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# MICRO-MESOSTRUCTURAL RELATIONSHIPS IN THE CONTINENTAL ECLOGITIC ROCKS OF THE SESIA-LANZO ZONE (ITALIAN WESTERN ALPS): A RECORD OF A SUBDUCTION CYCLE

ABSTRACT. — Detailed mapping in an area of the Eclogitic Micaschists Complex (Sesia-Lanzo Zone, Western Alps) in the lower Aosta Valley led to correlate three main phases of folding with the Alpine metamorphic history. A first Alpine structural and metamorphic reworking predates the onset of the eclogitic conditions. A reequilibration of the eclogitic assemblages under a lower pressure regime is accompanied by large and small scale foldings.

RIASSUNTO. — Il Complesso dei Micascisti Eclogitici della Zona Sesia-Lanzo è stato oggetto di un'indagine cartografico-strutturale nella sua porzione interna prospiciente l'asse della Valle d'Aosta. Vengono riconosciuti, come nuovi litotipi, micascisti con associazioni di alta pressione a cianite-cloritoide-granato e una associazione litologica di metabasiti e ultrabasiti metamorfiche con trasformazioni eclogitiche Alpine. Per mezzo dell'analisi strutturale si sono individuate tre principali generazioni di pieghe che accompagnano la storia metamorfica Alpina; le due più antiche sono correlate con l'evento di alta pressione mentre la terza corrisponde probabilmente all'evento Lepontino. Vengono segnalate tracce metamorfiche e strutturali di un evento Alpino precedente all'inizio delle condizioni eclogitiche.

## Introduction

Among the different units of the Alpine nappe pile the Eclogitic Micaschists Complex of the Sesia-Lanzo Zone represents a slice of continental crust recording a multistadial evolution under eclogitic conditions both in mafic and in felsic lithologies (DAL PIAZ et al., 1972; COMPAGNONI et al., 1977 b). Previous petrologic studies have shown that in the EMC the long Alpine metamorphic evolution is characterized by initial extremely high pressure — and relatively low temperature-conditions followed by a significant pressure — and moderately temperature-decrease (DAL PIAZ et al., 1972; COMPAGNONI & MAFFEO, 1973; COMPAGNONI et al., 1977 b). This multistadial metamorphic event is known as Early-Alpine; during this event, dated between 129 and 60 m.y. ago (HUNZIKER, 1974; DAL PIAZ et al., 1978), conditions corresponding to 500-600° C and 13-15 Kb were reached (COMPAGNONI, 1977;

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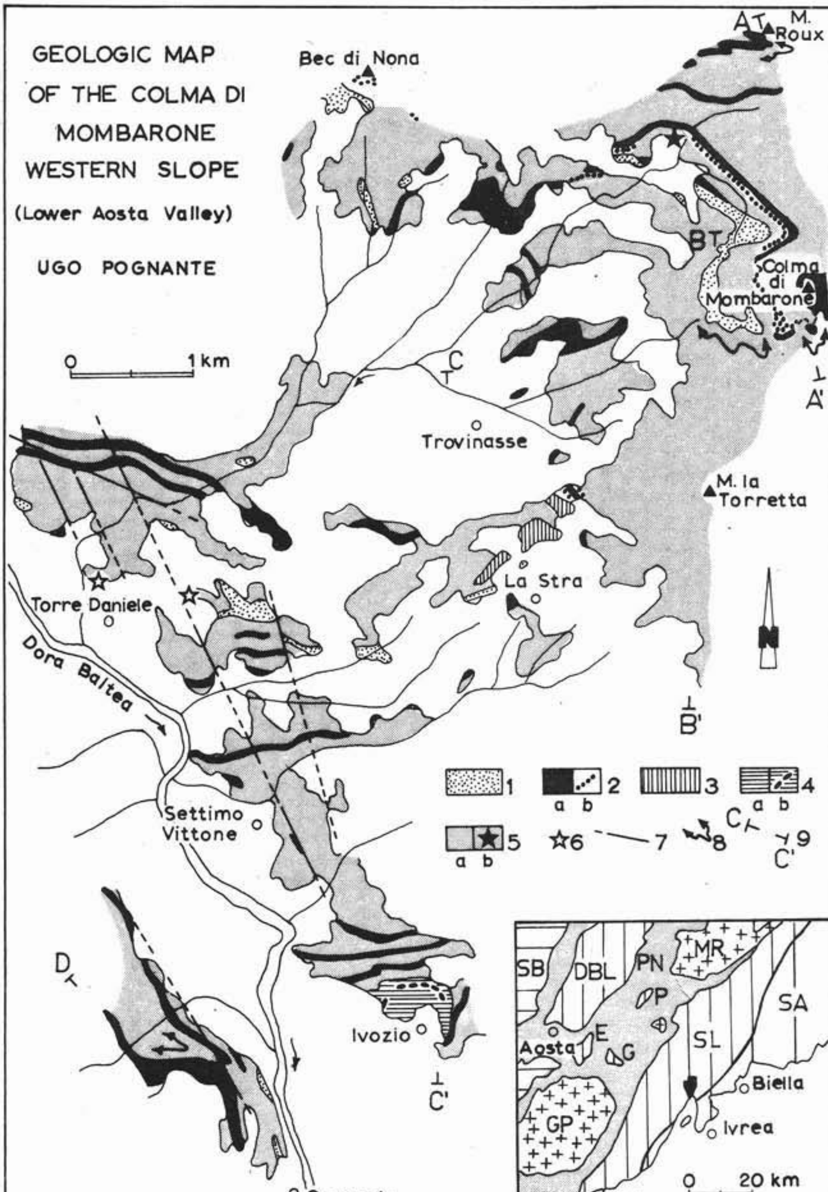


Fig. 1. — Geologic map of the Colma di Mombarone Western slope. 1) Marbles and carbonate schists; 2*a*) metagranitoids; 2*b*) jadeite megablastic layers; 3) amphibolic eclogites (La Stra); 4*a*) eclogitic metabasites (Ivozio); 4*b*) metamorphic ultramafics (Ivozio); 5*a*) eclogitic micaschists; 5*b*) kyanite-chloritoid-garnet micaschists; 6) post-metamorphic lamprophyric dykes; 7) faults and fracture zones; 8) main $B_2$ structures; 9) traces of cross sections shown in fig. 2. *SA*: Southern Alps; *LM*: Lanzo Massif; *SL*: Sesia-Lanzo Zone; *DBL*: Dent Blanche Nappe; *G*: Glacier-Rafray Klippe; *E*: M. Emilius Klippe; *P*: Pillonet Klippe; *PN*: Piemonte Ophiolite Nappe; *MR*: M. Rosa Unit; *GP*: Gran Paradiso Unit; *SB*: San Bernardo Unit.

