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Post-amphibolitic westward thrusting and fold vergence in the Ticino domain

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ABSTRACT

A westward overthrusting phase is recognized in the Pennine zone from Biasca to Bosco-Gurin. It developed mylonites which reveal a horizontal shearing towards the west. This deformation postdates the major amphibolitic deformation and is associated with a decreasing temperature. The Maggia steep zone and the Bosco-Gurin area are structurally reinterpreted in the light of this westward deformational event. The Maggia steep zone corresponds to a major post-nappe fold overturned towards the west. The Bosco-Gurin area corresponds to an overthrusting of the Antigorio granite towards the west. This westward overthrusting could be related to the major uplift of the Ticino domain at around 20 Ma.

RÉSUMÉ

Une phase de déformation E–W est décrite dans le domaine pennique des Alpes centrales. Cette déformation ductile, visible de place en place, est associée à des mylonites qui indiquent un cisaillement intense vers l'ouest. Ces cisaillements sont postérieurs à la déformation amphibolitique majeur qui correspond à des mouvements tangentiels vers le domaine externe. Les conditions pression–température, difficile à évaluer par l'analyse des seules lames minces, correspondent au trajet rétrograde du métamorphisme régional. A la lumière de cette déformation E–W, la zone verticale de Maggia est décrite comme un pli post-nappe déversé vers l'ouest, et le redoublement du granite d'Antigorio dans la région de Bosco-Gurin comme un chevauchement vers l'ouest. Cette déformation pourrait être reliée au soulèvement majeur du domaine Tessinois enregistré vers 20 Ma.

Introduction

The Pennine zone is part of the European crust which has been intensely deformed during the upper Cretaceous and Tertiary collision of two large plates, Europe and Africa (e.g. Argand 1911, Milnes 1978, Hsü 1979, Trümpy 1980). Slices of Hercynian basement, interleaved with Mesozoic cover, have undergone polyphase Alpine deformation and metamorphism (Schmidt & Preiswerk 1908). A Tertiary high-temperature episode has been well recorded throughout the zone, but the timing of metamorphic events is a matter of controversy (e.g. Hunziker 1970, Jäger 1973, Köppel & Grünenfelder 1978, Deutsch & Steiger 1985). Both Hercynian basement and Mesozoic cover of the Central Alps show intense ductile strain developed during metamorphic conditions of amphibolite grade. Composite foliation is usually flat-lying in the Simplon and Ticino domains and stretch directions exhibit a radiating pattern (Merle & Cobbold 1986), previously described for folds by Wenk (1955). Kinematic indicators of amphibolite grade indicate

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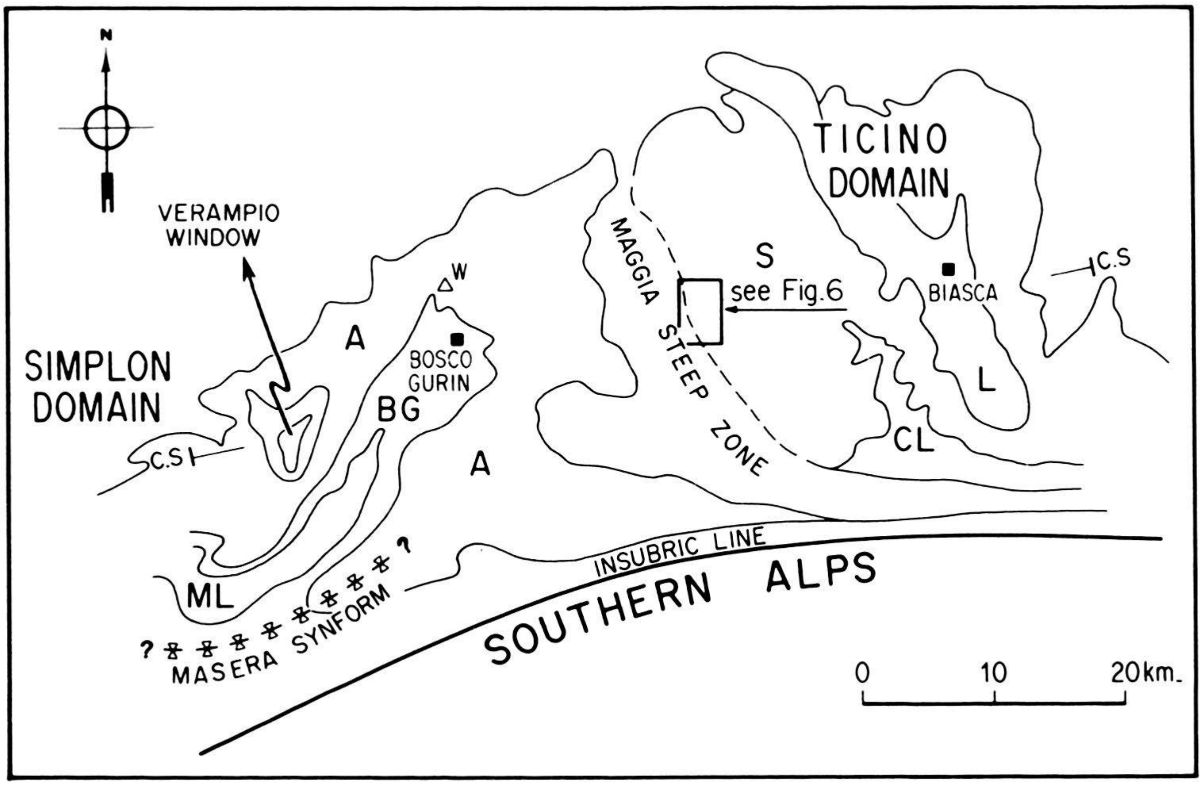


