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GUIDO GOSSO *

METAMORPHIC EVOLUTION AND FOLD HISTORY IN THE ECLOGITIC MICASCHISTS OF THE UPPER GRESSONEY VALLEY (SESIA-LANZO ZONE, WESTERN ALPS)

RIASSUNTO. — L'uso dell'analisi geometrica mesoscopica ha rivelato quattro generazioni di pieghe nel lembo di micascisti eclogitici che sovrasta la II Zona dioritico-kinzigitica in Valle di Gressoney. Tre di esse sono posteriori alla fase di sovrascorrimento tettonico che crea una litostratigrafia regionale composta di unità a diverso carattere metamorfico eoalpino.

Lo studio microstrutturale viene effettuato su campioni provvisti di scistosità datate per mezzo dell'analisi geometrica; esso permette di rivelare che le prime due generazioni di pieghe si producono in condizioni metamorfiche capaci sostanzialmente di conservare i minerali di alta pressione dell'evento eoalpino. La conversione delle paragenesi eoalpine in nuove associazioni di facies scisti verdi di bassa pressione raggiunge il suo culmine dopo la terza generazione di pieghe.

ABSTRACT. — The time relationships between folding and metamorphic evolution of the sheet of eclogitic micaschists overlying the II Zona dioritico-kinzigitica in the Gressoney Valley are investigated here. The recognition of four fold generations provides the samples for microstructural observations. Three generations of folds postdate the lithostratigraphy assembled by the phase of nappe emplacement that mixed up units carrying different grades of high-pressure metamorphism. The first two generations of folds occur under metamorphic conditions capable of preserving the high-pressure assemblages. The thermal climax of the metamorphic episode which transforms the high-pressure rocks into greenschist facies assemblages postdates the third fold generation.

The structural setting of the margin of the Sesia-Lanzo Zone facing the outer side of the alpine arc involves in many areas the three main complexes that have long been recognized in this Zone (for references see COMPAGNONI et al., 1977). The use of analysis of small scale structures appears to be the only applicable method for solving the complicated interplay between the Gneiss Minuti Complex, the Eclogitic Micaschist Complex and the II Zona Dioritico-kinzigitica. An attempt is made here to reconstruct the time relationships between folding and the evolution of the eclogitic assemblages in the sheet of eclogitic micaschists that overlies the II Zona Dioritico-kinzigitica in the Gressoney valley, by relating the fold history at the mesoscopic scale to microstructural observations and petrographic study on selected lithologies.

* Istituto di Petrografia dell'Università di Torino e Centro di Studio sui Problemi dell'Orogeno delle Alpi Occidentali.

Along the watershed between the upper Gressoney and Sesia valleys, from Cresta Rossa to Corno Rosso [1] the Sesia-Lanzo nappe has an excellent degree of exposure and is composed of three superposed tectonic units: 1) a higher sheet of metagranitoids, paraschists and metabasics, referable to the Eclogitic Micaschist Complex, 2) the II Zona Dioritico-kinzigitica, a unit of paraschists and metabasics, 3) a lower unit composed of metagranitoids (with minor paraschists) of the Gneiss Minuti Complex in the NW, flanked by the paraschists and metagranitoids of the Eclogitic Micaschist Complex to the SE (fig. 1).

The large scale tectonic setting of the Sesia-Lanzo Zone in the Gressoney area is represented in fig. 1. The II Zona Dioritico-kinzigitica, with the small overlying sheet of eclogitic micaschists, overlaps both the Eclogitic Micaschist and the Gneiss Minuti in a zone where these two Complexes are flanking each other. The contact area of the Eclogitic Micaschist and the Gneiss Minuti Complexes markedly corresponds to a zone of prevailing steep attitudes of the lithology, that extends from the upper Sesia valley to the Champorcher valley (near Hône in lower Val d'Aosta). The II Zona Dioritico-kinzigitica appears as a synformal structure where it is superposed upon the juxtaposition zone of the lower Complexes (Becca Torché-Becca Mortens SW of M. Nery, Monte Nery, Riva Valdobbia, and Gressoney St. Jean-Pont Trenta).

The II Zona Dioritico-kinzigitica and the Eclogitic Micaschist units preserve traces of the early-Alpine high pressure-low temperature metamorphic event which occurred with different grade and extent in each of them, producing distinctive high-pressure assemblages. The tectonic superposition now observed was reached after the high-pressure metamorphism (Dal Piaz et al., 1971); after this phase of tectonic imbrication a greenschist facies event of Lepontine age, culminating with formation of albite-oligoclase and biotite, produced assemblages of the same grade in all the units.

Outlines of the metamorphic setting of the units forming the Sesia-Lanzo nappe in the upper Gressoney valley are given in Dal Piaz et al. (1971), Compagnoni et al. (1977) and Compagnoni (1977).

In the uppermost sheet of Eclogitic Micaschists of Punta Plaida (fig. 2) the metabasics associated with the paraschists were mostly transformed into glaucophanites ($\pm$ garnet) during the high-pressure metamorphism; their pre-Alpine mineralogical composition (brown-hornblende + saussuritic plagioclase) is very seldomly preserved. Eclogite- or omphacitite-boundins possibly derived from basic dykes or dark enclaves of the granitoids also occur. In the metagranitoids, pseudomorphs of albite + actinolite + white mica, of the same type of those replacing

[1] All the topographical names appearing in the present paper refer to the Italian sheets at 1:25.000 scale Corno Bianco, Issime and Challant, edited by Istituto Geografico Militare (Firenze).

