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(Article begins on next page)

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

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10
11 **Abstract**

12
13 The Neolithic *greenstone* industry of Brignano Frascata (Province of Alessandria, Piemonte
14 Region, Northern Italy) was investigated with an archaeometric approach involving both morpho-
15 typological and mineral-petrographic methods, in order to reconstruct the manufacturing
16 techniques/habits and locate the supply sources of the raw materials. The outcomes were compared
17 with those collected on similar tools from other sites of the same region, namely in the Grue,
18 Ossona and Curone valleys, as well as others resulting from a pilot comparative study on analogous
19 geological specimens from close Quaternary alluvial and/or Oligocene conglomeratic deposits. This
20 survey proved that Brignano Frascata should be considered as a local *atelier* for the
21 production/trade of polished stone implements in Neolithic, devoted to daily uses with no ritual
22 purposes. Several indicators point to an *in situ* manufacturing (high number of retrieved
23 roughouts/fragmented tools, broken during production/use), which also fed trade/exchange forms on
24 short-to-medium distances. Although displaying gross processing features and lack of finishing,
25 these tools show an excellent selection of lithologies, marked by predominance of 'Na-pyroxene
26 rocks'. Several mineral-petrographic resemblances are observed with analogous geological samples
27 from local sources, as well as with coeval implements from other Northern Italy sites, suggesting a
28 common supply source or the existence of a trade channel. By considering the mineral-chemical
29 features of the rocks used to produce these tools, referred to the particular geologic context of
30 discovery (eastern part of the Voltri Group), the chance for the raw materials to derive from
31 secondary deposits of close conglomeratic formations and/or alluvial beds of streams flowing in the
32 adjoining valleys is proposed.

33
34 **Key-words:** Neolithic *greenstone* implement; eclogite; Na-pyroxenite; jadeitite; omphacitite;
35 Piemonte Zone meta-ophiolites and calc-schists; Western Alps.

36
37 **1. Introduction**
38

39 Polished stone implements dating from the Neolithic to the Copper Age (mostly axes, chisels
 40 and hatchets) were found in archaeological sites spread all over the Western Europe –
 41 especially in the Po plain, Northwestern Italy (Ricq-de-Bouard, 1993; D’Amico & Starnini,
 42 2011). Most of these tools were obtained by the manufacturing of *alpine greenstones* – rocks
 43 with peculiar colour and provenance, at times commonly referred to as ‘*Jades*’, characterized
 44 by a wide variety of microstructure, grain-size, deformation and retrogression alterations
 45 (D’Amico et al. 2004, D’Amico and Starnini, 2006a, 2012b; Giustetto et al., 2016). The term
 46 *greenstone* includes precious and valuable lithologies; consistently with the classification
 47 proposed by Giustetto and Compagnoni (2014), these rocks can be divided into two main
 48 groups:

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

50 a) jadeitite (consisting of jadeite up to 95-100 vol. %);

51 b) omphacitite (consisting of omphacite up to 95-100 vol. %);

52 c) mixed Na-pyroxenite (with intermediate modal compositions of jadeite/omphacite).

53 ii) ‘Na-pyroxene+garnet rocks’, comprising other three lithotypes:

54 a) eclogite (consisting of omphacite and garnet up to 25-75 vol. %);

55 b) garnet-omphacitite (mainly consisting of omphacite, with garnet between 5-25 vol. %);

56 c) omphacite-garnetite (mainly consisting of garnet, with omphacite between 5-25 vol. %).

57 However, it is to remark that other lithologies, characterized by green colour but different
 58 mineralogy (e.g. serpentinite, amphibolite and prasinite), have also been included under the
 59 *greenstone* term. The non-petrographic term ‘*Jade*’, traditionally used in trade and gemmology,
 60 includes two different rock types: i) ‘*jadeite jade*’, mainly consisting of jadeite ($\text{NaAlSi}_2\text{O}_6$);
 61 and ii) ‘*nephrite jade*’, usually consisting of an amphibole of the tremolite-ferro-actinolite
 62 series $[\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2]$. Only the former will be considered in this study. Besides, in
 63 addition to ‘*jadeite jade*’, another similar phase was identified in archaeological implements –
 64 namely ‘*omphacite jade*’, mostly consisting of omphacite $[(\text{Ca,Na})(\text{Mg,Fe}^{2+},\text{Al})\text{Si}_2\text{O}_6]$
 65 (D’Amico et al., 2004; Ou Yang, 2006; Ou Yang et al., 2011; McClure, 2012).

66 The pioneering studies of Gastaldi (1871), Damour (1881) and Franchi (1900) first established
 67 that these *greenstone* lithotypes occur in the metamorphic ophiolites (meta-ophiolites) and calc-
 68 schists of the Piemonte Zone, in the Western Alps. A more precise location is troublesome, as
 69 these rocks occur either as small (few m^3) primary outcrops at high altitude (D’Amico, 2005;
 70 Pétrequin et al., 2005a, 2005b, 2006; Compagnoni et al., 2012) or boulders in secondary clastic
 71 deposits downhill, derived from erosion of the formers (Compagnoni et al., 2006; D’Amico and
 72 Starnini, 2006a; D’Amico and De Angelis, 2009). Few *greenstone* outcrops/deposits were

73 discovered so far and the detailed petrographic studies are scarce. However, the occurrence of
74 eclogite/omphacitite *boudins* was reported from the Pellice Valley, in the Monviso meta-
75 ophiolite Massif (Borgogno, 2000; Giustetto et al., 2016). Primary outcrops of jadeitite,
76 omphacitite and fine-grained eclogite were also identified in the same massif (Pétrequin et al.,
77 2005a, 2005b, 2006c; Compagnoni et al., 2012). Recently, an attempt to set up an adequate
78 reference collection was made by analyzing with various techniques more than 500 specimens
79 of presumed alpine *greenstones* (mainly ‘*Jades*’), collected as raw materials or working debris
80 during prolonged prospections in the Monviso area of Piemonte, and in the Beigua area of the
81 Voltri Group in Liguria (‘JADE’ project; Pétrequin et al., 2012b; 2012c). The in-depth
82 archaeometric – especially mineral-petrographic – study of these implements is of paramount
83 importance to achieve information about their manufacturing techniques and material quality
84 (Chiarenza and Giustetto, 2010; D’Amico et al., 1992; 1997; 2013). A precise location of the
85 supply sources of raw materials, inferred by means of comparative studies with geological
86 samples of known provenance, might help in reconstructing the migratory/trade routes haunted
87 by our ancestors – an aim pursued also in other famous ‘*Jade*’ localities (e.g., the Caribbean:
88 Garcia-Casco et al., 2013). These *greenstone* tools underwent vast circulation all over the
89 Western Europe – i.e., in Southern France and along a corridor running from Southern Italy to
90 Great Britain (Pétrequin et al., 2002). Similar tools of presumed alpine origin were also found
91 in Slovakia and Czech Republic (Spišiak and Hovorka, 2005; Pétrequin et al., 2011).
92 This study deals with the characterization of the polished *greenstone* industry from the site of
93 Brignano Frascata (Italy). Over 300 stone implements were investigated with a dual
94 archaeologic and archaeometric approach, aimed at reconstructing their manufacturing
95 techniques and locating the raw materials supply sources. Partly presented in a preliminary
96 report by Giustetto and Compagnoni (2004), these data are detailed here for the first time.
97 Moreover, this work integrates the study of D’Amico et al. (2000), expanding the survey to the
98 whole Brignano Frascata lithic lithological types and also taking into account implements from
99 coeval sites from the nearby Curone, Grue and Ossona valleys (see square in Fig.1).

