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JADEITE MEGABLASTS FROM VALCHIUSELLA (SESIA-LANZO ZONE, WESTERN ALPS)***

RIASSUNTO. — Nella zona di Brosso (bassa Valchiusella), in prossimità del plutone terziario di Traversella, sono stati rinvenuti entro a parascisti del Complesso dei Micascisti Eclogitici (Zona Sesia-Lanzo) dei caratteristici livelli nodulari in gran parte costituiti da blasti di giadeite con dimensioni eccezionali (fino a 15 cm). I megablasti di giadeite sono immersi in una matrice poco abbondante a quarzo, fengite, ± granato, ± raro glaucofane e contengono abbondanti inclusioni di quarzo, fengite, granato e rutilo.

Il pirosseno dei megablasti, di cui si descrivono i caratteri chimici, ottici e cristallografici, è costituito per oltre il 90 % da molecola giadeitica, con subordinati Ac e Di-Hd.

La giadeite mostra in genere trasformazioni da incipienti ad avanzate in albite + mica bianca ± magnetite, ± pirosseno egirinico ± anfiboli blu ± epidoto (questi ultimi in caratteristiche strutture coronitiche attorno alle inclusioni di quarzo).

Le osservazioni di terreno e la peculiare mineralogia suggeriscono che i livelli a megablasti si sono formati durante l'evento eoalpino di alta pressione - bassa temperatura a spese di originari filoni acidi; la presenza di glaucofane tra i prodotti di trasformazione della giadeite, indica che la decomposizione di quest'ultima è avvenuta ancora in condizioni di alta pressione e bassa temperatura.

ABSTRACT. — Nodular layers consisting of ovoid crystals of jadeite in a quartz-phengite-(garnet) (glaucophane) matrix were found near the Traversella stock as intercalations in the eclogitic micaschists of the Brosso area (Sesia-Lanzo Zone). The crystals of jadeite are of unusual size (up to 15 cm). The Jd content is over 90 %, with minor Ac and Di-Hd.

The pyroxene megablasts are crowded with inclusions of quartz, phengite, garnet and rutile and may be partly to completely altered to albite + white mica ± magnetite ± acmite-rich pyroxene ± blue amphiboles ± epidote; the last three minerals form characteristic coronas around quartz inclusions.

Geological and mineralogical evidence suggests that the nodulas layers formed from pre-Alpine silicic dykes during the highest-pressure event of the early-Alpine high-pressure, low-temperature metamorphism; subsequent breakdown of jadeite occurred in a P-T range still within the blueschist facies.

Introduction

The widespread occurrence in the southeastern Sesia-Lanzo Zone (the so called Formazione dei Micascisti Eclogitici, s. NOVARESE, 1931) of assemblages bearing sodic

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pyroxene as a main constituent has been known since the end of 19th century (FRANCHI, 1900, 1903; NOVARESE, 1894, 1903; STELLA, 1894, 1903; ZAMBONINI, 1901). New studies (MONESE, OGNIBEN and VITERBO, 1967; EDGAR et al., 1969; VELDE and KIENAST, 1973; LIEBEAUX, 1975) have broadly defined the compositional range of these sodic pyroxenes, which vary from jadeite to omphacite in metagranitic rocks and paraschists, from omphacite to chloromelanite in the associated mafic rocks (eclogites, glaucophane eclogites, omphacitites).

Different sodic pyroxenes occur in the same rock, as shown by COMPAGNONI and MAFFEO (1973), who found in the metagranitic rocks of Monte Mucrone (Biella) nearly pure jadeite derived from the early breakdown of magmatic plagioclases, omphacites to chloromelanites growing at the expense of the original biotites, and finally aegirine-augites forming by the breakdown of the older Na-pyroxenes.

The correlation between composition of sodic pyroxenes and bulk chemistry of the eclogitic micaschists will be discussed in a subsequent paper (LOMBARDO et al., 1976); here we describe the unusual jadeite megablasts from the Colme area (lower Valchiusella) and their late-metamorphic alteration.

General geology of the Colme area

The rocks with jadeite megablasts crop out on the southern slope of Le Colme (north of the village of Brosso), on the ridge connecting Monte Gregorio (1953 m) with Monte Cavallaria (1464 m) and dividing lower Valchiusella from Val d'Aosta (fig. 1) (1). The upper part of this ridge consists of « eclogitic micaschists » (fig. 2) with interbedded omphacitites and eclogites; on the west and south the micaschists have been intruded by the Tertiary monzodiorite stock of Traversella and converted into hornfelses. Andesite dykes, mostly a few dm thick, are found in the micaschists, especially near Grange Piani (2).

The « eclogitic micaschists »

Essential components of these rocks are *quartz* (20-30 %), *phengite*, and *garnet*; *glaucophane* may locally be important; *rutile, apatite, clinozoisite/epidote* (often with *zoisite* cores) and rare *tourmaline* and *zircon* are found as minor accessories. A few micaschists (Grange Marlette) contain *stilpnomelane*.

Jadeite (3) occurs as rounded crystals, up to 1 cm long, which weather out in relief in the outcrop; jadeite encloses abundant crystals of quartz with minor garnet, phengite and rutile. *Garnet* occurs as idioblasts up to 3-4 mm in diameter, usually with massive cores and atoll-like rims enclosing quartz and/or flakes of phengite. *Glaucophane* occurs as prisms 0.1-0.3 mm

(1) The best approach to the area is by the small road which climbs from Brosso to the old quartz quarries northeast of Grange Piani and thence to Colle Pian dei Muli, between Le Colme and Monte Cavallaria.

(2) On the igneous geology of the area see especially KENNEDY (1931), and NOVARESE (1943).

(3) The spacing of the $\bar{2}21$ reflection ($d_{\bar{2}21} = 2.933$ Å) points to a Jd content near 82 % according to the diagram of ESSENE and FYFE (1967).

long and is the pale-coloured variety *gastaldite*. All constituents show clear traces of post-cristalline deformation, especially the phengites, which are kinked and bent.