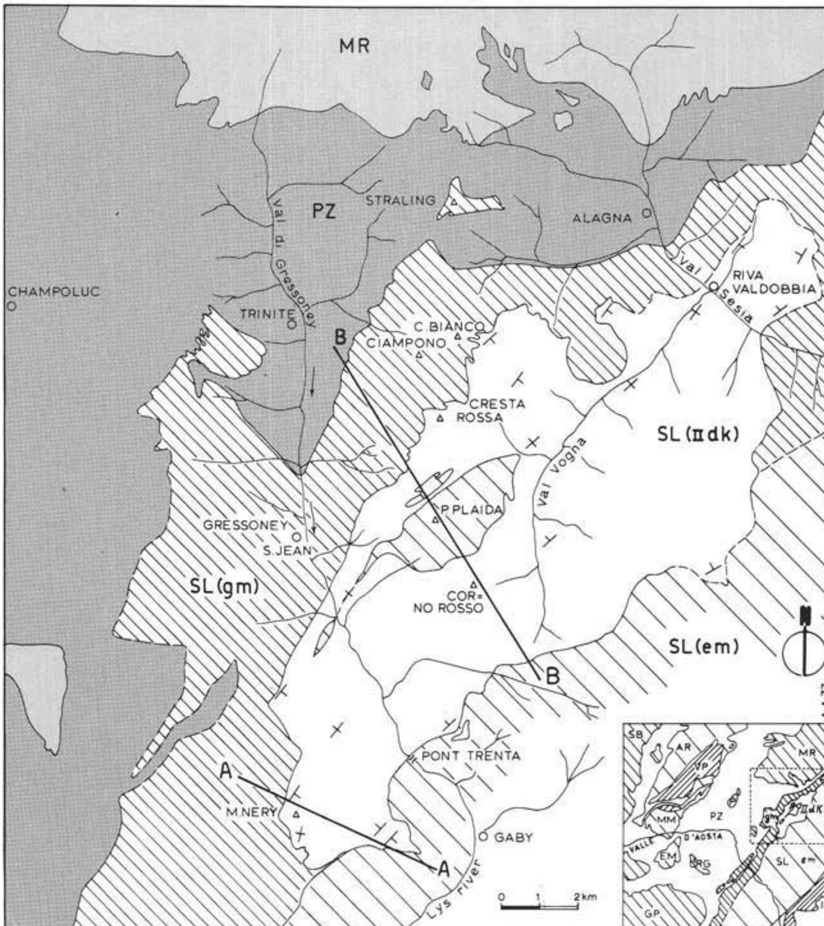


Fig. 1. — Tectonic scheme of the Northwestern margin of the Sesia-Lanzo Zone between the upper Sesia and Gressoney Valleys. St. Bernhard Nappe (SB); Monte Rosa (MR); Gran Paradiso Nappe (GP); Piemonte Zone (PZ); Ivrea Zone (IV).
Dent Blanche Nappe (MM: Mont Mary klippe; EM: Monte Emilius klippe; GR: Glacier-Rafray klippe; P: Pillonet klippe; AR: Arolla Series; VP: Valpelline Series).
Sesia-Lanzo Zone: SL (gm: Gneiss Minuti Complex; em: Eclogitic Micaschists Complex; IIdk: II Zona Dioritico-Kinzigitica). A-A, B-B: Location of cross sections represented in Fig. 2.

jadeite-rich pyroxenes in the internal sector of the Eclogitic Micaschist Complex (see Compagnoni, 1977) are preserved in places.

In the underlying II Zona Dioritico-kinzigitica eclogites are not present at all and the metabasics largely preserve brown-hornblende + plagioclase as relics of the pre-Alpine high-temperature metamorphism (Tab. 1). Therefore different high-pressure conditions must have operated in the two units before their tectonic imbrication took place.

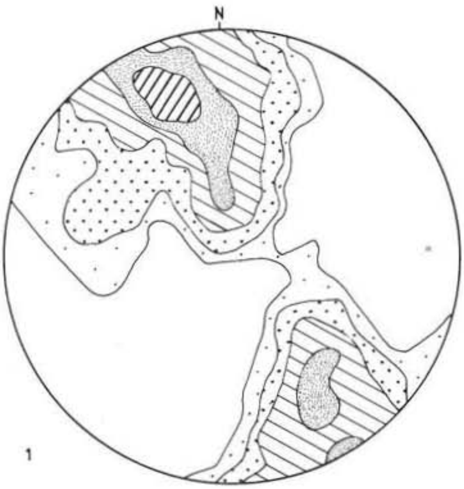
The II Zona Dioritico-kinzigitica also shows a marked metamorphic break with respect to the underlying units: on its Northwest it overlies the Gneiss Minuti Complex wich only has Alpine greenschist facies assemblages; in the Southeast it overlies the lower Eclogitic Micaschist Complex wich preserves assemblages typical of the eclogitic metamorphism (see DAL PIAZ et al., 1972).

Mesostructural data

On the base of overprinting criteria (see HOBBS, MEANS and WILLIAMS, 1976 (chp. 8) a time sequence of fold development was established in the area between Cresta Rossa and Corno Rosso (fig. 2). A detailed description of the mesostructure of this area will be dealt with in a separate paper.

Fig. 2. — Tectonic setting of the ridges flanking the upper Gressoney valley, near Gressoney St. Jean. Heavy lines indicate tectonic contacts between different complexes. The tectonic contact of the Punta Plaida Eclogitic Micaschists with the II Zona Dioritico-Kinzigitica is indicated by crosses. All the heavy lines are pre-B_2 tectonic contacts. Dashed lines are interpretative. For location of cross sections see Fig. 1.

A marked lithologic layering of pre-Alpine age is defined by the association of glaucophanites, glaucophane schists, marbles and phengite-garnet-chloritoid-glaucophane schists forming the paraschist bodies. They are interlayered with meta-granitoid and meta-aplite dykes. Large masses of well foliated garnet-glaucophane-micaschists derived from intrusives occur as lenses within the paraschists; in some places a sharp boundary between the ortho- and para-micaschists cannot be traced.



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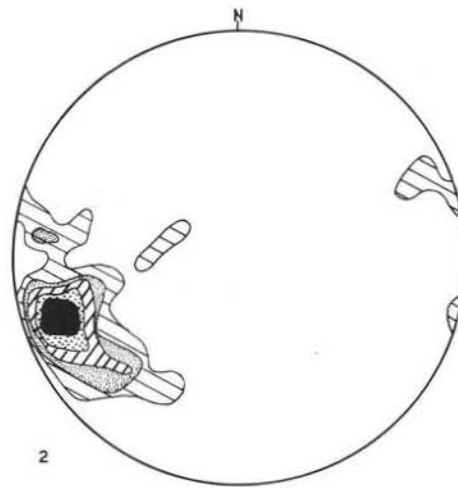

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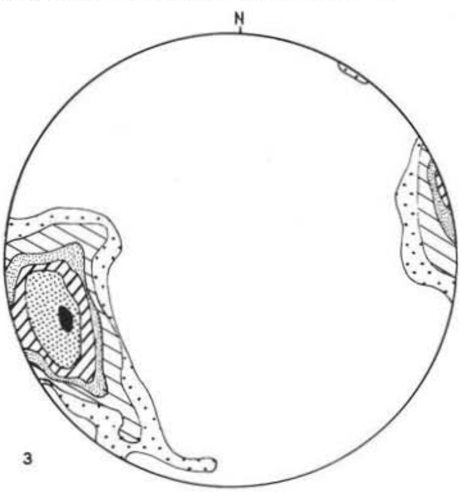

CONTOURING: 1; 2; 4; 6; 8; 10 %, PER 1 % AREA

Fig. 3. Synoptic orientation diagrams of some structural elements in the area corresponding to the entire cross section B-B; contouring by KALSBEEK's method. 1) 1058 poles to lithology and schistosity; 2) 131 axes of B_2 generation of folds; 3) 280 axes of B_3 generation of folds.