101 2. Materials and methods

103 2.1 Archaeological case study and materials

105 (INSERT FIGURE 1)

106 The Brignano Frascata site – in the Curone Valley near Alessandria, Piemonte region,
 107 located to the northeast of the Beigua massif, Voltri Group (Fig. 1) – is positioned on an
 108 orographic terrace 300 m a.s.l. on the right side of the Curone stream, with prolonged
 109 insolation and excellent water supply. The area was systematically excavated by
 110 archaeologists, uncovering several occupational phases from the ancient Neolithic (5400-
 111 4900 B.C., Venturino Gambari, 2004) to the Roman Age (1st century A.D.; Nebiacolombo,
 112 2004). A first excavation in 1984 uncovered remains of ancient Neolithic ceramic and lithic
 113 industries, typical of the Vhò Group (Bagolini and Biagi, 1975; Tiné, 1993). Among these,
 114 34 *greenstone* implements – including axes, hatchets, chisels, strikers recycled from worn
 115 cutting tools and disc-ring roughouts – completely or partly polished (on sharp edges), were
 116 studied by D’Amico et al. (2000). Presence of splinters, scraps or roughouts – probably due
 117 to defects/breakages – led to consider this as a possible manufacturing site for the
 118 production of cutting implements. A second, systematic superficial search led to recover
 119 more than 2000 ceramics and lithic implements, dating from the ancient Neolithic to the first
 120 phase of the ‘*Vasi a Bocca Quadrata*’ (VBQ; *Square Mouth Jars*) culture, as certified by
 121 presence of disc-rings and chisels. 185 stone implements – mostly cutting tools and disc-
 122 rings at different stages of their manufacturing process, a sample of which is shown in Fig. 2
 123 – were studied. Finally a third excavation, in ‘S. Giorgio’ hamlet, uncovered 12 *greenstone*
 124 implements (mostly for cutting) represented by fragmented roughouts (axe butts and cutting-
 125 edges) broken during manufacture or re-used as strikers. All 231 specimens – mostly in
 126 *greenstone* – including those studied by D’Amico et al. (2000), were taken into account for
 127 analysis (Table 1).

128 (INSERT FIGURE 2)

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

135 136 2.2 Methods

137
138 A dual approach – both archaeological (morpho-typological) and scientific (mineral-
 139 petrographic) – was adopted to study these implements (Chiari et al., 1996; Compagnoni et

140 al., 2006; Giustetto et al., 2008). The latter involved a global screening with non-destructive
141 methods (i.e., stereo-microscopic observations and density measurements) for a preliminary
142 lithotype screening. Further in-depth analyses were then performed on selected specimens –
143 basing on lithotype distribution and recurring mineral-petrographic features – with X-ray
144 powder diffraction (XRPD), optical microscopy with plane-polarized light and scanning
145 electron microscopy with energy dispersion spectrometry (SEM-EDS). Small cores (6 mm
146 in diameter), obtained by drilling broken tools/splinters with a diamond corona barrel, were
147 used to prepare both 30 µm-thick polished thin sections and rock powders. XRPD data were
148 collected in the 3-70° 2θ range using an automated Siemens D-5000 diffractometer with
149 $\theta/2\theta$ setup in Bragg-Brentano geometry, Cu-K α radiation and zero-background sample
150 holder. Data were processed with the Diffrac Plus (2005) software (EVA 11,00,3). A Zeiss
151 WL Pol optical polarizing microscope was used for optical observations. Electron
152 microscopy was performed with a SEM Stereoscan-360, Cambridge Instrument on polished,
153 carbon-coated thin sections. Chemical analyses were collected with an EDS Link-Pentafet,
154 Oxford instrument (operating conditions: 50 s counting time, 15 kV accelerating voltage, 25
155 mm working distance, 300 pA beam current). Data were processed with the INCA-200
156 Microanalysis Suite Software, version 4.08, calibrated on mineral standards using the ZAF
157 correction method.

158

159 3. Results

160

161 3.1 Morpho-typological examination

162

163 The 231 finished tools and roughouts from Brignano Frascata (Table 1) can be classified,
164 basing upon their functionality and traces of manufacture/use, as implements for cutting
165 (138 axes, hatchels and chisels; 60 %), striking (21 percussors; 9 %), abrading (9
166 grindstones and millstones; 4 %) and ornamental tools (6 disc-rings; 3 %). The rest (24 %) is
167 represented by (57) splinters. Implements for cutting are mostly axeheads roughouts or
168 fragments; small chisels with distinctive short and linear cutting-edge also appear. Their raw
169 processing state and/or fragmentary conditions (especially axes and hatchels) allow only
170 preliminary typological considerations, due to difficulties in checking their dimensions
171 (length, width and thickness) upon which the existing classifications are based (Pedrotti,
172 1996). Few complete and finished implements were found, mainly small axes completely

173 polished, whose shape was obtained by splintering and bush-hammering (a further stage, in
 174 which another tool is used to texturize the stone). The original stone surface is still visible on
 175 several implements. Seldom, a limited smoothing of the cutting-edge is observed. Several
 176 axe butts and cutting-edge fragments, related also to medium-to-large specimens, were
 177 recovered with chisel roughouts and other pieces, thus testifying the frequent breakings
 178 occurred during manufacture or use. Axe butts are mostly triangular, edged or rounded, with
 179 linear or slightly convex borders; cutting edges, when preserved, are curved. Several disc-
 180 ring roughouts were recovered in different steps of their production chain; 6 of them were
 181 studied, allowing to understand their manufacturing phases: i) a discoidal, not-too-thick
 182 *greenstone* pebble is progressively splintered refining its shape; ii) a central, bilateral hole is
 183 dug by fine-hammering with tough and sharp strikers, while adjusting the circular shape by
 184 exploiting the rock schistosity; iii) the surface is then polished by gentle abrading (Venturino
 185 Gambari, 2004).

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

194 (INSERT TABLE 1)

195 (INSERT TABLE 2)

196 (INSERT TABLE 3)

197

198 3.2 Density measurements and stereomicroscopy examination

199

200 (INSERT FIGURE 3)

201 The Brignano Frascata *greenstone* specimens (density determined for 206 out of 231 total
 202 tools; Table 1) can be divided (Fig. 3a) in lower density ($\approx 2.6-2.7$; serpentinites) and higher
 203 density rocks ($\approx 3.2-3.5$, including ‘Na-pyroxene rocks’ and ‘Na-pyroxene+garnet rocks’).
 204 A certain degree of overlapping within the latter group prevents a sharper lithotype
 205 discrimination. A third group with intermediate density is also identified ($\approx 2.9-3.0$),
 206 consisting of prasinite. Stereomicroscopy in reflected light, performed on the polished

207 surfaces of the implements, allowed for each specimen to evaluate the mineral grain-size
 208 range, heterogeneities and microstructural features (e.g., presence of veins). By combining
 209 the density values with these observations, a preliminary lithotype determination was
 210 achieved (Fig. 3b). ‘Na-pyroxene rocks’ (jadeitite + omphacitite + mixed Na-pyroxenite) are
 211 the most significant fraction (42 %), followed by ‘Na-pyroxene+garnet rocks’ – especially
 212 eclogite (37 %). Serpentinites and prasinites are scarcer (7 and 4 %, respectively); non-
 213 *greenstone* lithotypes are the residual 10 %. The same approach was used on those
 214 implements from Momperone (density determined for 32 out of 34 total tools; Table 2) and
 215 Villaromagnano (density determined for 22 out of 23 total tools; Table 3), statistically
 216 significant. The related distribution (Fig. 3c and 3d, respectively) shows that in the latter site
 217 serpentinites become preponderant. No further study was performed on serpentinites, due to
 218 their monotonous mineralogical composition, being mostly composed of antigorite,
 219 occurring all over the internal Piemonte zone (Giustetto et al., 2008). Similar conclusions
 220 may be drawn for prasinite. Further analyses were instead performed on representative ‘Na-
 221 pyroxene rocks’ and ‘Na-pyroxene+garnet rocks’. Contrarily to serpentinites, in fact, which
 222 are very common rocks all over the region, jadeite and/or omphacite-rich rocks are quite rare
 223 in the field and thus represent an ideal geologic material for provenance studies.
 224 Archaeological and archaeometric data for these tools, photographed in Figs. 4 through 7,
 225 are reported in Tables 4 through 6.

