GELÄNDEÜBUNG

Methoden der Kristallingeologie am Beispiel
Italienische Westalpen (Ivrea Zone)
B.GEO 110

SIEGFRIED SIEGESMUND

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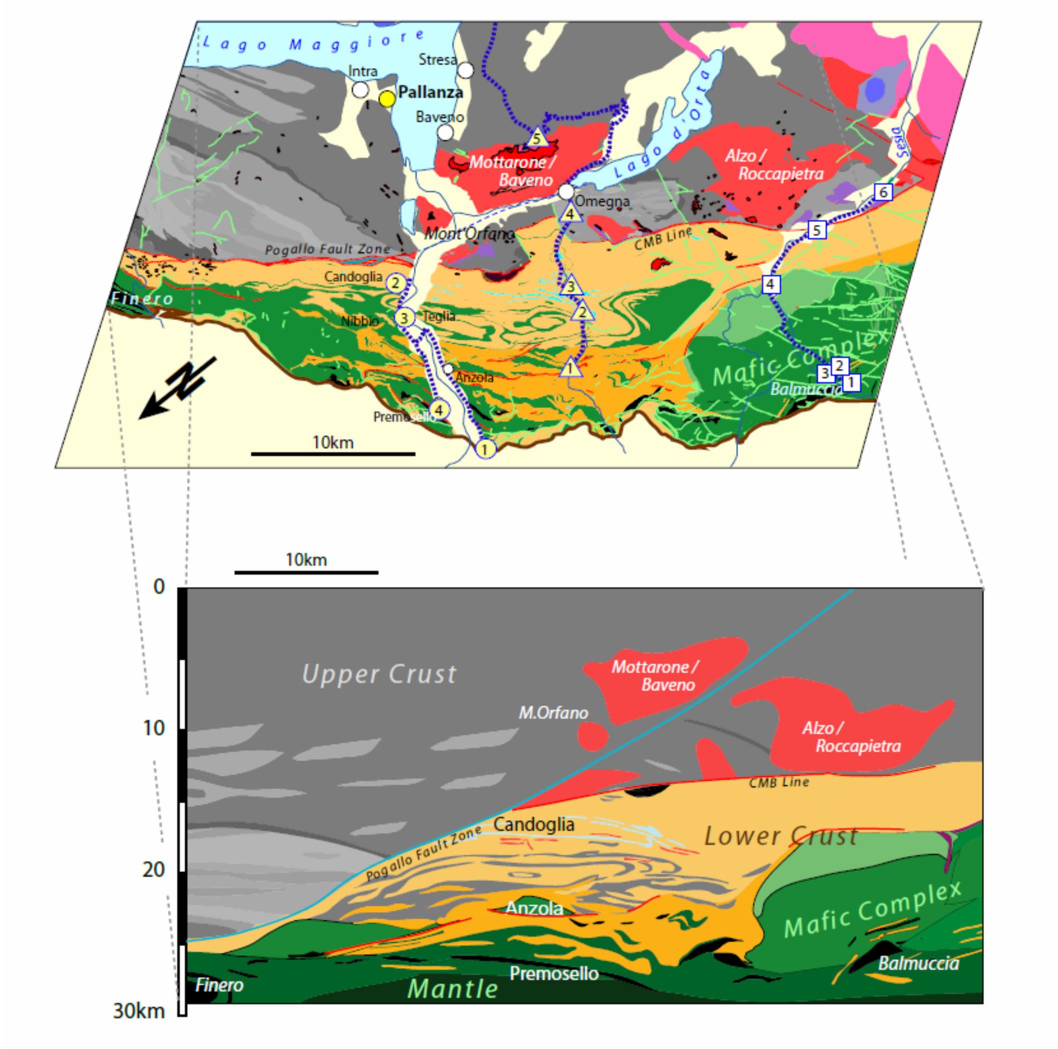


nach Brack, Burlini und Ulmer, 2007

IMPRESSIONEN AUS DER UNTERKRUSTE

von

Philipp Wischhöfer

Jedes Jahr um Pfingsten geht,
In Ivrea Panik um.
Alles bangt und alles fleht,
Geologen kommen rum.

Leut‘ aus Deutschland und der Schweiz,
Fallen bulliweise ein,
Sind getrieben von dem Reiz,
Nach erlesen Speis und Wein.

