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The crystalline basement of the Canavese Zone (Internal Western Alps) : new data from the area west of Ivrea (Northern Italy)

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ABSTRACT. — The Canavese Zone is a narrow tectonic unit exposed in the Internal Western Alps, between the Sesia Zone and the Ivrea Zone. This article describes the portion of the Canavese Zone that crops out at the outlet of Val d'Aosta between the villages of Fiorano and Lessolo. The Canavese Zone is bounded by the Internal and the External Canavese Lines, the last one representing the western end of the Insubric Line. In this area the Canavese Zone is composed of fault-bounded tectonic slices, which include both pre-Alpine basement and Permo-Mesozoic cover.

The crystalline basement, which is intruded by Late-Variscan granitoid rocks, consists of garnet-bearing paragneiss and two-micas schist with interlayers of orthogneiss with microaugen structure. The plutonic rocks include leucocratic granite and minor tonalite and diorite. The intrusion relationships are locally preserved, but the contact metamorphic minerals have been completely obliterated by the Alpine tectonic and metamorphic overprint. The stratigraphic cover consists of volcanics and volcaniclastics of probable Permian age, which are overlain by Triassic dolostones, Liassic polyphase breccias and Liassic red and black sandstones. The top of the sedimentary sequence consists of Liassic black shales with interbedded micritic limestones.

Three pre-Alpine deformation phases were recognized in the metamorphic basement. The second deformation phase, responsible for the main foliation, developed under low- to- medium grade metamorphic conditions, which produced Grt + Bt + Ms + Pl + Czo assemblages in metapelites and Hbl + Pl in metabasites. The Alpine tectono-metamorphic overprint developed along metric ductile shear zones at the boundary of tectonic slices and produced Prh + Pump + Act facies phyllonites.

In this portion of Canavese Zone, so far neglected by Alpine geologists, a peculiar crystalline basement was recognized and described, which is significantly different from that of both the Ivrea and Sesia Zones, but recalls the Scisti dei Laghi, or some Orobic sequences farther east.

KEY WORDS. — Canavese Zone, Structural analysis, Metamorphic evolution, Western Alps.

Le socle de la zone du Canavèse (Alpes occidentales internes) : nouvelles données sur la région située à l'ouest d'Ivrée (Italie du Nord)

RÉSUMÉ. — La zone du Canavèse est une étroite unité tectonique située dans la partie interne des Alpes occidentales, entre les zones de Sesia et d'Ivrée. Dans cet article on décrit la portion de la zone du Canavèse affleurant au débouché du val d'Aoste, entre les villages de Fiorano et de Lessolo. La zone du Canavèse est limitée par les lignes Interne et Externe du Canavèse, la dernière représentant la terminaison occidentale de la ligne Insubrienne. Dans cette partie, la zone du Canavèse est constituée de roches de socle et de couverture. Le socle métamorphique, recoupé par des roches intrusives, est composé de micaschistes gneissiques et de paragneiss à grenat avec des intercalations d'orthogneiss à structure micro-oeillée. Les roches plutoniques sont constituées de granite leucocrate, ainsi que de tonalite et diorite en quantité plus faible. Les relations entre plutonites et socle métamorphique sont localement conservées. La couverture est constituée de roches volcaniques et volcano-détritiques permiennes, recouvertes de roches calcaires triasiques - liasiques.

Trois phases de déformation pré-alpine ont été reconnues dans le socle métamorphique. La seconde, responsable de la foliation principale, s'est développée dans des conditions métamorphiques de bas à moyen degré, qui ont produit des associations à Grt + Bt

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+ Ms + Pl + Czo dans les métapélites et à Hbl + Pl dans les métabasites. L'empreinte tectono-métamorphique alpine s'est développée le long de zones métriques de cisaillement ductile, à la limite des écailles tectoniques, produisant des mylonites recristallisées dans le faciès à Prh + Pump + Act.

Cette partie de la zone du Canavèse, négligée par les géologues alpins, présente un grand intérêt pour la compréhension du socle du Canavèse, notablement différent de ceux des zones d'Ivrée et de Sesia.

Mots clés. — Zone du Canavèse, Analyse structurale, Évolution métamorphique, Alpes occidentales.