The *garnet omphacitites* occur as conformable intercalations, up to a few meter thick, in the eclogitic micaschists; they are dark-green, massive rocks, consisting of *omphacite,* with subordinate *white mica, quartz* and *glaucophane* as major con-

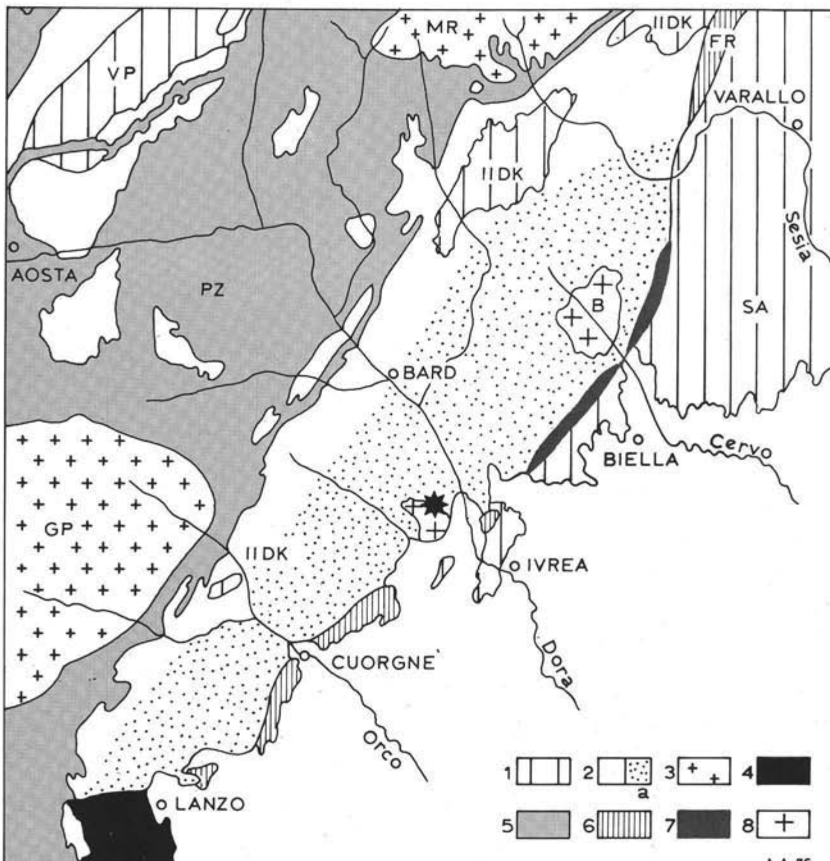

Fig. 1. — *Tectonic sketch map of the internal Northwestern Alps.* 1 - Southern Alps (SA), II Zona Dioritico kinzigitica (II Dk) and Valpelline Series (VP). 2 - Sesia-Lanzo Zone and Dent Blanche Nappe. 2 a - Eclogitic Micaschist Complex. 3 - Monte Rosa (MR) - Gran Paradiso (GP) Nappe. 4 - Lanzo Ultramafics. 5 - Piemonte Zone. 6 - Canavese Zone and Fobello-Rimella Schists (FR). 7 - Trachyandesite volcanics. 8 - Biella (B) and Traversella stocks. Star shows location of the Colme area.

stituents; *rutile, clinozoisite* (with cores of *zoisite*), *apatite* and *zircon* occur as minor accessories. Where *garnet* is plentiful omphacitites grade into eclogites and glaucophane eclogites.

Omphacite (4) forms prisms up to 1 cm long which in the field define a well developed lineation; under the microscope it shows a very pale green colour. The omphacite contains inclusion of garnet, quartz and rutile, more rarely of glaucophane and phengite. *Glaucophane* (5) occurs as stumpy prisms (0.5 to 4-5 mm long) enclosing garnet and quartz and more rarely phengite. *Garnet* is a grossular-rich almandine, with minor pyrope component (6).

Two other rock types, both probably derived from igneous rocks, were found in the Colme area: *a*) metagranitic rocks with cognate inclusions and *b*) leucocratic gneisses.

a) The *metagranitic rocks with inclusions* crop out on the southwest slope of Le Colme, between the altitude of 1500 m and the col west of the summit (fig. 2); they are conformably interlayered in the eclogitic micaschists and, like these, dip steeply to the south. As in other parts of the Eclogitic Micaschist Complex the metagranitic rocks are distinguished from the eclogitic micaschists derived from pre-Alpine paraschists by their homogeneity, both textural and mineralogical, and by the occurrence of dark ovoid inclusions up to a few decimeters in diameter (Dal Piaz et al., 1972; Compagnoni and Maffeo, 1973; Callegari et al., 1976).

Under the microscope these rocks can be classified as medium-grained *garnet-omphacite-phengite-quartz schists*; this mineral assemblage and the absence of K-feldspar relics suggest derivation from igneous rocks of tonalitic composition.

Quartz and *phengite* are the most abundant constituents, colourless *omphacite* forms a network of unoriented prisms enclosing the other minerals; oriented *phengite* marks a poorly-developed schistosity. *Glaucophane, rutile, apatite, zircon, clinozoisite* and *opaque minerals* are minor accessories. The occurrence of *allanite* relics as cores in clinozoisite is very significant, for this accessory is characteristic of rocks of metagranitic parentage throughout the Sesia-Lanzo Zone.

The mineral association of the *inclusions* (sodic pyroxene, phengite and subordinate garnet) is similar to that of the metagranitic rocks; the inclusions are, however, finer-grained and almost devoid of quartz.

b) The *leucocratic gneisses* occur as conformable bodies (up to a few tens of meters long) interbedded in the eclogitic micaschists. The largest outcrops in the area are found on the road to Colle Pian del Muli, northeast of point 1170 m and northwest of Le Colme, along the ridge to Monte Gregorio (fig. 2). In a few outcrops the leucocratic gneisses show conspicuous augen of K-feldspar (7) and, rarely, also megablasts of jadeite.

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(4) The values of the intermediate refractive index ($N_\beta = 1.673$) and spacing of the $\bar{2}21$ reflection ($d_{\bar{2}21} = 2.953$ Å) point to a composition near $Jd_{52}(Di+Hd)_{40}Ac_8$ according to the diagram of Essene & Fyfe (1967).

(5) The spacing of the 310 reflection ($d_{310} = 3.042$ Å), which is related to the content of Fe^{3+} (Coleman & Papike, 1968; Bocquet, 1974 a), points to a composition within the glaucophane field, but close to the glaucophane-crossite boundary.

(6) The values for refractive index ($n = 1.786$), length of unit-cell edge ($a_o = 11.626 \pm \pm 0.005$ Å) and the very low Mn content, point to a composition $Alm_{60}Gr_{31}Py_9$.

(7) Occurrences of augen gneisses in the Eclogitic Micaschist Complex appear to be rare. Up to now only the outcrop of Casa Nara, described by Novarese (1943, p. 50) was known in Valchiusella; the augen gneisses of Casa Nara are however very close to the Traversella stock and their high-pressure, low-temperature assemblages have been completely destroyed by contact metamorphism.