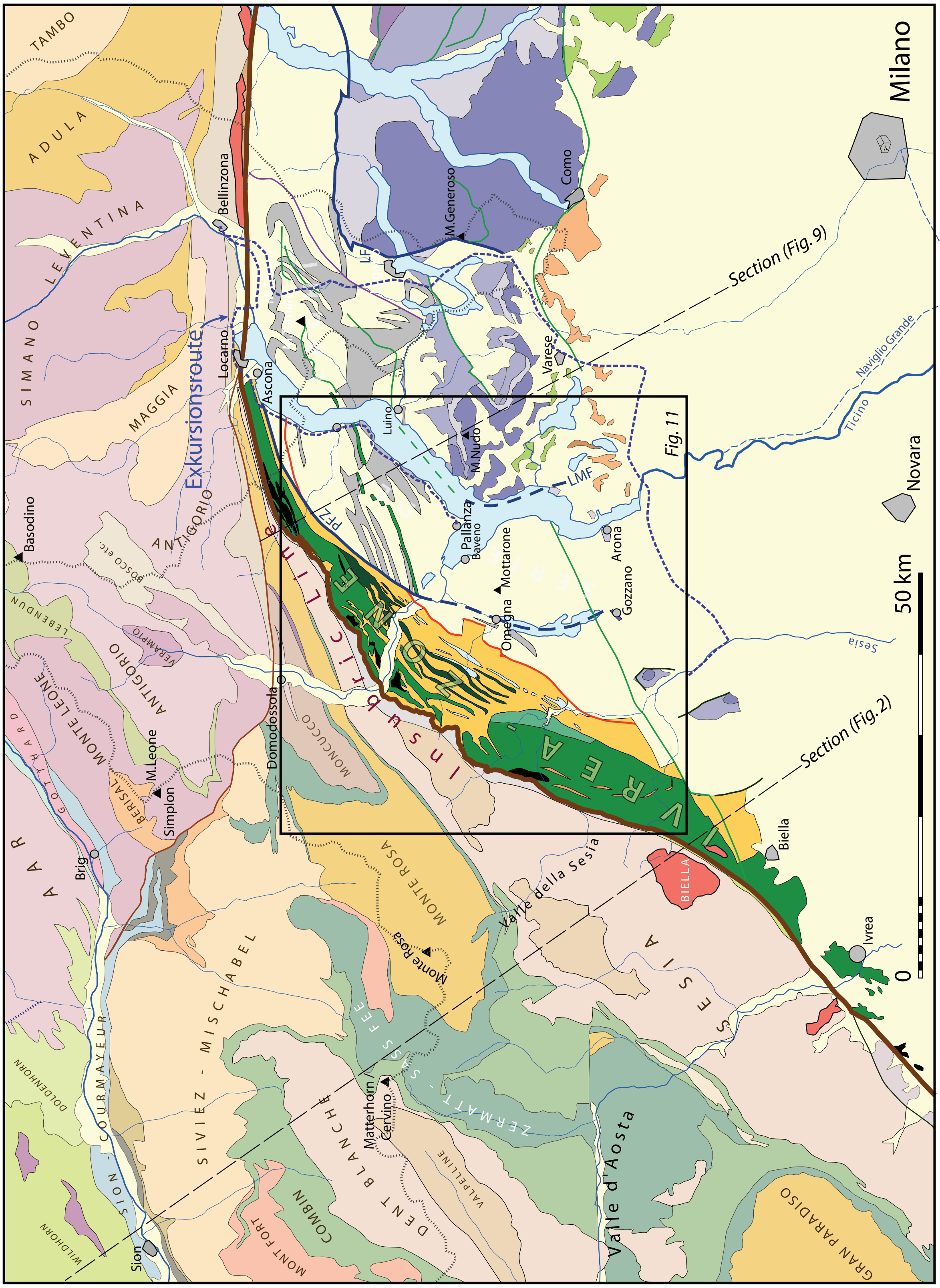
Doch auch Steine locken sie,
Gabbro, Marmor, Mylonit,
Denn wer sucht mit Akribie,
Nimmt die ganze Flöte mit.

Studis voller Ethanol,
Schwirren wild durch Fluss und Tal,
Finden Glimmer, Amphibol,
Und ein Brausemineral.

Angeführt von Siegesmund,
Mit dem roten Schaffnerhut,
Ist trotz leichtem Hammerschwund,
Das Verständnislevel gut.

„Klatsch, klatsch, Abfahrt!“, tönt es oft,
In den Bus geht es zurück,
Wer auf lange Pausen hofft,
Hat bei ihm nur selten Glück.

Trotzdem haben alle Spaß,
Hexe, Werwolf, Seherin,
Beißt auch einer mal ins Gras,
Führ‘ doch jeder wieder hin.



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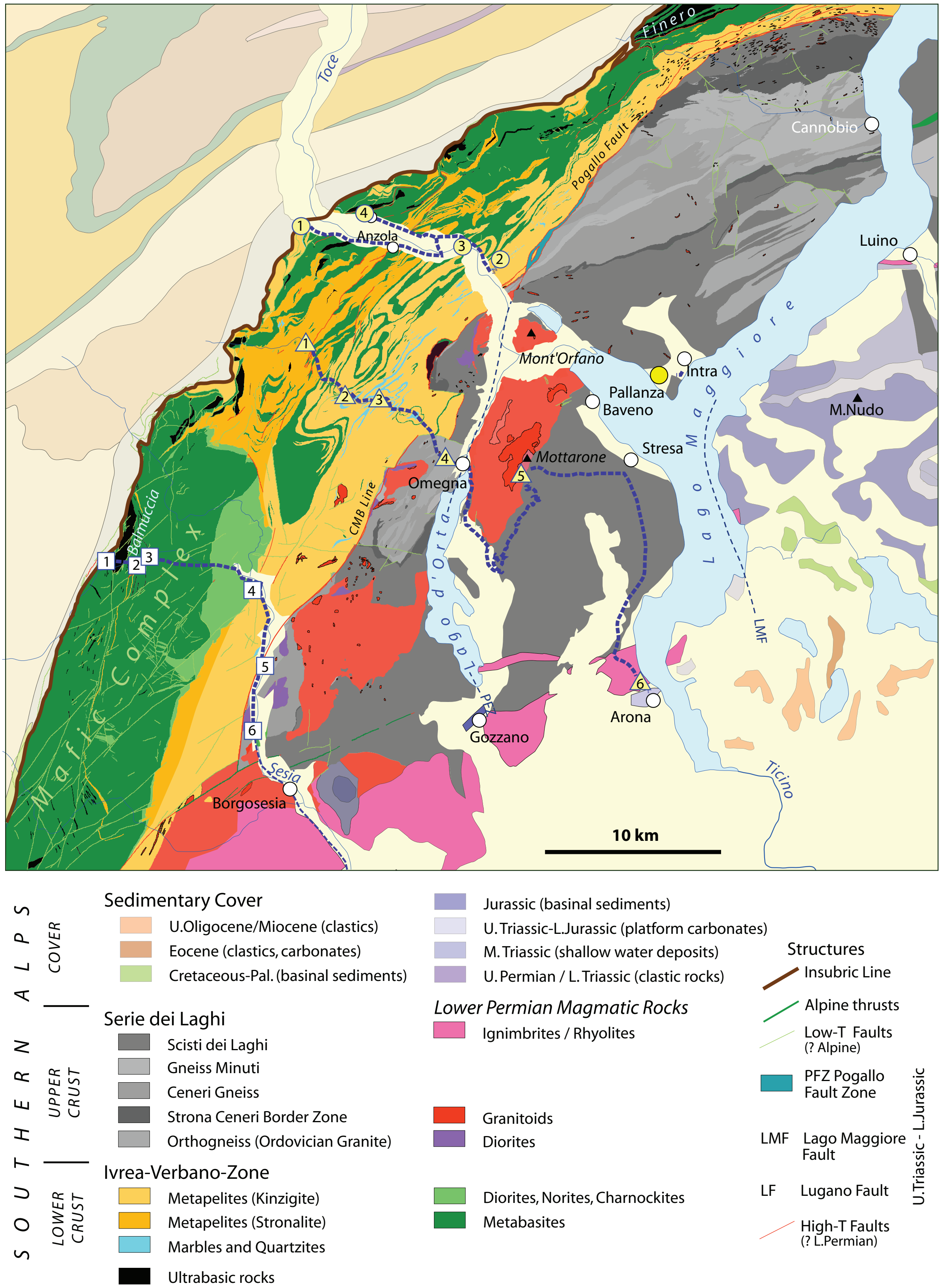

Fig. 11 - Geologische Karte des Seengebirges im Bereich des Lago Maggiore. Beziehung Karte - Krustenprofil s.a. Titelseite. Ivrea-Verbano-Zone und Serie dei Laghi vereinfacht nach einer Kompilation von T. James (2001).

