The Ivrea-Verbano zone - Valle d‘Ossola Excursion

September 18, 2009

Description of the Geology

1. Introduction

The Ivrea-Verbano (I-V) zone provides one of the most spectacular sections through rocks of lower crustal provenance upended and brought passively to the surface during Alpine orogenesis. The region outcrops in N.W. Italy and S. Switzerland, in the inner arc of the Western Alps (Fig. 1 and 2), and on account of its relative accessibility has been subjected to a substantial amount of structural, petrological, geochemical and petrophysical study by geoscientists during the past few decades (e.g. Schmid, 1967; Bertolani, 1969; Zingg, 1980; Rivalenti et al., 1981; Sills and Tarney, 1984; Bürgi and Klötzli, 1990; Handy and Zingg, 1991; Quick et al., 1992, 1994, 1995; Schnetger, 1994; Henk et al., 1997; Barboza et al., 1999; Snoke et al., 1999; Barboza and Bergantz, 2000).

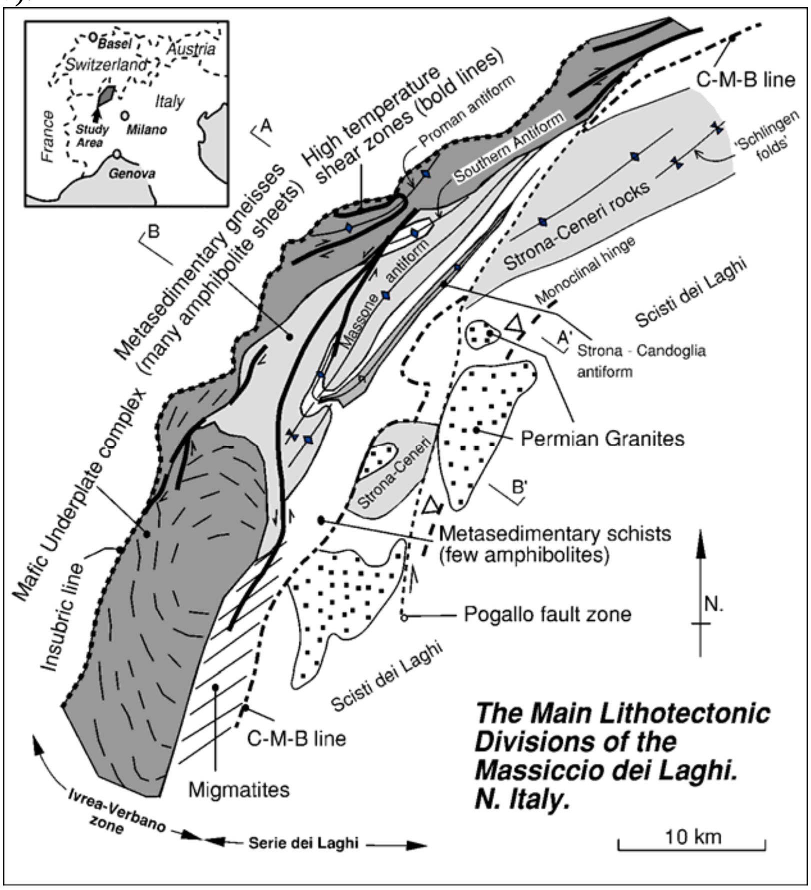

Fig. 1. Sketch map showing the main lithotectonic divisions of the Massiccio dei Laghi. A-A‘ and B-B' indicate the positions of the Valle d‘Ossola and Val Strona sections through the region. C-M-B line = the Cossato-Mergozzo-Brissago line, the tectonic contact between the Ivrea-Verbano and Serie dei Laghi terrains. Inset map shows the location of the Massicio dei Laghi in northern Italy.

Together with the metamorphic and igneous rocks of the adjacent Serie dei Laghi (SdL), collectively forming the Massiccio dei Laghi (Boriani et al., 1990), the rocks of the region record Palaeozoic accretion, metamorphic and magmatic processes, the effects of the Hercynian orogeny, post-orogenic magmatic underplating and associated lithospheric stretching and thinning, Mesozoic extension and effects associated with the position of the region in Alpine tectonism (e.g. Handy et al., 1999) (Fig.3). The assembly of the rocks in their relative stacking order close to what we see today (but prior to tilting to the vertical) probably dates from Permian time, so that it is possible to construct a crustal cross-section that might be taken as a model for a magmatically underplated and extended crustal section (e.g. Rutter et al., 1993; Schnetger, 1994; Quick et al., 1994; Henk et al., 1997). Rutter et al., (1999) and Khazanehdari et al., (2000) constructed a forward reflection seismic model based on this section as an aid to the interpretation of contemporary reflection seismic profiles of the lower continental crust.