226 (INSERT TABLE 4)

227 (INSERT TABLE 5)

228 (INSERT TABLE 6)

229 (INSERT FIGURE 4)

230 (INSERT FIGURE 5)

231 (INSERT FIGURE 6)

232 (INSERT FIGURE 7)

233

234 3.3. X-ray powder diffraction

235

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

241 (Schmidt and Stelcl, 1971; Woolley, 1983; D'Amico et al., 1995). If a single pyroxene
242 occurs, its characteristic reflections are sharp and well defined (Fig. 8a). When two or more
243 pyroxenes coexist in relevant amounts (such as in mixed Na-pyroxenite), their peaks are
244 split due to slight d_{hkl} differences (Fig. 8b). The mean composition of pyroxenes could be
245 estimated by plotting the d_{hkl} values of the most intense jadeite and omphacite reflections
246 [(221); (310); (002)] on a grid conceived by Giustetto et al. (2008), superposed to the
247 diagram of Morimoto et al. (1988).

248 (INSERT FIGURE 8)

249

250 3.4. Optical polarizing-microscopy and SEM-EDS

251

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

- 274 • 29 are ‘Na-pyroxene rocks’ [13 jadeitites, 10 omphacitites (including 2
275 omphacite/chlorite schists studied by D’Amico et al., 2000) and 6 mixed Na-
276 pyroxenites];
- 277 • 20 are ‘Na-pyroxene+garnet rocks’ (all eclogites);
- 278 • 8 are low-density *greenstone* lithotypes (7 antigoritic serpentinites; one prasinite);
- 279 • 3 are mafic granulites;
- 280 • 4 are other *HP* lithotypes (3 glaucophanites; one albite-lawsonite fels).

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

- 283 • 1 ‘Na-pyroxene rock’ (jadeitite);
- 284 • 4 ‘Na-pyroxene+garnet rocks’ (2 eclogites and 2 garnet-omphacitites – 1 of which
285 even with scarce jadeite)
- 286 • 1 quartz-arenite.

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

297 (INSERT FIGURE 9)

298 (INSERT FIGURE 10)

299

300 3.4.1 *Na-pyroxene rocks*

301

302 3.4.1.1 *Jadeitites*

303

304 In thin section, these rocks mostly consist of colourless-to-light-green jadeite,
305 forming granoblastic aggregates with squat-prismatic habit or having fine grain-
306 size and mylonitic microstructure, often crossed by veins with similar

307 mineralogy (BF-230-II; Fig. 11a). A metamorphic foliation is often observed,
308 defined by linear aggregates of rutile, titanite or zircon or by preferred
309 orientation of jadeite crystals. Occasionally, jadeite porphyroclasts with relict
310 appearance are observed with a dark/bluish core, due to tiny titanite/chlorite
311 inclusions and/or high Ti-content. Jadeite usually shows quite a complex,
312 oscillatory zoning. Most specimens analyzed by SEM-EDS show the presence of
313 pure jadeite ($Jd \geq 90\%$; Fig. 9), but also exhibit domains with Ca-richer and Fe-
314 poorer pyroxenes [$40\% \leq (Wo+En+Fs) \leq 60\%$; $Ae < 20\%$]. The microstructural
315 relationships among pyroxenes are quite complex: sometimes, idioblastic jadeite
316 overgrows small aggregates/domains of zoned omphacite (C-MP-CA/128; Fig.
317 11b); in other cases, a granoblastic jadeite matrix is crossed by tangled
318 omphacite aggregates with different Ca/Mg contents. White mica porphyroblasts
319 (paragonite) are often observed (Table 7); well-shaped domains, consisting of
320 white mica associated to clinozoisite, are interpreted as pseudomorphs after
321 former lawsonite.

(INSERT FIGURE 11)

323

324

3.4.1.2 *Omphacitites*

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326

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335

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).

336

3.4.1.3 *Mixed Na-pyroxenites*

337

338

339

340

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

341 pyroxenes are variable and complex. Sometimes granoblastic jadeite, including
 342 tiny omphacite exsolution blebs, is crossed by aggregates of strongly zoned
 343 omphacite crystals; the related analyses plot in two separate areas in the
 344 triangular diagram (e.g., C-FR-SO/90; Fig. 9). In other cases, the rock consists
 345 of an irregular aggregate of pyroxenes whose composition covers an almost
 346 continuous range between jadeite and omphacite (e.g., C-FR-O/11, Fig. 9 and
 347 12b). Frequently, bluish/green omphacite blasts are observed, characterized by
 348 high TiO₂-content (3-5 wt. %).

349 (INSERT FIGURE 12)

350 (INSERT TABLE 7)

352 3.4.2 *Na-pyroxene+garnet rocks*

354 3.4.2.1 *Eclogites*

355
 356 Under the polarizing microscope, omphacite forms a fine-to-medium-grained
 357 matrix with mylonitic or granoblastic microstructure, in which locally green-to-
 358 bluish-coloured patches are evident (Fig. 13a). Relict omphacite porphyroclasts
 359 with darker cores are also observed, containing tiny chlorite and zoisite
 360 inclusions. Lineation is marked either by alignments of small rutile/ilmenite
 361 aggregates or by preferred orientation of omphacite nematoblasts. Garnets are
 362 fine-grained, tens of μm up to few mm across, at times with atoll-like
 363 microstructure. Usually they form aggregates or chains, aligned parallel to
 364 foliation. EDS analyses sometimes reveal an extreme compositional zoning of
 365 pyroxenes in the ternary diagram (Fig. 10). The omphacite composition may be
 366 either homogeneous (e.g., C-FR-O/14 and C-FR-SOS/8) or covering a scattered
 367 range (e.g., C-FR-SO/48). Two pyroxenes often appear: an almost pure jadeite (C-
 368 FR-SO/12, C-MP-CA/2, O-VR-CR/1) coexisting with a more heterogeneous
 369 omphacite, occasionally extending into the aegirine/Ae-augite fields (Ae₅₀, C-MP-
 370 CA/2, Fig. 10). The subordinate jadeite domains show complex microstructural
 371 relationships with the other 'coexisting' pyroxenes: seldom, they occur amidst a
 372 zoned omphacite matrix (Fig. 13b); sometimes, jadeite veins appear to replace the
 373 omphacite matrix. Garnets are mainly almandine-rich (until Alm₆₅) with
 374 subordinate grossular ($\leq 40\%$), minor pyrope ($\leq 10\%$) and spessartine ($\leq 20\%$)

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

377 (INSERT FIGURE 13)

378

379 3.4.2.2 Garnet-omphacitites

380

381 The two analyzed samples (Table 8) belong to the sites of Casalnoceto and
382 Momperone. Garnets are scarce, with idioblastic to skeletal habit and an unusual
383 composition for eclogites ($\text{Grs} \geq 80\%$); their compositions are more typical for
384 rodingites.

385 (INSERT TABLE 8)

386

387 3.4.3 Other lithotypes

388

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

395 (INSERT FIGURE 14)

396 (INSERT TABLE 9)

397

398 3.5. Comparative analyses on geological samples

399

400 Despite their renowned rarity and preciousness, *greenstone HP*-metaophiolites are still
401 found nowadays. Primary outcrops are scarce, but secondary deposits have been identified
402 in the Voltri massif – westbound (high Erro valley), in the centre (high Orba valley) and
403 eastbound (Lemme and Ardana valleys) (Pétrequin et al., 2012c). Masked by a thick
404 vegetation, these rocks occur in the alluvial beds of streams, together with other more
405 common lithotypes (Pétrequin et al., 2012b; D'Amico and Starnini, 2012b).

