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The Canavese Zone between the Serra d'Ivrea and the Dora Baltea River (Western Alps)

By GIUSEPPE BIINO[1]) and ROBERTO COMPAGNONI[1])

ABSTRACT

The Canavese Zone, near Ivrea, is characterized by a crystalline basement and its Permo-Mesozoic cover. The crystalline basement, so far inexplicably ignored or misunderstood, resulted to consist of granite and diorite, intrusive into low-grade metamorphics composed of garnet-white mica phyllite, banded albite-actinolite-epidote metabasic rock and fine-grained biotite-albite-K-feldspar-white mica gneiss. The Canavese basement, therefore, is markedly different from that of both the Sesia and Ivrea Zones. The Permo-Mesozoic cover consists of Permian volcanics and volcanoclastics; Triassic dolostone; Liassic limestone, arenite and shale; shale with interbedded non-fossiliferous limestone of possible Malm age and upper Jurassic siliciclastic limestone (Bio' and Lago Pistono schists). A remnant of the Oligocene andesitic cover of the Sesia Zone also occurs. The Canavese Zone is bounded by two tectonic lines, here named External Canavese Line (ECL) and Internal Canavese Line (ICL), respectively. The ECL juxtaposes Sesia Zone rocks metamorphosed under Alpine eclogitic conditions and Canavese Zone rocks metamorphosed under Alpine prehnite-pumpellyite-actinolite facies conditions. The ECL was active, and/or re-activated, under brittle conditions. In contrast, the ICL was recrystallized syn-postkinematically under prehnite-pumpellyite-actinolite facies conditions and was for the most part not re-activated. The Canavese and Ivrea rocks, with the exclusion of the Oligocene andesite, exhibit the same Alpine metamorphic and mylonitic overprint. On this basis it is concluded that the Ivrea and Canavese Zones jointly experienced part of the Alpine orogenic history.

RÉSUMÉ

La Zone du Canavèse, aux alentours d'Ivrée, est caractérisée par un socle cristallin et par une couverture permo-mésozoïque. Le socle est constitué de granite et de diorite, intrusifs dans des terrains de faible degré métamorphique, composés de phyllades à grenat et mica blanc, de métabasites à albite-actinolite-épidote et de gneiss à grains fins, à biotite, albite, feldspath potassique et mica blanc. Il est nettement différent de celui des Zones de Sesia et d'Ivrée. La couverture permo-mésozoïque est constituée d'éléments volcaniques et pyroclastiques Permian, de dolomie triassique, de calcaire, arénite et schiste du Lias et de schiste à calcaire azoïque interstratifié, d'âge Malm possible, et calcaire silico-clastique du Jurassique supérieur («Scisti di Bio'» et «Scisti del Lago Pistono»). Un petit affleurement de la couverture andésitique Oligocène de la Zone Sesia a été découvert. La Zone du Canavèse est limitée par deux lignes tectoniques nommées ici Ligne Canavèse Externe (ECL) et Ligne Canavèse Interne (ICL). L'ECL borde des roches de la Zone du Sesia métamorphisées dans des conditions éclogitiques et des roches de la Zone du Canavèse rééquilibré dans le faciès a préhnite-pumpellyite-actinolite. L'ECL était active, ou a été réactivée, dans des conditions de déformations cassantes. Au contraire l'ICL a été, en grande partie, non réactivée depuis le métamorphisme alpin de basse pression et basse température. Les roches du Canavèse et d'Ivrée, à l'exception des andésites, montrent la même empreinte métamorphique alpine que les mylonites. Sur cette base on conclut que les Zones d'Ivrée et du Canavèse ont subi ensemble une partie de la remontée tectonique alpine.

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1. Introduction and geological setting

The Canavese Zone, as originally defined by ARGAND (1909a, b), is a long and narrow domain lying SE of the Sesia and NW of Ivrea-Verbano Zones (Fig. 1). The Austro-Alpine Sesia Zone is characterized by Early-Alpine eclogitic tectono-metamorphic events (HUNZIKER 1974, COMPAGNONI et al. 1977). The Ivrea-Verbano Zone of the Southern Alps is characterized by pre-Alpine granulite to amphibolite facies mineral assemblages (see ZINGG 1983 for a review). The contact between Canavese and Sesia Zones is a major tectonic feature, considered as the southernmost extension of the Periadriatic Lineament. This line divides the tectonic units of the Western Alps, which were deeply involved in the Alpine tectono-metamorphic reworking, from the Southern Alps, less affected by the Alpine orogeny. The contact with the Ivrea-Verbano Zone was originally recognized as a major tectonic feature by FRANCHI (1905) and named "Canavese Line" by NOVARESE (1929), but was underestimated in the later literature (for a general view see AHRENDT 1980, SCHMID et al. 1987), on the assumption that the Canavese basement has lithologic and metamorphic characters very close to those of the Ivrea Zone.