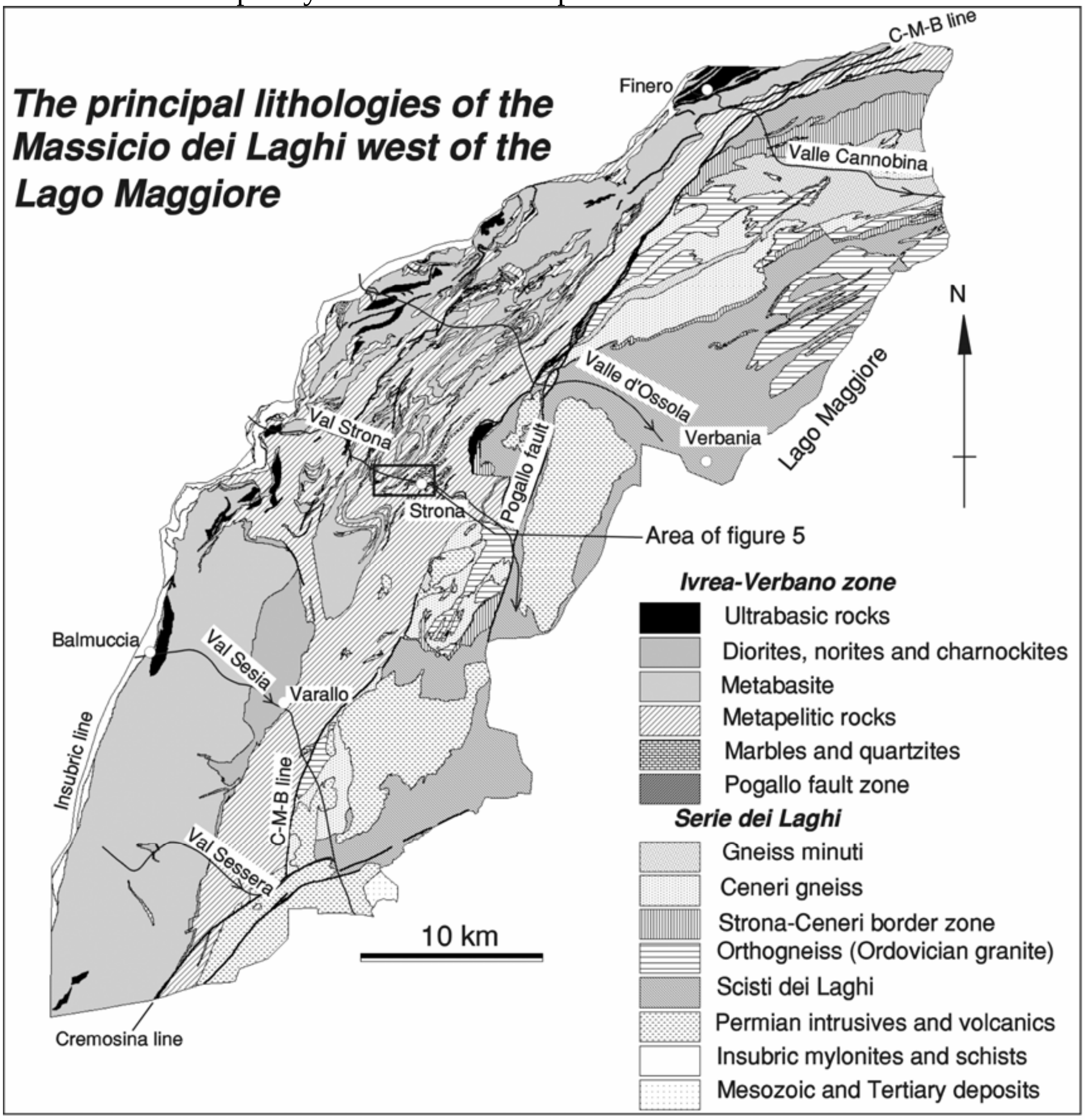

Figure 1. *Geologic map showing the main lithologies of the Massicio dei Laghi west of Lago Maggiore. This map is a compilation of all available published (and some unpublished) information, principally from Schmid, (1967), Boriani and Burlini (compilation, 1994), Brodie and Rutter (1987) Rutter et al. (1993), Quick et al. (1992, 1994, 1995), Snoke et al. (1999), Zurbriggen et al. (1998), Handy (1986), Vogler (1992), and James (2001).*

Previous work on the *structure* of the I-V zone has focused on geometry of the rocks forming the structurally lower igneous units and higher-grade (granulite and upper amphibolite facies) metamorphic rocks, in which schistosity defined by oriented micas is poorly developed or absent (Schmid, 1967; Zingg, 1980, Brodie and Rutter, 1987; Sinigoi et al., 1991; Quick et al., 1992, 1994, 1995, 2003; Rutter et al., 1993; Snoke et al., 1999). Newer geological mapping in the more schistose rocks of the structurally higher part of the complex, that outcrop adjacent to the SdL lying to the south-east has revealed the occurrence of large-scale superposed folds forming a complex interference pattern, that now allow a more complete tectonostratigraphic history of the region to be assembled (Rutter et al. 2007).

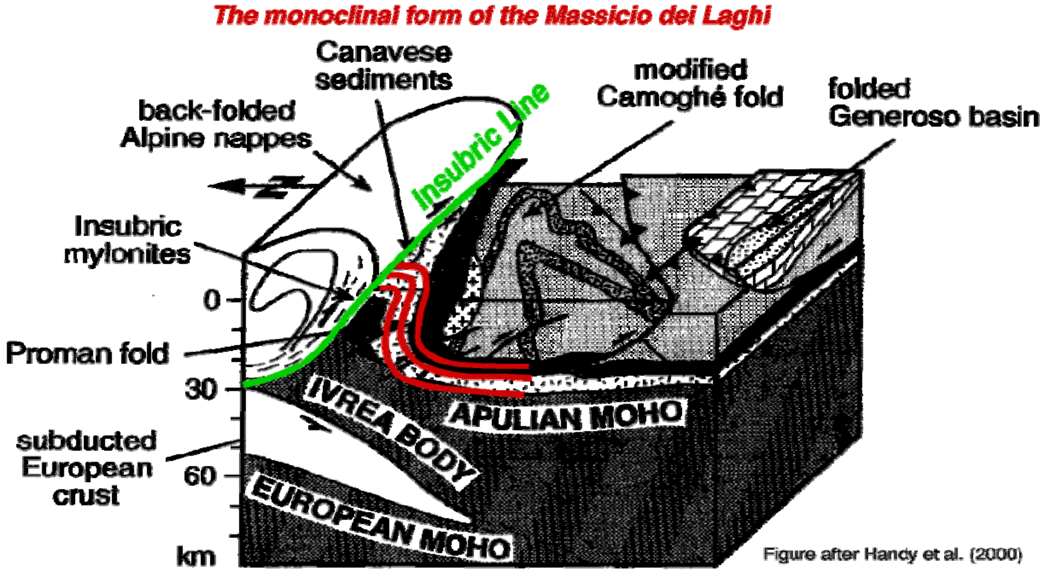

Fig. 3. Block diagram showing the relation between the Alpine orogenic rocks NW of the Insubric line and the upended lower crust of the Ivrea-Verbano zone to the SE (after Handy et al. (2000).