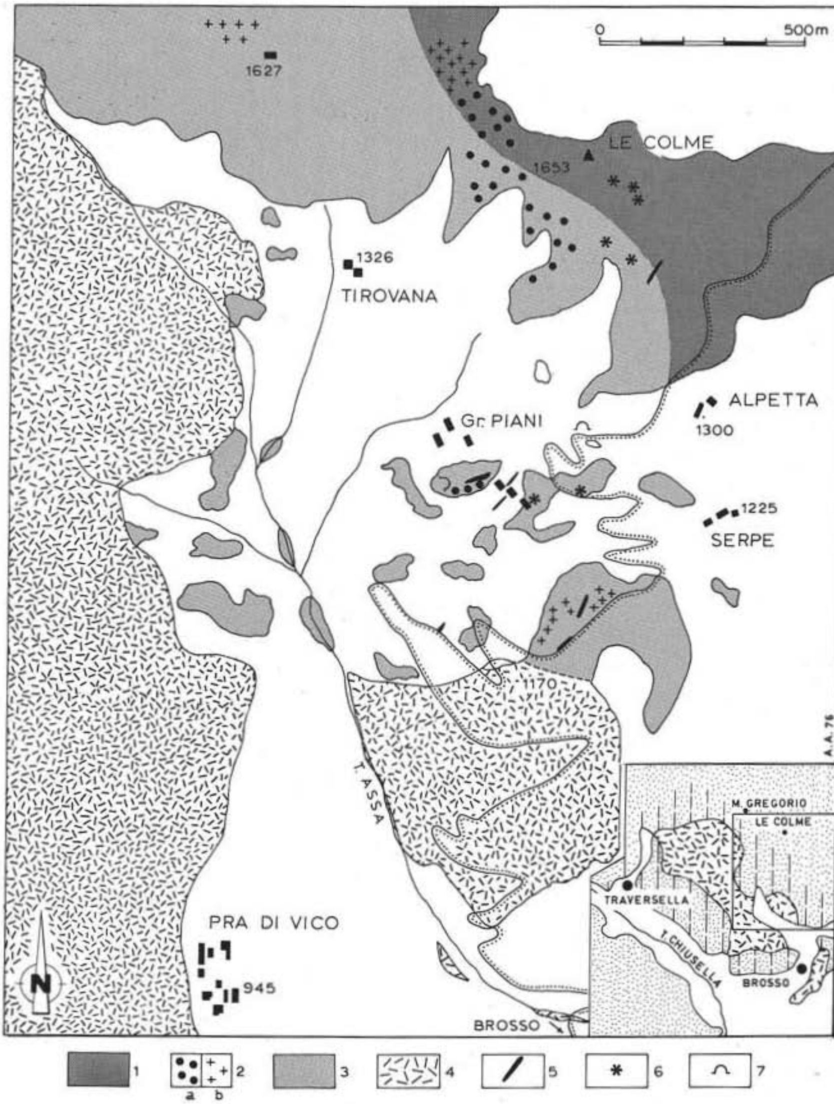

Fig. 2. — *Geologic sketch map of the Colme area.* 1 - Eclogitic micaschists. 2 a - Metagranitic rocks with inclusions. 2 b - Leucocratic gneisses. 3 - Contact aureole of the Traversella stock. 4 - Traversella stock. 5 - Andesite dykes. 6 - Outcrops of nodular layers. 7 - Quartz quarries. Inset shows position of the Colme area with respect to the Traversella stock.

Quartz, albite, jadeite, white mica ± *K-feldspar* are the essential constituents of the leucocratic gneisses; among the accessory minerals *apatite* and locally *fluorite* are abundant. *Jadeite* is found only rarely, since most outcrops of leucocratic gneisses lie in the contact aureole of the Traversella stock (fig. 2) and most of the jadeite has been replaced by a brownish symplectite, consisting of very fine-grained albite and white mica, or by aggregates of granoblastic albite enclosing skeletal white mica. The augen of *K-feldspar* appear under the microscope as porphyroclasts of *microcline* with « tartan » twinning, fractured and cemented by quartz; as elsewhere in the Eclogitic Micaschist Complex, they are relics of a pre-Alpine assemblage, now largely replaced by high-pressure, low-temperature minerals. *Phengite,* in large flakes, crumpled and bent, marks a poorly-developed schistosity.

Within the contact aureole of the Traversella stock (fig. 2) the high-pressure, low-temperature assemblages of the eclogitic micaschists have been overprinted by contact-metamorphic assemblages: in the innermost part of the aureole they are replaced by mineral assemblages of the hornblende-hornfels facies, whereas in the outermost part the thermal effect is marked by crystallization of albite, biotite, chlorite, actinolite, Fe-rich epidote and sphene (see KENNEDY, 1931; NOVARESE, 1943; ANDREOLI, 1970).

The rocks with jadeite megablasts

The rocks with jadeite megablasts occur in the « eclogitic » paraschists of Le Colme as intercalations ranging in thickness from a few dm to about 1 m, which in the field show a conspicuous pseudo-conglomeratic appearance, the quartz-mica matrix

Fig. 3. — *Nodular layer.* The layer shows conspicuous megablasts of jadeite (up to a decimeter in size) in a quartz-phengite matrix. Note strong differential erosion of the eclogitic micaschists enclosing the nodular layer. Near the top of Le Colme.

weathering away more easily than the jadeite nodules (fig. 3). The contact between the intercalations and the paraschists is sharp, and is marked by a thin layer of phengite.

Jadeite megablasts make as much as 70 % of the intercalations, the remainder being a quartz-phengite aggregate with minor garnet; the nodules are typically rounded to elongate and slightly flattened along the foliation (fig. 4); they range in length from 2 to 15 cm and average about 8 cm; some intercalations consist of alternating layers of nodules of different size.

The colour of the nodules is light grey on weathered, and bluish on freshly broken surfaces.

Microscopic examination shows that the nodules are *single* crystals of jadeite, surrounded by a matrix of quartz-phengite ± garnet and minor glaucophane. Most of the jadeite megacrysts show wavy extinction and a weakly developed sub-grain structure; they are typically poikiloblastic, containing abundant inclusions of quartz, phengite, pink garnet and minor accessories which make up as much as 50 % of the volume of the megacrysts (fig. 5). *Quartz* inclusions are the most common and range from 0.5 to 2 mm in diameter; their outline is generally lobate and extinction wavy; sometimes neighbouring grains display simultaneous extinction proving that they are parts of a single skeletal crystal. In a few megablasts quartz grains show

Fig. 4. — *Schistosity surface of a nodular layer.* Ovoids are single crystals of jadeite. Near the top of Le Colme.

a rough dimensional orientation (fig. 5). The *phengite* inclusions are less common and occur as rounded to lobate plates (1-5 mm) which apparently lack preferred orientation; a few phengites appear to be corroded by the enclosing jadeite. *Garnet* [8] inclusions are usually present in lesser amount thant those of quartz or white mica; however in a few jadeite megacrysts garnet is the most abundant included mineral. Garnet inclusions show atoll-like structure, enclosing quartz and/or white-mica flakes (fig. 6); the same structure is found in garnets of the surrounding micaschists. Among the accessory minerals *rutile* and *apatite* are very common as inclusions, while *pyrite, ilmenite* and *zircon* are quite rare.