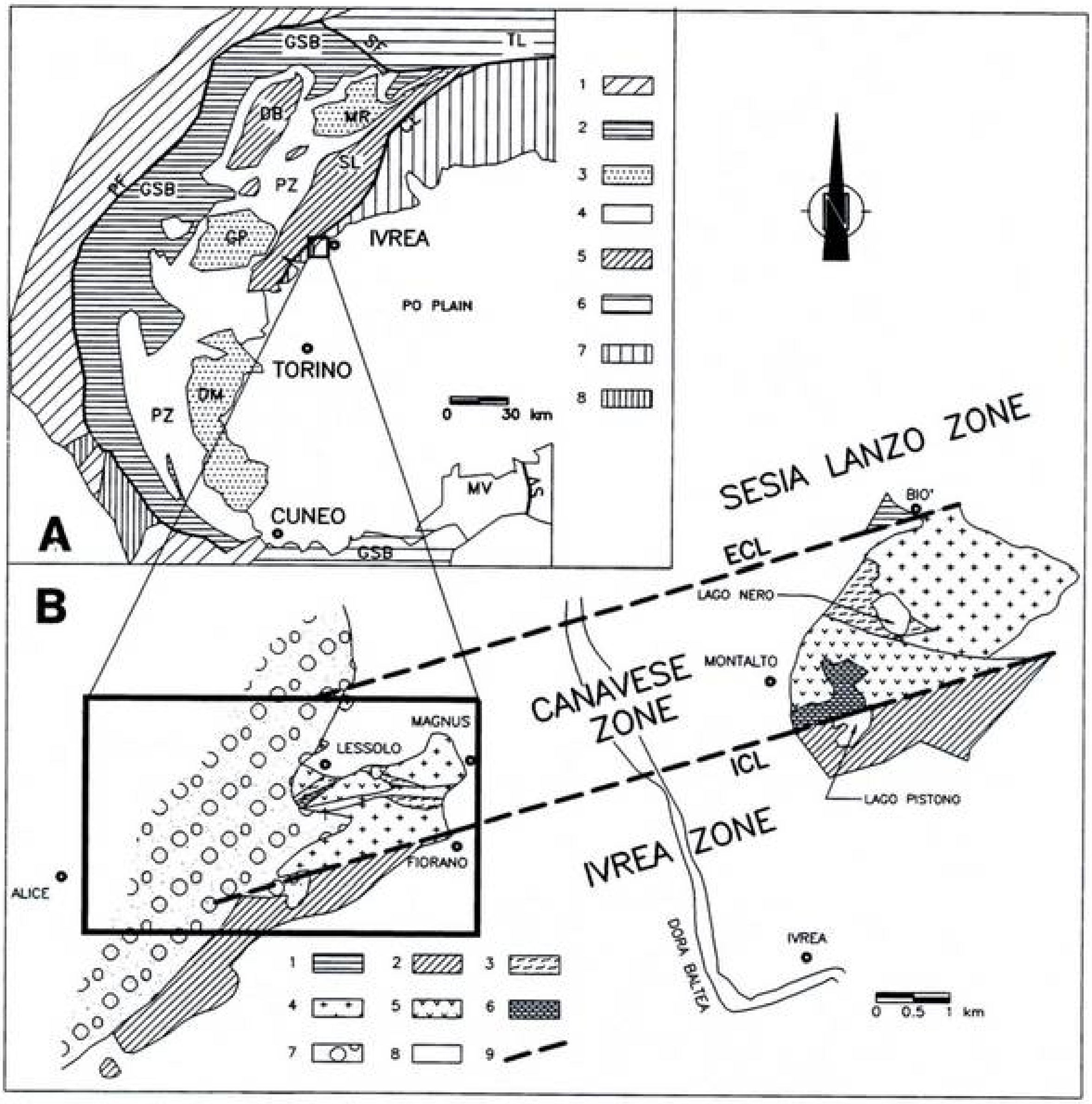

FIG. 1. – Simplified tectonic sketch map of the Western Alps.

A = 1 : Helvetic Domain ; 2-4 = Penninic Domain ; 2 : Briançonnais-Grand St. Bernard Zone (GSB). 3 : Internal Penninic Nappe (MR : Monte Rosa, GP : Gran Paradiso, DM : Dora-Maira) ; 4 : PZ : Piemonte Zone, MV : Voltri Massif. 5 : Austroalpine Domain (DB : Dent Blanche nappe, SL : Sesia-Lanzo Zone). 6 : Lower Penninic Nappes of the Ossola - Ticino area. 7 : Southalpine Domain. 8 : Allochthonous Flysch of Cretaceous to Eocene age. PF : Penninic frontal thrust ; SF : Simplon Fault ; CL : Canavese Line ; TL : Tonale Line ; SV : Sestri-Voltaggio Line. B = 1 : Sesia - Lanzo Zone ; 2 : Ivrea Zone ; 3-6 : Canavese Zone ; 3 : Pre-Alpine metamorphic basement ; 4 : Late - Palaeozoic plutonic rocks ; 5 : Permian volcanics ; 6 : Triassic to Liassic sedimentary cover ; 7 : Moraine deposits ; 8 : Alluvial and fluvioglacial deposits ; 9 : Tectonic line (ICL = Internal Canavese Line, ECL = External Canavese Line). The framed areas correspond to the enlarged map of figure 2.

1. – Introduction

The Periadriatic or Insubric Line is a main tectonic lineament in the Alps. It separates the rocks of the Southern Alps, which escaped Alpine ductile deformation and metamorphism, from the Penninic and Austroalpine domains, which were more deeply involved into the Alpine orogeny [e.g. Schmid *et al.*, 1989, with ref.]. The southwestern portion of the Insubric Line is named Canavese Line and separates the pre-Alpine granulite-facies rocks of the South-Alpine Ivrea Zone from the Alpine eclogite-facies rocks (« Eclogitic Micaschist Complex ») of the Austroalpine Sesia Zone. Between the Ivrea and Sesia Zones, a narrow tectonic unit is interposed, long since known as Canavese Zone [e.g., Argand, 1910]. It consists of a sheared and dismembered sequence, which includes pre-Alpine granitoids, Permian felsic volcanics and Mesozoic sediments. On both sides the Canavese zone is bounded by two parallel straight tectonic lines, which were named by Biino and Compagnoni [1989] External Canavese Line (ECL) and Internal Canavese Line (ICL), respectively (fig. 1). The two lines have different tectonic and metamorphic characters and ages : the ECL, the true southwestern end of the Insubric Line [corresponding to the South Canavese Line of Boriani and Sacchi, 1974], is a recent tectonic feature of brittle character ; the ICL is an older tectonic discontinuity, which developed under prehnite-pumpellyite-actinolite facies conditions.

In spite of the great interest devoted to the Canavese Line and the Canavese Zone by the Alpine geologists, most studies mainly deal only with the Permian and Mesozoic cover. The crystalline basement, mostly consisting of plutonic intrusive rocks, was usually ignored [e.g., Ahrendt, 1972] or considered as part of the Ivrea Zone [Baggio, 1965a].

Because the knowledge of the Canavese Zone is of great importance in the interpretation of the movements along the Insubric Line and of the Alpine palaeogeographic evolution, we started a systematic investigation of the Canavese Zone, mainly oriented to identify the characteristics of the crystalline basement [Biino *et al.*, 1988 ; Biino and Compagnoni, 1989]. This article is devoted to the sector between Lessolo and Fiorano, west of Ivrea, an area so far neglected by scientists, but where both igneous and metamorphic rocks of the crystalline Canavese basement are comparatively well exposed and preserve primary intrusive relationships.

2. – Previous studies and geologic setting

The Canavese zone is exposed between Torrente Malone and the Serra d'Ivrea and mainly consists of granitoids, Permian rhyolites and a Mesozoic cover (see, e.g., Sheet « Ivrea » N. 42 of the Geological Map of Italy at the scale 1 : 100 000). There is a general agreement that the Canavese cover consists of Permian volcanics and volcaniclastics and Mesozoic sedimentary rocks, originally dated by Issel [1893] by analogy with the Triassic limestones of Villanova.

Only Novarese [1893] quoted the occurrence in the Canavese Zone, near Belmonte, of chloritoid-bearing micaschists (« scisti a sismondina »), a possible representative of the crystalline basement. However, this lithotype was no longer mentioned in a later exhaustive monography on the Canavese Zone [Novarese, 1929], to which we refer for the previous references.

Baggio [1963, 1965a, 1965b], Elter *et al.* [1966] and Wozniak [1977] consider the Canavese Zone as part of the Southern Alps (Ivrea Zone) and consequently trace the Periadriatic Line to the external side of the Canavese Zone, between the Sesia and the Canavese Zones. Baggio [1965a] describes the Canavese crystalline basement as consisting of Ivrea mafic and felsic intrusive rocks with subordinate, mostly retrogressed, garnet-bearing micaschist and paragneiss. The Canavese Line is considered by Baggio [1965b] as a bundle of subparallel fractures and is traced between the Ivrea and the Canavese zones. According to Elter *et al.* [1966], the Canavese Zone is bounded by two tectonic contacts, the main one being located between the Canavese basement and the Sesia Zone.

