Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 64 (1984)

Heft: 1-2

Artikel: Metamorphism and deformation at the northwest margin of the Ivrea zone, Val Loana (N. Italy)

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DOI: https://doi.org/10.5169/seals-49539

Schweiz. mineral. petrogr. Mitt. 64, 151–167, 1984

Metamorphism and Deformation at the Northwest Margin of the Ivrea Zone, Val Loana (N. Italy)

by *Jörn H. Kruhl*[1]

Abstract

At the south end of Val Loana (N. Italy), the northwest margin of the Ivrea Zone is affected mainly by three deformational events:
- first, a pre-alpine deformation under upper amphibolite facies conditions,
- second, a pre-alpine one during continuously decreasing temperatures from amphibolite to greenschist facies indicating a continuous shear movement presumably related to upward thrusting of the Ivrea Zone,
- third, a deformation of pre-alpine or alpine age under conditions of very low grade metamorphism causing a large isoclinal fold which, as a continuation of the Finero Antiform, may probably be traced over a distance of at least 35 km from the NE-end of the Finero Complex to the Val d'Ossola in the SW.

At the south end of Val Loana, the Insubric Line (i.e. the south boundary of alpine deformation and metamorphism) is the southern boundary of a broad mylonite zone related to the first alpine deformation. Here alpine deformation and upper greenschist facies metamorphism started overprinting the pre-alpine rocks.

A third alpine deformational event affected the mylonites of the Insubric Line and produced distinct shear planes within the Ivrea rocks further to the SE.

Keywords: polyphase processes, regional metamorphism, mylonites, Ivrea-Verbano Zone, Northern Italy

INTRODUCTION

The study area is located at the northern margin of the Southern Alps, i.e. of the Ivrea Zone (Fig. 1), and at the southern margin of the «Alpine Root Zone» west of the Lago Maggiore (N. Italy). In this well exposed region, the pre-alpine deformation and metamorphism of mainly pelitic and basic rocks of the Southern Alps is bounded to the NW by deformation and metamorphism of the alpine Lepontine phase (ZINGG et al., 1976).

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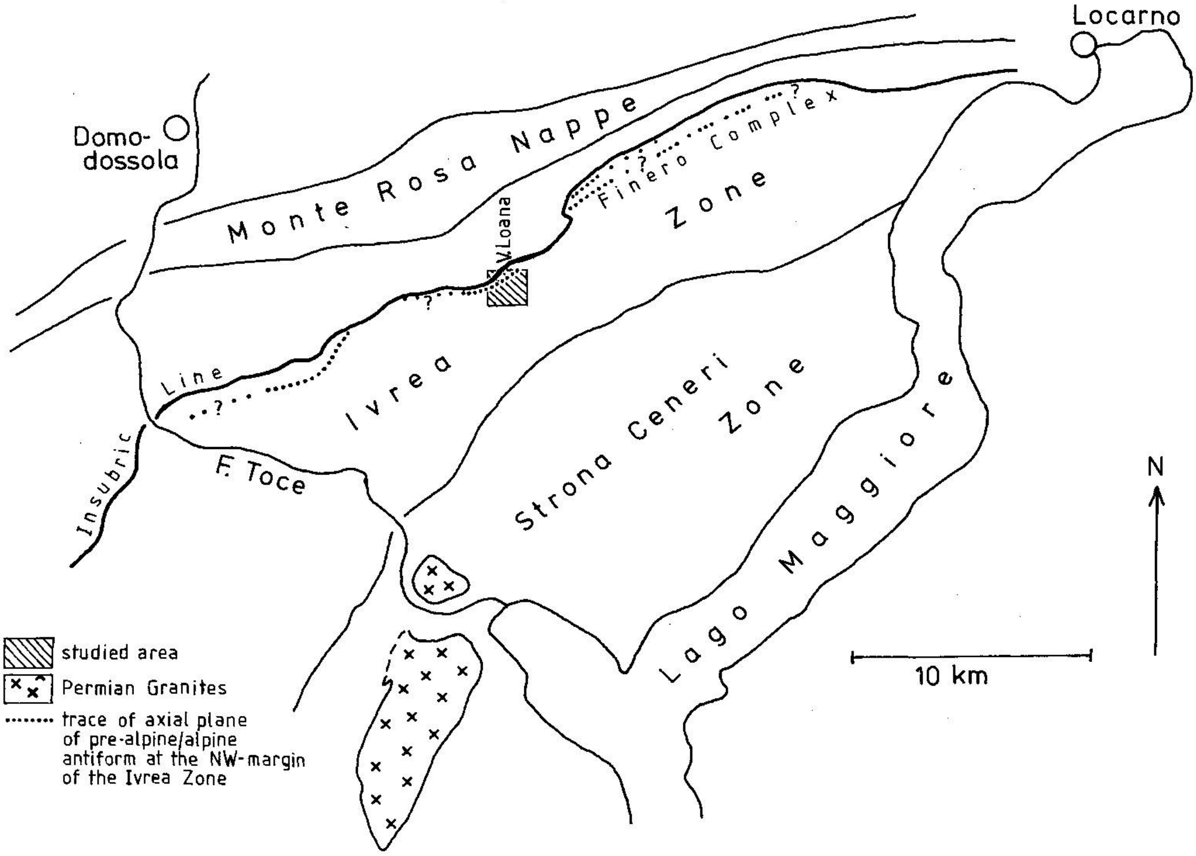


Fig. 1 Geological sketch of the area west of Lago Maggiore with the Southern Alps, Insubric Line and the «Alpine Root Zone». Indicated are the study area and the mapped and supposed parts of the trace of the axial plane of the large pre-alpine/alpine anticline near the Insubric Line (mainly after SCHMID 1966, KRUHL & VOLL 1976b, STECK & TIÈCHE 1976 and the present paper).

More to the SW, petrological and structural investigations of the Ivrea Zone have been made by SCHMID (1966, 1967), ZINGG (1980), and HUNZIKER & ZINGG (1980). Towards the NE, the Finero ultramafic body has been studied by LENSCH (1971), STECK & TIÈCHE (1976), and KRUHL & VOLL (1976, 1979a, b). Information on the "Alpine Root Zone" is provided by REINHARDT (1966), KRUHL & VOLL (1976), and ALTENBERGER et al.