2. Geological Setting and Summary of Published Work

The principal geologic units of the region are shown in Figs. 1 and 2. Fig.4 shows detail of the geology in the central part of the I-V zone, that includes the Valle d'Ossola section. The Massiccio dei Laghi is composed almost entirely of pre-Mesozoic rocks, bounded to the north-west and separated from the Alpine metamorphic belt by the Insubric line. The latter comprises a thick belt of mylonitic rocks dipping about 45° to the northwest (Schmid et al., 1987). Alpine metamorphism has had only a minimal effect on the rocks of the Massiccio dei Laghi, principally in the 4 or 5 km adjacent to the Insubric shear zone, and is manifested particularly as retrograde (greenschist facies) metamorphism in association with folding and fault zones that sometimes display evidence of frictional melting. The Massif itself comprises the I-V zone, lying to the north and west, separated from the SdL, lying to the south and east, by the C-M-B (Cossato-Mergozzo-Brissago) tectonic line (Boriani et al., 1990). The latter is a major vertical tectonic discontinuity of Permian age (Boriani and Villa, 1997; Mulch et al., 2002). The SdL is subdivided into the Strona-Ceneri zone, a varied group of psammitic and some pelitic schists and gneisses, that are separated from a monotonous metapelitic unit, the Scisti dei Laghi, by a prominent amphibolite horizon (Figs.1 and 2) (Boriani et al. 1990). The SdL is intruded by a suite of Permian granites (Graniti dei Laghi) (Fig. 1) that are completely untectonized and lie close to their original intrusive attitudes, as evidenced by the occurrence of large, oriented miarolitic cavities in their roof regions (review by Boriani and Giobbi, 2004).

The metamorphic foliation and primary banding in the I-V zone lying west of the Lago Maggiore (Figs. 1, 2 and 4) are generally steeply dipping and trend NE-SW, parallel to the Insubric line. The highest grade (granulite facies), and by inference the originally deepest buried, metamorphic rocks of the region outcrop in the NW part of the Ivrea-Verbano zone. This is consistent with pressure estimates made from metamorphic mineral assemblages (Schmid and Wood 1976, Zingg et al., 1990, Handy and Zingg, 1991, Henk et al., 1997). Fig. 6 shows a profile of synmetamorphic pressures and temperatures (after Henk et al., 1997, and T. Hoyle, unpublished data, 1999, this laboratory) in the central part of the region. The presently implied steepness of the geobaric gradient in the (vertical) I-V zone is probably attributable to the substantial stretching and thinning the region underwent during and after the Permian igneous activity (e.g. Brodie and Rutter, 1987; Handy and Zingg, 1991; Brodie, 1995), whereas the (older) constant pressures in the SdL correspond to a tract where the average dip of layering and schistosity is sub-horizontal or gently undulating. Extrapolation of the pressure trend in the I-V zone indicates a pressure on the order of 200 MPa in the vicinity of the C-M-B line, which is consistent with the hypabyssal depth of emplacement of the SdL granites implied by the presence of miarolitic cavities in the roof regions.

The high temperature-high pressure part of the I-V zone also hosts a large, basic intrusive complex of Permian age (the "Mafic Formation", Rivalenti et al., 1981, Zingg, 1983; Quick et al., 2003) in which primary igneous layering is well preserved. These observations have led to the conclusion by most geologists that the northwestern part of the Massicio dei Laghi was tilted to the vertical after Permian time, probably as a result of Alpine tectonism. On the other hand, Boriani and Giobbi (2004) interpret the geology of the contact region between the I-V zone and the SdL in terms of that contact lying in a vertical attitude during the Permian igneous activity, with the rocks of the I-V zone being brought into contact with the SdL along a vertical trans-tensional shear zone (the C-M-B line) containing mylonitic rocks and which was decorated by mafic and granitic igneous rocks intruded contemporaneously with movement.

Immediately west of the Lago Maggiore the attitude of the schistosity and banding changes from the predominantly steep dip of the I-V zone to the NW to a much lesser south-easterly dip on the SE side (Fig. 2). To the east of Lago Maggiore, fault-bounded sedimentary basins contain Permian volcanic and Triassic clastic sedimentary rocks, and early to mid-Jurassic sediments that record the onset of Tethyan rifting, and which lie with gently-dipping contacts upon the underlying metamorphic rocks of the SdL (Handy et al., 1999; Boriani and Giobbi, 2004). Quick et al. (2009) proposed a specific geometric connection between the magmatic underplating and Permian volcanic rocks lying to the south-east of the I-V zone.

The present day map view of the near-vertical part of the Massiccio dei Laghi to the west of Lago Maggiore therefore corresponds approximately to a cross section of how the region would have appeared when it was in the lower and middle crust during the late Permian or Triassic period. The effects of Alpine faulting and folding on this part of the section can be easily removed. The rocks of the Massicio dei Laghi are truncated to the south of the area shown on Fig.1 by another zone of Alpine faulting, the Cremosina line, and the Tertiary cover rocks of the Po-river basin.

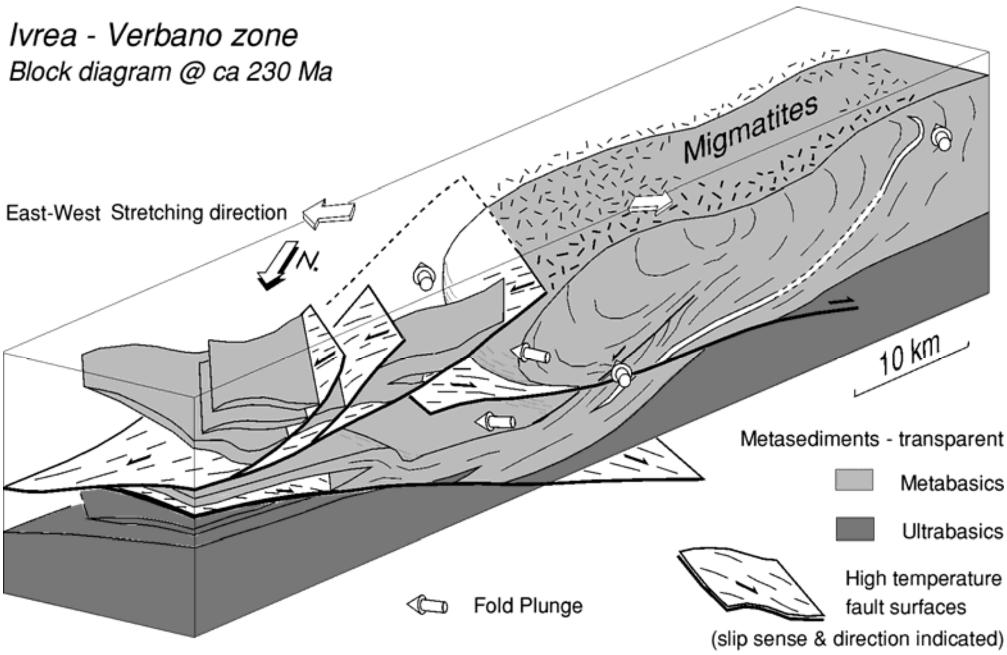

Fig. 4. Block diagram of the lowermost part of the Ivrea-Verbano zone (in its pre-tilting orientation) showing the relation between the Permian mafic intrusive complex, contact migmatization above, and sub-solidus, high temperature shear zones that continued to accommodate stretching after intrusive activity had ceased. The concentric arrangement of primary banding in the mafic complex is believed to have be produced by intrusion and crystallization during E-W crustal extension (modified after Rutter et al., 1993).

