JD-QTZ-BEARING METAPLAGIOGRANITE FROM THE MONVISO META-OPHIOLITE (WESTERN ALPS)

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ABSTRACT

In the Basal Serpentinite Unit of the Monviso meta-ophiolite (Val Varaita, Western Alps), a large jadeite-quartz-bearing metaplagiogranite body has been found, which shows magmatic contacts with eclogitic Pl-Cpx-FeTi oxide metagabbro. Primary texture and magmatic minerals in the metaplagiogranite are mostly obliterated by multistage Alpine re-equilibrations. The highest-pressure assemblage consisted of jadeite, quartz, phengite and rutile. Garnet and zoned ferroglaucophane developed immediately after the peak assemblage, and were followed by aegirine-rich clinopyroxene. Calculated phase compatibilities and phengite geobarometry indicate T = 575°C and P = 1.95 GPa as minimal temperature and pressure of formation for the peak assemblage in the metaplagiogranite, in agreement with garnet-clinopyroxene geothermometry from the associated FeTi-oxide metagabbro which yields T = 545±35°C at P = 2.0 GPa.

Major, trace, and REE data are typical of oceanic plagiogranite, and similar to those of metaplagiogranite from other meta-ophiolite units of the Western Alps, Northern Apennines and Corsica. Petrological and preliminary geochemical data suggest that the Monviso plagiogranite likely represents late stages of the plutonic activity in this sector of the Western Tethys, and could have formed by fractional crystallization of ocean-floor tholeiite magmas in Late Jurassic times.

INTRODUCTION

The Monviso meta-ophiolite, one of the best preserved relics of oceanic crust in the Western Alps, includes widespread metagabbroid sequences. Field, petrographical and major-element data indicate derivation of the metagabbroids from Pl-Cpx±Ol±Sp Mg-gabbro and Pl-Cpx-FeTi oxide Fe-gabbro protoliths (Lombardo et al., 1978; MONVISO, 1980; abbreviations after Kretz, 1973). Both protoliths likely originated by fractional crystallization of tholeitic melt at different fractionation stages (MONVISO, 1980). More differentiated intrusive rocks were unknown at Monviso until Castelli and Rostagno (1999) firstly described at Vernè (middle Val Varaita) a large body of jadeite-quartz-bearing metaplagiogranite, retaining magmatic contacts with Omp-Grt-Rt±Gln metagabbro, in the Basal Serpentinite Unit of the Monviso meta-ophiolite.

Plagiogranites are low-K, leucocratic rocks occurring in the ophiolite suites, and consist primarily of quartz and plagioclase with only minor amounts of ferromagnesian minerals (Coleman and Peterman, 1975). They formed by fractional crystallization of ocean-floor tholeiite magmas, and represent late stages of the plutonic activity in the Piedmont-Liguria domain (e.g. Beccaluva et al., 1977; Ohnenstetter and Ohnenstetter, 1980; Pognante et al., 1982; Pognante and Piccardo, 1984; Borsi et al., 1996; 1998). Plagiogranites are believed to be generated by magmatic processes similar to those thought to be active in present-day normal mid-oceanic ridges (Coleman and Peterman, 1975; Coleman and Donato, 1979).

In the eclogite-facies meta-ophiolites of Western Alps (Fig. 1), jadeite-quartz-bearing metaplagiogranites and metatrondhjemites are described as small veinlets and/or pods associated with eclogitic Pl-Cpx-FeTi oxide metagabbros at Monte Nero (Aosta Valley: Novo et al., 1989), in Val d’Ala di Lanzo (Leardi et al., 1984; Sandrone et al., 1986), in the Orsiera-Rocciavré klippe (Lombardo and Pognante, 1982; Pognante et al., 1982), and with ultramafics in the Lanzo peridotite body (Lombardo and Pognante, 1982; Pognante et al., 1985; Pognante, 1989). Layers of jadeite-quartz-bearing rocks are associated with Pl-Cpx±Ol±Sp MgAl-gabbro at Monviso (Schwartz et al., 2000), whilst in the Voltri Group, centimetre- to metre-thick plagiogranite dykes cut all lithologies of the ophiolite sequence (Borsi et al., 1996, with refs.).

Metaplagiogranites also occur in the external Ligurian-type ophiolite units of the Western Alps (Fig. 1), which mainly suffered blueschist-facies re-equilibrations. West of Monviso, albite granite to trondhjemite veins occur in the meta-ophiolite slices of Queyras and at Tour Real (Steen, 1975; Lemoine, 1980; Lagabrielle, 1981; Lombardo and Pognante, 1982; Carpéna and Caby, 1984). In the Alpine Corsica, leucocratic rocks (ranging from leucoferrodiorite to albitite) are mainly found as dykes in the upper cumulates and volcanics of the ophiolite sequence (Ohnenstetter and Ohnenstetter, 1980, with refs.). In the Sestri-Voltaggio Zone, as well as in Northern Apennines ophiolites, plagiogranites occur as centimetre- to metre-wide dykes cutting all the ophiolite sequence, up to the lower part of the volcano-sedimentary sequence (Serri, 1980; Borsi et al., 1996; 1998; Tiepolo et al., 1997; with refs.). In the Montgenèvre ophiolite, the largest Ligurian-type ophiolite complex of the Western Alps which escaped the high-pressure metamorphism, dioritic rocks form veins, dykes and diffuse impregnations within sheared gabbros, and dykes and sills of albitite were emplaced within peridotites and gabbros (Bertrand et al., 1987; Costa and Caby, 2001, with refs.).

In spite of mineralogical and chemical modification during (and possibly before) the Alpine metamorphism, metaplagiogranites are important, as they may provide significant information about the magmatic and metamorphic evolution of the Piedmont-Liguria meta-ophiolites. This note reports preliminary petrological and geochemical data on the Vernè metaplagiogranite, whilst a companion paper focuses on its U/Pb geochronology and palaeotectonic significance (Lombardo et al., 2002, this volume).