Ahrendt [1972] considers as « not metamorphic » the sedimentary rocks of the Canavese Zone, but recognizes that both the Canavese and the Ivrea zones were « affected by similar deformation phases ». The Canavese Line is traced at the internal side of the Sesia Zone. Along this line an uplift of the Sesia Zone relative to the Canavese and Ivrea Zones of at least 3.5 km since the Oligocene is envisaged. Ahrendt [1972] and Scheuring *et al.* [1974], which proved the Oligocene age of the trachy-andesite cover of the Sesia Zone, surprisingly trace the Canavese Line between the Sesia Zone and its volcanic Oligocene cover. This view is later reaffirmed by Ahrendt [1980]. Aubouin *et al.* [1977] consider the Canavese Zone as the suture of the Piemontese palaeo-ocean, i.e. the basin separating the Palaeo-European margin from the Adria plate.

Baggio [1965a, 1965b] gives the first correct microscopic description of the metamorphic rocks near Montalto, but ascribes them, together with the granites, to the Ivrea Zone. Elter *et al.* [1966], Ahrendt [1972], Wozniak [1977] and Biino [1985] report the presence of a peculiar Canavese metamorphic basement and describe new occurrences of probably pre-Alpine metamorphics, but do not clarify their relationships with the associated intrusive rocks. The scarcity of studies on the Canavese basement showed undeniable resulted evident in a general report on the pre-Alpine metamorphism of the Alps [Boriani *et al.*, 1974, p. 163-225], where for the first time a possible resemblance between the Canavese and the South Alpine Strona-Ceneri gneiss was suggested. However, the Canavese lithologies are intensely mylonitized, forming part of the Insubric mylonite belt of Schmid *et al.* [1987], and their exact position with respect to the adjacent Ivrea Zone is obscured by the Alpine tectono-metamorphic overprint. More recently, Biino and Compagnoni [1989] described in the Canavese Zone between Montalto and Biò, east of Ivrea, the occurrence of igneous and metamorphic rocks, which they ascribe to a peculiar crystalline basement, significantly different from those of the two tectonically juxtaposed Sesia and Ivrea Zones.

In the area between Lessolo and Fiorano, the only Canavese lithotype reported in the geologic literature [Issel, 1893 ; Spitz, 1919 ; Novarese, 1929 ; Baggio, 1965a ; 1965b ; Elter *et al.*, 1966 ; Ahrendt, 1972, Wozniak, 1977] is a dolomitic limestone, which was formerly worked in the two Lessolo quarries. The other Canavese lithologies were mostly neglected or mistaken with the Ivrea rocks. This is apparent in the 1 : 100 000 Geological Map of Italy (Sheet 42, Ivrea) surveyed by Franchi [1905], where « amphibole-pyroxene diorite » (actually a mafic granulite) and « kinzigite and sillimanite gneiss » (i.e. high-grade paraschists) of the Ivrea Zone are reported between Colleretto and Lessolo, and the « Canavese Series » is only represented by a small outcrop of « granite » exposed north of Lessolo and by a layer of « dolomitic limestones » in the Lessolo quarries.

3. – Geology and Petrography

A new 1 : 5 000 geological map of the area between Lessolo, Magnus and Fiorano was produced [Naldi, 1987], from which the presence of two contrasting tectonic zones was recognized. The two zones are divided by a NE-SW trending tectonic contact, which may be followed from the Church of Fiorano up to N of Case Garella, where it disappears under morainic deposits (fig. 2). This tectonic conctact is the Internal Canavese Line (ICL) of Biino and Compagnoni [1989]

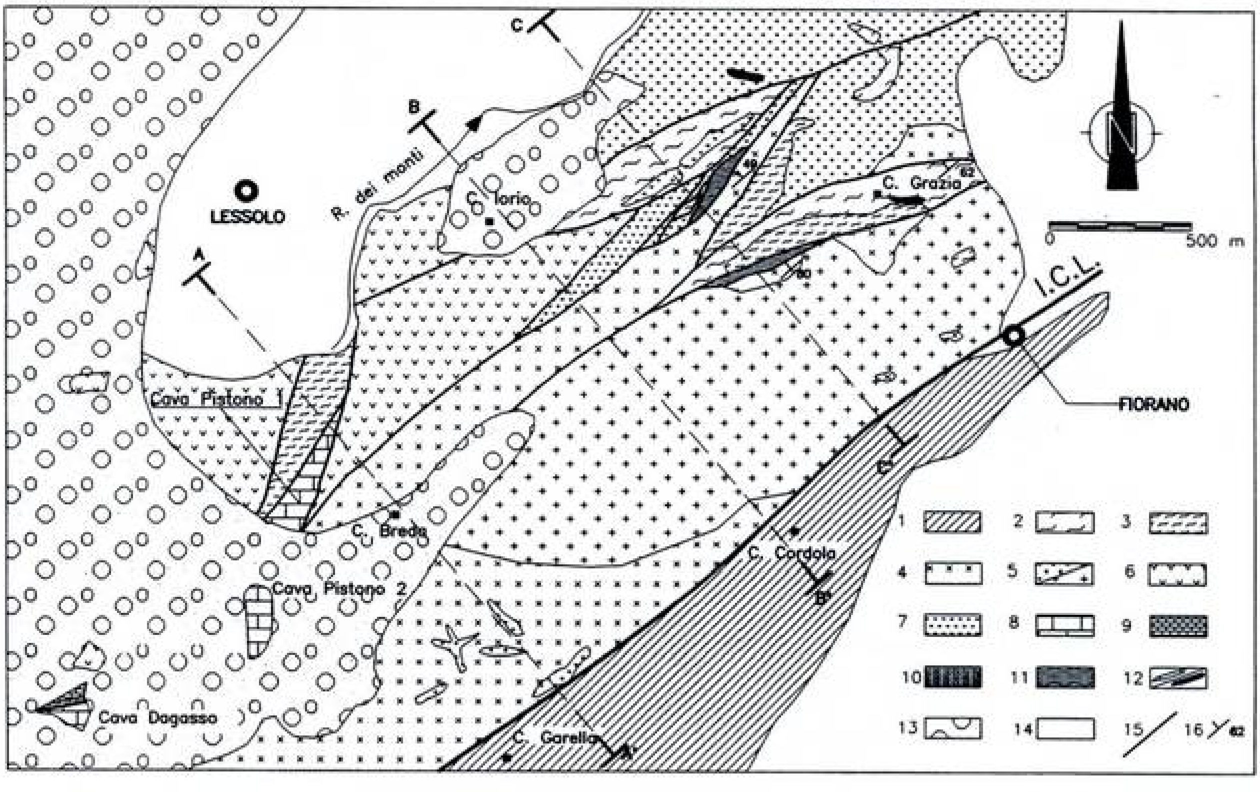

FIG. 2. – Geologic sketch map of the Canavese Zone between Fiorano and Lessolo.