DESMONS & GHENT, 1977). The multistadial Early-Alpine evolution is interpretable as the record of retrogressive reequilibrations of the initial eclogitic assemblages at various depths of a subduction zone during the exhumation episode. However only recently a prograde *P-T* history has been individuated (POGNANTE, 1979; REINSCH, 1979).

The study of an internal part of the EMC, in which the eclogitic assemblages are particularly well developed and the reequilibration under decompressional conditions of local volumes of rocks is incomplete, have favoured the refinement of the earliest Alpine tectono-metamorphic history. The present paper describes the existence of a preeclogitic stage documented by both microstructural and petrological evidence.

The area considered in this paper belongs to the most internal part of the EMC, and the lithologies represented are physically continuous with the ones occurring at M. Mucrone and described by DAL PIAZ et al. (1972) and COMPAGNONI & MAFFEO (1973). It is located on the left side of the lower Aosta Valley between Quassolo and Torre Daniele, and correspond to the Colma di Mombarone western slope (see geological map of fig. 1). The lithologies consist of garnet-omphacite micaschists (eclogitic micaschists) with interbedded lenses of amphibolic eclogites, and intercalations of marbles and jadeite-bearing metagranitoids; furthermore a sequence of eclogitic metabasites associated with ultramafics has been recognized near the village of Ivozio (POGNANTE, 1979).

Most of the rocks exhibit a strong eclogitic imprint with jadeite/omphacite-quartz-garnet assemblages; Late-Alpine reequilibration is very scarce in opposition to the more external areas of the Sesia-Lanzo Zone.

## Lithologies

### MICASCHISTS

The garnet-omphacite micaschists are coarse grained foliated rocks distinguished by the occurrence of abundant quartz veins and of pegmatite-like veins with quartz, jadeite and minor white mica. Quite common is the presence of glaucophane porphyroblasts which are specially developed in the vicinity of M. la Torretta. An uncommon kind of garnet-kyanite-chloritoid bearing micaschists has been observed SW of M. Roux. Due to their mineralogy, the association with marbles and metabasics, and the analogy with similar sequences described in other areas of the Sesia-Lanzo Zone (Mucrone area; DAL PIAZ et al., 1972), most of the micaschists can be ascribed to pre-Alpine, probably polymetamorphic, paraschists.

### METABASITES

If the Ivozio rocks are disregarded, metabasites mainly consist of amphibolic eclogites with minor bimineralic eclogites (garnet + omphacite) and scarce omphacitites. They generally occur as small lenses or boudins within the paraschists, but a single elongated body of layered eclogites — a few tens of metres thick and a few hundred of metres long — has been mapped at La Stra. Most of the amphibolic eclogites (type 1) contain omphacite and garnet porphyroblasts which overgrow an amphibolic matrix. At La Stra such metabasites are interbedded, at the cm to dm scale, with similar rocks containing zoisite porphyroblasts and tourmaline, and with bimineralic eclogites (type 2).

IVOZIO COMPLEX

The Ivozio complex appears as an antiformal structure infolded with the surrounding paraschists and metagranitoids; it consists of eclogites of type 1 and 2, eclogitic metabasites characterized by the widespread occurrence of pseudomorphs of paragonite and zoisite replacing original lawsonite (type 3) (COMPAGNONI et al., 1977 a), hornblende-rich metabasites containing dark hornblende and diopside porphyroclasts (type 4), and scarce ultramafic rocks. All these lithologies show intense mutual infolding. However primary layering have been observed between type 3 metabasites and eclogites of type 1 and 2. The hornblende-rich metabasites (type 4) are crosscut by Alpine metamorphic veins of garnet and omphacite. The ultramafic rocks occur as a discontinuous sheet several metres thick within the metabasics, and often show a layered appearance due to interbedding of metapyroxenite and antigoritic serpentinite layers (a few cm to a few metres thick) both rich in large relics of pre-Alpine diopside. The serpentinites are often distinguished by the occurrence of elongated pseudomorphs (a few cm long) of fine-grained antigorite.

CARBONATE ROCK

They are represented by dolomitic marbles and omphacite-bearing carbonate schists which are often mutually infolded. The carbonate rocks form two main discontinuous intercalations a few metres to a hundred metres thick within the paraschists. Thin layers of glaucophanitic eclogites, omphacitites and zoisitites often occur at the marble-micaschist contact.

METAGRANITOIDS

The jadeite ± K-feldspar bearing metagranitoids are widespread throughout the region. On the ground of their field occurrence and of their bulk composition they have been interpreted as felsic dykes (COMPAGNONI et al., 1977 b). Due to polyphase folding and transposition they are generally stratoid and concordant with the surrounding paraschists; only in very few places the original discordant relationships with the surrounding lithologies have been preserved. The dyke-paraschist contact is always sharp although the development of jadeite megablast layers is often observed near the contact between the two lithologies. These layers are composed of a quartz-phengite matrix and of jadeite crystals crowded with quartz grains and ranging in lenght up to ten centimetres (e.g. ANDREOLI et al., 1976; COMPAGNONI et al., 1977 b).

## Fold chronology and mesostructural data

Chronological techniques based on geometrical analysis of fold systems (Hobbs et al., 1976, with references) and already applied to the external part of the Sesia-Lanzo Zone (Gosso, 1977; Williams, 1977; Gosso et al., 1979; Minnigh, 1979; Compagnoni & Williams, in prep.), led to correlate the structure with the various metamorphic stages or events. An attempt is made here to correlate structure and metamorphism in a limited area of the internal part of the Eclogitic Micaschists Complex.