On the basis of the well known situation in the Ivrea Zone towards the SW and the NE, and towards the NW in the «Alpine Root Zone», the following questions can be raised for the attachment area at the south end of Val Loana:

- Which types of pre-alpine deformation and metamorphism occur in the pelitic and mafic rocks at the northwest margin of the Ivrea Zone?
- Is it possible to relate these events to the deformation and metamorphism of the Finero Complex and to the Val d'Ossola region?
- In which way are the alpine metamorphism and deformation bounded to the SE and do they overprint the northwest margin of the Ivrea Zone? That is, what is the nature of the boundary between the Central Alps and the Southern Alps called the Insubric Line?

THE ROCKS

The Ivrea Zone at Val Loana chiefly contains kinzigitic gneisses, quartz-plagioclase-biotite gneisses with more or less amount of muscovite, chlorite and garnet, and amphibolites, together with some pegmatites and marbles. The compositional layering of all these rocks strikes SW-NE (Fig. 2). The amphibolites are intercalated as layers, up to 100 m wide, in the gneisses and kinzigitic gneisses. The marbles and pegmatites reach a thickness of up to 10 m.

Beside quartz, plagioclase (oligoclase - andesine) and Ti-biotite the *kinzigitic gneisses* contain garnet, sillimanite, K-feldspar and zircon, rutile apatite, xenotime, tourmaline and ore as accessory minerals. Quartz and plagioclase show intergrowth (embayed structure), sillimanite is included in quartz as fibrolites, but also occurs as coarse prismatic grains. Within intensely red-brown coloured Ti-biotites Ti is exsolved as a lattice of sagenite crystals. Garnet crystals are grown to a size of 4–5 mm. Netlike cracks are numerous and typical for the garnets of the Ivrea-kinzigites.

There are no sharp boundaries to the *quartz-plagioclase-biotite gneisses* but a continuous transition. They contain little or no garnet and no sillimanite. Both gneisses and kinzigitic gneisses may show chlorite and muscovite as alteration products.

The *amphibolites* mainly contain plagioclase and green hornblende, and apatite, sphene and ilmenite as accessory minerals.

The *marbles* are rather pure. Besides calcite, they contain some quartz, phlogopite and diopside.

Numerous *pegmatites* occur within the gneisses. They strike parallel to the penetrative pre-alpine cleavage and are composed of quartz, K-feldspar, plagioclase and muscovite and minor zircon and tourmaline.

At Val Loana towards the NW the quartz-plagioclase-biotite gneisses of the Ivrea Zone continuously change to quartz-(plagioclase)-muscovite *mylonites*. The greatest mylonitization is seen in a ca. 50 m wide zone directly southeast of Alpe Cortenuovo (Fig. 2). Towards the NW mylonitization slowly decreases; lenses of *white* and *blue marble* are intercalated. Further NW these strongly mylonized rocks are limited by the less mylonized gneisses of the «Alpine Root Zone».

PRE-ALPINE DEFORMATION

The relationship between the different phases of deformation and the development of the structural features is schematically presented in plate 1. The area between Cima della Laurasca and Alpe Cortenuovo shows uninterrupted out-