1 : Ivrea Zone. 2-12 : Canavese Zone. 2 : Garnetiferous gneiss and micaschist ; 3 : Two-mica para-gneiss ; 4 : Diorite ; 5 : Two-micas leucogranite (small crosses) and biotite granite (large crosses) ; 6 : Massive and sheared rhyolite and andesite (Permian in age) ; 7 : Volcaniclastic breccia, consisting of centimetric rhyolitic clasts, more or less sheared by the Alpine tectonics (Permian in age) ; 8 : Grey dolostones and dolomitic limestones (probably of Middle Triassic age) ; 9 : Tectonic - sedimentary breccia of "Macchia vecchia" type with polyphase arenaceous-carbonate cement and clasts of red micritic limestone and arenaceous limestone (Lower to Middle Liassic) ; 10 : Red and black sandstones (Lower Liassic) ; 11 : Dark shales with local cm- to dm-thick boudinaged interlayers of limestones (probably of Middle Jurassic age) ; 12 : Andesitic (black), and granitic, leucogranitic and pegmatitic (white) dykes ; 13 : Morainic deposits ; 14 : Alluvial and fluvioglacial deposits ; 15 : Tectonic lines (ICL : Internal Canavese Line). 16 : Dip symbols refer to the shear zones of Alpine age.

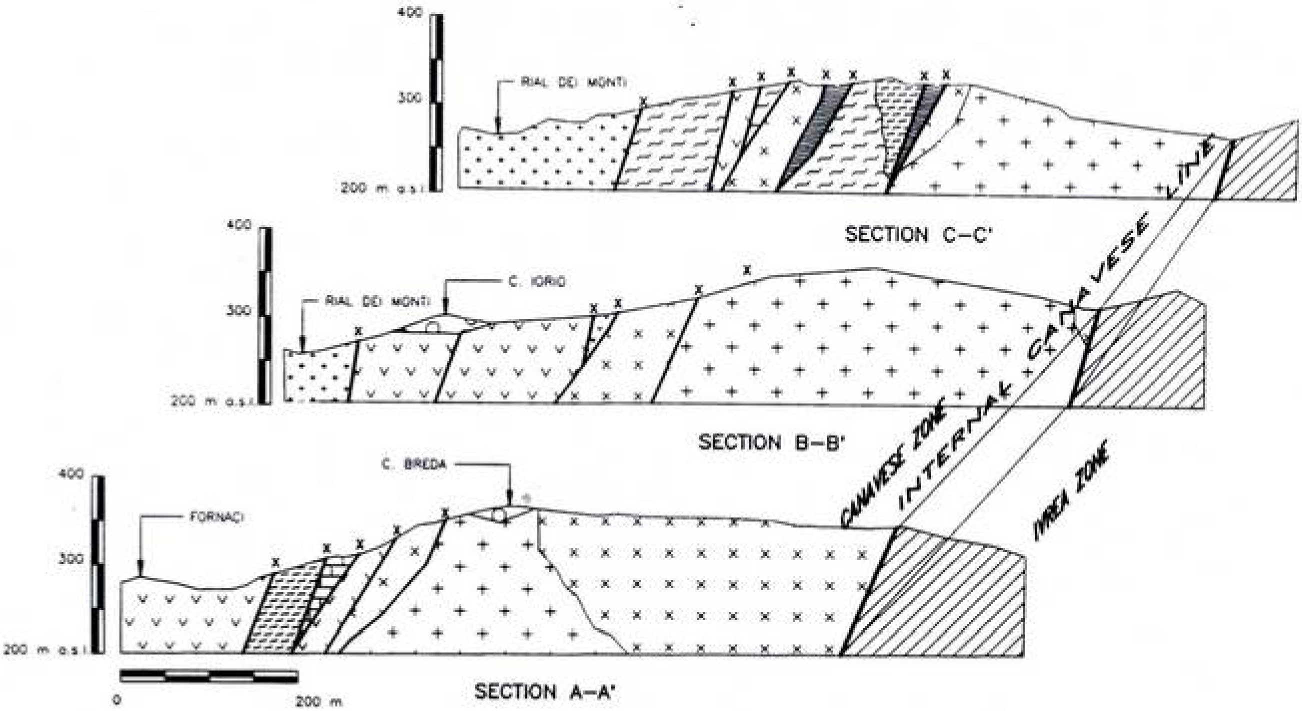

FIG. 3. – Interpretative geological cross sections of the Canavese Zone between Fiorano and Lessolo. Symbols as in figure 2. The main tectonic contacts (heavy lines) are NE-SW trending and steeply dipping to NW (parallel to the ICL). The regional Variscan foliation is truncated by the Alpine structures.

and is marked by mylonites of low- to very-low grade. The external tectonic boundary of the Canavese Zone, - i.e. the « External Canavese Line » (ECL) - is hidden under morainic deposits.

The new geologic survey of the areas between Lessolo and Fiorano has shown that the Canavese Zone consists of subvertical tectonic slivers trending roughly parallel to the ICL (fig. 2), which include both a crystalline basement and a cover. The basement consists of pre-Permian fine-grained metamorphics and medium-grained intrusives, and the cover includes Permian volcanics and Mesozoic sedimentary rocks. The recognized tectonic slivers may consist of one or more basement and/or cover lithologies (fig. 2). Interpretative geological cross sections of the Canavese Zone between Lessolo and Fiorano are shown in figure 3.

3.1. The metamorphic basement

As shown in the simplified geologic map of figure 2, the metamorphic rocks crop out within prevailing plutonic rocks, which form large bodies elongated parallel to the ICL and bounded by roughly vertical tectonic contacts.

The **metamorphic basement** consists of fine-grained **garnet-bearing gneiss** and **micaschist** with garnet, biotite and subordinate white mica, **two-micas gneiss** which includes small lenses of **metabasite**, and **orthogneiss** with microaugen structure.