The internal structure of the Sesia-Lanzo Zone in the lower Aosta Valley is

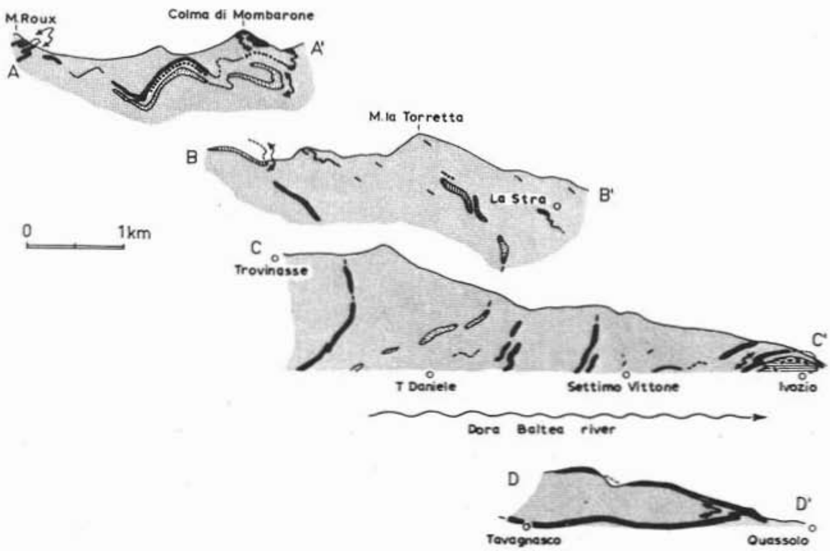


Fig. 2. — Geologic cross sections; legend as in fig. 1.

drawn in a set of cross sections of fig. 2. Four generation of Alpine folds ($B_1$-$B_4$) occurred in this area at the regional scale.

The oldest group of folds ($B_1$) is represented by small scale isoclinal folds associated with extensive transposition and new axial plane layering mainly defined by phengite and/or Na-pyroxenes. This folds group deforms and activates the recrystallization of the eclogitic assemblages (fig. 3).

$B_2$ folds represent the most prominent fold system in the area and are defined by lithologic layerings physically continuous over hundred of metres. They are tight or isoclinal and represent large recumbent folds in the cross section (M. Roux, Colma di Mombarone, Quassolo). Most part of the small and large scale infoldings between the main lithologies can be ascribed to $B_2$ deformations. Where $B_2$ folds are isoclinal, partial transposition and differentiated axial plane layerings can develope but no significant retrogradation of the HP assemblages has been observed in $B_2$ hinge areas and foliations. $B_2$ axes generally plunge gently to a few tens degrees toward WSW.

$B_3$ folds are strongly asymmetric — open to tight — and form small and large scale systems. The synformal and antiformal structures reported in the sections (specially West of the Colma di Mombarone and near Ivozio) are large examples of this folds generation. A lineation defined by penetrative microfolding and only locally associated with a faint axial plane layering occurs parallel to $B_3$ axes which are generally oriented E-W. This foliation is never defined by newly grown HP minerals; furthermore in areas of $B_3$ penetrative folding the eclogitic assemblages are strongly retrograded.

The youngest deformations ($B_4$) produced gentle large scale bending with N-S axes and small scale kinks. This fold generation is never penetrative below the hundred metres scale and is considered post-metamorphic due to lack of coheval — or younger — mineral growth. $B_4$ large scale structures are locally well developed; in particular the lower Colma di Mombarone western slope is part of the western limb of a large $B_4$ open antiform.

Worth noting is the presence of faults and fractures (striking from NNW-SSE to WNW-ESE), nearly parallel to the Aosta Valley trend.

The most penetrative structural feature is generally due to $B_1 + B_2$ deformations which produced a large scale transposition of the lithologies. These structures are superposed by $B_3$ folds which produced synforms and antiforms with open to tight interlimb angle at the megascale, and later by N-S $B_4$ gentle kink-folding. Therefore in the most part of the area the lithologic layering has a composite mesoscopic fabric due to $B_1 + B_2$ transpositional folding. Mineral layerings show at the microscope too composite fabrics.

## Petrography and microstructure

The petrographic and microstructural description of the main lithologies of the area follows here the listing adopted in the second chapter. The microstructures have been examined in accordance with the classical microstructural method (ZWART, 1960, 1962) and the criteria exposed and reviewed by VERNON (1978). Fabrics at the mineral aggregate scale (foliation morphology) and at the intragranular scale are regarded as a counterpart of mesoscale deformation and are related to the phase transformation history.

### MICASCHISTS

In the micaschists the intense reorientation of layer silicates seldomly allows the preservation of the earliest microstructures in the absence of a lithologic layering. The most frequent microstructures are therefore belonging to $B_2$ and $B_3$ folds. No prealpine microstructural or mineralogical relics are preserved in the micaschists. They are composed of quartz (30-40 %), phengite (30 %), omphacite (20-30 %),

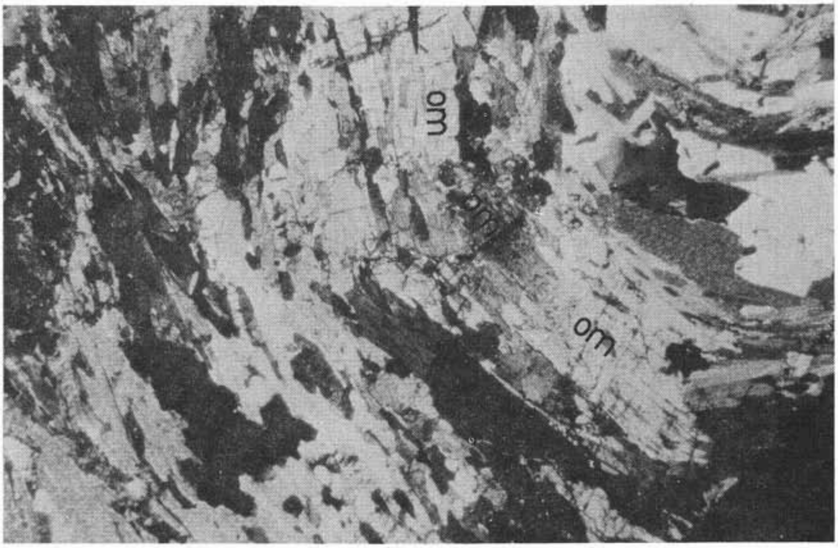


Fig. 3. — Eclogitic micaschist - Prismatic omphacites (*om*) folded by $B_1$ and partly recovered; the substructure is probably produced by recovered kinks. Crossed polars; 20 x (V 690).