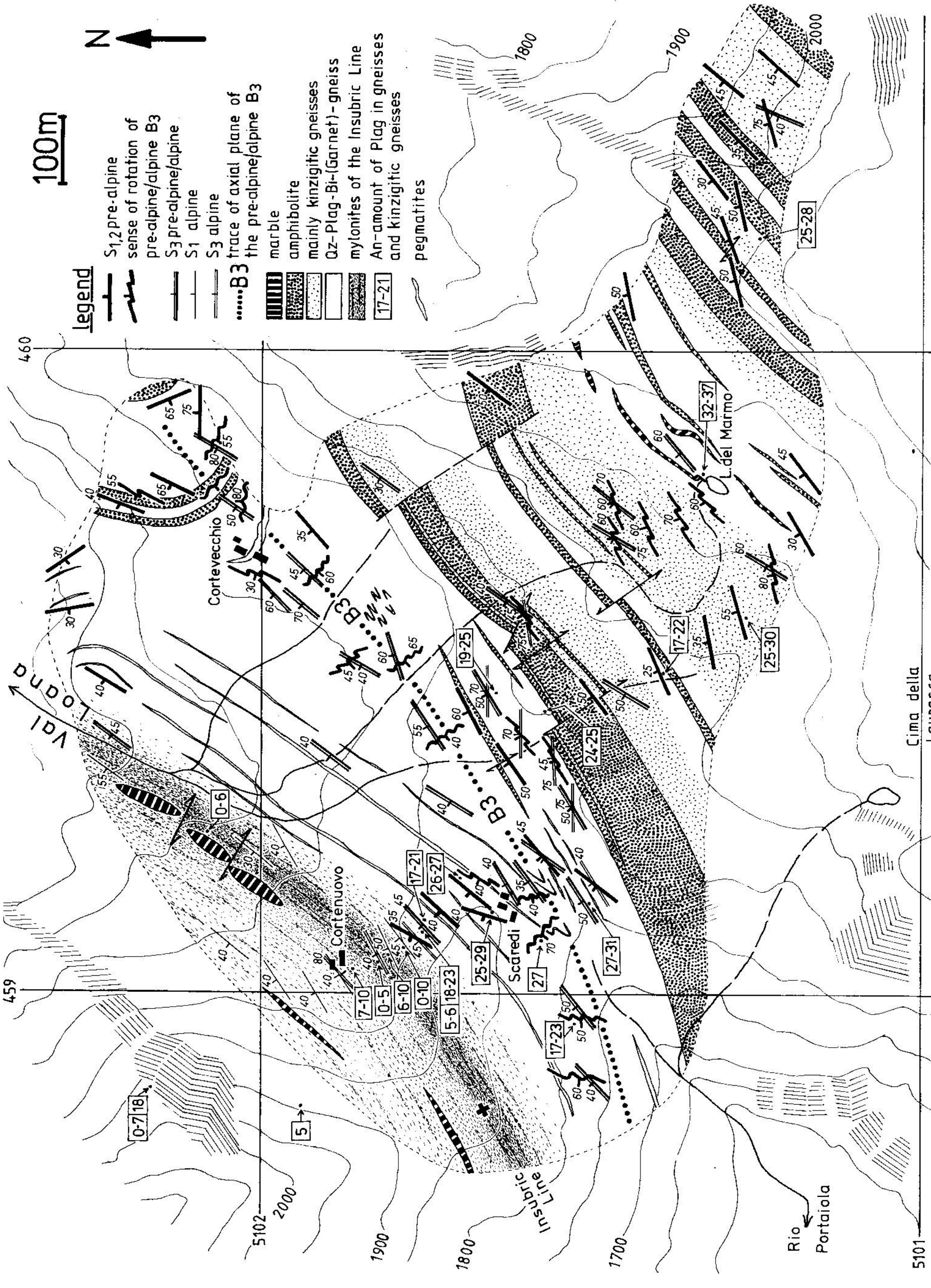


Fig. 2 Geological sketch of the study area at the south end of Val Loana: Northwestern margin of the Ivrea Zone and the Insubric Line.

crops and allows a detailed analysis of the different deformational events, which especially overprint the pelitic rocks.

In general, two phases of pre-alpine age and a third one - either of pre-alpine or of alpine age (in the following termed as third pre-alpine / alpine deformation) - occur in these rocks.

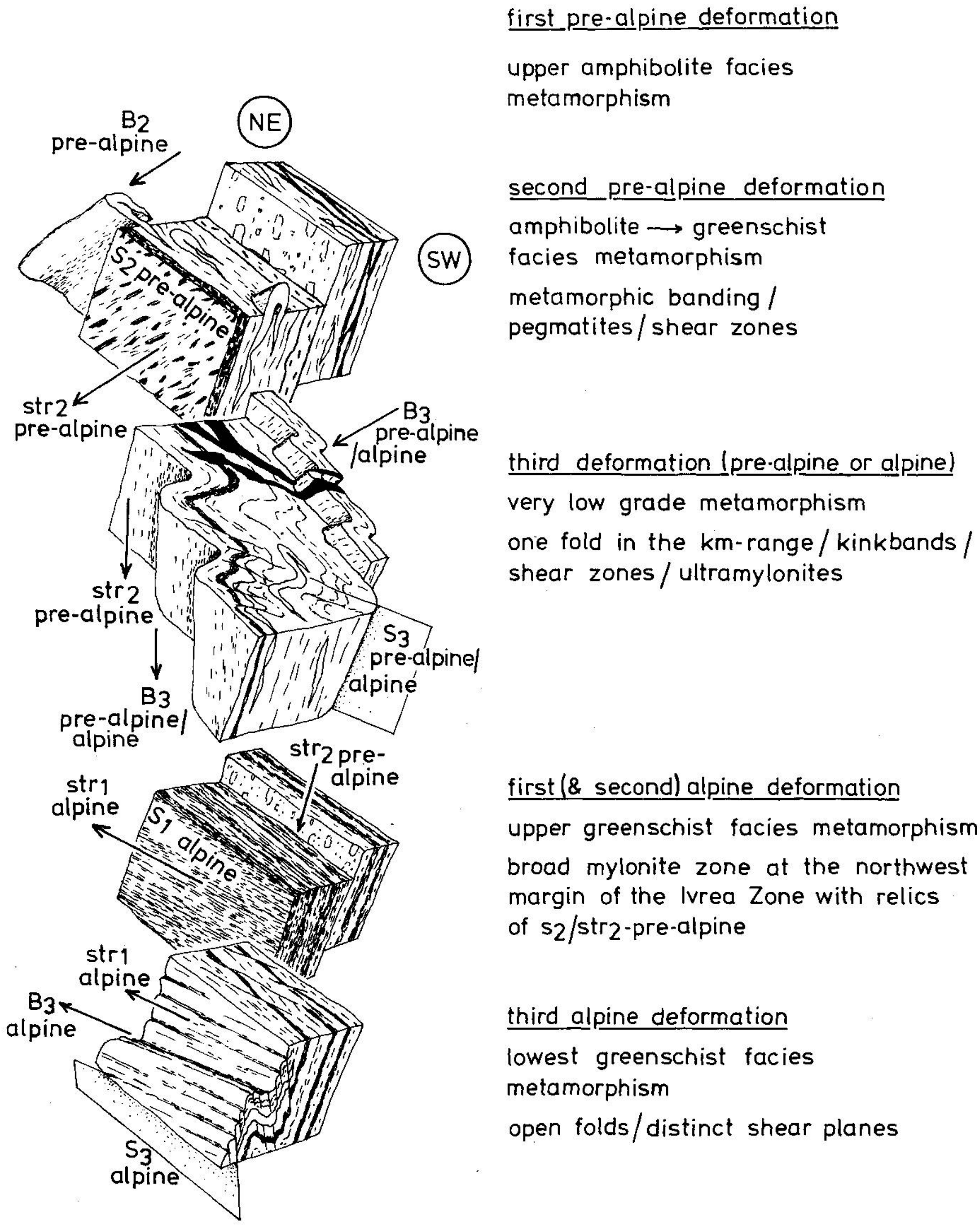


Fig. 3. Development of pre-alpine and alpine deformation and metamorphism at the northwest margin of the Ivrea Zone at Val Loana.

There are scarce indications of the *first pre-alpine deformation:* within the *kinzigitic gneisses* and *quartz-plagioclase-biotite gneisses* a first pre-alpine cleavage (s_1) is seldom preserved as relics rotated between shear planes of the second cleavage (s_2) or enclosed in feldspars or garnets (e.g. sillimanite, Fig. 5). The best indication of a first cleavage is given by the numerous quartz dikes reflecting the position of s_1 (according to VOLL 1960, 1968). They are isoclinally deformed during the second deformation.

Of course, it is not clear if this first pre-alpine deformation is only one event. Above all, in the pelitic rocks of such a high metamorphic grade we should rather expect a multifold deformation, which caused a strong flattening and at the end resulted in an apparently simple picture of the structural features.

