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Jadeitite in the Monviso meta-ophiolite, Piemonte Zone, Italian western Alps

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Abstract. — Following the search of jadeitite in the alluvial deposits at the mouths of the main alpine valleys, a systematic field survey around Monviso, italian western Alps, led to the discovery of a primary jadeitite outcrop. The jadeitite occurs as a tectonic block about 1 m^3 in volume near Punta Rasciassa, and is embedded in a serpentinised lherzolite of the basal serpentinite unit of the Monviso meta-ophiolite.

On hand specimen, the jadeitite is a very pale grass green, fine-grained massive rock surrounded by a darker retrogression margin and crosscut by coarser grained phlogopite-rich pockets and irregular discontinuous veins. A portion of the boudin consists of a peculiar rock with pegmatoid grain-size.

Microscopically, the fine grained jadeitite appears more heterogeneous with clinopyroxene composition ranging from jadeite to omphacite. Three main portions may be distinguished, which consist of clear clinopyroxene, clinopyroxene with accessory rutile, and dusty clinopyroxene, respectively. In all portions the matrix clinopyroxene occurs as aggregates of interlocked stumpy prismatic crystals with sharp compositional zoning, which locally contain larger cloudy clinopyroxene relics. Zircon is a typical ubiquitous accessory mineral. The coarser-grained veins and pockets consist of randomly oriented clinopyroxene idioblasts included in xenoblastic albite or aggregates of phlogopite and Mg-chlorite. In both the rock matrix and the veins a poikiloblastic allanitic epidote locally occurs. The pegmatoid portion consists of Cr-bearing omphacite and chlorite + phlogopite domains. Very rare garnet porphyroblasts locally occur, which contain inclusions of ilmenite and minor apatite.

The occurrence of rutile and the equilibration temperature deduced by the Y content of garnet suggest eclogite-facies conditions. The ubiquitous presence of zircon suggests that the jadeitite derived from a former felsic dyke (plagiogranite?), originally intrusive into upper mantle peridotite, which experienced a significant metasomatism during peridotite serpentinisation.

Riassunto. — L'occasionale ritrovamento di giadeititi nei depositi alluvionali allo sbocco delle principali vallate alpine ha portato ad una loro ricerca sistematica nel massiccio del Monviso e alla scoperta del primo affioramento nei pressi di Punta Rasciassa. Si tratta di un blocco di circa 1 m^3, incluso in lherzoliti serpentinizzate appartenenti all'unità basale del complesso meta-ofiolitico del Monviso.

Macroscopicamente, la giadeitite appare di colore verde pallido e grana molto fine, orlata da una porzione scura di retrocessione. Nella giadeitite a grana fine

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sono localmente presenti sacche e vene ricche in flogopite ed una porzione a grana pegmatoide.

La giadeitite è costituita principalmente da clinopirosseno la cui composizione varia da giadeite a onfacite, e risulta microstrutturalmente eterogenea con porzioni limpide, porzioni torbide e porzioni relativamente ricche in rutilo. Il clinopirosseno cresce principalmente in aggregati di individui prismatici tozzi, nei quali è evidente una marcata zonatura composizionale. Localmente sono presenti cristalli relitti di maggiori dimensioni, caratterizzati da un aspetto torbido. Le vene e le sacche contengono clinopirosseno, albite, flogopite e clorite, mentre la porzione pegmatoide consiste di domini a prevalente clinopirosseno e domini a prevalenti fillosilicati, con subordinata onfacite aciculare. Raramente sono stati osservati porfiroblasti di granato ed epidoto allanitico. Tra gli accessori è caratteristico lo zircone.

Le caratteristiche geologiche, petrografiche e minerochimiche della giadeitite suggeriscono un'origine legata a processi metasomatici associati alla serpentinizzazione della peridotite incassante, a partire da un protolite filoniano di tipo acido, probabilmente un plagiogranito.

KEY WORDS: *jadeitite, ophiolite, metamorphism, Monviso, western Alps.*

INTRODUCTION

From the early Neolithic to the Bronze Age, i.e. from the sixth to the second millennium BC in western Europe, prehistoric peasants used axes and chisels made of polished stones, collectively known as "green stones" (see *e.g.* Ricq-de-Bouard and Fedele, 1993). The "green stones" mainly consist of serpentinite, fine-grained eclogite and Na-pyroxenite (mostly omphacitite and jadeitite). Long since it has been established that "green stones" derive from the meta-ophiolites of the Piemonte Zone of the western Alps. Damour (1881), who analysed a sample from a private collection labelled "Green Jasper from Monviso, Piemonte", concluded it was made of jadeite and invited geologists and mineralogists to check carefully the Monviso area and search for this mineral. However, though primary outcrops of the other lithologies used as archaeologic implements (i.e., serpentinite, fine-grained eclogite and omphacitite) are well known in the Piemonte Zone, so far jadeitites have been found only as pebbles or boulders from "secondary" deposits, such as the alluvial post-orogenic Oligocene to Quaternary conglomerates. A search of jadeitite boulders in the alluvial deposits at the mouths of the main alpine valleys (Dino Del Caro, *personal communication,* 2001) showed that the most promising area was that around the Monviso meta-ophiolite. A systematic field survey of the area in summer 2002 led to the discovery of a jadeitite boudin on the northern side of Punta Rasciassa, Po valley (Fig.1): this new occurrence was preliminary reported at the International Eclogite Field Symposium (Compagnoni and Rolfo, 2003).

