The Neolithic greenstone industry of Brignano Frascata (Italy): Archaeological and archaeometric study, implications and comparison with coeval sites in the Grue, Ossona and Curone valleys

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The Neolithic *greenstone* industry of Brignano Frascata (Italy): archaeological and archaeometric study, implications and comparison with coeval sites in the Grue, Ossona and Curone valleys

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Abstract

The Neolithic *greenstone* industry of Brignano Frascata (Province of Alessandria, Piemonte Region, Northern Italy) was investigated with an archaeometric approach involving both morpho-typological and mineral-petrographic methods, in order to reconstruct the manufacturing techniques/habits and locate the supply sources of the raw materials. The outcomes were compared with those collected on similar tools from other sites of the same region, namely in the Grue, Ossona and Curone valleys, as well as others resulting from a pilot comparative study on analogous geological specimens from close Quaternary alluvial and/or Oligocene conglomeratic deposits. This survey proved that Brignano Frascata should be considered as a local *atelier* for the production/trade of polished stone implements in Neolithic, devoted to daily uses with no ritual purposes. Several indicators point to an *in situ* manufacturing (high number of retrieved roughouts/fragmented tools, broken during production/use), which also fed trade/exchange forms on short-to-medium distances. Although displaying gross processing features and lack of finishing, these tools show an excellent selection of lithologies, marked by predominance of 'Na-pyroxene rocks'. Several mineral-petrographic resemblances are observed with analogous geological samples from local sources, as well as with coeval implements from other Northern Italy sites, suggesting a common supply source or the existence of a trade channel. By considering the mineral-chemical features of the rocks used to produce these tools, referred to the particular geologic context of discovery (eastern part of the Voltri Group), the chance for the raw materials to derive from secondary deposits of close conglomeratic formations and/or alluvial beds of streams flowing in the adjoining valleys is proposed.

Key-words: Neolithic *greenstone* implement; eclogite; Na-pyroxenite; jadeitite; omphacitite; Piemonte Zone meta-ophiolites and calc-schists; Western Alps.

1. Introduction

Polished stone implements dating from the Neolithic to the Copper Age (mostly axes, chisels and hatchets) were found in archaeological sites spread all over the Western Europe – especially in the Po plain, Northwestern Italy (Ricq-de-Bouard, 1993; D'Amico & Starnini, 2011). Most of these tools were obtained by the manufacturing of *alpine greenstones* – rocks with peculiar colour and provenance, at times commonly referred to as '*Jades*', characterized by a wide variety of microstructure, grain-size, deformation and retrogression alterations (D'Amico et al. 2004, D'Amico and Starnini, 2006a, 2012b; Giustetto et al., 2016). The term *greenstone* includes precious and valuable lithologies; consistently with the classification proposed by Giustetto and Compagnoni (2014), these rocks can be divided into two main groups:

i) 'Na-pyroxene rocks' (the real '*Jades*'), including three lithotypes:

- a) jadeitite (consisting of jadeite up to 95-100 vol. %);
- b) omphacitite (consisting of omphacite up to 95-100 vol. %);
- c) mixed Na-pyroxenite (with intermediate modal compositions of jadeite/omphacite).

ii) 'Na-pyroxene+garnet rocks', comprising other three lithotypes:

- a) eclogite (consisting of omphacite and garnet up to 25-75 vol. %);
- b) garnet-omphacitite (mainly consisting of omphacite, with garnet between 5-25 vol. %);
- c) omphacite-garnetite (mainly consisting of garnet, with omphacite between 5-25 vol. %).

However, it is to remark that other lithologies, characterized by green colour but different mineralogy (e.g. serpentinite, amphibolite and prasinite), have also been included under the *greenstone* term. The non-petrographic term '*Jade*', traditionally used in trade and gemmology, includes two different rock types: i) '*jadeite* jade', mainly consisting of jadeite ($NaAlSi_2O_6$); and ii) '*nephrite* jade', usually consisting of an amphibole of the tremolite-ferro-actinolite series [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$]. Only the former will be considered in this study. Besides, in addition to '*jadeite* jade', another similar phase was identified in archaeological implements – namely '*omphacite* jade', mostly consisting of omphacite [$(Ca,Na)(Mg,Fe^{2+},Al)Si_2O_6$] (D'Amico et al., 2004; Ou Yang, 2006; Ou Yang et al., 2011; McClure, 2012).

The pioneering studies of Gastaldi (1871), Damour (1881) and Franchi (1900) first established that these *greenstone* lithotypes occur in the metamorphic ophiolites (meta-ophiolites) and calc-schists of the Piemonte Zone, in the Western Alps. A more precise location is troublesome, as these rocks occur either as small (few m^3) primary outcrops at high altitude (D'Amico, 2005; Pétrequin et al., 2005a, 2005b, 2006; Compagnoni et al., 2012) or boulders in secondary clastic deposits downhill, derived from erosion of the formers (Compagnoni et al., 2006; D'Amico and Starnini, 2006a; D'Amico and De Angelis, 2009). Few *greenstone* outcrops/deposits were discovered so far and the detailed petrographic studies are scarce. However, the occurrence of eclogite/omphacitite *boudins* was reported from the Pellice Valley, in the Monviso meta-ophiolite Massif (Borgogno, 2000; Giustetto et al., 2016). Primary outcrops of jadeitite, omphacitite and fine-grained eclogite were also identified in the same massif (Pétrequin et al., 2005a, 2005b, 2006c; Compagnoni et al., 2012). Recently, an attempt to set up an adequate reference collection was made by analyzing with various techniques more than 500 specimens of presumed alpine *greenstones* (mainly '*Jades*'), collected as raw materials or working debris during prolonged prospections in the Monviso area of Piemonte, and in the Beigua area of the Voltri Group in Liguria ('JADE' project; Pétrequin et al., 2012b; 2012c). The in-depth archaeometric – especially mineral-petrographic – study of these implements is of paramount importance to achieve information about their manufacturing techniques and material quality (Chiarenza and Giustetto, 2010; D'Amico et al., 1992; 1997; 2013). A precise location of the supply sources of raw materials, inferred by means of comparative studies with geological samples of known provenance, might help in reconstructing the migratory/trade routes haunted by our ancestors – an aim pursued also in other famous '*Jade*' localities (e.g., the Caribbean: Garcia-Casco et al., 2013). These *greenstone* tools underwent vast circulation all over the Western Europe – i.e., in Southern France and along a corridor running from Southern Italy to Great Britain (Pétrequin et al., 2002). Similar tools of presumed alpine origin were also found in Slovakia and Czech Republic (Spišiak and Hovorka, 2005; Pétrequin et al., 2011).

This study deals with the characterization of the polished *greenstone* industry from the site of Brignano Frascata (Italy). Over 300 stone implements were investigated with a dual archaeologic and archaeometric approach, aimed at reconstructing their manufacturing techniques and locating the raw materials supply sources. Partly presented in a preliminary report by Giustetto and Compagnoni (2004), these data are detailed here for the first time. Moreover, this work integrates the study of D'Amico et al. (2000), expanding the survey to the whole Brignano Frascata lithic lithological types and also taking into account implements from coeval sites from the nearby Curone, Grue and Ossona valleys (see square in Fig.1).

2. Materials and methods

2.1 Archaeological case study and materials

(INSERT FIGURE 1)

The Brignano Frascata site – in the Curone Valley near Alessandria, Piemonte region, located to the northeast of the Beigua massif, Voltri Group (Fig. 1) – is positioned on an orographic terrace 300 m a.s.l. on the right side of the Curone stream, with prolonged insolation and excellent water supply. The area was systematically excavated by archaeologists, uncovering several occupational phases from the ancient Neolithic (5400-4900 B.C., Venturino Gambari, 2004) to the Roman Age (1st century A.D.; Nebiacolombo, 2004). A first excavation in 1984 uncovered remains of ancient Neolithic ceramic and lithic industries, typical of the Vhò Group (Bagolini and Biagi, 1975; Tiné, 1993). Among these, 34 *greenstone* implements – including axes, hatchets, chisels, strikers recycled from worn cutting tools and disc-ring roughouts – completely or partly polished (on sharp edges), were studied by D'Amico et al. (2000). Presence of splinters, scraps or roughouts – probably due to defects/breakages – led to consider this as a possible manufacturing site for the production of cutting implements. A second, systematic superficial search led to recover more than 2000 ceramics and lithic implements, dating from the ancient Neolithic to the first phase of the '*Vasi a Bocca Quadrata*' (VBQ; *Square Mouth Jars*) culture, as certified by presence of disc-rings and chisels. 185 stone implements – mostly cutting tools and disc-rings at different stages of their manufacturing process, a sample of which is shown in Fig. 2 – were studied. Finally a third excavation, in 'S. Giorgio' hamlet, uncovered 12 *greenstone* implements (mostly for cutting) represented by fragmented roughouts (axe butts and cutting-edges) broken during manufacture or re-used as strikers. All 231 specimens – mostly in *greenstone* – including those studied by D'Amico et al. (2000), were taken into account for analysis (Table 1).

(INSERT FIGURE 2)

In addition, 79 Neolithic implements (mostly in *greenstone*) from the nearby and coeval archaeological sites of Momperone (34 tools), Casalnoceto (6 tools), Gremiasco (5 tools), Fabbrica Curone (2 tools), Pozzol Groppo (2 tools) and Volpeglino (1 tool) in the Curone Valley; Villaromagnano (23 tools) in the Ossona valley; Viguzzolo (5 tools) in the Grue valley; Sale (1 tool) in the plain between the Scrivia and Tanaro rivers (see the small blue rectangle in Fig. 1 and details in Fig. 16a), were also studied.

2.2 Methods

A dual approach – both archaeological (morpho-typological) and scientific (mineral-petrographic) – was adopted to study these implements (Chiari et al., 1996; Compagnoni et al., 2006; Giustetto et al., 2008). The latter involved a global screening with non-destructive methods (i.e., stereo-microscopic observations and density measurements) for a preliminary lithotype screening. Further in-depth analyses were then performed on selected specimens – basing on lithotype distribution and recurring mineral-petrographic features – with X-ray powder diffraction (XRPD), optical microscopy with plane-polarized light and scanning electron microscopy with energy dispersion spectrometry (SEM-EDS). Small cores (6 mm in diameter), obtained by drilling broken tools/splinters with a diamond corona barrel, were used to prepare both 30 μm-thick polished thin sections and rock powders. XRPD data were collected in the 3-70° 2θ range using an automated Siemens D-5000 diffractometer with θ/2θ setup in Bragg-Brentano geometry, Cu-Kα radiation and zero-background sample holder. Data were processed with the Diffrac Plus (2005) software (EVA 11,00,3). A Zeiss WL Pol optical polarizing microscope was used for optical observations. Electron microscopy was performed with a SEM Stereoscan-360, Cambridge Instrument on polished, carbon-coated thin sections. Chemical analyses were collected with an EDS Link-Pentafet, Oxford instrument (operating conditions: 50 s counting time, 15 kV accelerating voltage, 25 mm working distance, 300 pA beam current). Data were processed with the INCA-200 Microanalysis Suite Software, version 4.08, calibrated on mineral standards using the ZAF correction method.

3. Results

3.1 Morpho-typological examination

The 231 finished tools and roughouts from Brignano Frascata (Table 1) can be classified, basing upon their functionality and traces of manufacture/use, as implements for cutting (138 axes, hatchels and chisels; 60 %), striking (21 percussors; 9 %), abrading (9 grindstones and millstones; 4 %) and ornamental tools (6 disc-rings; 3 %). The rest (24 %) is represented by (57) splinters. Implements for cutting are mostly axeheads roughouts or fragments; small chisels with distinctive short and linear cutting-edge also appear. Their raw processing state and/or fragmentary conditions (especially axes and hatchels) allow only preliminary typological considerations, due to difficulties in checking their dimensions (length, width and thickness) upon which the existing classifications are based (Pedrotti, 1996). Few complete and finished implements were found, mainly small axes completely polished, whose shape was obtained by splintering and bush-hammering (a further stage, in which another tool is used to texturize the stone). The original stone surface is still visible on several implements. Seldom, a limited smoothing of the cutting-edge is observed. Several axe butts and cutting-edge fragments, related also to medium-to-large specimens, were recovered with chisel roughouts and other pieces, thus testifying the frequent breakings occurred during manufacture or use. Axe butts are mostly triangular, edged or rounded, with linear or slightly convex borders; cutting edges, when preserved, are curved. Several disc-ring roughouts were recovered in different steps of their production chain; 6 of them were studied, allowing to understand their manufacturing phases: i) a discoidal, not-too-thick *greenstone* pebble is progressively splintered refining its shape; ii) a central, bilateral hole is dug by fine-hammering with tough and sharp strikers, while adjusting the circular shape by exploiting the rock schistosity; iii) the surface is then polished by gentle abrading (Venturino Gambari, 2004).

The survey involved also those implements from Momperone (34 tools; Table 2) and Villaromagnano (23 tools; Table 3), due to their significant statistics. In Momperone, cutting instruments (axes edges/butts) prevail, mostly broken during manufacture/use with traces of bush-hammering. Several splinters and some disc-ring roughouts, similar to those described, were also found. Implements from Villaromagnano are mostly axes or fragments (edges/butts), broken during use for tree felling, with trapezoidal shapes and medium size/thickness (10-12 and 2 cm, respectively). Butts are flat and rounded; edges (the only polished portions) narrow and almost linear.

(INSERT TABLE 1)

(INSERT TABLE 2)

(INSERT TABLE 3)

3.2 Density measurements and stereomicroscopy examination

(INSERT FIGURE 3)

The Brignano Frascata *greenstone* specimens (density determined for 206 out of 231 total tools; Table 1) can be divided (Fig. 3a) in lower density (≈ 2.6-2.7; serpentinites) and higher density rocks (≈ 3.2-3.5, including ‘Na-pyroxene rocks’ and ‘Na-pyroxene+garnet rocks’). A certain degree of overlapping within the latter group prevents a sharper lithotype discrimination. A third group with intermediate density is also identified (≈ 2.9-3.0), consisting of prasinite. Stereomicroscopy in reflected light, performed on the polished surfaces of the implements, allowed for each specimen to evaluate the mineral grain-size range, heterogeneities and microstructural features (e.g., presence of veins). By combining the density values with these observations, a preliminary lithotype determination was achieved (Fig. 3b). ‘Na-pyroxene rocks’ (jadeitite + omphacitite + mixed Na-pyroxenite) are the most significant fraction (42 %), followed by ‘Na-pyroxene+garnet rocks’ – especially eclogite (37 %). Serpentinites and prasinites are scarcer (7 and 4 %, respectively); non-*greenstone* lithotypes are the residual 10 %. The same approach was used on those implements from Momperone (density determined for 32 out of 34 total tools; Table 2) and Villaromagnano (density determined for 22 out of 23 total tools; Table 3), statistically significant. The related distribution (Fig. 3c and 3d, respectively) shows that in the latter site serpentinites become preponderant. No further study was performed on serpentinites, due to their monotonous mineralogical composition, being mostly composed of antigorite, occurring all over the internal Piemonte zone (Giustetto et al., 2008). Similar conclusions may be drawn for prasinite. Further analyses were instead performed on representative ‘Na-pyroxene rocks’ and ‘Na-pyroxene+garnet rocks’. Contrarily to serpentinites, in fact, which are very common rocks all over the region, jadeite and/or omphacite-rich rocks are quite rare in the field and thus represent an ideal geologic material for provenance studies. Archaeological and archaeometric data for these tools, photographed in Figs. 4 through 7, are reported in Tables 4 through 6.