There are no recognizable folds and stretching directions of this first deformation.

The *second pre-alpine deformation* caused a metamorphic banding in the mm-range within gneisses and kinzigitic gneisses and a dimensional orientation of hornblende and plagioclase within the amphibolites, or of calcite within the marbles. In general all the rocks are affected grain by grain by the second deformation.

Quartz, feldspars and calcite show plastic deformation and are flattened and oriented - together with biotite, sillimanite and hornblende - parallel to the second pre-alpine cleavage (s_2). Garnets are broken and drifted apart parallel to s_2. In the amphibolites hornblende recrystallizes in s_2. Relics of old coarse grains remain.

S_2 strikes SW-NE and dips steeply towards NW. Moreover a stretching (str_2) is clearly developed, presented by the orientation of coarse elongated plagioclase grains in gneisses and kinzigitic gneisses, and by the orientation of the long axes of amphiboles within amphibolites. In general str_2 dips on the s_2-plane $\pm 50°$ towards NE, but may also show vertical positions or a steep plunging towards SW.

There are no larger folds produced by the second deformational event. Only quartz veins within gneisses and kinzigitic gneisses are isoclinically folded in the mm–cm range, with their axes steeply plunging towards the NE or SW, always parallel to str_2. The quartz veins are flattened parallel to s_2 and boudinered in such a way that the limbs of the second folds (B_2) are thinned and finally drawn asunder. The thickened B_2-crests form lenses with their long axes parallel to str_2.

At points with increased deformation mm-wide mylonites are produced, more often within the gneisses and kinzigitic gneisses and seldom within the amphibolites. Whether mylonitization increases towards the NW is not ascertainable. Because the formation of these mylonites seems to be related to the second deformation - although mainly with lower temperatures - it is useless to name them as an independent deformational event.

The pegmatites, which intruded the quartz-plagioclase-biotite gneisses around Alpe Scaredi and Cortevecchio, are also affected by the second pre-alpine deformation, but of a late stage. Feldspars are broken and drifted apart and quartz recrystallizes with up to 0.2 mm in diameter.

The second deformation – as a rotational deformation – caused a three-axial strain, a simple shearing, with the direction of main elongation parallel to the rotational axis.

The *third pre-alpine/alpine deformation* also affected all the rocks appearing at the northwest margin of the Ivrea Zone, but to a different extent.

Within the gneisses and kinzigitic gneisses we find single planes of the third cleavage (s_3), usually with mm-cm-distance, in mica-rich parts more intensely developed than in mica-poor parts. Pegmatites and amphibolites are only partly cut by s_3-planes. S_3 strikes SW-NE and plunges steeply to the NW.

Third folds (B_3) occur in gneisses and kinzigitic gneisses with wavelengths and amplitudes from mm to the km range, in pegmatites, amphibolites and marbles from cm to the km range. Essentially they are the result of a low temperature deformation. There are all sorts of changes from open bends to kinkbands (with and without s_3 developed) and to isoclinal folds within shear zones. They always bend the metamorphic foliation, including s_2-planes and mylonites. So far these folds may be clearly identified as third folds.

The fold axes lie always parallel to str_2, together with which they change their positions from plunging steeply NE to steeply SW. In this case the positions of B_3 are rather independent from the shear direction of the third rotational deformation but comply with the anisotropy within the deformed rocks produced by str_2.

The different minerals suffering plastic deformation during the second act of folding are deformed at low temperatures during the third act: quartz grains show wavy extinction and do not recrystallize (or occasionally just start to recrystallize), micas are bent and plagioclases and K-feldspars are broken and drifted asunder parallel to s_3. A stretching direction (str_3) is not developed.

Often – with increasing deformation – mm to m, wide shear zones are produced causing a fine Mylonitization. In particular within the kinzigites mm-cm wide black ultramylonites are frequently replacing s_3. Together with the different types of third folds they support the opinion that the third deformation occurred during decreasing temperatures.

A third fold of a larger scale is exposed around Alpe Scaredi, with a gneiss core of at least 500 m diameter extending from the Insubric Line in the NW to a band of compact amphibolite in the SE (plate 1, Fig. 2). Wavelength and amplitude are not determinable. In the northwest part of this large fold monoclinic second-order folds in the cm-m range are exposed with steeply plunging axes and with always the same vergency (Fig. 2). In the core of the fold at Alpe Scaredi, orthorhombic second-order folds occur, and further to the SE again mon-

