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ORIGINAL PAPER

Polished stone axes from Varna/Nössingbühel and Castelrotto/Grondlboden, South Tyrol (Italy)

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Abstract
A collection of polished stone axes from a late Neolithic site and an Early Bronze Age hill fort in South Tyrol (Italy) have been analysed through a multi-analytical approach, mainly based on non-destructive techniques (i.e. Raman spectroscopy, X-ray fluorescence and prompt gamma activation analysis) to identify the raw materials used in the same area during different periods and compare them with those in use in the surrounding territories. The analytical results suggest raw material exploitation strategies based on local or close sedimentary, metamorphic and magmatic rocks. Most of the artefacts are made from antigoritic serpentinite, whose origin is probably from Hohe Tauern (Austria) or related secondary deposits. These data confirm the importance of such raw material for the production of polished stone axes during recent prehistory and integrate the present knowledge about the distribution of antigoritic artefacts in north-eastern Italy and neighbouring countries.

Keywords Polished stone axes · South Tyrol (northern Italy) · Late Neolithic · Early Bronze Age · Mineralogical and chemical characterisation · Provenance

Introduction

In this work, we have investigated a collection of polished stone axes from two archaeological sites of South Tyrol (northern Italy): Castelrotto/Kastelruth Grondlboden site and the hill fort of Nössing (Fig. 1). The stone axes from the first locality come from late Neolithic layers, while those from the second one date back to the Early Bronze Age. We have adopted a multi-analytical approach, mainly based on non-destructive techniques to limit negative sampling effects, with the aim of characterising the raw materials used in the same area during different prehistoric periods and comparing them with those in use in the surrounding areas (e.g. Bernardini et al. 2009, 2011a, 2011b, 2012, 2014a, 2014b).

The effort to define the use of local or exotic rock types could help to understand the exploitation strategies of lithic raw materials and the function of the investigated stone axes in the economy of the Neolithic and Early Bronze Age communities of the Alps.

Archaeological background

The Castelrotto/Kastelruth Grondlboden site was discovered in 2006 during construction works in the centre of the town of

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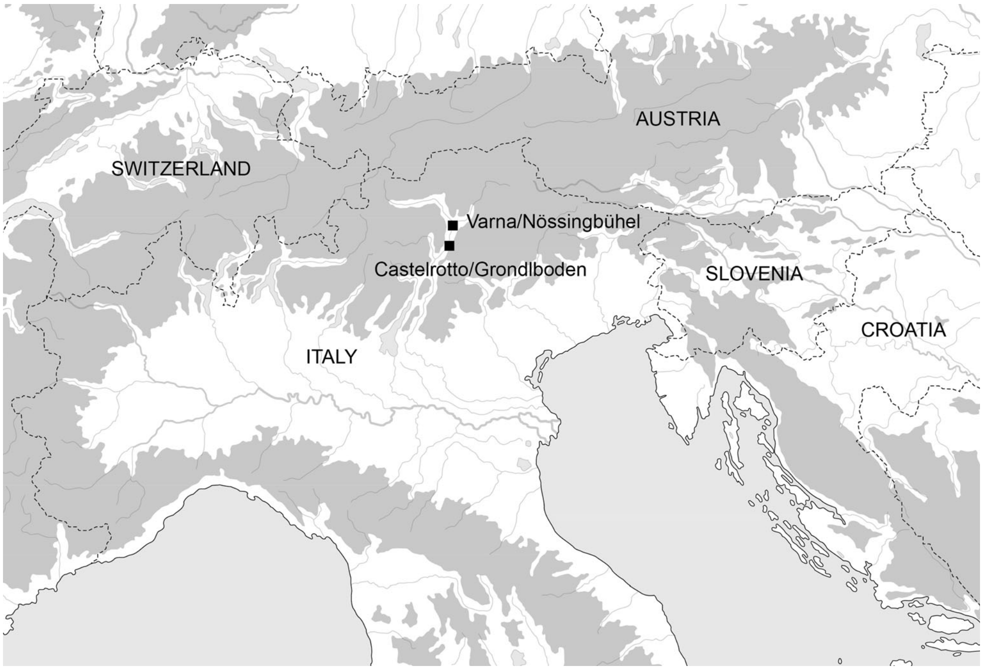


Fig. 1 Location of the Varna/Nössingbühel and Castelrotto/Grondlboden sites

the same name (Tecchiati 2007, 2008). In this occasion, several archaeological levels were discovered and an area of more than 1000 m^2 was extensively excavated in 2007/2008. The site is located in the Val Isarco, 20 Km north-east of Bolzano/Bozen, the main city of the South Tyrol region, on a high alpine plateau (1056 m a.s.l.) featured by gorges formerly excavated by glaciers and finally by tributaries of the Isarco River; also, minor streams, now regimented and partially drained, had a role in shaping the landscape. The site valley is surrounded by steep rocky slopes (porphyry and dolomite formations) and can be considered as a natural water collection basin.

The site was frequented for a wide time span, from the Neolithic to Modern Age, although in a discontinuous way. This lack of continuity—no Iron Age or Roman structures were discovered in situ—can be presumably attributable to the water instability of the area, although archaeological remains dating to the above-mentioned ages are well-spread over the surrounding territory. The Grondlboden plain, as testified by the stratigraphy of the area, was subject to frequent floods and landslides. Alluvial and colluvial layers have therefore totally buried the archaeological occupation layers. As a consequence, the Neolithic and the Early Bronze Age living floors were found alternated with thick (from 2 to 4 m) colluvial deposits. Drainage structures (mostly hydraulic channels or large stone floors) set during the Bronze Age and the Middle Ages confirm the humid and instable nature of the area.

The Neolithic occupation took place in a marshy environment where wooden remains (anthropogenic and natural) were perfectly preserved and pottery and stone remains (polished and flaked manufactures) were dispersed. The occupation was dated by ^{14}C (US 156, LTL 3142A: 4937 ± 50 BP, 3970–3760 BC 2σ; US 165, LTL 3145A: 5076 ± 40 BP, 3970–3780 BC 2σ) and dendrochronology to 4000–3600 BC (a detailed study of a larger set of absolute dates is in progress).

This Neolithic occupation could have been the cause of important anthropogenic landscape modifications in the surrounding areas suggesting slope degradation processes triggered by deforestation. Evidence on site exploitation suggest these processes occurred mostly during the late Neolithic, when the area was settled on a permanent basis (numerous post-holes alignments and stone or wood structures were discovered); these modifications testify to the transition from nomadic agriculture and «slash and burn» practices to productive activities in the framework of a permanent settlement.