(INSERT TABLE 4)

(INSERT TABLE 5)

(INSERT TABLE 6)

(INSERT FIGURE 4)

(INSERT FIGURE 5)

(INSERT FIGURE 6)

(INSERT FIGURE 7)

3.3. X-ray powder diffraction

XRPD analyses were performed on 24 implements mainly in *greenstone* from Brignano Frascata, allowing a detailed study of their mineralogical composition. In addition, 16 tools from other sites (Momperone, Villaromagnano, Casalnoceto, Gremiasco, Fabbrica Curone and Pozzol Groppo) were also analyzed (Tables 4-6). These rocks may contain more than one Na-pyroxene: usually both jadeite and omphacite, and seldom even aegirine-augite

(Schmidt and Stelcl, 1971; Woolley, 1983; D'Amico et al., 1995). If a single pyroxene occurs, its characteristic reflections are sharp and well defined (Fig. 8a). When two or more pyroxenes coexist in relevant amounts (such as in mixed Na-pyroxenite), their peaks are split due to slight d_{hkl} differences (Fig. 8b). The mean composition of pyroxenes could be estimated by plotting the d_{hkl} values of the most intense jadeite and omphacite reflections [(221); (310); (002)] on a grid conceived by Giustetto et al. (2008), superposed to the diagram of Morimoto et al. (1988).

(INSERT FIGURE 8)

3.4. Optical polarizing-microscopy and SEM-EDS

These techniques represent by far the most suitable approach to study these H*P* meta-ophiolites – as far as provenance studies are concerned (Giustetto and Compagnoni, 2014; Giustetto et al., 2016). The pronounced structural and compositional heterogeneity of these rocks (D'Amico, 2012; D'Amico and Starnini, 2012b), often observable even in the same sample (Compagnoni et al., 2007), prevents such a goal to be consistently obtained by means of simpler approaches, merely based on visual appearances (naked eye) or less invasive methods (Pétrequin et al., 2012b). Spectroscopic methods, such as infrared, Raman or even UV-visible-NIR spectroscopy in diffuse reflectance mode (also termed spectroradiometry; Errera et al., 2012a), though at times allowing mineral identification, lack the required accuracy for a thorough characterization of these *greenstones*. Despite their flaws, due to their (micro) destructiveness, these microscopic techniques – whenever applicable and eventually coupled to other approaches – represent so far the only viable approach capable of providing reliable mineral-petrographic data, essential to make lithologic comparisons. In particular, the petrographic study of rocks in thin section allows the identification of main, minor and accessory minerals, the estimate of their modal amounts, the evaluation of microstructural heterogeneity and chronological mineral relationships, while quantitative EDS analyses define the real composition and zoning of clinopyroxenes and garnets. Chemical data are plotted in the Morimoto et al. (1988) classification diagram for pyroxenes, and in the almandine (Alm)+spessartine (Sps) – grossular (Grs) – pyrope (Prp) diagram for garnets. 64 thin sections (including 34 sections already examined by D'Amico et al., 2000) were obtained from representative implements of the Brignano Frascata site. The results are the following:

- 29 are ‘Na-pyroxene rocks’ [13 jadeitites, 10 omphacitites (including 2 omphacite/chlorite schists studied by D’Amico et al., 2000) and 6 mixed Na-pyroxenites];
- 20 are ‘Na-pyroxene+garnet rocks’ (all eclogites);
- 8 are low-density *greenstone* lithotypes (7 antigoritic serpentinites; one prasinite);
- 3 are mafic granulites;
- 4 are other H*P* lithotypes (3 glaucophanites; one albite-lawsonite fels).

In addition, the examination of six tools from Momperone, Villaromagnano and Casalnoceto led to recognize the following lithologies:

- 1 ‘Na-pyroxene rock’ (jadeitite);
- 4 ‘Na-pyroxene+garnet rocks’ (2 eclogites and 2 garnet-omphacitites – 1 of which even with scarce jadeite)
- 1 quartz-arenite.

The 20 more representative samples were also analyzed by SEM-EDS – i.e., 9 ‘Na-pyroxene rocks’ (4 jadeitites, 3 omphacitites and 2 mixed Na-pyroxenites), 9 ‘Na-pyroxene+garnet rocks’ (7 eclogites and 2 garnet-omphacitites), one granulite and one quartz-arenite (Tables 4-6). EDS spot analyses for ‘Na-pyroxene rocks’ and ‘Na-pyroxene+garnet rocks’ are shown in Figs. 9 and 10, respectively. Tables 7 through 9 provide the mineralogical composition for 57 samples (serpentinite, prasinite, glaucophanite, quartz-arenite and albite-lawsonite fels excluded), as resulting by combining XRPD, optical polarizing-microscopy and SEM-EDS data. Selected chemical analyses for pyroxene and garnets are reported in the Supplementary Material (Tables S1 through S16).

(INSERT FIGURE 9)

(INSERT FIGURE 10)

3.4.1 Na-pyroxene rocks

3.4.1.1 Jadeitites

In thin section, these rocks mostly consist of colourless-to-light-green jadeite, forming granoblastic aggregates with squat-prismatic habit or having fine grain-size and mylonitic microstructure, often crossed by veins with similar mineralogy (BF-230-II; Fig. 11a). A metamorphic foliation is often observed, defined by linear aggregates of rutile, titanite or zircon or by preferred orientation of jadeite crystals. Occasionally, jadeite porphyroclasts with relict appearance are observed with a dark/bluish core, due to tiny titanite/chlorite inclusions and/or high Ti-content. Jadeite usually shows quite a complex, oscillatory zoning. Most specimens analyzed by SEM-EDS show the presence of pure jadeite (Jd ≥ 90%; Fig. 9), but also exhibit domains with Ca-richer and Fe-poorer pyroxenes [40% ≤ (Wo+En+Fs) ≤ 60%; Ae < 20%]. The microstructural relationships among pyroxenes are quite complex: sometimes, idioblastic jadeite overgrows small aggregates/domains of zoned omphacite (C-MP-CA/128; Fig. 11b); in other cases, a granoblastic jadeite matrix is crossed by tangled omphacite aggregates with different Ca/Mg contents. White mica porphyroblasts (paragonite) are often observed (Table 7); well-shaped domains, consisting of white mica associated to clinozoisite, are interpreted as pseudomorphs after former lawsonite.

(INSERT FIGURE 11)

3.4.1.2 Omphacitites

Under the polarizing microscope, pyroxenes form aggregates with a typical light-to-dark-green hue and variable grain-size. Fine-grained areas with mylonitic microstructure often alternate with granoblastic portions in the same sample. Seldom a lineation appears, defined by the preferred orientation of pyroxene prismatic blasts or by discontinuous chains of lenticular titanite aggregates and opaque ores. At SEM-EDS, small jadeitic domains show complex relationships with the surrounding omphacitic matrix. Omphacite is always zoned, with a Fe-content significantly higher than that of the analogous mineral observed in some jadeitites (even >30%, C-BR-CV/12; Fig. 9).

3.4.1.3 Mixed Na-pyroxenites

These rocks, where jadeite and omphacite coexist in almost equivalent modal amounts, show variable grain-size, colour and isotropic-to-foliated microstructure (C-FR-SO/90; Fig. 12a). The mutual relationships among pyroxenes are variable and complex. Sometimes granoblastic jadeite, including tiny omphacite exsolution blebs, is crossed by aggregates of strongly zoned omphacite crystals; the related analyses plot in two separate areas in the triangular diagram (e.g., C-FR-SO/90; Fig. 9). In other cases, the rock consists of an irregular aggregate of pyroxenes whose composition covers an almost continuous range between jadeite and omphacite (e.g., C-FR-O/11, Fig. 9 and 12b). Frequently, bluish/green omphacite blasts are observed, characterized by high TiO_2-content (3-5 wt. %).

(INSERT FIGURE 12)

(INSERT TABLE 7)

3.4.2 Na-pyroxene+garnet rocks

3.4.2.1 Eclogites

Under the polarizing microscope, omphacite forms a fine-to-medium-grained matrix with mylonitic or granoblastic microstructure, in which locally green-to-bluish-coloured patches are evident (Fig. 13a). Relict omphacite porphyroclasts with darker cores are also observed, containing tiny chlorite and zoisite inclusions. Lineation is marked either by alignments of small rutile/ilmenite aggregates or by preferred orientation of omphacite nematoblasts. Garnets are fine-grained, tens of μm up to few mm across, at times with atoll-like microstructure. Usually they form aggregates or chains, aligned parallel to foliation. EDS analyses sometimes reveal an extreme compositional zoning of pyroxenes in the ternary diagram (Fig. 10). The omphacite composition may be either homogeneous (e.g., C-FR-O/14 and C-FR-SOS/8) or covering a scattered range (e.g., C-FR-SO/48). Two pyroxenes often appear: an almost pure jadeite (C-FR-SO/12, C-MP-CA/2, O-VR-CR/1) coexisting with a more heterogeneous omphacite, occasionally extending into the aegirine/Ae-augite fields (Ae_{50}, C-MP-CA/2, Fig. 10). The subordinate jadeite domains show complex microstructural relationships with the other ‘coexisting’ pyroxenes: seldom, they occur amidst a zoned omphacite matrix (Fig. 13b); sometimes, jadeite veins appear to replace the omphacite matrix. Garnets are mainly almandine-rich (until Alm_{65}) with subordinate grossular (≤ 40%), minor pyrope (≤ 10%) and spessartine (≤ 20%)

components. Usually, a typical growth zoning is observed, with a systematic decrease in grossular component from core to rim (Fig. 10).

(INSERT FIGURE 13)

3.4.2.2 Garnet-omphacitites

The two analyzed samples (Table 8) belong to the sites of Casalnoceto and Momperone. Garnets are scarce, with idioblastic to skeletal habit and an unusual composition for eclogites (Grs ≥ 80%); their compositions are more typical for rodingites.

(INSERT TABLE 8)

3.4.3 Other lithotypes

Three axehead roughouts in glaucophanite and three disc-ring roughouts in mafic granulite (the latter also described by D'Amico et al., 2000) were studied in thin section. Fine-grained glaucophane aggregates are observed in the former, with a very modest retrogression into chlorite+albite. Granulites, on the other hand, consist of Ca-plagioclase locally transformed into epidote or pumpellyite, ortho- and clinopyroxene, olivine and spinel (Fig. 14, Table 9).

(INSERT FIGURE 14)

(INSERT TABLE 9)

3.5. Comparative analyses on geological samples

Despite their renowned rarity and preciousness, *greenstone* H*P*-metaophiolites are still found nowadays. Primary outcrops are scarce, but secondary deposits have been identified in the Voltri massif – westbound (high Erro valley), in the centre (high Orba valley) and eastbound (Lemme and Ardana valleys) (Pétrequin et al., 2012c). Masked by a thick vegetation, these rocks occur in the alluvial beds of streams, together with other more common lithotypes (Pétrequin et al., 2012b; D'Amico and Starnini, 2012b).
Some dozens of *greenstones* rocks – in the form of pebbles/cobbles/blocks deriving directly from the metamorphic substrate or the reworking of greenstone clasts from Oligocene conglomerate units located upstream – have been collected during field

prospections within stream beds and in alluvial terraced deposits in the Curone, Grue, Ossona and adjacent valleys – i.e., Staffora (running parallel to the Curone, on the eastern side), Scrivia and Lemme (on the western side) – all positioned on the eastern side of the Voltri massif. These geological samples were investigated with the same mineral-petrographic approach used for the Neolithic tools. The results of such a survey, limited to the blocks with dimensions comparable to the Neolithic artifacts (feasible raw materials for their production), will be exhaustively detailed in a forthcoming paper. Some interesting outcomes, however, are anticipated here.

Several '*Jade*' lithotypes (i.e., jadeitite, omphacitite and mixed Na-pyroxenite) and eclogite have been identified so far among the geological specimens, most having not only macroscopic – but also microscopic and compositional features comparable to those of the Neolithic tools from Brignano Frascata (and other close sites). Geologic jadeitites, for example, not only show mineral-chemical analogies inferred by XRPD and EDS techniques, but when observed under the polarizing microscope and SEM also have microstructures akin to those observed in some implements of the same lithotype. In particular, some jadeitites of prehistoric artifacts (i.e., BF-230-II and C-MP-CA/128; Figs. 9 and 11b) are very similar to geological specimens collected among the Quaternary boulders of the Val Lemme stream (e.g., VL14; Fig. 15a and b). These *common traits*, more than others, should be considered reliable 'markers' attesting a common origin. Other similarities, systematically recurring in most eclogite prehistoric tools, refer to the presence of a fine grain-size and of jadeite domains in a prevailing omphacite matrix. Moreover, high aegirine contents (up to Ae_{50}) are at times observed both in omphacitites and in eclogites, which are consistent with those detected on some analogous implements from Brignano Frascata (see Section 3.4; D'Amico et al., 2000). As to the 'Na-pyroxene rocks', significant analogies are also observed in the distribution of some minor and/or accessory minerals (e.g., white mica, zircon and titanite).

(INSERT FIGURE 15)

4. Discussion

4.1 Archaeological aspects

The typological features of the Brignano Frascata implements for cutting, though vague due to their often fragmentary conditions, indicate an ancient (excavations; Tiné, 1993) to middle (superficial collection; Nebiacolombo, 2004) Neolithic style. This is consistent with the dating of the site resulting from studies on ceramics and splintered stone. A clear distinction between the two chronological/cultural horizons is not always possible. Some considerations emerge from the study of chisels, possibly obtained by thin slivers (scraps resulting from the manufacturing of bigger instruments) and polished only on the cutting-edge (linear with plane-to-convex section), the rest being splintered or bush-hammered. Although this shaping apparently differs from that of middle Neolithic – in which chisels are bigger and improved – the studied context does not allow a sharp chronological attribution. As no certain acknowledgement exists for chisels in ancient Neolithic, probably both typologies existed at the same time (Padovan et al., 2004). Several morphological affinities, evidencing a similar occupational period, also occur in the tools of the other sites in the Curone Valley (Casalnoceto, Momperone and Villaromagnano).