Fig. 1. Simplified geological map of the Pennine zone (A = Antigorio nappe, L = Leventina gneiss, S = Simano nappe, CL = Cima Lunga unit, BG = Bosco-Gurin unit, ML = Monte Leone nappe, W = Wandfluhhorn). The location of the geological cross section of Figure 5 is indicated.

overthrusting towards the European foreland in the lineation direction i.e. north and northwest in the Ticino and Simplon domains, respectively. A detailled study of the major deformation coeval with the high temperature episode will be published elsewhere (MERLE et al., submitted).

In the Simplon domain, a post-amphibolitic ductile deformation has been recognized along the Simplon line (the Simplon phase of MANCKTELOW 1985, MERLE et al. 1986, MANCEL & MERLE 1987) and towards the Verampio window (STECK 1980, 1984, MERLE 1987). Kinematic indicators of greenschist grade reveal a radial displacement of higher units towards the S–SW in the Verampio window and towards the W–SW at the Simplon line (MERLE 1987, MANCKTELOW 1985).

The Ticino and Simplon domains are separated by a steep zone of N–S trend (Fig. 1), named the Maggia-Querzone (i.e. oblique zone) by PREISWERK (1918). This steep zone curves towards the south into parallelism with a vertical belt of E–W trend next to the Insubric line. To the west of the Maggia steep zone, in the Bosco-Gurin area, foliation planes become less steep and the Antigorio granite shows a vertical duplication which has been interpreted as a major post-nappe fold (HALL 1972, MILNES 1974). The aim of this paper is to provide new field data and a new structural interpretation of this intermediate domain and, thus, to contribute to the discussion of a very problematic area. Some structures and deformations observed in the field will be interpreted as due to westward thrusting and folding, postdating the high temperature deformation of amphibolite grade. The present work demonstrates that 1. an E–W deformation phase is responsible

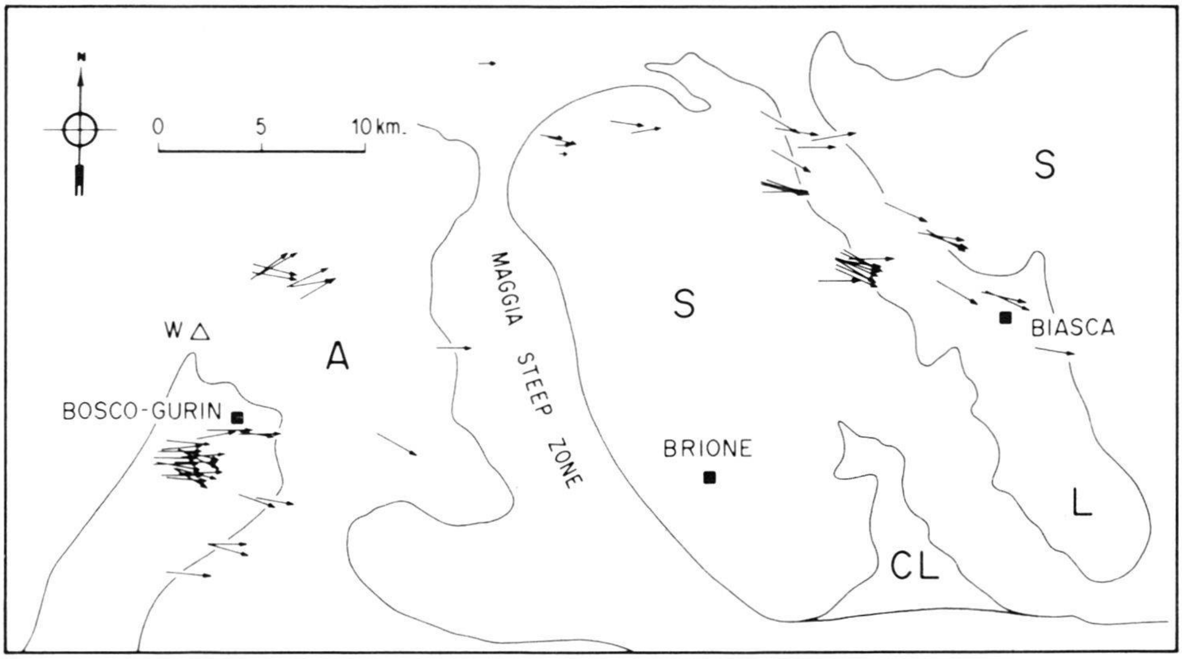


Fig. 2. Stretching lineations map of the westward phase. The measurement location coincides with the center of the arrow. Length of arrow is inversely proportional to plunge in degrees.