In this paper, petrography and mineral chemistry of this jadeitite is described and its origin and features compared with similar lithologies from prehistoric implements are discussed.

THE OPHIOLITIC BELT OF THE WESTERN ALPS

The Monviso meta-ophiolite composite unit (in the following referred to as "Monviso meta-ophiolite") belongs to the Piemonte Zone of Central and western Alps, which consists of fragments of former Tethyan oceanic lithosphere (meta-ophiolites) and its Mesozoic sedimentary cover (calcschists or "schistes lustrés"). During the Alpine orogeny, the rocks of the Internal Piemonte Zone experienced an early high-pressure (HP) eclogite-facies metamorphism, whereas those of the External Piemonte Zone experienced only blueschist facies conditions (Compagnoni, 2003 with ref. therein).

In the Monviso meta-ophiolite the Alpine metamorphism reached eclogite-facies conditions, with temperatures of about 600 °C (580 ± 40 °C: Schwartz *et al*., 2000; 620 ± 50 °C: Messiga *et al*., 1999) and pressures of about 20 kbar (19 ± 2 kbar: Schwartz *et al*., 2000; 24 kbar: Messiga *et al*., 1999). Locally, the eclogites of the Monviso meta-ophiolite are cut by omphacite metamorphic veins, which have been the subject of detailed structural, petrographic, fluid inclusions, and stable isotope studies suggesting they formed by local circulation of fluids at eclogite-facies conditions (Philippot and Selverstone, 1991; Nadeau *et al*., 1993; Philippot, 1993). Two retrograde metamorphic stages have been inferred, with equilibration under blueschist-