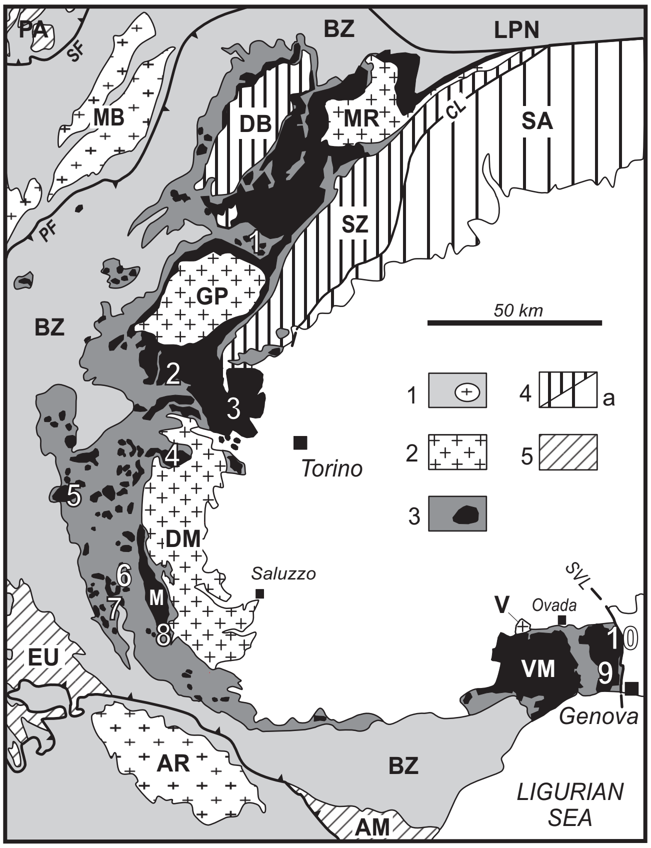

Fig. 1 - Structural sketch map of the Western Alps showing major ophiolite bodies and metaplagiogranite occurrences. 1: Helvetic and External Penninic units, and External Crystalline Massifs (Ar: Argentera, Mb: Mont Blanc - Aiguilles-Rouges). BZ: Briançonnais Zone, Lpn: Lower Penninic Nappes; 2: Internal Crystalline Massifs (MR: Monte Rosa, GP: Gran Paradiso, DM: Dora-Maira, V: Valosio); 3: Piedmont Zone, with ophiolite bodies shown in black, VM: Voltri Massif, M: Monviso); 4: Austroalpine units (DB: Dent Blanche Nappe, SZ: Sesia-Lanzo Zone) and Southern Alps (a); 5: Helminthoid Flysch nappes (PA: Préalpes, EU: Embrunais-Ubaye, AM: Alpi Marittime). CL: Canavese Line, SF: Subalpine Frontal Thrust, PF: Penninic Frontal Thrust. Numbers refer to location of metaplagiogranites from the Western and Ligurian Alps: 1) Monte Nero; 2) Val d'Ala di Lanzo; 3) Lanzo peridotite body; 4) Orsiera-Rocciavré; 5) Montgenèvre; 6) Queyras; 7) Tour Real; 8) Monviso (this work); 9) Voltri Group; 10) Sestri-Voltaggio Zone (see text for references).

GEOLOGICAL SETTING AND FIELD RELATIONSHIPS

The Monviso massif is an N-MORB type ophiolite complex of Jurassic age which suffered the eclogite-facies Alpine metamorphism (Lombardo et al., 1978; MONVISO, 1980; Lardeaux et al., 1987; Nisio et al., 1987; Philippot, 1988; Philippot and Kienast, 1989). It consists of six major lithotectonic units that from top to bottom are: Vallanta Unit, Forciolline Unit, Passo Gallarino Unit, Viso Mozzo Unit, Lago Superiore Unit, and Basal Serpentinite Unit (Lombardo et al., 1978; Lombardo et al., 2002). These units are interpreted as fragments of the oceanic lithosphere which floored the Piedmont domain of the Western Tethys. Well-preserved sequences of isotropic and/or layered cumulate metagabbroids are common in the Forciolline Units, where two different protoliths were identified. They are the Pl-Cpx±Ol±Sp gabbro and Pl-Cpx-FeTi oxide gabbro types, which in a conventional AFM diagram plot along a typical tholeiitic trend, and are characterized by Mg- and Fe-rich chemical compositions, respectively (Lombardo et al., 1978; MONVISO, 1980). Based on petrochemical data and scanty magmatic relics, also the foliated, Cr-Omp-Zo-Grt±Mg-Cld metagabbros from the Lago Superiore Unit and the foliated, Gln-bearing eclogites from the Lago Superiore and Passo Gallarino units have been described as Mg-gabbros and Fe-gabbros, respectively (Lombardo et al., 1978; MONVISO, 1980; Schwartz et al., 2000). As Fe-gabbro should be used only for gabbros with Fe-rich pyroxene and olivine (Le Maitre et al., 1989) like in the Skaergaard intrusion, the Monviso eclogites will be called hereafter FeTi-oxide metagabbros. Petrochemical investigations also showed the occurrence of intermediate metagabbros associated to the FeTi-oxide metagabbros of the Passo Gallarino Unit (Lombardo et al., 1978). These intermediate metagabbros are compositionally similar to well-preserved gabbronorites from the gabbronorite - Ilm-Mag gabbro layered sequence of Fonte Neiretto, Rocciavrè (Pognante et al., 1982).

All units of the Monviso meta-ophiolite experienced eclogite-facies peak conditions during the Alpine subduction, followed by exhumation first under blueschist-facies, and later under greenschist-facies conditions (Lombardo et al., 1978; Lardeaux et al., 1987; Philippot, 1990; Blake et al., 1995). The highest P-T conditions are recorded in Cr-rich magnesiochloritoid metatroctolite from the Lago Superiore Unit (P = 2.4 GPa at T = 620±50°C: Messiga et al., 1999), whilst the Viso Mozzo and Passo Gallarino Units are believed to have equilibrated at T = 450±50°C and P = 1.2±0.3 GPa (Schwartz et al., 2000).

Several geochronological data are available on the high-pressure metamorphism in the Monviso meta-ophiolite. Sm-Nd isochron ages of 60±12 and 62±9 Ma have been obtained (Cliff et al., 1998) on garnet + Na-pyroxene assemblages from the Lago Superiore Unit. Cliff et al. (1998) also report a phengite Rb-Sr age of 40±1 Ma that is younger than the $^{40}Ar/^{39}Ar$ phengite ages of *c.* 50 Ma reported by Moniè and Philippot (1989). These latter ages are in agreement with a Lu-Hf whole-rock garnet age of 49.1±1.2 Ma (Duchène et al., 1997). U-Pb ion microprobe dating of zircon from an omphacite-garnet-bearing metamorphic vein in the Lago Superiore Unit yielded an age of 45±1 Ma (Rubatto and Hermann, 2002).