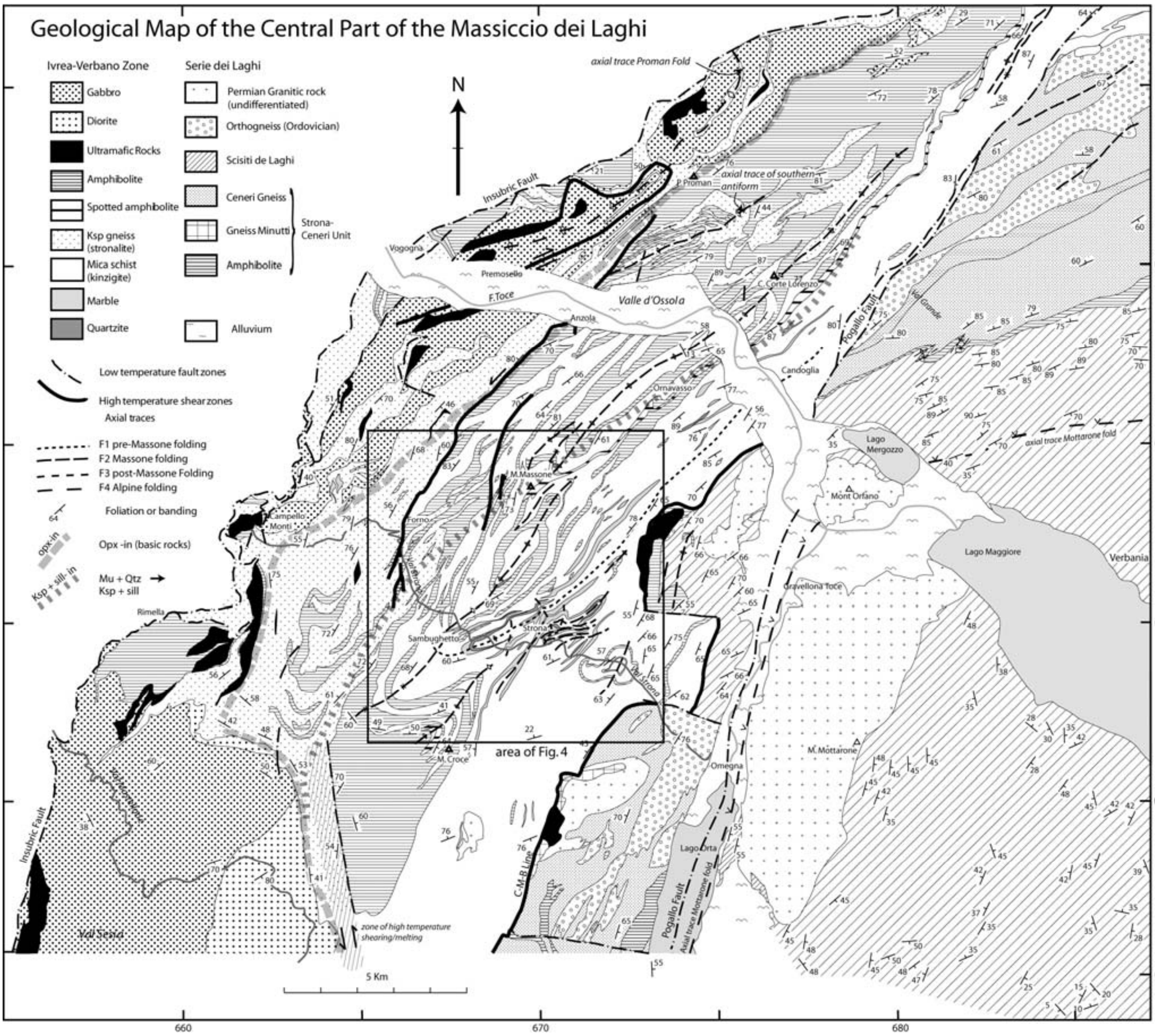

Fig. 5. Geological map of the central part of the Massicio dei Laghi, which includes the Valle d'Ossola section (after Rutter et al. 2007).

2.1 The Ivrea-Verbano zone

The I-V zone (Fig. 1) is dominated in its lower metamorphic grade (south-eastern) part by a thick unit of variably migmatized metapelitic schists (garnet, biotite, plagioclase, quartz, sillimanite ± muscovite), known in the European literature as the Kinzigite formation, that forms a strikingly continuous and uniform tract about 3 or 4 km wide along the entire length of the outcrop of the Ivrea-Verbano zone. As metamorphic grade increases north-westward, the rock texture changes due to progressive replacement of muscovite and biotite by K-feldspar and garnet (Schmid and Wood 1976, Zingg 1980), from schistose to a massively banded migmatitic gneiss, known locally as Stronalite. Locally associated with the Kinzigite formation in the central part of the outcrop is a more heterogeneous group of metasediments, comprising marbles, quartzites and less phyllosilicate-rich paragneisses (Fig. 2). The higher grade (more northwesterly outcropping) kinzigites are interlayered with bands of amphibolite from 1 to 200m thick, that have been interpreted as coeval mafic lavas or intrusives interlayered within an early (Palaeozoic) pelitic accretionary complex represented by the Kinzigite formation. According to Sills and Tarney (1984), these mafic rocks can be distinguished from younger, Permian intrusive mafic rocks on the basis of their rare-earth element patterns.