(8) The values of the refractive index ($n = 1.812$), and of the unit-cell edge ($a_o = 11.571 \pm \pm 0.009$ Å) and the high Mn content ($MnO = 16.55$ weight percent) point to a composition near $Alm_{55} Gr_1 Py_6 Sp_{38}$. This composition, quite unusual for garnets of the Eclogitic Micaschist Complex, probably reflects derivation of the rocks with jadeite megablasts from garnet-bearing aplites or pegmatites, in which garnets are usually spessartines or spessartine-rich almandines (see, for example, CALLEGARI, 1966).

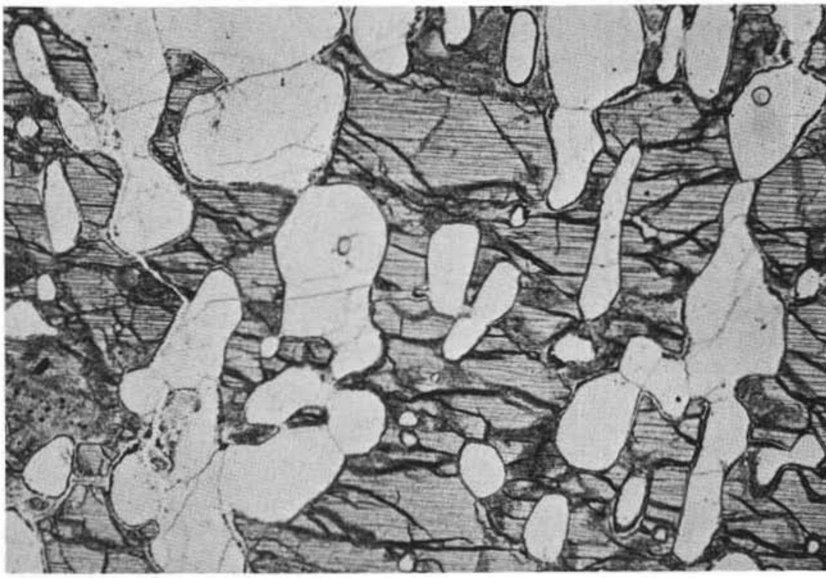

Fig. 5. — *Detail of a jadeite megablast (SL 472) crowded with quartz inclusions showing a rough dimensional orientation*. 45x, plane pol. light. Top of Le Colme.

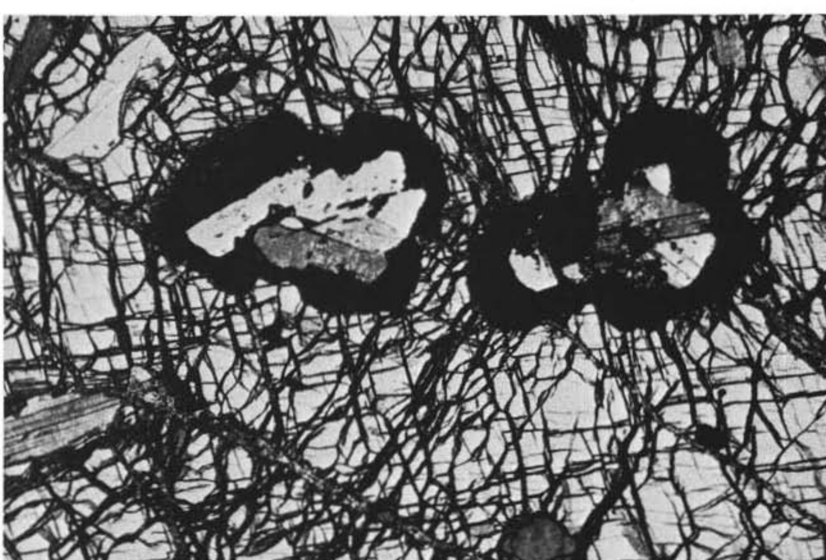

Fig. 6. — *Jadeite megablast (SL 88) with inclusions of garnet and phengite*. Garnet is atoll-like, with inclusions of phengite flakes. Top of Le Colme, 45x, crossed pol..

Chemical and physical data of the jadeite

As the jadeite megablasts from Le Colme contain abundant inclusions of quartz, garnet, phengite, etc., and veinlets of albite and white mica, a pure fraction was separated. A megablast was crushed and sieved to 150-200 mesh; the other minerals were then removed by means of a Frantz isodynamic separator and by repeated centrifuging in methylene iodide. The concentrate was examined optically and estimated to be 99 percent pure.

Chemical composition

The chemical analysis and the calculated formula of the jadeite from Le Colme are given in Table 1. The formula has been calculated on the basis of six oxygens

TABLE 1

Chemical and physical properties of the jadeite from Le Colme

Chemical composition (weight percent) (1)		Number of ions on the basis of 6 oxygens		Optical properties
SiO_2	58.96	Si	2.004	N_β = 1.661 ± 0.003 (2)
TiO_2	0.03	Al^{IV}	-----	Δ = 0.011
Al_2O_3	23.08	ΣT	2.004	$2V_\gamma$ = 70°
Fe_2O_3	1.61	Al^{VI}	0.925	$c \wedge \gamma$ = 36°
FeO	0.56	Ti	0.001	Dispersion r > v, weak
MnO	----	Fe^{3+}	0.041	Unit-cell data
MgO	0.26	Mg	0.013	a = 9.434±0.001 Å
CaO	1.32	Fe^{2+}	0.016	b = 8.576±0.001 Å
Na_2O	13.98	$\Sigma M1$	0.996	c = 5.229±0.001 Å
K_2O	0.12	Na	0.921	β = 107.61° ± 0.02
Total	99.92	Ca	0.048	V = 403.22 $Å^3$
H_2O^-	0.10	K	0.005	
		$\Sigma M2$	0.974	

Pyroxene components (molecular percent)

Jd	91.1
Ac	4.0
Di-Hd	4.9

Density (3)

Measured 3.35

Calculated .... 3.36 g/cm^3

1 - Chemical analysis by L. FIORA, Istituto di Petrografia, Università di Torino (wet chemical analysis, Na and K by flame spectrophotometry).
2 - Measured with Cargille liquids; the error includes correction for white light and temperature.
3 - Measured by centrifugation in heavy liquids.

per formula unit, $(M2)(M1)T_2O_6$, where M1 are the octahedrally-coordinated cations, M2 the larger cations and T the tetrahedrally-coordinated cations.

The jadeite from Le Colme has no Al in tetrahedral coordination and the sum of M1 cations in close to unity; a slight deficiency in the sum of M2 cations suggests that the value for Na_2O in the chemical analysis may be too low.