For what concerns the disc-rings, the predominance of roughouts and fragments at different working stages (in Brignano Frascata and Momperone) testifies the difficulties encountered for their manufacture, which is confirmed by comparison with the reports of experimental archaeologists. This procedure provides a gradual increase in the percussion of the centre of the discoid, where the risk of breakings is higher (Delcaro, 2004). By comparing the studied disc-ring roughouts with analogous complete implements from other sites, the central hole appears smaller. This suggests that – in addition to drilling by hammering – another step in the production chain was represented by the hole widening/finishing using abrasive *polissoir* in sandstone, while polishing the surface. Some disc-rings are in serpentinite, a common lithotype probably fitting better than others to manufacture. A single jadeitite disc-ring was found, unique from a petrographic point of view, though analogous objects in H*P* lithotypes (Na-pyroxenite or paragonite) were described from other Neolithic sites (Alba, Torino, Vho and near Bologna: Traversone, 1996; Zopfi, 1996; D'Amico et al., 1996). The provenance of the raw materials is still under discussion. Some authors suggested a possible exploitation of cobble/blocks from alluvial deposits of rivers flowing into the Po plain or morainic deposits accumulated at the outlet of Alpine valleys (Ricq-de-Bouard and Fedele 1993; Ricq-de-Bouard 1996; D'Amico et al. 2004; Giustetto et al., 2016). Others, however, have objected that at least the larger (15-36 cm long), ultra-polished jade ceremonial axes found in France, Germany, Benelux, and Great Britain – whose dimensions exceed those of clasts derived from fragmentation of the primary outcrops – should have a different origin (Pétrequin et al. 2005a, 2005b). Basing on ethnographic studies, a possible exploitation of quarries in the Western Alps at high altitudes in Neolithic was proposed (Pétrequin and Pétrequin 1993, Pétrequin et al. 2006a). This is also supported by signs of extraction found on presumed jadeitite and eclogite boulders – especially in the Monviso area of Piemonte and, at a minor extent, in the Voltri Group (Pétrequin et al. 2005b, 2006b, 2008).

The moderate dimensions (≤ 10-13 cm) of the few finished tools from Brignano Frascata indicate that they were probably used for everyday requirements (i.e., woodworking or other tasks) and not for ritual purposes (such as, for example, the large *greenstone* axes dated to the V-IV millennium BC, manufactured for prestige and symbolic use; Pétrequin et al., 1998). The morphological study of the many excavated fragmented roughouts (mostly axeheads) indicates that while some breakings occurred when splintering during manufacture, most happened while bush-hammering. This latter step represents, therefore, the production phase with the higher risk of accidents. Fractures occurring during use are instead certified by cutting edges showing traces of regrinding (suggested by tiny discontinuities on the polished surface) or visible damages. These lines of evidence – and the recognition of raw surfaces on some axehead roughouts broken during manufacture, with shapes reminiscent of fluvial pebbles (a feature observed also by Pétrequin and Pétrequin, 2017) – suggest that Brignano Frascata, similarly to the Rivanazzano workshop (D'Amico and Starnini, 2012b; Pétrequin et al., 2012a), should be considered a local *atelier* for the production of *greenstone* implements in Neolithic. In addition to scraps and fragments, the manufacturing *in situ* is also supported by the recovery of spheroidal strikers (for splintering) and recycling of broken roughouts/apprenticeships attempts marked by hollows, due to their use as anvils (Bernabò Brea et al., 1996, and parallel ethnographic studies: Petrequin and Jeunesse, 1996; Pétrequin and Pétrequin, 2012). A recent technological study (Mancusi, in the press) confirmed the occurrence in Brignano Frascata of an unspecialized manufacture, certified by the many implements obtained after reuse of wastes. In Northern Italy, these technological needs might have conditioned the choice of rough material during the Early-to-Middle Neolithic, favouring the gathering of cobbles and blocks from alluvial deposits (D'Amico and Starnini, 2012b). Conversely, during the Middle-Late Neolithic-Chalcolithic – when the flux of ritual axes outside the Po plain became relevant – the choice of the materials (also for export) may have followed a more esthetical selection, dictated by larger size, elegant shape and mineral features more suitable to polishing. This sample selection might have favoured, in later times, the quarrying of larger blocks from primary outcrops at higher altitudes, potential supply of raw materials for ceremonial axes destined to the Western and Northern Europe.

All these outcomes suggest for the studied sites a supply of raw materials from secondary conglomeratic deposits and/or alluvial deposits – as no evidence about recovery/mining from primary outcrops was found, consistently with the geological remarks (see Section 4.2). Brignano Frascata, therefore, should be considered a 'second-order' site, solely operating on secondary supplies (Mancusi, in the press). All other steps of the production chain (rough-hewing, splintering and bush-hammering) were performed *in situ*, as further hinted by the medium-to-small dimensions of the tools and the recovery of few polished specimens. The presence of a stable settlement on the plain level is confirmed by the recovering of grindstones or smoothers made in sandstone or serpentinite, respectively, related to sedentary activities such as corn grinding and ceramics processing. This local production might also imply that these implements could partly be addressed to trading or exchange purposes – though limited to short-to-medium distances – as even supported by the great number of tools at different steps of their production chain (elsewhere found as finished objects; Pessina and D'Amico, 1999).

4.2 Mineral-petrographic considerations and geological issues

The Brignano Frascata lithic industry shows a marked predominance of *greenstone* H*P* metamorphic lithotypes, consistently with the outcomes of most coeval sites of Northern Italy, whereas other rocks are only 10% of the lithological types. However, while most of these sites (Alba, Castello di Annone, Gaione, Ponte Ghiara, Rivanazzano, Rocca di Cavour, Sammardenchia and San Lazzaro di Savena; Mannoni and Starnini, 1994; D'Amico et al., 1995; 1997; 2013; D'Amico and Ghedini, 1996; D'Amico and Starnini, 2000, 2012b; Andò, 1998; Bernabò Brea et al., 2000; Borgogno, 2000; Giustetto et al., 2016; Fig. 1) show dominance of 'Na-pyroxene+garnet rocks' (eclogites even up to 66%), in Brignano Frascata 'Na-pyroxene rocks' (jadeitites + omphacitites + mixed Na-pyroxenites) slightly prevail (42% of the lithological types; Fig. 3b). Such values are high, if compared to other sites (e.g., Sammardenchia and Rivanazzano) where these '*Jades*' seldom reach 10%. The Monte Savino/Sassello site, where omphacitite is the prevailing lithotype (Garibaldi et al., 1996), represents an exception. Comparative studies with close and coeval settlements were also made with Momperone and Villaromagnano, in the Curone and Ossona valleys respectively, where despite the necessary caution due to a non-homogeneous sampling (excavation, surface recovering, harvesting), the statistics of the analyzed specimens is significant (Figs. 3c and 3d). Only *greenstones* were recovered in Momperone, with 'Na-pyroxene+garnet rocks' (44%, all eclogites) prevailing over 'Na-pyroxene rocks' (30%). In Villaromagnano, 'Na-pyroxene+garnet rocks' (all eclogites) and 'Na-pyroxene rocks' (26% each) are subordinate to serpentinites (44%), a trend opposite to that usually observed.

For what concerns the origin and provenance of the raw materials, two main geological sources of 'Na-pyroxene rocks' and 'Na-pyroxene+garnet rocks' have been so far identified in Northwestern Italy, namely in the Monviso and Monte Beigua (Voltri) massifs (D'Amico and Starnini, 2012b; Errera et al., 2012b; Pétrequin et al., 2012c; Fig. 1). Though separated by slightly more than 100 km as the crow flies, these regions underwent – between 5500 and 3500 B.C. – a very different cultural history, each characterized by a peculiar evolution and different contacts with neighboring peoples (Pétrequin et al., 2012b). From a geological point of view, the Monviso and Voltri regions, each divided into different subareas, belong to a common stump of H*P*-meta-ophiolites and share the same lithologies. Some peculiarities, however, can be pointed out and emphasized in the discussion that follows – by relating the mineral-petrographic features of the investigated Neolithic tools with those of geological specimens of known provenance. The individuation of sharp correspondences and geologic 'markers' is known to represent a hard task. These lithotypes, in fact, show a wide variety of grain size, microstructure, deformation features and compositional zoning – quite difficult to standardize (Giustetto and Compagnoni, 2014; D'Amico and Starnini, 2012b). This is the reason why only an in-depth mineral-petrographic exam (on both tools and geological samples) is the only viable method to pursue sharp and reliable provenance information. Such a goal may be achieved by combining accurate analytical methods (density, XRPD, optical polarizing, electron microscopy and even spectroscopic techniques) that – if considered alone – might lead to gross oversights. With the above in mind, some peculiar mineral-petrographic features about *greenstones* and/or other lithologies distinctive of the Monviso or Voltri massifs were extrapolated by the few previous coherent studies (Compagnoni et al., 2012; Giustetto et al., 2016) and by the reference collection for Project 'JADE' (Pétrequin et al., 2012b). Obviously, accurate comparisons could be performed only by referring to rigorous mineral-petrographic approaches – consistent with those adopted here (D'Amico, 2012). Moreover, the preliminary results of the pilot comparative study on *greenstone* conglomerate clasts from the eastern side of the Voltri area (see Section 3.5) have also been considered. On the other hand, spectroradiometric outcomes – a poor identification technique for minerals and rocks, applicable only to (possibly overestimated) jadeitites (Errera et al., 2012a) – were disregarded, as well as those resulting from sheer visual appearances (to the naked eye; Pétrequin et al., 2012b; Pétrequin and Errera, 2017).

Basing on these approaches, a pilot provenance study on a selection of *greenstone* artifacts from Brignano Frascata (26; eight of which also investigated here) was recently issued by Pétrequin and Pétrequin (2017), comparing them with about 1500 raw material specimens from known locations in the high Alps. Such an investigation apparently proved that while most roughouts and axeheads might originate from the secondary deposits of the Monte Beigua (Voltri) massif, a subordinate number (10) might instead derive from exploitations of primary outcrops and/or secondary deposits on the Monviso massif – located mostly on the Southern spurs. Despite their unequivocal appeal, these results appear arguable: the dubious consistency of these approaches in rendering the mineral-chemical complexity of these heterogeneous rocks, in fact, may dangerously bias the related characterizations. For instance, several lithotype determinations, achieved with spectroradiometry and/or sheer visual appearances, do not correspond to those inferred by means of strict mineral-petrographic methods. Moreover, other incongruities exist – and will be listed, whenever necessary, in the discussion that follows. All these limitations, in our opinion, may seriously undermine the reliability of any conclusion deduced by using these approaches.

(INSERT FIGURE 16)

By comparing the mineral-petrographic features of the Brignano Frascata implements (and closer findings; Fig. 16a) with those of other tools from coeval sites, as well as with those of consistent geologic specimens from traced sources, both analogies and differences are observed. The analogies refer to eclogites always being fine-grained and often containing subordinate jadeite domains in a prevailing omphacite matrix, a feature observed also in several geological samples collected from secondary deposits fed by the erosion of the Voltri Massif rocks (see Section 3.5). This aspect, therefore, should not be considered exclusive of the Monviso area – as hastily hinted by Errera et al. (2012b) and Pétrequin et al. (2012b). Also, pyroxenes show a complex and variable zoning, with exsolution omphacite 'blebs' in jadeite – as observed in some tools from Castello di Annone (Giustetto et al., 2016). Such a heterogeneity was seldom reported in analogous geological specimens, due to lack of detailed petrologic studies (Compagnoni et al., 1995). Though a rich literature exists on the Monviso eclogites (Rubatto and Hermann, 2003; Groppo and Castelli, 2010; Spandler et al., 2011; Castelli et al., 2014, with refs. therein), primary outcrops of 'Na-pyroxene+garnet'/'Na-pyroxene rocks' with features comparable to those observed in these implements are small and scarce (Pétrequin et al., 2013). Presence of omphacite blebs, ubiquitous zircon and accessory Ti-bearing phases (especially rutile) in jadeite was described in jadeitite outcrops from the Monviso massif (Compagnoni et al., 2007; 2012).

Similar jadeitite boulders (up to one m^3) were reported from the Po valley Quaternary succession, thus reinforcing the hypothesis for a supply of raw materials from secondary deposits (Forno et al., 2015). Presence of different pyroxenes, exsolutions and overgrowths were also described in jadeitites from Cuba (García-Casco et al., 2009), Antigua, Guatemala (Harlow et al., 2006; 2011) and Dominican Republic (Schertl et al., 2012). For what concerns the differences, the Brignano Frascata implements contain, both in eclogite and omphacitite, clinopyroxenes with a high aegirine content (up to Ae_{50}). Such unusual Ae values, reported also by D'Amico et al. (2000), are *not* typical of other 'alpine' recoveries (e.g., implements from Eastern Europe: Spišiak and Hovorka, 2005; Hovorka et al., 2008) attributed to a Monviso provenance, nor other '*Jade*' localities (e.g., Caribbean geological samples/artifacts: Garcia-Casco et al., 2009, 2013; Harlow et al., 2004). Similar Ae contents, however, have been occasionally observed in some omphacitites and eclogites from secondary deposits around the Voltri Massif (see Section 3.5) – and may therefore represent a distinctive 'marker' in comparative studies aimed at pinpointing the raw materials sources. On this basis, the presumed attribution of some Ae-rich eclogites in prehistoric tools (e.g., C-FR-SO/48; Fig. 10) to a Monviso provenance, based on spectroradiometry and macroscopic approaches, sounds misleading (Pétrequin and Errera, 2017; Pétrequin and Pétrequin, 2017). A typical richness in aegirine (distinctive also of the Momperone tools, e.g., C-MP-CA/2; Fig. 10) was even observed in some Castello di Annone specimens (Giustetto et al., 2016), whose garnet composition and zoning are also similar to those reported here. Furthermore, in both sites high percentages of broken/fragmented implements were retrieved. The marginal importance attributed to Castello di Annone in the production network of *greenstone* tools during Neolithic (Giustetto et al., 2016), coupled with the local *atelier* nature of Brignano Frascata (Section 4.1), may imply that a trade channel existed between these settlements. Alternatively, these common traits may also suggest a common material supply, reinforced by the tools of both sites occasionally containing pyroxene blasts with a bluish, Ti-rich core (similar to those reported by Harlow et al., 2003; 2004) and pseudomorphs after original lawsonite porphyroblasts (observed also in the Rivanazzano implements; D'Amico and Starnini, 2012a). This latter feature, due to the many similarities (both archaeological and mineral-petrographic) found between the Brignano Frascata and Rivanazzano *ateliers*, is probably not exclusive of *greenstones* from the Monviso area – as supposed by Pétrequin et al. (2012b). On the contrary, these features – and the presence of pyroxene porphyroclasts sporadically coupled with strong deformation, in the so-called 'omphacite schists' described by D'Amico et al., 1997 (i.e., BF20.1 and BF27; Table 7) –

further indicate a possible origin of the raw materials from the meta-ophiolites of the Voltri Group (D'Amico, 2012) – e.g. those exposed in the Staffora hydrographic basin (Mannoni et al., 1996), possibly drawn from an equivalent palaeo-unit dismantled after erosion (see below). This assumption contradicts the presumed provenance of these 'omphacite schists' from the Monviso massif, hastily hypothesized by Pétrequin and Pétrequin (2017) basing on spectroradiometry and visual appearance. Sporadic detection of Qtz/Ab in some jadeitites (i.e., BF 230 II and BF25; Table 7), a feature rare in Neolithic artifacts but found in some rocks from the eastern part of the Voltri massif ('Qtz-Ab-jades'; D'Amico, 2012; Pétrequin et al., 2012b), even reinforces such a belief. For what concerns garnets, despite moderate fluctuations in the (Alm+Sps) content, most Brignano Frascata eclogites show similar core-to-rim compositional variations (Fig. 10). This trend, coupled with the unusually high Ae-content of pyroxenes, may suggest that these rocks had a similar geologic history – and thus a common source. Garnet-omphacitites, instead, have quite a different garnet composition (Fig. 10). Minor and accessory minerals show a heterogeneous distribution, quite difficult to interpret. Recurring presence of white mica (paragonite) and titanite prevailing over rutile in many 'Na-Pyroxene rocks' (Table 7), observed also in the geological specimens from the close secondary deposits (see Section 3.5), may support an origin from the Voltri massif (D'Amico, 2012) instead of the Monviso (as inaccurately hinted for BF20.1 by Pétrequin and Pétrequin, 2017). Detection, in some eclogites, of significant glaucophane (e.g., 69361 and BF24) or apatite amounts (C-FR-SO/12, BF14.1, BF17 and BF22; Table 8), further supports this assumption (Pétrequin et al., 2012b).

