46.5 mm; rem. max thickness 34 mm.

Serra sa Furca (Mogoro)

SSF5. Proximal fragment; symmetrical trapezoidal in shape with rectilinear borders and broken base. Rectangular asymmetrical cross-section; clear traces of sawing on one edge, high asymmetry between cutting surfaces. Outlines of hammer traces at the centre of both surfaces are preserved. Rem. max length 44 mm; rem. max width 37 mm; rem. max thickness 15.7 mm.

SSF6. Distal fragment; trapezoidal symmetrical in shape with rectilinear borders severely broken lengthwise and chipped on one surface; double asymmetrical plane, accidentally chipped, with a slightly convex edge (Cd 2.97); asymmetrical oval cross-section. Outlines of hammer traces all over the surface. Rem. max length 62.3 mm; rem. max width 34 mm; rem. max thickness 11 mm.

Analytical methods

Minerals were identified by optical microscopy and X-ray powder diffraction, using a Philips (PW1710) diffractometer.

Mineral chemistry was determined at the Centro Studi Geominerari e Mineralurgici, CNR, Cagliari, on a fully automated ARL-SEMQ electron microprobe operating at a 20 kV and 20 nA sample current. Beam spot size was approximately 3 mm. Natural olivine, orthoclase, albite, anorthite, augite, ilmenite and chromite were used as standards. Raw data were corrected using the ZAF procedure.

Twelve samples were analysed for major elements (ICP-AES, whole rock fusion with meta-borate) and four samples for trace and rare earth (REE) elements (ICP-MS) at the Chemistry Labs, Vancouver (Canada).

Mineralogy and Petrography

CIC15, CIC16, CIC17, CIC18, CIC19, CA4, CA5, SSF5, SSF6, SG2 - This group of polished stone axes may be classified as «nephrites». Two main groups are distinguished, depending on whether they contain or lack epidote (fig. 3a, b). The «nephrites» reveal two main textural types: one is fine-grained and made up of a felt of interlocked needles of amphibole, rarely by coarse-grained amphibole crystals; the second type contains medium-grained crystals of amphibole (0.1-1 mm long) prevailing over tightly-intergrown amphibole needles. Some nephrites contain small opaque patches of Fe-oxide.

Table 1 lists the compositions of selected amphiboles, together with structural formulas based on 23 oxygens.

According to the classification of Leake *et al.* (1997), the amphiboles are calcic, with a fairly uniform composition, and plot in the actinolite or tremolite fields (fig. 4). They have low Al^{IV} (up to 0.116) and Al^{VI} (up to 0.075) contents, a high X_{Mg} ratio (0.86-0.92), and Na contents lower than 0.03.

Chlorite occurs as a colourless matrix mineral of small size or arranged as radial crystals. Selected compositions are listed in Table 1. The structural formula was calculated on the basis of 28 oxygens. Si contents range from 5.937 to 6.029 atoms per formula unit (apfu). The X_{Mg} ratio ranges from 0.77 to 0.91. Epidote occurs as both anhedral or subhedral grains, from 0.1 to 0.3 mm. A representative analysis of epidote is shown in Table 1. The structural formula is calculated on the basis of 12.5 oxygens. Al contents of epidote are 2.096 apfu, Ca contents approach the value of 1.914 apfu. Iron, calculated as trivalent iron, is 0.941.

SCIR30. This polished stone axe displays a granular texture consisting of large crystals of plagioclase, stilpnomelane, amphibole, chlorite, ilmenite and apatite. Plagioclase is the most abundant mineral (up to 50%) and consists mainly of homogeneous plagioclase (18% An). Amphibole occurs as small elongated grains (<0.2 mm long) growing into plagioclase and chlorite. Ilmenite crystals are very small (<0.1 mm) and highly fragmented. This rock is tentatively classified as metadiabase.