Pyroxene components (molecular percent) for the jadeite from Le Colme, calculated using the procedure outlined by BANNO (1959) ([9]) are given in Table 1. To show compositional variation they have been plotted in the triangle Jd-Ac-(Di+ +Hd) (fig. 7) with the pyroxene components (calculated in the same way) of the analyzed jadeites from the Sesia-Lanzo Zone (VELDE and KIENAST, 1973; LIEBEAUX, 1975; COMPAGNONI, new data). Three other analyzed jadeites from the Western Alps were also plotted; they are from: *a*) the nodular micaschists (metarhyolites) of Sant'Anna di Bellino, Acceglio Zone (LEFÈVRE and MICHARD, 1965; LEFÈVRE, 1974);

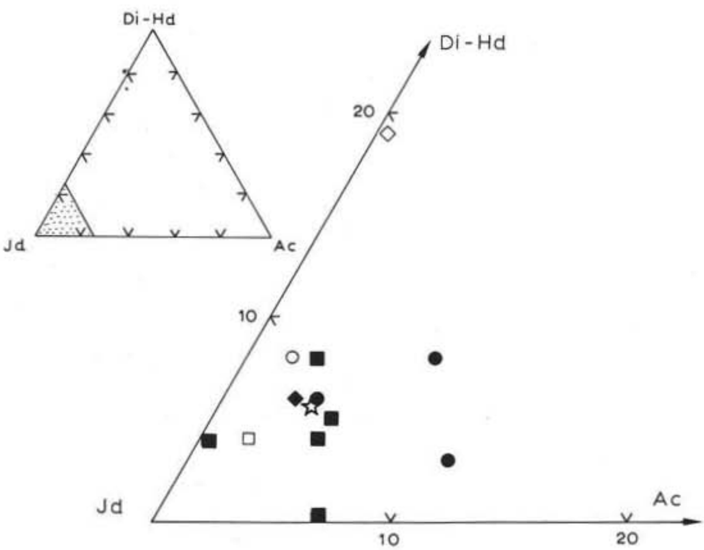

Fig. 7. — *Compositional variation in jadeites from the Western Alps.* Solid symbols, jadeites from metagranitic rocks (squares), eclogitic micaschists (dots) and jadeitites (diamonds) of the Sesia-Lanzo Zone. Open symbols, jadeites from the Acceglio Zone (square), Monviso (diamond) and Lanzo (dot). Star, jadeite from Le Colme. See text for details.

b) the light-coloured, very fine-grained matrix of a metagabbro, Lanzo Ultramafics (NICOLAS, 1966, card. n. 18) ([10]); *c*) a jadeitite supposed to come from the metaophiolites of Monviso (DAMOUR, 1881).

([9]) $$\mathrm{Jd} = \frac{\mathrm{Na}+\mathrm{K}}{\mathrm{Na}+\mathrm{K}+\mathrm{Ca}} \cdot \frac{100\ \mathrm{Al^{VI}}}{\mathrm{Al^{VI}}+\mathrm{Fe^{III}}}; \qquad \mathrm{Ac} = \frac{\mathrm{Na}+\mathrm{K}}{\mathrm{Na}+\mathrm{K}+\mathrm{Ca}} \cdot \frac{100\ \mathrm{Fe^{III}}}{\mathrm{Al^{VI}}+\mathrm{Fe^{III}}};$$

$$\mathrm{Di}+\mathrm{Hd} = 100 - (\mathrm{Jd}+\mathrm{Ac}).$$

([10]) The molecular composition of this jadeite is after NICOLAS; it agrees fairly well with the X-ray pattern and unit-cell data (EDGAR et al., 1969, table III, n. 39); the composition calculated from chemical analysis ($Jd_{76}Ac_{2}Di$ - Hd_{22}) shows a much higher proportion of diopside molecule, possibly resulting from admixture of zoisite in the analyzed material.

Most jadeites from the Western Alps fall in the range 90-95 Jd, the purest being those forming as pseudomorphs within the feldspars of igneous rocks from the breakdown of the albite component (Mucrone, Acceglio, Lanzo). A very high Jd content is characteristic also of jadeites from metagranitic rocks of the Sesia-Lanzo Zone; the jadeite from Le Colme falls in this group. There are few analyses of jadeites from eclogitic micaschists derived from pre-Alpine paraschists; however, the available data suggest that these jadeites may be significantly lower in Jd than those of the other two groups.

The jadeite from Monviso (DAMOUR, 1881) shows a much higher Di component than the other jadeites cited (Di + Hd = 18.8 mol. percent). Recalculation of the chemical analysis on the basis of six oxygens shows an excess of Ca and A1, probably resulting from admixture of another phase (zoisite or possibly lawsonite) as is apparent from the original description of the analyzed sample.

X-ray properties

From a portion of the jadeite which was purified for chemical analysis unit-cell parameters were obtained by least-squares refinement. 29 unambiguously indexed reflections of a powder pattern (Guinier camera, Cu K_α rad., quartz as internal standard) were used.

The cell constants of the jadeite from Le Colme (Table 1) are close to the constants determined by MCBIRNEY et al. (1967) on jadeite of composition $Jd_{94.2}Ac_{0.8}Di\text{-}Hd_{5.0}$ from the Motagua fault zone, Guatemala ($a = 9.439 \pm 0.001$ Å, $b = 8.5846 \pm 0.0004$ Å, $c = 5.226 \pm 0.002$ Å, $\beta = 107°27{,}5' \pm 0.9$, V = 404.0 Å^3).

Similar values were reported by COLEMAN & CLARK (1968) for jadeite of composition $Jd_{98.0}Ac_{1.0}Di\text{-}Hd_{1.0}$ from Clear Creek, New Idria serpentine mass, California. As already noted by COLEMAN & CLARK, however, their values are possibly too high, in view of the very high Jd content of this pyroxene ([11]).

Optical and physical properties

The colour of the purified jadeite is greyish white, while the megablasts in hand specimen are greyish-blue; the difference is probably caused by the small admixture of magnetite in the albite veinlets cutting the megablasts (see below).

Optical properties of the jadeite are given in Table 1. The intermediate refractive index is slightly higher than the values found for jadeites approaching the end-member composition (1.657-1.658) Birefringence is low, and dispersion (r>v) weak. $2V_\gamma$ and extinction angle are in the normal range for jadeites with Jd component over 90 percent.

The observed density and the density calculated for the composition determined by chemical analysis (Table 1) are in good agreement, but slightly higher than values previously reported for similar compositions.

([11]) Significantly lower values were found by PREWITT and BURNHAM (1966) on a jadeite of similar composition $(Na_{0.98}Ca_{0.02})$ $(Al_{0.99}Mg_{0.01})$ $(Si_{1.99}Fe^{3+}_{0,01})$ from the Santa Rita area of the New Idria district, and by FRONDEL and KLEIN (1965) on synthetic jadeite.