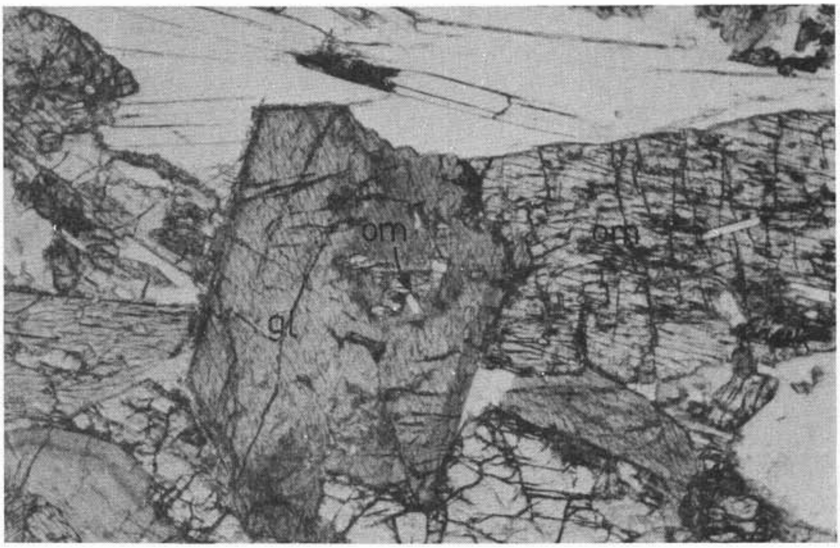


Fig. 4. — Eclogitic micaschist - Glaucophane I (*gl*) of the eclogitic stage II overgrows an omphacite (*om*) still preserved as relict in its core. Plane polarized light; 50 x (SL 1131).

garnet (10-20 %), glaucophane I (less than 10 %), rutile and apatite. Such assemblage is not altered in zones of intense reorientation of the microfabric elements into $B_1$ axial plane foliations (fig. 3) and a relatively poor reequilibration of this assemblage is observed in correspondence to $B_2$ cleavages and mineral layerings. Garnet is often rimmed by a later atoll-like accretion, and the core contains randomly oriented grains of rutile, quartz and epidote. A local and partial reequilibration related to $B_3$ crenulation produced the following alterations: omphacite → albite + + white mica + blue/green amphibole ± acmitic pyroxene ± epidote ± chlorite; garnet → chlorite + albite ± white mica ± epidote ± blue/green amphibole; glaucophane I → albite ± white mica ± green amphibole. The micaschists are locally distinguished by the presence of large (cm size) porphyroblasts of glaucophane I which overgrows a foliation of omphacite, garnet, white mica and rutile. The omphacite is corroded at the boundary with glaucophane I, however no albite occurs in cohexistence with the latter (fig. 4). Two generations of glaucophane are therefore observed: glaucophane I, which mainly developed at the expenses of omphacite, but without albite; glaucophane II (mainly crossite) which is found in equilibrium with albite in the alteration products after omphacite. Glaucophane II rims glaucophane I.

The peraluminous micaschists from M. Roux consist of quartz (40-45 %), paragonite (20 %), kyanite (10 %), garnet (10 %), chloritoid (10 %), Fe-carbonate, rutile, apatite and zoisite. Garnet and kyanite are skeletal over quartz grains defining a convolute internal foliation geometrically unrelated to the $S_e$. Large chloritoid I is associated with kyanite; their relationships are unclear. Chloritoid I, kyanite and paragonite are later replaced by fine needles of more deeply coloured chloritoid II which also corrodes garnet (fig. 5).

METABASITES

*Amphibolic eclogites* (*type 1*)

The amphibole-bearing eclogites have a fine grained foliated matrix in which Ca-Na amphibole (1) (20-30 %) and subordinate glaucophane are the main constituents, together with minor amounts of clinozoisite-epidote, white mica, rutile, Fe-carbonate and tourmaline. The matrix foliation ($S_e$) is overgrown by large porphyroblasts of garnet (20-40 %), omphacite (20-40 %) and locally of zoisite, which preserve an internal foliation ($S_i$) generally continuous with the $S_e$ (fig. 6). The amphiboles are sometimes irregularly zoned and range from colourless or pale blue-green Ca-Na varieties, to glaucophane and to less developed green amphibole rims. Rarely the amphibole cores contain opaque inclusions suggesting a derivation from pre-Alpine brown hornblende (e.g. COMPAGNONI, 1977). Garnet can have a skeletal core preserving individuals of corroded amphibole, rutile and clinozoisite, and a rim often cleared of inclusions. A similar, but less preserved, pattern is showed by the omphacites which are inequant and randomly oriented. The included and corroded amphiboles suggest reaction relationships with the host grains, either omphacite, garnet or zoisite, favouring the interpretation of disequilibrium relationships between the porphyroblasts and the foliated matrix.

(1) From X-ray data ($a_0 = 9.774 \pm 0.010$ Å, $b_0 = 17.892 \pm 0.016$ Å, $c_0 = 5.288 \pm 0.003$ Å, $\beta = 104.53 \pm 0.13°$, vol. 899.7 Å$^3$) colourless and pale blue-green amphiboles result Ca-Na varieties (BINNS, 1967; DOMENEGHETTI et al., 1980).

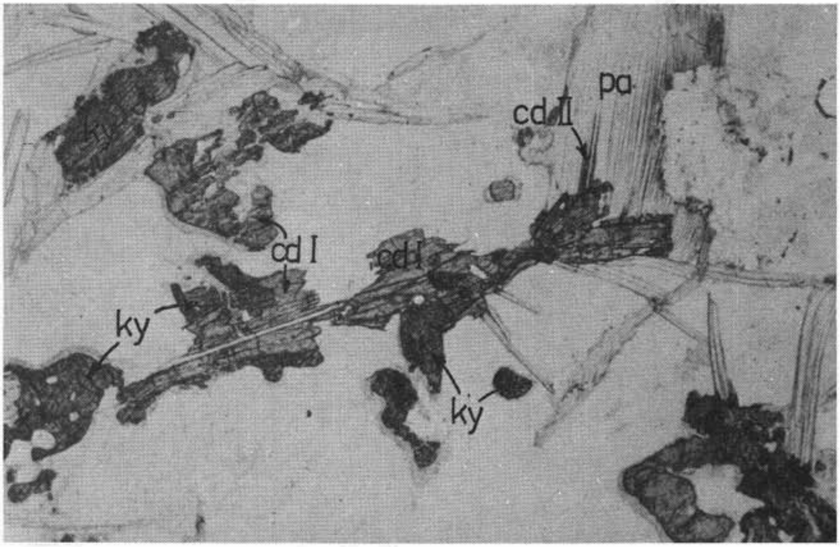


Fig. 5. — Kyanite-chloritoid-garnet micaschist - Kyanite (*ky*), chloritoid (*cd I*) and paragonite (*pa*) of the eclogitic stage I. Note a later generation of chloritoid II (*cd II*) rimming chloritoid I and penetrating along (001) cleavage planes of paragonite (*pa*). Plane polarized light; 50 x (SL 1522).