Several studies have been devoted to this key region of Alpine tectonics since the pioneering studies of the 19th century Piedmontese geologists and the Italian Geological Survey (see NOVARESE 1929). However, the conclusions of these different resear-

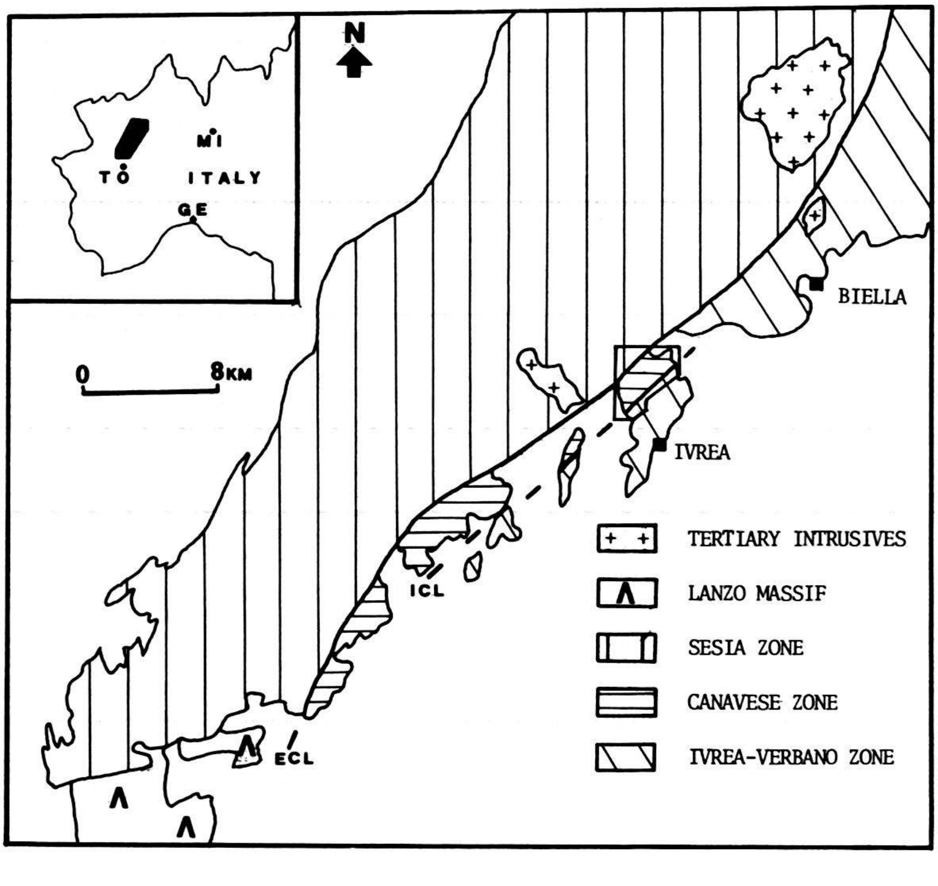


Fig. 1. Simplified tectonic sketch map of the Canavese region and location of the study area. ECL = External Canavese Line; ICL = Internal Canavese Line.

chers were quite contradictory, with respect to both the boundaries of the tectonic domain and the stratigraphic column. Although recent stratigraphic investigations have provided new information (Baggio 1965, Ahrendt 1972, Wozniak 1977), especially as to the Mesozoic cover, the basement was poorly studied. Because its lithologies were very often grossly misunderstood, emphasis is placed here on the description of the basement.

The Canavese Zone, in the study area near Ivrea, was subdivided into three main slices separated by tectonic contacts. For the sake of clarity, in the following they will be considered individually and named northern, southern and Lago Nero slice, respectively (Figs. 2 and 3). Each slice is composed of only a part of the stratigraphic sequence and contacts among lithotypes are mostly tectonic or tectonized.

In addition to lithologies typical of the Canavese Zone, a very small body of andesite crops out at the NW boundary of the area, close to the contact against the Sesia Zone.

2. The northern slice

The northern slice consists of a foliated porphyritic leucogranite on the NW side and a mainly massive diorite to the SE. Both granite and diorite are cut by a swarm of dm- to m-sized micro-leucogranite dykes; diorite is also intruded by diabase dykes.

In the few localities where it can be observed, the granite/diorite contact is always sheared. However, the occurrence of micro-leucogranite dykes within the diorite, identical to those crosscutting the porphyritic leucogranite, points to primary intrusive relations between the two igneous rocks, the granite being emplaced later than the diorite.

The contact between the diorite of the Canavese Zone and the high grade rocks of the Ivrea-Verbano Zone is always masked by a Quaternary cover several tens of meters wide: however, on both sides of the contact the closest outcrops show still slightly foliated rocks, with evident Alpine recrystallization (see section 6).

The *porphyritic leucogranite,* discovered by Pognante (1980), although markedly foliated, still retains widespread relics of magmatic minerals. The protolith was a leucocratic two-mica granite, consisting of K-feldspar phenocrysts enclosed in a medium-