The Basal Serpentinite Unit is widely exposed in the Val Varaita (Fig. 2), and consists of serpentinized peridotites, with lenses of metagabbroids and scarce remnants of a metasedimentary cover (Lombardo et al., 1978; 2002). Like in the Forciolline Unit, the protoliths of the metagabbroids included Pl-Cpx±Ol±Sp Mg-gabbro and FeTi-oxide gabbro. Minor chromite-bearing types were also found (Bogatto and Castelli, 1997). The metagabbroids either show well-developed eclogite-facies foliations or, in low-strain domains, coronitic reaction textures that likely formed during an earlier, "oceanic" metamorphic stage (Lombardo et al., 1978; Bogatto and Castelli, 1997).

North of the Vernè locality (Fig. 2), the Basal Serpentinite Unit hosts a a large, lens-shaped composite body about 300 m long and 70 m thick, in which FeTi-oxide metagabbro is in primary contact with jadeite-quartz-bearing metaplagiogranite (Castelli and Rostagno, 1999). The FeTi-oxide metagabbro retains relics of the magmatic texture, with dark-green porphyroclastic pyroxenes and Fe-Ti oxide spots that are armored by the omphacite-garnet bearing foliation. Primary textures are lacking in the pale greenish, medium-

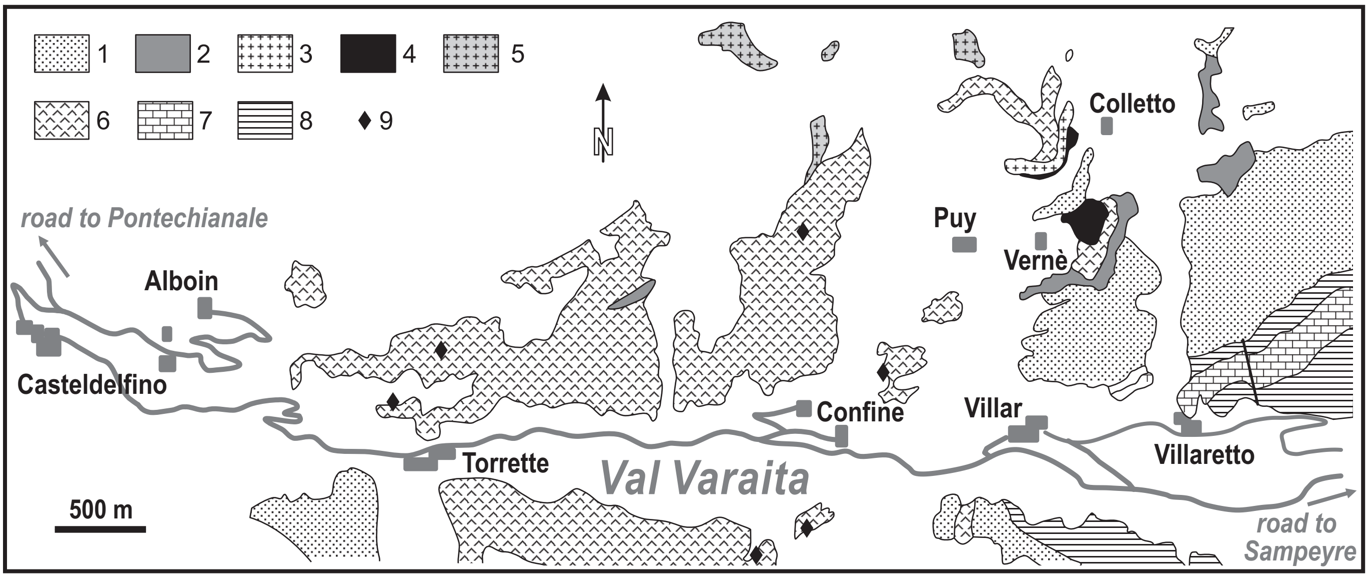

Fig. 2 - Simplified geological map of the Monviso meta-ophiolite along the northern side of middle Val Varaita (from Lombardo et al., 1978; Bogatto and Castelli, 1997; Castelli and Rostagno, 1999): 1: calc-schists; 2: undifferentiated metabasites; 3: metaplagiogranite; 4: FeTi-oxide metagabbro and eclogite; 5: metagabbro; 6: serpentinite; 7: carbonate schist and dolomitic marble; 8: Permian-Triassic quartzite and micaschist; 9: rodingitized gabbro lenses. The area covered by the map corresponds to the location in Fig. 1 of the Vernè metaplagiogranite (#8).

to fine-grained metaplagiogranite, where undeformed decimetre-wide domains pass to high-strain domains with a pervasive mylonitic foliation (Fig. 3a). However, folded boudins of the FeTi-oxide metagabbro are typically found within the metaplagiogranite (Fig 3a), and relict intrusive relationships between the metaplagiogranite and the metagabbro locally occur (Fig. 3b). At places, the contact is marked by a decimetre-thick rim of coarse-grained blue amphibole, similar to that described by Novo et al. (1989) in the Mt. Nero plagiogranite body.

Within the metaplagiogranite, centimetre-thick layers of a fine-grained, albite-quartz-bearing rock show very sharp contacts to the host rock, and are possibly relics of late magmatic dykes. Centimetre-thick metamorphic veins locally are found in both the FeTi-oxide metagabbro and the metaplagiogranite. Metamorphic veins in the metagabbro consist of garnet ± chlorite, those in the metaplagiogranite consist of quartz and garnet ± blue amphibole.

PETROGRAPHY AND MINERAL-CHEMISTRY

Magmatic texture and minerals in the Monviso plagiogranite are mostly obliterated by multistage Alpine re-equilibrations, and the rock now consists of albite, quartz and relict jadeite, with minor green Na-pyroxene, zoned blue amphibole, phengite, garnet, and accessory rutile, allanite and zircon (Fig. 4a). However, the presence of a primary hypidiomorphic fabric is locally suggested by the shape of some quartz domains, possibly pristine interstitial to euhedral plagioclase. Anhedral allanite and zircon are interpreted as relics of the igneous assemblage (see also Lombardo et al., 2002).