Establishing the origin of the raw materials for manufacturing the implements – whether from primary outcrops at high elevation (Pétrequin et al., 2002) or from alluvial, downhill secondary deposits – also represents a fundamental archaeometric issue. The first hypothesis needed the community to dispose of skilled gatherers, whose hard task – besides locating the distant primary outcrops on the mountains – was that of tearing off and bringing back raw stone boulders to be worked. The second option would have involved less effort, since these deposits were closer to the settlements and contained blocks already fragmented and selected by erosion and transport. The morphological examination of axehead roughouts, abundant in Brignano Frascata, proves that most have rounded shapes, typical of pebbles of Oligocene or Quaternary deposits – some even showing raw surfaces (Section 4.1). The performed geologic survey and ensuing petrographic study show that the conglomeratic horizons intercalated in the Tertiary Piemonte basin successions contain pebbles of both metamorphic and non-metamorphic ophiolites. Meta-ophiolites should have derived from the dismantlement, about 30 My ago, of the palaeo-Voltri Massif (or a possible equivalent unit, disappeared because of long lasting erosion), located to the west of the considered area. On the contrary, the non-metamorphic ophiolites should have derived from the Ligurids, i.e., the present-day Apennine exposed to the southeast. Therefore, the pebbles of H*P* meta-ophiolites collected by prehistoric men might *not* derive from the *present* Voltri Massif – because the present-day trend of the streams in the considered area (i.e., Lemme, Scrivia, Grue, Ossona, Curone and Staffora) is roughly from S/SE toward N/NW. Instead, these pebbles should have originated from the 'secondary' deposits of either the Tertiary conglomeratic horizons or the re-sedimented Quaternary alluvium. A geological sketch is presented here, based on the most recent geological maps and stratigraphic data, showing the location of the closer Oligocene conglomerate and Quaternary alluvial deposits, possible sources of raw materials for these Neolithic tools (Fig. 16a,b). The Oligocene stratigraphic succession of the Tertiary Piemonte Basin includes some lithostratigraphic units containing conglomerate bodies with clasts of meta-ophiolites. The closest ones are the Savignone Conglomerate (**sav**) and the Monastero Formation (**mst**), few km far from Brignano Frascata and the other investigated sites. The first, Rupelian in age, is a thick (up to 2200 m) unit made up of continental-to-shallow-water conglomerates and arenites, with subordinate marls and pelites. In its lower part (Monte Rivalta and Val Borbera Members), the conglomerate clasts essentially derive from Ligurian *Helminthoides* Flysch Units; in the upper part (Persi Member, $\mathbf{sav_c}$; Fig. 16b), they also derive from continental crystalline basement and meta-ophiolites with very low-grade, greenschist-facies or high-pressure metamorphic overprint. The Monastero Formation (also Rupelian) consists of sandy-muddy turbidites, followed by hemipelagic marls. In its lower part, a conglomerate lithozone is present ($\mathbf{mst_c}$; Fig. 16b) containing clasts from Ligurian *Helminthoides* Flysch Units (Antola Unit) and ophiolitic sequences, overprinted by high-pressure metamorphism (Marroni et al., 2010). The conglomerate bodies containing meta-ophiolitic clasts have been mapped in the Cabella Ligure sheet of the Geological Map of Italy at 1:50.000 (Marroni et al., 2010), corresponding to the southeastern part of the study area (Fig. 16b). In the rest of the area (comprised in the Voghera sheet at 1: 50.000 – Vercesi et al., 2014 – and the Alessandria/Voghera sheets at 1:100.000 of the Geological Map of Italy – Servizio Geologico d'Italia, 1969a; 1969b), these conglomerates have not been distinguished from the formations they are included in. To the southwest of the study area (west of the Scrivia valley), a thick succession of continental to shallow-water conglomerates and arenites, with subordinate marls and pelites, crops out (mor: Costa Cravara Breccia and Molare Formation;

Fig. 16b). These deposits, mainly Rupelian in age, contain abundant clasts of meta-ophiolitic rocks derived from their metamorphic substrate represented by the Voltri massif (Capponi and Crispini, 2008; d'Atri et al. 2016 and references therein). From these beds, greenstone cobbles and blocks are released as detrital materials into the Quaternary alluvial deposits in the adjoining valleys – e.g., the Curone, Grue and Ossona, as well as Staffora (on the eastern side of the Curone), Scrivia and Lemme (on the western side) valleys – and outlets in the plain. These alluvial deposits also gather clasts resulting from the dismantling of the primary '*Jade*' and/or eclogite blocks, located at higher altitudes in the eastern area of the Voltri massif. In addition to our surveys (see Section 3.5), presence of greenstone secondary blocks of presumed jadeitite, omphacitite and eclogite in the high Lemme valley – about 20 km as the crow flies from Brignano Frascata – was also signaled by Pétrequin et al. (2012c). These updated geologic/stratigraphic data, coupled with the wide range of lithotypes found in the tools of Brignano Frascata, further support the hypothesis of a secondary supply source. Such a heterogeneity, in fact, implies presence of an extensive choice/selection, similar to that available in an alluvial deposit gathering pebbles from higher and distant areas. This assumption is definitely strengthened by the outcomes of the ongoing pilot comparative study, performed on geological *greenstones* from these areas (see Section 3.5). These results undoubtedly show that some typical micro-structural and compositional features recur *both* in the studied prehistoric tools *and* in analogous *greenstones* collected from conglomerate deposits and/or alluvial beds in the adjoining valleys and streams. All these lines of evidence point to a feasible supply of raw materials from the local Quaternary alluvial deposits in the lower course of the nearby streams (e.g., Curone, Grue, Ossona, Staffora, Scrivia and Lemme), and from the lower Oligocene formations cropping out few km far as the crow flies – an opportunity already hinted by D'Amico (2012) and D'Amico and Starnini for the site of Rivanazzano (2006b, 2012b). The geological features of the few known primary outcrops at higher altitudes – scarce, small and distant – further reinforce the presumable belonging of these roughouts to secondary deposits, in which erosion imposes a natural selection causing the tougher, less-alterable lithotypes (e.g., 'Na-pyroxene rocks' and 'Na-pyroxene+garnet rocks') to undergo an enrichment. A direct supply source from primary outcrops at higher elevation seems even more unlikely by considering the scarcity of such blocks, limited to few jadeitite (Celle Ligure), eclogite (Urbe) or amphibolite (Sassello, Chapel of Rocca Colombo) boulders, with poor traces of exploitation (Pétrequin et al., 2012). Besides, a similar origin from boulders of the Monviso massif (Western Alps, at a distance of approximately 150 km as the crow flies; Errera et al., 2012b; Pétrequin et al., 2012c; Pétrequin and Pétrequin, 2017), though not completely ruled out (as hinted for some tools from Sammardenchia; D'Amico and Starnini, 2012b), appears even more questionable. Not only the covering of such distances would appear senseless – the same materials being available from much closer distances – but all detected mineral-petrographic features indicate, for those prehistoric tools investigated with a strict scientific approach, an origin from the Voltri (or palaeo-Voltri) massif. Basing on these evidences, the complex technical and economic system proposed for the Brignano Frascata site by Pétrequin and Pétrequin (2017), based on a double supply of raw materials – mainly from regional sources in the Voltri massif and secondarily from the Monviso outcrops – is yet to be acknowledged. A simpler single model, solely based on the finding of raw materials from nearby secondary deposits in the Eastern Voltri area, certainly appears more reasonable. While only further and accurate mineral-petrographic analyses could help in improving the statistical weight of this model of supply, particular care must be taken in order to avoid misinterpretations and/or overvaluations hinted by approaches that – despite their non-destructiveness – lack in providing a thorough characterization of the rocks. For what concerns lithotypes other than *greenstones*, moderate presence of glaucophanite among the analyzed artifacts (3 samples; see Section 3.4) strongly supports their origin from the Voltri Group. These rocks, often fine-grained, are in fact quite common all over the Voltri area – reaching nearly 10 % – but are typically lacking in the Monviso massif (D'Amico, 2012). Different considerations involve the significance of the granulite rocks (Table 9; Fig. 14), which certainly belong to the Ivrea-Verbano Zone, an important tectonic unit of the Western Alps located between the town of Ivrea and the Locarno Lake – exposed to the southeast of the Piemonte Zone. The maximum thickness of the Ivrea-Verbano Zone occurs in the Sesia valley, whose Quaternary alluvial deposits contain many basic granulites. These rocks might derive from a site downstream the confluence of the Sesia and Po rivers – the closest possible area with respect to the studied archaeological sites (see Fig. 16a).

5. Conclusions

The Neolithic *greenstone* industry of Brignano Frascata was studied with an archaeometric approach, involving both archaeological and mineral-petrographic aspects, supplying information about the manufacturing techniques and the origin of raw materials. It has been long ascertained that the '*Jades*' and eclogite of the archaeological implements found all over the Western Europe derive from the meta-ophiolites of the Piemonte Zone. However, a more accurate location is difficult to determine, due to the scarcity of detailed geological data of primary outcrops. A possible supply source from close secondary deposits is hypothesized here, basing on morphological/petrographic features and geological considerations. Although probably both supply models (exploitation of conglomerate deposits and/or alluvial beds vs. quarrying of primary outcrops at high altitudes) were exploited in the past, the former was privileged during the early/middle Neolithic, producing not too large, working-wood instruments for daily use. This model, recurring in Northern Italian sites, was adopted also in Brignano Frascata, thus satisfying the principle of the cost/benefit ratio (i.e., grabbing the best available technological material with the minimum effort). The quarrying of selected outcrops at high altitudes, aimed at obtaining big chunks of first-quality material for the production of large ceremonial axes to be exported over long distances, probably became important only later (V and IV Millennium BC) – and apparently did not involve the investigated site(s). Detailed geologic surveys of the surrounding district (Curona, Grue, Ossona and adjoining valleys – e.g., Staffora, Scrivia and Lemme) are at present performed, followed by laboratory analyses on apt geological samples collected from secondary deposits of *greenstones* – potential sources of raw materials. The preliminary results obtained by such an approach confirm that the *greenstones* used to manufacture the tools from Brignano Frascata and coeval adjacent sites might have been collected from secondary supply sources located nearby – e.g., close conglomeratic formations and/or alluvial deposits siding the course of the streams crossing the adjoining valleys, originating from the Voltri (or palaeo-Voltri) massif.

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Tables

	State Inventory	Excavation inventory	Other inventories	Label	Implement description	Lithotype	Notes (stereomicroscopy in reflected light/density)	Weight in air	Weight in H_2O	Density	Sampling
1			C-FR-NO/1		axehead roughout	(undefined lithotype)	weighing not reliable	62.1	38.9	2.68	
2			C-FR-SO/50		grindstone fragm.	sandstone	low density	451.9	277.3	2.59	
3			C-FR-SO/21		smoothing pebble	sandstone	low density	191.4	119.8	2.67	
4	69367		C FR SO		grindstone	sandstone	too heavy for reliable weighing	=	=	=	
5			C-FR-SO/ 8		grindstone fragm.	sandstone	too heavy for reliable weighing	=	=	=	
6		1900/43	C-FR-SO/97		file	sandstone	= = =	=	=	=	
7	69263	BF 422 31 III			sharpening stone	sandstone	= = =	=	=	=	
8	69260	BF 89 II			whetstone	sandstone	= = =	=	=	=	
9			C-FR-NO/3		grindstone fragm.	diabase	porphyiric diabase (basalt)	402.3	262.7	2.88	
10			C-FR-SOS/2-3		two slivers	eclogite	evident garnets; weighing not reliable	2.3	1.2	2.09	
11			C-FR-S/3		sliver	eclogite	red crystals (garnets/sulfides?), quartz and zoisite	68.4	45.4	2.97	
12			C-FR-SO/35		axehead cutting edge	eclogite	slightly regressed eclogite	13.1	8.7	2.98	
13			C-FR-SOS/11		sliver	eclogite	quite heterogeneous eclogitic rock	8.8	5.9	3.03	
14			C-FR-SO/ 3		sliver	eclogite	regressed eclogite, with amphibole and epidote	98	66.1	3.07	
15			C-FR-SO/83		sliver	eclogite	eclogite with many garnet and amphibole	12	8.2	3.16	
16			C-FR-SO/81		sliver	eclogite	eclogite with pale green omphacite and blue amphibole	19.3	13.2	3.16	
17		BF 4/5 II		BF24	pebble	eclogite	= = =	324.8	223.5	3.21	
18			C-FR-SO/70		axe butt fragment	eclogite	= = =	59.8	41.2	3.22	
19			C-FR-SO/92		sliver	eclogite	= = =	10	6.9	3.23	
20			C-FR-S/2		sliver	eclogite	eclogite with small garnets and possible zoisite	54.2	37.4	3.23	
21			C-FR-SO/77		axe butt roughout	eclogite	presence of whitish pyroxene and garnets	61.3	42.4	3.24	
22			C-FR-O/ 3		axehead roughout	eclogite	banded eclogite with mylonitic structure and sulfides	111	76.9	3.26	
23	69363		C FR SO		axehead roughout	eclogite	eclogite with evident idiomorphic garnets	131.6	91.4	3.27	
24			C-FR-SO/64		axehead fragment	eclogite	fine-grained eclogite	49.6	34.6	3.31	
25			C-FR-SO/52		axehead cutting edge	eclogite	= = =	12.9	9	3.31	
26			C-FR-N/29		axehead	eclogite	raw-grained eclogite	239.0	166.9	3.31	
27			C-BR-MD/1		axehead fragment	eclogite	raw-grained eclogite	74	51.7	3.32	
28			BR81B/3		sliver	eclogite	levels richer in omphacite or garnet; mica aggregates	22.9	16	3.32	
29			C-FR-SOS/ 7		striker	eclogite	portions rich in porphyroblastic garnets or pyroxenes	161.8	113.1	3.32	
30			C-FR-O/12		chisel	eclogite	evident garnets	14	9.8	3.33	
31			C-FR-SO/36		axehead fragment	eclogite	presence of carbonates; idioblastic garnets (1 mm)	45.4	31.8	3.34	
32			C-FR/1		ten small slivers	eclogite	= = =	6.7	4.7	3.35	