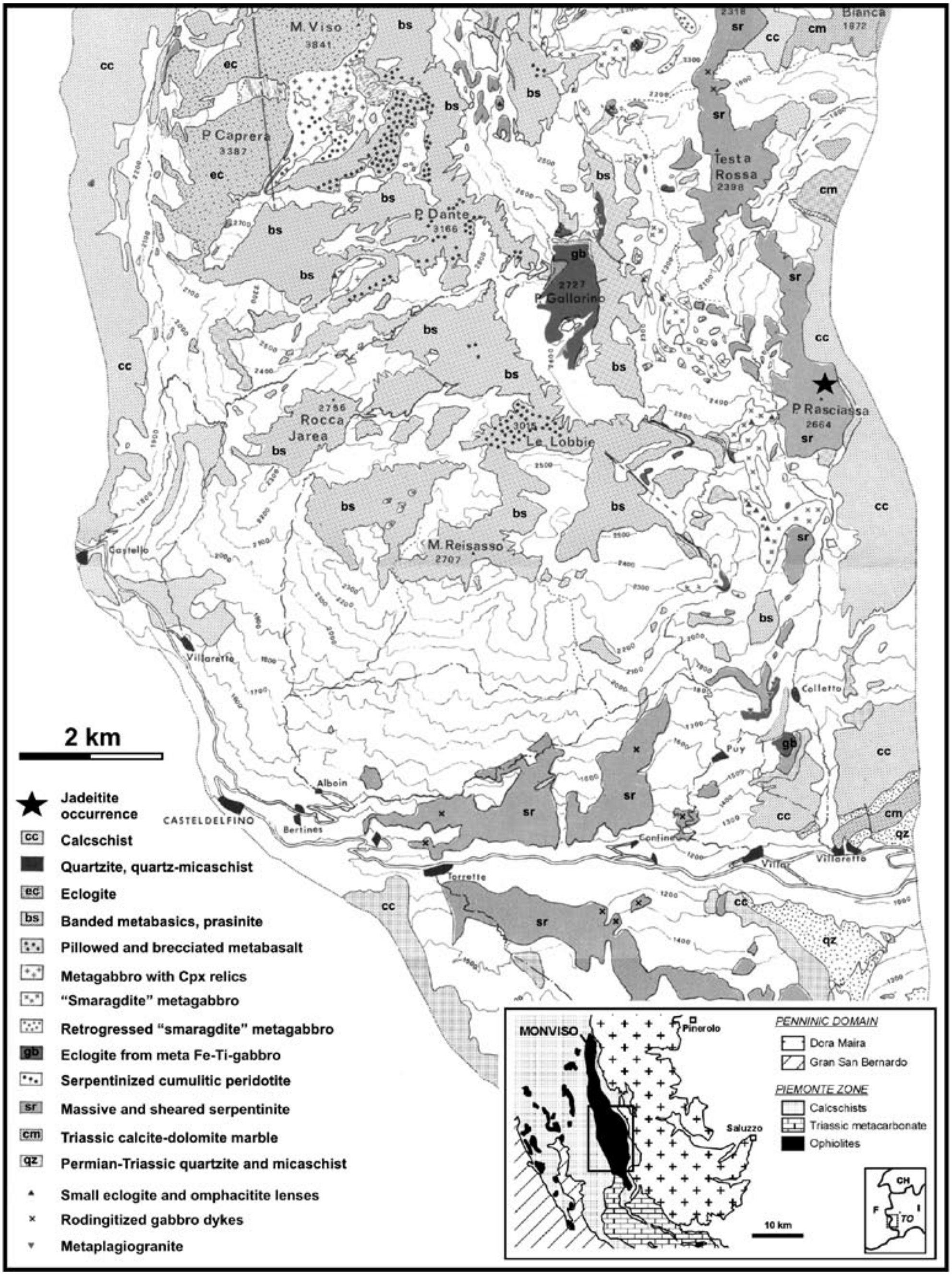

Fig. 1 - Geologic map of the Monviso metaophiolite complex (from Lombardo *et al*., 1978; metaplagiogranite occurrence reported by Castelli *et al*., 2002), showing the location of the studied jadeitite. Inset shows the location of the Monviso metaophiolite complex, within the framework of the Southwestern Alps. In the small inset the political boundaries among France (F); Italy (I) and Switzerland (CH) are reported. TO: Torino.

and greenschist-facies conditions, respectively. (Lombardo *et al*., 1978).

Geochronologic data on the Monviso meta-ophiolite suggest a Tertiary age for the Alpine HP metamorphism (Monié and Philippot, 1989; Duchêne *et al*., 1997; Cliff *et al*., 1998), which is in line with the radiometric ages obtained from other portions of the Internal Piemonte Zone. The most recent geochronologic study of the Monviso meta-ophiolite is a SHRIMP U-Pb determination on zircons from a syn-eclogitic metamorphic vein, which yielded an Eocene age of 45 ± 1 Ma (Rubatto and Hermann, 2003).

THE JADEITITE

The jadeitite was found at about 2400 m a.s.l. (coordinates: LAT_UTM: 4944144; LONG_UTM: 357530) in a small cirque on the northern side of Punta Rasciassa, Po valley (Fig. 1). It occurs as a loose block, about one cubic metre in size, within the massive or sheared antigorite serpentinite belonging to the "basal serpentinite" unit (Fig. 1) of the Monviso meta-ophiolite (cf.: Lombardo *et al*., 2002). Though not in its primary setting, it is evident that the jadeitite is a boudin which was originally located at most a few tens of meters upstream within the same serpentinite (Fig. 2a).

The very pale grass green, massive, and fine grained jadeitite, locally contains irregular cm-sized coarse grained phlogopite-rich pockets and veins (Fig. 2c). On one side of the block, a coarse grained portion with peculiar pegmatoid grain-size occurs, which consists of cm-sized crystals of bright green clinopyroxene and light grey chlorite flakes (Fig. 2b). The jadeitite block is mantled by a darker retrogression margin from 10 to 20 cm thick (Fig. 2b).

PETROGRAPHY

Under the microscope, even the fine grained jadeitite is heterogeneous, being formed by variously distributed: 1) portions mainly consisting of clear, inclusion free, clinopyoxene; 2) portions where clinopyroxene is associated with up to about 10 vol.% of rutile; 3) portions with dusty clinopyroxene, dense with micron-sized mineral inclusions, and 4) portions with coarser grained veins and pockets of phlogopite + Mg-chlorite (Fig. 2c). In all portions, the clinopyroxene occurs as aggregates of interlocked blocky crystals less

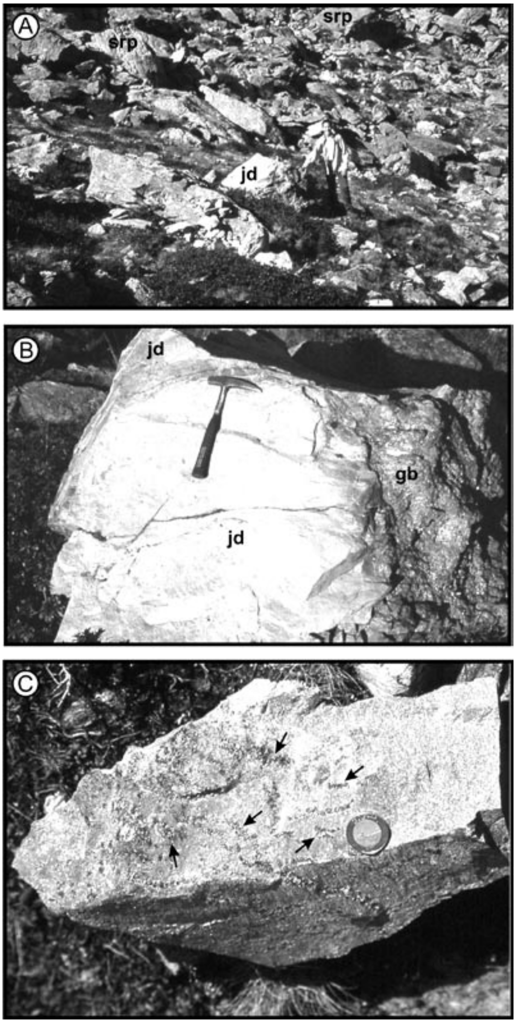

Fig. 2 - Field appearance of the Monviso "jadeitite" at Punta Rasciassa. A) Panoramic view of the jadeitite boudin (jd) among the coarse serpentinite debris (srp) in the small cirque N of Punta Rasciassa, Monviso meta-ophiolite. B) Close-up view of the jadeitite boudin. The lighter jadeitite in the centre (jd) is in contact with a coarse-grained pegmatoid portion (gb) on the right. Note on the upper-left the darker retrogressed margin. C) Jadeitite sliver, in which mm-thick veins and pockets of Mg-chlorite ± phlogopite (arrows) are evident.