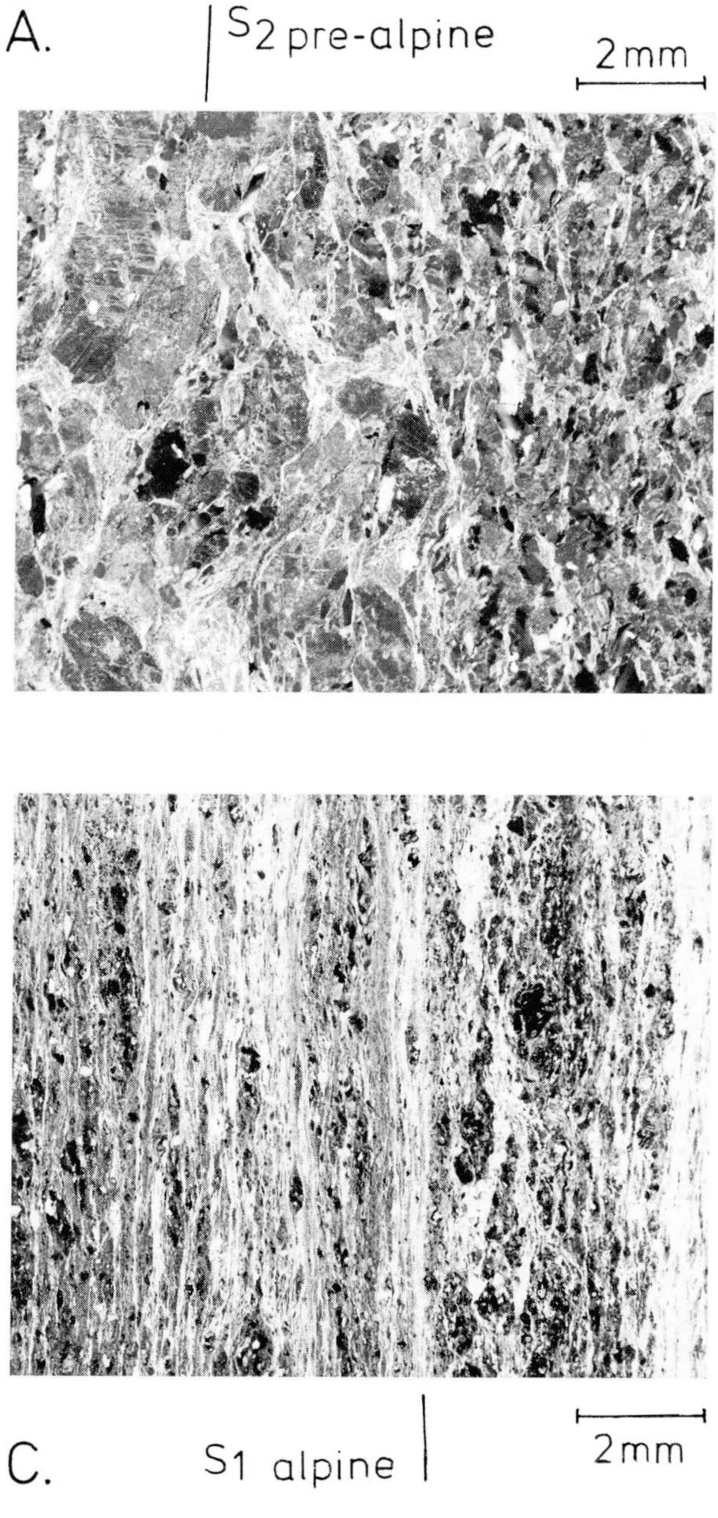
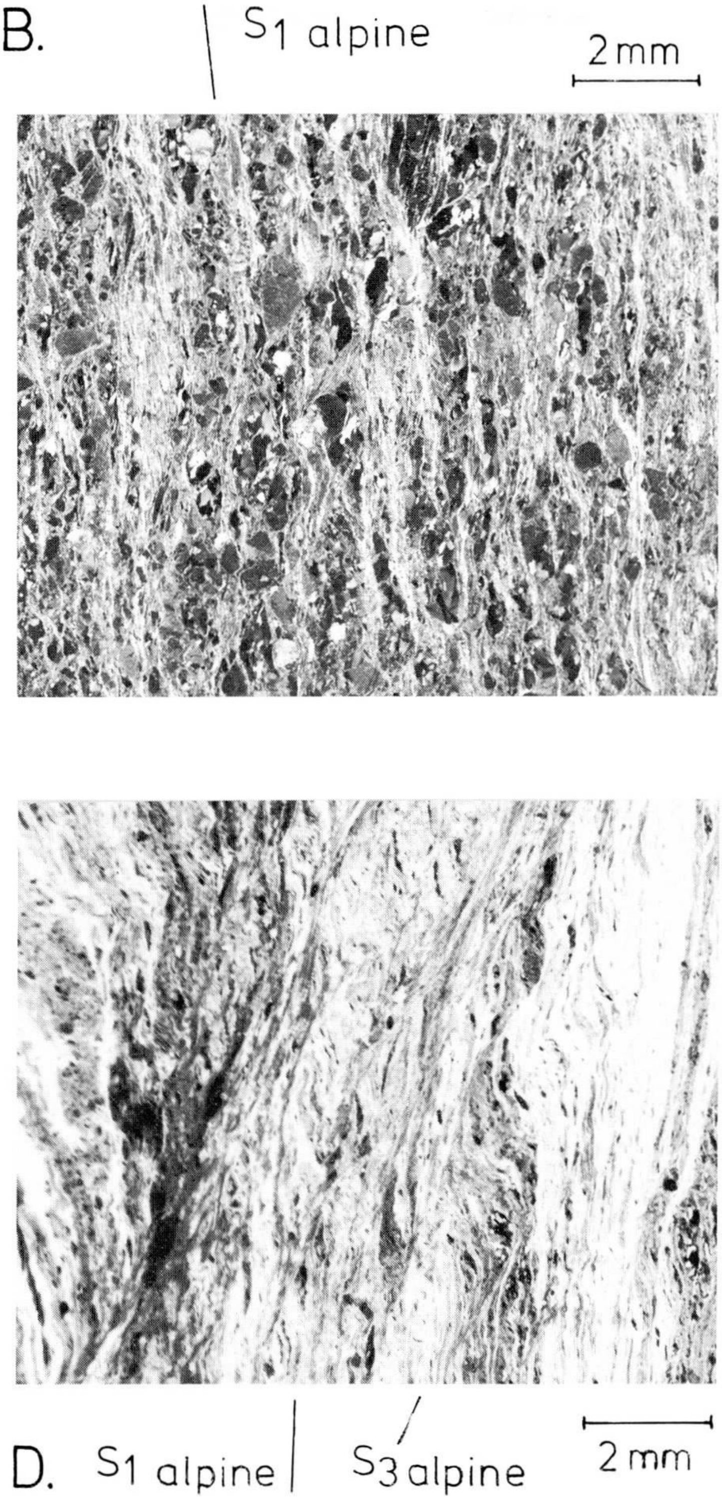


Fig. 4 Pre-alpine gneisses and alpine mylonites at the Insubric Line (Val Loana): Increasing alpine mylonitization from SE to NW (from A to D) within Ivrea gneisses. The letters A–D point to the locations of the four samples in plate 1. The thin section photographs are oriented with their left sides to the SE and their right sides to the NW.