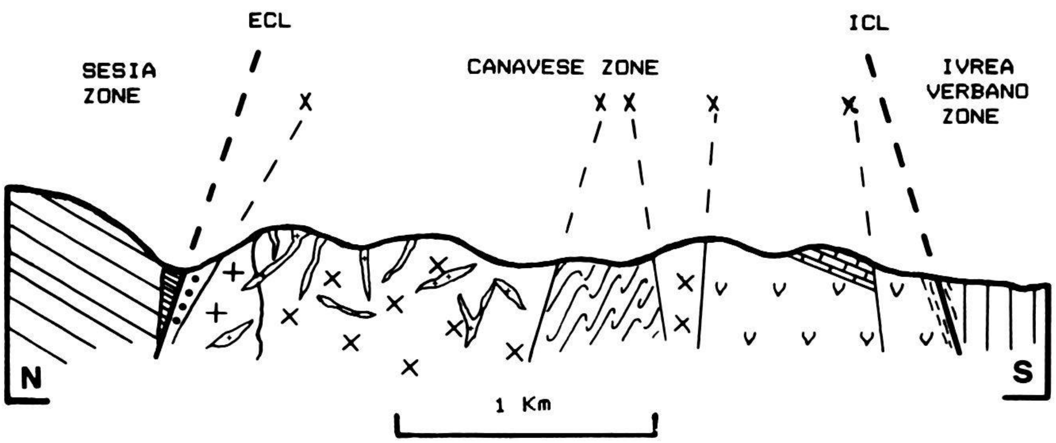
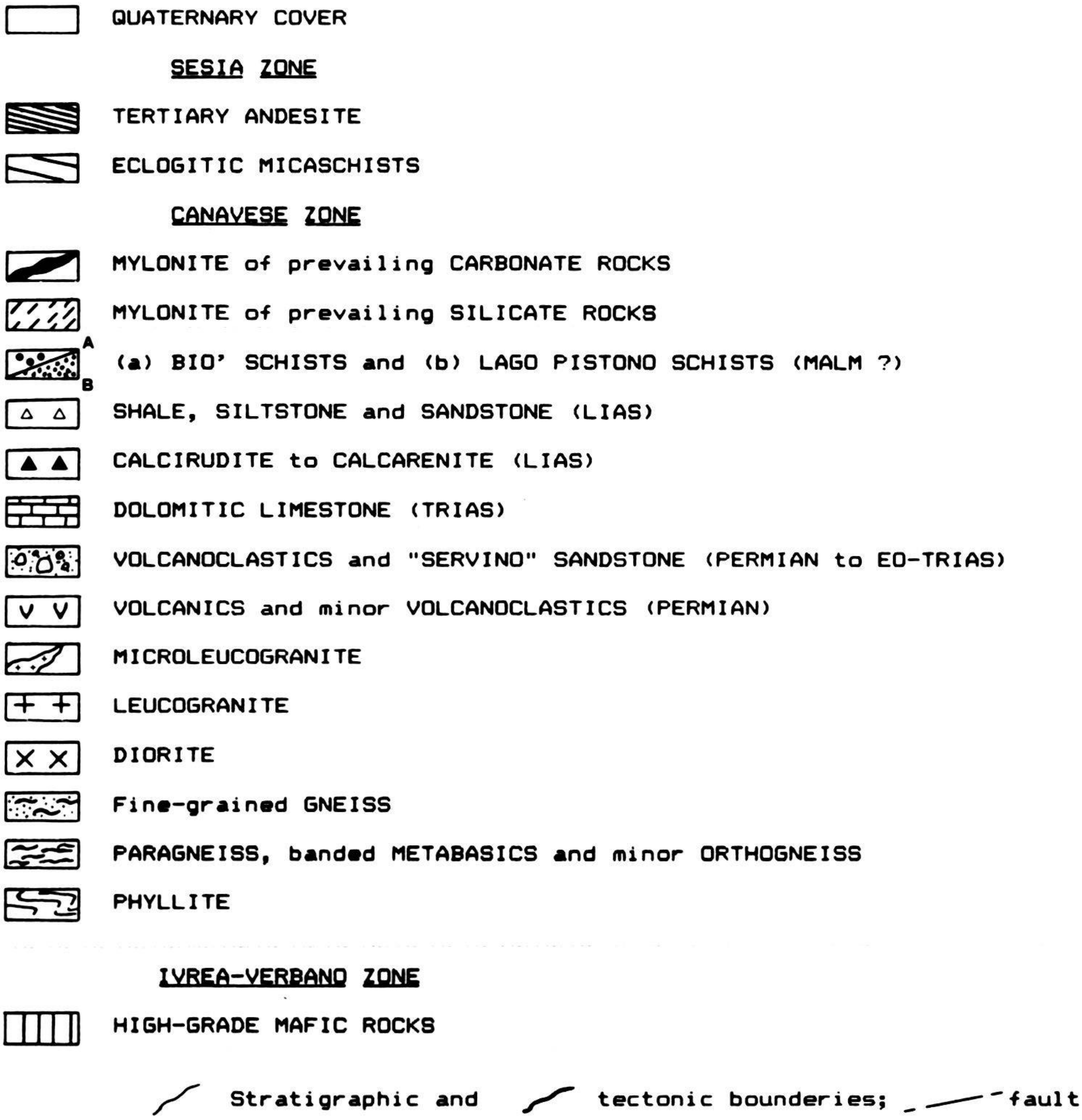


Fig. 2. Schematic geologic section across the study area. Symbols as in Fig. 3.



Legend to Figs. 2 and 3.

grained matrix of quartz, plagioclase, white mica and biotite with accessory allanite, zircon and apatite. Commonly the largest muscovite flakes contain sericitic-white mica pseudomorphs after magmatic andalusite. The Alpine metamorphism developed albite, clinozoisite, Fe-epidote, chlorite, white mica, pumpellyite, prehnite and stilpnomelane.

The metagranite includes both xenoliths and autoliths several centimeters across. The fine-grained *xenoliths,* which exhibit a marked compositional layering, consist of sericitized plagioclase, oriented green-amphibole and minor biotite. Their mineralogic and structural features are very similar to those of the fine-grained gabbros recently discovered in the Canavese zone near Belmonte by Biino et al. (1986). The *autoliths,* which have a granodioritic composition, consist of phenocrysts of quartz, plagioclase and rare K-feldspar, included in a fine-grained groundmass of biotite and dark green