Five axes from the late Neolithic level have been included in the present study (KGB318, KGB490-KGB493). They were discovered in a very small area (few square meters) featured by the presence of hearts, post-holes and pits severely eroded by later alluvial phenomena. It is possible that the axes were originally located into a pit perhaps used as a hoard and successively degraded by natural events; as a consequence of this natural action, the axes were probably randomly distributed on the surface of erosion without suffering any long transportation.

The hill fort of Nössing/Nössingbühel, included in the municipality of Varna, is located 660 m a.s.l. on the left bank of Isarco River, north of Bressanone/Brixen, in South Tyrol. It was discovered in 1912 and excavated in the late 1960s (Polacco et al. 1967, 1969; Favaretto 1974) by the

University of Padua. The site, including its stratigraphic evidence and material culture, is under reexamination to define cultural features and chronological development of the Early Bronze Age in the high Adige basin. The archaeological findings and the numerous radiocarbon dates show that the site was permanently settled during the whole Early Bronze Age until up to the beginning of the Medium Bronze Age.

Archaeological materials suggest contacts with the Polada culture, mainly spread over north-eastern Italy and the Garda Lake area, and with the Straubing culture of southern Bavaria probably through the territories and related local communities of Inn valley.

Three axe blades from this site have been analysed (CN1895-CN1897). All of them were discovered during the archaeological excavations of the University of Padua. Axe CN1895 comes from Trench I, layer A2, while axes CN1896 and CN1897 come from Trench I, layers D and B, respectively. Radiocarbon dating of layer B of Trench II has given an age range of 1737–1541 cal. BC 2σ (MAMS 23502, 3360 ± 22 BP), corresponding to the whole Early Bronze Age II and the early Middle Bronze Age, according to the chronology of de Marinis (1999). However, the associated archaeological artefacts suggest a chronology within the Early Bronze Age. Several radiocarbon dates available for layer D (ETH 22215, 3575 ± 60 BP, 2040–1744 BC 2σ; MAMS 23504, 3624 ± 22 BP, 2111–1915 BC 2 σ; MAMS 23501, 3545 ± 21, 1949–1776 BC 2σ) indicate that it should be referred to the Early Bronze Age IA and IB, as it is suggested by archaeological findings too. The layer A2 of Trench I can be dated to a late phase of the Early Bronze Age II, only on the basis of pottery typology since absolute dates are not available.

Materials and methods

Typology

Among the Neolithic materials from Castelrotto/Grondlboden (Fig. 2), two relatively small axe blades (KGB491 and KGB493) share similar morphological features. In frontal view, they show a sub-trapezoidal shape with a curve or straight cutting edge and concave lateral sides with a sub-rectangular cross-section. The surfaces are well-polished with the exception of the concave lateral sides, probably shaped to fix the blade within a shock-absorbing antler material, which was in turn modelled for insertion into a wooden handle.

Despite the very similar rock type (see the chapters below), artefacts KGB318 and KGB492 show different morphologies. The first blade shows a massive triangular body with an oval cross-section with clear hammering traces on the sides and on the proximal parts of the frontal surfaces, while artefact KGB492 is characterised by a rectangular shape with an irregular flat oval cross-section. The heel is missing and the cutting edge is partially broken.

Axe KGB490 is a well-polished rectangular artefact, lacking the cutting edge, with a sub-rectangular cross-section and a rectangular heel with blunted angles.

As far as the small Early Bronze Age assemblage from Nössing hill fort is concerned (Fig. 2), we notice that axe blade CN1895 has, in frontal view, a trapezoidal shape with straight sides and heel, a slightly curved cutting edge and a sub-rectangular cross-section. Its surfaces are well-polished with the exception of the lateral sides where hammering traces are visible. Axe blade CN1896 is a not well-refined artefact showing an irregular sub-triangular body where flaking traces are evident with the exception of the well-polished cutting edge. The last artefact, CN1897, is a distal fragment of a massive axe or chisel blade with a short straight cutting edge and an oval cross-section. The surviving original surfaces are quite well-polished.

Finally, small fractures and notches are visible along the cutting edges of the artefacts from both sites, suggesting they were used in practical activities.

X-ray diffraction

Small powdered samples taken from six axe blades (generally less than 0.5 g) have been analysed by XRD at the Department of Mathematics and Geosciences of the University of Trieste using a STOE D 500 X-ray diffractometer at room temperature (Table 1). CuKα radiation was used through a flat graphite crystal monochromator. The current and voltage were set at 20 mA and 40 kV, respectively. The 2θ scanning angle ranged from 2° to 60°, with 0.01° steps and a counting time of 2 s/step.

Raman spectroscopy

Reliable Raman spectra have been obtained only for samples CN1896 and KGB491. The Raman spectra were collected by a Renishaw InVia Spectrometer (objective ×50 with 0.75 NA, 1200 lines/mm grating, 576-pixel CCD detector). The excitation was a near-infrared diode laser at 785 nm excitation, delivering 16 mW at the sample surface, focused on a spot of approximately 10 μm^2.

Portable X-ray fluorescence

Serpentinite artefacts CN1896, CN1897 and KGB491 (Table 1) have been analysed by means of a portable X-ray fluorescence spectrometer (PXRF), built at the Multidisciplinary Laboratory (MLAB) of the "Abdus Salam" International Centre of Theoretical Physics (ICTP) (Tuniz et al. 2013). The system is based on light, compact and relatively low-cost components, including a set of low-