Exhumation and deformation history of the lower crustal section of the Valstrona di Omegna in the Ivrea Zone, southern Alps

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Abstract: The Ivrea Zone (southern Alps) is one of the key regions interpreted as exposing a section of the lower continental crust and was the subject of several review-type articles. The Ivrea–Verbano Zone was rotated into an upright position along the Insubric mylonite belt. In the southeast, this unit is in contact with the Strona Ceneri Zone, which is interpreted as upper continental crust crossing the Permian Cossato–Mergozzo–Brissagio Line (CMB Line). The CMB mylonites are locally overprinted by the mylonites and cataclasites of the Pogallo Line, which was active during the Jurassic. In addition, the sinistral, steeply inclined Rosarolo shear zone was active over a long time span from the ductile into the brittle field, i.e. from the Early Permian (high-temperature ultra-mylonites) to the Neo-Alpine basic dykes and pseudotachylites. The high-temperature mylonites accommodated crustal extension and may be related to normal faults generated by magmatic underplating. The reactivation at different crustal levels during exhumation and tilting is documented by strain increments at decreasing P/T conditions. Its present subvertical orientation was attained during the Neo-Alpine deformation. Constraints on its exhumation history are based on new $^{40}Ar/^{39}Ar$ hornblende ages, K–Ar biotite ages and zircon fission-track data along the NE–SW trending Valstrona section. A re-interpretation of existing U–Pb monazite ages is included, based on a higher closure temperature for monazite. The oldest monazite ages are observed in proximity to the Pogallo Line (*c.* 292 Ma). Heat input by mafic intrusions was sufficient to reset the U–Pb monazite system, as is evidenced by the youngest ages in the vicinity of the Insubric Line. The re-interpretation favours the hypothesis that the oldest monazite ages are the result of complete resetting by a Permian thermal event. The $^{40}Ar/^{39}Ar$ hornblende ages and K–Ar biotite ages document the cooling after Permian heating. Roughly parallel age progressions decrease from the Pogallo Line (hornblende: 271 Ma vs. biotite: 227 Ma) towards the Insubric Line (hornblende: 201 Ma vs. biotite: 156 Ma). Zircon fission-track ages run parallel to the biotite ages in the upper part of the profile, whereas towards the Insubric Line a significant deviation from the biotite age progression is attributed to tilting of the basement during the Oligocene. Zircon fission-track ages around 38 Ma are found close to the Insubric Line. No age offset, neither at the CMB nor at the Pogallo Line, is observed. This confirms the hypothesis that the Pogallo Line is an oblique normal fault, and that the CMB Line has accommodated only minor vertical displacement. The capture of the different cooling ages confirms the tilting of the Ivrea–Verbano Zone during the Neo-Alpine deformation and contradicts the tilting of the Ivrea–Verbano Zone during the Permian.

Introduction

The Ivrea–Verbano Zone (IVZ) is located between Locarno and Ivrea in the southern Alps of the Piedmont Region of Italy and the Swiss Canton of Ticino. Together with the adjacent Strona–Ceneri Zone, it was the first key region interpreted in terms of an exposed cross-section of the lower to middle continental crust (e.g. Berckhemer 1969; Mehnert 1975; Fountain 1976; Fountain & Salisbury 1981) (Fig. 1). However, the pre-Permian evolution of the region is still a matter of discussion (e.g. Hunziker & Zingg 1980; Schmid 1993; Handy *et al.* 1999; Vavra *et al.* 1996). Following its Palaeozoic tectonometamorphic history, the Ivrea crustal section has been exhumed to shallower crustal levels, tilted and emplaced into its present position. Over the last 20 years, a number of review articles were published on its metamorphic petrology and structural evolution (e.g. Zingg

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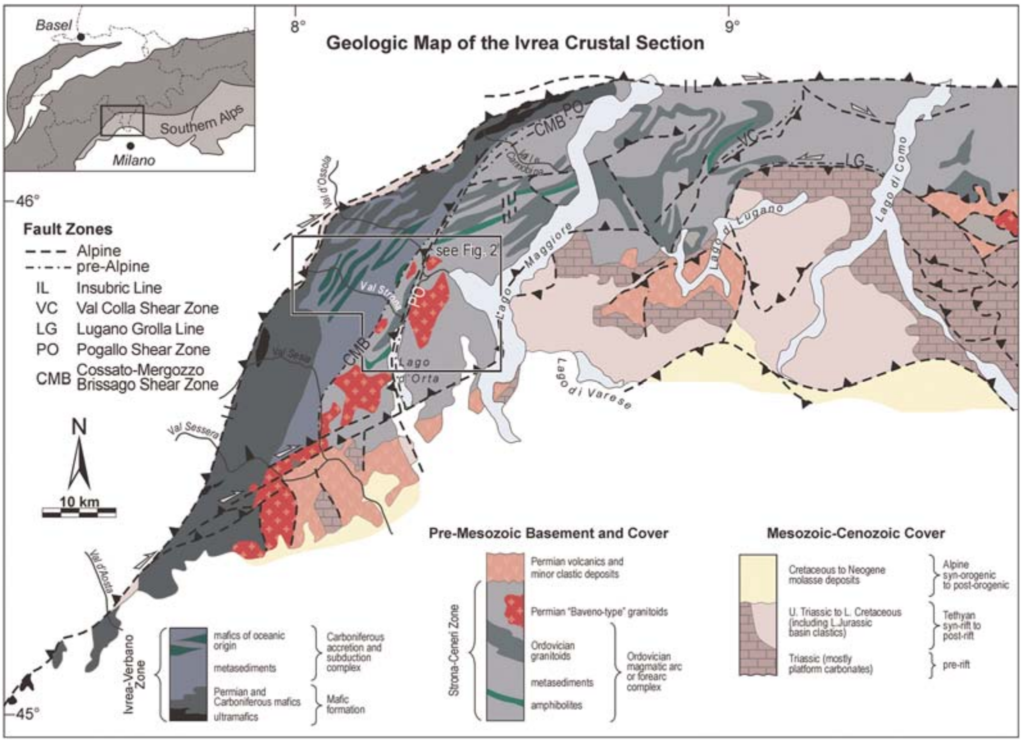

