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The Bergell pluton (Southern Switzerland, Northern Italy): overview accompanying a geological-tectonic map of the intrusion and surrounding country rocks

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Abstract

The major rock types and tectonic units compiled in the attached geological map (BERGER, 1996) are briefly described. The tectonic units surrounding the Bergell pluton comprise the entire stack of Alpine nappes from the Penninic Adula-Gruf nappe to the Upper Austroalpine units and the Southern Alps. The text facilitates access to the existing literature, briefly summarizes the results of very recent work and serves as an introduction into the regional geology of the Bergell pluton and country rocks.

Keywords: plutonic rocks, nappe tectonics, map sheet, Bergell (Bregaglia) intrusion, Insubric line, Central Alps, Grisons, Northern Italy.

Contents

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1. Introduction

The Bergell pluton, also referred to as the Bregaglia-Jorio or Masino-Bregaglia intrusion, is a calc-alkaline suite of gabbro, diorite, tonalite and granodiorite and represents one of the few late-Alpine intrusions present in the Alps. It is one of the best-investigated igneous complexes amongst the so-called Periadriatic intrusions, situated in the vicinity of the Periadriatic line.

The Bergell pluton is unique for its very special and fascinating structural setting within the stack of Alpine nappes (Penninic and Austroalpine nappes) that are backfolded into the steeply north-dipping orientation characteristic for the Southern Steep Belt. The southern limit of the Southern Steep Belt is defined by the Insubric mylonite belt (or Insubric line, a segment of the Periadriatic line) which juxtaposes the Central Alps against the Southern Alps. Due to excellent three-dimensional exposure and a pronounced axial plunge to the east (locally up to 25°) the contact of the Bergell pluton with the country rocks can be examined from east to west over an interval of at least 10 km of original crustal depth. Hence, the Bergell area provides a rare opportunity to observe the three-dimensional geometry of an entire pluton (from its floor to its roof), which intruded at a depth of 15–20 km. The geological-tectonic map of BERGER (1996), included in this volume, helps to visualize the complicated relationships between pluton and country rocks.

A second principal reason for compiling and describing a new map is that this gives an opportunity to present some results from work on the petrology and structure of the Bergell pluton and surrounding rocks carried out in recent years mainly by groups from the University of Basel and ETH Zürich. While detailed results of these new investigations have been or will be published elsewhere, this contribution aims at providing the essentials of the macroscopic field geological data base. Hopefully, it will stimulate further studies and also be helpful during excursions to this fascinating area.

This text is meant to serve as explanatory notes accompanying the map attached to this volume (BERGER, 1996). Hence, its primary aim is a brief description of all major rock types and tectonic units defined within the area mapped. Abundant references will help the reader to gain access to the existing literature and to indicate the sources used to compile this map. A very brief geological overview will be given after the description of all the mapped rock units.

2. General remarks

The attached map (BERGER, 1996) is not meant to be strictly a geological map, nor is it purely a tectonic map. Similar rock types within different tectonic units are mapped as separate entities in order to facilitate the tectonic overview. Conversely, the map indicates all the major mappable lithological units, as far as possible at the chosen scale (1:50'000). It was decided to leave the Quaternary cover blank and undiscriminated because we primarily aim at a geological-tectonic overview of pre-Quarternary rocks. Much care has been taken to map the outlines of outcrops as precisely as possible in critical areas (i.g. near important tectonic contacts), whereas we were less meticulous in assigning particular areas to lithological-tectonic units in less crucial areas (particularly within the Bergell pluton).

Admittedly, this procedure may be problematic in many respects. However, a compromise had to be made between accuracy in outlining outcrops, and our principle goal of giving an easily readable overview. In the next chapters we proceed from bottom to top in terms of tectonic units, followed by a description of the calc-alkaline suite of the Bergell pluton. Some rock types, such as marble, amphibolite and ultramafics are mapped without specifying the tectonic position (see "Various Rock Types" in legend of map).