Microstructural relations in low-strain domains indicate that the peak eclogite-facies assemblage included jadeite, quartz, phengite and rutile. Colorless jadeite occurs as small anhedral crystals that are pseudomorphically replaced by poikiloblastic albite, very fine-grained Fe-oxides and scanty K-feldspar (Fig. 4a). Composition varies in different

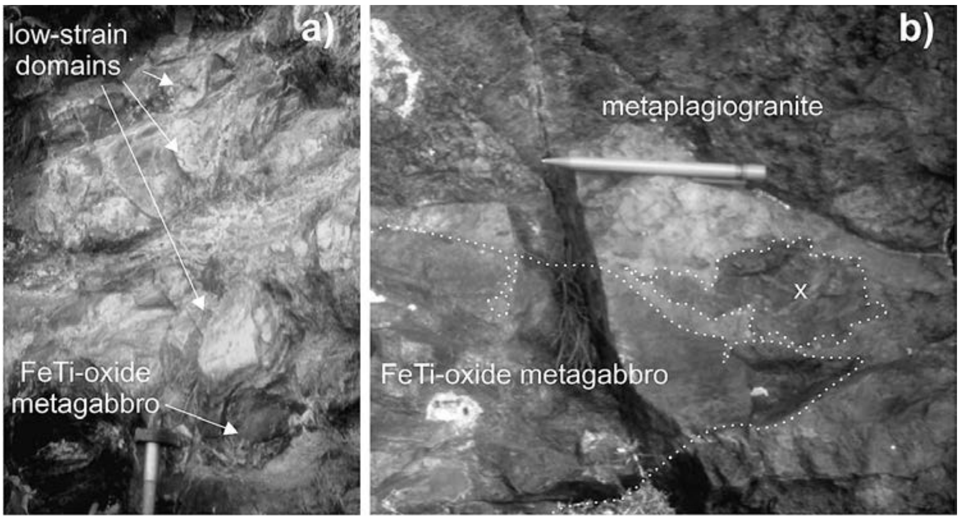

Fig. 3 - Field occurrence of the Vernè metaplagiogranite. a) Domains of undeformed metaplagiogranite are separated by centimetre- to decimetre-thick shear zones. Note the small boudin of FeTi-oxide metagabbro at bottom-right. b) Relict intrusive contact between the metaplagiogranite and FeTi-oxide metagabbro. The dotted lines outline the very sharp and irregular contact and bound a small xenolith of FeTi-oxide metagabbro (x) enclosed in the plagiogranite.

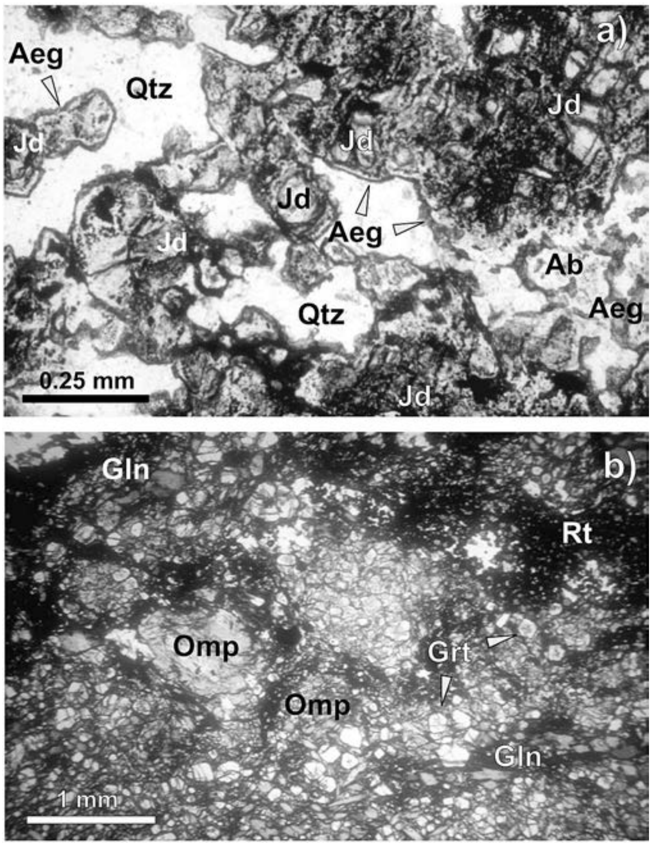

Fig. 4 - a) Relict high-pressure granoblastic texture in the Vernè metaplagiogranite. Jadeite (Jd) is mostly replaced by albite (Ab) and very fine-grained Fe oxides. Thin coronas of green aegirine-augite to augite (Aeg) continuously rim the former jadeite domains. Sample OF2628, parallel light. b) Relict hypidiomorphic texture in the FeTi-oxide metagabbro associated with the metaplagiogranite. Large subhedral crystals of omphacite (Omp) after igneous pyroxenes are set in a matrix of fine-grained omphacite + idioblastic garnet (Grt) and glaucophane (Gln). Fine-grained rutile (Rt) replaces primary Fe-Ti oxides. Sample OF2732, parallel light. Abbreviations after Kretz (1973).

grains ($0.67<X_{Jd}<0.91$, $0.09<X_{Aeg}<0.23$; see also Fig. 5a and Table 1, analytical details are given in the Appendix), but no regular zoning was detected. Minor phengite (Si = 3.4-3.7 atoms p.f.u.) occurs as subhedral flakes arranged in a spaced foliation.

The peak metamorphic assemblage is locally cut by a net of centimetre-thick, high-pressure metamorphic veins consisting of equant idioblastic garnet and minor blue amphibole set in a finer-grained matrix of quartz. The vein garnet is weakly zoned (Fig. 5b and Table 1), with slightly increasing almandine and decreasing grossular toward the rim (e.g. $Alm_{82-89}Grs_{12-6}Py_{2-4}Adr_{0-6}$). The vein blue amphibole is a zoned ferroglaucophane (Figs. 5c, d and Table 1), with decreasing Mg content at rim ($0.32<X_{Mg}<0.37$ at core and $0.24<X_{Mg}<0.28$ at rim, respectively). A few garnet idioblasts and some ferroglaucophane crystals also occur at places within the jadeite domains of the host metaplagiogranite. They show the same chemical composition and zoning pattern as the vein garnet and ferroglaucophane.

In the plagiogranite, a typical, post-metamorphic peak re-equilibration stage consists of thin reaction coronas of green, aegirine-rich clinopyroxene that contour the original jadeite domains (Fig. 4a). The same coronitic reaction occurs around garnet and ferroglaucophane in both the metamorphic veins and the host metaplagiogranite, allowing to constrain the timing of Grt-Fe-Gln-bearing veins relative to the jadeite-bearing, peak assemblage in the metaplagiogranite. The green Na-pyroxene shows different compositions (Fig. 5a and Table 1) in different microdomains. The Na-pyroxene replacing jadeite shows the widest range in the aegirine component and ranges from aegirine-augite to aegirine. Compositions of Na-pyroxene rimming ferroglaucophane and garnet are constantly richer in the aegirine component and lie almost entirely in the aegirine field of Morimoto et al. (1988).