33			C-FR-SO/67		axe butt fragment	eclogite	= = =	93.5	65.6	3.35	
34		17	C-FR-SO/76		axe fragment/roughout	eclogite	= = =	61.1	42.9	3.36	XRPD
35			C-FR-SO/62		axehead fragment	eclogite	= = =	48.7	34.2	3.36	
36			C-FR-SO/17		axehead roughout	eclogite	eclogite with mylonitic structure and garnets in bands	118	83	3.37	
37			C-FR-NE/6		axehead roughout	eclogite	presence of pure pyroxene levels, lacking garnets	52.3	36.8	3.37	
38			C-BR-CV/10		axe butt roughout	eclogite	eclogite with mylonitic structure	65.8	46.3	3.37	
39			C-FR-SO/84		big sliver	eclogite	= = =	83.1	58.5	3.38	
40			C-FR-SO/85		sliver	eclogite	rare garnets	29.4	20.7	3.38	
41			C-FR-SO/34		chisel/striker fragm.	eclogite	presence of amphibole	23	16.2	3.38	
42			C-FR-SO/19		axe roughout fragment	eclogite	very small garnets; possible pseudomorphosis on lawsonite	35.2	24.8	3.38	
43			C-FR-SO/15		axe roughout fragment	eclogite	banded eclogite with pure omphacite levels	54.9	38.7	3.39	
44			C-FR-SO/12		axehead roughout	eclogite	eclogite with jadeitic portions	228.6	161.2	3.39	thin section
45	69358		C FR SO		axehead roughout	eclogite	*stricto sensu* eclogite with homogeneous garnets	196.2	138.4	3.39	
46	69373		C FR SO		axehead	eclogite	*stricto sensu* eclogite with small garnets	106.8	75.4	3.40	
47			C-FR-SO/26		axe butt fragment	eclogite	= = =	149.7	105.7	3.40	
48			C-FR-SOS/6		sliver	eclogite	banded eclogite with jadeite veins	16	11.3	3.40	
49			C-FR-SO/42		axe roughout fragment	eclogite	very fine-grained garnets	64.7	45.7	3.41	
50			C-FR-SO/27		axehead fragment	eclogite	= = =	31	21.9	3.41	
51	69371		C FR SO		axehead fragment	eclogite	*stricto sensu* eclogite with porphyroblastic garnets	112.1	79.2	3.41	
52			C-FR-N/2		axe butt roughout	eclogite	= = =	53.5	37.8	3.41	
53			C-FR-NE/2		axehead fragment	eclogite	possible presence of white mica porphyroblasts	33.4	23.6	3.41	
54	69253	BF 279 III		BF26.1	axehead	eclogite	eclogite/serpentinite schist	54.9	38.8	3.41	
55			C-FR-SO/56		axe butt fragment	eclogite	= = =	50.5	35.7	3.41	
56			C-BR-CV/ 3		axehead	eclogite	= = =	70	49.5	3.41	
57			C-FR-SO/44		axehead roughout	eclogite	evident presence of garnets	112.8	79.8	3.42	
58			C-FR-SO/14		axe butt roughout	eclogite	= = =	96.1	68	3.42	
59			C-BR-CV/5		axehead roughout	eclogite	big garnets	79.1	56	3.42	
60			C-FR-SOS/8		sliver	eclogite	= = =	50.4	35.7	3.43	thin section
61			C-FR-SO/29		axe butt fragment	eclogite	very fine-grained garnets	34.3	24.3	3.43	
62			C-FR-SO/40		axe butt fragment	eclogite	small garnets	63.9	45.3	3.44	
63			C-FR-SO/88		sliver	eclogite	= = =	24.4	17.3	3.44	
64			C-FR-O/9		sliver	eclogite	evident euhedral garnets	16.2	11.5	3.45	
65			C-FR-SO/59		axe fragment/roughout	eclogite	= = =	109	77.4	3.45	thin section
66			C-FR-SO/48		axe butt fragment	eclogite	= = =	346.4	246	3.45	thin section

67			C-FR-SO/16		axe butt fragment	eclogite	abundant, pale garnets	77.4	55	3.46	
68			C-FR-O/4		axe butt fragment	eclogite	lineated omph. and big garnets; porphyrocl. magmatic pyrox.	66.4	47.2	3.46	
69			C-FR-SO/101		sliver	eclogite	small, pale garnets aligned in chains; big vein of omphacite	18	12.8	3.46	
70			C-FR-O/8		axe butt roughout	eclogite	very fine-grained garnets	46.1	32.8	3.47	
71			C-FR-N/6		sliver	eclogite	= = =	76.4	54.4	3.47	
72			C-FR-SO/47		axe butt fragment	eclogite	abundant garnets (two kinds: pale and dark) and rutile	99.9	71.3	3.49	
73			C-FR-SO/89		sliver	eclogite	= = =	19.6	14	3.50	
74			C-BR-CV/9		axehead recycling	eclogite	= = =	92.7	66.3	3.51	
75			C-FR-O/14		axehead fragment	eclogite	= = =	60.1	43	3.51	thin section
76			C-FR-O/10		axehead fragment	eclogite	very fine-grained garnets	46.4	33.2	3.52	
77			C-BR-CV/11		axehead roughout	eclogite	mylonitic structure, garnet porphyroblasts and white mica	182.8	131	3.53	
78		BF 102 IV/14.1		BF14.1	axehead roughout	eclogite	raw-grained eclogite	106.7	76.8	3.57	
79	69370		C FR SO		axehead roughout	eclogite	= = =	394.5	284	3.57	
80	69351		C FR NE		axehead roughout	eclogite	*stricto sensu* eclogite with abundant garnets	121.8	87.8	3.58	
81			C-FR-SO/37		axe butt fragment	eclogite	small idiomorphic garnets, amphibole and glaucophane	22.6	16.3	3.59	
82	69355		C-FR-O	PIEM 30	axehead roughout	eclogite	presence of chloritoid; weighing not reliable	106.8	75.4	3.40	thin section
83	69362		C-FR-SO	PIEM 34	axehead roughout	eclogite	*lato sensu* eclogite; weighing not reliable	96.1	68.0	3.42	thin section
84	69361		C-FR-SO	PIEM 33	axehead roughout	eclogite	possible zoisite and glaucophane crystals; relict omphacite	83.1	58.5	3.38	thin section
85	69356		C-FR-SO	PIEM 31	axehead	eclogite	fine-grained, regressed omphacite, atoll-like garnets and rutile	99.9	71.3	3.48	thin section
86	69353		C-FR-SO	PIEM 28	chisel roughout	eclogite	with chloritoid porphyroblasts, chlorite, epidote and ilmenite	52.3	36.8	3.37	thin section
87			C-FR-SO/7		big sliver	eclogite	containing lineated amphibole	=	=	=	
88			C-FR-SO/24		small chisel	eclogite	= = =	20.3	=	=	
89			C-FR-SO/61		axehead fragment	eclogite	euhedral garnets; too small for reliable weighing	=	=	=	
90	69254			BF30 (agg.)	striker	eclogite	= = =	76.4	54.4	3.48	
91	69250			BF22 (agg.)	axehead	eclogite	= = =	99.9	71.3	3.49	
92	69249			BF35.1(agg)	striker	eclogite	= = =	46.1	32.8	3.47	
93	69248			BF17 (agg.)	striker	eclogite	= = =	46.4	33.2	3.52	
94		BF 420-429/10		BF10	sliver	eclogite	weighing not too reliable	6.7	4.7	3.35	
95	BF163-164.179-180 III/35.2			BF35.2(agg.)	sliver	eclogite	= = =	19.6	14.0	3.50	
96	BF227-228 243-44 III/13			BF13 (agg.)	striker	eclogite	= = =	63.9	45.3	3.44	
97	BF262 IV-V/20.3			BF20.3(agg.)	small pebble	albite/lawsonite fels	= = =	=	=	=	
98			C-FR-SOS/5		sliver	jadeitite	prysmatic crystals/veins with Jd and Omph; unreliable weighing	6.9	4.7	3.14	
99	69251	BF E3 1		BF25	pestle	jadeitite	= = =	215.3	147.2	3.16	thin section
100	69364		C-FR-SO		axehead fragment	jadeitite	folded mylonitic structure	9.5	6.5	3.17	

101			BF-3		axehead fragment	jadeitite	light green colour	5.2	3.6	3.25	XRPD
102			GG81		axehead fragment	jadeitite	= = =	11.4	7.9	3.26	
103			C-FR-NO/2		big sliver	jadeitite	= = =	294.7	204.5	3.27	thin section
104			C-FR-SO/65	PIEM 24	striker fragment	jadeitite	= = =	52.4	36.5	3.30	
105	69366		C FR SO		ascia abbozzo	jadeitite	= = =	14.3	10	3.33	
106			C-FR-SO/68		ascia abbozzo fr.	jadeitite	= = =	34.3	24	3.33	
107			C-FR-SO/23		axe butt fragment	jadeitite	small elongated glaucophane crystals	45	31.5	3.33	
108			C-FR-O/2		axehead roughout	jadeitite	presence of omphacite in veins or portions	108.8	76.4	3.36	
109			C-FR-SO/41		striker fragment	jadeitite	= = =	168.2	118.3	3.37	thin section
110			BR81B/2		small sliver	jadeitite	dark green	2.8	2	3.50	XRPD
111			C-FR-NE/7	PIEM 25	axehead fragment	jadeitite	relicts of magmatic pyroxene	66.4	47.2	3.46	thin section
112			C-FR-SO/57	PIEM 23	axehead roughout	jadeitite	= = =	161.5	113.0	3.33	
113			C-FR-SO/66		striker fragment	jadeitite	= = =	=	=	=	thin section
114			C-FR-SO/94	PIEM 20	disc-ring roughout	jadeitite	= = =	131.6	91.4	3.27	
115	69262	BF 230 II			grindstone	jadeitite	= = =	239	167	3.30	thin section
116	74918			BF21 (agg.)	axehead	jadeitite	= = =	34.3	24.3	3.43	
117		BF 161-178 II/19		BF19	axehead fragment	jadeitite	= = =	30.6	21.1	3.22	
118		BF 454-463 I/23		BF23	cutting edge fragment	jadeitite	= = =	22.9	16	3.32	
119		BF 89 II/32		BF32	sliver	jadeitite	too small for reliable weighing	6.7	4.7	3.34	
120		BF268 II/20.2		BF20.2 (agg.)	axehead fragment	jadeitite	= = =	111	76.9	3.26	
121			BR81B/1		axehead roughout	glaucophanite	other phases in addition to glaucophane	44.6	29.9	3.03	
122	69357		C FR SO	PIEM 32	axehead roughout	glaucophanite	omphacitite turned into glaucophanite; epidote, rutile, garnet	323.4	=	=	thin section
123	69354		C FR SO	PIEM 29	axehead roughout	glaucophanite	= = =	=	=	=	thin section
124			C-FR-SO/60	PIEM 21	axe fragment/roughout	glaucophanite	schist with glaucophane, jadeite and quartz	=	=	=	thin section
125			C-FR-SOS/10		sliver	glaucophanite	presence of glaucophane	29.2	19.8	3.11	
126		BF 263 II/29.1		BF29.1	disc-ring roughout	basic granulite	= = =	52.2	33.7	2.82	
127		BF 310 II/34		BF34	disc-ring roughout	basic granulite	= = =	101.3	66	2.87	
128		BF263 II/29.2		BF29.2 (agg.)	disc-ring roughout	basic granulite	= = =	144.5	94.0	2.85	thin section
129			BF-4		axehead fragment/sliver	mixed Na-pyroxenite	too small for reliable weighing	5.2	3.6	3.26	XRPD
130			C-FR-SO/11		axe butt fragment	mixed Na-pyroxenite	mixed Na-pyroxenite with glaucophane	135.1	91	3.06	
131			C-BR-CV/8		axe butt roughout	mixed Na-pyroxenite	= = =	73.9	50.3	3.13	
132			C-FR-SO/13		axehead fragment	mixed Na-pyroxenite	pale green jadeite crystals, wrapped in an omphacite matrix	26.7	18.3	3.18	
133			C-FR-SO/86		big sliver	mixed Na-pyroxenite	presence of pseudomorphosis on possible lawsonite	222.2	152.5	3.19	
134			C-FR-SO/82		axe butt roughout	mixed Na-pyroxenite	slightly altered mixed Na-pyroxenite	30.6	21.1	3.22	