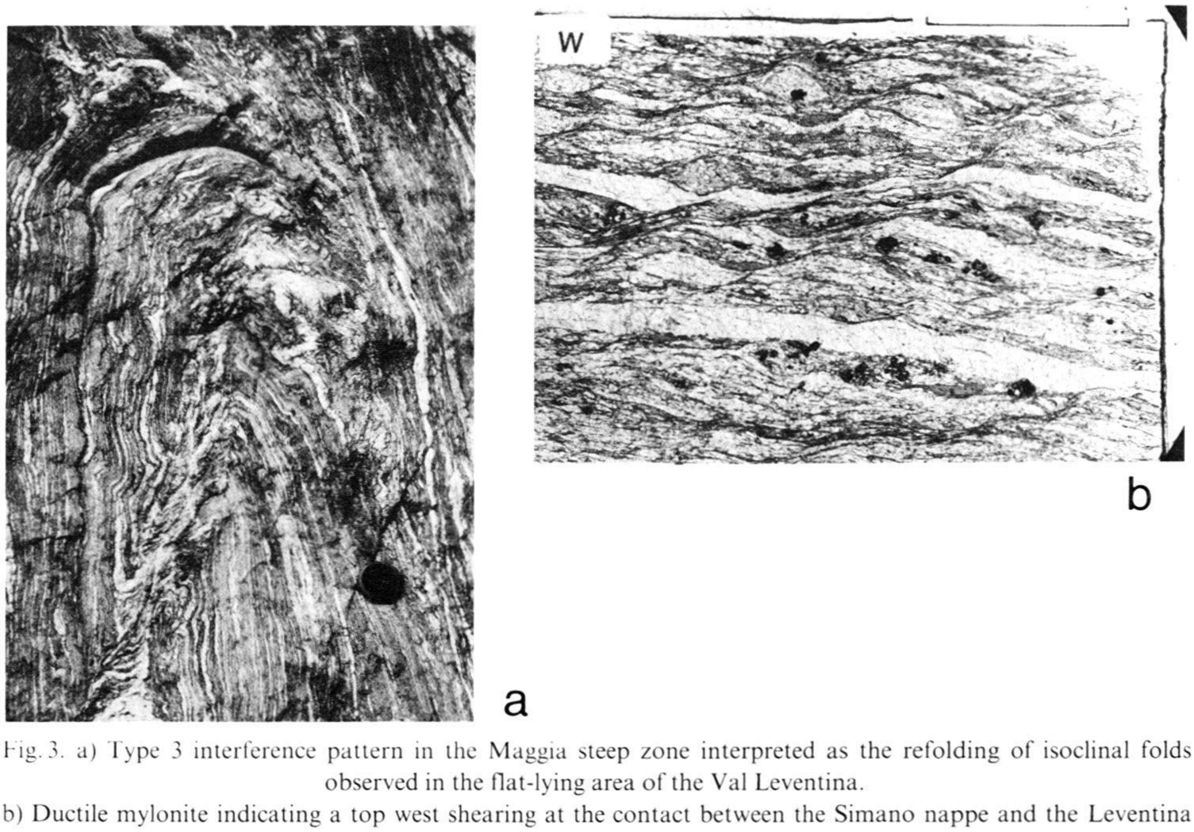


Fig. 3. a) Type 3 interference pattern in the Maggia steep zone interpreted as the refolding of isoclinal folds observed in the flat-lying area of the Val Leventina.

b) Ductile mylonite indicating a top west shearing at the contact between the Simano nappe and the Leventina gneiss. Note the grain shape fabric within quartz ruban indicative of dynamical recrystallization by grain boundary migration (scale bar: 1 cm).

for the refolding of earlier foliation planes and stretching lineations and that 2. the finite structural pattern can no longer be interpreted as the result of deformation associated with the high temperature episode alone.