Fig. 1. Geological overview of the western part of the southern Alps (modified from Handy *et al.* 1999). The region consists of the metamorphic basement of the Ivrea–Verbano Zone (IVZ) and the Strona–Ceneri Zone (SCZ), and the Mesozoic to Cenozoic sedimentary cover. The outlined area around the Valstrona and Lago Maggiore was selected for structural and geochronological research (cf. Fig. 2).

et al. 1990; Boriani *et al.* 1990; Schmid 1993; Handy *et al.* 1999; Boriani & Giobbi 2004). In spite of this, the age, kinematics and geometry of the tectonic movements, which are responsible for exposing this almost complete crustal section at the Earth's surface, are the subject of ongoing debates (e.g. Handy & Zingg 1991; Schmid 1993; Handy *et al.* 1999).

Schmid *et al.* (1987) related the emplacement of the IVZ into its subvertical position adjacent to the Insubric Line to the Alpine orogeny, whereas Boriani *et al.* (1990) argued that vertical tilting took place prior to this, i.e. in the Permian. Handy *et al.* (1999) and Mulch *et al.* (2002) documented that the Strona Ceneri Zone (SCZ) was already moderately to steeply dipping in pre-Alpine times while the IVZ was tilted later, i.e. during the Late Oligocene to Early Miocene (Schmid *et al.* 1987).

Geochronological data are often used to constrain the timing and rates of geological processes, which are the major objectives in understanding the tectonic evolution of a region. In this study, the geochronology of a spectacular cross-section in the Valstrona di Omegna is presented (Fig. 2). This crustal section reveals different levels of the continental crust including granulite facies rocks in the NW and amphibolite facies in middle/upper crustal levels in the SE. Late Palaeozoic magmatism and its impact on the host formations is coeval at all crustal levels. This event is characterized by the emplacement of large mafic intrusions in the lower crust, resulting in the partial melting of metasediments and by plutonic and volcanic activity at higher crustal levels (e.g. Schmid 1978, 1979; Fountain 1986, 1989; Schmid 1993; Voshage *et al.* 1990; Rivalenti *et al.* 1975, 1981; Quick *et al.* 1994; Snoke *et al.* 1999; Peressini *et al.* 2007).

In order to bracket the exhumation history of the Ivrea Zone, dense sampling was performed in several field campaigns along the Valstrona profile (Fig. 2) and various minerals were geochronologically investigated. In this paper, we present new $^{40}Ar/^{39}Ar$ ages for hornblende, K–Ar ages on biotite and fission-track ages for zircon. Published U–Pb monazite ages (Teufel & Schärer *et al.* 1989; Henk *et al.* 1997) from almost identical sample localities along the Valstrona, as well as

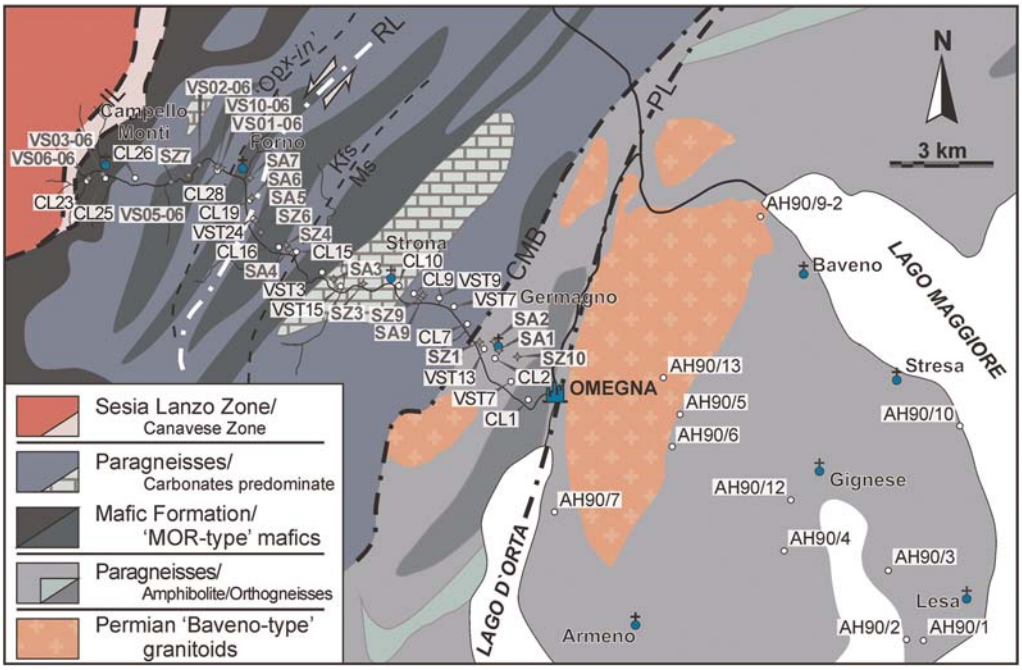

Fig. 2. Geology and sample sites along the Valstrona di Omegna–Lago Maggiore profile (modified after Bertolani 1969 and Handy *et al.* 1999). Sample sites for K–Ar Bt dating are indicated by open circles, whereas samples subjected to Ar–Ar Hbl and Zr fission-track dating are represented by grey stars.

published age data from other areas of the Ivrea Zone (Vavra *et al.* 1996; Boriani *et al.* 1990; Boriani and Villa 1997; Henk *et al.* 1997) are included to complete the dataset of the study. Together with available petrological data and structural field studies (Sills & Tarney 1984; Henk *et al.* 1997), we provide new constraints on the timing, kinematics and also to some extent on the displacement rates across distinct faults. The Rosarolo shear zone was selected to document the long-lasting time span and heterogeneity of deformation structures starting in the Permian.