GRI67. This sample is a fine-grained blueschist and consists of glaucophane and lawsonite (fig. 3c) with accessory Fe-oxide (mainly hematite) and minor phengite. Representative glaucophane, lawsonite and

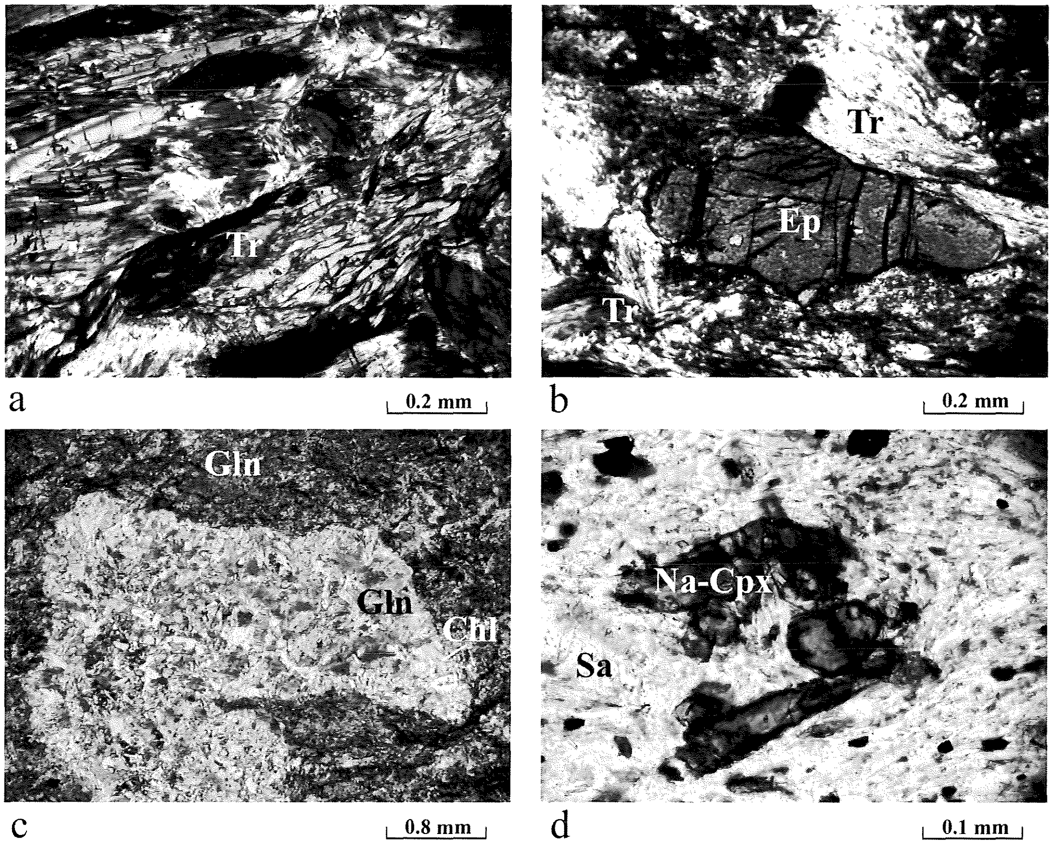

Fig. 3 – Photomicrographs of polished stone axes from Sardinia. a: sample SG2, «nephrite»; b: sample CA5, epidote-bearing «nephrite»; c: sample GRI67, glaucophane schist with a patch which recall an angular clast; d: sample GRI65, phonolite. a, b, c: crossed polar; d: plane-polarized light. Mineral abbreviations according to Bucher and Frey (1994).

phengite analyses are listed in Table 1. The structural formula of blue amphibole was calculated to 13 cations, except for Ca+Na+K. According to the classification of Leake *et al.* (1997), it is a ferroglaucophane, with Al^{IV} and Al^{VI} contents of 0.048 and 1.407 apfu, respectively, a low X_{Mg} ratio (0.49) and Na contents of 1.89 apfu. The composition of lawsonite is very close to the ideal composition, with negligible Fe contents (0.032 apfu). Muscovite is a celadonite-rich phengite with Si of 7.056 apfu, K of 1.961 apfu, and Mg+Fe = 1.249 apfu. Patches with a larger grain size, which recall angular clasts made up of the same rock matrix materials, are worthy of note (fig. 3c).

SG5. This rock consists of quartz, muscovite, biotite, andalusite and Fe-oxide. Quartz mainly occurs as single crystals up to 10 microns across. Muscovite occurs as either small or medium-grained flakes with random orientation. Andalusite occurs as euhedral crystals or coarse columnar aggregates, and shows typical pale to pinkish pleochroism. Due to lack of preferred mineral orientation and similarity with contact metamorphic rocks, this

TABLE 1

Representative microprobe analyses of minerals of Sardinian polished stone axes. Crystal chemical formulas of minerals calculated on basis of following oxygens: calcic amphibole (23 oxygens), sodic amphibole (13 CNK), epidote (12.5 oxygens), chlorite (28 oxygens), muscovite (22 oxygens), lawsonite (8 oxygens). All iron is assumed to be divalent except for epidote and glaucophane. Symbols: mineral abbreviations according to Bucher and Frey (1994).