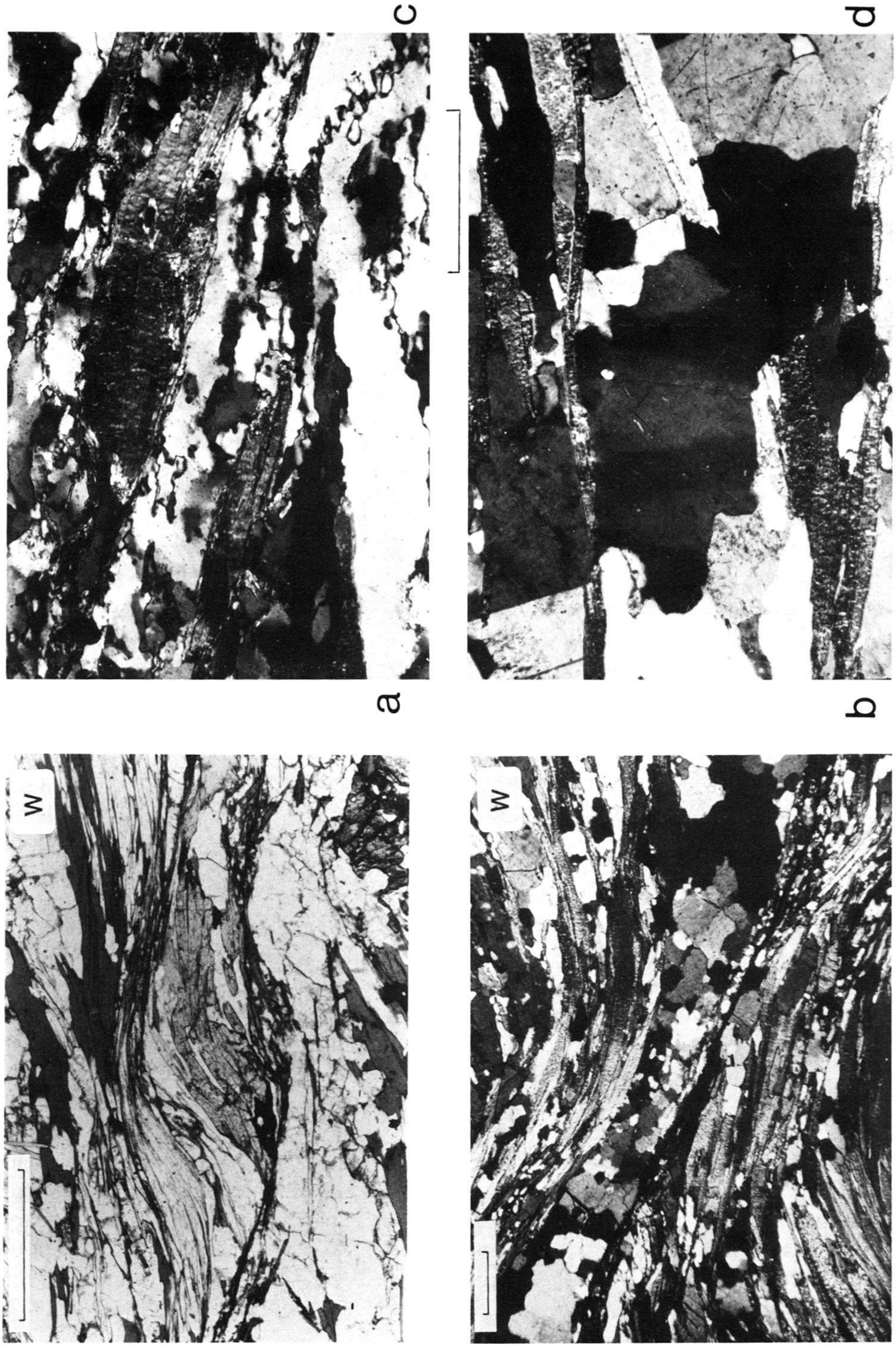
The westward overthrusting phase

A second consistent pattern of E–W stretching lineations is observed and is superimposed on the high temperature stretching lineations (Fig. 2). This second internal strain is scarce on the scale of the zone but is frequently associated with ductile mylonites. The shearing sense can be determined at outcrop or from thin sections and corresponds to a top west shearing (Fig. 3b). C/S structures (Berthe et al. 1979, Platt & Vissers 1980, Gapais & White 1982, Simpson & Schmid 1983) are the most common shear criteria within those mylonites and are of remarkable consistency from Bosco-Gurin to Biasca.

The westward deformation is associated with a decreasing temperature. Pressure-temperature conditions cannot be determined with complete accuracy from thin sections. Optical observations show that the main folliation is defined by a quartz + plagioclase + muscovite + biotite + straurolite + kyanite assemblage. According to the petrogenetic grid of Harte & Hudson (1979), this paragenesis indicates P–T conditions at around 650 °C, 6–10 kbar. These P–T conditions are contemporaneous of the top North shearing (Merle et al., submitted). In contrast, westward shear bands are clearly later than the growth of garnet, staurolite or kyanite porphyroblasts (Fig. 4a). Moreover, chloritic aggregates are often localized within microscale shear bands. The quartz microstructures nicely document that the closing stages of deformation occurred at lower temperature. The different recrystallization behaviour of quartz in thin section displays clearly high-temperature microstructures outside shear bands and lower temperature within shear bands (Fig. 4b, c and d). Tabular grains with more or less equilibrated grain boundaries are observed outside shear bands whereas the suturing of grain boundaries within shear bands developed very small grains. The change in grain size of recrystallized grains is especially well documented in thin sections. A cold overprint producing deformation bands is sometimes observed outside shear bands. These features indicate that the westward deformational event took place during retrograde metamorphic conditions. Brittle shear bands can also be observed at some places, especially in the Maggia steep zone. The sense of displacement is then always consistent with the one deduced from ductile shear bands. The association of ductile and brittle shearing structures can be attributed to a drop in temperature during the westward deformation.