Four generations of folds (B_1 to B_4) affect all the units, and their styles and orientations can be summarized as follows:

The B_1 folds are isoclinal and commonly rootless, ranging in scale below one meter; their orientation is dispersed. A mineral layering parallels the axial plane in the schists and forms also in the metabasics, though less frequently.

The B_2 are tight or isoclinal; their dimensions range from one mm to some hundred meters. Hinge shapes are acute or rounded depending on lithology and scale of folding. B_2 axes plunge gently towards 250° and their axial plane surfaces may have any dip, *due to subsequent reorientation by* B_3 *folds* (fig. 2). Small scale mineral layerings associated with axial plane schistosities are common, though of limited extent. New layerings are mostly developed in meta-aplitic dykes and schists. *Where there are no overprinting relationships this fold generation may very easily be confused with* B_3.

The B_3 folds are open to tight, with rounded hinges at the scale of several hundred meters, and closer to a chevron style at the small scale. Orientation of B_3 axes coincides with that of B_2 in the measured area of about 9 square kilometers. Axial plane surfaces dip gently towards NNW. Axial plane layerings are less common than in B_2 folds, and are only developed in the schists.

The B_4 folds are small scale kinks, only locally penetrative; however larger B_4 structures with very open limbs were also observed; kink planes are subvertical and strike mostly 40° or 130°, with gently dipping axes. Low grade minerals may occur in vein sets parallel to kink planes.

Orientation diagrams of some structural elements for the entire measured area are reported in fig. 3.

Microstructures and metamorphic evolution of the eclogitic micaschists of Punta Plaida

The microstructures of minerals corresponding to critical stages in the metamorphic evolution (see Tab. 1) were qualitatively examined under the microscope, whenever these minerals contribute to fabrics related to folds or foliations of known relative age. New foliations are not assumed to develop pervasively, that is to say *they are labelled chronologically only when occurring as axial plane to folds whose age is known on the basis of overprinting relationships.* Such a rigid criterium excludes on the one hand the possibility of sampling all the critical stages of metamorphic transformations in specimens suitable also for microstructural analysis, but makes, on the other hand, more reliable the determination of the relative chronology of mineral transformations with respect to the fold history.

In the Eclogitic Micaschists of Punta Plaida the most intense textural reorganization, with development of new pervasive foliations, takes place where folding is tight or isoclinal and leads to transposition of the lithology. A mm scale differentiated layering forms axial planar to B_1 folds in metabasics and micaschists; relics of preexisting schistosities are scarce. The axial plane foliations of B_2 and B_3 generations of folds are less pronounced. As a result of partial to complete transposition and local production of new small scale layerings, the mesoscopic fabric is composite all over the area. Lithologic boundaries predating Alpine metamorphism are also largely preserved. The composite fabric of these rocks is evident also at the microscope scale since the occurrence of earlier mineral relics is often related to some preserved portions of older fabrics.

B_1 and earlier microstructures

In thin sections cut perpendicularly both to B_1 and B_2 the fabric of *micaceous glaucophanites* is layered at the scale of 0.1 to 1 mm. The principal mineral constituents are glaucophane, white mica, clinozoisite (possibly derived from zoisite), opaques and scarce albite. The morphology of the layering appears as follows close to hinges of B_1 folds that persistently bend it: white mica layers consist of very elongated individuals displaying a strong preferred orientation shown by uniform extinction in crossed polars; pairs of white mica grains develop sutured margins

TAB. 1

Synoptic scheme of the assemblages covering the entire evolution recognizable in the units of the Sesia-Lanzo Zone in the Gressoney Valley
(see also DAL PIAZ et al., 1971 and 1972)

UNIT	LITHOLOGY	RELICS OF PRE-ALPINE ASSEMBLAGES	ALPINE METAMORPHISM HIGH PRESSURE EVENT	ALPINE METAMORPHISM LOW PRESSURE GREENSCHIST EVENT
ECLOGITIC MICASCHIST COMPLEX (Punta Plaida Element)	SCHISTS	(bi) gar	pheng glauc gar chld zois	alb chl clz-ep gr-bi alb-olig
	AMPHIBOLITES	br-hbl (plag)	glauc gar zois	alb chl act clz-ep bi alb-olig
	MARBLES			trem-act
	METAGRANITOIDS with	(bi)	(Na-cpx) pheng gar	alb chl gr-bi
	ENCLAVES		omph gar pheng	alb act chl gr-bi
II ZONA DIORITICO-KINZIGITICA	SCHISTS	plag bi sill gar (cord?)	ky glauc zois gar chld	alb chl clz-ep gr-bi act alb-olig
	AMPHIBOLITES	br-hbl plag	glauc zois	alb chl act gr-bi clz-ep alb-olig
	MARBLES	diops? wh-mi		trem-act alb wh-mi
GNEISS MINUTI COMPLEX	METAGRANITOIDS with	(bi) k-feld plag		alb chl act clz-ep stilp gr-bi alb-olig
	ENCLAVES	hbl bi		alb chl gr-bi clz-ep
ECLOGITIC MICASCHIST COMPLEX	SCHISTS	(bi) gar	pheng glauc gar zois Na-cpx	alb chl clz-ep gr-bi alb-olig
	AMPHIBOLITES	(br-hbl) (plag)	omph glauc gar zois	alb chl act clz-ep gr-bi
	MARBLES			trem-act
	METAGRANITOIDS with	bi	(jd) pheng gar	alb chl gr-bi
	ENCLAVES		omph gar pheng	alb act chl gr-bi

In brackets: minerals recognizable only as pseudomorphs.

along B_1 axial planes, producing the well known decussate arrangement of grain boundaries. Clinozoisite is mainly concentrated in monomineralic layered aggregates of equigranular size (0,01 to 0,1 mm) and does not show any evident shape fabric; this morphology does not vary along B_1 hinge zones. Large glaucophanes form layers up to 2 mm thick in which a maximum amount of 10 % of white mica and interstitial albite of later generation may occur. The pre-B_1 glaucophane layering has much the same appearance of the hornblende foliation in relict pre-Alpine amphibolites (N face of Punta Oro). Outside the zone where a pre-B_1 glaucophane fabric is preserved, glaucophane layers are consisting of inequant prismatic grains (dimensions ratio = 4 : 1) with a strong shape orientation; their size is smaller than 0.3 mm. Larger grains up to 1,5 mm are associated to them and represent relics of the glaucophane fabric preexisting to B_1 since their size and internal microstructure are similar to those of large grains forming B_1 hinges (Fig. 4).