Towards the higher grade (and potentially deeper) side of the I-V zone, increasing numbers and thicknesses of Permian mafic intrusive sheets occur, eventually dominating the outcrop pattern (Fig. 5). They are commonly concordant with the lithologic banding in the host metasediments, but occasionally show cross-cutting relationships. These have distinctive rare earth patterns compared to the older amphibolites interlayered with the kinzigites, but they cannot readily be distinguished in the field. The geology of the southern end of the Ivrea-Verbano zone is dominated by an intrusive layered mafic complex, some 10 km wide and extending along strike for some 40 km (Fig. 1). This 'Mafic Formation' (Rivalenti et al., 1981; Zingg, 1983; Quick et al., 2003) is dated radiometrically (Pin, 1986) at about 280-295 Ma (Permian) and displays vertical primary igneous layering on its western side, where the rocks have been held at high temperatures in the subsolidus regime sufficiently long for granular, metamorphic textures to develop, whereas the originally shallower, eastern side of the complex still displays igneous textures. The Mafic Formation and the complex of thinner intrusive sheets extending further northeast along the outcrop represent an excellent example of lower crustal mafic underplating (Fig. 3).

At various positions within the I-V zone, but particularly towards the western edge, sheet-form or lensoid ultramafic bodies outcrop. These include peridotites, dunites and pyroxenites. Quick et al., (1995) argue that none of these bodies are connected to a contiguous mass of ultrabasic rocks at depth. Although some of them are clearly of upper mantle origin (e.g. Boudier et al., 1984), they may have become detached and incorporated as tectonic slices into the Kinzigite formation during a Palaeozoic accretionary process (Quick et al., 1995). Nevertheless, the proximity of the present outcrop of the I-V zone to the gravity high that represents the dense geophysical 'Ivrea body' at depth (Berkhemer, 1968) suggests that contiguous mantle rocks lie not very far beneath and to the NW of the presently exposed rocks of the I-V zone.

The development of the Permian intrusive complex was accompanied by heterogeneous regional stretching. Virtually every linear feature in the metamorphic rocks (elongation of mineral clusters, orientation of amphibole long axes, minor fold axes, rodding of quartzofeldspathic segregations, synmagmatic boudinage features in the contact migmatites and the intrusive rocks) was stretched in a direction plunging NE at about 30° (Rutter et al., 1993; Quick et al., 1992). In the country rocks, those of the NE part of the Ivrea-Verbano zone were most affected, as implied by the total convergence of lineations to a common 30° NE orientation, thinning of mappable geological units, and preservation of the apparently steepest geobaric gradient (Henk et al., 1997)(Fig. 6).

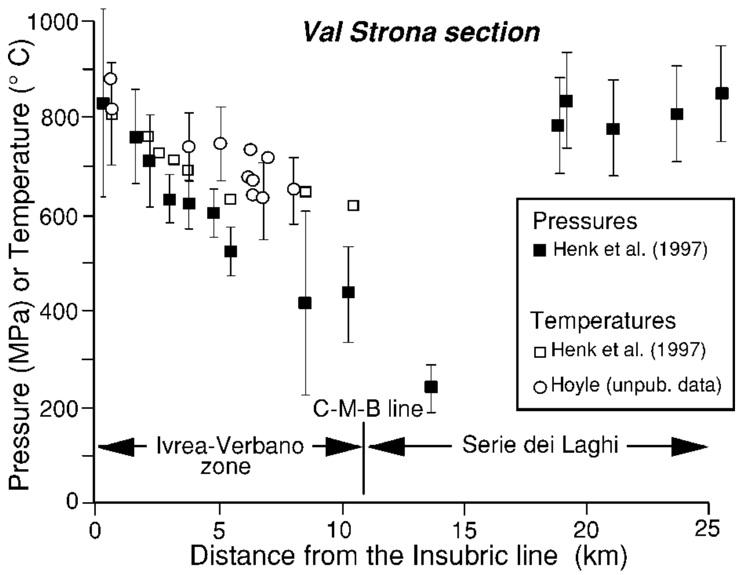

Fig. 6. Peak metamorphic pressure/temperature variations with distance from the Insubric line in the I-V and SdL section in the central part of the Massicio dei laghi (maionly based on Henk et al. 1997). The geobaric gradient in the I-V zone is steep, as might be expected in a stretched terrain.

During the post-intrusive cooling history, continued stretching of the crust was accommodated by slip on localized, high-temperature shear zones which share the same regional movement picture as the more pervasive deformation in the earlier, higher temperature part of the history (Brodie and Rutter, 1987). Depressurization of the section is evidenced by the occurrence at the margins of high temperature shear zones at the base of the crustal section (near the Insubric line) of oriented symplectites (Brodie, 1995), produced by the local breakdown of cpx + gar to opx + plag at intergranular interfaces oriented normal to the stretching direction, across which the interfacial normal stress was smallest. This down-pressure reaction in the granulite facies records the removal of 6 to 10 km of overburden (according to the assumed degree of non-hydrostatic loading) associated with movement on that shear zone and any contemporaneously active shear zones lying above. Restoring the section to an horizontal orientation of the layered mafic intrusion by rotation about the axial orientation of Alpine folds means that the Permian stretching deformation would have been oriented almost east-west (Rutter et al., 1993) (Fig. 4).