Geological setting

The Ivrea Zone exposes a crustal section of the southern Alpine basement and is a SW–NE elongated body in the western Alps of Italy and Switzerland (Fig. 1). It is composed of the Ivrea–Verbano Zone (IVZ, 'formazione diorite-kinzigitica' by Novarese 1929) and the adjacent Strona–Ceneri Zone (SCZ, Serie dei Laghie of Boriani *et al.* 1990), and was the first region interpreted as an exposed cross-section of the entire continental crust (e.g. Berckhemer 1969; Mehnert 1975; Fountain 1976). The lowermost part of this section is often interpreted to represent the laminated lower crust, known from seismic sections all over the world. These are characterized by densely packed multiple sets of reflectors referred to as seismic lamellae (e.g. Fountain 1976; Burke & Fountain 1990; Rutter *et al.* 1993; Rabbel *et al.* 1998; Weiss *et al.* 1999).

The Ivrea Zone is separated from the Sesia Zone of the Central Alps by the greenschist facies Insubric mylonite belt (Fig. 1). The rocks tectonically incorporated into this mylonite belt are derived from the IVZ and the Sesia Zone, as well as from the Permo-Mesozoic sediments of the Canavese Zone. Shear criteria indicate that the mylonites accommodated back thrusting synchronous with back folding of the Central Alpine nappes. This was followed by a dextral strike-slip motion related to large transcurrent displacements in the Central Alps (Schmid *et al.* 1987).

The Pogallo Line, a 1–3 km-wide shear zone of mylonites, marks the subvertical contact between the SCZ and IVZ (Handy 1987). Hodges and Fountain (1984) first interpreted this shear zone in terms of a tilted normal fault of Mesozoic age. Boriani *et al.* (1990) identified the Cossato–Mergozzo–Brissagio Line (CMB-Line), which is closely associated with the Pogallo Line. The CMB Line (see Fig. 1) marks the transition between the IVZ and SCZ SW of the Val d'Ossola, where the Pogallo Line breaks away from the lithological contact between these two basement units (see discussion in Schmid 1993 and Boriani & Giobbi 2004). The CMB Line is characterized as a Late Variscan strike-slip zone showing a spatial and temporary relationship with mafic and granitic igneous rocks, i.e. the Appinite Suite. The continuity of the metamorphic pressure gradient across the CMB Line indicates that the vertical displacement was negligible (Handy *et al.* 1999).

While residing in the lower crust, the amphibolite to granulite facies paragneisses of the IVZ were intruded by huge volumes of mafic to intermediate plutonic rocks, known as the Mafic Complex (Rivalenti *et al.* 1981; Voshage *et al.* 1990). Most prominent in the south, the Mafic Complex dominates the IVZ along its limit with the Sesia Zone of the Central Alps. In the north, it is comprised of numerous sill-like intrusions up to several hundred of metres thick, whereas in the south, particularly in the Val Mastallone, mafic rocks up to 10 km thick occur. Along the northwestern border of the Mafic Complex, in the vicinity of the Insubric Line, several ultramafic bodies crop out. They extend from Baldissero in the south to Finero in the north. The geochemical composition and P–T conditions characterize them as derived from continental mantle material (Rivalenti *et al.* 1975, 1981; Garutti *et al.* 1978/1979; Shervais 1978/1979; Voshage *et al.* 1988; Hartmann & Wedepohl 1993).

Mafic rocks that contribute to the metamorphic history of the IVZ are separated into three groups (Zingg *et al.* 1990; Schmid 1993): (i) mafics of oceanic origin alternating with paragneisses (Sills & Tarney 1984); (ii) large bodies of 'Anzola gabbro'-type mafics; and (iii) parts of the banded mafics within the granulite facies region of the IVZ such as those within the layered complex (Rivalenti *et al.* 1981). The mafic rocks predating the 270 Ma magmatic event comprise the gabbrodiorites of the Mafic Complex in the Valsesia (see discussion in Voshage *et al.* 1990). Pin (1986) reported concordant 285 Ma U–Pb ages of magmatic zircons for these diorites. More recently, Peressini *et al.* (2007) found that the magmatic activity was bracketed between 290 Ma and 288 Ma.

At a higher structural level, the central part of the IVZ, known as the Kinzingite Formation (Novarese 1929), becomes dominant. In the Valstrona crustal profile, amphibolite-facies metapelites (the so-called kinzigites) and minor amphibolites constitute the uppermost part of the profile, whereas granulite-facies metapelites (known as stronalites) and mafic rocks make up the lowermost part in close proximity to the Mafic Complex. The appearance of subordinate silicate marbles, pegmatites and microgranites has also been described by Bertolani (1969). The degree of metamorphism of the Kinzigite Formation increases from amphibolite facies conditions in the SCZ and the lower part of the IVZ to granulite facies conditions close to the Insubric Line (Zingg 1983; Sills 1984; Henk *et al.* 1997). According to Sills (1984), granulite-facies metamorphism in the metapelites from the NW section of the Strona Valley reached maximum P–T conditions of 750 ± 50 °C and 6 ± 1 kbar. Henk *et al.* (1997) found peak metamorphic conditions of 810 ± 50 °C and 8.3 ± 2.0 kbar for a metagabbro from the base of the Mafic Complex. The lowest metamorphic conditions were obtained from alumosilicate-bearing gneisses near Omegna in the SCZ with P–T conditions of 580 ± 30 °C and 2.3 ± 0.5 kbar (Henk *et al.* 1997).