The fine-grained rock that cuts the metaplagiogranite consists of small poikiloblastic albite, quartz, green Na-pyroxene, ferroglaucophane, and large subhedral zircon. The fabric is similar to that of the metaplagiogranite but quartz, that concentrates in irregular granoblastic domains, and randomly oriented ferroglaucophane are more abundant. No relict jadeite has been found, but the lens-shaped albite poikiloblasts are continuously rimmed by the same coronas of aegirine-rich pyroxene that contour the jadeite domains in the metaplagiogranite.

The FeTi-oxide metagabbro associated to the metaplagiogranite retains medium- to fine-grained eclogite-facies assemblages, consisting of omphacite, almandine-rich garnet and rutile. Relics of granular hypidiomorphic gabbroic structure are locally preserved, with pseudomorphic replacement of euhedral to subhedral magmatic pyroxene by omphacite and of interstitial magmatic ilmenite by rutile (Fig. 4b). Glaucophane occurs either as fine-grained subhedral crystals at garnet rims and in the omphacite groundmass, or as large poikolablasts hosting corroded relicts of both the omphacite and garnet.

The coarse-grained blue amphibole locally rimming the contact with the plagiogranite is mainly a ferroglaucophane. Its X_{Fe} is lower than that of the ferroglaucophane from both the metaplagiogranite and the quartz-garnet-ferroglaucophane veins (Figs. 5c, d).

GEOCHEMISTRY

Preliminary geochemical data on a representative sample of the Vernè metaplagiogranite are given in Table 2 and plotted in Figs. 6 to 8. The sample shows high contents of silica and Na_2O, and a very high Na_2O/K_2O ratio. On the basis of normative feldspar proportions, it falls in the trondhjemite field of Barker (1979), but the normative plagioclase-quartz ratio and the high iron content are not typical of trondhjemite (Barker, 1979). The lack of primary major minerals also hampers the color index definition that is used to name low-K leucocratic rocks in ophiolites (e.g. Ohnenstetter and Ohnenstetter, 1980). Based on both the chemical and normative composition, the sample can be defined as a leucocratic, Fe-rich quartz-diorite. As further geochemical investigations are still in progress, classification as oceanic plagiogranite (Coleman and Peterman, 1975; Coleman and Donato, 1979) or ophiolitic plagiogranite (see Ohnenstetter and Ohnenstetter, 1980 for a discussion) is preferred here, in agreement with its position in the AFM diagram (Fig. 6).

Despite extensive Alpine recrystallization, the pristine chemical composition of the Vernè metaplagiogranite seems to have been largely retained, as major and trace element data are similar to those of metaplagiogranites from other meta-ophiolite units of the Western Alps, Northern Apennines and Corsica (Beccaluva et al., 1977; Ohnenstetter and Ohnenstetter, 1980; Pognante et al., 1982; Leardi et al.,

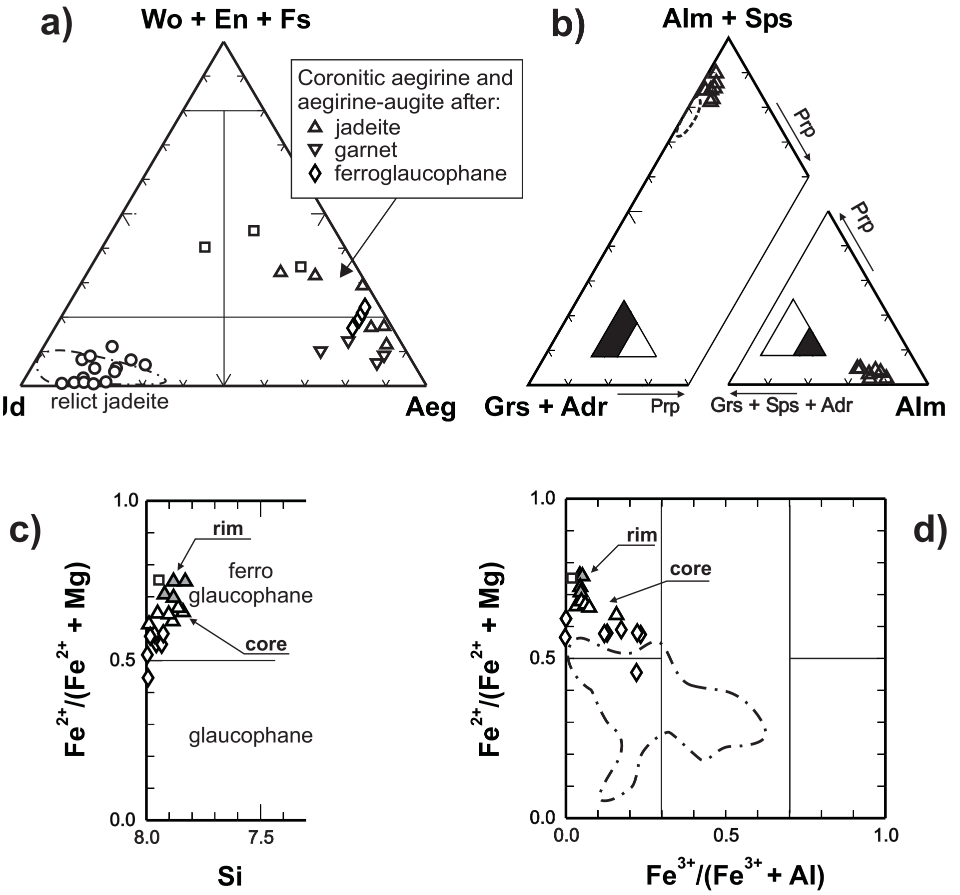

Fig. 5 - Mineral compositions from the Vernè metaplagiogranite. a) relict jadeite and green coronitic aegirine-rich clinopyroxenes after jadeite, garnet and ferroglaucophane, respectively. The dashed-dotted line contours the compositional field of jadeitic clinopyroxenes from the Western Alps metaplagiogranites (Droop et al., 1990). This field also includes the compositions of jadeite in metagabbro from the Lago Superiore Unit (Schwartz et al., 2000). Compositions of coronitic aegirine-augite after jadeite (empty squares) in a metaplagiogranite from the Susa Valley (Pognante, 1989) are also shown. b) Garnet; the dotted line defines the compositional field of garnet from the Western Alps metaplagiogranites (Droop et al., 1990). c) -d) sodic amphiboles: nomenclature after Leake et al. (1997). Empty and full triangles correspond to core and rim compositions of ferroglaucophane, respectively. Empty diamonds refer to the coarse-grained ferroglaucophane locally rimming the contact between the metaplagiogranite and FeTi-oxide metagabbro. The dashed-dotted line bounds the field of sodic amphiboles from the Western Alps meta-ophiolites (Droop et al., 1990), and the empty square refers to ferroglaucophane in a metaplagiogranite from the Susa Valley (Pognante, 1989).