The larger grains often have a porphyroclastic appearance (fig. 5); they are fractured into smaller pieces and pulled aside but still show a common optical orientation; the fractures are filled by white mica, green amphibole, opaques, rutile, and small newly grown pale glaucophanes. Inside the clasts extinction domains with low angle lattice misorientation can be recognized. The extinction pattern may be diffuse, or extinction domains are separated by sharp low angle boundaries. The nature of these sharp boundaries is yet uncertain; they may be either kink bands, or fractures which are possibly in the axial plane of kinks, or subgrain walls formed by recovery processes. Small new euhedral grains are formed within the extinction domains and at the subboundaries; the new optically strain free grains appear both in basal and prismatic sections and show large lattice misorientation with respect to the host grain; they may grow into both the neighbouring extinction domains. At the rim of the porphyroclasts the new grains show a well developed shape fabric parallel to the external foliation (the foliation preexisting to B_2), even in strain shadow areas at the edges of the clasts.

The grain size reduction mechanism is here interpreted as a recrystallysation process and must have occurred as a consequence of B_1 microfolding, since deformation of the old coarse glaucophanes with generation of new strain-free grains is observed as a relict microstructure in B_1 hinges (Fig. 4), moreover B_2 microfolds persistently bend the foliation consisting of the newly formed small glaucophanes.

A more intensely coloured variety of glaucophane, with sensibly lower 2 V values (average of ten U-stage measurements of 2 V for each type: 38° in the pale glaucophane and 27° in the more coloured variety) rims the small glaucophane grains. The porphyroclasts as well are affected along narrow zones by the same transformation into a more coloured glaucophane; this transformation obviously postdates the grain size reduction (*i.e.* it postdates B_1).

B_1 folds in metamorphic *dykes* of *granitic* to *aplitic* composition show a mesoscopic axial plane compositional layering. At the microscope scale the degree of reorientation of micas in the axial plane foliation is almost complete; relics of micas sitting across the new foliation are very scarce.

B_2 microstructures

Glaucophane micaschists. Quartz-albite-glaucophane-epidote micaschists, with chloritoid and garnet in varying amounts, are the most abundant lithology in the Eclogitic Micaschists of this area. They may derive either from granitoids or from paraschists.

Garnet shows some chloritization predating B_2 in glaucophane schists, as chlorite shadows flow into the B_2 foliation.

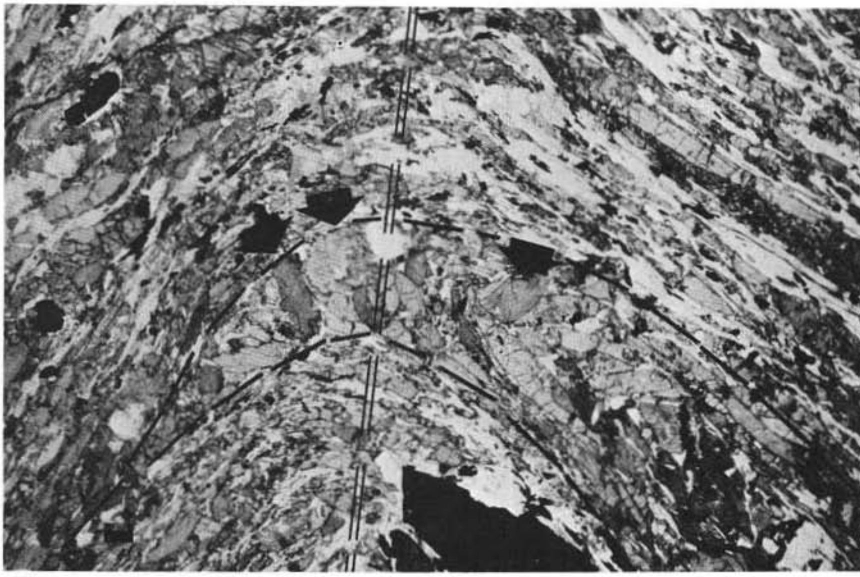

Fig. 4. — B_1 fold refolded by B_2 in a white mica-epidote glaucophanite. Remnants of fabric elements pre-existing to B_1, are represented by grains of larger size sitting across the foliation (arrows) or converging into a hinge configuration of the B_2 refolded microfold. Some of the large grains have a porphyroclastic microstructure. Double dashed line: B_2 axial plane trace; dashed line: contour of B_1 microfold. Plane polarized light; scale bar = 0.1 mm. Sample SL 1003.

Fig. 5. — Part of a coarse glaucophane porphyroclast, sitting within the small size glaucophane with a shape foliation. The rock is the white mica-epidote glaucophanite of Fig. 4. Newly grown grains (arrows) form also across sharp subboundaries which separate low-angle extinction domains (a-a). See text for further explanation. Dashed line: contour of the porphyroclast; f = fracture zone. Crossed polars; scale bar = 0.1 mm. Sample SL 733.