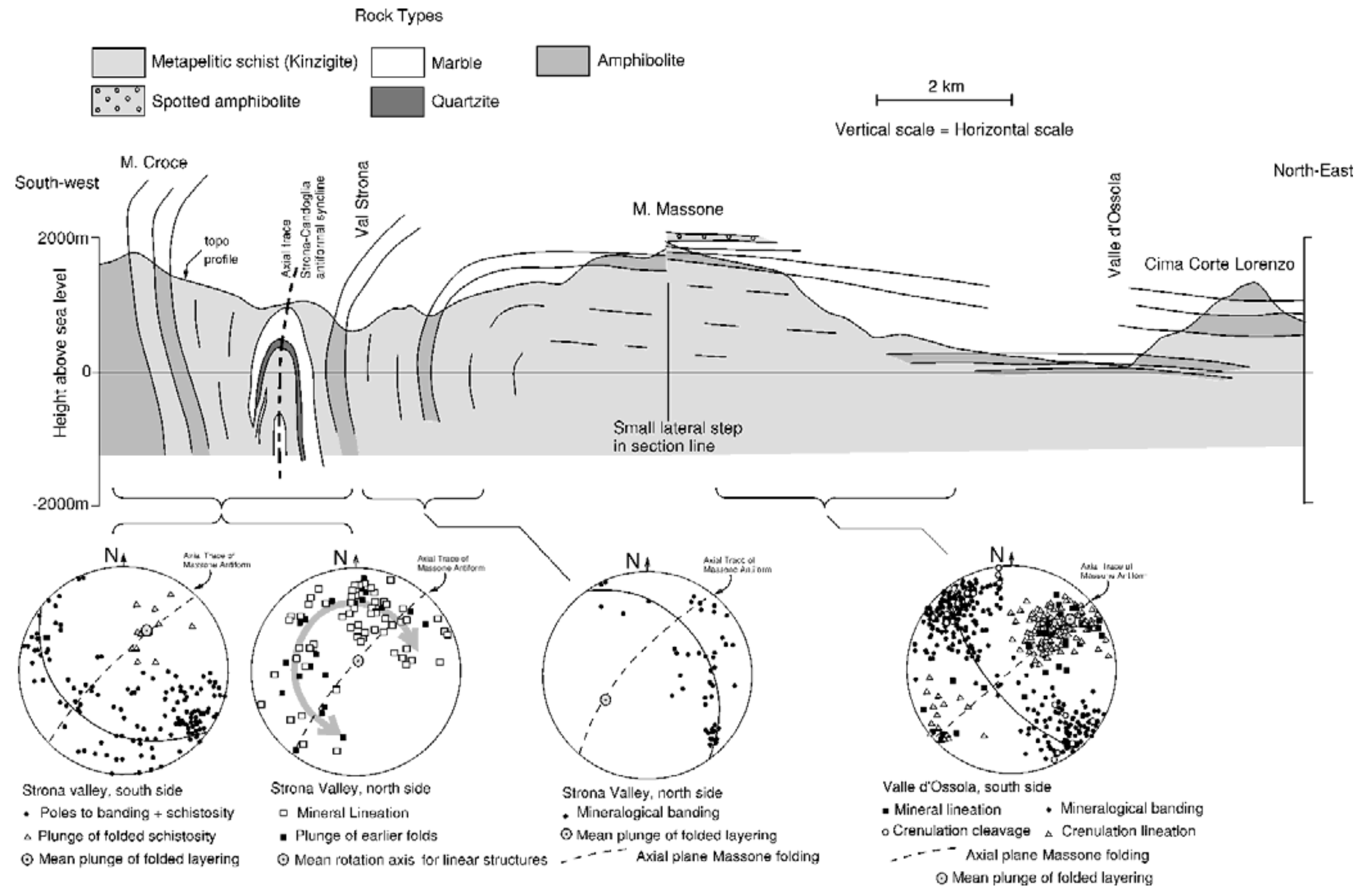

Fig. 7. Vertical geological cross-section parallel to the axial plane of the main Massone fold, showing the marked plunge culmination between M. Massone and Val Strona, and the refolding of the earlier Strona-Candoglia antiformal syncline, cutting the section where it passes through Val Strona.

The earliest schistosity and associated folds developed in the metasedimentary rocks in the upper part if the I-V zone have been refolded by at least two further major episodes, that are associated with axial-planar crenulation cleavages, and both of which deform leucosome segregations within the kinzigites, which had therefore previously suffered an episode of partial melting. One of these episodes produced a major antiformal fold structure that can be traced some 40 km along strike (Figs. 1, 2 and 5). The axial region passes through the summit of M. Massone (on the watershed between Valle d'Osssola and Val Strona), hence this folding event is identified as the 'Massone folding'. In the NE part of the region, Massone-age fold axes plunge consistently NE at about 30°, parallel to almost all other linear structures of different ages occurring in the rocks. It is inferred that in the NW part of the region all these linear structures were pulled into parallelism by regionally-pervasive ductile stretching. Further southeastward, the Massone fold plunge becomes horizontal in the vicinity of M. Massone itself, and then steepens rapidly, passing through the vertical as it meets Val Strona (Fig. 7). In this region earlier, gently plunging tectonic lineations can be seen to be folded around the hinge of the main Massone fold (Figs. 5, 7 and 8). As it approaches the NE extremity of the mafic complex, the Massone fold structure maintains a steep north-easterly plunge but rapidly loses amplitude. The schistosity developed axial-planar to the Massone folds is clearly a crenulation of earlier schistosity in the Val Strona - Massone region, with oriented sillimanite growths in the hinges of the crenulations, indicative of formation at high temperature. Superimposed on the Massone folding is the local development of open to tight folds with axial planar crenulation cleavage, and with axial traces lying in a more north-south orientation relative to the Massone axial trace. Wavelengths lie in the range 500 m and smaller.

A traverse along the Valle d'Ossola (Fig. 8) displays the curious arrangement of apparently four large antiformal structures in succession, each several km in amplitude, without any synformal structures beween them. Figs. 3, 8 and 9 shows this arrangement and how the folds can be reconciled. Two of the fold cores, the Southern Antiform (Schmid, 1967) and the Strona-Candoglia Antiform are interpreted to be part of a complex, large-scale Type-2 fold interference pattern (Ramsay, 1967), with the early fold axial surface folded about the Massone antiform. The fold axis linking the two antiforms curves around outside the plane of the section shown in Fig. 9. Smaller scale interferences between Massone age folding and earlier structures are particularly well displayed in Val Strona, where their axial trends lie at high angles to one-another.