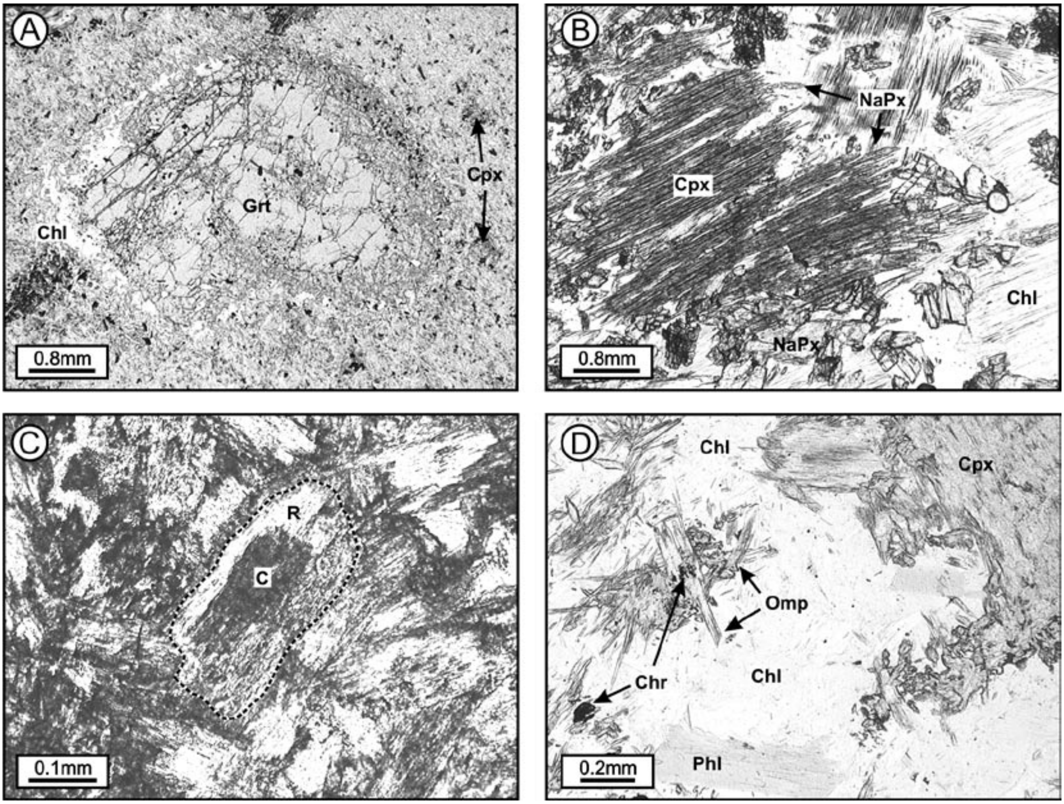

Fig. 3 – Microstructures of the Punta Rasciassa "jadeitite" boudin. A) Microphotograph of a garnet bearing Na-pyroxenite (sample Jd10). Garnet (Grt) rim is crowded with inclusions of ilmenite and apatite, minor jadeite and omphacite, and is partially replaced by chlorite (Chl). Note in the matrix the occurrence of "cloudy" crystals of Na-pyroxene (Cpx). Plane polarized light (PPL). B) Microphotograph of the portion with pegmatoid grain-size (sample Jd3). A "cloudy" porphyroclast of clinopyroxene (Cpx) is in contact with chlorite (Chl) and is rimmed with neoblastic topotactic Na-pyroxene (NaPx). PPL. C) Microphotograph of the matrix Na-pyroxene (sample Jd7) which is sharply zoned with a dusty core "C" and a clear rim "R". The superimposed dotted line defines an individual crystal. PPL. D) Microphotograph of a metamorphic pocket in a rutile-bearing omphacitite (sample Jd5), which consists of Cr-bearing omphacite (Omp), chromite (Chr), chlorite (Chl) and phlogopite (Phl). PPL.

than 0.5 mm across, which systematically show from core to rim a strong and sharp compositional zoning (Fig. 3c). Locally in the fine grained matrix, coarser clinopyroxenes up to several mm across occur with a cloudy core, crowded with very fine grained oriented inclusions, which appear to be relict portions, most probably derived from former igneous crystals (Fig. 3b). Distinctive accessory minerals are zircons, few micrometers across, commonly showing a blocky prismatic shape. Veins and intergranular pockets consist of randomly oriented clusters of idioblastic clinopyroxene surrounded by xenoblastic albite or phlogopite and Mg-chlorite (Fig. 3d). A light purple allanite locally occurs as poikiloblasts in both the rock matrix and the veins. The portion with pegmatoid grain-size consists of greenish clinopyroxene domains and chlorite ± phlogopite, which may include clinopyroxene needles. Very few small garnets (<1 mm) locally occur, which are partially retrogressed to chlorite; a single garnet porphyroblast about 6 mm across was observed (Fig. 3a), which contains inclusions of ilmenite and minor apatite in both the core and the rim.