At the scale of the study area (Fig. 7a), foliation trends show a complex pattern which probably results from the interference of at least two superimposed deformation. From the structural data available, a westward phase in the Pennine zone and a dextral

Fig. 4. Microstructures within ductile mylonites indicating that the top west shearing developed during retrograde metamorphic conditions. a) A kyanite porphyroblast bent between two dextral shear bands (scale bar: 0.20 cm). Sample located at the contact between the Simano nappe and the Leventina gneiss. b and c) Change in grain size of quartz grain within microscale shear bands. The suturing of grain boundaries within shear bands indicate a low temperature deformation (b, scale bar: 0.46 mm; c, scale bar: 0.236 mm). d) Quartz microstructures outside shear bands indicate a high temperature deformation. Note, however, a cold overprint producing deformation bands (scale bar: 0.236 mm). b, c and d from ductile mylonites located at the contact between the Antogorio granite and the Bosco-Gurin unit.


a
b
c
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W
W

transcurrent shearing at the contact between both tectonic plates (e.g. ZINGG & SCHMID 1983, SCHMID et al. 1987) seem good candidates to explain this structural pattern. The data are insufficient, however, to determine the relative timing between westward and dextral transcurrent phases. As both events postdate the major deformation of amphibolite grade, and as no evidence has been found to indicate that one deformation is superimposed on the other, we suggest that both deformations may have approximately the same age. Yet it is usually assumed that the dextral shearing occurred during a long period related to the Tertiary kinematics of the Adriatic subplate, whereas the westward phase is likely to have occurred during a shorter period corresponding to the rapid cooling of the rocks recorded from geochronological data (see HURFORD 1986). That is to say that dextral shearing probably both predates and outlasts the westward thrusting and folding in the Pennine zone. We return to this problem later.

The Maggia steep zone

An E–W geological cross section (Fig. 5) shows that the Maggia steep zone can be interpreted as a large post-nappe fold overturned towards the west. The structure is due to refolding of earlier foliation planes defined by minerals indicative of amphibolite grade metamorphism. The major antiformal structure trending N–S is well exposed in the field around the Passo del Redorta and northwards to the Triangolino (Swiss national grid 698.8/135.8). The flat-lying foliation rapidly becomes vertical without any significant associated internal strain. A crenulation cleavage is visible from place to place (SIMPSON 1982), but only rarely is any sort of axial plane cleavage to be seen. Minor folds are widespread in the steep zone and are also overturned towards the west (Fig. 6). Occasional interference patterns could be due to refolding of earlier folds described in the flat lying area and associated with movements towards the north and the northwest. Type 3 interference patterns (RAMSAY 1967) are the most common (Fig. 3a) but some eye structures have also been observed. The major syncline is not observed in the field but has been inferred from basement nappes relationships. As previously mentioned, the Maggia steep zone apparently developed without significant internal strain. Occasional shearing structures are consistent with westward overturning of the Maggia zone. It seems that strain during folding has been mainly restricted to the contact between major basement units (Fig. 4 and 5). Thus mylonites at least 10 m thick occur at the contact between the Leventina gneiss and the Simano nappe (Swiss national grid 706.2/141.45). Horizontal shearing seems to have occurred during Maggia folding and to have become localized at the contact between major units. Some cataclasite rocks described along the Leventina–Simano contact (IROUSCHEK & HUBER 1982) could indicate that this deformation lasted under brittle conditions.

Towards the southern steep zone, it is now well established that dextral transcurrent shearing has been strongly localized at the contact between both tectonic plates, European and Adriatic subplate. This shearing can be explained in terms of the Tertiary kinematics of Adriatic subplate (LAUBSCHER 1971, MALAVIEILLE et al. 1984, CHOUKROUNE et al. 1986). Dextral shear criteria have been described along much of the Insubric line (COBBOLD 1980, ZINGG & SCHMID 1983, SCHMID et al. 1987, MERLE 1987, HEITZMANN 1987).