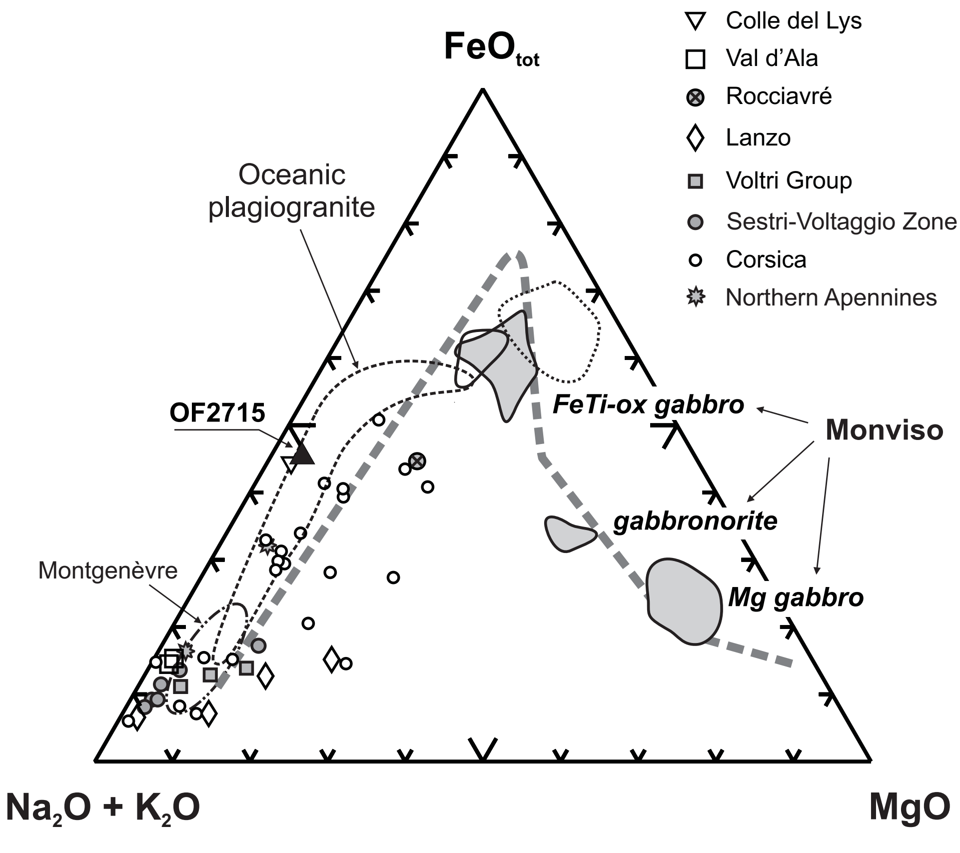

Fig. 6 - AFM diagram showing the composition of the Vernè metaplagiogranite OF 2715 compared to the compositions of the gabbro suite of central Monviso and to other metaplagiogranites of the Western Alps, Corsica, and Northern Apennines. Gray fields are from Lombardo et al.(1978) and MONVISO (1980). Compositional fields of FeTi-oxide metagabbros from Viso Mozzo (solid line), and Lago Superiore - Passo Gallarino (dotted line) given by Schwartz et al. (2000) are also shown. Sources of other data are: Colle del Lys, Pognante and Toscani (1985); Val d'Ala, Leardi et al. (1984); Rocciavré and Lanzo peridotite body, Pognante et al. (1982, 1985); Montgenèvre, Bertrand et al. (1987); Voltri Group and Sestri-Voltaggio Zone, Borsi et al. (1996); Corsica, Ohnenstetter and Ohnenstetter (1980). Northern Apennines: average compositions of plagiogranites and quartz-diorites (Serri, 1980). The thick dashed line shows the differentiation trend of the Corsican ophiolite intrusives (Ohnenstetter and Ohnenstetter, 1980); the compositional field of oceanic plagiogranite is from Coleman and Peterman (1975). See text for discussion.

Table 1 - Representative compositions of minerals from the Vernè plagiogranite.

	1	1	2	2	3	4
Analysis	*1113*	*1114*	*1138*	*1144*	*11324*	*11210*
Symbol	○	○	△	△	▽	◇
SiO_2	58.26	57.32	52.42	53.12	52.30	52.67
TiO_2	0.00	0.00	0.12	0.11	0.09	0.00
Al_2O_3	19.24	18.00	0.81	2.71	3.12	1.32
FeO_{tot}	6.03	8.75	26.75	19.33	25.04	24.61
MnO	0.00	0.00	0.23	0.12	0.20	0.49
MgO	0.46	0.38	1.83	4.79	1.14	2.02
CaO	1.21	0.73	3.00	8.46	3.75	5.34
Na_2O	14.30	14.02	11.80	9.35	11.64	10.87
K_2O	0.00	0.00	0.09	0.00	0.16	0.06
total	99.50	99.20	97.05	97.99	97.44	97.38
Si	2.014	2.004	1.997	1.986	1.980	2.004
Al^{IV}	0.000	0.000	0.003	0.014	0.020	0.000
Σ T	*2.014*	*2.004*	*2.000*	*2.000*	*2.000*	*2.004*
Al^{VI}	0.784	0.742	0.034	0.105	0.119	0.059
Fe^{3+}	0.146	0.200	0.838	0.580	0.758	0.737
Ti	0.000	0.000	0.004	0.003	0.003	0.000
Mg	0.023	0.020	0.104	0.267	0.064	0.115
Fe^{2+}	0.029	0.056	0.015	0.024	0.035	0.047
Mn	0.000	0.000	0.007	0.004	0.006	0.016
Σ M1	*0.982*	*1.018*	*1.001*	*0.984*	*0.985*	*0.973*
Ca	0.045	0.027	0.123	0.339	0.152	0.218
Na	0.959	0.951	0.872	0.677	0.855	0.802
Σ M2	*1.003*	*0.978*	*0.994*	*1.016*	*1.007*	*1.020*
Quad	4.8	5.1	12.2	31.7	12.8	19.1
Jd	80.3	74.7	3.4	10.5	11.8	6.0
Aeg	14.9	20.2	84.4	57.8	75.4	74.9