406 Some dozens of *greenstones* rocks – in the form of pebbles/cobbles/blocks deriving
407 directly from the metamorphic substrate or the reworking of greenstone clasts from
408 Oligocene conglomerate units located upstream – have been collected during field

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

455 For what concerns the disc-rings, the predominance of roughouts and fragments at different
456 working stages (in Brignano Frascata and Momperone) testifies the difficulties encountered
457 for their manufacture, which is confirmed by comparison with the reports of experimental
458 archaeologists. This procedure provides a gradual increase in the percussion of the centre of
459 the discoid, where the risk of breakings is higher (Delcaro, 2004). By comparing the studied
460 disc-ring roughouts with analogous complete implements from other sites, the central hole
461 appears smaller. This suggests that – in addition to drilling by hammering – another step in
462 the production chain was represented by the hole widening/finishing using abrasive *polissoir*
463 in sandstone, while polishing the surface. Some disc-rings are in serpentinite, a common
464 lithotype probably fitting better than others to manufacture. A single jadeitite disc-ring was
465 found, unique from a petrographic point of view, though analogous objects in HP lithotypes
466 (Na-pyroxenite or paragonite) were described from other Neolithic sites (Alba, Torino, Vho
467 and near Bologna: Traversone, 1996; Zopfi, 1996; D’Amico et al., 1996). The provenance of
468 the raw materials is still under discussion. Some authors suggested a possible exploitation of
469 cobble/blocks from alluvial deposits of rivers flowing into the Po plain or morainic deposits
470 accumulated at the outlet of Alpine valleys (Ricq-de-Bouard and Fedele 1993; Ricq-de-
471 Bouard 1996; D’Amico et al. 2004; Giustetto et al., 2016). Others, however, have objected
472 that at least the larger (15-36 cm long), ultra-polished jade ceremonial axes found in France,
473 Germany, Benelux, and Great Britain – whose dimensions exceed those of clasts derived
474 from fragmentation of the primary outcrops – should have a different origin (Pétrequin et al.
475 2005a, 2005b). Basing on ethnographic studies, a possible exploitation of quarries in the
476 Western Alps at high altitudes in Neolithic was proposed (Pétrequin and Pétrequin 1993,

477 Pétrequin et al. 2006a). This is also supported by signs of extraction found on presumed
478 jadeitite and eclogite boulders – especially in the Monviso area of Piemonte and, at a minor
479 extent, in the Voltri Group (Pétrequin et al. 2005b, 2006b, 2008).

480 The moderate dimensions ($\leq 10\text{-}13$ cm) of the few finished tools from Brignano Frascata
481 indicate that they were probably used for everyday requirements (i.e., woodworking or other
482 tasks) and not for ritual purposes (such as, for example, the large *greenstone* axes dated to
483 the V-IV millennium BC, manufactured for prestige and symbolic use; Pétrequin et al.,
484 1998). The morphological study of the many excavated fragmented roughouts (mostly
485 axeheads) indicates that while some breakings occurred when splintering during
486 manufacture, most happened while bush-hammering. This latter step represents, therefore,
487 the production phase with the higher risk of accidents. Fractures occurring during use are
488 instead certified by cutting edges showing traces of regrinding (suggested by tiny
489 discontinuities on the polished surface) or visible damages. These lines of evidence – and
490 the recognition of raw surfaces on some axehead roughouts broken during manufacture, with
491 shapes reminiscent of fluvial pebbles (a feature observed also by Pétrequin and Pétrequin,
492 2017) – suggest that Brignano Frascata, similarly to the Rivanazzano workshop (D’Amico
493 and Starnini, 2012b; Pétrequin et al., 2012a), should be considered a local *atelier* for the
494 production of *greenstone* implements in Neolithic. In addition to scraps and fragments, the
495 manufacturing *in situ* is also supported by the recovery of spheroidal strikers (for
496 splintering) and recycling of broken roughouts/apprenticeships attempts marked by hollows,
497 due to their use as anvils (Bernabò Brea et al., 1996, and parallel ethnographic studies:
498 Pétrequin and Jeunesse, 1996; Pétrequin and Pétrequin, 2012). A recent technological study
499 (Mancusi, in the press) confirmed the occurrence in Brignano Frascata of an unspecialized
500 manufacture, certified by the many implements obtained after reuse of wastes. In Northern
501 Italy, these technological needs might have conditioned the choice of rough material during
502 the Early-to-Middle Neolithic, favouring the gathering of cobbles and blocks from alluvial
503 deposits (D’Amico and Starnini, 2012b). Conversely, during the Middle-Late Neolithic-
504 Chalcolithic – when the flux of ritual axes outside the Po plain became relevant – the choice
505 of the materials (also for export) may have followed a more esthetical selection, dictated by
506 larger size, elegant shape and mineral features more suitable to polishing. This sample
507 selection might have favoured, in later times, the quarrying of larger blocks from primary
508 outcrops at higher altitudes, potential supply of raw materials for ceremonial axes destined
509 to the Western and Northern Europe.

510 All these outcomes suggest for the studied sites a supply of raw materials from secondary
 511 conglomeratic deposits and/or alluvial deposits – as no evidence about recovery/mining
 512 from primary outcrops was found, consistently with the geological remarks (see Section
 513 4.2). Brignano Frascata, therefore, should be considered a ‘second-order’ site, solely
 514 operating on secondary supplies (Mancusi, in the press). All other steps of the production
 515 chain (rough-hewing, splintering and bush-hammering) were performed *in situ*, as further
 516 hinted by the medium-to-small dimensions of the tools and the recovery of few polished
 517 specimens. The presence of a stable settlement on the plain level is confirmed by the
 518 recovering of grindstones or smoothers made in sandstone or serpentinite, respectively,
 519 related to sedentary activities such as corn grinding and ceramics processing. This local
 520 production might also imply that these implements could partly be addressed to trading or
 521 exchange purposes – though limited to short-to-medium distances – as even supported by
 522 the great number of tools at different steps of their production chain (elsewhere found as
 523 finished objects; Pessina and D’Amico, 1999).

524

525 4.2 Mineral-petrographic considerations and geological issues

526

527 The Brignano Frascata lithic industry shows a marked predominance of *greenstone* HP
 528 metamorphic lithotypes, consistently with the outcomes of most coeval sites of Northern
 529 Italy, whereas other rocks are only 10% of the lithological types. However, while most of
 530 these sites (Alba, Castello di Annone, Gaione, Ponte Ghiara, Rivanazzano, Rocca di Cavour,
 531 Sammardenchia and San Lazzaro di Savena; Mannoni and Starnini, 1994; D’Amico et al.,
 532 1995; 1997; 2013; D’Amico and Ghedini, 1996; D’Amico and Starnini, 2000, 2012b; Andò,
 533 1998; Bernabò Brea et al., 2000; Borgogno, 2000; Giustetto et al., 2016; Fig. 1) show
 534 dominance of ‘Na-pyroxene+garnet rocks’ (eclogites even up to 66%), in Brignano Frascata
 535 ‘Na-pyroxene rocks’ (jadeitites + omphacitites + mixed Na-pyroxenites) slightly prevail
 536 (42% of the lithological types; Fig. 3b). Such values are high, if compared to other sites
 537 (e.g., Sammardenchia and Rivanazzano) where these ‘Jades’ seldom reach 10%. The Monte
 538 Savino/Sassello site, where omphacitite is the prevailing lithotype (Garibaldi et al., 1996),
 539 represents an exception. Comparative studies with close and coeval settlements were also
 540 made with Momperone and Villaromagnano, in the Curone and Ossona valleys respectively,
 541 where despite the necessary caution due to a non-homogeneous sampling (excavation,
 542 surface recovering, harvesting), the statistics of the analyzed specimens is significant (Figs.
 543 3c and 3d). Only *greenstones* were recovered in Momperone, with ‘Na-pyroxene+garnet