The **garnet-bearing gneiss** and **micaschist** form individual tectonic slices near Case Grazia, Case Iorio, and small fragments included in the granitic slice exposed north of Case Grazia (fig. 2). In the core of the slices, the garnetiferous gneiss is brownish in colour and shows a pervasive foliation, typically marked by cm- to dm-long intrafolial quartz stringlets. Frequently, veins of Fe-rich epidote parallel to the rock foliation also occur. Close to tectonic contacts, the pre-Alpine gneiss is progressively sheared and converted to an Alpine phyllonite, which is greenish in colour for the widespread development of chlorite. The garnetiferous gneiss and micaschist show a planar foliation, defined by alternating layers rich in quartz + feldspar and white-mica + biotite + garnet, respectively (fig. 4). Two mineral assemblages may be recognized : the older assemblage, considered as pre-Alpine in age, consisted of quartz, plagioclase, biotite, pale greenish muscovite, garnet, clinozoisite and accessory apatite, rutile, allanite, ilmenite and opaque minerals ; the younger assemblage, most likely Alpine in age, consists of albite after plagioclase, chlorite after garnet and biotite, and newly-grown green biotite, sericitic white mica, prehnite and pumpellyite. The garnet porphyroclasts, embedded in sericitic layers, exhibit pressure shadows filled with quartz and

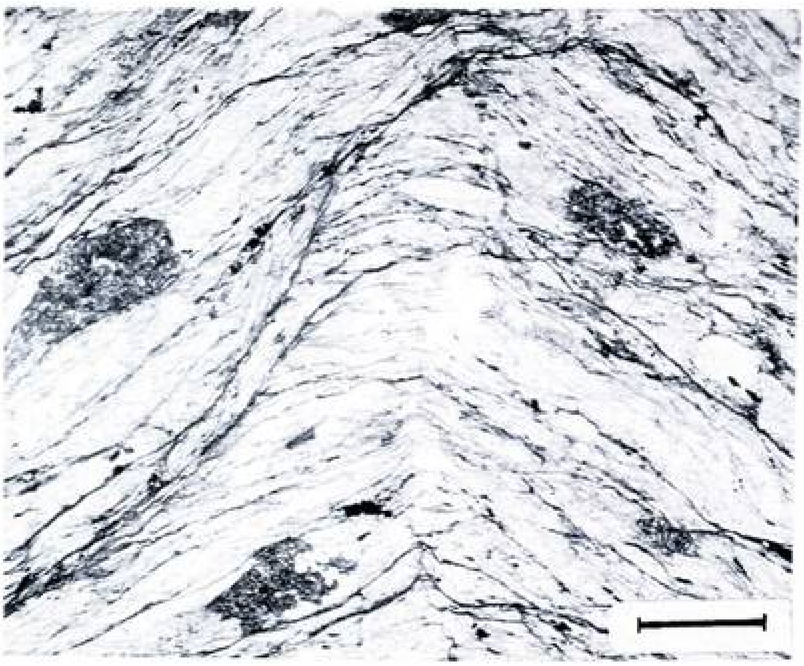

FIG. 4. – Photomicrograph of a garnet-bearing micaschist of the Canavese basement (ZC 255). A pre-Alpine foliation defined by muscovite preferred orientation and by garnet porphyroclasts is deformed by Alpine centimetric open folds and dark microshear planes. Plane polarized light. Scale bar = 1 mm.

biotite. Usually, the garnet contains a S_i, discordant to S_e and defined by the alignment of small quartz inclusions. The sheared rock types mainly consist of very-fine grained quartz, chlorite and sericite, but still preserve relics of garnet.

The **two-micas gneiss** makes up the slice bounding Cava Pistono 1 (fig. 2) and part of the slice of Case Grazia (where it is associated with the garnet-bearing gneiss) and a few xenoliths in the granitic slice north of Case Grazia (fig. 2). The two-micas gneiss is distinguished from the garnet-bearing gneiss by its greenish colour, a less pervasive gneissic foliation and by the absence of the intrafolial quartz stringlets. The two-micas gneiss shows a planar foliation defined by quartz and feldspar domains alternating with white mica domains, chloritized biotite and minor quartz. Garnet is lacking or accessory. The original, pre-Alpine assemblage consisted of plagioclase - now mostly altered to albite, sericite and epidote -, quartz, biotite, and white mica. The accessory minerals are titanite, apatite, allanite, zircon and opaques. The neoblastic Alpine minerals include albite, chlorite, pumpellyite, Fe-free and Fe-rich epidote and recrystallized quartz. The phyllonites, developed at the expense of this gneiss, mainly consist of very fine-grained sericite, chlorite and quartz. Under the microscope the phyllonites show a network of conjugate shear planes, rich in sheet silicate (P domains), which split the rock in lens-like domains, mainly consisting of quartz or albite + quartz (Q domains).

The dm-thick of a greenish, roughly foliated, **metabasite** was found within the two-micas gneiss of Case Grazia. The rock appears as a mylonite, characterized by oriented chlorite, which envelops submillimetric lens-like domains of albite and minor porphyroclastic hornblende. The accessory phases are opaque minerals and rare carbonate minerals.

The **orthogneiss** with micro-augen texture crops out east of Case Iorio (fig. 2). It is light grey in colour and exhibits a typical augen fabric with millimetric K-feldspar porphyroclasts. In thin section, the orthogneiss consists of both K-feldspar and minor plagioclase phenoclasts, and polycrystalline aggregates of the two minerals, included in a foliated matrix of quartz, albite, K-feldspar and white mica. The accessory phases are apatite, minor opaques and rare zircon. The Alpine overprint mainly produced plagioclase retrogression to sericite and development of chlorite around opaques.

In the two-micas gneiss of Case Grazia, a dm-thick layer of a **hololeucocratic gneiss** occurs. The rock exhibits a rough foliation defined by quartz + albite aggregates with preferred dimensional orientation and oriented white mica flakes. For its occurrence and mineralogy, this gneiss is considered to derive through transposition and metamorphism from an original pre-Alpine aplitic dyke.

An outline of mineral parageneses characteristic of the main metamorphic stages of the evolution of the Canavese Zone is reported in figure 5.

3.2. The plutonic rocks

The igneous rocks, intrusive into the metamorphic basement, consist of dioritoids with hornblende, clinopyroxene and local orthopyroxene, and granitoids.

The **dioritoids** crop out between Case Cordola and Case Iorio. Near Case Garella, the dioritoids are crosscut by granitic and aplitic dykes. They are dark-brown on weathered surface and massive. Black amphibole and light green altered plagioclase may be recognized on hand specimen. Unlike the mafic granulites of the adjoining Ivrea zone, for which they have been so far mistaken, the dioritoids do not show a compositional layering, but the distinction is not easy in the field owing to the presence of the Alpine tectono-metamorphic overprint. On the ground of mineral mode, the dioritoids range in composition from gabbrodiorite through quartz-bearing diorite to tonalite. The rocks are hypidiomorphic and consisted of plagioclase, clinopyroxene, orthopyroxene, green hornblende, biotite, local quartz and accessory apatite and zircon. Myrmekitic intergrowths locally occur. The Alpine metamorphic retrogression converted the plagioclase to a felt of sericite + spongy epidote ; the clinopyroxene to actinolitic amphibole ; the orthopyroxene to chlorite + serpentine ; the biotite and the hornblende to chlorite. Locally, patches of pumpellyite, blasts of prehnite within biotite, and Fe-rich epidote rims around opaque minerals also occur.