135			C-FR-SO/95		polished sliver	mixed Na-pyroxenite	possible presence of epidote	26.8	18.5	3.23	
136			C-FR-SO/28		axehead roughout	mixed Na-pyroxenite	slightly regressed mixed Na-pyroxenite	244.2	168.7	3.23	
137			C-BR-CV/ 1		axehead/striker	mixed Na-pyroxenite	= = =	150.3	103.9	3.24	
138			C-BR-CV/ 4		axe butt fragment	mixed Na-pyroxenite	= = =	109.7	75.9	3.25	
139			C-BR/1		chisel roughout	mixed Na-pyroxenite	presence of both jadeite and omphacite; possible garnets	28.9	20	3.25	
140			C-BR-CV/ 6		axehead fragment	mixed Na-pyroxenite	partially chloritized garnet porphyroblasts; zoisite aggregates	102.6	71.2	3.27	
141			C-FR-N/4		sliver	mixed Na-pyroxenite	= = =	4.1	2.85	3.28	
142			C-FR-SO/18		striker fragment	mixed Na-pyroxenite	= = =	23	16	3.29	XRPD
143			C-FR-SO/49		striker roughout	mixed Na-pyroxenite	pale green jadeite crystals, wrapped in an omphacite matrix	185.4	129.1	3.29	
144			C-BR-CV/ 2		axehead roughout	mixed Na-pyroxenite	= = =	93.2	64.9	3.29	
145			C-FR-SO/91		sliver	mixed Na-pyroxenite	= = =	14.5	10.1	3.30	
146			C-FR-SO/93		sliver	mixed Na-pyroxenite	= = =	13.2	9.2	3.30	
147			C-BR-CV II/1		axehead/striker	mixed Na-pyroxenite	= = =	140.4	98	3.31	
148			C-FR-SO/96		polished sliver	mixed Na-pyroxenite	= = =	27.5	19.2	3.31	
149			C-FR-O/ 6		axehead/striker	mixed Na-pyroxenite	heterogeneous and atypical rock	161.5	113	3.33	
150			C-FR-N/1		axehead fragment	mixed Na-pyroxenite	= = =	110.9	77.6	3.33	
151	69255	BF84 193-194 III		BF9	axehead fragment	mixed Na-pyroxenite	= = =	95.3	66.8	3.34	
152			C-FR-SO/32		small axehead roughout	mixed Na-pyroxenite	= = =	24.8	17.4	3.35	
153			C-FR-SO/43		small axehead roughout	mixed Na-pyroxenite	= = =	29.9	21	3.36	
154			C-FR-SO/69		axe butt fragment	mixed Na-pyroxenite	bright green crystals coupled to pale green ones	36.3	25.5	3.36	
155			C-FR-SO/46		axe butt fragment	mixed Na-pyroxenite	= = =	50.5	35.5	3.37	
156			C-FR-SO/9		pebble fragment	mixed Na-pyroxenite	= = =	61	42.9	3.37	thin section
157			C-FR-O/11		axe butt fragment	mixed Na-pyroxenite	= = =	105.5	74.2	3.37	thin section
158			C-FR-SO/ 1		axehead roughout	mixed Na-pyroxenite	jadeite aggregates in an omphacite matrix; quartz	51.7	36.4	3.38	
159			C-FR-S/1		axehead fragment	mixed Na-pyroxenite	heterogeneous rock; presence of both jadeite and omphacite	24	16.9	3.38	
160			C-FR-N/5		axehead	mixed Na-pyroxenite	presence of both jadeite and omphacite; possible garnets	118.8	83.8	3.39	
161			C-FR-NE/1		axehead fragment	mixed Na-pyroxenite	= = =	19.7	13.9	3.40	XRPD
162			BF-2		axehead fragment/sliver	mixed Na-pyroxenite	= = =	5.2	3.7	3.47	XRPD
163			BR81B/4		sliver	mixed Na-pyroxenite	rutile and ilmenite define lineation; unreliable weighing	2.9	2.1	3.63	
164			C-FR-NE/3		axehead fragment	mixed Na-pyroxenite	too small for reliable weighing	=	=	=	
165			C-FR-SO/78	PIEM 18	big sliver	mixed Na-pyroxenite	= = =	79.1	56.0	3.42	thin section
166			C-FR-SO/87	PIEM 17	big sliver	mixed Na-pyroxenite	= = =	51.7	36.4	3.38	thin section
167	69257	BF235 IV/28		BF28 (agg.)	pestle	mixed Na-pyroxenite	= = =	45	31.5	3.33	
168			C-FR-SO/90		pebble fragment	mixed Na-pyroxenite	= = =	33.8	23.7	3.35	

169			C-FR-SOS/12		grindstone	(undefined lithotype)	= = =	=	=	=	
170			C-FR-SOS/13		(undefined artifact)	(undefined lithotype)	= = =	=	=	=	
171			C-FR-SOS/14		(undefined artifact)	(undefined lithotype)	= = =	=	=	=	
172			C-FR-SOS/15		(undefined artifact)	(undefined lithotype)	= = =	=	=	=	
173			BF-1		axehead fragment	omphacitite	weighing hardly reliable	8.8	5.9	3.06	XRPD
174			C-FR-SO/ 2		sliver roughout	omphacitite	partially regressed omphacitite, covered by carbonates	61	40.1	2.92	
175			C-FR-SO/10		small axehead roughout	omphacitite	several reddish veins with possible quartz	48.6	32.2	2.96	
176			C-FR-SO/53-54-55		three small slivers	omphacitite	with mylonitic structure; too small for reliable weighing	3	2	3.00	
177			C-FR-SO/73		axehead roughout	omphacitite	strongly regressed omphacitite with epidote	177.8	118.7	3.01	
178			C-FR-SO/ 4		sliver	omphacitite	Binoc.: omphacitite a quarzo ed anfibolo	201	136.2	3.10	
179	69360		C FR SO		chisel	omphacitite	omphacitite with chloritoid	7.3	5	3.17	
180			C-FR-NE/5		axehead fragment	omphacitite	presence of zoisite	8.6	5.9	3.19	
181			C-FR-SO/80		sliver	omphacitite	presence of zoisite	12.5	8.6	3.21	
182			C-FR-SO/71		axe fragment/ roughout	omphacitite	= = =	312.7	215.3	3.21	thin section
183			C-FR-O/ 7		axe butt roughout	omphacitite	regressed omphacitite, with chlorite aggregates	65.4	45.2	3.24	
184			C-FR-SO/20		small axe roughout	omphacitite	= = =	49.1	34.1	3.27	
185			C-FR-SO/22		small axe roughout	omphacitite	possible presence of zoisite in pale plagues	22.3	15.5	3.28	
186			C-BR-CV/12		big axe roughout	omphacitite	= = =	534	371.2	3.28	thin section
187			C-FR-SO/38		axe butt fragment	omphacitite	presence of superficial carbonate crusts	12.8	8.9	3.28	
188			C-FR-SO/63		axehead fragment	omphacitite	quite homogeneous rock	45.9	32.2	3.35	
189			C-FR-SO/25		small axe roughout	omphacitite	presence of pseudomorphosis on probable lawsonite	29.5	20.7	3.35	
190			C-FR-O/ 1		striker	omphacitite	= = =	205	144	3.36	
191	69372		C FR SO		axehead fragment	omphacitite	= = =	37.2	26.2	3.38	XRPD
192			C-FR-SO/100		striker/cobble	omphacitite	pyroxene with dark green colour	54.2	38.2	3.39	
193			C-FR-SO/30		recycled axe fragment	omphacitite	= = =	43.4	30.6	3.39	
194			C-FR-SO/6		axe cutting edge draft.	omphacitite	= = =	55.5	39.2	3.40	XRPD
195			C-FR-SO/39		axehead fragment	omphacitite		52.6	37.3	3.44	
196			BF-5		axehead fragment/sliver	omphacitite	pyroxene with dark green colour	3.9	2.8	3.55	XRPD
197	69350		C FR NE	PIEM 27	axehead roughout	omphacitite	partly regressed fine-grained omphacitite, altered on the border	52.4	36.5	3.30	
198	69349		C-FR-SO	PIEM 26	axehead roughout	omphacitite	presence of subordinate jadeite and ilmenite	161.8	113.1	3.33	thin section
199			C-FR-SO/58	PIEM 22	axehead roughout	omphacitite	= = =	74	51.7	3.32	thin section
200			C-FR-SOS/ 1		axe cutting edge fragm.	omphacitite	too small for reliable weighing	=	=	=	
201		BF229 IV/11		BF11 (agg.)	axehead	omphacitite	= = =	22.3	15.5	3.28	
202		BF422-31 III/33		BF33 (agg.)	axehead roughout	omphacitite	= = =	28.9	20.0	3.26	

203		BF 90 I/15		BF15	pebble	prasinite	prasinitic micaschist	164.9	104.2	2.72	
204			C-FR-SO/75		axe roughout/fragment	prasinite	very heterogeneous rock	175.9	115.9	2.93	
205			C-FR-SO/ 5		fragmented pebble	prasinite	= = =	91.8	60.8	2.96	
206			C-FR-SO/33		axe cutting edge draft.	prasinite	= = =	67.4	44.8	2.98	
207	69352		C FR SO		axehead roughout	prasinite	strongly regressed, with abundant albite	84	56.4	3.04	
208			C-FR-SO/98		axe roughout/fragment	prasinite	= = =	214.9	144.4	3.05	
209			C-BR-CV/ 7		axe cutting edge draft.	prasinite	prasinite crossed by veins of possible albite	48	32.3	3.06	
210			C-FR-N/3		axe butt fragment	prasinite	= = =	127.4	86	3.08	
211			C-FR-SO/79		sliver/axe roughout	prasinite	too small for reliable weighing	=	=	=	thin section
212			C-FR-SO/31		axehead roughout	aegirin-augite and chlorite schist	= = =	133.2	93.5	3.36	thin section
213		BF 404 II/27		BF27	axe butt fragment	omphacite/chlorite schist	= = =	60.5	41.2	3.13	
214		BF 252 III/20.1		BF20.1	axe butt fragment	omphacite/chlorite schist	= = =	44.5	30.5	3.18	
215			C-FR-NE/4		axehead fragment	serpentinite	= = =	16.3	9.8	2.51	
216	69258	BF 163-164/179-180 III		BF31	axehead	serpentinite	antigoritic serpentinite	21.9	13.3	2.55	
217			C-FR-SOS/ 4		axe cutting-edge fragm.	serpentinite	altered serpentinite	27.6	17	2.60	
218			C-FR-SOS/ 9		sliver	serpentinite	= = =	12.5	7.7	2.60	
219			C-FR-SO/45		axehead roughout	serpentinite	= = =	50.9	31.5	2.62	
220			C-FR-SO/72		smoother/grindstone	serpentinite	= = =	85	52.7	2.63	
221			C-FR-SO/99		sliver	serpentinite	= = =	16.9	10.5	2.64	
222			C-FR-O/5		disc-ring roughout	serpentinite	= = =	230.9	144	2.66	
223			C-FR-O/13		pebble fragment	serpentinite	= = =	73	46.3	2.73	
224			C-FR-SO/74		axe roughout/fragment	serpentinite	= = =	144.5	94	2.86	
225		BF 247 IV/14.2		BF14.2	small sliver	serpentinite	antigoritic serpentinite; too small for reliable weighing	=	=	=	
226		BF 279 III/26.2		BF26.2	sliver	serpentinite	antigoritic serpentinite; too small for reliable weighing	=	=	=	
227		BF131-132 147-148-II/12		BF12 (agg.)	disc-ring roughout	serpentinite	= = =	118.2	72.7	2.58	
228		BF163-180 II/16		BF16 (agg.)	disc-ring roughout	serpentinite	= = =	84.7	52.3	2.62	
229		BF235 II/18.1		BF18.1 (agg.)	sliver	serpentinite	too small for reliable weighing	=	=	=	
230		BF266 III/18.2		BF18.2(agg.)	sliver	serpentinite	too small for reliable weighing	=	=	=	
231	69261	BF 159 IV			axehead	steatite	too small for reliable weighing	=	=	=	

Table 1. Inventory codes, label, typology, preliminary lithotype determination and density value of the 231 polished stone implements and artefacts coming from the archaeological site of Brignano Frascata, based on density measurements and stereo-microscopy observations in reflected light of the tools polished or raw surfaces; the related treatments for analytical purposes are also indicated.

	State Inventory	Excavation inventory	Other inventories	Label	Implement description	Lithotype	Notes (stereomicroscopy in reflected light/density)	Weight in air	Weight in H_2O	Density	Sampling
1			C-MP-I/ 7		striker fragment	serpentinite	= = =	82.5	51.4	2.65	
2			C-MP-CA/37		disc-ring roughout	serpentinite	= = =	76.9	48.0	2.66	
3			C-MP-CA/126	C-MP-C/ 1	ascia abbozzo	serpentinite	= = =	146	91.2	2.66	
4			C-MP-CA/ 1		anellone fr.	serpentinite	= = =	83.7	52.3	2.67	
5			C-MP-CV/ 6		discoidal pendant	serpentinite	= = =	10	6.3	2.70	
6			C-MP-CA/131	C-MP-C/ 6	axehead fragm./roughout	serpentinite	= = =	20.6	13	2.71	
7			C-MP-CA/133	C-MP-C/ 8	pebble/disc-ring roughout	serpentinite	= = =	305.3	196.4	2.80	
8			C-MP-CA/132	C-MP-C/ 7	sliver	prasinite	= = =	20.3	13.4	2.94	
9			C-MP-CA/ 3		axehead fragm./roughout	prasinite	= = =	36.9	24.5	2.98	
10			C-MP-CA/129	C-MP-C/ 4	big sliver	omphacitite	possible presence of zoisite	158.2	105.7	3.01	
11			C-MP-CA/135	C-MP-C/10	sliver	omphacitite	possible presence of zoisite	65.3	44.9	3.20	
12			C-MP-CA/127	C-MP-C/ 2	axehead fragment.	omphacitite	= = =	140.2	97.2	3.26	
13			C-MP-I/1		axehead/striker fragment	garnet-omphacitite	presence of rare garnets	108.3	75.8	3.33	thin section
14			C-MP-I/3		ascia fr. tagliente	garnet-omphacitite	presence of rare garnets; too small for reliable weighing	=	=	=	
15			C-MP-CV/ 3		axehead fragment.	mixed Na-pyroxenite	presence of rare garnets	55.7	38.4	3.22	
16			C-MP-CA/39		axe butt fragment	mixed Na-pyroxenite	presence of both jadeite and omphacite	127.2	88.7	3.30	
17			C-MP-I/ 4		axe butt fragment	mixed Na-pyroxenite	no garnets are observed	25.7	18.1	3.38	
18			C-MP-CA/130	C-MP-C/ 5	axe/sliver fragment	mixed Na-pyroxenite	= = =	7.6	5.5	3.62	
19			C-MP-CA/128	C-MP-C/ 3	axehead fragment.	jadeitite	= = =	183	128.2	3.34	thin section
20			C-MP-CV/ 4		striker fragment	eclogite	banded eclogite, with garnet-rich and omphacite-rich levels	86.5	58.5	3.09	
21			C-MP-CA/134	C-MP-C/ 9	sliver	eclogite	presence of zoisite aggregates	68.1	46.8	3.20	
22			C-MP-CV/ 2		axehead roughout	eclogite	= = =	96.1	66.1	3.20	
23			C-MP-CA/ 7		axehead roughout	eclogite	= = =	492.8	339	3.20	
24			C-MP-CA/ 6		sliver	eclogite	presence of zoisite	165.3	114.4	3.25	
25			C-MP-CV/ 5		chisel roughout/fragm.	eclogite	fine-grained eclogite with oriented omphacite crystals	55.3	38.8	3.35	
26			C-MP-CA/38		small sliver	eclogite	= = =	11.5	8.1	3.38	
27			C-MP-CA/2		axehead fragment	eclogite	= = =	63.2	44.6	3.40	thin section
28			C-MP-CA/5		sliver	eclogite	= = =	10.2	7.2	3.40	
29			C-MP-I/ 5		striker fragment	eclogite	= = =	53	37.6	3.44	
30			C-MP-I/6		striker fragment	eclogite	= = =	36.7	26.1	3.46	XRPD
31			C-MP-I/ 2		striker	eclogite	eclogite with mylonitic structure; 2 different pyroxenes	30.4	21.8	3.53	
32			C-MP-CV/1		axe butt fragment	eclogite	= = =	70.3	50.6	3.57	XRPD

33			C-MP-CA/4		small sliver	eclogite	too small for reliable weighing	3.7	2.7	3.70	
34			C-MP-CA/136	C-MP-C/25	axehead fragment	eclogite	too small for reliable weighing	=	=	=	

Table 2. Inventory codes, label, typology, preliminary lithotype determination and density value of the 34 polished stone implements and artefacts coming from the archaeological site of Momperone, based on density measurements and stereo-microscopy observations in reflected light of the tools polished or raw surfaces; the related treatments for analytical purposes are also indicated.