The host serpentinite still preserves relics of both the original upper mantle clinopyroxene and a granoblastic microstructure due to the prevalent development of pseudomorphic replacement reactions during serpentinisation.

Mineral chemistry

Minerals from the Punta Rasciassa jadeitite were analysed at the Department of Mineralogical and Petrological Sciences, University of Torino, Italy with a Cambridge SEM-EDS, operating at 15 kV accelerating voltage, 50 s counting time and 2.70-2.80 A beam current. SEM-EDS quantitative data (spot size = 2μm) were acquired and processed using the Microanalysis Suite Issue 12, INCA Suite version 4.01; the raw data were calibrated on natural and synthetic mineral and oxide standards and the ΦρZ correction (Pouchou and Pichoir, 1988) was applied. Analyses of minerals were processed by using the software of Ulmer (1986). Representative mineral analyses are reported in Table 1, while compositional variations of clinopyroxenes and garnet are reported in Fig. 5.

The clinopyroxene composition varies depending on the microstructural site (Fig. 5a). The cloudy clinopyroxene porphyroclasts (Fig. 3b, 4c), which include abundant apatite and are crowded with ilmenite segregations, range from ferrian omphacite (X_{Jd} = 0.33-0.34; X_{Ae} = 0.26-0.27) to aluminian aegirine-augite (X_{Jd} = 0.10-0.16; X_{Ae} = 0.32-0.34) (Rock, 1990) and are partly replaced by retrograde phlogopite and Mg-chlorite (X_{Mg} < 0.80). Matrix clinopyroxene, the most abundant mineral, is compositionally heterogeneous and its composition varies from calcian to calcian-ferrian jadeite ($X_{Jd} \leq 0.83$; $X_{Ae} \geq 0.05$) to ferrian omphacite ($X_{Jd} \geq 0.20$; $X_{Ae} \leq 0.27$). Compositional heterogeneities of clinopyroxene in the matrix are clearly evident also from back-scattered SEM images (Fig. 4a) showing that the clinopyroxene core is made of tiny (≤ 10 μm) blebs of ferrian omphacite ($X_{Jd} \leq 0.56$; $X_{Ae} \geq 0.14$) in an almost pure jadeite ($X_{Jd} \leq 0.97$; $X_{Ae} \geq 0.03$), which we interpret as exsolution, while the rim consists of ferrian omphacite ($X_{Jd} \geq 0.49$; $X_{Ae} \leq 0.17$) (Fig. 5a). Similar microstructures have been reported by Harlow *et al.* (2006) in jadeite axes from Antigua; coexisting jadeite and omphacite have been also found in an eclogite-facies meta-quartzdiorite from the southern Sesia Zone, western Alps (Matsumoto and Hirajima, 2005) and in a jadeite-bearing lawsonite eclogite from Guatemala (Tsujimori *et al*, 2005), as well as in various metabasites from the Ligurian Alps (Cortesogno *et al.,* 2002); the coexistence of two Na-pyroxenes suggests a metamorphic crystallization at temperatures lower than the *solvus* (Matsumoto and Hirajima, 2005 with ref. therein). Dusty portions of matrix jadeititic clinopyroxenes differ from clear grains in that they contain tiny (1-2 μm) titanite, included during crystallization. Clinopyroxenes included in garnet are both ferrian jadeite ($X_{Jd} \leq 0.66$; $X_{Ae} \leq$ 0.30) and ferrian omphacite ($X_{Jd} \geq 0.37$; $X_{Ae} \geq 0.27$) suggesting the coexistence of two Na-pyroxenes even if the compositional gap is not as pronounced as in the matrix. Clinopyroxene in metamorphic veins and pockets is compositionally variable from aegirine-poor omphacite to aegirine-rich ferrian omphacite (X_{Jd} = 0.18-0.50; X_{Ae} = 0.09-0.26), being locally rich in either Cr ($Cr_2O_3 \leq$ 4.42 wt%) or Ti ($TiO_2 \leq$ 0.63 wt%). In some metamorphic pockets, Cr-bearing omphacite is associated with relict chromite, chlorite and phlogopite (Fig. 3d).