All over the studied area, two types of **granitoids** were recognized : a biotite leucogranite and a two-micas leucogranite (fig. 2). The **biotite leucogranite,** largely exposed north of Fiorano, is usually medium grained and light greyish to greenish in colour, this being related to biotite chloritization. It shows a hypidiomorphic fabric and consists of K-feldspar, plagioclase, quartz, biotite and accessory apatite, zircon and opaques. As in diorites, myrmekite developed at the K-feldspar-plagioclase contacts. The Alpine metamorphic overprint produced prehnite, pumpellyite and chlorite from biotite, albite from K-feldspar, spongy clinozoisite and sericitic white mica from plagioclase, and titanite. Stilpnomelane tufts commonly occur in albite. Close to tectonic contacts, the granite becomes cataclastic and a significant grain-size reduction of the magmatic minerals is observed.

PRE-ALPINE BASEMENT (micaschists, orthogneisses and metabasites)	METAMORPHIC EVOLUTION OF CANAVESE ZONE		
PARAGENESES MINERALS	Magmatic	Pre-Alpine	Alpine
QUARTZ	——	——	——
PLAGIOCLASE	—— Olig	——	—— Ab
K- FELDSPAR	——		
BIOTITE	——	——	—— green
WHITE MICA	——	——	—— sericitic
GARNET		——	
EPIDOTE		—— Czo	——
ILMENITE	——	——	
CHLORITE			——
PREHNITE			——
PUMPELLYITE			——
RUTILE		——	
AMPHIBOLE		—— Hbl	—— Act

FIG. 5. – Mineral parageneses characteristic of the main metamorphic stages of the evolution of the Canavese Zone.

The **two-micas leucogranite** is exposed in the eastern sector of the considered area, south of Magnus (fig. 1). It is easily distinguishable by its whitish colour and the presence of millimetric muscovite flakes. It is hypidiomorphic and consists of K-feldspar, plagioclase, quartz, white mica, biotite, and accessory apatite, rare zircon, xenocrystic garnet, and very rare opaques. The Alpine metamorphic minerals are chlorite after biotite, albite after K-feldspar, and sericite after the plagioclase core.

The granitoids contain both **xenoliths** of dioritoids and metamorphic rocks, and **autoliths** of **mafic cumulates**. The diorite xenoliths occur as clusters of cm- to dm-sized angular pieces clearly intruded and fragmented by the host granite. The **metamorphic xenoliths** are usually dm-sized fragments of garnetiferous gneiss, similar to that exposed in the tectonic slice of Case Grazia. The **mafic cumulates** are fine grained and consist of alternating layers rich in brown hornblende, plagioclase or red biotite, respectively, with accessory apatite and zircon.

3.3. The Permian volcanic and volcaniclastic cover

The volcanics were firstly described in this sector by Novarese [1929], which quoted the only presence of andesite near the Lessolo quarry. Actually, volcanics are much more widespread : the whole area between the Lessolo quarries and the Magnus granite consists of volcanic and volcaniclastic rocks, ranging in composition from **andesite to rhyolite,** through **trachy-andesite**. In the tectonic slice east of Case Iorio, a volcanic breccia composed of fragments of rhyolite, with ignimbritic structure, and andesite was also recognized. The **rhyolite** crops out on the southeastern side of Rio dei Monti, east of Cava Pistono. The rhyolite shows a oligo- to meso-porphyritic texture with phenocrysts of corroded quartz, locally glomero-porphyritic euhedral plagioclase, K-feldspar, biotite completely replaced by white mica, and accessory apatite, zircon and opaque minerals. The lava groundmass is wholly replaced by a foliated sericitic felt, in which small laths of altered feldspars may be recognized locally.

The **trachy-andesite,** usually reddish in colour, crops out all over the studied area. It exhibits a microporphyritic structure with phenocrysts of plagioclase, showing normal discontinuous zoning, K-feldspar, quartz, ilmenite, chloritized orthopyroxene and accessory opaques, apatite, titanite and zircon. The groundmass, originally with pilotaxitic texture, is mostly devitrified, as suggested by the presence of spherulitic textures. A very fine-grained dispersion of hematite is responsible for the reddish colour. Black and varicoloured (mainly red and green) andesites were also recognized in places.

The **volcaniclastic rocks** are exposed east of Case Iorio in a small tectonic slice pinched between metamorphic rocks. They consist of mm- to cm-sized subangular fragments of rhyolite with ignimbritic texture and andesite included in a very fine-grained matrix, where only chlorite and sericite may be recognized. Some volcanic fragments are crosscut by quartz veins of probable late-magmatic origin.

The Alpine deformation completely erased the primary relationships between the crystalline basement, the volcanic rocks and the sedimentary cover. However, the presence of **andesite dykes** crosscutting the basement and a comparison with similar lithologies better preserved in other sectors of the Canavese Zone suggests that the volcanic sequences is the stratigraphic Permian cover of the crystalline basement.

3.4. The Mesozoic cover

The best Mesozoic sedimentary sequence is exposed in the Lessolo quarries, known in the literature as Cava Dagasso and Cava Pistono (fig. 2). **The sedimentary cover**, long since known [Issel, 1893], is the only portion of the Canavese Zone between Lessolo and Fiorano extensively described in the geological literature. It includes Triassic dolomitic limestones [Spitz, 1919], a Liassic polyphase pink sedimentary breccia, and red and black sandstones of probable Liassic age. In a small tectonic slice, pinched between metamorphic and plutonic rocks, black slates with interbedded limestones of possible Liassic age have been discovered as well. All lithologies suffered the effects of the Alpine tectonic and metamorphic re-equilibration under prehnite- pumpellyite- actinolite facies conditions.

4. – Metamorphic and structural evolution

From field and microscopic data it is clears that the investigated rocks experienced at least two different tectono-metamorphic events. The older one, recorded only in the metamorphic basement rocks, is characterized by low-medium grade mineral assemblages, consisting of biotite, garnet and sodic plagioclase in gneiss, and green hornblende and calcic plagioclase in metabasic rocks. Locally, these regional metamorphic mineral assemblages appear to have been overprinted by a thermal recrystallization, mostly obliterated by the later Alpine retrogression. This thermal overprint is especially clear in the micaschist exposed near Case Grazia, which contains sericitic pseudomorphs probably after contact andalusite. The intrusives, which were emplaced during the latest phases of the Variscan orogeny [see Hunziker *et al.*, 1992, with ref.], indicate that the tectono-metamorphic event responsible for the development of the basement metamorphism must be Variscan, or even older, in age. On the contrary, the second tectono-metamorphic event, characterized by the development of subvertical NE-SW trending shear planes and accompanied by Prh + Pump facies metamorphic overprint is Alpine in age.