The metamorphic pressure gradient across the IVZ is about 0.41 kbar/km in the Valstrona section. This implies significant crustal thinning, particularly in the lowermost 5 km of the crust (Henk *et al.* 1997). These authors estimated that about 4 km of crustal attenuation occurred during the Early Permian. This estimate is in agreement with observations made by Sills and Tarney (1984), whereas Brodie and Rutter (1987) inferred only 2 km of lower crustal thinning in the IVZ. A higher pressure gradient of 1.7 kbar/km in the Valle Cannobina, located in the NW of the Valstrona (Fig. 1), suggests heterogeneous stretching subparallel to the lateral extent of the IVZ, which is attributed to the activity of the Pogallo shear zone (Handy *et al.* 1999). Normal faulting at the low angle Pogallo shear zone took place between 180 and 230 Ma (Hodges & Fountain 1984; Handy 1987).

The timing of peak metamorphism is still a matter of discussion. SHRIMP U–Pb data from a magmatic zircon population, with crystal shapes characteristic of calc-alkaline magmatites, yield a crystallization age of 355 ± 6 Ma (Varva *et al.* 1996). The oldest metamorphic zircon rims in the metasediments of the IVZ are Early Permian (*c.* 296 Ma). In contrast, U–Pb ages for monazite and zircon from the SCZ point to a mid-Palaeozoic metamorphic event at *c.* 400 Ma (Köppel & Grünfelder 1978/1979; Köppel 1974; Rigaletti *et al.* 1994). A numerical simulation (Henk *et al.* 1997) of the temperature development in the IVZ, in response to the emplacement of the Mafic Complex, suggests that the metamorphic peak occurred prior to 300 Ma. The range of U–Pb monazite ages (assuming a closure temperature of *c.* 600 °C) between 272 Ma and 292 Ma document the heating pulses related to the magmatic underplating, which had created the typical granoblastic structure in the Ivrea Zone. Additional geochronological data for the IVZ recorded the progressive cooling from the high temperatures prevailing during the Permo-Carboniferous metamorphic peak to temperatures of around 300 °C in the Jurassic (e.g. Zingg *et al.* 1990).

Results

Structural geology of the study area

Metamorphic foliation and banding in the IVZ are generally steeply inclined and trend NE–SW. An eastward plunge of stretching lineations is remarkably constant. Recently, Rutter *et al.* (2007) proposed that large-scale superimposed folding in the upper part of the IVZ in the Valstrona section occurred during regional migmatization, probably during the Hercynian orogeny. The IVZ in the Valstrona cross-section is bounded to the northwest by the Insubric mylonite belt. It is in contact with the adjacent SCZ to the southeast across the CMB Line (Boriani *et al.* 1990, see also Fig. 1). The CMB Line is considered to be a major subvertical tectonic discontinuity of Permian age (Boriani & Villa 1997; Mulch *et al.* 2002; or Boriani & Giobbi 2004). Starting in Permian times, the region was subjected to large-scale injection by basic magmas, accompanied by pervasive east–west stretching and crustal thinning of several kilometres. A network of conjugate high-temperature, low-angle shear zones in a layered lower crustal section related to this stretching has been identified (Brodie & Rutter 1987; Brodie *et al.* 1989, 1992; Rutter *et al.* 1993; Snoke *et al.* 1999). The corridor of shear zone outcrops, which passes through Anzola (Val d'Ossola) and Forno (Valstrona), can be traced for more than 20 km. The radiometric ages from the Anzola shear zone indicate that it relates to extension, which commenced prior to 280 Ma (Brodie *et al.* 1990), approximately coeval with the intrusion of the Mafic Complex. Metabasic rocks incorporated into inhomogeneous shear zones and transformed into mylonites and ultramylonites were deformed by dislocation creep accompanied by prograde dynamic recrystallization (Dornbusch & Skrotzki 2001).

The displacements along the CMB Line are clearly contemporaneous with the Permian mafic underplating events, and lead to the juxtaposition of the IVZ with the SCZ (Giobbi & Brodie 2004). The CMB mylonites are locally overprinted by a younger amphibolite to greenschist facies mylonite zone, the Pogallo Line. Mylonitization along the Pogallo Line clearly postdates the activity of the CMB in the Early Permian. The age of the Pogallo Line has been previously constrained to 160–240 Ma (Zing *et al.* 1990). In the Valstrona area, the Pogallo Line is only evidenced by brittle deformation due to the oblique low-angle normal fault geometry of the Pogallo Line, which has been reoriented in Alpine times (Handy 1987).

In the Valstrona cross-section, a long-term steeply inclined (present-day coordinates) shear zone is found, referred to as the Rosarolo shear zone (Fig. 2). The oldest high-temperature ultramylonites found in metabasic rocks can be related to the Anzola-type shear zones and incorporated mafic injections. At this time, the whole sequence was presumably in a horizontal position. The subsequent formation of pseudotachylites and other brittle deformation features took place within the upper crust. Shear sense criteria are principally sinistral, and antithetic shears only appear subordinate. The simplified sketches shown in Figure 3 illustrate that high-temperature mylonitization took place in the lower crust as part of an extensional fault system, while the evidence of frictional melting and brittle faulting indicates sinistral strike-slip movement in the middle and upper crust. In the following section, we describe the Rosarolo shear zone and argue in more detail to document the long time span and heterogeneity of deformation structures.

Fabrics of the Rosarolo shear zones

On the whole, the study area can be described as a high-strain shear zone. In its central parts, it consists of a network of sub-parallel anastomosing shear zones at the cm to m scale. Each of these minor mylonitic shear zones displays structures, which indicate that several strain increments occurred at different P/T conditions (Fig. 4). A large number of macro- and microstructures provide evidence that—with respect to present-day coordinates—sinistral shear operated over a long time span from the ductile to the brittle field (Ahrendt *et al.* 1990; Clausen 1990; see below). Only in a few cases are subordinate structures with an antithetic (dextral) sense observed. Because of distinct rheological contrasts between individual layers, which are mainly controlled by the ratio of mafic to felsic minerals, brittle and ductile deformation may also have operated more or less simultaneously. This resulted in a large variety of deformation structures and complex interactions of deformation processes. Macroscopically, the significance of rheological contrasts is best documented by ductile flow of felsic layers filling gaps produced by brittle faults affecting more mafic layers (Fig. 4b). Frequently, the common leucocratic segregations are cut by early formed mylonitic foliations, but were deformed and partly obliterated within the high strain cores of small-scaled shear zones (Fig. 4c).