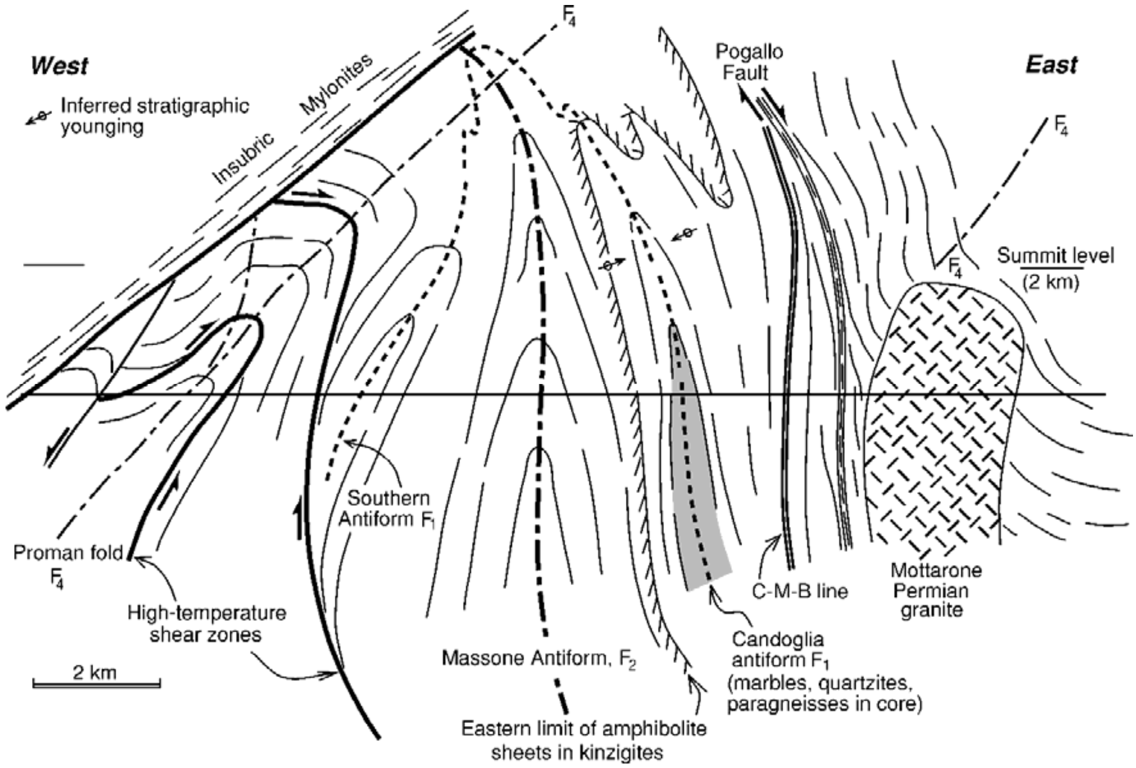

Fig. 8.   Vertical cross-section along the Valle d'Ossola showing the relations between the superimposed folding episodes and the high- and low-temperature faulting (after Rutter et al. 2007)

On the SE side of the Ivrea-Verbano zone, exclusively on the SE limb of the major Massone fold structure, substantial amounts of minor granitoid sheets, often pegmatitic, are found, forming both concordant and discordant lenses up to a few 10's of m thick and ca 100 m long. These are inferred to be of Permian age. It is difficult to establish clear timing relationships between intrusion of these bodies and the Massone and superimposed folding episodes.

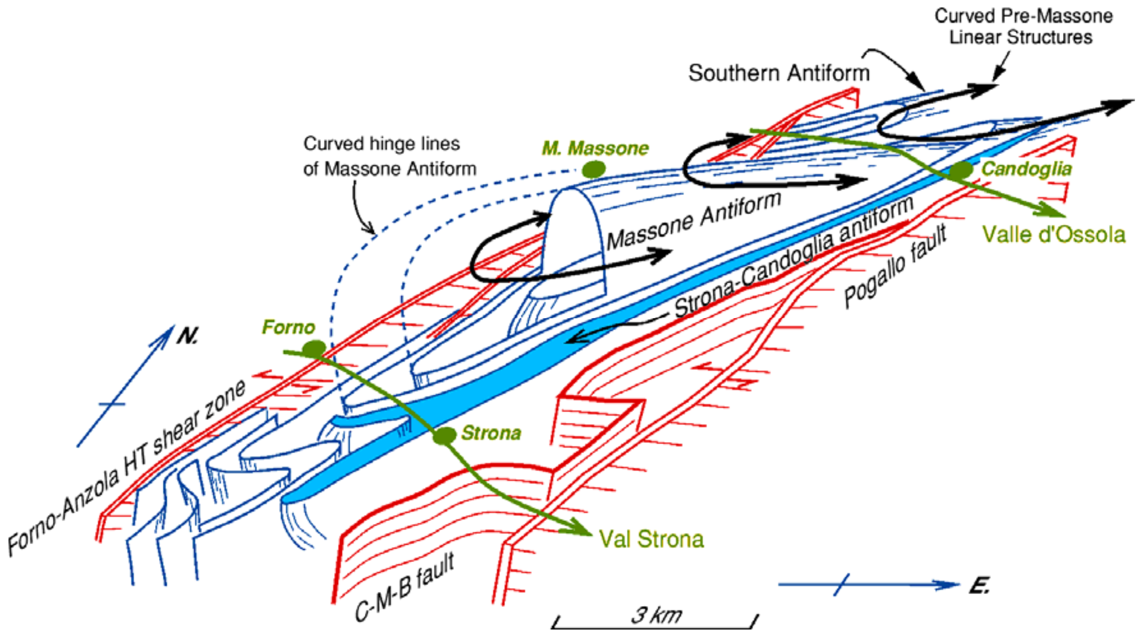

Fig. 9. Block diagram to illustrate the geometry of the Massone and earlier folds, and the high-temperature shear zones.

The Massone folding and the earlier episodes predate the intrusion of the Mafic Formation, which at least locally produced sufficient heat to cause contact migmatization and granulite facies metamorphism of the immediate metasedimentary cover (Schmid and Wood, 1976; Henk *et al*., 1997). Schmid and Wood (1976) suggested that the mafic intrusion was responsible for all the observed migmatization and degranitization of the region. However, more recent work has shown that this episode of melting is more localized and superimposed on an earlier episode of regional metamorphism and migmatization (Barboza *et al*., 1999; Rutter et al. 2007), perhaps coeval with the earliest (pre-Massone) folding and perhaps produced during the Hercynian orogenic event.

Tectonic Environment	Event	Associated Small-Scale Structures	Associated Major Structures
Hercynian Orogeny or earlier.	Pre-Massone folding (F_1).	Mineral stretching lineation, axial planar schistosity. Early folds, migmatization and regional metamorphism.	Strona-Candoglia syncline. Southern Antiform.
	Massone folding (F_2).	Axial-planar crenulation fabric. Folding of leucosomes and granitoid sheets.	Massone Antiform.
	Post-Massone folding (F_3).	Open, chevron-style coarse crenulation. Axial-planar crenulation fabric.	No obvious large-scale structures.
Post-orogenic extension.	Intrusion of Mafic Formation.	Contact metamorphism and migmatization.	Mafic Formation. C-M-B line shearing and igneous activity.
	Regional subsolidus stretching.	Linear features aligned where strain is highest. High temperature shear zones.	High-temperature shear zone formation. Pogallo faulting.
Alpine Orogenesis.	Alpine backthrusting on Insubric Line and associated folding (F_4) and faulting.	Brittle faults bearing greenschist assemblages. Some with frictional melting. Increasing frequency towards Insubric line.	Regional-scale monoclinal structure forms - Proman fold and folding about Serie dei Laghi granites.