Sample #	CA4	CA4	CIC18	CIC18	SG2	SG2	CIC19	CIC19	GRI67	GRI67	GRI67
Mineral	Act	Ep	Act	Chl	Tr	Chl	Tr	Chl	Gln	Ms	Lws
SiO_2 (wt%)	56.86	36.73	57.13	30.00	56.10	30.01	55.96	30.37	55.22	51.05	37.20
TiO_2	0.01	0.05	0.05	0.00	0.01	0.00	0.01	0.00	0.05	0.00	0.00
Al_2O_3	0.51	21.84	0.40	18.03	0.59	16.70	0.70	17.71	8.58	23.10	31.50
FeO_{tot}	5.92	13.81	5.57	13.40	3.34	6.35	3.48	6.42	16.27	4.23	0.79
MnO	0.11	0.13	0.05	0.10	0.10	0.10	0.13	0.19	0.18	0.03	0.00
MgO	20.47	0.13	20.86	25.54	21.40	29.80	22.10	29.61	7.48	3.69	0.00
CaO	12.86	21.90	12.46	0.05	12.77	0.01	13.12	0.06	1.54	0.07	17.33
Na_2O	0.15	0.00	0.11	0.20	0.04	0.00	0.06	0.00	6.76	0.00	0.00
K_2O	0.05	0.00	0.03	0.00	0.02	0.00	0.02	0.00	0.04	11.12	0.02
Total	96.94	94.59	96.66	87.32	94.38	82.97	95.58	84.36	96.12	93.29	86.84
Si	7.967	2.996	7.997	5.937	7.976	6.029	7.881	6.000	7.952	7.056	1.993
Al^{IV}	0.033	0.004	0.003	2.063	0.024	2.971	0.116	2.000	0.048	0.944	-
Al^{VI}	0.051	2.096	0.063	2.144	0.075	0.984	0.00	2.125	1.407	2.820	1.989
Ti	0.001	0.003	0.005	-	0.010	-	-	-	-	-	-
Fe^{3+}	-	0.941	-	-	-	-	-	-	0.259	-	-
Fe^{2+}	0.694	-	0.652	2.218	0.397	1.067	0.410	1.061	1.700	0.489	0.035
Mn	0.013	0.090	0.006	0.017	0.012	0.017	0.016	0.032	0.022	0.004	-
Mg	4.275	0.016	4.352	7.533	4.535	8.923	4.639	8.718	1.606	0.760	-
Ca	1.931	1.914	1.869	0.011	1.945	0.020	1.980	-	0.238	0.010	0.995
Na	0.041	-	0.030	0.077	0.004	-	-	-	1.887	-	-
K	0.009	-	-	-	-	-	-	-	-	1.961	0.001
X_{Mg}	0.86	-	0.87	0.77	0.92	0.89	0.92	0.89	0.49	-	-

lithotype is tentatively classified as andalusite-hornfels.

GRI65. This igneous rock has a porphyritic texture (porphyritic index ~2%) and colour index ≤5. The phenocrysts are millimetre-sized euhedral sanidine and microphenocrysts of häuyne and minor aegirine-augite (fig. 3d). The groundmass is made up of oriented microlith laths of sanidine (80-85 vol%), aegirine-augite and foids. Widespread small magnetite and ilmenite crystals occur in the groundmass. Accessory minerals are titanite and very rare apatite. The rock is classified as a phonolite.

BULK ROCK CHEMISTRY

Analyses of major elements of the twelve samples, together with the composition of one phonolite sample (203F; from Beccaluva *et al.*, 1977) from Montiferro are listed in Table 2. Trace and rare earth elements of four samples and the composition of phonolite sample 203F are listed in Table 3.

The SiO_2 contents of the «nephrites» show a small range between 52.34 and 55.89 wt%; TiO_2 is usually lower than 0.18 wt%. Al_2O_3 and Fe_2O_{3tot} range from 1.59 to 3.37 wt% and from 4.79 to 10.38 wt%, respectively. MgO is