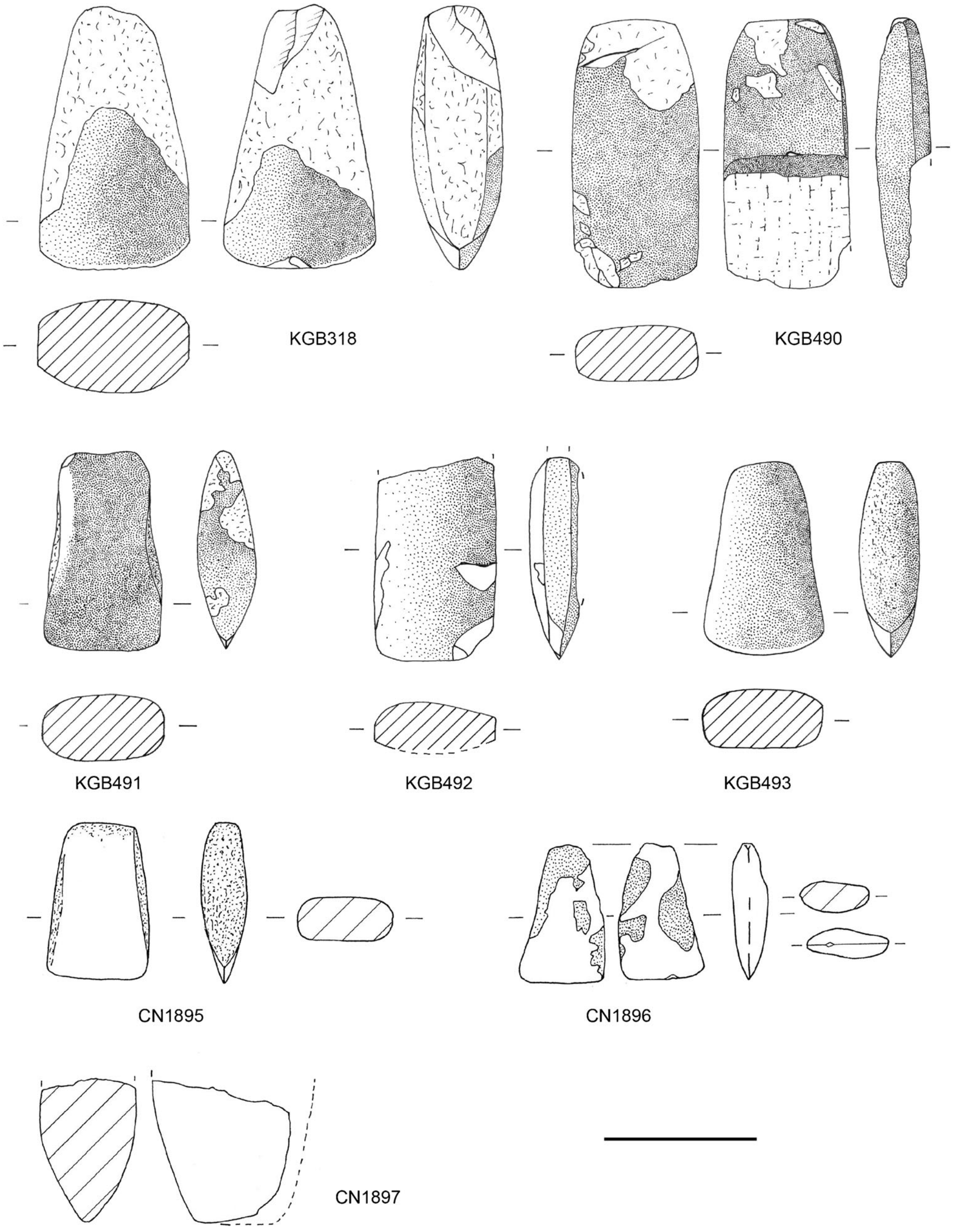


Fig. 2 Drawings of the studied polished stone axes. Scale bar, 5 cm; drawings: Umberto Tecchiati

Table 1 List of the studied polished stone axes. XRD X-ray diffraction, PGAA prompt gamma activation analysis, RAMAN Raman spectroscopy, PXRF portable X-ray fluorescence

Number	Site	Typology	Analytical methods
KGB318	Castelrotto/Grondlboden	Axe blade	XRD; PGAA
KGB490	Castelrotto/Grondlboden	Axe blade	XRD
KGB491	Castelrotto/Grondlboden	Axe blade	RAMAN; PXRF
KGB492	Castelrotto/Grondlboden	Axe blade	XRD; PGAA
KGB493	Castelrotto/Grondlboden	Axe blade	XRD
CN1895	Varna/Nössingbühel	Axe blade	XRD; PGAA
CN1896	Varna/Nössingbühel	Axe blade	RAMAN; PXRF
CN1897	Varna/Nössingbühel	Axe blade	XRD; PXRF

power X-ray tubes, energy dispersive detectors and a high-contrast hybrid detector (working in the single photon counting mode).

Flat surfaces of the axes have been carefully selected to perform the analysis in order to avoid surface irregularity effects (Potts et al. 1997) and four analyses have been performed for each sample. The samples have been irradiated with a collimated X-ray beam (30 kV and 0.010 mA) produced by an Amptek Mini X-ray tube (target material, Ag; voltage, 10–40 kV; max current, 200 μA; focal spot size, 2 mm; analysed spot size diameter, about 10 mm; cone angle, 120°). The resulting scattered beam has been measured using an Amptek Super X-123SDD silicon drift detector (SDD) and the corresponding spectra have been acquired by means of a multichannel analyzer (MCA). Concentrations of some major and trace elements have been obtained using "simple quantitative analysis-elemental sensitivity" approach in QXAS-AXIL quantitative X-ray analysis package (software developed by the IAEA). The system has been calibrated using several geological standards certified by the US Geological Survey (W-2a, BCR-2, AGV-2, SCo-1, GSP-2, DNC-1a, BHVO-2; Tables 2 and 3). The accuracy is generally between 5 and 10% for major elements and between 10 and 20% for trace ones (Table 2).

Prompt gamma activation analysis

The analysis of major and a few trace elements of magmatic samples (CN1895, KGB318, KGB492) has been carried out at the prompt gamma activation analysis (PGAA) facility of the Budapest Neutron Centre (Table 1), operating at the $9.6 \cdot 10^7$ cm^{-2} s^{-1} intensity horizontal cold neutron beam (for the recent developments of the Budapest PGAA system, see Szentmiklósi et al. 2010). This technique is a non-destructive method for quantitative determination of all major and some trace

Table 2 Some major (wt%) and trace (ppm) elements of the serpentinite-polished stone axes obtained by PXRF

Sample	CN1896–1	CN1896–2	CN1896–3	CN1896–4	Average	Std. Dev.
TiO_2 (wt%)	0.05	0.06	0.10	0.34	0.14	0.14
Fe_2O_3	7.50	8.57	6.33	12.34	8.69	2.60
MnO	0.09	0.11	0.10	0.13	0.11	0.02
CaO	1.23	1.91	1.86	5.34	2.58	1.86
Cr_2O_3	0.07	0.11	0.10	0.23	0.13	0.07
Ni (ppm)	336.39	383.39	353.12	571.68	411.14	108.78
V	26.81	49.23	37.38	78.07	47.87	22.12
Cu	27.85	26.93	37.52	47.37	34.92	9.58
Zn	147.69	157.66	143.49	212.27	165.28	31.89
Sample	CN1897–1	CN1897–2	CN1897–3	CN1897–4	Average	Std. Dev.
TiO_2 (wt%)	1.44	0.25	0.38	0.28	0.59	0.57
Fe_2O_3	13.76	7.14	10.80	10.45	10.54	2.71
MnO	0.18	0.15	0.17	0.18	0.17	0.01
CaO	5.34	0.88	5.38	7.69	4.82	2.85
Cr_2O_3	0.16	0.04	0.18	0.17	0.14	0.07
Ni (ppm)	617.92	515.12	612.97	878.80	656.20	155.77
V	229.71	130.99	51.72	40.48	113.23	87.48
Cu	54.36	30.91	62.04	206.79	88.52	79.95
Zn	260.86	120.81	230.63	274.73	221.76	69.77
Sample	KGB491–2	KGB491–3	KGB491–4	KGB491–5	Average	Std. Dev.
TiO_2 (wt%)	0.06	0.07	0.09	0.12	0.09	0.03
Fe_2O_3	7.17	7.20	8.10	8.32	7.70	0.60
MnO	0.10	0.10	0.11	0.11	0.10	0.01
CaO	0.43	0.38	3.54	2.76	1.78	1.62
Cr_2O_3	0.05	0.06	0.09	0.11	0.08	0.03
Ni (ppm)	410.16	407.97	492.35	404.02	428.63	42.56
V	29.20	48.23	44.19	52.70	43.58	10.20
Cu	27.62	21.20	51.02	37.85	34.42	13.02
Zn	112.86	110.27	147.59	133.29	126.00	17.70