4.1. Variscan evolution

The presence in the studied area of relics of pre-Alpine structures and mineral assemblages enables to recognize in the metamorphic rocks of the Canavese basement three major deformation phases : a F_{v1} (early-Variscan foliation), defined by isoclinally folded quartz and epidote stringlets and transposed by the main Variscan foliation, F_{v2}, which is in turn deformed by a third deformation phase, F_{v3}.

Foliation F_{v1} is difficult to be identified in the field, because it was mostly obliterated by the transposition foliation F_{v2}. However, the frequent occurrence of intrafolial folds points to the presence of a mineralogic layering older than the regional foliation. Furthermore, garnets of metapelites contain an S_i, defined by alignments of quartz grains, discordant to S_e, i.e. F_{v2}, which is the main regional foliation in the area and is syn-kinematic with respect to the main pre-Alpine, most likely Variscan, metamorphic event. It is clear from the diagram of figure 6 that the regional foliation F_{v2} is steeply dipping and is characterized by a N-S distribution of the foliation poles, with a maximum concentration oriented around 75° => N 5° E. Therefore, F_{v2} is oblique to the main Alpine tectonic alignment, represented by mylonitic shear zones oriented NE-SW (cf. fig. 2 and 3). The deformation phase F_{v3}, characterized by chevron-type metric folds, is not accompanied by the development of a new foliation and new minerals. As reported above, meta-aplitic dykes are boudinaged, transposed and parallelized to the foliation F_{v2}. The

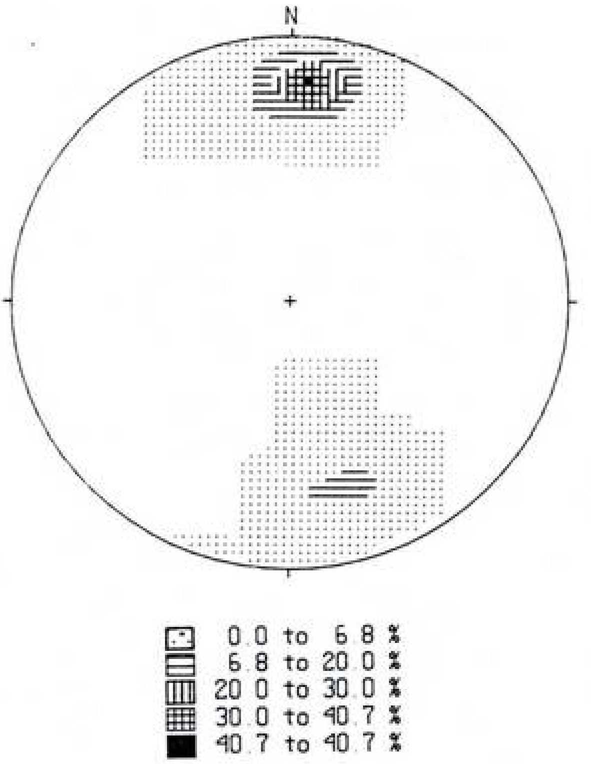

FIG. 6. – Distribution of the main Variscan foliation (S_{v2}) in the Fiorano - Lessolo area of the Canavese Zone. The foliation poles are plotted in the Schmidt equal-area grid. The maximum frequency is oriented N-S, oblique with respect to the main tectonic alignments of Alpine age.

foliation of meta-aplitic dykes is consistent with that of the surrounding gneiss and no evidence of older foliations or folds is found. Therefore it may be suggested that the granitic protoliths, from which both meta-aplitic dykes and micro-augen gneiss derive, were emplaced before the transposition event, responsible for F_{v2}, but later than F_{v1}.

4.2. Alpine evolution

The most obvious effect of the Alpine deformation is the development of mylonitic shear zones bounding the subvertical NE-SW trending lens-like tectonic slices. The mylonitic zones, ranging in thickness from a few decimeters to about 10 m, show a marked foliation F_{A1} (Alpine foliation), whose characters change depending on the involved lithology.

The mylonitized diorites are reddish brown in colour and show a marked foliation. The mylonitized volcanics are purple and show a foliation defined by white mica, which separates mm-thick microlithons of poorly deformed rock (fig. 7). In such mylonites, shear zones cross-cutting the mylonitic foliation are very obvious. These microshear zones, arranged « en echelon », cut the main mylonitic foliation and rotate into it. In the Liassic shales, the main foliation is mylonitic and the interbedded limestones show calcite veins isoclinally folded and parallelized to the main foliation. In the pre-Alpine basement, the Alpine mylonitic deformation produced phyllonites green in colour owing to the widespread occurrence of chlorite. The Alpine mylonitic bands are subvertical and may plunge both to SE and to NW. In the metabasites, the Variscan assemblage is overprinted by very-low grade minerals (Pl is replaced by Prh and Hbl is retrogressed to actinolitic amphibole and to Chl + Pump).

The mylonitic foliation F_{A1} is deformed by cm- to dm-sized asymmetric open folds F_{A2}, with sub-horizontal axes and sub-vertical axial planes directed NNE-SSW. In the Liassic shales these folds may produce closely-spaced crenulation cleavage.

Since this mylonitic deformation overprinted the whole Canavese, Mesozoic rocks included, it fellows that it must be of Alpine age.

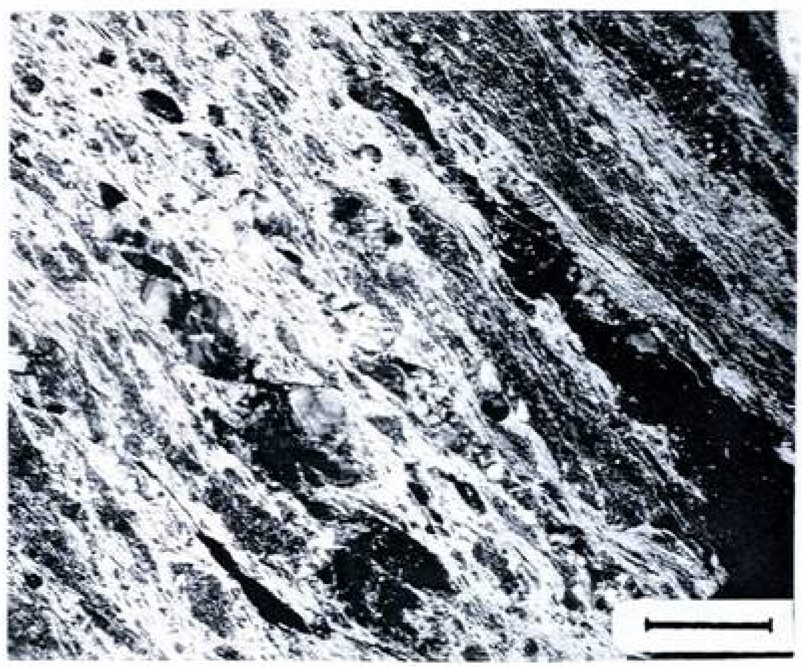

FIG. 7. – Microphotograph of a mylonite derived through Alpine deformation from a Permian rhyolite (ZC 273). Note the protomylonite with K-feldspar phenoclasts (in black), which grades to a sericite - chlorite - quartz phyllonite. Crossed polarized light. Scale bar = 0.5 mm