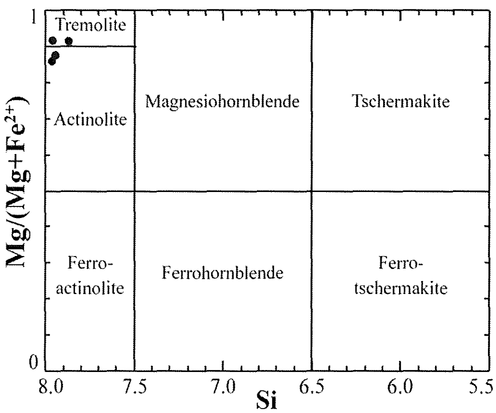

Fig. 4 – Plot of calcic amphibole of polished stone axes from Sardinia, in classification diagram of Leake et al. (1997).

slightly variable, between 18.65 and 24.16 wt%, while CaO ranges from 10.16 to 13.20 wt%. K_2O (<0.24), Na_2O (0.27) and MnO (<0.11) contents are very similar among the various «nephrites». Compared with chondrite, Ba, Th, and Sr contents of «nephrites» vary greatly. Rb, Nd, and Sr show a marked negative anomaly, and Ta and Th show a positive anomaly. Worthy of note is Ti enrichment with respect to Y and Yb. The chondrite-normalised REE patterns (Sun and McDonough, 1989) of two «nephrite» axes are shown in fig. 5a. They show LREE enrichment of about 5-100 times, MREE enrichment of about 1-20 times, and HREE enrichment of about 6-10 times, compared with chondrite values. Chondrite-normalised REE patterns show a slightly positive Eu anomaly and are enriched in LREE with respect to HREE.

The glaucophane schist and metadiabase have similar chemical compositions, except for P_2O_5 contents and LOI, the latter being higher in the glaucophane schist. The bulk chemistry of the metadiabase is similar to that of Fe-gabbros, with MgO contents of 3.51 wt% and Al_2O_3 of 14.81 wt%. It is also characterised by high TiO_2 (2.95 wt%) and P_2O_5 (1.10 wt%). The FeO_{tot}/MgO and MgO/CaO ratios of metadiabase are 3.70 and 0.45, respectively. The REE patterns of the latter show a slight decrease in LREE and flat HREE contents. According to the Ti/Y and Nb/Y (Pearce, 1982) and TiO_2 and Zr/P_2O_5 ratios (Floyd and Winchester, 1975) and the REE patterns, the protolith may be an igneous alkaline mafic rock.

The andalusite-hornfels shows SiO_2 of 64.82 wt% and Al_2O_3 of 17.87 wt%. The MgO/Fe_2O_3 ratio is 0.28. In the Na_2O vs. TiO_2/Zr diagram of Garcia *et al.* (1994), the sample plots between Al-rich shale and normal shale, but is far from immature sandstone. The trace and REE contents of these rocks are very similar to those of North American shale (Gromet *et al.*, 1984).

Phonolite has silica contents of 59.94% and total alkalis of 13.9 wt%; CaO and Fe_2O_3 are 1.51 and 2.50, respectively. MgO and TiO_2 are less than 0.5 wt%; P_2O_5 is negligible. This rock was classified as a phonolite according to both the R1R2 diagram of De La Roche *et al.* (1980) and the TAS diagram (Le Bas *et al.*, 1986). It is characterised by high normative nepheline (about 15%) and low normative anorthite (0.12%). This sub-aluminous character is supported by an agpaitic index of 0.998, which indicates a peralkaline tendency.

Discussion

Mineralogical and petrological characterisation of the examined Sardinian polished stone axes provides some useful information on their raw materials. However, conclusions are only approximate, since only a small number of samples was examined. In addition, the samples represent a group of 54 polished stone axes collected from the surface, a part which does not allow precise chronological or cultural attribution.

The commonest lithologies are «nephrites», with very minor glaucophane schist, andalusite hornfels, and only one sample of volcanic rock.

These data are partially consistent with the raw materials of Neolithic polished stone axes

TABLE 2

Major elements of twelve samples of polished stone axes, and composition of peralkaline phonolite (sample 203F) from Montiferro.