3. Penninic units

3.1. ADULA-GRUF NAPPE

The "Gruf complex" crops out east of Val Mera and structurally below the floor of the Bergell pluton (at its present-day western and northwestern margin and in the window of Bagni del Masino). Traditionally (e.g. STAUB, 1946; WENK, 1973), it has been mapped as a separate tectonic entity with respect to the Adula nappe sensu stricto, exposed west of Val Mera. However, the same migmatitic gneisses, characteristic for most of the "Gruf complex" (BUCHER-NURMINEN and DROOP, 1983; WENK, 1973; SCHMUTZ, 1976; MOTICSKA, 1970; WENK and CORNELIUS, 1977; HANSMANN, 1981) are also found in the southern part of what is indisputably considered to be part of the Adula nappe (BLATTNER, 1965; BRUGGMANN, 1965; HÄNNY, 1972; HEITZMANN, 1975). More importantly, structural investigations (HAFNER, 1993; DAVIDSON et al., 1996; BERGER et al., 1996) demonstrate that the Cressim antiform, a major backfold that brings the Adula nappe into a steeply north-dipping overturned orientation west of Val Mera

(HEITZMANN, 1975; HAFNER, 1993), can be traced directly into the "Gruf complex" and into the syn-magmatically folded Bergell pluton. Hence, there is no justification for a tectonic separation across Val Mera, except immediately south of Chiavenna, where the Forcola normal fault causes a structural discordance between the gneisses of the Adula-Gruf nappe cropping out on opposite sides of the valley.

According to SCHMID et al. (1996 a, b), the Adula-Gruf nappe represents the distal European margin, originally situated north of the N-Penninic suture. The northern part of the Adula nappe is characterized by eclogite facies metamorphism. However, none of this early (very probably Tertiary) metamorphism (TROMMSDORFF, 1990; PARTZSCH et al., 1994) is preserved in the area of our map because of a pronounced Barrovian-type ("Lepontine") metamorphic overprint.

Migmatitic gneisses: Migmatitic quartzo-feldspatic gneiss is the predominant rock type east of Val Mera and over much of the area mapped west of Val Mera. However, small lenses (tens of meters) and cm-sized nodules of other rock types of considerable petrological interest occur throughout the migmatitic gneiss, especially east of Val Mera. These include ultramafic and mafic rocks (larger occurrences are mapped as "various rock types"), metapelite and calc-silicate. Metapelitic schist and gneiss inclusions have been subject of detailed petrological investigations by BUCHER-NURMINEN and DROOP (1983), DROOP and BUCHER-NURMINEN (1984) and WENK et al. (1974). Sapphirine-orthopyroxene granulites, found in boulders in Val Codera (DROOP and BUCHER-NURMINEN, 1984; see also WENK and CORNELIUS, 1977 for locations), show that granulite facies conditions (10 kbar and 810 °C) pre-dated final equilibration at 3–4 kbar and 600–650 °C that took place after emplacement of the Bergell pluton. Tonalite along the western margin of the Bergell pluton cooled through its solidus at intermediate pressures of approximately 6.5 kbar (REUSSER, 1987; DAVIDSON et al., 1996). Some isotope data point to a pre-Alpine age of migmatization (GULSON, 1973; HÄNNY et al., 1975). Structural evidence, however, clearly points to an Alpine age for most of the migmatites (HÄNNY, 1972; HAFNER, 1993). DAVIDSON et al. (1996) and BERGER et al. (1996) regard migmatization to be contemporaneous with (or slightly post-dating) final emplacement of the Bergell pluton.