Alteration of the jadeite megablasts

The jadeite megablasts of Le Colme are commonly altered, being partly to completely replaced by complex pseudomorphs consisting mainly of albite. Three types of alteration, which probably formed in different stages of the metamorphic evolution, can be distinguished.

The first type is found only along primary cracks inside the jadeite crystals and consists of thin (5-10 micron), mesh-like veinlets of albite with very fine-grained (1 to 2 microns) magnetite and/or hematite (the latter probably forming from

Fig. 8. — *Jadeite megablast (SL 86) showing well-developed albite veinlets (type 1 alteration).* Fine-grained magnetite marks the position of the cracks from which alteration started. 45x, plane polarized light.

martitization of magnetite); the opaque minerals tend to be concentrated in the center of the veinlets. Alteration products in veinlets thicker than 5-10 micron include in addition to albite and magnetite, extremely fine-grained white mica, in part paragonitic ([12]), growing perpendicularly to the walls of the veinlets. Where the veinlets thicken both albite and white mica become coarser-grained and mica flakes less oriented, but magnetite and hematite still cluster along the central portion of the veins, marking the original position of the fractures from which the alteration presumably started (Fig. 8).

This transformation occurs throughout the Sesia-Lanzo Zone in the more Jd-rich pyroxenes. It occurs also in other jadeites of the Western Alps (BOCQUET, 1974 b); paragonite, however, has been definitely identified only in the breakdown products

([12]) X-ray powder patterns of these micas (CuKα rad.) showed 002 reflections at 2ϑ diagnostic both of paragonite and of muscovite or phengite.

of the jadeite from the Acceglio Zone (LEFÈVRE and MICHARD, 1965; LEFÈVRE, 1974).

A more advanced stage is represented by the second type of alteration, which is characterized by veinlets consisting of albite and white mica, with minor clinozoisite/epidote, glaucophane ([13]), and green acmite-rich pyroxene ([14]). Thin coronas of small blue amphiboles and/or green pyroxene and/or epidote develop around the quartz inclusions, marking the position of the original quartz-jadeite interface; the minerals in the coronas show strong preferred orientation, which appears to be

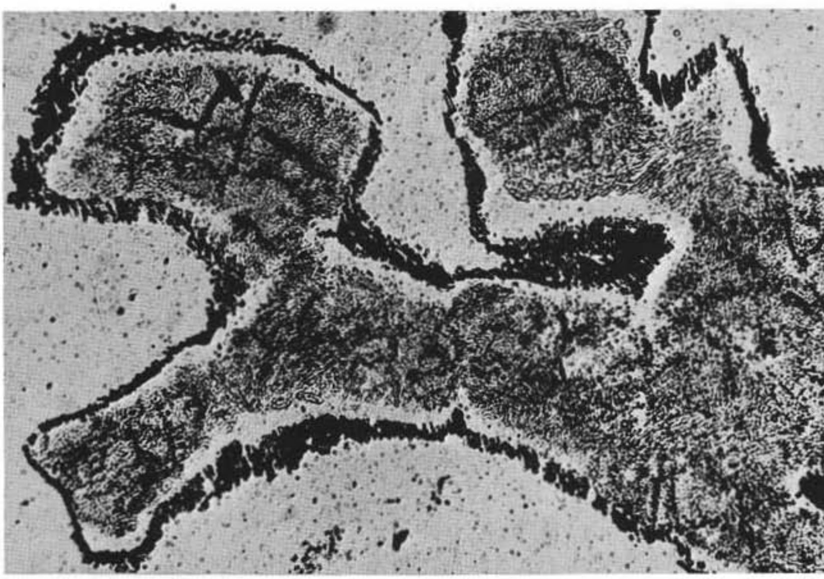

Fig. 9. — *Coronas of acmite-rich pyroxene and blue amphibole around quartz inclusions (type 3 alteration).* Note strong preferred orientation of both minerals. Jadeite is completely replaced by a fine-grained aggregate of albite and white mica. Jadeite megablast (TV 56) from the contact aureole of the Traversella stock. Lower slope of Le Colme (Alpe Piani). 140x, plane polarized light.

controlled by that of the jadeite lattice (homoaxial growth with Z axes coinciding). From textural relationships the acmitic pyroxene appears to be later than the blue amphibole; both are strongly zoned, with rims showing a deeper colour than the cores. In a few megablasts the glaucophane needles are rimmed by a green amphibole, probably an actinolite-rich member.

Type 2 alteration also occurs in jadeites from other areas of the Eclogitic Micaschist Complex; a few examples are the Mucrone metagranitic rocks (COMPAGNONI and MAFFEO, 1973), the pegmatoid veins crossing the jadeite-rich micaschists of Settimo (lower Val d'Aosta) and the eclogitic micaschists of Santa Elisabetta (Cuorgné). Type 2 alteration is probably the « feldspath-uralitisirung » described by

([13]) $2V_\alpha$ small; O.A.P. $\parallel$ (010); α = colourless; β = violet; γ = blue.

([14]) $c\hat{}\alpha = 10\text{-}20°$, 2V and elongation both negative, medium to strong dispersion ($r < v$).

FRANCHI (1902) in sodic pyroxenes of eclogitic micaschists from the Oropa Valley; a difference which may be noted is the apparent lack of acmite-rich pyroxenes in the alteration described by FRANCHI.

In the Western Alps similar transformations have been reported in jadeites from Vanoise (BOCQUET, 1974 b), Ambin (GAY, 1971) and Acceglio (LEFÈVRE and MICHARD, 1965). Though apparently much rarer, the glaucophane-pyroxene coronas around quartz inclusions were also found in a few localities (e.g. Ambin, BOCQUET, 1974 b, p. 279).

A third type of alteration, probably caused by contact metamorphism, is found only in nodular layers lying inside the contact aureole of the Traversella stock. In these layers the jadeite is partly to completely replaced by a very fine-grained brownish symplectite, which X-ray examination shows to consist of albite and white mica. A network of fine-grained magnetite marks the position of the cracks from which the alteration started. A few of the jadeite megablasts showing this type of alteration also display the characteristic pyroxene-amphibole coronas around quartz inclusions (fig. 9). These coronas, however, differ from those described in type 2 alteration in that the blue amphibole is strongly coloured and has the optical orientation of crossite ([15]).

While the first type of alteration occurs both in contact and in regional metamorphism and does not appear to be markedly sensitive to changes in P and T, the composition of the blue-amphibole forming in the coronas seems to be largely controlled by the P-T conditions during the breakdown of the jadeite. This is well shown by the contrast between the deeply coloured crossite (or possibly Mg-riebeckite) in type 3 alteration (resulting from contact metamorphism) and the pale-coloured glaucophane in type 2 alteration (occurring in rocks which were subjected only to regional metamorphism).