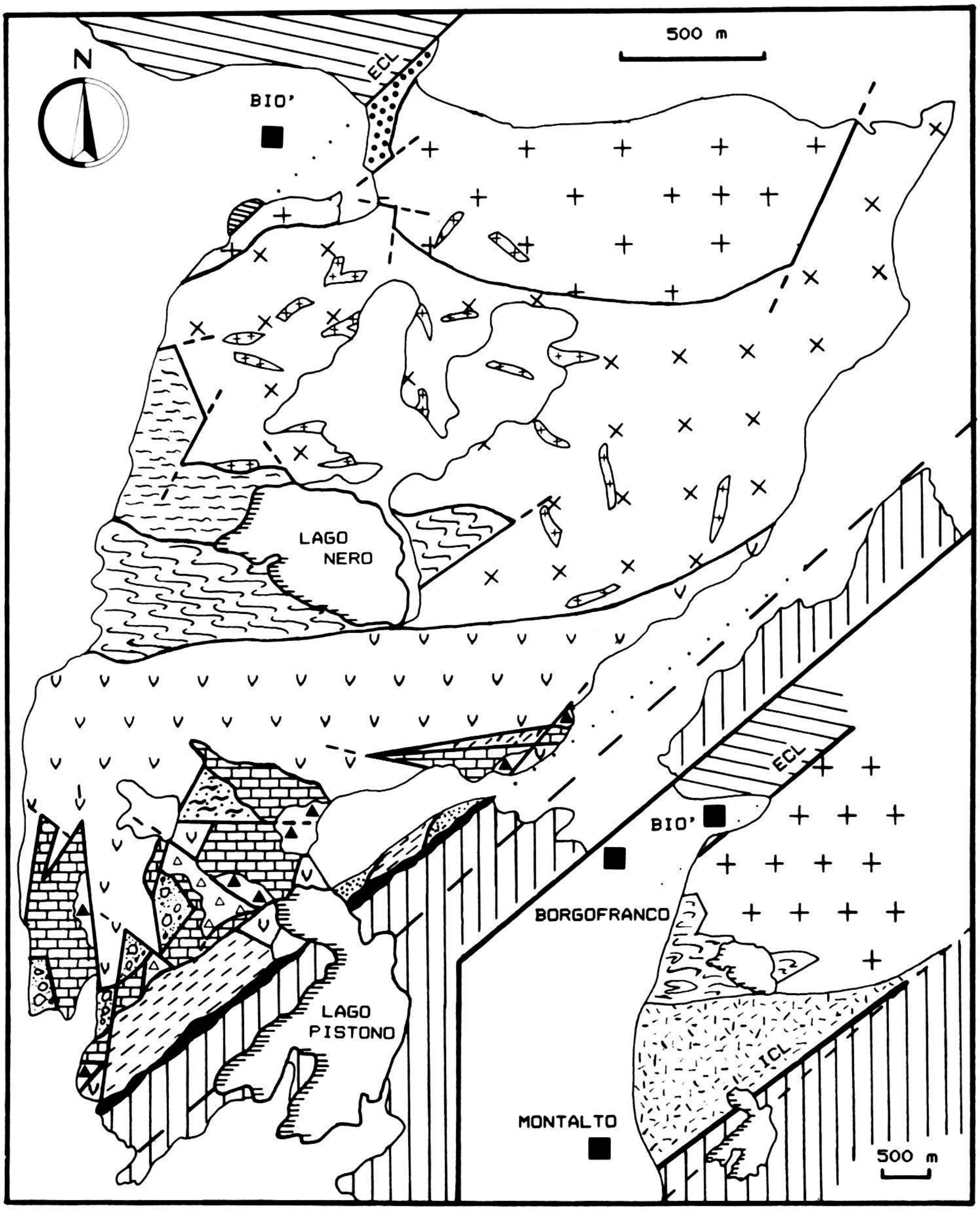


Fig. 3. Simplified geological map and tectonic sketch-map of the Canavese Zone near Ivrea. ECL = External Canavese Line; ICL = Internal Canavese Line. The dashed line marks a minor fault in the Ivrea-Verbano Zone, characterized by morphological evidence. In the tectonic sketch map (lower right) the northern, Lago Nero and southern tectonic slices (between ECL and ICL) are distinguished by different ornaments.

amphibole as well as quartz, plagioclase and K-feldspar. Both xenoliths and autoliths show an Alpine metamorphic overprinting characterized by the same assemblages as in the metagranite.

The *diorite* ranges compositionally from gabbrodiorite to anorthosite through diorite (the dominant rock-type) and quartz-bearing diorite. Cumulus texture and magmatic lamination are commonly preserved. The diorite consists of the following minerals, reported in order of crystallization: plagioclase and rare clinopyroxene, apatite, brown hornblende, biotite, opaque ores and quartz. The Alpine metamorphic overprinting usually produced pseudomorphic alterations, the most significant being: plagioclase replaced by a brownish felt of spongy epidote and white mica, whose concentration suggest an inverse zoning, brown hornblende rimmed by actinolite, and biotite converted to chlorite + pumpellyite. Locally prehnite and stilpnomelane also occur.

All over the diorite body both xenoliths and autoliths – from a few cm to several dm across – are very common. The *xenoliths,* which have a gabbro-noritic composition, are fine grained and show a granoblastic texture. They are altered to Alpine metamorphic minerals, and only rare relics of clinopyroxene, biotite, spinel and hornblende are preserved. Plagioclase is completely saussuritized and orthopyroxene is converted to serpentine, talc and actinolite. Less commonly cm-sized rounded quartzite xenoliths also occur.

The *autoliths* appear to be cumulates of brown hornblende, clinopyroxene and apatite.

The *micro-leucogranite* intruding the diorite locally forms a network of dykes, whose field appearance is reminiscent of an intrusion breccia. They have the same mineralogy as the foliated porphyritic granite, but are finer-grained. On geochemical grounds the dykes appear to be differentiation products of the main foliated porphyritic granite (Biino 1985).

The three *diabase* dykes found intruding the diorite are approximately one meter across and show wide chilled margins, obvious magmatic foliation and the central portion crowded with plagioclase and olivine phenocrysts. The fine-grained groundmass consists of plagioclase, olivine, swallow-tail Ti-augite and skeletal opaque ores. Magmatic minerals are usually pseudomorphically replaced by albite, actinolite, white mica and chlorite. These dykes show a marked alkaline character (Biino 1985), which suggests a correlation with the diabases described in the Southern Alps by Bigioggero et al. (1981). Their marked alkaline character – indicative of a extensional anorogenic environment – together with the chilled margins suggest that they were emplaced at shallow depths into an already cooled igneous basement. In view of the presence of the Alpine metamorphic overprinting dated as 60 to 70 Ma (Zingg et al. 1976), dyke emplacement must be older than Paleocene.