544 rocks' (44%, all eclogites) prevailing over 'Na-pyroxene rocks' (30%). In Villaromagnano,
545 'Na-pyroxene+garnet rocks' (all eclogites) and 'Na-pyroxene rocks' (26% each) are
546 subordinate to serpentinites (44%), a trend opposite to that usually observed.
547 For what concerns the origin and provenance of the raw materials, two main geological
548 sources of 'Na-pyroxene rocks' and 'Na-pyroxene+garnet rocks' have been so far identified
549 in Northwestern Italy, namely in the Monviso and Monte Beigua (Voltri) massifs (D'Amico
550 and Starnini, 2012b; Errera et al., 2012b; Pétrequin et al., 2012c; Fig. 1). Though separated
551 by slightly more than 100 km as the crow flies, these regions underwent – between 5500 and
552 3500 B.C. – a very different cultural history, each characterized by a peculiar evolution and
553 different contacts with neighboring peoples (Pétrequin et al., 2012b). From a geological
554 point of view, the Monviso and Voltri regions, each divided into different subareas, belong
555 to a common stump of *HP*-meta-ophiolites and share the same lithologies. Some
556 peculiarities, however, can be pointed out and emphasized in the discussion that follows –
557 by relating the mineral-petrographic features of the investigated Neolithic tools with those of
558 geological specimens of known provenance. The individuation of sharp correspondences
559 and geologic 'markers' is known to represent a hard task. These lithotypes, in fact, show a
560 wide variety of grain size, microstructure, deformation features and compositional zoning –
561 quite difficult to standardize (Giustetto and Compagnoni, 2014; D'Amico and Starnini,
562 2012b). This is the reason why only an in-depth mineral-petrographic exam (on both tools
563 and geological samples) is the only viable method to pursue sharp and reliable provenance
564 information. Such a goal may be achieved by combining accurate analytical methods
565 (density, XRPD, optical polarizing, electron microscopy and even spectroscopic techniques)
566 that – if considered alone – might lead to gross oversights. With the above in mind, some
567 peculiar mineral-petrographic features about *greenstones* and/or other lithologies distinctive
568 of the Monviso or Voltri massifs were extrapolated by the few previous coherent studies
569 (Compagnoni et al., 2012; Giustetto et al., 2016) and by the reference collection for Project
570 'JADE' (Pétrequin et al., 2012b). Obviously, accurate comparisons could be performed only
571 by referring to rigorous mineral-petrographic approaches – consistent with those adopted
572 here (D'Amico, 2012). Moreover, the preliminary results of the pilot comparative study on
573 *greenstone* conglomerate clasts from the eastern side of the Voltri area (see Section 3.5)
574 have also been considered. On the other hand, spectroradiometric outcomes – a poor
575 identification technique for minerals and rocks, applicable only to (possibly overestimated)
576 jadeitites (Errera et al., 2012a) – were disregarded, as well as those resulting from sheer
577 visual appearances (to the naked eye; Pétrequin et al., 2012b; Pétrequin and Errera, 2017).

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

593 (INSERT FIGURE 16)

594 By comparing the mineral-petrographic features of the Brignano Frascata implements (and
 595 closer findings; Fig. 16a) with those of other tools from coeval sites, as well as with those of
 596 consistent geologic specimens from traced sources, both analogies and differences are
 597 observed. The analogies refer to eclogites always being fine-grained and often containing
 598 subordinate jadeite domains in a prevailing omphacite matrix, a feature observed also in
 599 several geological samples collected from secondary deposits fed by the erosion of the
 600 Voltri Massif rocks (see Section 3.5). This aspect, therefore, should not be considered
 601 exclusive of the Monviso area – as hastily hinted by Errera et al. (2012b) and Pétrequin et al.
 602 (2012b). Also, pyroxenes show a complex and variable zoning, with exsolution omphacite
 603 ‘blebs’ in jadeite – as observed in some tools from Castello di Annone (Giustetto et al.,
 604 2016). Such a heterogeneity was seldom reported in analogous geological specimens, due to
 605 lack of detailed petrologic studies (Compagnoni et al., 1995). Though a rich literature exists
 606 on the Monviso eclogites (Rubatto and Hermann, 2003; Groppo and Castelli, 2010; Spandler
 607 et al., 2011; Castelli et al., 2014, with refs. therein), primary outcrops of ‘Na-
 608 pyroxene+garnet’/‘Na-pyroxene rocks’ with features comparable to those observed in these
 609 implements are small and scarce (Pétrequin et al., 2013). Presence of omphacite blebs,
 610 ubiquitous zircon and accessory Ti-bearing phases (especially rutile) in jadeite was
 611 described in jadeitite outcrops from the Monviso massif (Compagnoni et al., 2007; 2012).

612 Similar jadeitite boulders (up to one m³) were reported from the Po valley Quaternary
613 succession, thus reinforcing the hypothesis for a supply of raw materials from secondary
614 deposits (Forno et al., 2015). Presence of different pyroxenes, exsolutions and overgrowths
615 were also described in jadeitites from Cuba (García-Casco et al., 2009), Antigua, Guatemala
616 (Harlow et al., 2006; 2011) and Dominican Republic (Schertl et al., 2012). For what
617 concerns the differences, the Brignano Frascata implements contain, both in eclogite and
618 omphacitite, clinopyroxenes with a high aegirine content (up to Ae₅₀). Such unusual Ae
619 values, reported also by D'Amico et al. (2000), are *not* typical of other 'alpine' recoveries
620 (e.g., implements from Eastern Europe: Spišiak and Hovorka, 2005; Hovorka et al., 2008)
621 attributed to a Monviso provenance, nor other 'Jade' localities (e.g., Caribbean geological
622 samples/artifacts: Garcia-Casco et al., 2009, 2013; Harlow et al., 2004). Similar Ae contents,
623 however, have been occasionally observed in some omphacitites and eclogites from
624 secondary deposits around the Voltri Massif (see Section 3.5) – and may therefore represent
625 a distinctive 'marker' in comparative studies aimed at pinpointing the raw materials sources.
626 On this basis, the presumed attribution of some Ae-rich eclogites in prehistoric tools (e.g.,
627 C-FR-SO/48; Fig. 10) to a Monviso provenance, based on spectroradiometry and
628 macroscopic approaches, sounds misleading (Pétrequin and Errera, 2017; Pétrequin and
629 Pétrequin, 2017). A typical richness in aegirine (distinctive also of the Momperone tools,
630 e.g., C-MP-CA/2; Fig. 10) was even observed in some Castello di Annone specimens
631 (Giustetto et al., 2016), whose garnet composition and zoning are also similar to those
632 reported here. Furthermore, in both sites high percentages of broken/fragmented implements
633 were retrieved. The marginal importance attributed to Castello di Annone in the production
634 network of *greenstone* tools during Neolithic (Giustetto et al., 2016), coupled with the local
635 *atelier* nature of Brignano Frascata (Section 4.1), may imply that a trade channel existed
636 between these settlements. Alternatively, these common traits may also suggest a common
637 material supply, reinforced by the tools of both sites occasionally containing pyroxene blasts
638 with a bluish, Ti-rich core (similar to those reported by Harlow et al., 2003; 2004) and
639 pseudomorphs after original lawsonite porphyroblasts (observed also in the Rivanazzano
640 implements; D'Amico and Starnini, 2012a). This latter feature, due to the many similarities
641 (both archaeological and mineral-petrographic) found between the Brignano Frascata and
642 Rivanazzano *ateliers*, is probably not exclusive of *greenstones* from the Monviso area – as
643 supposed by Pétrequin et al. (2012b). On the contrary, these features – and the presence of
644 pyroxene porphyroclasts sporadically coupled with strong deformation, in the so-called
645 'omphacite schists' described by D'Amico et al., 1997 (i.e., BF20.1 and BF27; Table 7) –

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

667 Establishing the origin of the raw materials for manufacturing the implements – whether
668 from primary outcrops at high elevation (Pétrequin et al., 2002) or from alluvial, downhill
669 secondary deposits – also represents a fundamental archaeometric issue. The first hypothesis
670 needed the community to dispose of skilled gatherers, whose hard task – besides locating the
671 distant primary outcrops on the mountains – was that of tearing off and bringing back raw
672 stone boulders to be worked. The second option would have involved less effort, since these
673 deposits were closer to the settlements and contained blocks already fragmented and
674 selected by erosion and transport. The morphological examination of axehead roughouts,
675 abundant in Brignano Frascata, proves that most have rounded shapes, typical of pebbles of
676 Oligocene or Quaternary deposits – some even showing raw surfaces (Section 4.1). The
677 performed geologic survey and ensuing petrographic study show that the conglomeratic
678 horizons intercalated in the Tertiary Piemonte basin successions contain pebbles of both
679 metamorphic and non-metamorphic ophiolites. Meta-ophiolites should have derived from