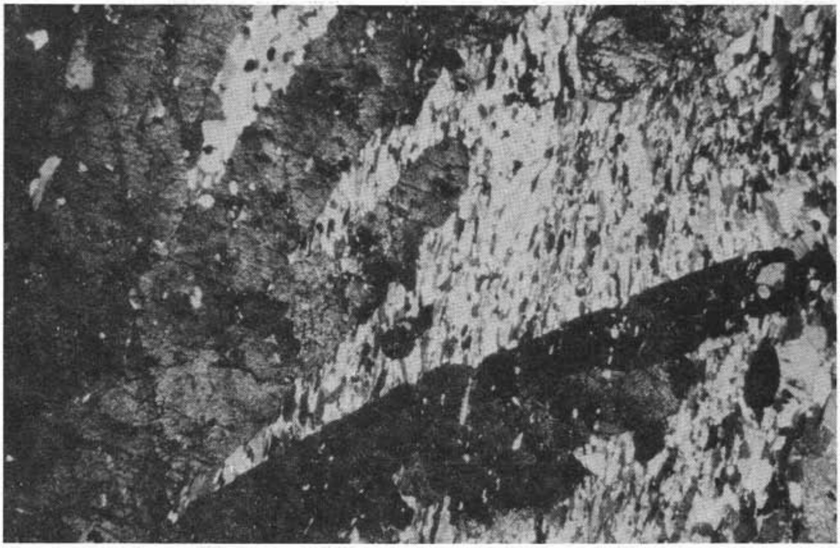

Fig. 6. — Amphibolic eclogite (type 1) - A preeclogitic foliation defined by Ca-Na amphibole, clinozoisite/epidote, white mica and rutile is overgrown by omphacite porphyroblasts developed during the eclogitic stage I. Crossed polars; 20 x (SL 1407).

On microstructural bases a number of reequilibration and crystallization periods can be suggested for the amphibolic eclogites:

*a*) development of a foliated matrix formed by clinozoisite/epidote, rutile, white mica and most of the Ca-Na and glaucophanic amphiboles; they predate the porphyroblastesis;

*b*) porphyroblastesis of garnet, omphacite and zoisite; a reequilibration of the amphiboles during the porphyroblastesis is suggested by patchy zoning and disequilibrium boundaries of the amphiboles, and by amphibole veins in garnet;
*c*) $B_1$ folding accompanied or followed by a partial recrystallization of the omphacitic pyroxene without appearance of any new phase;
*d*) local reequilibrations related to $B_3$ folding produced replacement of omphacite by albite + white mica + green amphibole ± Mg-Fe chlorite ± epidote; garnet transforms into chlorite + white mica + albite + epidote; Ca-Na amphibole and glaucophane are rimmed by green amphibole + albite ± Mg-Fe chlorite.

*Eclogites (type 2)*

The eclogites mainly consist (up to 90 %) of coarse grained omphacite and garnet with minor amounts of white mica (phengite and paragonite), rutile, clinozoisite/epidote, Fe-carbonate (Fe-dolomite and calcite) and quartz. No foliations are present inside the lithologic layering and the minor mineralogical components occupy random interstitial positions between omphacite and garnet. Locally the eclogitic assemblage shows a more or less advanced alteration producing albite, blue or green amphibole, epidote, white mica after omphacite, and Mg-Fe chlorite, epidote after garnet.

*Metabasites type 3*

They are foliated and porphyroblastic rocks occurring exclusively in the Ivozio area, and are interlayered with amphibolic eclogites. The matrix foliation is defined by Ca-Na amphibole (20-30 %) crystallographically and dimensionally oriented together with fine grained clinozoisite and zoisite (20-30 %), and scarce white mica and rutile. This foliation is overgrown by porphyroblastic garnet (10-20 %) and omphacite (5-20 %). The latter also occurs in the matrix as grains with no preferred dimensional orientation. Garnet includes an $S_i$ marked by amphibole and zoisite connected with the external foliation $S_e$ (fig. 7). In this assemblage the occurrence of rhomb-shaped aggregates of paragonite and zoisite (± late albite) is observed. They are interpreted as pseudomorphs after lawsonite by analogy with the observations of COMPAGNONI (1977) at Cuorgné. The pseudomorphs may either have a random orientation or are flattened within the amphibole-zoisite foliation.

*Hornblende-rich metabasites (type 4)*

They consist of pale green hornblende, diopside, garnet, omphacite, chlorite, rutile, clinozoisite/epidote and minor apatite. The hornblende [2] (30-70 %) occurs either as large porphyroclasts rich in opaque trails suggesting its derivation from

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(2) From X-ray data ($a_o = 9.889 \pm 0.008$ Å, $b_o = 17.975 \pm 0.023$ Å, $c_o = 5.345 \pm 0.028$ Å, $\beta = 105.63 \pm 0.63°$, vol. 914.9 Å$^3$) the large amphibole porphyroclasts result hornblendes.

prealpine brown hornblende, or as fine grained recrystallized amphiboles defining a faint dimensional foliation. Also the diopsidic pyroxene (0-40 %) shows two textural positions occurring either as large relics crowded with opaque inclusions or as small grains associated with the recrystallized amphibole, and with chlorite, clinozoisite/epidote and rutile. A pseudomorphic pre-Alpine (?) transformation of the pyroxene porphyroclasts into large hornblende grains is preserved in a few occurrences. After the first Alpine stage producing hornblende and pyroxene recrystallization, and the growth of chlorite, clinozoisite/epidote and rutile, large garnet