Table 3 Major (wt%) and some trace (ppm) elements of the magmatic polished stone axes analysed by PGAA. FeO_t total Fe content

	CN1895	KGB318	KGB492
SiO_2 (wt%)	51.7	55.6	55.1
TiO_2	2.06	1.16	1.20
Al_2O_3	16.8	17.9	17.6
FeOt	9.9	8.0	9.0
MnO	0.22	0.13	0.20
MgO	5.87	4.97	5.28
CaO	8.74	7.54	7.05
Na_2O	3.60	2.23	2.43
K_2O	0.96	2.33	2.02
B (ppm)	11.97	24.49	8.23
Cl	136.7	138.1	194.8
Sc	34	29	29
V	267	160	169
Cd	0.25	0.11	0.00
Nd	46.3	46.1	30.1
Sm	5.45	4.71	5.78
Gd	6.89	4.78	5.02

elements in samples of various physical and chemical forms. Since neutrons can penetrate deep into the sample material, PGAA provides an average bulk composition for an irradiated volume of a few cm^3. This non-destructive analytical technique is based on the detection of characteristic gamma photons, emitted after (n, γ) reactions (Révay and Belgya 2004). The prompt-gamma spectra were collected by a Compton-suppressed HPGe detector, which has been accurately calibrated. The acquisition times have been set between 1900 s and 5400 s, in order to achieve the statistically sufficient counts in the characteristic spectrum peaks for the elements determined. The gamma-ray spectra were evaluated using the Hypermet-PC program (Révay et al. 2005). The quantitative analysis is based on the k_0 principle (for a detailed description see Révay 2009; Kasztovszky et al. 2008), using the spectroscopic data libraries developed at the Budapest laboratory (Choi et al. 2007). The composition was determined using the methods described by Révay (2009). Self-absorption of prompt-gamma photons due to the 20–30 cm thickness of the samples, as well as background from the blank measurement have been taken into account. The accuracy of the results is lower than 3 and 10% for major and trace elements, respectively (Révay 2009). PGAA has been applied successfully in the characterisation of various archaeological stone objects (e.g. Kasztovszky et al. 2008; Szakmány et al. 2011; Bernardini et al. 2014a, 2014b, 2017).

Results

Macroscopic description

All the samples have been observed using a stereomicroscope at the Department of Mathematics and Geosciences of Trieste University.

Samples CN1896, CN1897 and KGB491 are manufactured from serpentinitic metamorphosed greenish ultramafic rocks (Fig. 3). In these samples, pyroxene relics are quite abundant, occurring as whitish or brownish patches up to about 1 cm large, often interpenetrated with serpentine. Magnetite is present in small grains showing an irregular shape.

Sample KGB493 is produced with a probable metamorphic mafic rock characterised by a brownish colour, presence of chlorite, relics of probably pyroxene and opaques (Fig. 3).

Two types of igneous products with effusive/sub-effusive texture have been recognised. More precisely, sample CN1895 is a black basaltic rock with a microphyric to aphyric texture. The only recognisable mineralogical phase is feldspar, probably plagioclase, which is present in the form of small partially altered and slightly zoned crystals (< 1 mm) set inside a glassy groundmass (Fig. 3). Samples KGB318 and KGB492 appear as igneous rocks of basic-intermediate composition showing a light brown colour which is probably related to weathering processes since the rock looks greenish where the powder for XRD analysis has been taken. Both of them show a porphyric texture with plagioclase phenocrysts and microphenocrysts ranging from 0.01 to 1.0 cm, which look quite altered and zoned. Femic phenocrysts (probably amphibole), as well as rare opaques, are also visible (Fig. 3).

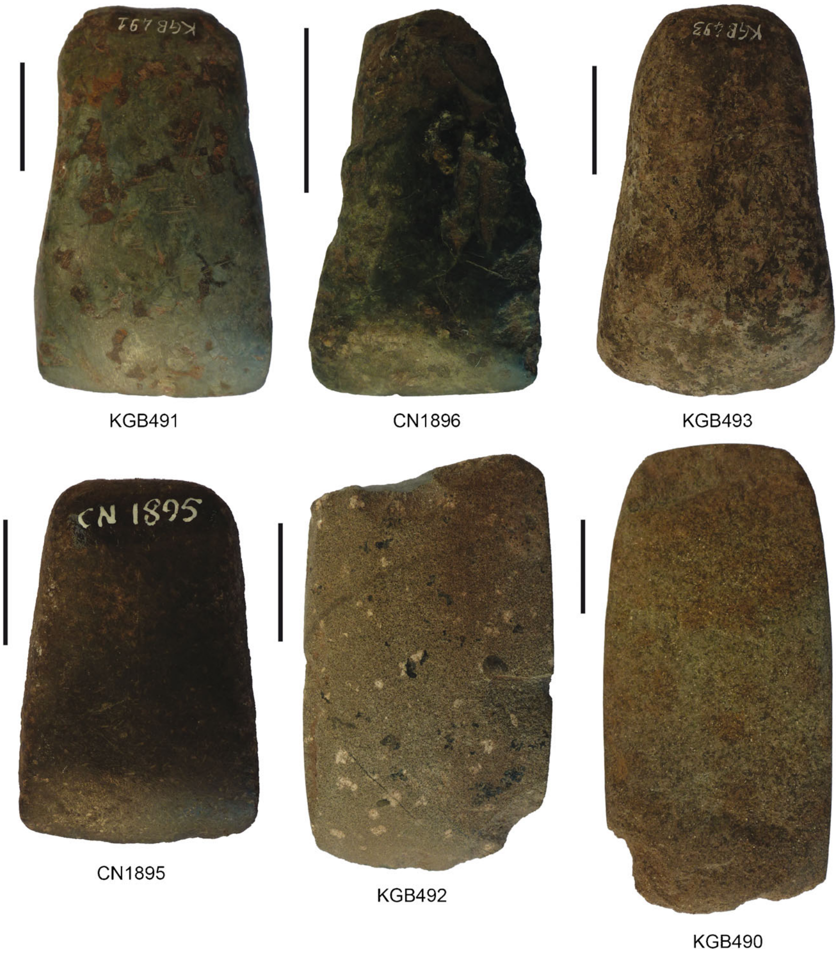
Sample KGB490 is an arenite with a greenish colour.