680 the dismantlement, about 30 My ago, of the palaeo-Voltri Massif (or a possible equivalent
681 unit, disappeared because of long lasting erosion), located to the west of the considered area.
682 On the contrary, the non-metamorphic ophiolites should have derived from the Ligurids, i.e.,
683 the present-day Apennine exposed to the southeast. Therefore, the pebbles of HP meta-
684 ophiolites collected by prehistoric men might *not* derive from the *present* Voltri Massif –
685 because the present-day trend of the streams in the considered area (i.e., Lemme, Scrivia,
686 Grue, Ossona, Curone and Staffora) is roughly from S/SE toward N/NW. Instead, these
687 pebbles should have originated from the ‘secondary’ deposits of either the Tertiary
688 conglomeratic horizons or the re-sedimented Quaternary alluvium. A geological sketch is
689 presented here, based on the most recent geological maps and stratigraphic data, showing the
690 location of the closer Oligocene conglomerate and Quaternary alluvial deposits, possible
691 sources of raw materials for these Neolithic tools (Fig. 16a,b). The Oligocene stratigraphic
692 succession of the Tertiary Piemonte Basin includes some lithostratigraphic units containing
693 conglomerate bodies with clasts of meta-ophiolites. The closest ones are the Savignone
694 Conglomerate (**sav**) and the Monastero Formation (**mst**), few km far from Brignano Frascata
695 and the other investigated sites. The first, Rupelian in age, is a thick (up to 2200 m) unit
696 made up of continental-to-shallow-water conglomerates and arenites, with subordinate marls
697 and pelites. In its lower part (Monte Rivalta and Val Borbera Members), the conglomerate
698 clasts essentially derive from Ligurian *Helminthoides* Flysch Units; in the upper part (Persi
699 Member, **sav_c**; Fig. 16b), they also derive from continental crystalline basement and meta-
700 ophiolites with very low-grade, greenschist-facies or high-pressure metamorphic overprint.
701 The Monastero Formation (also Rupelian) consists of sandy-muddy turbidites, followed by
702 hemipelagic marls. In its lower part, a conglomerate lithozone is present (**mst_c**; Fig. 16b)
703 containing clasts from Ligurian *Helminthoides* Flysch Units (Antola Unit) and ophiolitic
704 sequences, overprinted by high-pressure metamorphism (Marroni et al., 2010). The
705 conglomerate bodies containing meta-ophiolitic clasts have been mapped in the Cabella
706 Ligure sheet of the Geological Map of Italy at 1:50.000 (Marroni et al., 2010),
707 corresponding to the southeastern part of the study area (Fig. 16b). In the rest of the area
708 (comprised in the Voghera sheet at 1: 50.000 – Vercesi et al., 2014 – and the
709 Alessandria/Voghera sheets at 1:100.000 of the Geological Map of Italy – Servizio
710 Geologico d'Italia, 1969a; 1969b), these conglomerates have not been distinguished from the
711 formations they are included in. To the southwest of the study area (west of the Scrivia
712 valley), a thick succession of continental to shallow-water conglomerates and arenites, with
713 subordinate marls and pelites, crops out (mor: Costa Cravara Breccia and Molare Formation;

714 Fig. 16b). These deposits, mainly Rupelian in age, contain abundant clasts of meta-ophiolitic
715 rocks derived from their metamorphic substrate represented by the Voltri massif (Capponi
716 and Crispini, 2008; d’Atri et al. 2016 and references therein). From these beds, greenstone
717 cobbles and blocks are released as detrital materials into the Quaternary alluvial deposits in
718 the adjoining valleys – e.g., the Curone, Grue and Ossoa, as well as Staffora (on the eastern
719 side of the Curone), Scrivia and Lemme (on the western side) valleys – and outlets in the
720 plain. These alluvial deposits also gather clasts resulting from the dismantling of the primary
721 ‘Jade’ and/or eclogite blocks, located at higher altitudes in the eastern area of the Voltri
722 massif. In addition to our surveys (see Section 3.5), presence of greenstone secondary blocks
723 of presumed jadeitite, omphacitite and eclogite in the high Lemme valley – about 20 km as
724 the crow flies from Brignano Frascata – was also signaled by Pétrequin et al. (2012c). These
725 updated geologic/stratigraphic data, coupled with the wide range of lithotypes found in the
726 tools of Brignano Frascata, further support the hypothesis of a secondary supply source.
727 Such a heterogeneity, in fact, implies presence of an extensive choice/selection, similar to
728 that available in an alluvial deposit gathering pebbles from higher and distant areas. This
729 assumption is definitely strengthened by the outcomes of the ongoing pilot comparative
730 study, performed on geological *greenstones* from these areas (see Section 3.5). These results
731 undoubtedly show that some typical micro-structural and compositional features recur *both*
732 in the studied prehistoric tools *and* in analogous *greenstones* collected from conglomerate
733 deposits and/or alluvial beds in the adjoining valleys and streams. All these lines of evidence
734 point to a feasible supply of raw materials from the local Quaternary alluvial deposits in the
735 lower course of the nearby streams (e.g., Curone, Grue, Ossoa, Staffora, Scrivia and
736 Lemme), and from the lower Oligocene formations cropping out few km far as the crow
737 flies – an opportunity already hinted by D’Amico (2012) and D’Amico and Starnini for the
738 site of Rivanazzano (2006b, 2012b). The geological features of the few known primary
739 outcrops at higher altitudes – scarce, small and distant – further reinforce the presumable
740 belonging of these roughouts to secondary deposits, in which erosion imposes a natural
741 selection causing the tougher, less-alterable lithotypes (e.g., ‘Na-pyroxene rocks’ and ‘Na-
742 pyroxene+garnet rocks’) to undergo an enrichment. A direct supply source from primary
743 outcrops at higher elevation seems even more unlikely by considering the scarcity of such
744 blocks, limited to few jadeitite (Celle Ligure), eclogite (Urbe) or amphibolite (Sassello,
745 Chapel of Rocca Colombo) boulders, with poor traces of exploitation (Pétrequin et al.,
746 2012). Besides, a similar origin from boulders of the Monviso massif (Western Alps, at a
747 distance of approximately 150 km as the crow flies; Errera et al., 2012b; Pétrequin et al.,

748 2012c; Pétrequin and Pétrequin, 2017), though not completely ruled out (as hinted for some
749 tools from Sammardenchia; D’Amico and Starnini, 2012b), appears even more questionable.
750 Not only the covering of such distances would appear senseless – the same materials being
751 available from much closer distances – but all detected mineral-petrographic features
752 indicate, for those prehistoric tools investigated with a strict scientific approach, an origin
753 from the Voltri (or palaeo-Voltri) massif. Basing on these evidences, the complex technical
754 and economic system proposed for the Brignano Frascata site by Pétrequin and Pétrequin
755 (2017), based on a double supply of raw materials – mainly from regional sources in the
756 Voltri massif and secondarily from the Monviso outcrops – is yet to be acknowledged. A
757 simpler single model, solely based on the finding of raw materials from nearby secondary
758 deposits in the Eastern Voltri area, certainly appears more reasonable. While only further
759 and accurate mineral-petrographic analyses could help in improving the statistical weight of
760 this model of supply, particular care must be taken in order to avoid misinterpretations
761 and/or overvaluations hinted by approaches that – despite their non-destructiveness – lack in
762 providing a thorough characterization of the rocks. For what concerns lithotypes other than
763 *greenstones*, moderate presence of glaucophanite among the analyzed artifacts (3 samples;
764 see Section 3.4) strongly supports their origin from the Voltri Group. These rocks, often
765 fine-grained, are in fact quite common all over the Voltri area – reaching nearly 10 % – but
766 are typically lacking in the Monviso massif (D’Amico, 2012). Different considerations
767 involve the significance of the granulite rocks (Table 9; Fig. 14), which certainly belong to
768 the Ivrea-Verbano Zone, an important tectonic unit of the Western Alps located between the
769 town of Ivrea and the Locarno Lake – exposed to the southeast of the Piemonte Zone. The
770 maximum thickness of the Ivrea-Verbano Zone occurs in the Sesia valley, whose Quaternary
771 alluvial deposits contain many basic granulites. These rocks might derive from a site
772 downstream the confluence of the Sesia and Po rivers – the closest possible area with respect
773 to the studied archaeological sites (see Fig. 16a).