3. The Bio' Schists

A small slice of metasedimentary rocks is exposed north of Bio', close to the contact with the Sesia Zone. The Bio' Schists have been interpreted in various ways in the Canavese geological literature. They are composed of a continous sequence of folded pelite, siltite and arenite with interbedded arkose and impure limestone. The Bio' Schists are considered to be Malm in age (Biino & Compagnoni 1989a) such as the Lago Pistono Schists (see section 5).

4. The Lago Nero slice

The intermediate slice, which is mainly exposed in the basin of Lago Nero (see fig. 3), is entirely made up of metamorphic rocks; namely, phyllites, banded metabasics with interlayered transposed dykes of intermediate composition, and fine-grained paragneisses with minor orthogneisses and impure quartzites.

The phyllites, reported on the Ivrea geological sheet as Permian schists (FRANCHI 1905), were considered as shales of Malm age by ARGAND (1909b) and SPITZ (1919). BAGGIO (1965) has given the first petrographic description. The other lithotypes making up the Lago Nero slice, regarded by SISMONDA (1848), FRANCHI (1905) and NOVARESE (1929) as rocks peculiar to the Canavese Zone, were considered as mylonitized Ivrea Zone rocks by BAGGIO (1965), AHRENDT (1972) and WOZNIAK (1977).

The *phyllites* are very fine-grained and dark in colour; they consist of submillimetric alternations of albite + quartz and white mica + Mn-rich garnet + chlorite + graphitoid film layers. Several deformation phases were recognized in the phyllites. The oldest one is preserved as hinges of intrafolial isoclinal folds. The second one is characterized by cm-sized open to chevron microfolds developing a crenulation in the phyllitic layers. The third phase only produced kink bands without development of a true crenulation. These ductile deformations are usually overprinted by several systems of fractures and microfaults.

The *metabasics* consist of alternations of mm-sized light-green and dark-green layers mainly composed of Fe-rich epidote and actinolite, respectively. Under the microscope variable amounts of accessory albite, chlorite, quartz, sphene and rutile may be recognized as well.

Interbedded with the metabasics *quartz – feldspar lenses* locally occur, which microscopically show a relict porphyritic texture. They consist of very thin layers, which are composed either of quartz, Fe-epidote, pale green amphibole, chlorite, Fe-sulphides, adularia with local albite enrichment, or of relict plagioclase + amphibole phenoclasts enclosed in a groundmass of quartz, plagioclase (albitized), white mica, green amphibole and dismembered, long prismatic, apatites. Locally plagioclase phenoclasts are rimmed with myrmekite-like quartz-plagioclase intergrowths, similar to the textures described in plagiogranites by COLEMAN & DONATO (1977, p. 153–154). Amphibole phenoclasts commonly show a skeletal habit. The presence of both relict myrmekite-like intergrowths and porphyritic plagioclase and amphibole, together with the small thickness of the lenses, suggests that they are derived from transposed and boudinaged dykes of intermediate chemical composition.

The paragneisses are interlayered with minor cm-sized layers of orthogneisses (meta-volcanics) and impure quartzite. The *paragneisses* consist of mm-sized alternations of quartz + albite +/− chloritized biotite layers and white mica + opaque ore + albite + zoisite + chloritized biotite layers. The *orthogneisses* consist of white mica-rich layers alternating with layers composed of oligoclase-quartz- K-feldspar -porphyroclasts enclosed in a quartz + albite + adularia + sericite + Fe-poor and Fe-rich epidote + chlorite + sphene groundmass. Mineralogy and relict fabric point to a derivation from a volcanic and/or volcanoclastic protolith of rhyolitic composition.

The *impure quartzite,* in addition to quartz, contains rare pale green amphibole, opaque ore and chlorite. Quartzite locally contains millimetric layers consisting of intergranoblastic to poikiloblastic garnet with minor Fe-rich epidote.

The paragneisses exhibit a deformation pattern consistent with that shown by the phyllites, i.e. intrafolial isoclinal folds overprinted by cm-sized tight folds. This second generation of folds is characterized by vertical axes and the development of an axial-plane crenulation/foliation, overgrown by newly-formed biotite flakes replaced by chlorite. The development of biotite – a mineral incompatible with the assemblages characterizing the Alpine metamorphic re-equilibrations – suggests a pre-Alpine (very probably Variscan) age for the two observed fold phases. The Alpine tectonics mainly produced shear zones and brittle deformation, accompanied by the development of mm- to cm-thick albite + quartz +/– adularia +/– chlorite veins and tension gashes. In addition to such Alpine veins crosscutting the main foliation, an older generation of cm- to dm-sized quartz + albite veins also occurs, which is certainly pre-Alpine because it is isoclinally folded.

5. The southern slice

The southern slice mainly consists of Permian volcanics and volcanoclastics, with large remnants of the Mesozoic cover. The crystalline basement crops out only as small lenses aligned along a minor E-W trending tectonic line.

The crystalline basement

The small lenses of basement consist of *fine-grained gneisses* greenish in colour, only locally exhibiting an obvious foliation, folded by cm-sized open folds and overprinted by a complex pattern of brittle deformation. Microscopically the fine-grained gneisses are composed of poikiloblastic albite, Fe-epidote, chlorite and white mica. The albite poikiloblasts may include small idioblastic garnets and corroded crystals of white mica and quartz.