X-ray diffraction

XRD analysis (Fig. 4) indicates that sample CN1897 contains mainly antigoritic serpentine (> 80%) with a minor fraction of pyroxene (< 20%) in agreement with the macroscopic observations. Samples KGB318 and KGB492 are similar and contain prevalently quartz, some feldspar, amphibole and chlorite. Sample KGB490 only shows the presence of quartz and minor feldspar. Samples KGB493 and CN1895 show the same paragenesis including feldspars, amphibole and chlorite, but, in KGB493, the presence of pyroxene can also be seen.

Raman spectroscopy

Our Raman spectra for samples CN1896 and KGB491 are very similar, presenting modes at about 230, 375, 460, 525, 630, 681 and 1041 cm^{-1} (Fig. 5). Literature data show how the modes are similar in the three polymorphs but are shifted to lower wavenumbers in the antigorite variety with respect to


KGB491 CN1896 KGB493

CN1895 KGB492 KGB490

Fig. 3 Photographs of selected polished stone axes showing the different rock types. Scale bars, 2 cm

lizardite and chrysotile (230–234, 385–389 and 690–692 cm^{-1}) (Rinaudo et al. 2003; Petriglieri et al. 2015; Zhao et al. 2016; Bloise et al. 2016 among others). Moreover, the presence of a peak at about 1044 cm^{-1} has allowed the discrimination of antigorite from the other polymorphs (Petriglieri et al. 2015). Consequently, our two spectra are representative of antigorite.

Portable X-ray fluorescence

Major elements of serpentinite axes CN1896, CN1897 and KGB491, obtained by portable X-ray fluorescence (Table 2), show CaO/TiO_2 ratios and Fe_2O_3/MnO indistinguishable from those obtained for the serpentinite-polished stone axes found in north-eastern Italy, Slovenia and north-western Croatia (8–20 vs. 4–28 and 62–79 vs. 60–82, respectively; Bernardini et al. 2011a, 2011b).

Prompt gamma activation analysis

In the TAS (total alkali silica; Le Maitre et al. 1989) classification diagram, two of the investigated magmatic samples (KGB318 and KGB492) correspond to basaltic andesite, while sample CN1895 to basalt (Table 3 and Fig. 6).

Discussion and conclusions

Three of the investigated axes (CN1896, CN1897, KGB491) are made from antigoritic serpentinite**,** which often shows relics of clinopyroxene. Such mineralogical features make these artefacts very similar to the numerous serpentinite polished stone axes discovered in Friuli Venezia Giulia (north-eastern Italy), Slovenia and the Croatian part of Istria peninsula, an area often defined as *Caput Adriae* in archaeological literature. These artefacts come from archaeological sites dated to a large time span, from the Neolithic to the Bronze Age (Bernardini et al. 2011a, 2011b).

An accurate mineralogical, petrographic and geochemical comparison between serpentinite axes from *Caput Adriae* and the main natural outcrops of such lithologies in the Eastern Alps has allowed to identify the most probable primary source in the Hohe Tauern area (central Austria). In the case of the serpentinite axes from *Caput Adriae*, their morphology, often recalling that of fluvial pebbles, and the known manufacturing

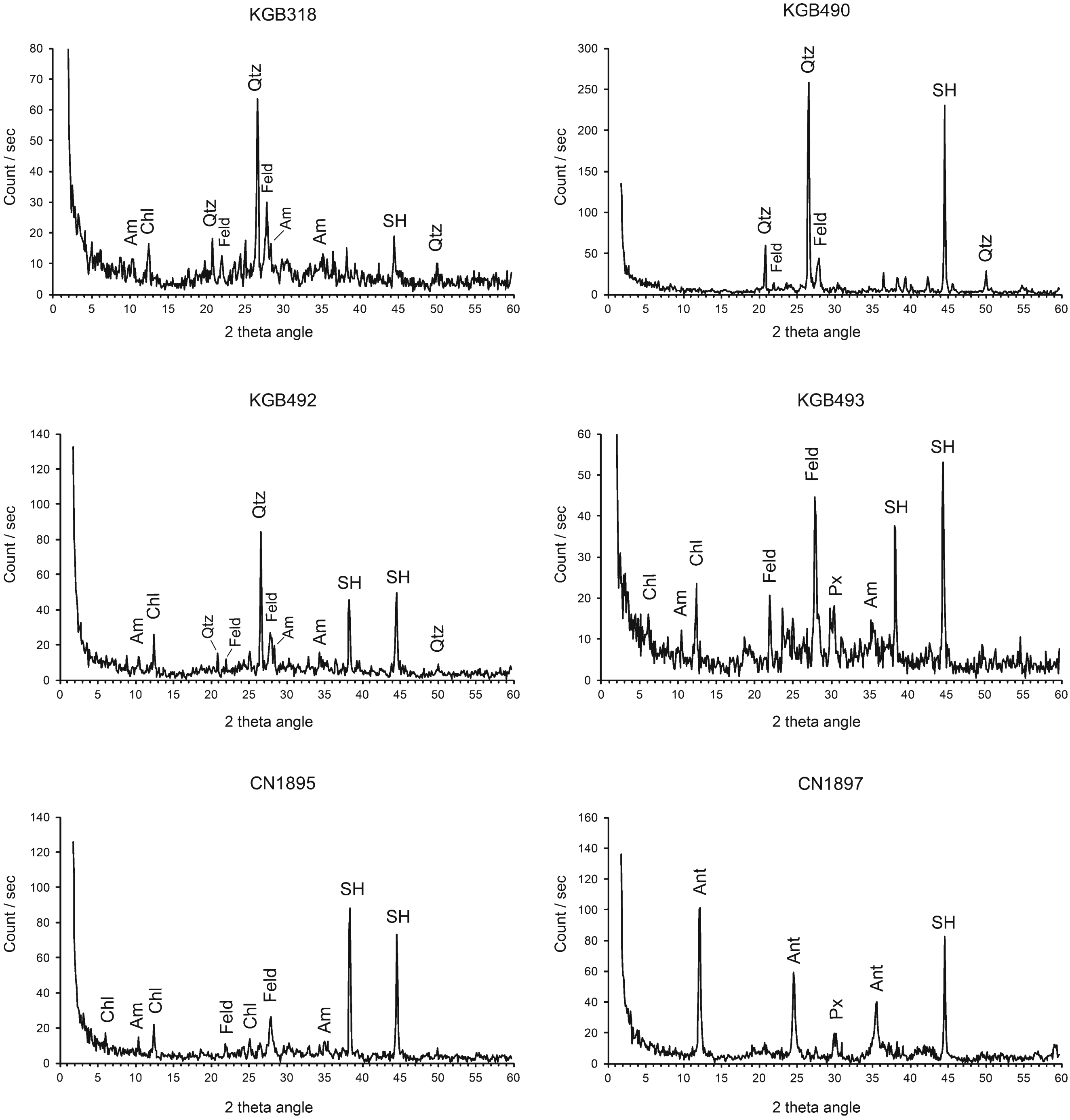


Fig. 4 XRD spectra of the analysed axes. Am amphibole, Ant antigorite, Chl chlorite, Feld feldspar, Px pyroxene, Qtz quartz, SH sample holder

places, suggested a large exploitation of the secondary deposits of the Drava River (Bernardini et al. 2011a, 2011b).