	State Inventory	Excavation inventory	Other inventories	Label	Implement description	Lithotype	Notes (stereomicroscopy in reflected light/density)	Weight in air	Weight in H_2O	Density	Sampling
1			VRM/10		axehead roughout	serpentinite	= = =	118.2	72.7	2.60	
2			VRM/11		pebble/smoother	serpentinite	= = =	67.5	42	2.65	
3			VRM/13		pebble/smoother	serpentinite	= = =	46.5	29	2.66	
4			VRM/15		(undefined artifact)	serpentinite	= = =	144.9	90.4	2.66	
5			VRM/14		pebble/sliver	serpentinite	= = =	75.8	47.3	2.66	
6			VRM/2		grindstone fragment	serpentinite	= = =	218.4	136.3	2.66	
7			VRM/5		flat pebble/axe roughout	serpentinite	= = =	307.5	192.5	2.67	
8			VRM/12		pebble/smoother	serpentinite	= = =	13.2	8.4	2.75	
9			VRM/1		grindstone fragment	serpentinite	= = =	598.4	387	2.83	
10			VRM/9		axehead roughout	serpentinite	= = =	131.6	85.2	2.84	
11			VRM/6		axehead fragment	mixed Na-pyroxenite	= = =	28	19.6	3.33	XRPD
12			VRM/16		axehead fragment	mixed Na-pyroxenite	= = =	48.1	33.7	3.34	XRPD
13			O-VR-CR/3		axehead fragment	mixed Na-pyroxenite	= = =	21.2	14.8	3.31	
14			VRM/8		axe	jadeitite	= = =	189.8	130.9	3.22	
15			VRM/20		axe	jadeitite	= = =	140.7	98.7	3.35	XRPD
16			VRM/4		axe	eclogite	banded eclogite, with garnet-rich and omphacite-rich levels	236.9	164.7	3.28	
17			VRM/19		big axe	eclogite	presence of very small garnets	529.8	375.3	3.43	
18			VRM/3		axehead fragm./roughout	eclogite	presence of rutile and/or ilmenite	130.8	93	3.46	
19			VRM/18		axe	eclogite	= = =	323.6	231.4	3.51	
20			O-VR-CR/2		axehead fragment	eclogite	= = =	56.5	39.8	3.38	
21			O-VR-CR/1		axehead fragm./roughout	eclogite	= = =	261.7	186.5	3.48	thin section
22			VRM/7		axehead fragment	(undefined lithotype)	too small for reliable weighing	=	=	=	
23			O-VR-CR/4		striker fragment	omphacitite	= = =	120.7	84.6	3.34	

Table 3. Inventory codes, label, typology, preliminary lithotype determination and density value of the 23 polished stone implements and artefacts coming from the archaeological site of Villaromagnano, based on density measurements and stereo-microscopy observations in reflected light of the tools polished or raw surfaces; the related treatments for analytical purposes are also indicated

Inventory code	Sample code/label	Site	Typology	Notes	Density (g/cm^3)	Analyses XRPD	O.M.	SEM	Picture
Na-PYROXENE ROCKS									
JADEITITES: 17									
69262	BF 230 II	Brignano Frascata	grindstone	irreg. spheroidal morphology; flat-convex sect.	3.30	X	X	X	(1)
=	C-FR-NO/2	Brignano Frascata	big sliver	strong zoning of Na-Pyroxenes	3.27	X	X	X	(2)
=	C-FR-SO/41	Brignano Frascata	striker fragment	=	3.37	X	X	X	(3)
=	C-FR-SO/94	Brignano Frascata	disc-ring roughout	granoblastic structure	3.27		X		(4)
=	C-FR-SO/57	Brignano Frascata	axehead roughout	=	3.33		X		(5)
=	C-FR-SO/65	Brignano Frascata	striker fragment	accessory: white mica	3.30		X		(6)
=	C-FR-NE/7	Brignano Frascata	axehead fragment	igneous cpx relicts; granoblastic structure	3.46		X		(7)
=	BF-3	Brignano Frascata	axe roughout/sliver	pale green hue	3.25	X			(8)
=	BR81-B/2	Brignano Frascata	small axe sliver	dark green hue; accessory: Fe-glaucophane	3.50	X			=
BF161-178II/19	BF19*	Brignano Frascata	axehead fragment	accessory: white mica	3.22		X		(9)
BF268II/20.2	BF20.2*	Brignano Frascata	axehead fragment	=	3.26		X		=
74918	BF21*	Brignano Frascata	axehead	Ti-rich Na-pyroxene	3.43		X		=
BF454-463I/23	BF23*	Brignano Frascata	axehead fragment	rich in phengite	3.32		X		(10)
BF-E31	BF25*	Brignano Frascata	striker	parallelepiped-shaped; flat-convex section	3.16		X		(11)
BF89II/32	BF32*	Brignano Frascata	manufacture sliver	=	3.34		X		(12)
C-MP-C/3	C-MP-CA/128	Momperone	axehead fragment	homogeneous rock	3.34	X	X	X	(13)
=	VRM/20	Villaromagnano	axe		3.35	X			(14)
OMPHACITITES: 17									
=	C-BR-CV/12	Brignano Frascata	big axe roughout	=	3.28	X	X	X	(15)
=	C-FR-SO/71	Brignano Frascata	axe fragment/roughout	arched cutting edge	3.21	X	X	X	(16)
=	C-FR-SO/58	Brignano Frascata	axe fragment/roughout	acc: Mg-chlorite probably after garnet	3.32		X		(17)
69349	69349	Brignano Frascata	axehead roughout	isosc. triang.-shaped, flat-convex sect.; ilmenite	3.33		X		(18)
69350	69350	Brignano Frascata	axehead roughout	triang.-shaped, biconvex sect.; omph. regressed	3.30		X		(19)
=	BF-1	Brignano Frascata	axe fragment/sliver	=	3.06	X			(20)
=	BF-5	Brignano Frascata	axe fragment/sliver	dark green hue	3.55	X			(21)
69372	69372	Brignano Frascata	axehead fragment	indef. shape, biconvex sect., arched cutting edge	3.38	X			(22)
=	C-FR-SO/6	Brignano Frascata	axe cutting edge draft.	homogen. omphacite; acc. nepheline	3.40	X			(23)
=	C-FR-SO/31	Brignano Frascata	axehead roughout	Ae-augite-chlorite schist	3.36	X	X	X	(24)
BF229 IV/11	BF11*	Brignano Frascata	axehead	=	3.28		X		=
BF422-31III/33	BF33*	Brignano Frascata	axehead roughout	=	3.26		X		=
BF 252III/20.1	BF20.1*	Brignano Frascata	axe butt fragment	omphacitic-chloritic schist; abundant omphacite	3.18		X		(25)
BF 404 II/27	BF27*	Brignano Frascata	axe butt fragment	omphacite-chlorite schist; partly regressed omph.	3.13		X		(26)
=	C-GR-III/5	Gremiasco	sliver	=	3.45	X			(27)
=	GG56/834	Gremiasco	axe	zoisite pseudom. after laws.;calcite, quartz acc. min.	3.24	X			=
=	CSN93/1	Casalnoceto	axehead fragment	=	3.36	X			=
MIXED Na-PIROXENITES: 12									
=	C-FR-O/11	Brignano Frascata	axe butt fragment	accessory: magnetite and hematite	3.37	X	X	X	(28)
=	C-FR-SO/90	Brignano Frascata	pebble fragment	=	3.35	X	X	X	(29)
=	C-FR-SO/87	Brignano Frascata	big sliver	isolated garnet (?)	3.38		X		(30)
=	C-FR-SO/78	Brignano Frascata	big sliver	=	3.42		X		(31)
=	C-FR-NE/1	Brignano Frascata	axehead fragment	=	3.40	X			(32)
=	C-FR-SO/18	Brignano Frascata	striker fragment	=	3.29	X			(33)
=	BF-2	Brignano Frascata	axe fragment/sliver	accessory: hematite	3.47	X			(34)
=	BF-4	Brignano Frascata	axe fragment/sliver	=	3.26	X			(35)
BF84 193-194III	BF9*	Brignano Frascata	axehead fragment	indef. shape, flat-convex sect.,linear cutting-edge	3.34		X		(36)
BF235 IV/28	BF28*	Brignano Frascata	pestle	=	3.33		X		=
=	VRM/6	Villaromagnano	axehead fragment	=	3.33	X			(37)
=	VRM/16	Villaromagnano	axehead fragment	=	3.34	X			(38)

Table 4. Minero-petrographic characterization of 46 polished stone implements (12 of which, marked by '*', also described by D'Amico et al., 2000) in 'Na-pyroxene rocks' from Brignano Frascata and/or other coeval archaeological sites in the Grue, Curona and Ossona valleys, analysed by XRPD, optical polarizing microscope and/or SEM-EDS, as indicated. In the last column, numbers refer to pictures in Figs. 4 and 5.

Na-PYROXENE + GARNET ROCKS									
Inventory code	**Sample code/label**	**Site**	**Typology**	**Notes**	**Density (g/cm^3)**	**Analyses XRPD**	**O.M.**	**SEM**	**Picture**
ECLOGITES: 27									
=	C-FR-SOS/8	Brignano Frascata	sliver	portions richer in garnets and others in pyrox.	3.43	X	X	X	(39)
=	C-FR-SO/59	Brignano Frascata	axe fragment/roughout	=	3.45	X	X	X	(40)
=	C-FR-SO/48	Brignano Frascata	axe butt fragment	garnet composition: Grs_{90} Adr_{10}	3.45	X	X	X	(41)
=	C-FR-O/14	Brignano Frascata	axehead fragment	garnets also with skeletal habit	3.51	X	X	X	(42)
=	C-FR-SO/12	Brignano Frascata	axehead roughout	portions with jadeitic composition	3.39	X	X	X	(43)
69353	69353	Brignano Frascata	chisel roughout	rectang.shape, biconv.sect; chloritoid, chlorite, epidote	3.37		X		(44)
69355	69355	Brignano Frascata	axehead roughout	indef. shape, arched cutting-edge; chloritoid rich	3.40		X		(45)
69356	69356	Brignano Frascata	axehead	isosceles triang.shape; atoll-like garnets & rutile	3.48		X		(46)
69361	69361	Brignano Frascata	axehead roughout	trapez.shape,flat-convex sect.;zoisite, lawson.,glaucoph.	3.38		X		(47)
69362	69362	Brignano Frascata	axehead roughout	trapezoidal shape, biconvex section, arched cutting-edge	3.42		X		(48)
17	C-FR-SO/76	Brignano Frascata	axe fragment/roughout	=	3.36	X			(49)
BF420-429/10	BF10*	Brignano Frascata	manufacture sliver	retrogressed garnet, zoisite	3.35		X		(50)
BF227-8 243-4III/1	BF13*	Brignano Frascata	striker	=	3.44		X		=
BF 102IV/14.1	BF14.1*	Brignano Frascata	axehead roughout	coarse-grained eclogite	3.57		X		(51)
69248	BF17*	Brignano Frascata	striker	=	3.52		X		=
69250	BF22*	Brignano Frascata	axehead	=	3.49		X		(52)
BF 4/5 II	BF24*	Brignano Frascata	pebble	accessory mineral: glaucophane	3.21		X		(53)
69253/BF 279 III	BF26.1*	Brignano Frascata	axehead	trapezoidal shape, flat-convex sect.,thinned cutting-edge	3.41		X		(54)
69254	BF30*	Brignano Frascata	striker	=	3.48		X		=
69249	BF35.1*	Brignano Frascata	striker	=	3.47		X		=
BF163-179III35.2	BF35.2*	Brignano Frascata	manufacture sliver	=	3.50		X		=
=	C-FB-C/1	Fabbrica Curone	axe fragment/roughout	=	3.55	X			=
=	C-MP-CA/2	Momperone	axeheah fragment	Ae-rich Na-pyroxene	3.40	X	X	X	(55)
=	C-MP-CV/1	Momperone	axe butt fragment	=	3.57	X			(56)
=	C-MP-I/6	Momperone	striker fragment	=	3.46	X			(57)
=	S-BI-I/2	Pozzol Groppo	axe fragment/roughout	=	3.31	X			(58)
=	O-VR-CR/1	Villaromagnano	axe fragment/roughout	=	3.48	X	X	X	(59)
GARNET-OMPHACITITES: 2									
69238	69238	Casalnoceto	axe fragment/roughout	sub-trapezoid.shape; arched cutting-edge; rare garnets	3.38	X	X	X	=
=	C-MP-I/1	Momperone	axe/striker fragment	rare garnets and pumpellyite	3.33	X	X	X	(60)

Table 5. Minero-petrographic characterization of 29 polished stone implements (10 of which, marked by '*', also described by D'Amico et al., 2000) in 'Na-pyroxene + garnet rocks' from Brignano Frascata and/or other coeval archaeological sites in the Grue, Curona and Ossona valleys, analysed by XRPD, optical polarizing microscope and/or SEM-EDS, as indicated. In the last column, numbers refer to pictures in Figs. 5 and 6.

OTHER LITHOTYPES Inventory code	Sample code/label	Site	Typology	Notes	Density (g/cm^3)	Analyses XRPD	O.M.	SEM	Picture
QUARTZ-ARENITE: 1									
=	CN 91-102	Casalnoceto	millstone fragment	=	=	X	X	X	=
GLAUCOPHANITES (BLUESCHISTS): 3									
=	C-FR-SO/60	Brignano Frascata	axe fragment/roughout	acc. minerals: garnet, jadeite and quartz	=		X		(61)
69354	69354	Brignano Frascata	axehead roughout	isosc.triang.-shaped, irreg.sect, large talon; albite	=		X		(62)
69357	69357	Brignano Frascata	axehead roughout	indef. shape; irreg. sect.; acc.epidote,garnet,rutile	=		X		=
BASIC GRANULITES: 3									
BF 263 II/29.1	BF29.1*	Brignano Frascata	disc-ring roughout	=	2.82		X		=
BF263 II/29.2	BF29.2*	Brignano Frascata	disc-ring roughout	=	2.85		X	X	(63)
BF 310 II/34	BF34*	Brignano Frascata	disc-ring roughout	=	2.87		X		(64)
ANTIGORITIC SERPENTINITES: 7									
BF131/2-147/8-II/1	BF12*	Brignano Frascata	disc-ring roughout	=	2.58		X		(65)
BF 247IV/14.2	BF14.2*	Brignano Frascata	manufacture sliver	=	=		X		(66)
BF163-180II/16	BF16*	Brignano Frascata	disc-ring roughout	=	2.62		X		=
BF235 II/18.1	BF18.1*	Brignano Frascata	manufacture sliver	=	=		X		=
BF266 III/18.2	BF18.2*	Brignano Frascata	manufacture sliver	=	=		X		=
BF 279 II/26.2	BF26.2*	Brignano Frascata	manufacture sliver	magnetite aggregates	=		X		(67)
BF 163/4-179/80 II	BF31*	Brignano Frascata	axe	irreg.triang-shaped; flat-convex sect.;linear cutting-edge	2.55		X		(68)
PRASINITIC MICASCHIST: 1									
BF 90 I/15	BF15*	Brignano Frascata	pebble	=	2.72		X		(69)
LAWSONITE-ALBITE FELS: 1									
BF262 IV-V/20.3	BF20.3*	Brignano Frascata	small pebble	=	=		X		=

Table 6. Minero-petrographic characterization of 16 polished stone implements (12 of which, marked by '*', also described by D'Amico et al., 2000) made of lithotypes different than 'Na-pyroxenites' and 'Na-pyroxene + garnet rocks' from Brignano Frascata and/or other coeval archaeological sites in the Grue, Curona and Ossona valleys, analysed by XRPD, optical microscopy in plane-polarized light and/or SEM-EDS as indicated. In the last column, numbers refer to pictures in Fig. 7.