The garnet poikiloblasts (Fig. 3a, 4b) show a very little pyrope increase from core (Grs_{03-05} Alm_{58-59} Prp_{16-18}) to rim (Grs_{03-06} Alm_{59-60} Prp_{17-21}) (Fig. 5b). This lack of zoning is also supported by the homogeneous content of yttrium (about 1100 ppm), which indicates metamorphic *T* (Y in Grt, Pyle and Spear (2000) calibration) of about 500 °C (Gloria Vaggelli, *personal communication,* 2007). The presence of single inclusions of ilmenite, jadeite and omphacite (Fig. 4b) indicates that the garnet did overgrow a matrix already consisting of these minerals. Garnets are locally surrounded by a retrogression rim of Mg-chlorite (X_{Mg} < 0.74).

The metamorphic veins consist, in addition to clinopyroxene, of almost pure albite (Ab_{98}) and allanite (La = 2.14 wt%; Ce = 8.00 wt%; Nd = 4.42 wt%). Distinctive domains and pockets in the portion with pegmatoid grain-size (Fig. 2c, 3d) contain minor Cr-bearing omphacite and relict chromite together with abundant Mg-chlorite (clinochlore to penninite: X_{Mg} < 0.90) and very pale Ti-poor ($TiO_2 \leq$ 0.73 wt%) homogeneous phlogopite (X_{Mg} = 0.80-0.82).

In conclusion, the petrographic and minerochemical study of the jadeitite recognizes

TABLE 1

Representative microprobe analyses of clinopyroxene, garnet, feldspar, phlogopite and chlorite from the Punta Rasciassa "jadeitite"

MINERAL	*CLINOPYROXENE*										*GARNET*		*FELDSPAR*	*PHLOGOPITE*	*CHLORITE*
ANALYSES	**9Cpx25r**	**9Cpx26s**	**9Jd27s**	**10Cpx9c**	**11Jd16**	**11Cpx17**	**11Cpx19**	**11Jd20**	**7Cpx40**	**3Cpx71c**	**10Grt1c**	**10Grt5rr**	**7Pl39**	**4Phl68**	**3Chl77**
SAMPLE	**Jd8b**	**Jd8b**	**Jd8b**	**Jd10**	**Jd10**	**Jd10**	**Jd10**	**Jd10**	**Jd7**	**Jd5**	**Jd10**	**Jd10**	**Jd7**	**Jd5**	**Jd5**
texture	*rim*	*exsolved core (Omp)*	*exsolved core (Jd)*	*cloudy crystals*	*matrix (Jd)*	*matrix (Omp)*	*inclusion in Grt*	*inclusion in Grt*	*metam. vein*	*metam. vein*	*core*	*rim*	*metamorphic vein*	*metamorphic vein*	*metamorphic vein*
SiO_2	57.02	56.39	58.89	54.39	57.13	55.58	54.99	55.87	56.37	54.12	37.52	37.15	67.60	40.57	31.31
TiO_2	0.00	0.53	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.42	0.00	0.00	0.00	0.00	0.00
Al_2O_3	13.88	13.44	24.50	4.72	17.96	9.62	9.55	16.49	12.80	8.00	21.04	20.71	19.99	14.13	16.84
Fe_2O_3	3.39	5.40	1.04	9.58	9.51	8.07	8.80	10.61	3.55	7.56	2.17	2.83	0.00	0.48	0.00
FeO	0.14	0.00	0.00	2.14	0.00	1.21	1.19	0.57	0.00	0.63	26.36	26.00	0.00	8.01	9.35
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.37	4.37	0.00	0.00	0.00
MgO	6.85	6.01	0.01	9.13	0.40	7.39	6.35	0.46	7.44	6.37	4.42	4.98	0.00	22.10	29.38
CaO	9.66	7.81	0.37	13.68	0.95	10.46	9.06	1.45	10.40	7.85	4.07	4.00	0.49	0.00	0.00
Na_2O	9.70	10.77	15.63	6.99	14.72	8.98	9.22	14.14	9.19	9.97	0.00	0.00	11.72	0.73	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.04	0.00
H_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.16	12.33
Total	100.64	100.34	100.44	101.15	100.67	101.31	99.16	99.58	99.75	99.4	100.94	100.03	99.80	99.23	99.19
Si	1.976	1.963	1.975	1.957	1.977	1.957	1.983	1.971	1.975	1.953	2.958	2.947	2.954	2.921	6.093
Ti	0.000	0.014	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.000	0.000	0.000	0.000	0.000
Al	0.567	0.552	0.968	0.200	0.732	0.399	0.406	0.685	0.529	0.340	1.955	1.937	1.030	1.199	3.862
Fe^3	0.093	0.141	0.026	0.324	0.248	0.249	0.272	0.298	0.094	0.224	0.129	0.169	0.000	0.026	0.000
Fe^2	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	1.737	1.725	0.000	0.482	1.522
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.358	0.294	0.000	0.000	0.000
Mg	0.354	0.312	0.001	0.490	0.021	0.388	0.341	0.024	0.389	0.343	0.519	0.589	0.000	2.372	8.523
Ca	0.359	0.291	0.013	0.527	0.035	0.395	0.350	0.055	0.390	0.304	0.344	0.340	0.023	0.000	0.000
Na	0.652	0.727	1.016	0.488	0.988	0.613	0.645	0.967	0.624	0.698	0.000	0.000	0.993	0.103	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.830	0.000
OH	0	0	0	0	0	0	0	0	0	0	0	0	0	2	16

Structural formulae have been calculated on the basis of 4 cations and 6 oxygens for pyroxene, 8 cations and 12 oxygens for garnet, 5 cations and 8 oxygens for feldspar, 8 cations and 11 oxygens and 2 OH for phlogopite, 20 cations and 28 oxygens and 16 OH for chlorite, respectively.

a decompressional evolution characterized by an earlier eclogite-facies metamorphic event followed by a blueschist and a later greenschist facies retrogression, similar to that reported from all over the Monviso meta-ophiolite slices (Lombardo *et al.*, 1978).