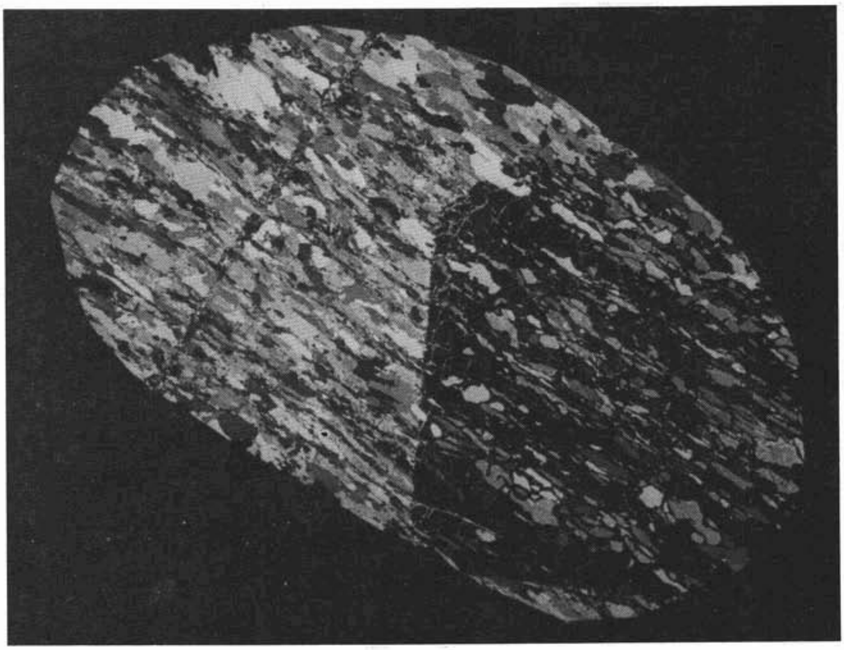


Fig. 7. — Type 3 metabasites - A preeclogitic foliation marked by Ca-Na amphibole and fine grained clinozoisite + zoisite is overgrown by porphyroblastic garnet of the eclogitic stage I. Note omphacite bearing metamorphic vein crosscutting the preeclogitic foliation. Crossed polars; 5 x (SL 1565).

poikyloblasts (5-20 %) develope and omphacite (0-10 %) often rims the recrystallized diopside. Narrow rims of albite ± green amphibole after omphacite, and of epidote + Mg-Fe chlorite at the expense of garnet locally develope.

### Metapyroxenites and serpentinites

Pyroxenites consist of diopsidic pyroxene (60-70 %), Mg-Fe chlorite (20-25 %) and minor antigorite, magnetite and sphene. The pyroxenes occur as porphyroclasts crowded with opaque inclusion trails and surrounded by aggregates of small grains without inclusions. Microstructurally the latter aggregates could represent the recrystallization product of the large reequilibrated porphyroblasts. Mg-Fe chlorite with minor lenses of antigorite and sphene locally defines a persistent layering. This foliation wraps around the pyroxene porphyroclasts. Small and clear diopside grains flow away from the large clasts into the matrix foliation. Chlorite replaces the pyroxenes along the fractures; both minerals are later overgrown and rimmed by antigorite.

Serpentinites represent metre scale layers within the pyroxenites and consist of antigorite (60-80 %), Mg-Fe chlorite (10-20 %), magnetite, diopside, and minor talc and carbonate. Due to the random orientation of the antigorite aggregates the foliation is poorly developed; however it is locally marked by the alignment of polycrystalline lenticular aggregates of diopside and opaque trails. Chlorite occurs as large corroded flakes partially replaced by antigorite. The diopside grains display the same duality as in the pyroxenites, with cores crowded with opaque inclusions and coronas of clear newly formed grains; both are replaced by antigorite. A third, less abundant, grain size class of smaller diopside needles is associated and appears to be stable with antigorite. Though uncertain the original occurrence of olivine is suggested by the presence of elongated pseudomorphs consisting of fine antigorite aggregates randomly oriented with respect to the foliation.

METAGRANITOIDS

Metagranitoids have a faint mineralogical layering due to the relatively poor mica content. They can however develope a planar mineral fabric. The mineralogical

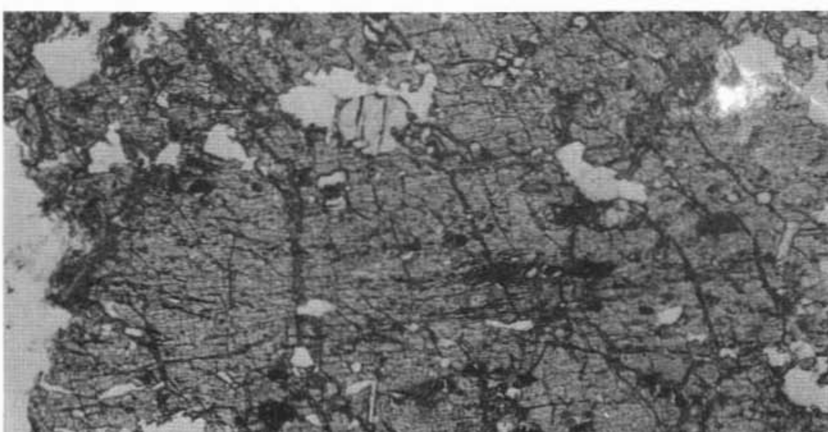


Fig. 8. — Jadeite bearing metagranitoids - A foliation ($S$) defined by rutile, Fe-carbonate and quartz is preserved within a jadeite megablast; no crystallographical planes of the host jadeite are related to $S_1$. Plane polarized light; 50 x (SL 1449).

composition of the eclogitic assemblage is quartz (30-40 %), jadeitic pyroxene (30 %), phengite (5-10 %), apatite, zoisite and minor rutile and garnet. K-feldspar (microcline, 0-30 %) often occurs and represents, with scarce allanite, the only relic of the pre-Alpine magmatic assemblage; it appears to be stable with the other minerals developed under eclogitic conditions. The jadeitic pyroxene usually contains blebs of quartz. A series of posteclogitic transformations locally develope over several mineralogical sites. Jadeite is altered into albite, white mica, epidote, chlorite, magnetite and is rimmed by homoaxial acmitic pyroxene and blue amphibole (mainly crossite); a green amphibole and, in a few occurrences, stilpnomelane later overgrows crossite. Where jadeitic pyroxenes are strongly retrogressed microcline is replaced by albite, and allanite and zoisite are rimmed by epidote.