Sample	CA4	CA5	SSF5	SSF6	CIC17	CIC18	CIC19	SG2	GRI65	S.CIR30	SG5	GRI67	203F
SiO_2 (wt.%)	55.78	54.71	52.34	53.16	53.83	55.89	52.76	53.43	59.94	49.87	64.82	50.17	57.86
TiO_2	0.08	0.16	0.22	0.11	0.07	0.12	0.14	0.18	0.33	2.95	0.89	2.75	0.44
Al_2O_3	1.59	3.76	2.85	2.81	1.74	1.81	2.92	3.37	19.63	14.81	17.87	14.22	20.56
Fe_2O_3	6.84	7.08	6.35	7.47	10.38	6.77	4.96	4.79	2.50	14.45	7.21	13.08	2.84
MnO	0.18	0.16	0.22	0.16	0.45	0.11	0.17	0.12	0.18	0.27	0.08	0.13	0.12
MgO	21.20	18.65	21.13	22.27	17.35	22.26	22.58	24.16	0.38	3.51	2.02	5.19	0.56
CaO	12.00	12.12	13.20	10.16	11.96	11.36	10.96	10.32	1.51	7.84	0.42	7.02	1.33
Na_2O	0.18	0.27	0.14	0.14	0.16	0.23	0.14	0.10	7.90	4.75	1.01	4.49	8.49
K_2O	0.17	0.24	0.21	0.18	0.22	0.23	0.18	0.14	6.09	0.20	3.01	0.57	6.15
P_2O_5	0.02	0.08	0.08	0.10	0.02	0.09	0.05	0.06	0.01	1.10	0.12	0.29	0.10
LOI	3.09	3.36	4.36	3.50	1.79	2.35	3.46	4.50	1.06	0.37	3.33	3.25	1.34
Total	101.13	100.59	101.10	100.06	97.97	101.22	98.32	101.17	99.53	100.12	100.78	101.16	99.79

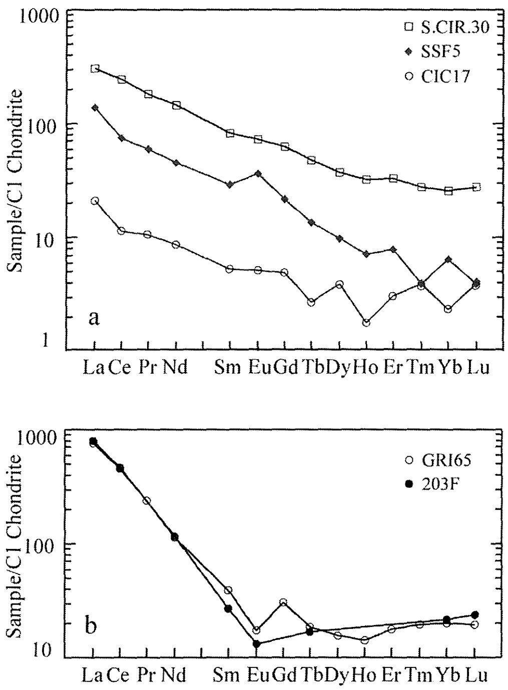

Fig. 5 – Chondrite-normalised (Sun and McDonough, 1989) REE patterns for some polished stone axes from Sardinia; a: «nephrite» and metadiabase; b: phonolite axe and a peralkaline phonolite from Montiferro.

found in northern Italy and western Europe (D'Amico *et al.*, 1991, 1992, 1995, 1996, 1997), where most artefacts are made from metamorphic rocks (i.e., jadeitite, eclogite, serpentinite, prasinite) and minor volcanics.

«Nephrites» have also been reported, but as minor components (only 1.2% of all lithologies). In studied Neolithic sites in Sardinia, «nephrites» make up 95% of all lithologies, and jadeitite, eclogite and serpentinite axes have not yet been found. This may be due either to a sampling shortage or to an actual lack of this lithotype among Sardinian Neolithic axes. In fact, Lovisato (1886) described finding jadeitite, serpentinite, metagabbro and eclogite axes mainly in northern Sardinia.

TABLE 3

Trace and rare earth element data for selected polished stone axes from Sardinia. Composition of a peralkaline phonolite (sample 203F) from Montiferro. Symbols as in Table 1