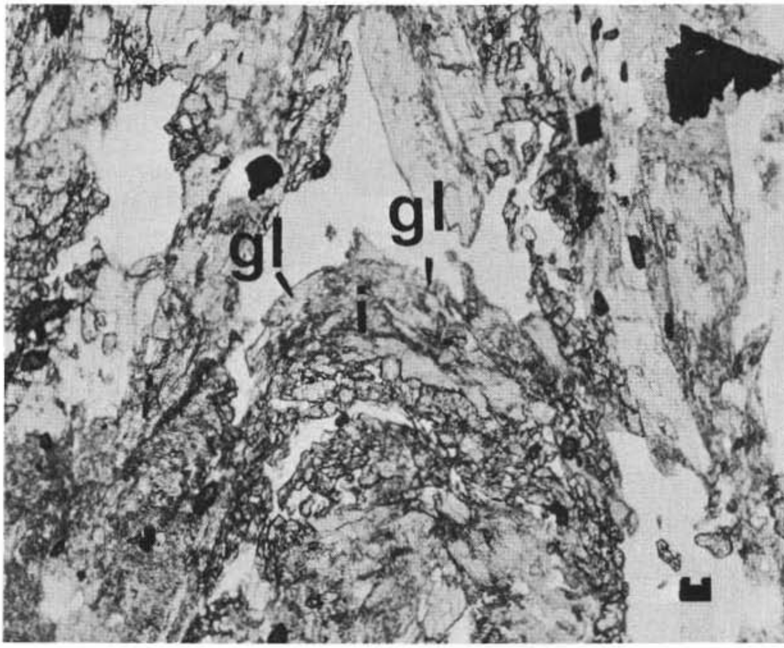

Fig. 6. — Eclogitic micaschist with retrograde transformation of glaucophane, producing albite-chlorite--actinolite intergrowths in a B_2 microfold. gl = relict glaucophane grain; i = intergrowth. Two glaucophane grains, above the retrogressed grain, have been apparently rotated into the new orientation, without suffering retrogression. Plane polarized light; scale bar = 0.1 mm. Sample SL 1013.

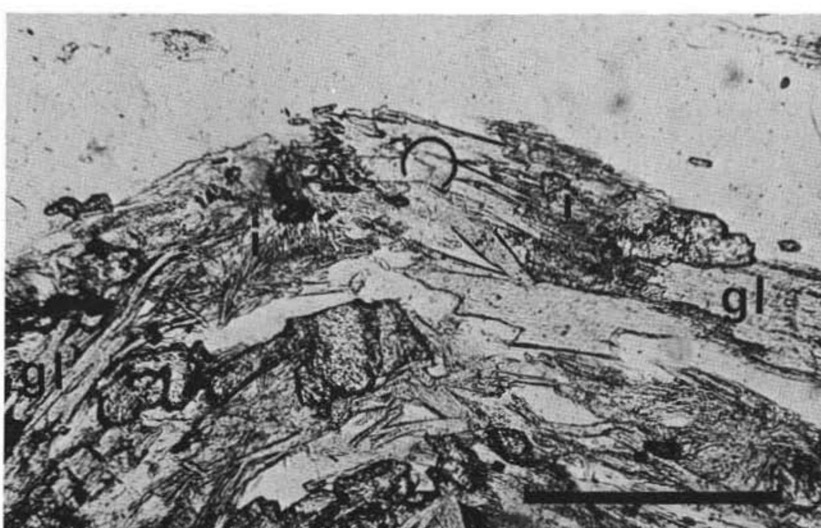

Fig. 7. — Kinking and suturing of kink band boundaries of chlorites in a B_2 microfold of an eclogitic micaschist; chlorite is here a retrogradation product of glaucophane. gl = glaucophane; i = retrograde intergrowths of albite I, actinolite and chlorite; sutured kinks of chlorite within open circle. Plane polarized light; scale bar = 0.1 mm. Sample SL 999.

In the paramicaschists *chloritoid* pre-dates B_2 microfolding. Lack of positive evidence for post - B_1 growth of cloritoid in the area, together with its coexistence with the oldest early-Alpine high - pressure minerals (garnet, Na-pyroxenes and phengite) of the same micaschists in the internal part of the Eclogitic Micaschist Complex, favour the hypothesis of its pre B_1 growth.

Glaucophane of a very pale-coloured variety,in both ortho- and paramicaschists, retrogrades to fine grained intergrowths of chlorite, actinolite and albite I (fig. 6). This transformation can be relatively dated with respect to B_2 folding. Within the intergrowths the largest chlorite flakes (0.1 mm) deriving from glaucophane are kinked perpendicular to their elongation, and the kink boundaries are often sutured; the retrogression of glaucophane in these cases is said to have occurred during or prior to B_2.

The micaschists with large amounts of phengitic micas develop a differentiated layering of mm scale in B_2 hinges. The new layering consists of phengite-rich domains with minor clinozoisite and glaucophane, flanking quartz-rich domains with very scarce phengite and clinozoisite. *No albite occurs* within the quartz polycristalline aggregates of the quartz-rich domains forming B_2 differentiated layerings, *unless it is related to glaucophane retrogression.*

B_3 microstructures

During B_3 folding the preexisting foliations of the *glaucophane micaschists* are crenulated at the microscale; all stages ranging from simple crenulation of pre- B_3 foliations to true B_3 schistosities occur, with various grades of differentiation. The new foliations are parallel to axial planes of B_3 mesoscopic folds. White mica layers ± biotite, alternating with quartz-albite-garnet-sphene-glaucophane ± chloritoid ± opaques-rich layers are the main components of B_3 layerings. In rocks where a true differentiated cleavage forms, the configuration of micas sitting in the new quartz-rich domains is dominantly controlled by zig-zag serrations of boundaries between V-shaped couples of grains that assume a decussate microstructure. The serrations have the same appearance of those observed by ETHERIDGE and HOBBS (1974, fig. 1*a*) to develope after kinking, in a stage preceeding nucleation, during a recrystallisation experiment on phlogopites; similar sutured grains were also experimentally obtained by TULLIS (1976, fig. 3*a*) in a fluorophlogopite sample hydrostatically recrystallised. MEANS (1968) obtained the same configurations by static annealing of previously kinked fluorophlogopites. The amplitude of the mica serrations, in the glaucophane micaschists varies, according to whether a single or several steps connect two adjacent mica individuals (fig. 8).

A different internal microstructure of the grains is observed when the B_3 cleavage is not differentiated and the quartz- and mica-rich domains predating B_3 are only crenulated. Very small amplitude serrations develop in the inner prolongation of straight kink band doundaries and commonly occur in kinked individuals that still preserve a bent portion on their outer margin.