The jadeite megablast layers consist of jadeitic pyroxenes of unusual size — up to 10 cm — occurring in a foliated matrix of quartz, white mica, and scarce fine grained jadeite, garnet and zoisite. The jadeite megablasts contain an internal foliation defined by quartz, rutile and Fe-carbonate, and also include poikyloblastic garnet (fig. 8).

Such $S_i$ is very likely a remnant of a mineral foliation preexisting to the jadeite crystallization, since it is not mimetic over any crystallographical direction of the host jadeite; moreover it is continuous also through the garnet grains included in the jadeite megablasts. However no continuity is observed between the external foliation and the one, probably older, included in the megablasts. The megacrysts alteration follows the retrogradation process described for the jadeite of the metagranitoids.

## Mineral growth versus deformation history

A classical diagram is used in table I and II to describe the metamorphic and structural evolution of the various lithologies. The results are reported separately for four different chemical compositional groups: basites, granitoids, paraschists, ultramafics and amphibolites. Shadowed vertical stripes provide the time connections between the stages of the metamorphic evolution in different rock types as obtained from mesoscopic analysis. The reliability of the synchronism of $B_1$ folds in the two lithological groups of table 1 is lower than that of $B_2$ and $B_3$ in the same table; this is due to the marked transpositional nature of $B_1$ folds. In all cases the latters are overprinted by $B_2$. In no cases minerals listed in each metamorphic stage can be regarded as a true mineralogical assemblage, since more than one lithology is enclosed in the list.

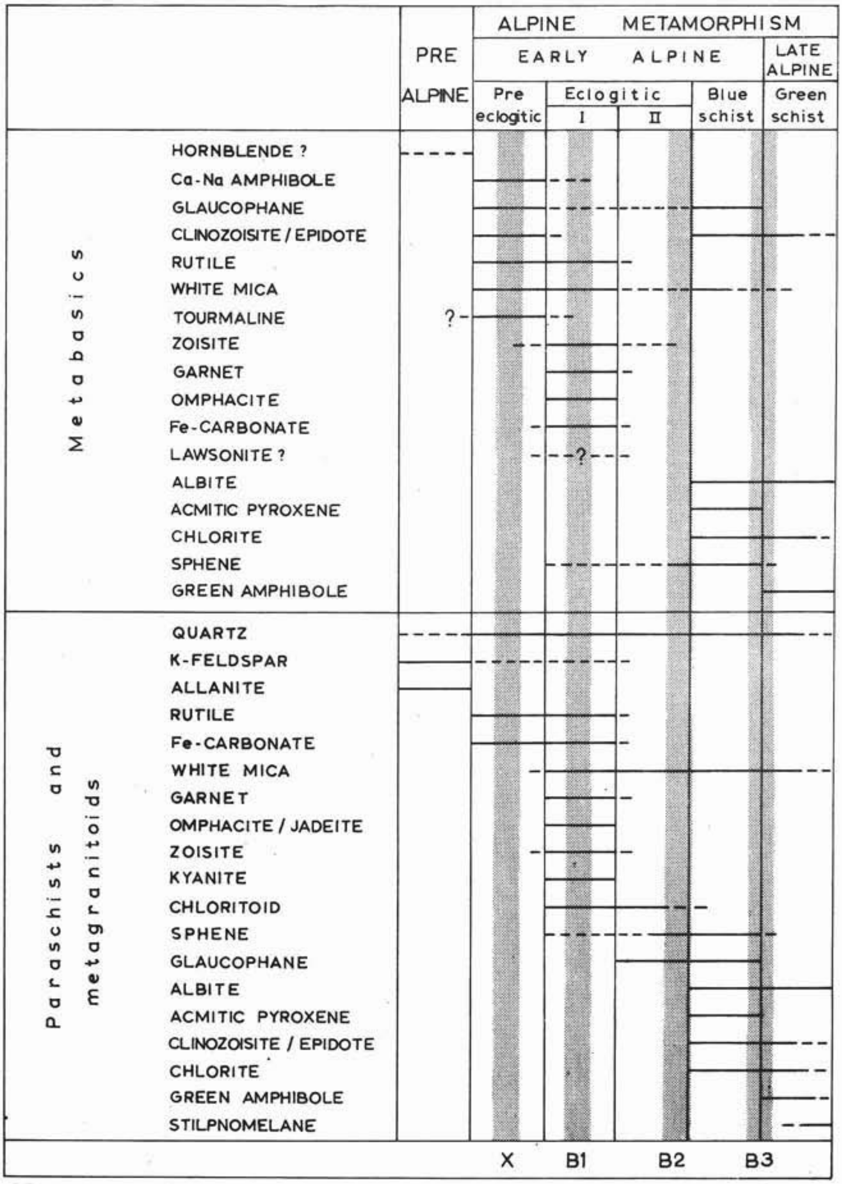
The study of the microstructural relationships leads to propose for this area five Alpine stages of mineral growth or reequilibration: preeclogitic, eclogitic I and II, blueschist, greenschist (Table 1). Magmatic and metamorphic relics of pre-Alpine assemblages (K-feldspar, allanite and probably brown hornblende completely reequilibrated in Alpine age) are listed as a single group.

### Preeclogitic stage

It is evidentiated in the foliated matrix of the metabasic rocks (Ca-Na amphibole and/or glaucophane, clinozoisite/epidote ± zoisite, rutile and white mica) and in

TABLE 1

*Structural and metamorphic evolution of metabasics, paraschists and metagranitoids*




the included *S* of the jadeites of the jadeite megablast bearing layers (quartz, Fe-carbonate, rutile). Though mimetic growth of these assemblages over pre-Alpine foliations cannot be excluded, the existence of a granular scale Alpine deformation (*X*) is very likely associated with the first reequilibration episode of the Alpine evolution.

Eclogitic stage I

In the metabasics and in part of the metagranitoids the preeclogitic foliations are overgrown by porphyroblastic garnet, omphacite/jadeite and zoisite developed during the eclogitic event. In the paraschists garnet, omphacite, white mica, kyanite and chloritoid I grow during this stage. Omphacite is deformed and/or reoriented by $B_1$ structures but remain stable in the $B_1$ axial plane foliation. $B_1$ is therefore regarded as a syneclogitic folding event.

Eclogitic stage II

In the second eclogitic stage porphyroblastic glaucophane overgrows the pre-existing eclogitic assemblage in the paraschists; in this stage the Na-pyroxene is still stable. The glaucophane probably form together with chloritoid II. The eclogitic assemblages I and II are not significantly retrogressed before and during the reorientation process associated with $B_2$ folding. Textural data on lawsonite formation are insufficient to define its time of growth and its destabilization into pseudomorphs of zoisite and white mica.