Na-PYROXENE ROCKS

Legend: ○ <5% ◗ 5% - 20% ● 20% - 60% ⬤ >60%

JADEITITES	**omphacite**	**jadeite**	**garnet**	**chloritoid**	**quartz**	**glaucophane**	**amphibole**	**zoisite**	**clinozoisite-epidote**	**white mica**	**chlorite**	**albite**	**rutile**	**ilmenite**	**titanite**	**zircon**	**apatite**	**allanite**	**sulphides**	**oxides**	**Notes**
C-FR-SO/41	○	⬤													○	○					
C-FR-NO/2	◗	⬤														◗		○			access. crystals with Y/Ir
BF 230 II	○	⬤			○								◗		○	◗					accessory: native Cu
C-MP-CA/128	○	⬤													○	○					From Momperone
C-FR-SO/94	○	⬤						○		◗			○			○					
C-FR-SO/57	○	⬤													◗	○					
C-FR-SO/65	○	⬤								◗						◗					
C-FR-NE/7	○	⬤						◗		◗			◗		○						
BF19	○	⬤													◗	◗					descr. D'Amico et al.2000
BF20.2	○	⬤								◗					◗	○					descr. D'Amico et al.2000
BF21	○	⬤											◗		○						descr. D'Amico et al.2000
BF23	○	⬤							◗	◗					◗	○					Ti-rich pyroxene
BF25	○	⬤			○					◗		○	◗			◗					descr. D'Amico et al.2000
BF32	○	⬤													◗	○					descr. D'Amico et al.2000
OMPHACITITES																					
C-BR-CV/12	⬤	○			◗				◗	◗	◗	◗						○		○	
C-FR-SO/71	⬤	○									◗				○				◗		
C-FR-SO/58	⬤										◗			○							
69349	⬤										◗			○							
69350	⬤																				
C-FR-SO/31	●								◗		●	◗		●	○		○				
BF11	⬤						○								◗	○					descr. D'Amico et al.2000
BF33	⬤							◗		◗			○						○		descr. D'Amico et al.2000
BF20.1	●							◗		◗	●				◗						Omphacite-schist descr. by D'Amico et al.2000
BF27	●							◗		◗	●										Omphacite-schist descr. by D'Amico et al.2000
MIXED Na-PYROXENITES																					
C-FR-O/11	●	●												○						○	Ti-rich pyroxene
C-FR-SO/90	●	●											◗			○					
C-FR-SO/87	●	●	○										◗								
C-FR-SO/78	●	●									◗		◗			○					
BF9	●	●												◗	○		○				descr. D'Amico et al.2000
BF28	●	●											◗			◗					descr. D'Amico et al.2000

Table 7. Mineralogical composition (vol. %) of 30 'Na-pyroxene rocks' (jadeitite, omphacitite and mixed Na-pyroxenite) studied in thin section by means of the optical polarizing microscope and/or SEM-EDS. All samples are from Brignano Frascata, except when otherwise indicated.

Na-PYROXENE + GARNET ROCKS

Legend ○ <5% ◗ 5% - 20% ● 20% - 60% ⬤ >60%

ECLOGITES	omphacite	jadeite	garnet	chloritoid	quartz	glaucophane	amphibole	zoisite	clinozoisite-epidote	white mica	chlorite	albite	rutile	ilmenite	titanite	zircon	apatite	allanite	sulphides	oxides	Notes
C-FR-SOS/8	●		●								●							○			
C-FR-SO/59	●	○	●			○			○	○	●	◗	◗	○			○				
C-MP-CA/2	●	○	◗								●		◗	○			○	○			From Momperone
C-FR-SO/48	⬤		◗								◗		○	◗	○						
O-VR-CR/1	⬤	○	◗			○							◗		○			○			From Villaromagnano
C-FR-O/14	●		●		○									●					○		
C-FR-SO/12	●	●	●												◗	○	◗				
69353	⬤		◗								●			◗							
69355	⬤		◗	◗																	
69356	●		●																		
69361	●	◗	◗			●															
69362	⬤		◗										◗	◗							
BF10	⬤		◗					◗	◗	◗	●			○	○		○				descr. D'Amico et al. 2000
BF13	⬤		◗						◗	◗			◗		○						descr. D'Amico et al. 2000
BF14.1	⬤		◗								◗						◗				descr. D'Amico et al. 2000
BF17	⬤		◗														◗	◗			descr. D'Amico et al. 2000
BF22	⬤		◗										◗				◗				descr. D'Amico et al. 2000
BF24	●	○	◗			◗			◗		◗		◗		○			○			descr. D'Amico et al. 2000
BF26.1	●		●						○	○	◗		○	○	○						descr. D'Amico et al. 2000
BF30	●		●						○	○	◗		○		○						descr. D'Amico et al. 2000
BF35.1	⬤		◗					◗		◗	◗		○	○							descr. D'Amico et al. 2000
BF35.2	●		●										○	○							descr. D'Amico et al. 2000
GARNET-OMPHACITITES																					
69238	⬤	○	◗								◗				◗		◗				From Casalnoceto
C-MP-I/1	⬤		◗												◗						From Momperone

Table 8. Mineralogical composition (vol. %) of 24 'Na-pyroxene+garnet rocks' (eclogite and garnet-omphacitite) studied in thin section by means of the optical polarizing microscope and/or SEM-EDS. All samples are from Brignano Frascata, except when otherwise indicated.

BASIC GRANULITES

Legend ○ <5% ◗ 5% - 20% ● 20% - 60% ⬤ >60%

	anorthite	olivine	amphibole	orthopyroxene	clinopyroxene	spinel	hornblende	pumpellyite	Notes
BF29.1	●	◗	◗	●	◗	◗			described by D'Amico et al. (2000)
BF29.2	●	◗	◗	●	◗	◗	○	○	described by D'Amico et al. (2000)
BF34	●	◗	◗	●	◗	◗	○	○	described by D'Amico et al. (2000)

Table 9. Mineralogical composition (vol. %) of 3 mafic granulites studied in thin section by means of the optical polarizing microscope and/or SEM-EDS. All samples are from Brignano Frascata.

Figure Captions

Figure 1. Map of Northern Italy: main towns are indicated, as well as the location of the Monviso (Vi) and Voltri (Vo) massifs – possible sources for the supply of raw materials. The location of the archaeological site of Brignano Frascata and other close ones in the Curone, Grue and Ossona valleys (Momperone, Villaromagnano, Casalnoceto, Gremiasco, Fabbrica Curone, Pozzol Groppo, Volpeglino, Viguzzolo and Sale) is indicated by the small blue rectangle (more specific information about the position of each site is provided in Fig. 16a). The location of eight coeval archaeological sites [1) Alba, 2) Castello di Annone, 3) Gaione; 4) Ponte Ghiara; 5) Rivanazzano; 6) Rocca di Cavour; 7) Sammardenchia; 8) San Lazzaro di Savena)], taken into account for archaeometric comparison, is also shown.

Figure 2. Neolithic polished greenstone implements (all from Brignano Frascata, except when otherwise indicated); **a**) instruments for cutting (axehead roughouts and/or fragments): i) C-FR-O/6, ii) C-FR-O/1, iii) C-FR-N/5, iv) C-FR-SO/48, v) C-FR-SO/45, vi) C-FR-SO/20; **b**) disc-ring roughouts and fragments at different working steps: i) C-MP-CA/133 (from Momperone), ii) C-FR-O/5, iii) BF29.2, iv) BF12, v) C-FR-SO/94.

Figure 3. a) Density histogram and b) lithotype distribution of 231 archaeological implements from Brignano Frascata, obtained by combining density measurements and stereo-microscopic observations. Lithotype distribution of similar implements from the sites of c) Momperone (34 tools) and d) Villaromagnano (23 tools).

Figure 4. Photographs of Neolithic greenstone implements in 'Na-pyroxene rocks' from Brignano Frascata and other nearby sites in the Curone, Grue and Ossona valleys, investigated with an in-depth mineral-petrographic approach; numbers refer to the last column of Table 4.

Figure 5. Photographs of Neolithic greenstone implements in 'Na-pyroxene rocks' (21-38) and 'Na-pyroxene+garnet rocks' (39-40) from Brignano Frascata and other nearby sites in the Curone, Grue and Ossona valleys, investigated with an in-depth mineral-petrographic approach; numbers refer to the last column of Tables 4 and 5.

Figure 6. Photographs of Neolithic greenstone implements in 'Na-pyroxene+garnet rocks' from Brignano Frascata and other nearby sites in the Curone, Grue and Ossona valleys, investigated with an in-depth mineral-petrographic approach; numbers refer to the last column of Table 5.

Figure 7. Photographs of Neolithic implements in lithotypes different than 'Na-pyroxene rocks' and 'Na-pyroxene+garnet rocks' from Brignano Frascata and other nearby sites in the Curone, Grue and Ossona valleys, investigated with an in-depth mineral-petrographic approach; numbers refer to the last column of Table 6.

Figure 8. X-ray powder diffraction pattern of: a) a jadeitite (BF-230-II) and b) a mixed Na-pyroxenite (C-FR-SO/90) from Brignano Frascata. While in the former the reflections typical of clinopyroxenes – i.e., $\overline{2}21$, 310 and 002 – are single, in the latter they are split (magnification in the upper right square) due to the presence of both jadeite (Jd) and omphacite (Omph) (wavelength: Cu-Kα radiation).

Figure 9. Compositional variation of pyroxenes in 'Na-pyroxene rocks' analyzed by SEM-EDS (4 jadeitites, 3 omphacitites and 2 mixed Na-pyroxenites plotted in the ternary diagram of Morimoto et al., 1988).

Figure 10. Compositional variation of 'Na-pyroxene + garnet rocks' analyzed by SEM-EDS [pyroxenes and garnets, plotted in the ternary diagram of Morimoto et al., 1988 and in the grossular (Grs) – pyrope (Prp) – almandine + spessartine (Alm+Sps) diagram, respectively; arrows indicate the compositional zoning from core (C) to rim (R) of 7 eclogites and 2 garnet-omphacitites].

Figure 11. Thin section photomicrographs of jadeitite: a) squat, prismatic jadeite blasts (Jd) containing small inclusions with omphacitic composition (Omph); euhedral zircons (Zrn) are also observed (BF-230 II; photomicrograph, plane-polarized light); b) granoblastic aggregates of idioblastic jadeite crystals (dark grey: Jd) surrounding small plagues with omphacitic composition (light grey: Omph); zircons (Zrn) are also observed (C-MP-CA/128; SEM image, BSE).

Figure 12. Thin section photomicrographs of mixed Na-pyroxenite: a) whitish pyroxene matrix in which fine-grained jadeite aggregates (Jd.1), alternating to bigger Jd crystals (tens of µm across: Jd.2), surround a greener, Ca-richer omphacite porphyroblast (Omph); brown rutile crystals (Rt) are also observed (C-FR-SO/90; optical polarizing microscope, plane-polarized light). b) pyroxene matrix in which an omphacitic weave (light grey: Omph) surrounds and crosses fragmented jadeite blasts (dark grey: Jd), which contain small omphacite inclusions (C-FR-O/11; SEM image, BSE).

Figure 13. Thin section photomicrographs of eclogite: **a**) small garnet (Grt) with tiny inclusions in the core surrounded by a zoned pyroxene matrix, composed of prismatic Fe-rich omphacite (Omph.1) with yellow-to-bluish pleochroism (Ti up to 5%) and less coloured, fine-grained Fe-poorer pyroxenes (Omph.2); opaque ores (Op) are sulphides (C-FR-O/14; optical polarizing microscope, plane-polarized light). **b**) pyroxene matrix where small jadeite domains (dark grey: Jd) appear amidst a prevailing Fe-rich, zoned omphacite (light grey: Omph). Foliation is defined by alignments of small titanite crystals (Ttn) (O-VR-CR/1; SEM image, BSE).

Figure 14. Photomicrograph of a mafic granulite, made of Ca-plagioclase (Pl) (partially regressed to zoisite and rarer pumpellyite), orthopyroxene (Opx), clinopyroxene (Cpx), green hercynitic spinel (Hc) and brown hornblende (Ho) (BF29.2; optical polarizing microscope, crossed polarizers).

Figure 15. Geologic jadeitite from the Val Lemme (VL14): a) thin section photomicrograph, in which granoblastic aggregates of idioblastic jadeite crystals (dark grey: Jd) surround small plagues with omphacitic composition (light grey: Omph; SEM image, BSE – compare with Fig. 11b); b) compositional variation of pyroxenes, analyzed by EDS and plotted in the ternary diagram of Morimoto et al. (1988).

Figure 16. a) Map of the southeastern part of Piemonte region with the location of the investigated archaeological sites (related numbering proceeding from Fig. 1): 9) Brignano Frascata, 10) Momperone, 11) Villaromagnano, 12) Casalnoceto, 13) Gremiasco, 14) Fabbrica Curone, 15) Pozzol Groppo, 16) Volpeglino, 17) Viguzzolo, 18) Sale. The red polygon corresponds to the area represented in Fig. 16b. b) Geological scheme of the southeastern

part of the study area (see red polygon in Fig. 16a). The distribution of the lithostratigraphic units of the Tertiary Piemonte Basin succession containing meta-ophiolitic pebbles (**mor**: Costa Cravara Breccia and Molare Formation; **sav**: Savignone Conglomerate; **mst**: Monastero Formation) is shown, as well as the distribution of Quaternary alluvial deposits (**tal**; **all**). Geological boundaries redrawn from Piana et al. (in the press), for the Piemonte part, and from Servizio Geologico d'Italia (1969a, b, c; 1971), Marroni et al. (2010), and Vercesi et al. (2014), for the Liguria and Lombardia part. Within the Savignone Conglomerate and the Monastero Formation, the distinction of the conglomerate bodies containing meta-ophiolitic clasts ($\mathbf{sav_c}$; $\mathbf{mst_c}$) has been possible only for the area delimited by the dashed line, corresponding to the northwestern part of the Cabella Ligure sheet of the Geological Map of Italy at 1:50.000 (Marroni et al., 2010).