The origin of jadeitite

The discovery of a massive jadeitite within the serpentinite of the Monviso meta-ophiolite is very important for the understanding of the origin of an unusual rock type, which has been used by the Prehistoric people as a raw material to make stone implements.

As with the jadeitite from other famous and well studied localities (e.g. Burma and Guatemala: cf. Harlow *et al.*, 2007 with ref. therein), the Punta Rasciassa jadeitite occurs as a tectonic block in a serpentinised upper mantle peridotite, which still preserves rare mineralogical and structural relics of the high-*T* ultramafic protolith. The occurrence of jadeitite within serpentinite suggests that the two rocks were closely associated at least as early as the Alpine eclogite-facies metamorphism.

The jadeitite composition does not fit that of any fresh igneous protolith: therefore, its composition must have been acquired later through a metasomatic process. This process should have occurred in the presence of an abundant hydrous fluid phase, such as that present during the peridotite serpentinisation. The occurrence of a metasomatising fluid during the jadeitite formation is supported by: i) the "pegmatitic" grain size in some portions; ii) the irregular metamorphic pockets enriched in chlorite and phlogopite (an hydrated and K-bearing metamorphic phase); iii) the strong and oscillatory compositional zoning of many Na-pyroxenes. On this base, the Punta Rasciassa jadeitite is therefore interpreted as a metasomatic rock derived from an igneous protolith

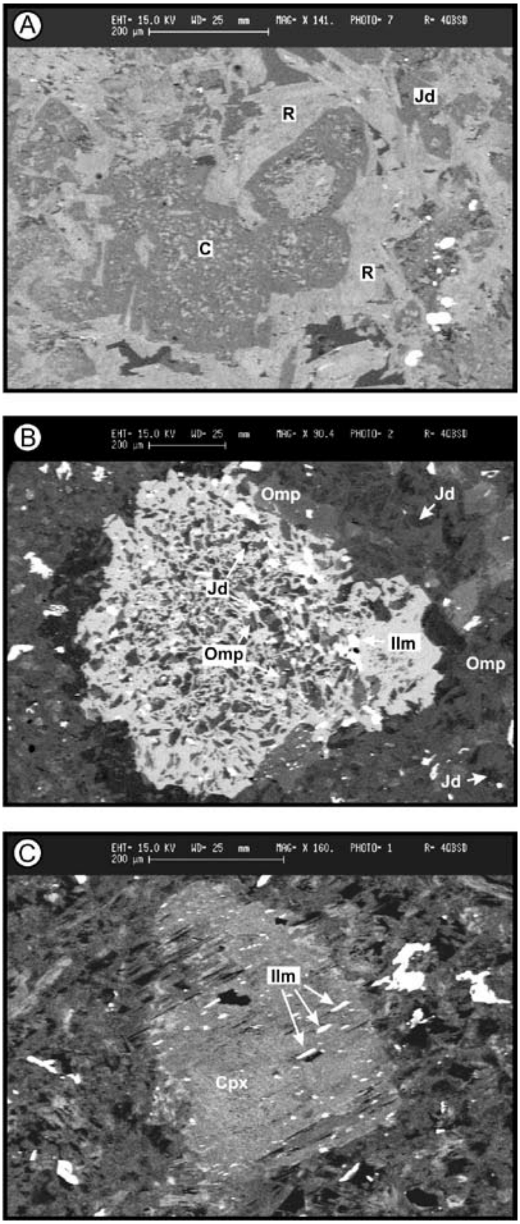

Fig. 4 - Back-scattered SEM images of the Punta Rasciassa "jadeitite". A) Typical appearance of a Na-pyroxenite (sample Jd7), which mainly consists of stumpy prismatic crystals of sharply zoned Na-pyroxene with a euhedral jadeite core (C - dark portions) showing very fine-grained exsolution blebs of omphacite (lighter portions), and an omphacite rim (R). Crystals of Na-poorer jadeite (Jd) also occur. The white grains are rutile. B) Garnet-bearing Na-pyroxenite (sample Jd10). The garnet poikiloblast includes single crystals of ilmenite (Ilm), jadeite (Jd) and omphacite (Omp), and the matrix mainly consists of interlocked stumpy prismatic crystals of jadeite (Jd) and omphacite (Omp). C) In the matrix of the garnet bearing Na-pyroxenite (sample Jd10), the "cloudy" porphyroclasts of Na-pyroxene (Cpx) are crowded with ilmenite segregations (Ilm) and are inhomogeneous with Na-richer (darker) and Na-poorer (lighter) portions.