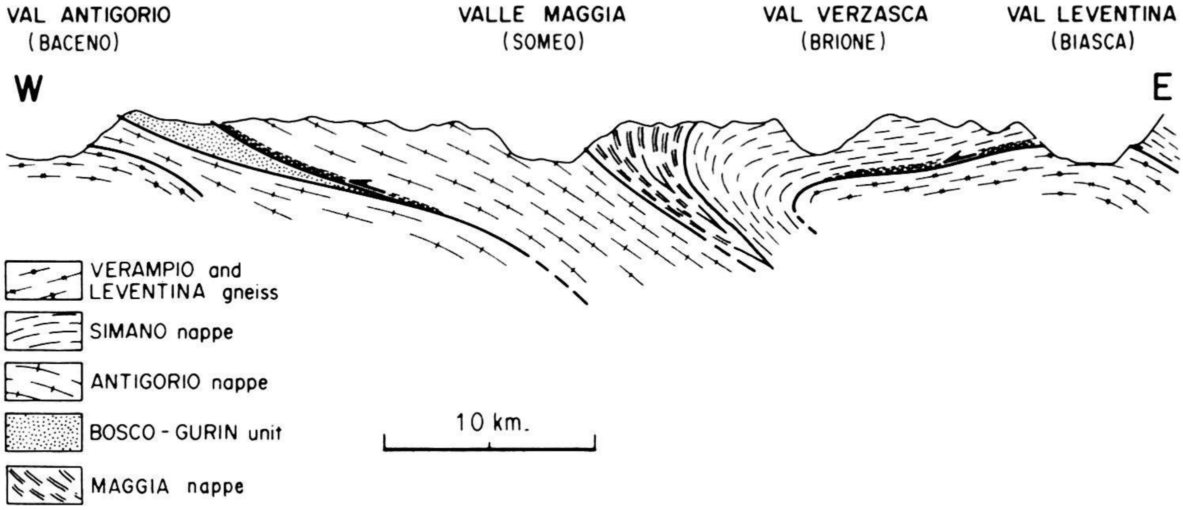

Fig. 5. General geological cross section from the val Leventina to the Verampio window. Note the mylonites at the contact between major units, revealing an intense shear deformation with the upper block moving towards the west.

The Bosco-Gurin thrust

The duplication of the Antigorio granite visible on geological maps and cross sections has been previously ascribed to a post nappe fold, whose southeast trending hinge is well exposed at the Wandfluhhorn locality (HUNZIKER 1966). Some authors have inferred that the upper granitic sheet could correspond either to the normal limb of an antiform facing northeast (HALL 1972) or to the inverted limb of a synform facing southwest (MILNES 1974). Both of these authors described the nappe pile on one side of the axial surface as the inverted equivalent of that on the other. The basement nappes of the Simplon group were then reinterpreted in the light of the following bold hypothesis: a syncline would exist in the Simplon domain and all basement units located above the axial surface (i.e. Monte Leone and Berisal nappes) would correspond to those located below it (MILNES 1974). We would like to present strain data collected in the Bosco-Gurin area which does not support such an hypothesis but leads to a new and simpler structural one.

The Bosco-Gurin area displays a well developed E–W trending stretching lineation (Fig. 2). On foliation plane of constant attitude, the trend of stretching lineation may locally changes progressively from N130E to N90E at outcrop scale. This strongly suggests that the earlier amphibolitic lineation (trending N130E in average) has been reoriented into the new direction of stretching. Homogeneous strain is recorded in the core of the granite and no clear shear criteria can be seen within it, except at the contact between the upper granitic sheet and the underlying paragneisses (i.e. the Bosco-Gurin unit). Strain increases markedly towards the base of the granite and within Bosco-Gurin units which become mylonitic in thin zones (Swiss national grid 678.3/128.8). The sense of shearing is again particularly obvious and indicates overthrusting towards the west (Fig. 4b, c and d).

On this basis, we interpret the duplication of the Antigorio granite as due to overthrusting towards the west (Fig. 5). The internal strain associated with this overthrusting is mainly recorded within the highly ductile levels of the Bosco-Gurin unit. Further field works are then necessary to map the exact location of the thrust which probably occurred