The Permian cover

The Permian cover, firstly described in the Montalto area by Bonarelli (1901), consists of volcanics and volcanoclastic sediments, the latter being more abundant towards the top of the sequence. Where deformation is less pronounced, volcanics still preserve original features such as flow structures and ignimbritic "fiamme". The interbedded sediments are usually difficult to distinguish from volcanics, because the deformed volcanics acquired a sandy appearance.

Volcanics are mainly porphyritic rhyolites with porphyritic index up to about 50. Phenocrysts are usually fragmented and/or corroded quartz, deeply albitized K-feldspar and minor albitized plagioclase. Some lithotypes also contain euhedral biotite phenocrysts, completely replaced by a white mica + chlorite + sphene + opaque ores assemblage. The groundmass consists of very pale green sericitic white mica, roughly oriented parallel to a poorly developed foliation and very small and rare quartz and feldspars crystals. More mafic volcanics were also found, mostly consisting of plagioclase phenocrysts included in a sericitic groundmass.

Frequently the volcanics also contain *xenoliths* either of aphyric to porphyritic lavas of similar composition and texture, or of minor fine-grained quartz-rich phyllite and phyllitic quartzite, similar to that of the basement.

Being mainly composed of volcanic debris, the volcanoclastic rocks are difficult to distinguish from the interlayered lavas, unless they preserve sedimentary structures such as cross-bedding. *Volcanoclastics* are either coarse-grained deposits consisting of cm-sized clasts of pinkish quartz and/or volcanic pebbles, or medium to fine-grained reddish to greyish-green unsorted immature sandstones, which frequently appear deformed and recrystallized. The finer-grained sediments are distinguished from associated volcanics only under the microscope, for the abundance of clasts of quartz, phyllite and white mica flakes enclosed in a sericitic matrix.

The uppermost volcanoclastics consist of polygenic *dark grey sandstones* (lower Triassic ?), rich in quartz grains, which may be considered as "Servino" following AHRENDT's (1972) suggestion.

As a whole the Permian sequence exhibits both moderate deformation and metamorphic recrystallization: only close to tectonic contacts and shear zones a visible foliation is developed, accompanied by a significant increase in the grain-size of white mica.

The Mesozoic cover

The oldest members of the Mesozoic cover are *dolomitic limestones,* which are whitish-grey, rarely pinkish, in colour and locally contain darker grey interlayers. In some places there are structures suggesting both bioturbation and dessication, and remnants of foraminifera and *Dasycladaceae* were described by WOZNIAK (1977) and BIINO (1985). The dolomitic limestones were considered as Middle Triassic in age by ISSEL (1893), PARONA (1924) and ELTER et al. (1966), and Upper Triassic by BAGGIO (1965) and AHRENDT (1972). STURANI (1975, p. 165), though favouring a Middle Triassic age, reports the presence of dolostones with a Norian "Hauptdolomit" facies.

The top of the dolomitic limestone is marked by an irregular erosional surface, which is covered by a fine-grained pinkish to pinkish-violet *calcarenite to calcirudite limestone.* Interbedded in the pinkish limestone, *encrinal limestones* are locally found, which have given a fauna dated as Liassic by SPITZ (1919) and as lower Sinemurian by STURANI (1964). This Liassic facies is well correlated with shallow-water facies such as the Hierlatz limestones and the Adneth limestones of the Swiss Austro-Alpine and Broccatello of the Luganese region (SPITZ 1919, BAGGIO 1965, CARRARO & STURANI 1972).

After the deposition of the pinkish limestone a *calciruditic to calcarenitic* synsedimentary tectonic breccia developed, locally very coarse-grained, containing clasts of Triassic dolomitic limestone, pinkish Liassic limestone and reddish calcarenite. The matrix may either be a reddish haematite-stained marl or recrystallized sparry calcite. This calciruditic to calcarenitic limestone, also considered to be Liassic in age, is locally injected as sedimentary dykes into the underlying Triassic and crystalline basement rocks. The pinkish beds contain cm- to dm-sized clasts of Triassic dolomitic limestones, minor basement metamorphics, volcanics, and microscopic fragments of calcite, quartz, feldspar, biotite and white mica. In these rocks bedding appears clearly overprinted by a planar crenulation cleavage and clasts are locally strongly deformed. This facies is similar to the Macchia Vecchia of the Luganese region (Baggio 1965, Elter et al. 1966).

Greyish-black *shales, siltstones* and *sandstones* with very minor carbonatic component are exposed. A stratigraphic contact between Triassic dolostone and this sequence was observed by G. Elter (1987, pers. comm.). Towards the base of the sequence sandstones with graded bedding prevail, whereas towards the top the pelitic fraction progressively increases. The whole sequence, intensively deformed, exhibits two main fold phases and late shear zones commonly mineralized with sparry calcite. A Liassic age was suggested by Novarese (1929) on the ground of the lithological similarities to Austro-Alpine lithotypes, such as the Fleckenmergel of Sostegno (Carraro & Sturani 1972).

Younger sequences of the Mesozoic Canavese cover, such as the *Calpionella limestone* (Baggio 1963) and *Palombini shale* (Elter et al. 1966), are not exposed in the Montalto area.

Along the western side of Lago Pistono, close to the contact with the Ivrea granulite, two very small outcrops of schists are exposed. These Lago Pistono Schists consist of cm-thick grey, non fossiliferous *limestone* with micritic appearance, interbedded with *shale*, both affected by the Alpine deformation and locally grading into mylonite (see section 6). Lago Pistono schists may be correlated with Bio' schists and the shale and limestone of Levone (Levone Shales of Sturani 1975), considered to be Malm in age, because of the occurrence of interbedded red radiolarian cherts.