	5	5	6	6
Analysis	*1112*	*1111*	*11216*	*11315*
Symbol			△	▲
			core	rim
SiO_2	53.37	54.60	55.04	54.51
TiO_2	0.21	0.34	0.07	0.00
Al_2O_3	21.80	21.32	9.83	10.83
Fe_2O_3	n.c.	n.c.	2.74	0.75
FeO	4.67	4.44	17.10	20.17
MnO	0.00	0.29	0.11	0.05
MgO	3.89	3.65	5.50	3.58
CaO	0.16	0.00	0.17	0.54
Na_2O	0.50	0.18	7.35	7.49
K_2O	10.96	10.70	0.00	0.00
H_2O	4.44	4.47	2.09	2.07
total	100.00	100.00	100.00	100.00
Si	3.603	3.666	7.885	7.880
Ti	0.011	0.017	0.008	0.000
Al	1.735	1.688	1.660	1.845
Fe^{3+}	n.c.	n.c.	0.295	0.082
Fe^{2+}	0.263	0.250	2.049	2.439
Mn	0.000	0.017	0.013	0.006
Mg	0.391	0.366	1.174	0.771
Ca	0.012	0.000	0.026	0.084
Na	0.066	0.023	2.042	2.099
K	0.944	0.917	0.000	0.000
X_{Mg}			0.36	0.24

	7
Analysis	*1126*
Symbol	▲
SiO_2	36.77
TiO_2	0.13
Al_2O_3	19.92
Fe_2O_3	0.75
FeO	38.16
MnO	0.41
MgO	0.86
CaO	3.10
total	100.10
Si	3.009
Ti	0.008
Al	1.921
Fe^{3+}	0.046
Fe^{2+}	2.611
Mn	0.028
Mg	0.105
Ca	0.272
Grs	6.3
Alm	86.6
Prp	3.5
Sps	0.9
Adr	2.3
TiAl-Grt	0.4

1: jadeite, 2: aegirine to aegirine-augite after jadeite, 3: aegirine at garnet rim, 4: aegirine at Fe-glaucophane rim, 5: phengite, 6: Fe-glaucophane, 7: garnet (symbols as in Fig. 5). Structural formulae calculated on basis of Morimoto et al. (1988) for clinopyroxenes, of 11 oxygens and all Fe as Fe^{2+} for micas, of Spear and Kimball (1984) for Na-amphibo1es, and assuming stoichiometry and charge balance for garnets; n.c.: not calculated; H_2O calculated from stoichiometry in micas and Na-amphiboles.

1984; Pognante and Toscani, 1985; Bertrand et al., 1987; Borsi et al., 1996, 1998). The Monviso metaplagiogranite lies along a typical MORB differentiation trend, but this relatively large plutonic body is compositionally less evolved than most trondhjemite veinlets, pods and or dykes which are found in other meta-ophiolite units (Fig. 6). However, this composition is not unique as Pognante and Toscani (1985) reported a very similar bulk composition from a plagiogranite - FeTi gabbro body at Colle del Lys, Susa Valley. The trace element spider diagram of the Monviso metaplagiogranite normalized to MORB composition is given in Fig. 7 and compared to available profiles of eclogite-facies metaplagiogranite dykes from the Voltri Group (Borsi et al., 1996) and metatrondhjemite veinlets from Val d'Ala (Leardi et al., 1984). Although some elements are missing in the compared profiles, the pattern is very similar. Relative to the Voltri Group and Val d'Ala rocks, Sr, P, and Ti are about 10 times enriched in the Monviso metaplagiogranite that also shows the highest Zr content. It is worth noting that a high Zr content was also reported in the Colle del Lys metaplagiogranite (Zr = 1016 ppp: Pognante and Toscani, 1985).

The chondrite-normalized REE abundances (Fig. 8) range between 60 and 100 times chondrite. This range is

Table 2 - Major (wt%), trace and RE (ppm) element data, and CIPW norm of the Monviso plagiogranite OF2715 from Vernè.

SiO_2	65.68	Rb	8	La	26.9	Q	14.1
TiO_2	0.78	Sr	78	Ce	83.4	or	2.4
Al_2O_3	14.37	Ba	70	Pr	12.8	ab	63.7
Fe_2O_3(*)	7.77	Cs	<1	Nd	62.3	an	4.6
MnO	0.13	Pb	4	Sm	18.4	di	4.6
MgO	0.62	Y	150	Eu	4.69	hy	5.4
CaO	2.20	Zr	1282	Gd	19.5	mt	3.3
Na_2O	7.46	Hf	29	Tb	3.4	il	1.5
K_2O	0.41	Nb	13	Dy	23.2	ap	0.4
P_2O_5	0.18	Ta	1	Ho	5.22		
LOI	0.46	Th	2	Er	13.5		
		U	<1	Tm	2.31		
Total	100.06	Ni	20	Yb	16.5		
		Co	5	Lu	2.56		
		V	8				
		Cr	7				
		Cu	8				
		Ga	42				
(*) Total Fe as Fe_2O_3		Zn	135				

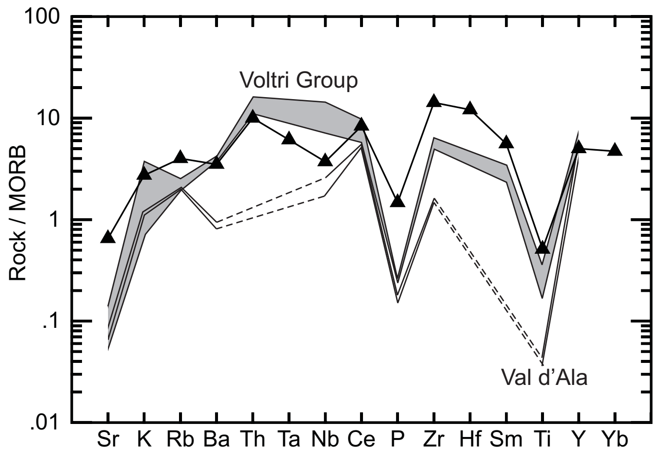

Fig. 7 - MORB-normalized (Pearce, 1982) spider diagram for the Vernè metaplagiogranite (triangles). Patterns of plagiogranites from the Voltri Group (Borsi et al., 1996: Table 1; Ta, Hf and Yb values not available) and quartz-jadeite rocks from the Val d'Ala (Leardi et al., 1984: Table 3; Th, Ta, Hf, Sm and Yb values not available) are shown for comparison.