Fig. 10. Tabulation of the geological history and associated structural developments in the I-V zone. (after Rutter et al. 2007).

At various positions within the Ivrea-Verbano zone, but particularly towards the western edge, sheet-form or lensoid ultramafic bodies outcrop. These include peridotites, dunites and pyroxenites. Quick *et al*. (1995) argue that none of these bodies are now connected to a contiguous mass of ultrabasic rocks at depth. Although some of them are clearly of upper mantle origin (e.g. Boudier *et al*., 1984), they may have become detached and incorporated as tectonic slices into the precursors to the kinzigites during a Palaeozoic accretionary process (Quick *et al*., 1995). Nevertheless, the proximity of the present outcrop of the Ivrea-Verbano zone to the gravity high that represents the dense 'Ivrea body' at depth (Giese *et al*., 1982) suggests that contiguous mantle rocks lie not very far beneath and to the NW of the presently exposed rocks of the Ivrea-Verbano zone.

The development of the Permian mafic intrusive complex was accompanied by regional stretching (Quick *et al*., 1994; Snoke *et al*., 1999). Virtually every linear feature in the metamorphic rocks (mineral stretching lineation, fold axes, rodding of quartzofeldspathic segregations, synmagmatic boudinage features in the contact migmatites and the intrusive rocks) was pulled into a common orientation plunging NW at about 30° (Rutter *et al*., 1993). The rocks of the NE part of the Ivrea-Verbano zone seem to have been most affected, as implied by the convergence of lineations to a common orientation, thinning of mappable geological units, and preservation of the apparently steepest geobaric gradient.

During the post-intrusive cooling history, continued stretching of the crust was accommodated by slip on localized, high-temperature shear zones which share the same movement picture as the more pervasive deformation in the earlier, higher temperature part of the history (Brodie and Rutter, 1987). The block diagram of Fig.4 shows the relationship between intrusion of the mafic complex in actively-stretching lower crust and the continuation of sub-solidus stretching by means of slip on high-temperature, plastic extensional faults. Fig. 10 shows in tabular form the geological history of the I-V zone.

2.2 The Serie dei Laghi

The Ivrea-Verbano zone is in contact on its south-eastern margin with the Serie dei Laghi (Boriani et al., 1990a) (Figs. 1, 2 and 5). The C-M-B line, which forms the main contact, is a poorly exposed tract that sometimes displays 'annealed' mylonitic textures, but is often 'decorated' by gabbro-dioritic and other intrusive rocks of Permian age (Boriani and Giobbi, 2004). The C-M-B line is itself transected at a small angle by a younger mylonitic fault zone, the Pogallo fault, that has been interpreted as having been a low-angle extensional fault of Triassic or Jurassic age (Hodges and Fountain, 1984, Schmid et al., 1987; Zingg et al., 1990). However, it continues the same movement picture as the earlier, higher temperature stretching events. The rocks of the Serie dei Laghi were probably displaced into contact with the underlying Ivrea-Verbano zone rocks along a low-angle C-M-B shear zone early in the post-Hercynian stretching event which culminated in the magmatic underplating. The rocks of the C-M-B line do not appear to be affected by any of the main folding events that affected the adjacent Ivrea-Verbano zone or the Serie dei Laghi.

The rocks of the Serie dei Laghi comprise a series of metasedimentary schists and gneisses (Scisti dei Laghi, Cenerigneiss and Gneiss Minuti, Boriani et al., 1990b) with minor amphibolite sheets, that are cut by orthogneisses of Ordovician age (Fig. 2). The origin of the Cenerigneiss is disputed. Boriani et al. (1990b) argue that it is metasedimentary, whilst Zurbriggen et al., (1997) consider it to have formed from an anatectically-derived, S-type intrusive. The outcrop of the rocks of the Strona-Ceneri unit (comprising Cenerigneiss, Gneiss Minuti, and gneisses including amphibolites and ultramafic rocks that comprise an envelope to the unit called the Strona-Ceneri border zone, Giobbi et al., 1997) form a distinctive tract (Figs. 1 and 2), now separated into two parts by 14 km of left-lateral displacement on the Pogallo fault. The Strona-Ceneri unit probably comprises an early isoclinal fold core set in a ‘matrix‘ of Scisti dei Laghi (Bächlin, 1937). The SdL also hosts a number of isotropically-textured, undeformed granitic intrusions of Permian (275-280 Ma) age (Boriani et al., 1995; Figs. 1 and 2), and which range in diameter from 1 km to more than 10 km.

The metamorphic rocks of the SdL are folded at least twice on a range of scales but it is unclear whether any of the folding events can be geometrically directly correlated with folding events in the Ivrea-Verbano zone. All fold structures and their associated schistosities are cut by the Pogallo fault line, and apparently undeformed gabbrodioritic rocks of Permian age cut the C-M-B line also. Thus it seems likely that the Permian stretching and magmatism comes after all folding and foliation-producing events. Earliest folds and associated axial planar penetrative schistosity (S1) trend NE-SW, parallel to the general trend of the Strona-Ceneri group outcrop. Ordovician orthogneisses and migmatized metasediments contain reoriented xenoliths of foliated rocks, yet the orthogneissses are themselves variably and sometimes intensely foliated. Thus the foliation in orthogneisses is generally designated S2 (e.g. Borghi, 1989; Zurbriggen et al., 1998). Superposed, large scale folds are developed that have steeply-dipping axial planes (S3), that trend about 15° closer to N-S than the general trend of the Strona-Ceneri zone, and that fold the orthogneisses bodies and their foliation. This episode appears to include the kilometric scale, moderately NE plunging close to tight folds that have been termed ‘schlingenbau‘ (Bächlin 1937), and whose outcrops are traced in map view by the major lithologic units in the Strona-Ceneri zone (Boriani and Burlini, 1994). On the basis of cross-cutting relations between folds and minor intrusives that have been dated radiometrically, the schlingen folds are widely held to have formed during Hercynian igneous and metamorphic activity (Zurbriggen et al., 1997, 1998).

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