Considering the shear zone as a whole, the mylonitic foliations are steeply inclined and strike NNW–SSE, grading into the NE–SW striking


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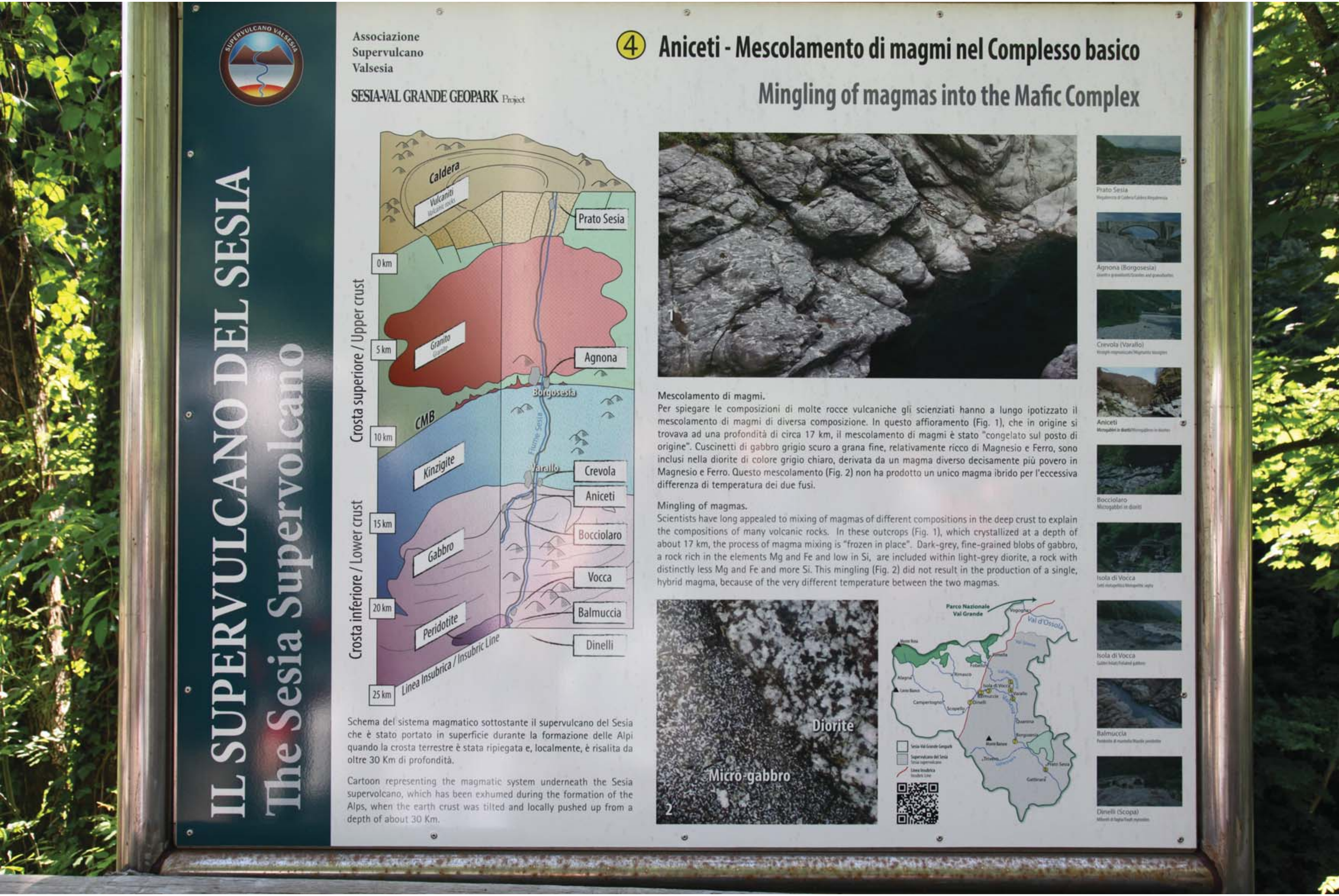

④ Aniceti - Mescolamento di magmi nel Complesso basico

Mingling of magmas into the Mafic Complex

Schema del sistema magmatico sottostante il supervulcano del Sesia che è stato portato in superficie durante la formazione delle Alpi quando la crosta terrestre è stata ripiegata e, localmente, è risalita da oltre 30 Km di profondità.

Cartoon representing the magmatic system underneath the Sesia supervolcano, which has been exhumed during the formation of the Alps, when the earth crust was tilted and locally pushed up from a depth of about 30 Km.

Mescolamento di magmi.

Per spiegare le composizioni di molte rocce vulcaniche gli scienziati hanno a lungo ipotizzato il mescolamento di magmi di diversa composizione. In questo affioramento (Fig. 1), che in origine si trovava ad una profondità di circa 17 km, il mescolamento di magmi è stato "congelato sul posto di origine". Cuscinetti di gabbro grigio scuro a grana fine, relativamente ricco di Magnesio e Ferro, sono inclusi nella diorite di colore grigio chiaro, derivata da un magma diverso decisamente più povero in Magnesio e Ferro. Questo mescolamento (Fig. 2) non ha prodotto un unico magma ibrido per l'eccessiva differenza di temperatura dei due fusi.

Mingling of magmas.

Scientists have long appealed to mixing of magmas of different compositions in the deep crust to explain the compositions of many volcanic rocks. In these outcrops (Fig. 1), which crystallized at a depth of about 17 km, the process of magma mixing is "frozen in place". Dark-grey, fine-grained blobs of gabbro, a rock rich in the elements Mg and Fe and low in Si, are included within light-grey diorite, a rock with distinctly less Mg and Fe and more Si. This mingling (Fig. 2) did not result in the production of a single, hybrid magma, because of the very different temperature between the two magmas.