6. The mylonite marking the Canavese-Ivrea contact

The tectonic contact between the Canavese and Ivrea-Verbano Zones is marked by a continuous zone of mylonite, from about one meter to several tens of meters wide. These rocks were discovered by Franchi (1905, in Novarese 1929), and considered as tectonic breccias, formed at the expense both of lithotypes of the Ivrea-Verbano Zone and of volcanic + sedimentary rocks of the Canavese cover.

Though all lithologies cropping out in the area are involved, altered greenish high-grade Ivrea-Verbano rocks and purple to greenish sericitic schists, derived from Permian volcanics of the Canavese Zone, are dominant. Locally, the transition between the undeformed country rock and the mylonite may be observed in the field. Within the shear zone, an alignment of strongly deformed cm- to m-thick "Calcari Porcellanacei" lenses (Franchi 1905, in Novarese 1929) occur, which consist of greenish silicate rock fragments enclosed in a porcelain-like carbonatic mylonitic matrix. Because of this appearance, these carbonate rocks were hypothetically considered by Ahrendt (1972) and Wozniak (1977) as Portlandian to Berriasian limestone. These rocks being the subject of a specific study (Biino & Compagnoni 1989b), only their main features will be described here.

Under the microscope fragments of both rocks and minerals may be recognized. The silicate rock fragments consist of both mafic and felsic high-grade granoblastic rocks, composed of plagioclase + clinopyroxene +/− hornblende and quartz + K-feldspar +/− plagioclase respectively or their alteration products. The carbonate rock fragments are composed of very fine-grained strained calcite grains, with preferred dimensional orientation, including: large calcite crystals, characterized by wavy extinction and repeated deformation twins, rounded crystals of clinopyroxene, brown hornblende, red brown biotite, Ca-plagioclase or their pseudomorphic alteration products. Commonly, alignments of sphene fragments deriving from crushed cm-sized crystals, mark the mylonitic foliation. All these features suggest that a significant portion of the carbonate matrix is derived by shearing and grain-size reduction from marbles of the Ivrea-Verbano Zone. However, the discovery of Liassic breccia fragments with preserved sedimentary structures and of remnants of a sea urchin spine indicates that at least part of the mylonite also derives from biogenic Liassic limestones of the Canavese cover.

The metamorphic syn- to post-tectonic re-equilibration produced peculiar mineral assemblages in the mylonites, including prehnite, pumpellyite, chlorite, stilpnomelane, Fe-epidote, actinolite, albite, phengitic white mica, garnet and sphene (Martinotti 1971). Garnet occurs as coronas around relics of albitized plagioclase and pyroxene. Garnet in the two sites shows different compositions (Biino & Compagnoni 1989b).

7. The andesite

The andesite, yellowish in colour and deeply altered, is located between the Sesia Zone and the foliated granite of the Canavese basement SW of the Bio' Schists (Biino 1985).

Microscopically it displays a porphyritic texture consisting of plagioclase, biotite and amphibole phenocrysts in a fine-grained matrix mainly composed of the same minerals. The plagioclase is partly altered to sericite and albite, but still maintains its magmatic twinning and zoning, amphibole is replaced by lizardite, and biotite is chloritized.

The andesite shows mineral alterations inconsistent with the metamorphic conditions shown by the Canavese rocks: thus it is probably the southwesternmost extension of the Oligocene stratigraphic cover of the Sesia Zone, which is widely exposed NE of the Serra d'Ivrea (Ahrendt 1969 and Scheuring et al. 1974).

8. The Alpine metamorphic overprint

In the Canavese Zone the Alpine metamorphic overprint was first recognized by Franchi (1905), but this was later mostly denied (cf.: Ahrendt 1972) or disregarded (cf.: Baggio 1972 or Wozniak 1977). In the Canavese cover the metamorphic grade was evaluated by Zingg et al. (1976) at the anchimetamorphism – epizone limit using illite crystallinity. K-Ar radiometric measurements on sericitic white micas from Mezozoic cover gave ages ranging from 60 to 70 Ma (Zingg et al. 1976).

From the present study it is evident that the Alpine metamorphic overprint occurs all over the Canavese and the adjoining Ivrea-Verbano Zones. The metamorphic re-equilibration is strongly dependent on the rock bulk chemistry and the amount of strain, and volcanic, plutonic and high-grade rocks appear to have been the most affected, particularly along shear planes. The mineral assemblages indicate a metamorphic re-equilibration typical of the prehnite-pumpellyite-actinolite facies (Turner 1980). The compatibilities of such mineral assemblages and the Fe-content in the epidote (Liou et al. 1985) suggest a temperature between 300 and 350 °C and a pressure around 2 Kbars for the Alpine metamorphic re-equilibration of the Canavese and the adjoining Ivrea-Verbano Zones (Biino & Compagnoni 1989b). The presence of at least three generations of successive veins, characterized by Fe-epidote, prehnite + pumpellyite +/− actinolite, and quartz + albite respectively, suggest some variation in the physico-chemical parameters controlling metamorphism, especially the fluid phase.

9. The Alpine tectonics

Two main tectonic lines appear to bound the Canavese Zone (Biino et al. 1988). There is an external line which does not appear to have undergone the metamorphic recrystallization seen in either the Sesia or the Canavese Zones. This external line – here defined as External Canavese Line (ECL) – appears as a shallow fault.