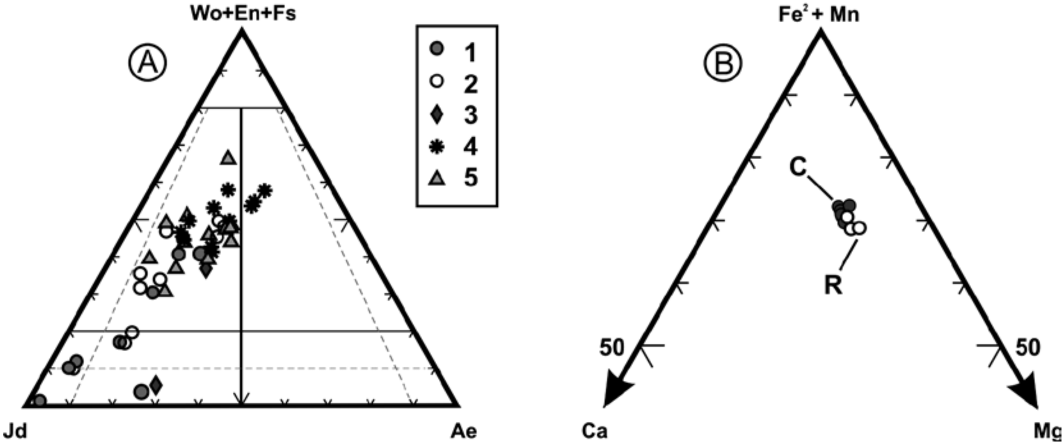

Fig. 5 – A) Compositions of clinopyroxenes from the Punta Rasciassa "jadeitite" in the jadeite-aegirine-(wollastonite + enstatite + ferrosilite) diagram of Morimoto *et al*. (1988); dashed lines bound the additional compositional fields proposed by Rock (1990). Analysed samples: Na-pyroxenite with dark and clear portions (Jd8b); garnet-bearing Na-pyroxenite (Jd10); rutile-bearing omphacitite (Jd5); Na-pyroxenite with pegmatoid grain-size (Jd3). Symbols: 1) matrix crystals (exsolved core); 2) matrix crystals (rim); 3) inclusions in garnet; 4) relic cloudy porphyroclasts; 5) in metamorphic veins. B) Garnet compositions of the garnet-bearing Na-pyroxenite (Jd10) are shown in the (Fe^{2+} + Mn) – Ca - Mg diagram. C: garnet core; R: garnet rim.

during the peridotite serpentinisation, a process that may have occurred during either ocean-floor or orogenic (subduction) serpentinisation: since it is well known that serpentinisation is a desilication process, in the first case analcime should have first formed at the expense of a sodic plagioclase and then converted to jadeite, whereas in the second case jadeite should have formed directly from the albite breakdown.

As to the nature of the jadeitite protolith, both the dusty clinopyroxene porphyroclasts with oriented ilmenite segregations and the small ubiquitous stumpy prismatic zircons support an igneous protolith. In particular, these types of zircons were reported by Pupin (1992) from late magmatic differentiates of basaltic melts, such as Na-granite, Na-syenite or plagiogranite, and by Castelli *et al*. (2002) from a meta-plagiogranite from the Monviso meta-ophiolite.

Comparison with Neolithic implements

A systematic petrographic study of the polished stone implements from Mediterranean France (Ricq-de-Bouard *et al*., 1990) and Northern Italy (Compagnoni *et al*., 1995; D'Amico *et al*., 1995, 2004; Giustetto and Compagnoni, 2004) has shown that, especially in the Neolithic period, jadeitite was at least 15-20 % of the raw material used by Prehistoric people. These jadeitites show a wide spectrum of microstructures, Na-pyroxene composition, and accessory minerals. Following the Na-pyroxene nomenclature suggested by Rock (1990), which is more detailed with respect to that of Morimoto *et al*. (1988), jadeitites only composed of pure jadeite are relatively rare, mostly containing one or more other Na-pyroxenes with higher diopside and/ or aegirine components. Even pure jadeite usually contains omphacite blebs suggesting an origin by exsolution. As to the accessory minerals, the ubiquitous zircon and the Ti-bearing minerals (rutile, titanite or ilmenite) are very important, the former for the genetic interpretation and the latter for the geotectonic provenance. As for the zircon significance, we refer to the former section on the jadeitite origin, whereas the local occurrence of rutile together with that of antigorite in the host serpentinite and the garnet equilibration temperature of 500°C, are consistent with the eclogite-facies conditions of the Internal Piemonte Zone (Compagnoni *et al*., 1995; 2006). However, given the great petrographic (and most probably also genetic) variability shown by archaeological jadeitites, data are still too few to dissert on the origin of the raw material of prehistoric implements (see *e.g.* Pétrequin *et al.*, 2006) and it is just possible to conclude that the Monviso meta-ophiolite is one of the most promising source areas from the western Alps. Therefore, a more detailed petrologic and geologic work on new jadeitite outcrops is needed before drawing more reliable conclusions.

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