A. Sample 1995 B (R 459.08 / H 5101.57); quartz-plagioclase gneiss; An = 27%. B. Sample 1997 (R 459.07 / H 5101.78); quartz-plagioclase-muscovite gneiss; An = 0–10%. C. Sample 1998 (R 459.06 / H 51.01.80); quartz-plagioclase-muscovite gneiss; An = 6–10%. D. Sample Ha 232 (R 459.03 / H 51.1.86); quartz-plagioclase-muscovite gneiss.

oclinic folds, but with the opposite vergency (Fig. 2). Pegmatites with a thickness of up to some meters and – in the NE – amphibolitic layers are bent round this fold. The SE-limb is strongly flattened and thinned down to a ca. 100 m wide s_3-shear-zone. The sense of shearing at distinct shear planes in this zone fits, as far as recognizable, the required vergency within this SE-limb of the large fold. The shearing might be caused by the compact amphibolites close by. Further SE within kinzigitic rocks, gneisses and amphibolites second order folds of the third deformation show the same vergency. That points to the fact that there is no general conversion of the folding, i.e. the wavelength of this large third fold should be at least some km.

The trace of axial plane of B_3 is outlined in Fig. 2. It strikes about 60°, from Alpe Cortevecchio in the NE to Alpe Scaredi and then approximately parallel to Rio Portaiola down to the Val Grande in the SW.

Some of the ultramylonites within the kinzigitic rocks SE of Alpe Scaredi even cut these third folds. It is not quite certain if they still belong to the last stage of that pre-alpine/alpine event or even to the low-temperature stage of the subsequent alpine deformation further NW.

ALPINE DEFORMATION

From Alpe Scaredi towards the NW to Alpe Cortenuovo we come into a wide shear zone, which starts with distinct shear planes about 100 m NW of Scaredi, reaches a maximum intensity at about 50 m SE of Cortenuovo and slowly decreases towards the NW. To the NE and to the SW, the northwest margin of the Ivrea Zone is accompanied by this shear zone. This shearing may be related to a *first alpine deformational event* in the northerly adjacent Gneiss Zone («Alpine Root Zone») (ALTENBERGER et al.). NW of Alpe Scaredi this first alpine deformation overprints the pre-alpine gneisses which are bent round that large third fold of pre-alpine or alpine age. In Fig. 4 this continuous process of increasing mylonitization is presented. In these pre-alpine rocks between Alpe Scaredi and Alpe Cortenuovo indeed alpine shear planes are approximately parallel to the pre-alpine s_2, but muscovite, formed during and after the second pre-alpine deformation, is folded and sheared in these mylonites (see section metamorphism), and the new stretching direction (= $str_{1\text{-alpine}}$) is completely different from the old pre-alpine one: $str_{1\text{-alpine}}$ shows a plunging from flat SW to horizontal and flat NE, according to $str_{1\text{-alpine}}$ in adjoining areas to the NE and SW along the NW-margin of the Ivrea Zone. In unaffected bands between the alpine shear planes sometimes the steeply plunging pre-alpine str_2 (plagioclase, muscovite) is preserved.

In this alpine shear zone with increasing mylonitization the amount of muscovite increases, plagioclase is broken and drifted apart, and quartz recrystallizes.

Further to the NW, the intercalated lenses of blue and white marble and even a dolomitic layer are affected by the mylonitization.

From these deformational features we come to the conclusion that at the end of Val Loana between Scaredi and Cortenuovo the alpine deformation dies within 50-100 m towards the SE. How far to the SE the alpine mylonites are present within the Ivrea gneisses cannot be determined with certainty. But we may expect distinct alpine shear planes at least some km to the SE.

At Cortenuovo the alpine s_1 is intersected by later cleavage planes (Fig. 4D) and bent around open folds in the cm range. This is a *third alpine deformational event* which has produced large folds in the 100 m range in the «Alpine Root Zone» further to the SW and to the NE (KRUHL & VOLL 1976, KRUHL 1979). In this part of the mylonitic zone the alpine s_2 as a result of the second alpine deformation is not developed. The third deformation continues the rotational deformation of the first alpine event (clockwise, viewed along the fold axes to the NE). The third alpine cleavage ($s_{3\text{-alpine}}$) forms distinct shear planes with 3-10 mm distance; third folds ($B_{3\text{-alpine}}$) within the mica-rich mylonites show angles between the limbs of about 50°, their axes are always parallel to str_1, i.e. they dip flatly SW to NE. Within the mylonites a third alpine stretching is not developed. Quartz recrystallizes during the third deformation and forms small new grains up to 0.03 mm in diameter.

This third alpine deformation does not only fold the alpine mylonites at the northern margin of the Ivrea Zone but also overprints the pre-alpine Ivrea rocks towards the SE. At least as far as 500 m into the Ivrea Zone $s_{3\text{-alpine}}$ occurs and cuts the pre-alpine structures: Large third folds do not occur, but the sense of rotation along $s_{3\text{-alpine}}$-planes remains the same as in the «Alpine Root Zone». Especially in the SE-limb of the large fold around Scaredi the cleavage planes related to this fold may be distinguished from $s_{3\text{-alpine}}$ because of the different sense of intersection with $s_{2\text{-pre-alpine}}$ (Fig. 2). How far to the SE the third alpine deformation overprints the rocks of the Ivrea Zone has not yet been determined.

Late alpine tectonic events produced mainly systems of kinkbands and faults which also influence the northwest margin of the Ivrea Zone. That system of kinkbands and faults striking NW-SE is dominant. The sense of shearing is clockwise in general (Fig. 2). Some of the faults run approximately parallel to the metamorphic banding. For example there is a distinct fault north of the mylonite zone which continues to the NE and SW. It is a result of late movements in the mylonite zone with decreased temperatures, and there are no important displacements.

PRE-ALPINE METAMORPHISM (AND ITS RELATIONSHIP TO THE DEFORMATION)

Textures and mineral parageneses of the kinzigitic rocks and gneisses reflect conditions of at least upper amphibolite facies. Within the kinzigitic gneisses the parageneses are influenced by relative abundance of Si and Al. Up to 20 Vol-% garnet (pyrope-almandine) and up to 10 Vol-% sillimanite are present. Together with intensely red-brown Ti-rich biotite, quartz, K-feldspar, and oligoclase with exsolved microcline they form a coarse granoblastic paragenesis which is stable during the *first pre-alpine deformation*. Quartz and plagioclase show embayed structures.