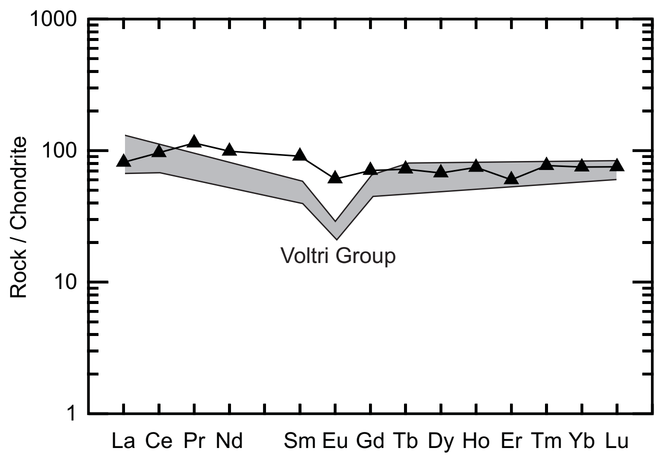

Fig. 8 - Chondrite-normalized REE pattern of the Vernè metaplagiogranite (triangles), compared to plagiogranite patterns from the Voltri Group (Borsi et al., 1996: Table 1; Pr, Dy, Ho, Er and Tm values not available). Data normalized according to chondrite abundances of Nakamura (1974).

similar to that displayed by plagiogranites from the Voltri Group (Borsi et al., 1996). However, the Monviso metaplagiogranite shows a less differentiated composition, being characterized by a flatter pattern and higher LREE contents, and by a very-weak negative Eu anomaly.

DISCUSSION AND CONCLUSIONS

To our knowledge, the Vernè metaplagiogranite is the largest plagiogranite body in the eclogite-facies ophiolites of the Western Alps, and its finding in the Basal Serpentinite Unit provides significant information about the magmatic and metamorphic evolution of the Monviso meta-ophiolite. The 152±2 Ma crystallization age (SHRIMP U-Pb zircon age: Lombardo et al., 2002) indicates that the Vernè plagiogranite likely represents late stages of the plutonic activity within the Piedmont oceanic crust now exposed in the Monviso meta-ophiolite. This age is younger by some 10 million years than the crystallization age of a FeTi-oxide metagabbro from the Lago Superiore Unit (163±2 Ma: Rubatto and Hermann, 2002). Together, these two ages constrain the plutonic activity in the Monviso meta-ophiolite to Callovian - Kimmeridgian times (Lombardo et al., 2002).

The occurrence of both the metaplagiogranite and different metagabbro types (Bogatto and Castelli, 1997) in the Basal Serpentinite Unit of Val Varaita suggests that this unit may host the products of a composite intrusive activity. Speculating about likely mechanisms of generation for the Vernè plagiogranite appears premature, insofar as only one sample was chemically analyzed. We note, however, that modeling of plagiogranite genesis in terms of fractional crystallization in a closed system appears to be the model preferred by a number of workers on Alpine and Apennine ophiolites (e.g. Serri, 1980; Borsi et al., 1998). The model of Borsi et al. (1998) is based on predictions of the MELTS free energy minimization algorithm (Ghiorso and Sack, 1995) and assumes a parental magma approaching MORB in composition, but characterized by relatively high Na and Ti contents. In this model, residual liquids of qtz-diorite composition are generated after *ca*. 75% crystal fractionation, and the conjugated fractionated solids show compositions which are consistent with the associated gabbroic rocks. As pointed out by Tiepolo et al. (1997), however, La_N/Sm_N variations in cpx of Mg- to Fe-gabbroids from the Northern Apennines are difficult to reconcile with simple fractional crystallization models. These Authors suggest that some other differentiation process (possibly infiltration of LREE-enriched liquids in a crystal mush) must have played a role in modifying the degree of LREE fractionation in the liquids. Field evidence of FeTi-oxide metagabbro closely associated with the Vernè metaplagiogranite may also suggest their syngenetic origin from immiscible liquids at high degree of differentiation (Philpotts, 1976, 1979). Isotopic studies and further chemical data are needed to substantiate this hypothesis.

During the Alpine metamorphism, both the plagiogranite and the associated FeTi-oxide gabbro suffered multistage re-equilibrations. Preliminary peak temperature estimates in the FeTi-oxide metagabbro suggest T = 545±35°C at P = 2.0 GPa (garnet-clinopyroxene geothermometry: Ellis and Green, 1979), that are in agreement with estimates of Blake et al. (1995) who reported 519 < T < 575°C at P ≤ 1.9-2.0 GPa in an eclogite lens cropping out east of Vernè, just below the Basal Serpentinite Unit. In the plagiogranite, the jadeite + quartz ± phengite assemblage and the ferroglaucophane + garnet vein assemblage also help constraining the P-T conditions of the eclogitic stage, by considering: a) the phengite geobarometer of Massonne and Schreyer (1987), b) the stability field of the jadeite + quartz assemblage, and 3) the stability of the ferroglaucophane + garnet vein assemblage calculated from measured mineral compositions (data from Table 1; calculation and solution models according to Connolly, 1990 and Castelli et al., 1997; thermodynamic data from Holland and Powell, 1998). The Si = 3.7 atoms p.f.u. isopleth for phengite (Massonne and Schreyer, 1987) consistently plots in the jadeite + quartz stability field, and intersection between the 3.7 phengite isopleth and the upper thermal stability limit of ferroglaucophane + almandine-rich garnet occurs at T = 575°C, P = 1.95 GPa. These P-T values constrain the minimal temperature and pressure for the peak assemblage jadeite + quartz ± phengite.

The peak P-T conditions estimated in the Vernè metaplagiogranite and FeTi-oxide metagabbro are lower than those inferred by Messiga et al. (1999) for magnesiochloritoid metatroctolite from the Lago Superiore Unit (P = 2.4 GPa at T = 620±50°C), but similar to those of Schwartz et al. (2000) for the eclogitic stage in the same Lago Superiore Unit (P = 1.9±0.2 GPa at T = 580±40°C). Like the omphacite + garnet veins described in other Monviso eclogites (Philippot and Kienast 1989), the garnet + ferroglaucophane + quartz veins in the Vernè metaplagiogranite and the garnet ± chlorite veins in the associated FeTi-oxide metagabbro point to mineral deposition from fluids in extensional fractures under pressures and temperatures that are close to peak metamorphic conditions.

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APPENDIX
Analytical techniques

Mineral spot analyses were performed on polished thin sections with a LINK-EDS equipped Cambridge scanning electron microscope at the Department of Mineralogic and Petrologic Sciences, University of Torino. Natural silicates and oxides were used as standards, and as monitors to check the accuracy of measurements. The accelerating voltage was 15 kV and the integration time 50s.

Geochemical data were collected at CRPG-CNRS, Nancy, using ICP-AES and ICP-MS techniques for major and other elements, respectively. Detection limits and relative errors are given at the CRPG web page (<http://www.crpg.cnrs-nancy.fr/SARM/>).

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