The coexistence in a single grain of bent, kinked and sutured portions, combined together as in fig. 9, is very rare; whenever observed, this association always shows the bending in the outer part of the grain. This appears to suggest a fourfold sequence of microstructural development involving the stages of 1) bending of a single mica grain, 2) subsequent appearing in the inner part of the grain (zone of maximum curvature) of discrete kink planes, 3) migration of kink band boundaries to produce small scale serrations, and 4) formation of larger steps in the suture (decussate stage). Each stage is expected to spread from the inner to the outer

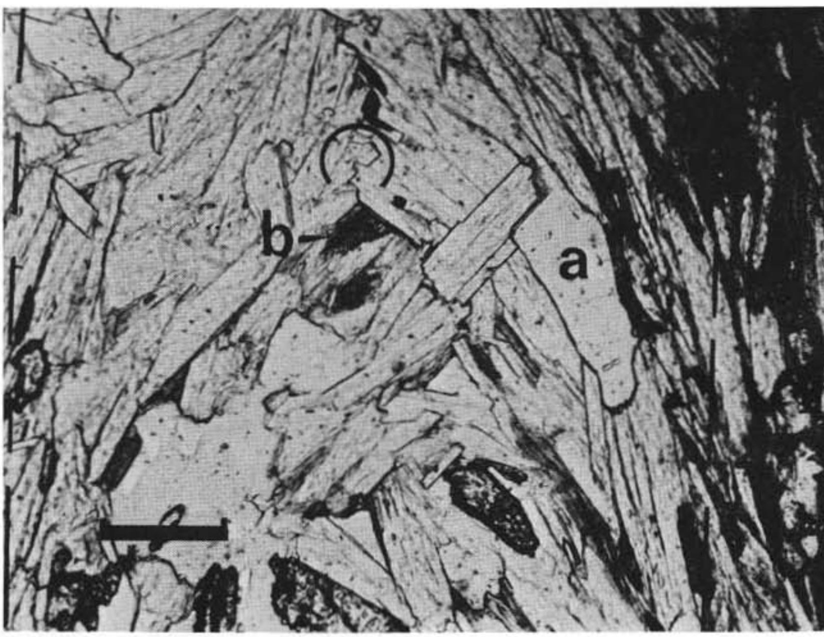

Fig. 8. — Migrated kinks in phengites sitting across a quartz-rich domain, differentiated during B_3 crenulation cleavage, in an eclogitic micaschist. Mica-rich domains (dashed lines) define a true new cleavage. Irregular type of serration of the kink band boundary is represented within the open circle. Triangular shaped biotite (b) grows between couples of phengite subindividuals. Strain-free albite (a) replaces white mica and is controlled by a preexisting large amplitude serration. Plane polarized light; scale bar = 0.1 mm. Sample SL 770.

side of the bent grains; two successive stages of the sequence are commonly associated in a single individual.

The four stages of microstructural evolution of white micas are believed to reproduce in this natural sample the sequence of bending, kinking and serration of kinks observed by Etheridge and Hobbs (1974) in adjacent portions of the phlogopite specimen experimentally deformed and annealed at increasing temperature.

The occurrence in single grains of white mica of stages 1) to 4) confirms that bending, kinking and suturing of kinks play a role as an important orienting mechanism in the development of a crenulation cleavage type of schistosity, as proposed for some types of mica fabric by WILLIAMS, MEANS and HOBBS (in press).

B_3 axial plane foliations in the glaucophane-chloritoid micaschists show many transitional types of cleavage morphology, ranging from simple crenulation of pre-B_3 layerings to well developed newly differentiated crenulation cleavages. Large scale suturing corresponding to stage 4) of the above sequence was rare in the B_3 crenulation cleavage without formation of distinct mineral layerings. Well developed decussate margins across couples of V-shaped grains are by far the commonest stage in rocks displaying evolved B_3 differentiated layerings.

The V-Shaped couples of serrated grains appear to control the growth of other minerals significant for the metamorphic evolution of the rock.

The widespread growth of *porphyroblastic albite* with *oligoclase rims* postdates B_3 microfolding. At more advanced stages of the previously described suturing of white micas kinked during B_3 microfolding, i.e. when large scale serrations are already formed, optically unstrained individuals of albite grew at the expenses of mica grains of the newly reorganized mica aggregate. Albite grains are very seldomly twinned, and at early stages of growth their boundaries are controlled by (001) and {001} planes of micas (fig. 8). In more advanced stages of the porphyroblastic growth, albite grain boundaries may cut through several grains of mica, whatever the orientation of the latter may be. Albite growth is believed to follow these stages since the oligoclase rims occur both around albites of small size, controlled by the mica boundaries, and around the fully grown porphyroblasts (fig. 10). Growth of albite at the expenses of white mica is proved by the preservation of bleb-like lenses of the latter inside the blasts of albite; the chemical unbalance of this replacement is not considered here (no paragonite was revealed by X-ray check of partially albitized micaschists).

The timing of *biotite* growth may also be evaluated with respect to the white mica configuration produced by B_3, since biotite growth is mostly related to sites where white mica occurs. The commonest shape of biotite grains is platy or triangular; platy biotites overgrow single grains of white micas, mostly replacing their lattice without apparent deformation. The triangular shaped biotites grow inside cuspate spaces bounded by couples of sutured white mica individuals (*b* in fig. 8). The inner side of the triangle may touch white mica, quartz, albite, chlorite or sphene. In these cases the biotite cleavages parallel one of the surrounding white mica grains, being always straight and unaffected by the suturing process that took place across the adjacent white micas. Syn- to post-B_3 age of biotite growth is also suggested by the absence inside biotites of the deformation and recovery features occurring in the white micas as an effect of the B_3 crenulation.