Considering the mineralogical and petrographic similarities between the serpentinite axes from Varna/Nössingbühel and Castelrotto/Grondlboden and those from the *Caput Adriae* and the proximity of both sites to the western part of Hohe Tauern region, it is likely that the studied axes originate from the Hohe Tauern region or from the secondary raw material deposits close to the archaeological sites (Fig. 8). In the case of the artefacts from Nössing, connections with the Austrian territory are already revealed by the typology of other archaeological artefacts.

Three axes (CN1895, KGB 318 and KGB492) are made from magmatic rocks. More specifically, sample CN1895 is a basalt composed of plagioclase and amphibole and minor chlorite as secondary phase (Figs. 4 and 6). The macroscopic aspect, the mineralogical composition, the major and the few trace elements of this basaltic sample obtained by PGAA

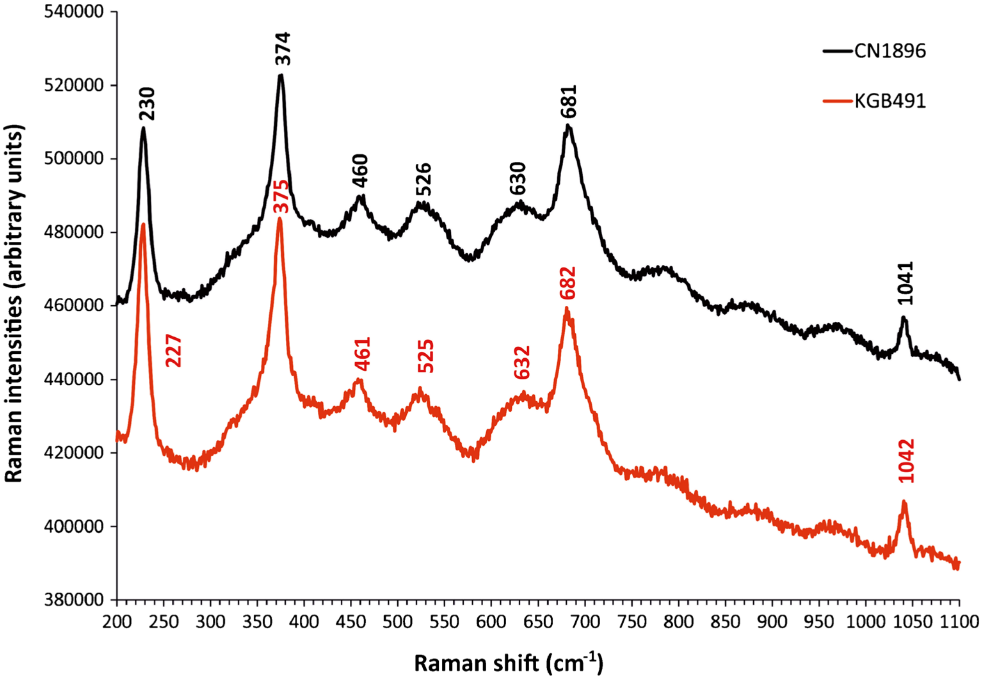


Fig. 5 Raman spectra of the analysed axes

indicate a general affinity with rare Oligocene basaltic andesite dykes outcropping in the western South Tyrol (Figs. 7a and 8; Del Moro et al. 1981; Rizzi 1996–1997, sample 16, coordinates 46° 41′ 9″ N, 10° 21′ 58″ E) not far from Varna/Nössingbühel, despite the analysed axe shows a little lower silica content. Unfortunately, Oligocene dykes of western South Tyrol have not been yet studied in detail and a few geochemical data are still unpublished (Rizzi 1996–1997). For comparison, here we report in Table 4 some selected analysis of basaltic andesite and andesite dykes outcropping in the above-mentioned area.

Samples KGB318 and KGB492 are produced from undistinguishable porphyric rocks, containing prevalent quartz, minor feldspar with some amphibole and chlorite, with a chemical basaltic-andesite affinity (Figs. 4 and 6). The XRD results show a quite high amount of quartz, which contrasts with the macroscopic and the chemical features of the axes. No quartz has been, indeed,