Fibrous sillimanite crystals are formed parallel to s_1 and in close connection to biotite, and then - probably with further increasing temperatures - coarse sillimanite crystals. The production of this fibrous sillimanite might have occurred as a reaction quartz + muscovite + Mg-chlorite $\rightleftharpoons$ biotite + sillimanite + H_2O (WINKLER 1979, p. 227) during an early stage of metamorphism or eventually as an exsolution of the muscovite-component of biotite (WINKLER 1979, Fig. 5–6) and subsequent reaction with quartz:

muscovite + quartz $\rightleftharpoons$ sillimanite + K-feldspar + H_2O.

Both reactions could explain the close connection between biotite and sillimanite and should have occurred in the upper amphibolite facies.

During the *second pre-alpine deformation* the feldspars still suffer plastic deformation, are flattened parallel to s_2, recrystallize, and grow up again during times of static annealing. The fibrous sillimanite is bent round B_2 and afterwards is enclosed by coarse biotite and K-feldspar crystals (Fig. 5), which essentially remain undeformed. After this early stage of the second pre-alpine deformation pegmatites intrude parallel to s_2, which are later affected by greenschist facies deformation. The breakdown of sillimanite & K-feldspar, which can be described with the reaction

sillimanite + K-feldspar + H_2O $\rightleftharpoons$ muscovite + quartz (Fig. 5),

occurs during and at the end of the second deformation. The necessary amount of H_2O to induce this reaction during retrograde metamorphism could have been introduced along s_2 shear zones. Some muscovite crystals are still oriented parallel to s_2, but most of them are not. Nevertheless they are affected by the following third deformation. This implies that the muscovite is of pre-alpine age and without any relation to the alpine deformation and metamorphism overprinting the northwest margin of the Ivrea Zone.

Along the s_2-parallel shear zones, coarse plagioclase, K-feldspar and garnet often suffer brittle deformation: they are broken and drifted apart. Quartz is plastically deformed and shows small recrystallized grains (with up to 0.1 mm diameter); sometimes even quartz is broken. Garnet is chloritized, and chlorite crystals are formed parallel to str_2. The s_2-parallel shear zones reflect to a large extent deformation during decreasing temperatures.

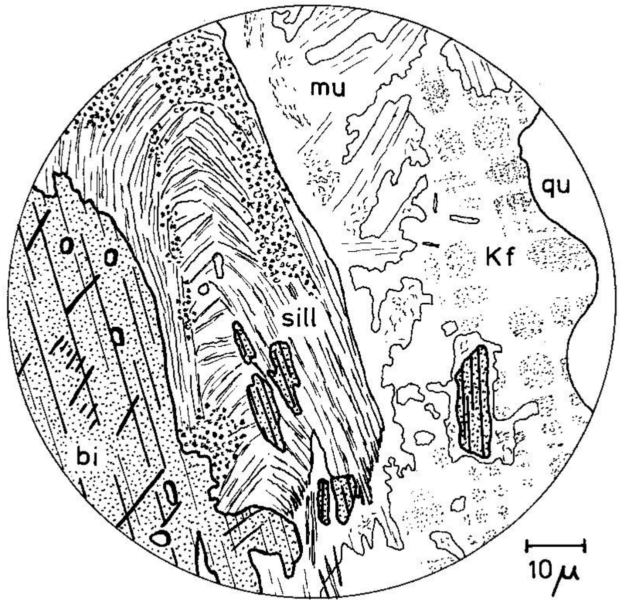


Fig. 5 Kinzigitic gneiss of the Ivrea Zone: with Ti-rich biotite (bi), sillimanite (sill) isoclinally folded around $B_{2\text{-pre-alpine}}$, K-feldspar (Kf) and quartz (qu) with typical embayed boundary, and with muscovite, newly grown at the boundary between K-feldspar and sillimanite. Thin section drawing of sample 1978 (R 460.77/H 5101.17).

In the amphibolites the paragenesis of green hornblende & oligoclase-andesine is stable during the second deformation.

All this leads to the conception that the second deformation began under upper amphibolite facies conditions, then developed mainly during amphibolite and greenschist facies conditions, with decreasing temperatures, and finally subsided in the lowest part of greenschist facies. According to the model of tilting and upward thrusting of the Ivrea Zone (HUNZIKER & ZINGG, 1980, a.o.) all these movements related to the uplift should belong to the second pre-alpine deformation.

During further declining temperatures the third *pre-alpine/alpine* deformation took place. In kinzigitic rocks and gneisses biotite crystals exsolute sphene, are bleached and altered to chlorite. Garnet too is chloritized. Biotite and muscovite are bent and kinked round B_3, plagioclase is broken, and quartz shows an intensely wavy extinction together with polygonization and sometimes marginally starting recrystallization, indicating temperatures of somewhat less than 300° C (VOLL 1976). Chlorite is newly grown between the fragments of broken feldspars and between the widened basal planes of muscovite and biotites in the crests of small third folds.

Within the s_3-parallel very low temperature mylonites, muscovite is sheared to small particles and quartz recrystallized grains of the second deformation are extremely flattened and stretched, mainly without new recrystallization.

ALPINE METAMORPHISM (AND ITS RELATIONSHIP TO THE DEFORMATION)

The conditions of metamorphism in the «Alpine Root Zone» northwest of the studied area and the relationship to the deformation are described by KRUHL & VOLL (1976), KRUHL (1979), and ALTENBERGER et al. In these papers it is shown that the mylonitization at the southern margin of the «Alpine Root Zone» occurred at decreasing temperatures in the upper greenschist facies of the Lepontine metamorphism.

The pre-alpine gneisses northwest of Alpe Scaredi are overprinted by this alpine metamorphism: With the beginning of the strong mylonitization towards the NW the pre-alpine oligoclase crystals change to albite. In the beginning, only their margins are diffusionally altered to albite at distinct alpine shear planes, and clinozoisite and calcite are set free. Then all the oligoclase is albitized. This never occurs in the pre-alpine mylonites of the second and third deformation towards the SE.