Layers and inclusions of ultramafic and mafic rocks, of metapelite, and particularly calc-silicate, tend to be concentrated directly underneath the floor of the pluton exposed at its western margin (Val Codera, Valle dei Ratti) and in Bagni del Masino (partly mapped by WENK and CORNELIUS, 1977; see also detailed map in upper Val Codera by DIETHELM, 1989, his Fig. 3.4., and HANSMANN, 1981). Most of these rock types could not be mapped at the 1:50'000 scale and are included within the migmatitic gneisses. These discontinuous layers are considered to be remnants of the tectonically higher Bellinzona-Dascio zone (DAVIDSON et al., 1996). Because these rock types concentrate at the pluton margin, DIETHELM (1989) suggested that the Bergell pluton was emplaced along a former nappe boundary. This boundary is situated between the underlying Adula-Gruf nappe and the overlying Bellinzona-Dascio zone which is, according to DAVIDSON et al. (1996), correlated with the Chiavenna ophiolite and the Misox zone (SCHMID et al., 1996b).

A boundary between the migmatitic gneiss of the Adula-Gruf nappe and the gneisses and schists of the Bellinzona-Dascio zone is, however, mapped in Valle dei Ratti east of Val Mera. This boundary is not easy to define because migmatitic gneiss is the predominant rock type in both tectonic units (see map by MONTRASIO and SCIESA, 1988). Based on MOTICSKA (1970, we thank E. Wenk for providing the original field maps) and mapping by ROSENBERG (1996) this contact could only be traced as a well-defined lithological boundary in the upper Valle dei Ratti, between leucocratic gneiss (Adula-Gruf nappe) and more biotite-rich rocks (gneisses and schists of the Bellinzona-Dascio zone, with abundant ultramafic rocks, amphibolite and calc-silicate). It is again well-marked west of Val Mera by the Paina marble (FUMASOLI, 1974; HEITZMANN, 1975, 1987a), a greenschist facies mylonite horizon, which cannot be traced eastwards across Val Mera. Detailed descriptions of the occurrences of migmatites west of Val Mera are found in BLATTNER (1965), HÄNNY (1972) and HAFNER (1993).

Quartzo-feldspatic gneisses: This lithological unit is composed of biotite (± muscovite) gneiss, fine-grained granitic gneiss, K-feldspar augen gneiss, and a well-foliated fine-grained banded gneiss formation (Donadio Gneiss, see HÄNNY, 1972). The boundary between these rock types and the migmatitic gneisses in Val Bodengo was mapped in detail by HÄNNY (1972) and its eastwards continuation is taken from the compilation by MONTRASIO and SCIESA (1988).

Micaschist: This garnet-staurolite-kyanite-sillimanite bearing banded micaschist has been mapped by HÄNNY (1972, see his chapter 2.3.1.)

and WEBER (1966). Its occurrence is limited to the structurally higher parts of the Adula-Gruf nappe between Valle Bodengo and Valle della Forcola (see HÄNNY, 1972, and WEBER, 1966, for a detailed description of these micaschists). The northernmost band of micaschist, known as the Soazza zone, asymptotically approaches the Forcola normal fault and is cut off by this fault in the lowermost Valle della Forcola.

Sivigia gneiss: This hypersthene-amphibole-biotite-labradorite gneiss (WENK, 1992) occurs as a mappable unit in upper Val Codera (WENK and CORNELIUS, 1977, and DIETHELM, 1989). It is interpreted to be the product of metasomatic alteration of ultramafic breccia by WENK (1973, 1982, 1986).