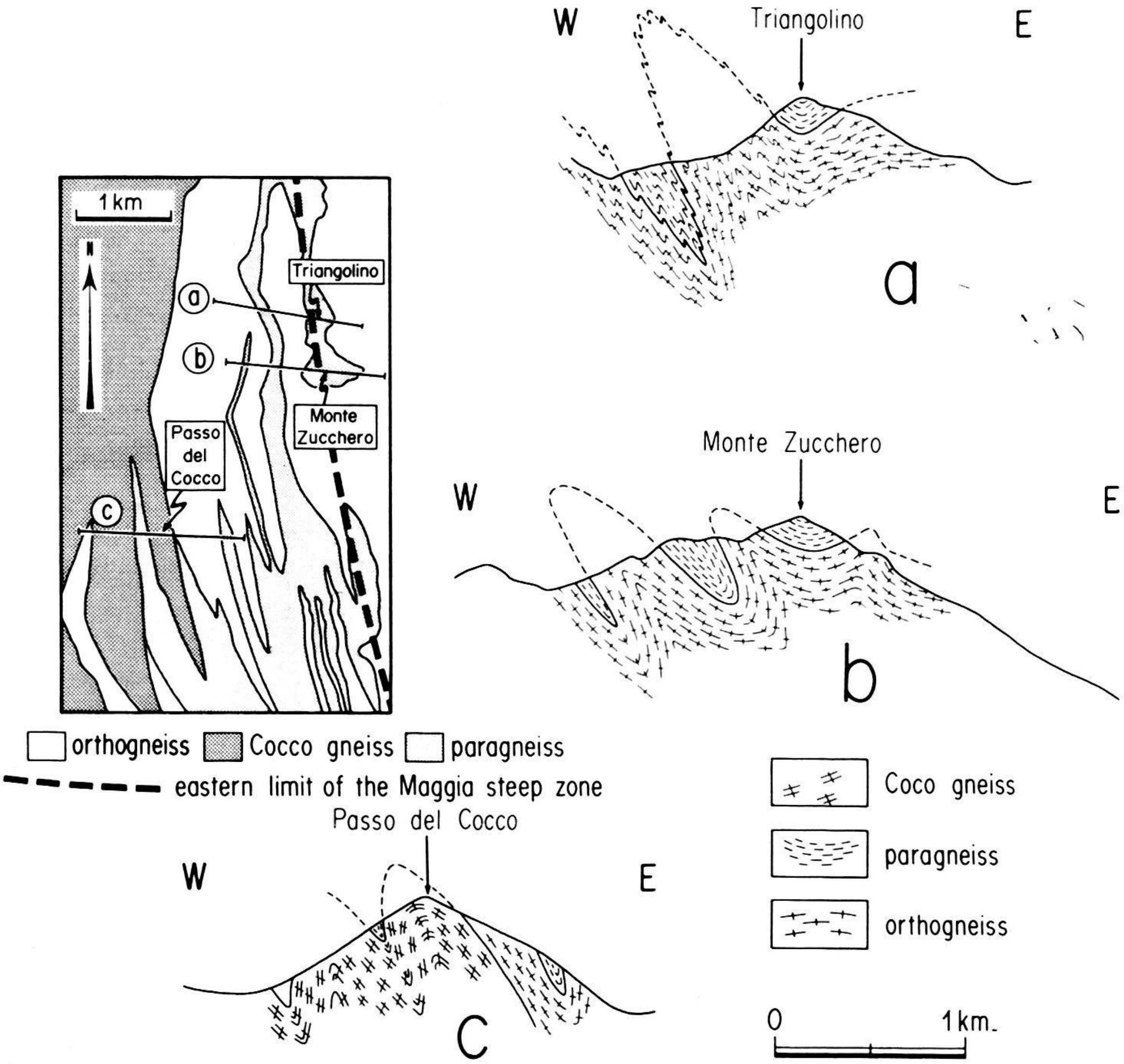

Fig. 6. Geological cross sections showing minor folds of the Maggia steep zone in the area located on Figure 1.

in a set of ductile shear zones within the Bosco-Gurin unit. This overthrusting is compatible with the retrograde westward phase observed from Biasca to Bosco-Gurin. The Wandfluhhorn fold which has been described as a recumbent northeast or east closing structure with extremely curved hinge line, could be a ductile termination of the Bosco-Gurin thrust. An alternative hypothesis is to interpret the Wandfluhhorn fold as a structure associated with the retrograde deformation described in the Simplon area. It is located just at the eastern limit of this post-amphibolitic ductile strain and many minor folds have been described which are geometrically similar to the Wandfluhhorn and consistent with the bulk sense of shear of the Simplon phase (MERLE 1987). In this case, the northern limit of the Bosco-Gurin thrust remains to be recognized in the core of the Antigorio granite itself.

To the south, the thrust structure becomes rather complex possibly because it interacts with the dextral shearing of the southern vertical belt. The Antigorio granite is refolded into a synformal structure (the Masera synform). On a map, the hinge of this fold seems to curve in a manner consistent with the dextral sense of shearing.

Discussion

Numerous geochronological data (e.g. WERNER et al. 1976, WAGNER et al. 1977, HURFORD 1986) indicate that a major uplift of the Ticino domain occurred at around 20–25 Ma and a model of differential uplift and cooling within the Central Alps has recently been proposed (BRADBURY & NOLEN-HOEKSEMA 1985). In this model, the dominant uplift occurs earlier in the east (Ticino domain) and later in the west (Simplon domain). We argue that major uplift of the eastern part of the Central Alps could not occur without a significant deformation at the western margin of the Ticino domain. At a deeper structural level, the deformation is likely to involve inverse faulting and folding as a response to the space problem linked to the differential uplift.

Recent structural work (SCHMID et al. 1987, and submitted) has shown that the Central Alps were backthrust over the southern Alps along the north-dipping Insubric mylonite belt. This deformation could be due to the uplift of the Ticino domain (HURFORD 1986). We suggest that backthrusting along the Insubric line and westward thrusting and folding in the Pennine zone were coeval as both events can be interpreted as