About 300 m to the NW we pass the alpine oligoclase boundary, where albite is altered to oligoclase, i.e. an alpine maximum temperature of about 500° is reached (VOLL, 1968). The alpine maximum temperature in the mylonites at the southern margin of the «Alpine Root Zone» between Finero and Val d'Ossola is given by ca. 480° C (KRUHL 1979, ALTENBERGER et al.). The mylonitization outlasts this maximum temperature and still occurs during decreasing temperatures.

This leads to temperatures of about 350° C for the following third alpine deformation: Coarse muscovite is bent round B_3, quartz is plastically deformed, polygonized, and recrystallized with diameters of 10–50 μ. The recrystallized grains are oriented with their flat sides parallel to $s_{3\text{-alpine}}$.

DISCUSSION

In Fig. 3 rough overview is given on the development of pre-alpine and alpine deformation and metamorphism at the northwest margin of the Ivrea Zone at Val Loana.

The first pre-alpine deformation occurred under conditions of at least the upper amphibolite facies.

The second pre-alpine deformation occurred during continuously decreasing temperatures in the amphibolite and greenschist facies. This is shown by the change of parageneses and by the continuous change of structural features from metamorphic banding and mineral orientation induced by plastic deformation to low temperature shear zones with brittle deformation. At the southern end of Val Loana the change of parageneses is bounded to those rocks strongly affected by shear movements during the second pre-alpine deformation. For example the formation of coarse muscovite during the second pre-alpine deformation is related to broad zones with increased deformation. These zones are apparently situated at some places within the Ivrea body and are not related to any alpine overprinting.

The second pre-alpine deformation at the S-end of Val Loana may also be related to the second deformational event of the Finero complex: Strain system and conditions of metamorphism are roughly the same (KRUHL & VOLL 1976, 1976a, b). Especially s_2-parallel shear zones during decreasing temperatures are developed in both areas.

The third pre-alpine/alpine deformation again ocurred during decreasing temperatures, in the range of very low grade metamorphism.

The most striking effect of this deformation is a large fold in the km-range with the core around Alpe Scaredi, a fully developed NW-limb and a thinned and sheared SE-limb within pre-alpine gneisses (Fig. 2., plate 1). This fold is a continuation of the Finero Antiform (LENSCH 1968, KRUHL & VOLL 1976a, b): Both folds belong to the third pre-alpine/alpine deformation and show the same grade of metamorphism. The orientations of the axial planes of both folds coincide and the fold axes show similar directions - although the subvertical axes around Alpe Scaredi are more influenced by the pregiven unisotropy of the Ivrea gneisses than the 40–60° SW plunging fold axes at the SW-end of the Finero Complex, which might be influenced by the third alpine deformational event (KRUHL & VOLL 1979a, b).

Presumably we may trace this fold towards the SW, to the Val d'Ossola, and relate it to the northern of those two folds found by SCHMID (1966, 1967) between Val d'Ossola and Val Grande. That implies that by the third pre-alpine/alpine deformation an anticline structure was produced which follows the northwest margin of the Ivrea Zone from at least the end of the Finero Complex in the NE to the Val d'Ossola in the SW (as already supposed by SCHMID, 1966), i.e. over a minimum distance of about 35 km.

It is clear that this large fold is not related to the third alpine deformation in the «Alpine Root Zone»: Neither the orientation of the fold axes nor the fact that the pre-alpine/alpine B_3 is isoclinal fits the alpine B_3, and the grade of metamorphism is slightly different. Otherwise at those points where the alpine B_3 affects the rocks of the Ivrea Zone the third pre-alpine/alpine fold is cut by the alpine s_3, i.e. is clearly older than the third alpine deformation. But we cannot exclude that this large fold around Alpe Scaredi was formed at the same time as the first or even second folds of alpine age now exposed in the «Root Zone» further to the NW, however more far away and in a different level of the crust.

In general it is still uncertain whether the third deformation near Finero, as well as at Val Loana, is of pre-alpine or early alpine age. In other words, till now it is not clear if this deformation is a continuation and ending of that deformational process in the Ivrea Zone which started at a high grade of metamorphism and then occurred during decreasing temperatures down to a very low grade stage; or if it is a completely independent event of probably alpine age only related to the pregiven unisotropy of the Ivrea rocks.

The strong mylonitization of the Ivrea gneisses northwest of Alpe Scaredi belongs to the alpine Lepontine phase. Its structural features are completely different from the pre-alpine ones and may be related to those of the «Alpine Root Zone» further to the NW. In this mylonite zone a strip of the Ivrea Zone, up to 200 m wide, is reworked and overprinted by alpine deformation and metamorphism. Contrary to the area around the Finero, the southern boundary of Lepontine phase at Val Loana is not a distinct tectonic plane but a narrow zone with a continuous transition of deformation and metamorphism. Nevertheless we may name the SE-boundary of this zone, where alpine metamorphism (change from oligoclase to albite) and the strong alpine deformation starts, the south boundary of alpine events, i.e. Insubric Line.

From this point of view, other definitions of the Insubric Line i.e. as a late fault at the NW-margin of the mylonite zone (AHRENDT, 1980), are rather meaningless. If the character of the Insubric Line as interface between the Central Alps and the Southern Alps is accepted, this lineament should be placed there, where the Central Alps are joined to the Southern Alps, i.e. where the alpine deformation and metamorphism die towards the south. At Val Loana this takes place at the southern boundary of the mylonite zone.

The third alpine deformation of low to very low grade metamorphism overprints the mylonites of the Insubric Line at Val Loana in the same way as, for instance, further NE at Finero (KRUHL & VOLL 1976, 1979a). Its effect on the NW-margin of the Ivrea Zone is limited to the formation of distinct shear planes without major change of mineralogical composition and structure of the total rock sequence. Therefore it seems to be useful not to include this area with the alpine metamorphic region.

Acknowledgements

Financial support for the field work was provided by the Deutsche Forschungsgemeinschaft (DFG). I thank H. v. Platen for helpful discussions and R. Yadav and H. Newsom for correcting the English.

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Revised manuscript received 8 May, 1984.

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Insubric Line & northern margin of the Ivrea Zone

plate 1

between Alpe Cortenuovo and Cima della Laurasca, Val Loana (Prov. Novara, N-Italy)