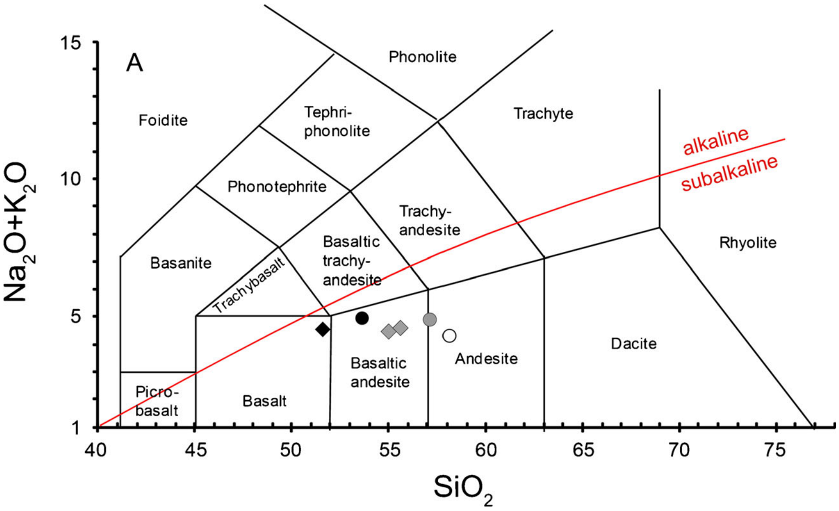
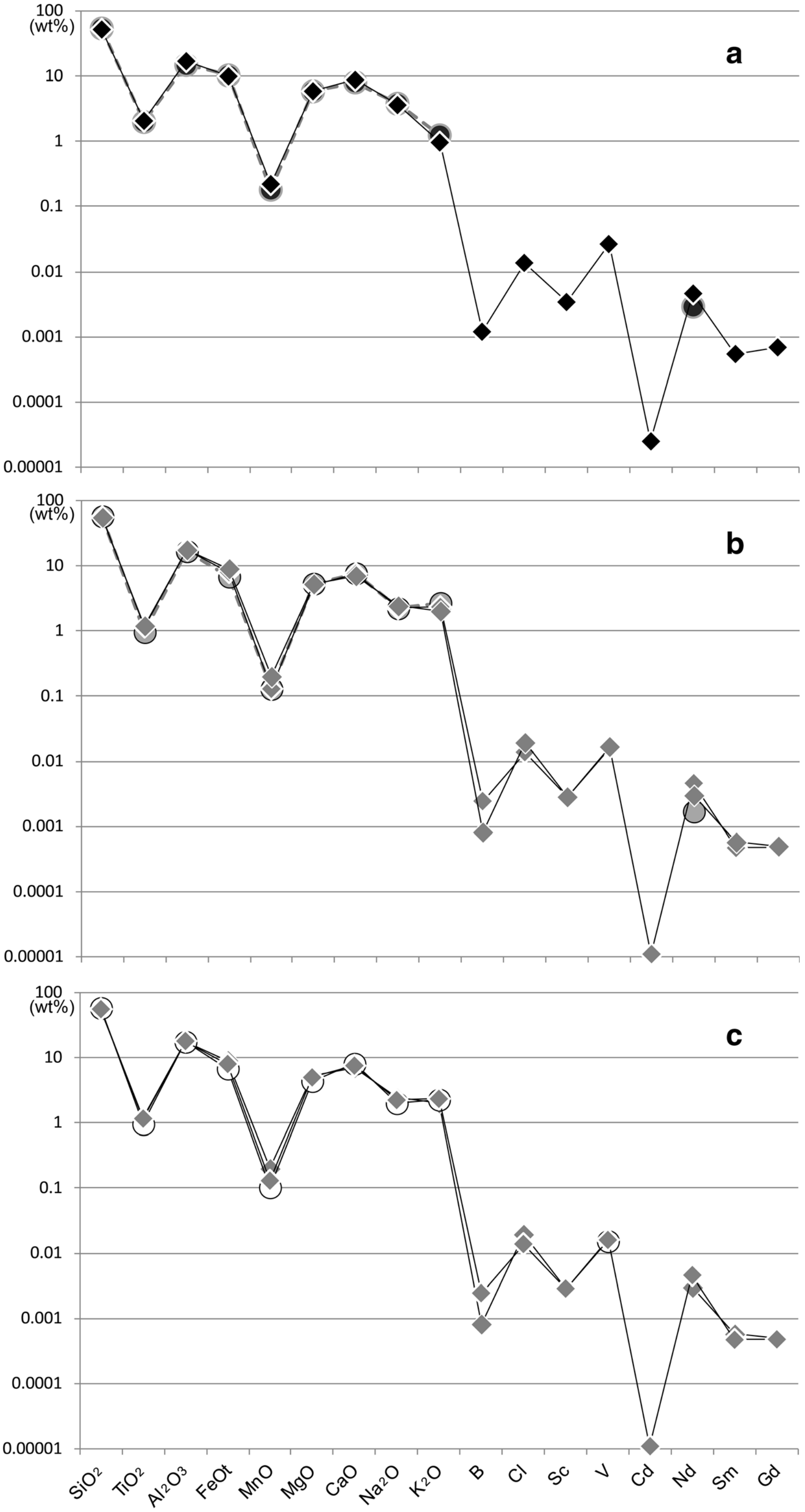


Fig. 6 Total alkali–silica (TAS) classification of the stone axes analysed by PGAA (diamonds) and three selected samples of similar rocks from western South Tyrol (black and grey circles, Rizzi 1996–1997) and Funes/Villnöss basin close to Bressanone/Brixen (white circle, Benciolini et al. 2001). The red line defines the fields proposed by Miyashiro (1974). Black diamond, axe CN1895 from Varna/Nössingbühel; Grey diamonds, axes KGB318 and KGB492 from Castelrotto/Grondlboden; black circle, basaltic andesite from western South Tyrol (sample 16 from Rizzi 1996–1997); grey circle, high-K andesite from western Alto Adige (sample 114 from Rizzi 1996–1997); white circle, andesitic lava from Funes/Villnöss basin (sample TPZ53 from Benciolini et al. 2001)



observed via stereomicroscope and the silica content indicates an intermediate composition ($SiO_2 = 55$ wt%). A possible explanation could be related to weathering, which could have transformed the glassy groundmass, visible at the stereomicroscope, into microcrystalline quartz.

Similar mineralogical paragenesis, textural and chemical features are again reported for the Oligocene dykes

◀ **Fig. 7** **a** Spider diagram of the major and trace elements of sample CN1895 (black diamond) in comparison with the composition of a basaltic rock from western South Tyrol (black circles; Rizzi 1996–1997, sample 16). **b** Spider diagrams of the major and trace elements of samples KGB318 and KGB492 (grey diamonds) in comparison with a high-K andesite from western South Tyrol (grey circles; Rizzi 1996–1997, sample 114). **c** Spider diagrams of the major and trace elements of samples KGB318 and KGB492 (grey diamonds) in comparison with an andesitic lava from Funes/Villnöss basin (white circles; Benciolini et al. 2001, sample TPZ53)

outcropping in western South Tyrol and in particular for high-K andesites (Figs. 7b and 8, Table 4; Rizzi 1996–1997, sample 114, coordinates 46° 46′ 3″ N, 10° 1′ 37″ E).

Chemical features of KGB318 and KGB492 are also comparable to the composition of Permian rocks of the Athesian Volcanic District and in particular to that of andesitic lavas outcropping in the Funes/Villnöss basin (Figs. 7c and 8; Benciolini et al. 2001), very close to the Nössing hill fort. However, mineralogical and textural features of Funes/Villnöss andesitic lavas are not reported in detail (Benciolini et al. 2001), thus limiting the comparison to chemical composition.

The raw material of axe KGB490 contains prevalent quartz and a minor fraction of feldspar. The colour and the presence of rare small feldspar crystals suggest a strong similitude with Ladinian analogues of the Livinallongo formation ("Pietra Verde del Cadore"), which outcrops in several zones of the Dolomitic area (Leonardi 1967), east of Adige valley up to the Cadore valley.

Also, for sample KGB493, the only available results are those of XRD analysis, showing the presence of feldspar, chlorite, pyroxene and amphibole, thus limiting the possibility to precisely define its provenance. The raw material is probably a variably metamorphosed gabbroic rock similar to lithotypes outcropping in the Aurine Alps and in the Sole and Martello valleys.