5. – Discussion and conclusions

In the geologic literature the crystalline basement of the Canavese Zone has been usually mistaken for that of the adjoining Ivrea Zone [Baggio, 1963 ; Elter *et al.*, 1966 ; Wozniak, 1977], or was interpreted as representing an independent tectonic unit forming the root of the Austro-Alpine nappes [Argand, 1910]. In this paper, field, petrographic and structural data were provided, which unambiguously show the existence west of Ivrea of a pre-Alpine crystalline basement belonging to the Canavese Zone, consisting of metamorphic rocks intruded by late-Variscan granitoids. This metamorphic basement is peculiar to the Canavese Zone and differs significantly from both the Sesia and the Ivrea Zones, as was reported by Biino *et al.* [1988] in the area east of the Dora Baltea river.

The pre-Alpine metamorphic rocks exhibit a main foliation which is the result of the transposition of an older foliation, as shown by the presence of intrafolial isoclinal folds. This event also deformed the original contacts between different metamorphic lithologies. In particular, the orthogneiss is isoclinally folded together with the surrounding garnetiferous metapelites, and the axial plane foliation is consistent in the two lithotypes. A further evidence for this isoclinal folding is shown by the boudinaged hololeucocratic gneiss (derived from a primary aplitic dyke), which is interlayered within the biotite paragneiss. Therefore, it may be concluded that igneous protoliths of both the orthogneiss and the hololeucratic gneiss (their dyke swarm), intruded into a metamorphic basement, were later deformed and metamorphosed most probably during the Variscan orogeny.

This metamorphic basement was later intruded by late-Variscan plutonic rocks, ranging in composition from gabbrodiorite to granite. The primary intrusion relationships are suggested by the preservation of the original intrusive contact and by the presence, within the granitoids, of large xenoliths of foliated and metamorphic rocks. This is further supported by the widespread occurrence of granitic and aplitic dykes crosscutting the metamorphic basement. The presence of diorite xenoliths within the biotite granite and the dykes of the two-micas granite, which cross cut both dioritoids and biotite granite, suggest the following intrusion order : diorite and tonalite => biotite granite => two micas granite. The pre-Alpine geological setting of the Canavese crystalline basement is summarized in the cartoon of figure 8.

In conclusion, the metamorphic evolution of the Canavese basement is characterized by a pre-Alpine low-medium grade metamorphic event associated to a pervasive ductile deformation of unknown age, but certainly pre-dating the Late Palaeozoic magmatism, followed by a second Alpine metamorphic event of very-low grade, associated with a mylonitic deformation, which affected both the basement and the Permian to Liassic cover. This second metamorphic event was dated from 60 to 76 Ma by Zingg *et al.* [1976] and by Zingg and Hunziker [1990]. Therefore, the Canavese Zone shows a tectonometamorphic history quite different from that which affected both the Sesia and the Ivrea Zones. Really, the main exhumation stage of the high-grade rocks of the Ivrea Zone occurred in the early-Mesozoic during an extensional tectonic regime [Zingg *et al.*, 1990] ; whereas the Sesia Zone shows a strong low T - high P metamorphic overprint [e.g.

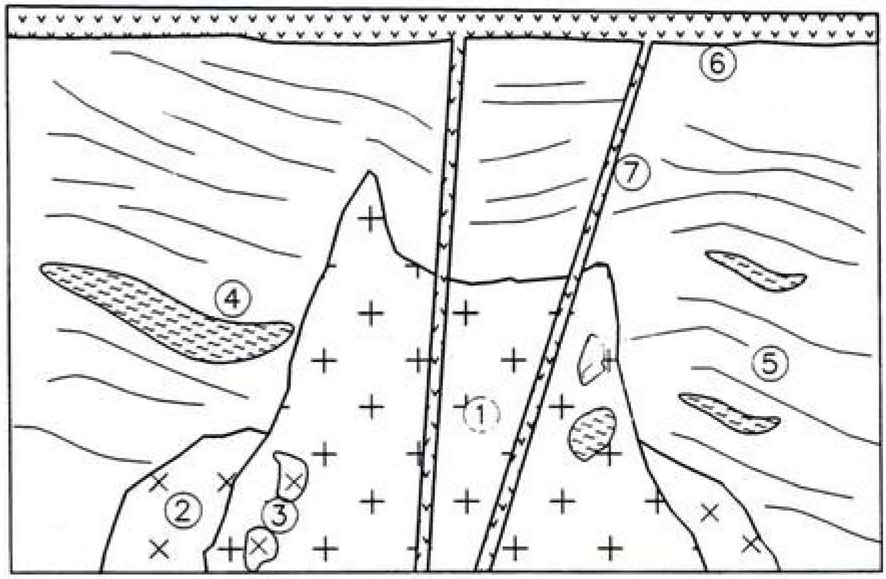

Fig. 8. – Reconstruction of the relationships between plutonic and metamorphic rocks of the Canavese Zone during the Permian. 1 : Plutonic rocks of granitic composition ; 2 : Plutonic rocks of dioritic composition ; 3 : Xenoliths of metamorphic and dioritic rocks ; 4 : Micro-augen orthogneiss ; 5 : Pre-Alpine metamorphic basement ; 6 : Permian volcanic and volcaniclastic cover. 7 : Andesite to rhyolite dykes.

Compagnoni *et al.*, 1977] of Middle Cretaceous age [Oberhänsli *et al.*, 1985]. On the contrary, the Canavese basement shows close lithostratigraphic and metamorphic similarities with easternmost sectors of the crystalline basement of the Southern Alps, such as the Serie dei Laghi [Boriani *et al.*, 1990] or some tectonic unit of the Orobic Alps [Milano *et al.*, 1988]. Furthermore, the Permo-Mesozoic Canavese cover shows a strong stratigraphic affinity to the cover sequences of the Southern Alps. The similarities with the South Alpine cover and with the metamorphic basement are then striking. According to the good litho-stratigraphic and metamorphic affinity, the Canavese Zone may be considered as a highly attenuated remnant of the Southern Alps upper crust exposed close to the Insubric Line. According to Schmid *et al.* [1987] and Schmid [1993], it is difficult to decide how much of this attenuation had already occurred during the crustal thinning of early - Mesozoic age and how much is due to Alpine movements along the Insubric Line.

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