Blueschist stage

The appearance of albite, blue amphibole, acmitic pyroxene, white mica, epidote and chlorite replacing the jadeitic/omphacitic pyroxene marks a further reequilibration stage under blueschist metamorphic conditions. This stage lasts until $B_3$ deformation that redistributes these destabilization products into differentiated $B_3$ foliations.

Greenschist stage

The Late-Alpine stage is poorly developed and produces albite, white mica, green amphibole, chlorite, epidote and stilpnomelane. These minerals correspond to a greenschist facies imprint postdating the high pressure assemblages and could be partly of Lepontine age (Compagnoni et al., 1977 b).

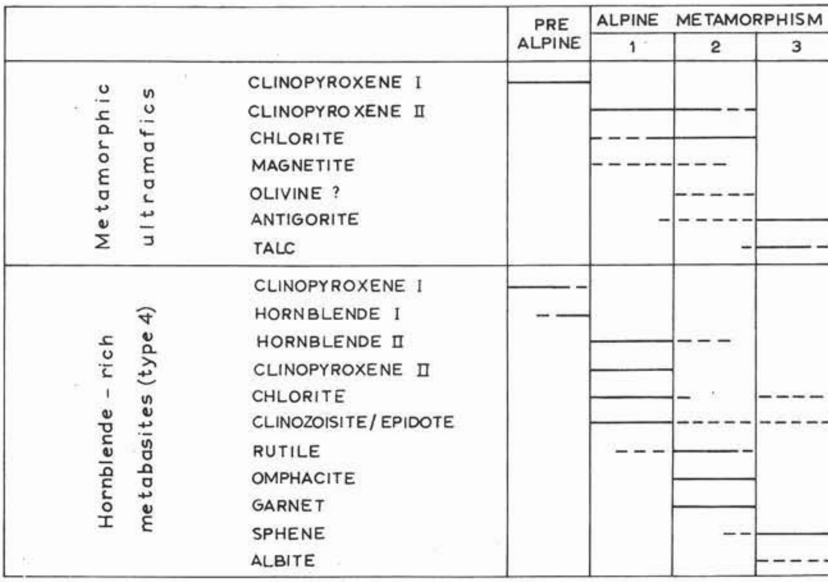
The microstructural and metamorphic evolution of the ultrabasites and of the hornblende rich metabasites (type 4) of the Ivozio complex is summarized in Table 2; it has been separated from the evolution of the other lithologies for the lack, or scarcity, of typomorphic minerals and of a clear structural history. Three stages can however be defined and they are tentatively correlated with preeclogitic, eclogitic and blueschist-greenschist stages respectively. The pre-Alpine relics (clinopyroxene I and hornblende I) are listed in a single group.

*First stage* - In the ultramafics a first recrystallization of diopsidic pyroxene takes place with the growth of Mg-Fe chlorite and magnetite. Type 4 metabasites show a recristallization of diopside and amphibole, and a growth of chlorite, clinozoisite/epidote and rutile.

*Second stage* - Probably olivine form at this stage in a few ultramafics with Mg-Fe chlorite, diopside and minor antigorite. In type 4 metabasites omphacite

TABLE 2

*Metamorphic evolution of ultramafics and hornblende-rich metabasites (Type 4)*




borders diopside, and garnet, often overgrowing the recristallized amphibole, develops with rutile and probably clinozoisite.

*Third stage* - In the ultramafics olivine (?), Mg-Fe chlorite and diopside are replaced by antigorite and minor talc, while in type 4 metabasites garnet transforms into chlorite + epidote, rutile into sphene, and omphacite breaks down into albite + + green amphibole.

## Conclusions

The detailed mapping of the Eclogitic Micaschists Complex in the lower Aosta Valley has shown a wide spectrum of pre-Alpine lithologies reequilibrated under Early-Alpine eclogitic conditions, including jadeite bearing paraschists and metagranitoids, amphibolic eclogites, marbles and ultramafites. The latter were formerly known only at the contact between the Eclogitic Micaschists Complex and the II Zona Diorito-Kinzigitica (DAL PIAZ et al., 1971).

Among the paraschists it is noteworthly the finding of chloritoid-garnet-paragonite schists containing individual blasts of kyanite, a mineral so far recognized only as rare pseudomorphs after pre-Alpine sillimanite (DAL PIAZ et al., 1972). The kyanite-chloritoid coexistence also indicates that chloritoid as well developed during the eclogitic event.

Mineralogical and microstructural evidences indicate that most of the amphibole bearing eclogites derive from pre-Alpine hornblende amphibolites. Microstructure and zoning of the amphibole — represented by Ca-Na varieties and minor glaucophane — suggest a continuous reequilibration starting from pre-eclogitic conditions. On the contrary in the micaschists the porphyroblastic glaucophane appears to develope later than garnet and omphacite growth, mainly at the expense of the latter.

The existence of a metamorphic stage predating the *PT* climax and accompanied by a granular scale foliation, prooves a mineral reequilibration during a prograde pressure trajectory of the unit. Mineralogical and textural relics of this stage can then be regarded as the earliest trace of an Alpine metamorphic reactivation, and have been recently found by POGNANTE (1979) and REINSCH (1979) in the internal Sesia-Lanzo Zone. Yet this prograde metamorphic stage must not be confused with the other retrogressive stages marking the posteclogitic evolution and recorded in most lithologies of the EMC both as pseudomorphic or as coronitic reactions after jadeitic pyroxenes.

If the interpretation of a subduction mechanism is accepted to explain the development of high pressure metamorphism, therefore in the EMC of the lower Aosta Valley many stages of this subduction process, from the earliest sinking down towards deep crustal levels to the later exhumation, are recorded. Moreover the stability of the eclogitic assemblages during two deformation phases ($B_1$ and $B_2$) and the existence of a preeclogitic deformation ($X$) confirm that the deep crustal environment where the HP assemblages formed was tectonically active at a penetrative scale.

$B_1$ and $B_2$ eclogitic deformations could be respectively correlated, within the history traced by Gosso et al. (1979) along a section from the Sesia to the Monte Rosa nappes, with the main nappe emplacement and with the postnappe phase of high pressure folding which occurred slightly after the pressure peak.

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