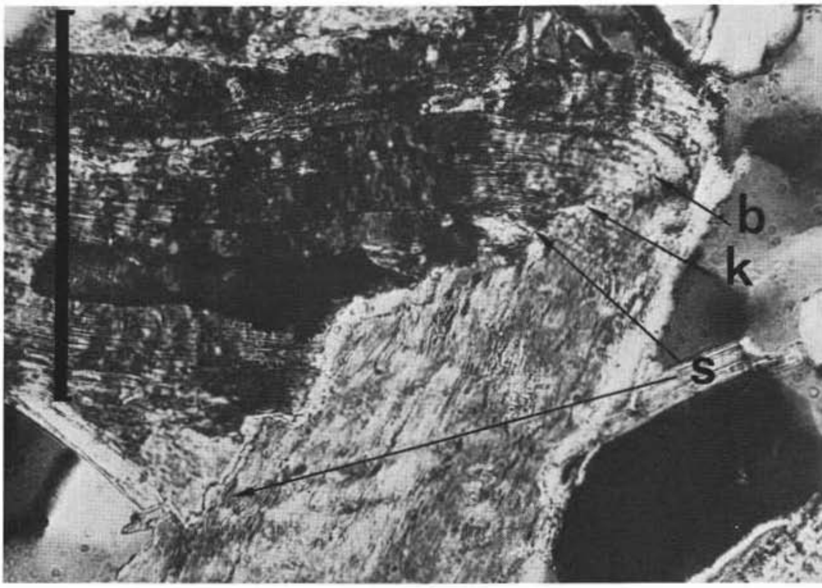

Fig. 9. — Coexisting stages of bending, kinking and suturing of kink band boundaries in a phengite grain of an eclogitic micaschist. The grain occurs in a mica-rich domain deformed during B_3 crenulation cleavage. No differentiation of a new mineral layering associated to B_3 axial plane is observed at this stage of development of the B_3 cleavage. b = bent portion of the grain, along which basal cleavage planes are continuous (stage 1 in the text); k = kinked portion without apparent migration of the kink band boundary (stage 2); s = portion of the grain which is sutured with different amplitudes (stages 3 and 4). Crossed polars; scale bar = 0.1 mm. Sample 7072.

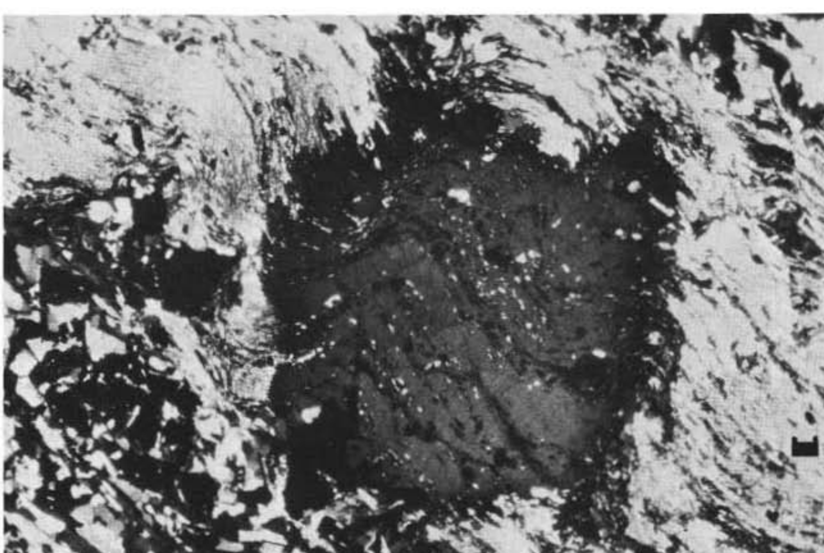

Fig. 10. — Oligoclase rim around an albite porphyroblast overgrowing B_3 crenulation of mica-rich layers of an eclogitic micaschist. Crossed polars; scale bar = 0.1 mm. Sample SL 1002.

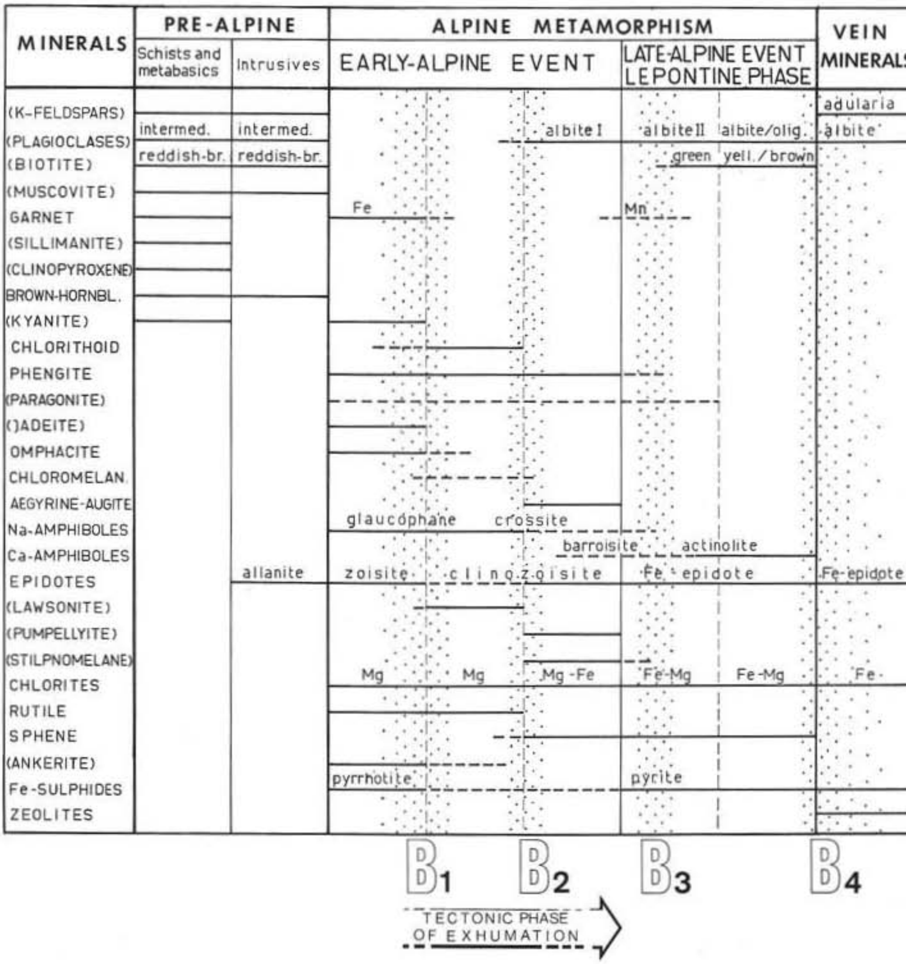

Fig. 11. — Time relationships of folding and metamorphic evolution; the petrographic grid is integrated with that from Compagnoni (1977). Horizontal time scale is only relative. Timing of fold generations is indicated as maximum and minimum ages. Minerals in brackets do not occur in the Punta Plaida Eclogitic Micaschists.

Discussion

Microstructure and metamorphism

The relations between growth of minerals belonging to different stages of the Alpine metamorphic evolution and fold generations leads to the following history for the sheet of Eclogitic Micaschists occurring at Punta Plaida.