IL SUPERVULCANO DEL SESIA
The Sesia Supervolcano

Associazione
Supervulcano
Valsesia

SESIA-VAL GRANDE GEOPARK Project

⑥ Crevola- Contatto tra il Complesso Basico e le kinzigiti
Contact between the Mafic Complex and the kinzigites

Schema del sistema magmatico sottostante il supervulcano del Sesia che è stato portato in superficie durante la formazione delle Alpi quando la crosta terrestre è stata ripiegata e, localmente, è risalita da oltre 30 Km di profondità.

Cartoon representing the magmatic system underneath the Sesia supervolcano, which has been exhumed during the formation of the Alps, when the earth crust was tilted and locally pushed up from a depth of about 30 Km.

Fusione parziale della crosta.
Vi trovate a circa 15 km di profondità nella crosta terrestre, al contatto tra il Complesso Basico e le rocce crostali che esso ha intruso. Queste, fortemente deformate (Fig. 1), con pieghe caotiche e strutture dette "boudinage", testimoniano uno stiramento.
L'intenso calore liberato dal Complesso Basico ha fatto fondere in parte le rocce crostali, originando delle porzioni chiare (neosoma) intercalate al residuo non fuso delle rocce preesistenti di colore più scuro (paleosoma). Le parti chiare rappresentano proprio il prodotto della fusione parziale della crosta ed hanno composizione granitica (Fig. 2, 3). Da questi fusi migrati verso l'alto hanno avuto origine i graniti che si trovano nella crosta superiore, come si vede allo stop di Agnona, e ad attivare l'eruzione del supervulcano.

Partial Melting of the Crust.
We are about 15 Km deep in the Earth's crust, at the contact between the gabbro of the Mafic Complex and the crustal rocks that it intruded. The crustal rocks (Fig. 1) are strongly deformed with many complexly wrinkled layers and evidence of stretching called "boudinage". To identify boudinage, look for layers with thin intervals like gum that has been stretched.
Intense heat released from the crystallizing Mafic Complex has partially melted the crustal rocks, producing light and dark segregations. The darkest portions of the outcrop, called paleosomes, are what remain of the primitive rock. The lightest granitic portions, called leucosomes, crystallized from the partial melts (Fig. 2, 3). Migration of partial melts to higher crustal levels crystallized granitic rocks that can be observed at the Agnona stop and helped drive the eruption of the Sesia supervolcano.


PLUTONIC ROCK TYPES
Q = quartz
A = alkali feldspar
P = plagioclase feldspar
numbers = percent Q or P
Q
Quartzolite
90
90
Quartz-rich granitoid
60
60
Alkali-feldspar granite
Alkali-feldspar quartz syenite
Granite
(Syeno-granite)
(Monzo-granite)
Grano-diorite
Quartz diorite/ Quartz gabbro
20
20
Quartz syenite
Quartz monzonite
Quartz monzodiorite/ monzogabbro
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65
90
Monzodiorite/ Monzogabbro
Diorite/ Gabbro
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Streckeisen 1976

IL SUPERVULCANO DEL SESIA
The Sesia Supervolcano

Associazione
Supervulcano
Valsesia

SESIA-VAL GRANDE GEOPARK Project

⑦ Agnona - Intrusione di magmi diversi nella crosta superiore

Intrusion of different kinds of magmas in the upper crust

I magmi della crosta profonda invadono la crosta superiore.
Le rocce che vedete (Fig. 1) sono il risultato del mescolamento di magmi diversi nella risalita dalla crosta profonda verso la superficie, ad una profondità di circa 10 km. Rocce dioritiche grigie, simili a quelle del Complesso Basico, sono mescolate con magmi granitici più chiari, derivati dalla fusione parziale della crosta. Per ultime si sono formate delle pegmatiti, filoni di roccia contenenti cristalli di grandi dimensioni (Fig. 2).

Deep crustal magmas invading the upper crust.
The complex relationships in this outcrop (Fig. 1) record multiple intrusions of magmas at a depth of about 10 Km in the Earth's crust as they rose from the deep crust toward volcanic centers at the surface. Dark-grey dioritic rocks, which crystallized from magma rising upward from the deeper gabbro intrusion we call the Mafic Complex, are mingled with white granitic rocks that crystallized from magma produced by partial melting of the crust. The latest magmatic intrusions are represented by pegmatitic veins, identifiable by the large size of the crystals, mostly quartz, feldspar and mica (Fig. 2).

Schema del sistema magmatico sottostante il supervulcano del Sesia che è stato portato in superficie durante la formazione delle Alpi quando la crosta terrestre è stata ripiegata e, localmente, è risalita da oltre 30 Km di profondità.

Cartoon representing the magmatic system underneath the Sesia supervolcano, which has been exhumed during the formation of the Alps, when the earth crust was tilted and locally pushed up from a depth of about 30 Km.


1 km
50


Active volcanic island arc
Remnant arc
Spreading back-arc basin
Trench
Forearc accreted terrane
Cumulates
MANTLE WEDGE
OCEANIC CRUST of sediment + hydrated mafic rocks
Srp + Brc + Tlc
Amphibole + chlorite + epidote
Possible ada
Amp + Phl ± Srp
MANTLE
Eclogite rock of clinopyroxene + garnet ± amphibole
0
km
50


PLUTONIC ROCK TYPES
Q = quartz
A = alkali feldspar
P = plagioclase feldspar
numbers = percent Q or P
Q
A
P
Quartzolite
Quartz-rich granitoid
Alkali-feldspar granite
Granite
(Syeno-granite)
(Monzo-granite)
Grano-diorite
Tonalite
Alkali-feldspar quartz syenite
Quartz syenite
Quartz monzonite
Quartz monzodiorite/ monzogabbro
Quartz diorite/ Quartz gabbro
Syenite
Monzonite
Monzodiorite/ Monzogabbro
Diorite/ Gabbro
Alkali-feldspar syenite
90
60
20
5
10
35
65
P/(A+P) × 100
~~26,5~~
62,5


$^{143}Nd=($ … $)_0 + ^{147}Sm(e$ … $-1)$
$^{143}Nd/^{144}Nd=(^{143}Nd/^{144}Nd)_0 + ^{147}Sm/^{144}Nd(e^{\lambda t}-1)$
Nd → inkomp. Element für Erdmantelminerale