774

775 5. Conclusions

776

777 The Neolithic *greenstone* industry of Brignano Frascata was studied with an archaeometric
778 approach, involving both archaeological and mineral-petrographic aspects, supplying
779 information about the manufacturing techniques and the origin of raw materials. It has been
780 long ascertained that the ‘*Jades*’ and eclogite of the archaeological implements found all over
781 the Western Europe derive from the meta-ophiolites of the Piemonte Zone. However, a more

782 accurate location is difficult to determine, due to the scarcity of detailed geological data of
783 primary outcrops. A possible supply source from close secondary deposits is hypothesized here,
784 basing on morphological/petrographic features and geological considerations. Although
785 probably both supply models (exploitation of conglomerate deposits and/or alluvial beds vs.
786 quarrying of primary outcrops at high altitudes) were exploited in the past, the former was
787 privileged during the early/middle Neolithic, producing not too large, working-wood
788 instruments for daily use. This model, recurring in Northern Italian sites, was adopted also in
789 Brignano Frascata, thus satisfying the principle of the cost/benefit ratio (i.e., grabbing the best
790 available technological material with the minimum effort). The quarrying of selected outcrops
791 at high altitudes, aimed at obtaining big chunks of first-quality material for the production of
792 large ceremonial axes to be exported over long distances, probably became important only later
793 (V and IV Millennium BC) – and apparently did not involve the investigated site(s). Detailed
794 geologic surveys of the surrounding district (Curona, Grue, Ossona and adjoining valleys – e.g.,
795 Staffora, Scrivia and Lemme) are at present performed, followed by laboratory analyses on apt
796 geological samples collected from secondary deposits of *greenstones* – potential sources of raw
797 materials. The preliminary results obtained by such an approach confirm that the *greenstones*
798 used to manufacture the tools from Brignano Frascata and coeval adjacent sites might have
799 been collected from secondary supply sources located nearby – e.g., close conglomeratic
800 formations and/or alluvial deposits siding the course of the streams crossing the adjoining
801 valleys, originating from the Voltri (or palaeo-Voltri) massif.

802

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812

813

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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 ₂ O	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	porphyritic 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	<i>stricto sensu</i> eclogite with homogeneous garnets	196.2	138.4	3.39	
46	69373		C FR SO		axehead	eclogite	<i>stricto sensu</i> 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	<i>stricto sensu</i> 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	<i>stricto sensu</i> 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	<i>lato sensu</i> 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	prismatic 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	=	=	=	

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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 ₂ O	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	=	=	=	

1179 **Table 2.** Inventory codes, label, typology, preliminary lithotype determination and density value of the 34 polished stone implements and artefacts coming from the
1180 archaeological site of Momperone, based on density measurements and stereo-microscopy observations in reflected light of the tools polished or raw surfaces; the
1181 related treatments for analytical purposes are also indicated.

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	State Inventory	Excavation inventory	Other inventories	Label	Implement description	Lithotype	Notes (stereomicroscopy in reflected light/density)	Weight in air	Weight in H ₂ O	Density	Sampling
1			VRM/10		axehead roughout	serpentinite	===	118.2	72.7	2.60	
2			VRM/11		pebble/smoothed	serpentinite	===	67.5	42	2.65	
3			VRM/13		pebble/smoothed	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/smoothed	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

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Na-PYROXENE ROCKS									
Inventory code	Sample code/label	Site	Typology	Notes	Density (g/cm ³)	Analyses			Picture
						XRPD	O.M.	SEM	
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)

1214 **Table 4.** Minero-petrographic characterization of 46 polished stone implements (12 of which, marked by "*", also
1215 described by D'Amico et al., 2000) in 'Na-pyroxene rocks' from Brignano Frascata and/or other coeval
1216 archaeological sites in the Grue, Curona and Ossona valleys, analysed by XRPD, optical polarizing
1217 microscope and/or SEM-EDS, as indicated. In the last column, numbers refer to pictures in Figs. 4 and 5.

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

1228 **Table 5.** Minero-petrographic characterization of 29 polished stone implements (10 of which, marked by ‘*’, also
 1229 described by D’Amico et al., 2000) in ‘Na-pyroxene + garnet rocks’ from Brignano Frascati and/or other
 1230 coeval archaeological sites in the Grue, Curona and Ossona valleys, analysed by XRPD, optical polarizing
 1231 microscope and/or SEM-EDS, as indicated. In the last column, numbers refer to pictures in Figs. 5 and 6.
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OTHER LITHOTYPES		Site	Typology	Notes	Density (g/cm ³)	Analyses			Picture
Inventory code	Sample code/label					XRPD	O.M.	SEM	
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		=

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Table 6. Minerog-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																						
<i>Legend:</i> ○ <5% ◐ 5% - 20% ● 20% - 60% ● >60%																						
	omphacite	jadeite	garnet	chloritoid	quartz	glaucophane	amphibole	zoisite	clinozoisite	epidote	white mica	chlorite	albite	rutile	ilmenite	titanite	zircon	apatite	allanite	sulphides	oxides	Notes
JADEITITES																						
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

1293 **Table 7.** Mineralogical composition (vol. %) of 30 'Na-pyroxene rocks' (jadeitite, omphacitite and mixed Na-
1294 pyroxenite) studied in thin section by means of the optical polarizing microscope and/or SEM-EDS. All
1295 samples are from Brignano Frascata, except when otherwise indicated.
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Na-PYROXENE + GARNET ROCKS																					
<i>Legend</i> ○ <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

1310 **Table 8.** Mineralogical composition (vol. %) of 24 'Na-pyroxene+garnet rocks' (eclogite and garnet-omphacitite)
 1311 studied in thin section by means of the optical polarizing microscope and/or SEM-EDS. All samples are from
 1312 Brignano Frascata, except when otherwise indicated.

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BASIC GRANULITES									
<i>Legend</i> ○ <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)

1318 **Table 9.** Mineralogical composition (vol. %) of 3 mafic granulites studied in thin section by means of the optical
 1319 polarizing microscope and/or SEM-EDS. All samples are from Brignano Frascata.

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1323 **Figure Captions**

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1326 **Figure 1.** Map of Northern Italy: main towns are indicated, as well as the location of the Monviso
 1327 (Vi) and Voltri (Vo) massifs – possible sources for the supply of raw materials. The
 1328 location of the archaeological site of Brignano Frascata and other close ones in the
 1329 Curone, Grue and Ossona valleys (Momperone, Villaromagnano, Casalnoceto,
 1330 Gremiasco, Fabbrica Curone, Pozzol Groppo, Volpeglino, Viguzzolo and Sale) is
 1331 indicated by the small blue rectangle (more specific information about the position of
 1332 each site is provided in Fig. 16a). The location of eight coeval archaeological sites [1)
 1333 Alba, 2) Castello di Annone, 3) Gaione; 4) Ponte Ghiara; 5) Rivanazzano; 6) Rocca di
 1334 Cavour; 7) Sammardenchia; 8) San Lazzaro di Savena)], taken into account for
 1335 archaeometric comparison, is also shown.