A set of reactions can be written for the breakdown of jadeite to albite, magnetite and white mica, showing that it may be described as a constant-aluminum process (CARMICHAEL, 1969), producing an Al-rich phase (white mica) together with an Al-poor phase (albite) and involving only addition of H^+ and K^+ and removal of Na^+ and Ca^{++}:

$$\underset{\text{Jd}}{NaAlSi_2O_6} + \underset{\text{Qz}}{SiO_2} \rightarrow \underset{\text{Ab}}{NaAlSi_3O_8} \qquad (1)$$

$$2\,\underset{\text{Ac}}{NaFeSi_2O_6} + \underset{\text{Hd}}{CaFeSi_2O_6} + 2\,H_2O \rightarrow \underset{\text{Mt}}{Fe_3O_4} + 2\,Na^+ + Ca^{++} + 6\,SiO_2 + 4\,OH^- \qquad (2)$$

([15]) Optical properties ($2V_\alpha$ small; O.A.P. $\perp$ 010 and approximately $\perp$ to c; α = pale yellow, β = blue, γ = lavender blue; $\gamma > \beta > \alpha$) fall in type C of BORG (1967) which includes most crossites and a few Mg-riebeckites.

$$6\,\underset{\text{Jd}}{NaAlSi_2O_6} + K^+ + 2\,H^+ \rightarrow 3\,\underset{\text{Ab}}{NaAlSi_3O_8} + \underset{\text{White mica}}{(K,Na)Al_2[AlSi_3O_{10}(OH)_2]} + 2\,Na^+ \quad (3)$$

Magnetite (and/or haematite) is produced from the breakdown of the acmitic and hedenbergitic components (2). The silica formed by this reaction is used up in the conversion of jadeite to albite (1). Direct precipitation of iron can thus occur only in undersaturated environments (i.e. inside the jadeite crystals); were free silica is available (i.e. around the quartz inclusions) the iron (and the mobile cations Na^+ and Ca^{++}) are taken up in silicates like glaucophane and acmite-rich pyroxene.

Reactions (1) and (2) may be combined into a single reaction:

$$6\,\underset{\text{Jd}}{NaAlSi_2O_6} + 2\,\underset{\text{Ac}}{NaFeSi_2O_6} + \underset{\text{Hd}}{CaFeSi_2O_6} + 2\,H_2O \rightarrow$$

$$6\,\underset{\text{Ab}}{NaAlSi_3O_8} + \underset{\text{Mt}}{Fe_3O_4} + 2\,Na^+ + Ca^{++} + 4\,OH^- \quad (4)$$

wich in turn may be differently combined with (3) to give varying proportions of albite, magnetite and white mica.

Discussion

Field evidence suggests that prior to the Alpine metamorphism the nodular layers (and most intercalations of leucocratic gneisses) were silicic dykes cutting pre-Alpine paraschists. This interpretation is based both on structural observations (e.g. the type of contact with the eclogitic micaschists) ([16]) and on mineralogical evidence (e.g. the occurrence of K-feldspar relics). Judging from the mineralogical transformations observed in the less thoroughly recrystallized granitoids of the Mucrone area (Compagnoni and Maffeo, 1973) the mineral assemblage of the nodular layers probably consisted of quartz, K-feldspar, sodic plagioclase and minor biotite.

Both the petrographic relations with the quartz-phengite « groundmass » and the abundance of quartz inclusions suggest that the jadeites from Le Colme are megablasts, i.e. exceptionally large crystals, which grew as an intergranular phase from a fine-grained aggregate consisting of quartz and albite. A pseudomorphic growth on albitized K-feldspar phenocrysts, like that described by Lefèvre and Michard (1965) for the jadeite from the Acceglio Zone does not seem likely for the jadeites from Le Colme.

([16]) The conformable relations between nodular layers and eclogitic micaschists result from transposition during the Alpin metamorphism.

Mineral assemblages in the Colme area show the same association of jadeite with quartz and garnet in silicic rocks and of omphacite with garnet in mafic rocks which characterizes the entire Eclogite Micaschist Complex. Accordingly the P-T field in which the megablasts formed should be about the same as that inferred for the high-pressure, low-temperature assemblages elsewhere in the Eclogitic Micaschist Complex (e.g. Monte Mucrone, COMPAGNONI and MAFFEO, 1973); that is, load pressures greater than 12.5 to 15.5 kb for temperatures ranging between 400° C and 500° C (17).

From experimental evidence the breakdown of jadeite to albite implies decrease in the P/T ratio from higher pressures, corresponding to the jadeite-forming event (« eclogitic » event), to lower pressures or higher temperatures (alteration event); the second possibility (i.e. alteration with increasing temperatures), however, is ruled out by the occurrence of glaucophane among the products of the jadeite breakdown, which points to P-T conditions still within the blueschist facies (18).

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REFERENCES

ANDREOLI M. (1970) - *Le trasformazioni delle paragenesi dei « micascisti eclogitici » nell'aureola di contatto dell'ammasso intrusivo di Traversella. Studio petrografico.* Tesi, Ist. Petr. Univ. Torino, 176 p.

BANNO S. (1959) - *Aegirinaugites from crystalline schists in Sikoku.* J. Geol. Soc. Jap., 65, 652-657.

BOCQUET J. (1974 a) - *Blue Amphiboles of the Western Alps. Chemistry and Physical Characters.* Schweiz. Min. Petr. Mitt., 54, 425-448.

BOCQUET J. (1974 b) - *Etudes minéralogiques et pétrologiques sur les métamorphismes d'âge alpin dans les Alpes françaises.* Thèse, Grenoble, 489 p.

BORG I. Y. (1967) - *Optical properties and cell parameters in the glaucophane-riebeckite series.* Contr. Miner. Petrol., 15, 67-92.

CALLEGARI E. (1966) - *I granati di alcune differenziazioni aplitico-pegmatitiche del massiccio dell'Adamello.* Mem. Acc. Pat. Sci. Lett. Arti, 78, 363-377.

(17) The widespread occurrence of zoisite-bearing eclogites in the Eclogitic Micaschist Complex points to temperatures higher than 450° C.

(18) See e.g., the discussion of DE ROEVER (1972) on mineral assemblages in the Fuscaldo metabasites, Calabria. A point which should be stressed in this connection is that in the Colme area, as in the entire Eclogitic Micaschist Complex, albite is *not* in equilibrium with jadeite; on the contrary it forms only from the breakdown of the latter, together with white mica, blue amphibole and acmite-rich pyroxene.

CALLEGARI E., COMPAGNONI R., DAL PIAZ G.V., FRISATTO V., GOSSO G. & LOMBARDO B. (1976) - *Nuovi affioramenti di metagranitoidi nella zona Sesia-Lanzo.* Rend. Soc. It. Min. Petr., 32, 97-111.