The mineral relics of the eclogitic episode (Tab. 1) are of the same type as those well preserved in the internal part of the Eclogitic Micaschist Complex; it is then possible to relate the early-Alpine evolution of the Punta Plaida Micaschists to the scheme proposed by Compagnoni (1977); this scheme extends also to the

Lepontine event which affected all the Western border of the Sesia-Lanzo Zone (fig. 11). It has been adopted for the present paper after a joint examination with R. Compagnoni of the thin sections of the Punta Plaida rocks, which were integrated with those of the other sectors of the Sesia-Lanzo Zone.

No geochronological data are yet available as to the age of the early-Alpine pale coloured glaucophane, that is here observed to produce new grains. At the moment its development may be considered either synchronous with the eclogitization or slightly postdating it. A minimum age can however be assigned to B_1 folds since they formed at a stage in which glaucophane of the pale-coloured variety was still able to produce new recrystallised grains without retrogressive effects.

A large number of microstructures associated with B_2 folds proves that this generation of folds postdates minerals related to the eclogitic event such as garnet, Na-pyroxene, chloritoid and glaucophane. B_2 generation is related to a different metamorphic environment, as it occurs in the Punta Plaida Eclogitic Micaschists together with the beginning of the destabilization of garnet and glaucophane: their retrograde minerals are deformed by B_2 (mainly albite I and chlorite). The rims of more deep coloured glaucophane with smaller 2V values are possibly accompanying these retrograde transformations. However the destabilization of Na-bearing minerals of the high-pressure event does not appear to be extensive during B_2, since no albite contributes to form the differentiated axial plane layering of this fold generation and since passive rotation of glaucophanes into B_2 foliations is the commonest case (fig. 6).

B_2 fold generation mesoscopically folds the tectonic contacts of the Eclogitic Micaschists with the II Zona Dioritico-kinzigitica, thus proving that some of the retrogression of the eclogitic assemblages began when piling of the units was accomplished; all the fold generations postdating B_1 are then deforming a newly assembled lithostratigraphy composed of nappes carrying high-pressure metamorphic associations of various grades.

The same scheme of fold development is recorded across the tectonic contact of the II Zona dioritico-kinzigitica with the Gneiss Minuti Complex (see figs. 1 and 2); this gives an idea of the pervasivity of post B_1 folding with respect to the scale of the nappe lithostratigraphy.

The B_3 generation of folds can be related to the Lepontine metamorphic overprint, in the sense that the folding predates the formation of oligoclase rims around albite during the low pressure greenschist facies metamorphism that affects all the external border of the Sesia-Lanzo Zone. The age of 38 m.y. of this event is radiometrically recorded in biotites (Hunziker, 1974). Porphyroblastesis of albite II with frequent oligoclase rims, yellowish-brown biotite, intense chloritization and biotitization of garnets and replacement of chloritoid by white mica ± chlorite, are generally static phenomena that modify the overall texture assumed by the rocks during B_3 folding.

Tectonics and metamorphism

The geometrical analysis of the Gressoney area (Gosso, in prep.) and the microstructural observations on the Eclogitic Micaschists of Punta Plaida suggest that *the main tectonic features* (i.e. the geometrical informations needed for drawing a geological cross section) of this sector of the Sesia-Lanzo Zone *are due to* B_2 *and* B_3 *generations of folds,* which developed definitely later than the eclogitic metamorphism (see also Dal Piaz et al., 1972). They are connected with the partial transformation of the high-pressure assemblages into lower-pressure associations. This transformation evolves after B_3 into a new metamorphic event under greenschist facies conditions.

A subduction mechanism has been proposed by many writers to be responsible of the extreme P-T regime during the eclogitic metamorphism of the Eclogitic Micaschist Complex, and several tectonic models have been compiled for reconstructing the geometry of such a large scale process (see Compagnoni et al., 1977, for references). At present no large scale structures of a tectonic phase surely synchronous with the high-pressure metamorphism have been unraveled in the Sesia-Lanzo Zone, as B_1 folds do not exceed the meter scale even in the other areas where the structure has been investigated in detail (Mucrone and Bard area, P. F. Williams and K. Passchier, pers. comm.); moreover they appear to have formed after the development of the highest-pressure assemblages. As a consequence no structural data exist that can clarify the tectonic environment in the deepest stage of subduction.

A subsequent problem faced by plate tectonists is to search for a feasible mechanism capable of bringing towards the surface the subducted units and their preserved assemblages from the deep environment in which they underwent the eclogitic metamorphism. For the Sesia-Lanzo Zone such mechanism must have operated before B_3, the generation of folds that slightly predates the final temperature rise of the Alpine metamorphic cycle. B_1 and B_2 generations of folds represent in the Gressoney area the traces of the tectonic activity recorded inside the nappes during the time span in which exhumation must have occurred (fig. 11). These two fold generations appear also to be related with metamorphic conditions which are capable of preserving the high-pressure assemblages, and probably still connected with the wedge shaped thermal depression (Oxburgh and Turcotte, 1970) typical of a subduction zone.

The identity of B_1 and B_2 generation of folds with the tectonic process that translated large bodies to the surface, or if these two fold generations represent a mesoscopically recorded expression of it, must however be verified in detail, since a structural profile across the entire Sesia-Lanzo Zone showing the sense of asymmetry of B_2, or of possibly existing large B_1 folds, is not available. A sense of asymmetry of B_2 structures is however recorded in the narrow zone covered by fig. 1. This asymmetry is S-shaped if viewed towards NE (fig. 2) and suggests a fold geometry postdating the nappe emplacement which is still consistent with a subduction system dipping internally with respect to the Alpine arc. An extimate of the translational component accompanying B_2 folding such as to justify B_2 to be regarded as a later phase of nappe emplacement can not be made.

Indications concerning the pre-B_2 uplift mechanism may be gathered by reconstructing the relative position in the vertical pile, of the units of the Sesia-Lanzo Zone which suffered different grades of high-pressure metamorphism. The imbrications of the II Zona Dioritico-kinzigitica on the Gneiss Minuti Complex, and at Punta Plaida of the Eclogitic Micaschist Complex over the II Zona Dioritico-kinzigitica, must be the effect of a thrusting event capable of positioning the more deeply subducted bodies at the uppermost levels of the pile and here operating even within a single Alpine nappe as the Sesia-Lanzo Zone is. Such event of thrusting is most probably related to a tectonic process of decoupling of the type envisaged by ERNST (1975) as the mechanism responsible for the exhumation of subducted bodies.

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