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1337 **Figure 2.** Neolithic polished greenstone implements (all from Brignano Frascata, except when
 1338 otherwise indicated); **a)** instruments for cutting (axehead roughouts and/or fragments): i)
 1339 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-
 1340 SO/20; **b)** disc-ring roughouts and fragments at different working steps: i) C-MP-CA/133
 1341 (from Momperone), ii) C-FR-O/5, iii) BF29.2, iv) BF12, v) C-FR-SO/94.

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1343 **Figure 3.** a) Density histogram and b) lithotype distribution of 231 archaeological implements from
 1344 Brignano Frascata, obtained by combining density measurements and stereo-microscopic
 1345 observations. Lithotype distribution of similar implements from the sites of c)
 1346 Momperone (34 tools) and d) Villaromagnano (23 tools).

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1348 **Figure 4.** Photographs of Neolithic greenstone implements in ‘Na-pyroxene rocks’ from Brignano
 1349 Frascata and other nearby sites in the Curone, Grue and Ossona valleys, investigated with
 1350 an in-depth mineral-petrographic approach; numbers refer to the last column of Table 4.

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1352 **Figure 5.** Photographs of Neolithic greenstone implements in ‘Na-pyroxene rocks’ (21-38) and
 1353 ‘Na-pyroxene+garnet rocks’ (39-40) from Brignano Frascata and other nearby sites in the
 1354 Curone, Grue and Ossona valleys, investigated with an in-depth mineral-petrographic
 1355 approach; numbers refer to the last column of Tables 4 and 5.

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1357 **Figure 6.** Photographs of Neolithic greenstone implements in ‘Na-pyroxene+garnet rocks’ from
 1358 Brignano Frascata and other nearby sites in the Curone, Grue and Ossona valleys,
 1359 investigated with an in-depth mineral-petrographic approach; numbers refer to the last
 1360 column of Table 5.

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1362 **Figure 7.** Photographs of Neolithic implements in lithotypes different than ‘Na-pyroxene rocks’
 1363 and ‘Na-pyroxene+garnet rocks’ from Brignano Frascata and other nearby sites in the
 1364 Curone, Grue and Ossona valleys, investigated with an in-depth mineral-petrographic
 1365 approach; numbers refer to the last column of Table 6.

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1367 **Figure 8.** X-ray powder diffraction pattern of: a) a jadeitite (BF-230-II) and b) a mixed Na-
 1368 pyroxenite (C-FR-SO/90) from Brignano Frascata. While in the former the reflections
 1369 typical of clinopyroxenes – i.e., $\bar{2}11$, 310 and 002 – are single, in the latter they are split
 1370 (magnification in the upper right square) due to the presence of both jadeite (Jd) and
 1371 omphacite (Omph) (wavelength: Cu-K α radiation).

1372

- 1373 **Figure 9.** Compositional variation of pyroxenes in ‘Na-pyroxene rocks’ analyzed by SEM-EDS (4
1374 jadeitites, 3 omphacites and 2 mixed Na-pyroxenites plotted in the ternary diagram of
1375 Morimoto et al., 1988).
1376
- 1377 **Figure 10.** Compositional variation of ‘Na-pyroxene + garnet rocks’ analyzed by SEM-EDS
1378 [pyroxenes and garnets, plotted in the ternary diagram of Morimoto et al., 1988 and in the
1379 grossular (Grs) – pyrope (Prp) – almandine + spessartine (Alm+Sps) diagram,
1380 respectively; arrows indicate the compositional zoning from core (C) to rim (R) of 7
1381 eclogites and 2 garnet-omphacites].
1382
- 1383 **Figure 11.** Thin section photomicrographs of jadeitite: a) squat, prismatic jadeite blasts (Jd)
1384 containing small inclusions with omphacitic composition (Omph); euhedral zircons (Zrn)
1385 are also observed (BF-230 II; photomicrograph, plane-polarized light); b) granoblastic
1386 aggregates of idioblastic jadeite crystals (dark grey: Jd) surrounding small plagues with
1387 omphacitic composition (light grey: Omph); zircons (Zrn) are also observed (C-MP-
1388 CA/128; SEM image, BSE).
1389
- 1390 **Figure 12.** Thin section photomicrographs of mixed Na-pyroxenite: a) whitish pyroxene matrix in
1391 which fine-grained jadeite aggregates (Jd.1), alternating to bigger Jd crystals (tens of μm
1392 across: Jd.2), surround a greener, Ca-richer omphacite porphyroblast (Omph); brown
1393 rutile crystals (Rt) are also observed (C-FR-SO/90; optical polarizing microscope, plane-
1394 polarized light). b) pyroxene matrix in which an omphacitic weave (light grey: Omph)
1395 surrounds and crosses fragmented jadeite blasts (dark grey: Jd), which contain small
1396 omphacite inclusions (C-FR-O/11; SEM image, BSE).
1397
- 1398 **Figure 13.** Thin section photomicrographs of eclogite: **a)** small garnet (Grt) with tiny inclusions in
1399 the core surrounded by a zoned pyroxene matrix, composed of prismatic Fe-rich
1400 omphacite (Omph.1) with yellow-to-bluish pleochroism (Ti up to 5%) and less coloured,
1401 fine-grained Fe-poorer pyroxenes (Omph.2); opaque ores (Op) are sulphides (C-FR-O/14;
1402 optical polarizing microscope, plane-polarized light). **b)** pyroxene matrix where small
1403 jadeite domains (dark grey: Jd) appear amidst a prevailing Fe-rich, zoned omphacite
1404 (light grey: Omph). Foliation is defined by alignments of small titanite crystals (Ttn) (O-
1405 VR-CR/1; SEM image, BSE).
1406
- 1407 **Figure 14.** Photomicrograph of a mafic granulite, made of Ca-plagioclase (Pl) (partially regressed
1408 to zoisite and rarer pumpellyite), orthopyroxene (Opx), clinopyroxene (Cpx), green
1409 hercynitic spinel (Hc) and brown hornblende (Ho) (BF29.2; optical polarizing
1410 microscope, crossed polarizers).
1411
- 1412 **Figure 15.** Geologic jadeitite from the Val Lemme (VL14): a) thin section photomicrograph, in
1413 which granoblastic aggregates of idioblastic jadeite crystals (dark grey: Jd) surround
1414 small plagues with omphacitic composition (light grey: Omph; SEM image, BSE –
1415 compare with Fig. 11b); b) compositional variation of pyroxenes, analyzed by EDS and
1416 plotted in the ternary diagram of Morimoto et al. (1988).
1417
- 1418 **Figure 16.** a) Map of the southeastern part of Piemonte region with the location of the investigated
1419 archaeological sites (related numbering proceeding from Fig. 1): 9) Brignano Frascata,
1420 Momperone, 11) Villaromagnano, 12) Casalnoceto, 13) Gremiasco, 14) Fabbrica
1421 Curone, 15) Pozzol Groppo, 16) Volpeglino, 17) Viguzzolo, 18) Sale. The red polygon
1422 corresponds to the area represented in Fig. 16b. b) Geological scheme of the southeastern

1423 part of the study area (see red polygon in Fig. 16a). The distribution of the
1424 lithostratigraphic units of the Tertiary Piemonte Basin succession containing meta-
1425 ophiolitic pebbles (**mor**: Costa Cravara Breccia and Molare Formation; **sav**: Savignone
1426 Conglomerate; **mst**: Monastero Formation) is shown, as well as the distribution of
1427 Quaternary alluvial deposits (**tal**; **all**). Geological boundaries redrawn from Piana et al.
1428 (in the press), for the Piemonte part, and from Servizio Geologico d'Italia (1969a, b, c;
1429 1971), Marroni et al. (2010), and Vercesi et al. (2014), for the Liguria and Lombardia
1430 part. Within the Savignone Conglomerate and the Monastero Formation, the distinction
1431 of the conglomerate bodies containing meta-ophiolitic clasts (**sav_c**; **mst_c**) has been
1432 possible only for the area delimited by the dashed line, corresponding to the northwestern
1433 part of the Cabella Ligure sheet of the Geological Map of Italy at 1:50.000 (Marroni et
1434 al., 2010).