In conclusion, the study of the polished stone axes from Varna/Nössingbühel and Castelrotto/Grondlboden suggests an exploitation strategy of raw materials based on local or close

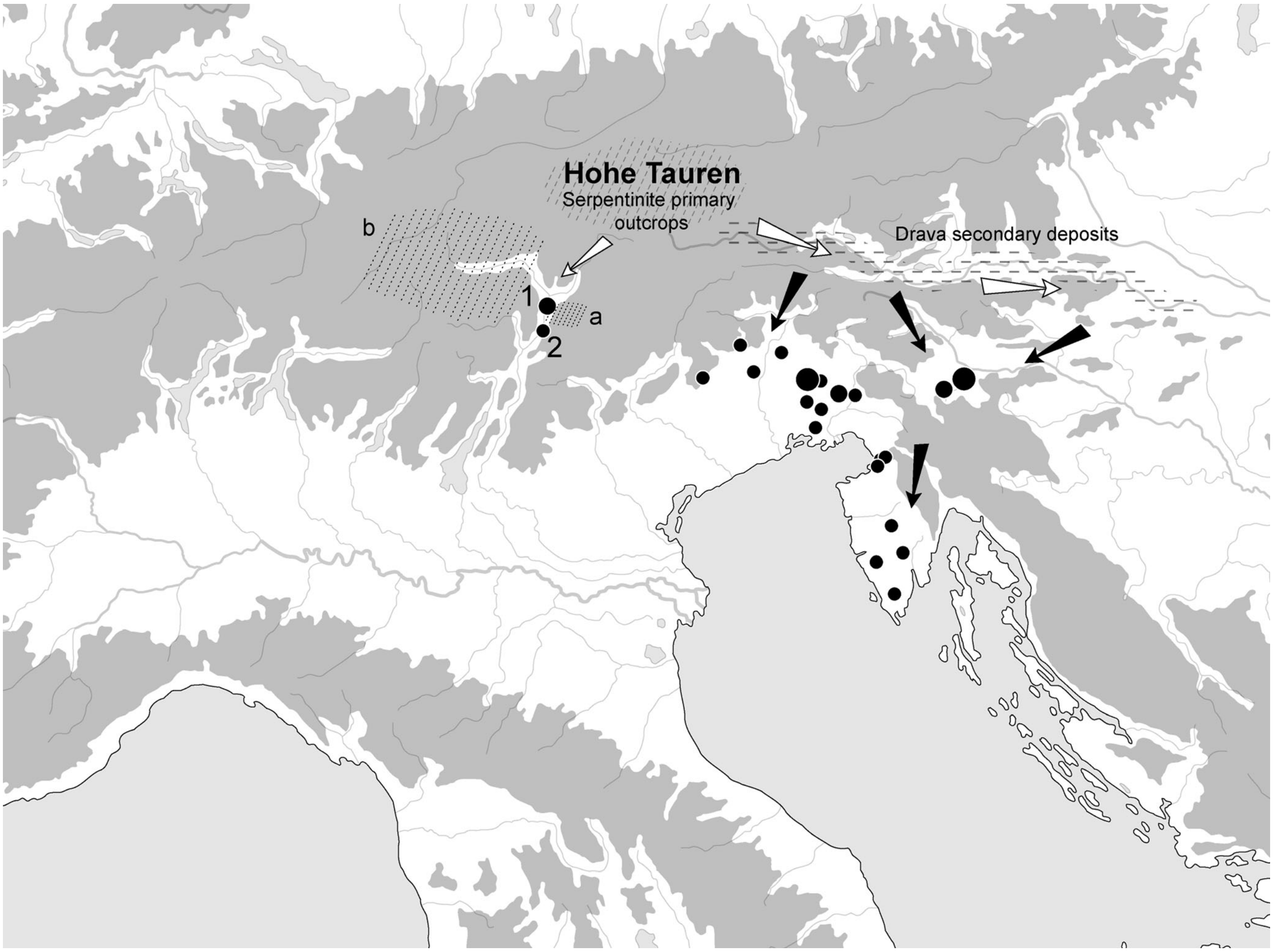


Fig. 8 Distribution of antigoritic serpentinite polished stone axes in north-eastern Italy, Slovenia and Croatia with the indication of the most probable raw material source. For a list of the samples, see Bernardini et al. 2011a. Numbers 1 and 2 indicate Varna/Nössingbühel and Castelrotto/Grondlboden sites, respectively; letters a and b indicate the approximate outcropping areas (parallel dashed lines) of andesitic lavas of the Funes/Villnöss basin (Benciolini et al. 2001) and of Oligocene dykes studied by Rizzi (1996–1997), respectively

Table 4 Selected XRF analysis of basaltic andesite (16, 98) and andesite (114) samples from western South Tyrol (Rizzi 1996–1997). FeO$_t$ total Fe content

	16	98	114
SiO_2 (wt%)	53.72	54.37	57.19
TiO_2	1.98	0.99	0.96
Al_2O_3	14.73	16.05	16.79
FeOt	10.25	9.07	6.83
MnO	0.18	0.20	0.13
MgO	5.83	4.97	5.32
CaO	8.01	8.75	7.69
Na_2O	3.78	2.76	2.23
K_2O	1.24	2.37	2.69
P_2O_5	0.29	0.48	0.17
Cr (ppm)	148	55	39
Ni	11	16	19
Ba	110	586	132
Rb	45	113	231
Sr	306	755	347
La	14	32	16
Ce	38	74	35
Nd	29	38	17
Zr	238	99	181
Y	35	28	31
Nb	10	15	7

rock types. Most of the artefacts are made from antigoritic serpentinite, whose origin is likely from Hohe Tauern (Austria) or related secondary deposits. These data confirm the importance of such raw material for the production of polished stone axes during recent prehistory and integrate our knowledge on the distribution of serpentinite artefacts in northern Italy and neighbouring countries (Bernardini et al. 2011a, 2011b; Fig. 8). Antigoritic serpentinite is the only rock type present in both the late Neolithic and Early Bronze Age polished stone axes assemblages here considered.

Interestingly enough, no high-pressure metaophiolites, such as jades and eclogites, from north-western Italy have been identified. It is well-known that such rock types are the most common high-quality raw materials largely used by the Neolithic communities in northern Italy and beyond. After the Neolithic period, the long-distance exchange of jade and eclogite axes decreases while local lithic raw materials are increasingly exploited for the production of stone artefacts (e.g. D'Amico and Starnini 2006; Pétrequin et al. 2012).

The local or close provenance of the raw materials, the medium/low level of manufacturing quality and the probable use-wear traces along the cutting edges suggest that the artefacts were practical tools, probably used in wood working activities.

Despite polished stone axes are particularly common during the Neolithic period, the presence of such tools in the Bronze Age contexts is not so rare. For example, artefacts similar to those from Nössing have been reported from several contemporaneous sites located in western Veneto (Salzani 1996) or from Ledro pile-dwellings (Rageth 1974).

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