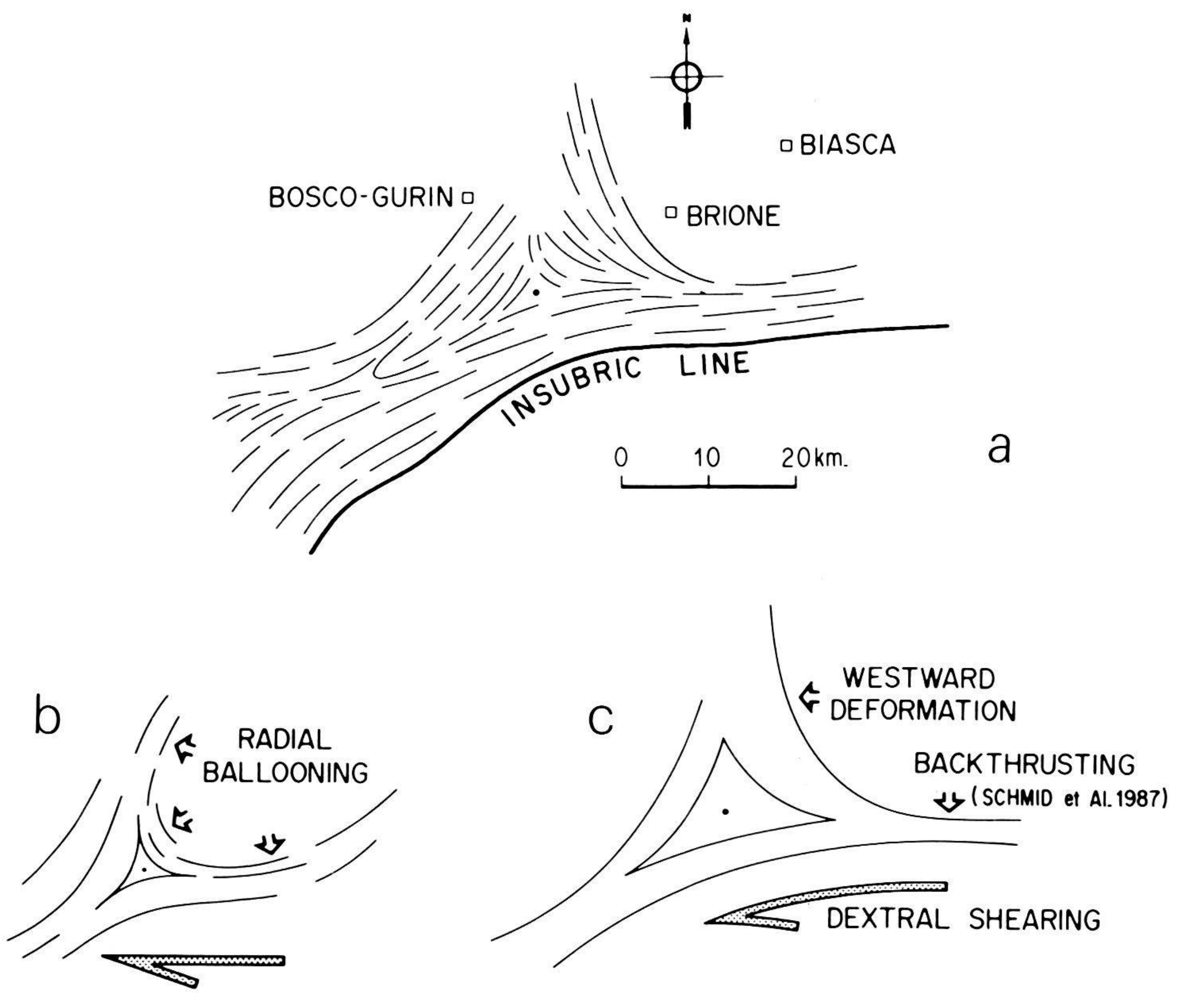

Fig. 7. a) Foliation trajectories in the study area (main data from KNUP 1958). Note the triangular pattern next to the Insubric line. b) Strain trajectories resulting from the superposition of a radial ballooning and a dextral simple shear (after BRUN 1983). c) Foliation trajectories interpreted as an interference between the uplift of the Ticino domain and the dextral simple shear along the Insubric line (further explanation in the text).

the result of deformation occurring at the western and southern margin of the uplifting Ticino domain around 20–25 Ma. These deformation could be explained in terms of dextral transpression in front of a rigid indenter. The indenter would be the Adriatic subplate with the Ivrea zone at its northwestern front (SCHMID et al., submitted, MERLE et al., submitted). According to this hypothesis, the post amphibolitic westward thrusting and fold vergence would correspond to a lateral escape of rocks as the result of the oblique convergence of the Adriatic subplate.

This hypothesis enables us to explain the triangular pattern of foliation attitudes in the study area. The combination of westward overthrusting in the Pennine zone and backthrusting along the Insubric line during the main uplift of the Ticino domain is similar to the deformation occurring at the periphery of an ascending pluton. Such deformation is usually linked to the ballooning effect described in most of these plutons (e.g. WHITEHEAD & LUTHER 1975). A recent study (BRUN & PONS 1981, BRUN 1983) has shown that the combination of pluton deformation with transcurrent shear deformation yields a triangular pattern of foliation attitudes i.e. a triple point due to the interference of both deformations (Fig. 7b). It is possible to interpret foliation trajectories observed in the field as such an interference pattern (Fig. 7c). In this particular case, the main foliation was already developed during the previous amphibolitic deformation so that foliation planes are only rotated towards the principal strain plane related to interfering deformations. This interpretation is, therefore, only an analogical one, but seems satisfactory for explaining the triangular pattern of foliation attitudes.

Conclusion

New data and structural interpretation presented in this paper can be summarized as follow.

1. An unknown ductile phase has been recognized in the Pennine zone of the Central Alps from Biasca to Bosco-Gurin. It postdates the high-temperature northward episode and developed mylonites which reveal a top west shearing. This retrograde ductile phase is associated with westward thrusts and fold vergence.

2. The Maggia steep zone is interpreted as a major post-nappe fold overturned towards the west.

3. The duplication of the Antigorio granite in the Bosco-Gurin area is thought to be the result of overthrusting towards the west.

4. Such a westward overthrusting phase in the Pennine zone is believed to be coeval with the major uplift of the Ticino domain at around 20 Ma.

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