CARMICHAEL D.M. (1969) - *On the Mechanism of Prograde Metamorphic Reactions in Quartz-bearing Pelitic Rocks.* Contr. Miner. Petrol., 20, 244-267.

COLEMAN R.G. & PAPIKE J.J. (1968) - *Alkali amphiboles from the Blueschists of Cazadero, California.* J. Petrology, 9, 105-122.

COLEMAN R.G. & CLARK J.R. (1968) - *Pyroxenes in the blueschist facies of California.* Am. J. Sci., 266, 43-59.

COMPAGNONI R. & MAFFEO B. (1973) - *Jadeite-bearing metagranites l.s. and related rocks in the Mount Mucrone Area (Sesia-Lanzo zone. Western Italian Alps).* Schweiz. Min. Petr. Mitt., 53, 355-378.

DAL PIAZ G.V., HUNZIKER J.C. & MARTINOTTI G. (1972) - *La zona Sesia-Lanzo e l'evoluzione tettonico-metamorfica delle Alpi nordoccidentali interne.* Mem. Soc. Geol. It., 11, 433-460.

DAMOUR A. (1881) - *Nouvelles analyses sur la jadéite et sur quelques roches sodifères.* Bull. Soc. Minér. Fr., 4, 157-164.

DE ROEVER E.W.F. (1972) - *Lawsonite-albite-facies metamorphism near Fuscaldo, Calabria (Southern Italy), its geological significance and petrological aspects.* Thesis, Amsterdam, 171 p.

EDGAR A.D., MOTTANA A. & MACRAE N.D. (1969) - *The chemistry and cell parameters of omphacites and related pyroxenes.* Min. Mag., 37, 61-74.

ESSENE E.J. & FYFE W.S. (1967) - *Omphacite in Californian metamorphic rocks.* Contr. Miner. Petrol., 15, 1-23.

FRANCHI S. (1900) - *Sopra alcuni giacimenti di rocce giadeitiche nelle Alpi occidentali e nell'Appennino ligure.* Boll. R. Comit. Geol. It., 31, 119-158.

FRANCHI S. (1902) - *Ueber Feldspath-Uralitisirung der Natron-Thonerde Pyroxene aus den eklogitischen Glimmerschiefern der Gebirge von Biella (Graiische Alpen).* N. Jb. Miner. Geol. Paläont., 21, 112-126.

FRANCHI S. (1903) - *Sul rinvenimento di nuovi giacimenti di rocce giadeitiche nelle Alpi occidentali e nell'Appennino ligure.* Boll. Soc. Geol. It., 22, 130-134.

FRONDEL C. & KLEIN C. Jr. (1965) - *Ureyite, $NaCrSi_2O_6$, a new meteoritic pyroxene.* Science, 149, 742-744.

GAY M. (1971) - *Le Massif d'Ambin et son cadre de Schistes lustrés (Alpes Franco-Italiennes).* Thèse, Lyon, 296 p.

KENNEDY W.Q. (1931) - *The Igneous Rocks, Pyrometasomatism and Ore Deposition at Traversella, Piedmont-Italy.* Schweiz. Min. Petr. Mitt., 11, 76-139.

LEFÈVRE R. (1974) - *Microanalyse par émission ionique secondaire d'un pyroxène jadéitique d'âge alpin de la Bande d'Acceglio (Alpes cottiennes italiennes).* Bull. Soc. géol. Fr., 16, 248-254.

LEFÈVRE R. & MICHARD A. (1965) - *La jadéite dans le métamorphisme alpin, à propos des gisements de type nouveau de la bande d'Acceglio (Alpes cottiennes italiennes).* Bull. Soc. Fr. Minéral. Cristallogr., 88, 664-677.

LIEBEAUX C. (1975) - *Caractères généraux des roches du faciès éclogitique de la zone de Sesia-Lanzo (Alpes Italiennes).* Lab. Petr. Univ. Paris VI, Thèse III cycle, 95 p.

LOMBARDO B., COMPAGNONI R., FIORA L., FACCHINELLI A. (1976) - *Composition of some Na-pyroxenes from the eclogitic micaschists of lower Val d'Aosta (Sesia-Lanzo Zone, Western Alps).* S.I.M.P., Meeting on « High pressure - low-temperature metamorphism of the oceanic and continental crust in the Western Alps », Genova, 24-29 September 1976 (abs.).

MCBIRNEY A., AOKI K., BASS M.N. (1967) - *Eclogites and jadeite from the Motagua fault zone, Guatemala.* Am. Miner., 52, 908-918.

MONESE A., OGNIBEN G. & VITERBO C. (1967) - *Il pirosseno omfacitico delle pirosseniti comprese nei micascisti eclogitici di Tavagnasco (Valle d'Aosta).* Mem. Acc. Pat. Sci. Lett. Arti, 80, 5-9.

NICOLAS A. (1966) - *Etude pétrochimique des Roches Vertes et de leurs minéraux entre Dora Maira et Grand Paradis (Alpes piémontaises).* Thèse, Nantes, 299 p.

NOVARESE V. (1894) - *Relazione sul rilevamento eseguito nelle Alpi Occidentali (Valli dell'Orco e della Soana) nella campagna del 1893.* Boll. R. Comit. Geol. It., 25, 215-230.

NOVARESE V. (1903) - *Nuovi giacimenti piemontesi di giadeititi e rocce giadeitoidi.* Boll. Soc. Geol. It., 22, 135-140.

NOVARESE V. (1931) - *La formazione dioritico-kinzigitica in Italia.* Boll. R. Uff. Geol. It., 56, 1-62.

NOVARESE V. (1943) - *Il sistema eruttivo Traversella-Biella.* Mem. descr. Carta Geol. It., 28, 90 p.

PREWITT C. T. & BURNHAM C. W. (1966) - *The crystal structure of Jadeite, $NaAlSi_2O_6$.* Am. Miner., 51, 956-975.

STELLA A. (1894) - *Relazione sul rilevamento eseguito nell'anno 1893 nelle Alpi Occidentali (Valli dell'Orco e della Soana).* Boll. R. Comit. Geol. It., 25, 343-371.

STELLA A. (1903) - *A proposito della diffusione delle rocce a giadeite nelle Alpi Occidentali.* Boll. Soc. Geol. It., 22, 141-142.

VELDE B. & KIENAST J. R. (1973) - *Zonéographie du métamorphisme de la zone de Sesia-Lanzo (Alpes piémontaises): étude des omphacites et grenats des micaschistes éclogitiques à la microsonde électronique.* C. R. Acad. Sc. Paris, 276, 1801-1804.

ZAMBONINI F. (1901) - *Su un pirosseno sodifero dei dintorni di Oropa nel Biellese.* Atti R. Accad. Lincei, 10, 240-244.