Sample	CIC17	SSF5	S.CIR30	GRI65	203F
Sc (ppm)	-	-	-	-	1.1
V	5	25	90	10	-
Cr	68.4	68.4	68.4	-	-
Co	19.5	9.5	32.0	<5.0	0.3
Ni	5	15	5	<5	-
Sn	3	2	5	4	-
Cu	<5	<5	<5	<5	-
Zn	70	90	140	120	-
Ga	5	7	25	34	-
Rb	4.0	4.0	2.2	198.0	252.0
Sr	78.8	19.7	512.0	33.1	462.0
Y	6.5	13.5	46.5	25.0	30.0
Zr	33.0	49.0	357.0	1155.0	1364.0
Nb	1	8	86	178	194
Ag	1	2	1	1	-
Cs	1.0	0.5	0.1	4.1	-
Ba	18.0	24.0	77.5	33.0	13.0
La	5.0	33.0	72.5	178.5	187.0
Ce	7.0	46.0	147.5	277.0	287.0
Pr	1.0	5.6	17.1	22.3	-
Nd	4.0	21.0	68.0	53.5	54.0
Sm	0.8	4.4	12.7	6.0	4.1
Eu	0.3	2.1	4.2	1.0	0.76
Gd	1.0	4.4	12.9	6.2	-
Dy	1.0	2.5	9.4	4.0	-
Ho	0.1	0.4	1.8	0.8	-
Er	0.5	1.3	5.5	2.9	-
Tm	0.1	0.1	0.7	0.5	-
Tb	0.1	0.5	1.8	0.7	0.63
Yb	0.4	1.1	4.4	3.4	3.7
Lu	0.1	0.1	0.7	0.5	0.6
Hf	1	1	9	29	30
Ta	0.5	1.5	6.5	10.0	8.1
W	1	2	1	1	-
Pb	30	65	25	40	-
Th	1	5	9	32	44
U	0.5	2.5	2.5	7.5	-

Raw materials are unlikely to have come from a single geologic source. The considerable lithological variations, which include metapsammite, greenstone, glaucophane schist and phonolite, suggest that the raw materials came from various areas. Nevertheless, except for phonolite, the raw materials of the other axes come from an exotic source. This is easy to prove because, in Sardinia, high-pressure rocks such as glaucophane schist and «nephrites» are lacking, whereas glaucophane schist, eclogite and serpentinite are common in the Alps and NE Corsica. The Alpine origin of the jadeitite, eclogite, and serpentine axes described by Lovisato (1886) is well ascertained, whereas the origin of the «nephrite», most probably multiple, is more problematic.

«Nephrite» has been found at several archeological sites in northern Italy, often associated with eclogite and jadeitite. In all the sites studied, a very small percentage of axes are made of «nephrite». Primary deposits of «nephrite» are known in Val de Faller, Peschiavo, Les Haudères, Gottard (Swiss Alps), Isère Valley (France), Sestri Levante-Monterosa (Italy), Mt. Hartz (Germany), south western Poland, and Pakile (Finland) (Gunia, 1999). Secondary deposits of «nephrite» have been reported from morainic deposits in Scandinavia and Germany (Gunia, 1999). Glaucophane schists are common both in the Alps and in Alpine Corsica (Gibbons *et al.*, 1986). The hypothesis of a Corsican source for both the Sardinian «nephrite» and glaucophane schist appears attractive, but still awaits confirmation.

There is petrographical evidence that local raw materials were used to produce polished stone axes in Sardinia. Phonolite, similar to that of sample GRI65 outcrops extensively in the Pliocene volcanic complex of Montiferro, central Sardinia. This complex consists of two main magmatic series of alkaline affinity (Beccaluva *et al.*, 1977): one sequence of terms from analcite-basanite to tephritic phonolite; and one, more extensive, containing terms from alkaline to mildly-alkaline basalt, to phonolite (sometimes peralkaline). Some geochemical features of peralkaline phonolite are relatively high Zr, Hf, Th, and Rb contents, and depletion in Y, Nb, Ta and intermediate REE. The latter defines a characteristic V-shaped REE pattern (fig. 5b) (Beccaluva *et al.*, 1977). Table 1 lists the chemical analyses of phonolitic axe sample GRI65, which is very similar to peralkaline phonolite 203F of Montiferro. This is confirmed by the REE pattern, which is characteristic of phonolite of the volcanic series from alkali-basalt to phonolite, and by the aegirine-augite composition of clinopyroxene.

One other point which deserves further exploration is the quality and working of raw materials. Most of the implements are finished tools such as axes, chisels and axe-amulets, but unfinished or rough–hewn instruments made by hammering have also been found. This suggests circulation of partially processed materials to be completed locally, as in other regions of Southern Italy (Leighton, 1992).

CONCLUDING REMARKS

The 14 samples of polished stone axes from central Sardinia allow us to draw the following conclusions:

1. «Nephrite» axes make up 95% of sampled Sardinian Neolithic polished stone axes.
2. The origin of «nephrite» and glaucophane schist is undoubtedly exotic to Sardinia, since these kinds of rocks («nephrites» or high-pressure rocks such as glaucophane schist) are not known on the island and their occurrence is precluded, for geological reasons.
3. The polished stone axe made of phonolite (GRI65) certainly comes from a local source, since its mineralogical and geochemical features are very similar to the peralkaline phonolite of the Montiferro area.

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