The internal Canavese boundary, interpreted by Boriani & Sacchi (1974) as the southern end of the Cremosina Line, is characterized by the occurrence of mylonite re-equilibrated under the prehnite-pumpellyite-actinolite facies conditions. This Canavese boundary – here named the Internal Canavese Line (ICL) – shows features indicating a deeper origin, and it appears not to have moved significantly after the mylonitic recrystallization. Significant pre- to syn-mylonitic movement along the ICL is also suggested by the juxtaposition of the low-grade metamorphics of the Canavese basement against the Ivrea-Verbano high grade rocks and by the occurrence, within the mylonite, of Ivrea lithotypes at present not exposed in the area.

The internal tectonic setting of the Canavese Zone consists of several wedges, separated by shear zones, from cm to m thick, with well developed Alpine metamorphic re-equilibration. This Alpine deformation is accompanied by the development of mm- to cm-thick albite + actinolite + epidote + pumpellyite veins. These veins are always NE-SW trending, i.e. parallel to the ICL, and cut the rocks of both the Ivrea-Verbano and the Canavese Zones.

The Alpine deformation produced a system of pluricentimetric open folds, overprinted by kinks, which only locally develop as open folds. Lithologic boundaries and tectonic contacts are cut by two main sets of faults with offsets varying from a few decimeters to several tens of meters; the older fault system trends NNE-SSW and the younger fault system trends NW-SE.

10. Discussions and conclusions

From the present study it appears that the Canavese Zone consists of a Permo-Mesozoic cover overlying a pre-Alpine crystalline basement.

The Canavese basement consists of both low-grade metamorphic and plutonic rocks. The former are composed of garnet-white mica phyllite, banded albite-actinolite-epidote metabasic rock with interlayered transposed dykes of intermediate igneous rocks, and fine-grained paragneiss with minor volcanoclastic orthogneiss and impure quartzite. The plutonic rocks are mainly diorite to quartz-diorite and leucogranite. As suggested by Biino et al. (1986) in the Cuorgne' area and by Naldi (1987) in the Fiorano area, the igneous rocks of the Montalto area are likely to be intrusive into the low-grade metamorphic basement. Consequently the Canavese basement consists of metamorphic rocks of probable Variscan age intruded by late-Variscan plutonics.

Therefore the Canavese basement is significantly different from that of both the adjoining Sesia and Ivrea Zones, which are made of pre-Alpine amphibolite to granulite facies metamorphic rocks. At the present time, the nearest metamorphic rocks showing pre-Alpine low grade mineral assemblages, similar to that of the Canavese basement, are near the Adamello massif in the South-Alpine basement of the Orobic Alps (CALLEGARI, pers. comm.).

The possible relation of the Canavese basement to the Orobic part of the Alps is further supported by the characteristics of the Mesozoic cover. The Mesozoic Canavese cover includes Triassic to Neocomian terrains, whose lithofacies may be compared with that of coeval sequences making up the cover of the lower Austroalpine Grisonide nappes of the Central Alps (SPITZ 1919, STAUB 1924, ELTER et al. 1966, STURANI 1973). At the same time, the youngest members of the Mesozoic Canavese cover are markedly similar to upper Jurassic to Neocomian lithotypes of the Ligurian terraines (ELTER et al. 1966, STURANI 1973). This affinity, indicative of a progressive sea floor deepening, is a result of the establishment of oceanic conditions in the neighbouring Ligurian-Piedmontese basin. Therefore the Canavese Mesozoic sediments were deposited on the continental margin bordering the southern side of this ocean and were characterized by an independent paleogeographic evolution.

The present location of the low-grade Variscan Canavese basement, between the two higher grade Variscan basement complexes of the Sesia and Ivrea-Verbano Zones, is the result of Mesozoic extensional and sinistral transcurrent movements. Juxtaposition of the Canavese and Ivrea-Verbano basement complexes is probably coeval with the movement of the Pogallo Line (HODGES & FOUNTAIN 1985, SCHMID et al. 1987, HANDY 1987). This is in agreement with recent plate kinematic reconstructions of the Jurassic Atlantic-Tethys system, which suggest important relative motions between Africa and Europe, resulting in a sinistral transcurrent boundary between the two continents (BIJU-DUVAL et al. 1977, LAUBSCHER & BERNOULLI 1977).

During the earliest phases of the Alpine orogeny the Canavese domain, which was originally a single paleogeographic unit, was disrupted and strongly deformed. It now forms what is in effect a shear zone, between the folded and metamorphosed Penninic + Austro-alpine nappes and the Ivrea Zone of the Southern Alps, which mainly records brittle Alpine deformation.

At present the Canavese Zone is bounded by two almost parallel tectonic lineaments. The *Internal Canavese Line,* which separates the Canavese Zone from the Ivrea Zone, is marked by a mylonite band. This mylonite is characterized by a pervasive Alpine prehnite-pumpellyite-actinolite facies overprint, which also affected the entire Canavese basement and cover. Because the Alpine overprint is mainly post-tectonic and consistent all over the Canavese and the adjoining Ivrea Zones, the ICL is likely to be an older, very probably Early-Alpine, tectonic lineament, which did not suffer significant reactivation after Alpine metamorphic overprinting. This means that the Canavese and Ivrea Zones jointly experienced uplift from a depth of approximately 5–7 km, corresponding to the prehnite-pumpellyite-actinolite facies conditions. If the age of the Alpine overprint given by ZINGG et al. (1976) is correct, the most significant tectonic movements of the area during the last 60–70 Ma took place mainly along the ECL.

On the other hand, the *External Canavese Line,* separating the Canavese Zone from the Sesia Zone, is a brittle fault. It is the result of a late or recently reactivated movement. This movement could be related to the post Oligocene rotation of the internal Sesia Zone, suggested by LANZA (1984) on the basis of palaeomagnetic data.

The conclusion of this study supports ARGAND's original interpretation (1909b), which considered the Canavese as an independent tectonic Zone between the Ivrea and Sesia Zones.

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