3.2. CHIAVENNA OPHIOLITE AND BELLINZONA-DASCIO ZONE

Traditionally, these two tectonic units are treated separately. They are indeed spatially separated and different in terms of the dominating rock types. The Bellinzona-Dascio zone is restricted to the Southern Steep Belt (MILNES, 1974, 1978; MILNES and PFIFFNER, 1980), situated immediately north of the Jorio tonalite (west of Val Mera) and north of the southern Bergell tonalite (east of Val Mera). The Chiavenna ophiolite, on the other hand, is found north of, and structurally above, the Adula-Gruf nappe, but underneath the structurally higher Tambo nappe. In the present map we chose to group the Bellinzona-Dascio zone and Chiavenna ophiolite together for two reasons: (1) they are linked together by a zone that follows the western contact of the Bergell pluton where ultramafic, mafic, metapelitic and calc-silicate rocks are concentrated (see above: "Adula-Gruf nappe, migmatitic gneisses"), and (2) they occupy the same tectonic position above the Adula nappe. Together they are considered to represent the N-Penninic suture zone (SCHMID, 1996b). Also, note that the Tambo nappe, situated above the Chiavenna ophiolite, has no remnants in the Southern Steep Belt, where the Bergell pluton (the Jorio tonalite extending westwards to Bellinzona) occupies the tectonic position of Tambo and Suretta nappes (DAVIDSON et al., 1996; BERGER et al., 1996).

The Chiavenna mafic-ultramafic complex is interpreted as an overturned ophiolitic sequence (SCHMUTZ, 1976) whereas the Bellinzona-Dascio zone encompasses a lithologically very heterogeneous suite of upper crustal metagranitoids and metasediments, with isolated boudins of mafic and ultramafic rocks (FUMASOLI, 1974; HEITZMANN, 1975; MOTICSKA, 1970). The Bellinzona-Dascio zone may be interpreted as a mélange zone and is structurally correlated with the Chiavenna ophiolite and ultimately with the Misox zone. For the compilation of these units in our map we used data from SCHMUTZ (1976), HEITZMANN (1975), MOTICSKA (1970), and ROSENBERG (1996).

Gneisses and schists of the Bellinzona-Dascio zone: West of Val Mera, fine-grained biotite schist with abundant sillimanite and a pronounced layering consisting of thin leuco- and melanocratic layers, is the predominant and characteristic rock type of the Bellinzona-Dascio zone (see FUMASOLI, 1974; HEITZMANN, 1975; and MOTICSKA, 1970, for the eastern part of the Bellinzona-Dascio zone). Intercalations of thin amphibolite layers and aplitic and pegmatitic dikes are characteristic. Towards the east, large bodies of granitic gneiss (migmatitic in Valle dei Ratti) become relatively more abundant and are difficult to distinguish from the granitic gneisses of the Adula-Gruf nappe. Larger occurrences of other rock types, also characteristic for the Bellinzona-Dascio zone (ultramafics, larger amphibolite bands, marbles including calc-silicates) are mapped separately (see "various rock types" in legend). The only detailed study of a peridotite body within the Bellinzona-Dascio zone west of our map (SCHMIDT, 1989) demonstrates that this body represents a relic of an ophiolitic sequence.

Ultramafic rock: The Chiavenna ultramafic rocks (predominantly peridotite) generally overlie mafic rocks, calc-silicates and marbles. The Chiavenna mafic-ultramafic complex and the pelitic gneisses of the overlying Tambo nappe exhibit an interesting zonation of different parageneses studied in detail by SCHMUTZ (1976). Grade of metamorphism increases very rapidly towards the south (from forsterite-antigorite to forsterite-enstatite-spinel), corresponding to an estimated metamorphic field gradient of 40–50 °C/km (SCHMUTZ, 1976). This indicates that regional metamorphism gives way to contact metamorphism in this area due to late-stage rapid exhumation of the high-grade Adula-Gruf unit and the Bergell pluton along a subvertical tectonic contact situated between the Chiavenna ophiolite and the Adula-Gruf nappe (the Gruf line of BERGER et al., 1996).

Mafic rocks: Massive or layered amphibolites are usually found adjacent to the peridotites. These mafic rock types are predominant and probably represent former gabbros, basaltic lavas and dikes. Gradations into plagioclase- and hornblende-rich calc-silicate are often observed near the original top of the overturned ophiolitic sequence (SCHMUTZ, 1976).

Marble and calc-silicate: The origin of these rocks, discussed by SCHMUTZ (1976), is uncertain. If they represent the original sedimentary cover of the ophiolitic sequence, the meta-radiolarites, characteristic for many S-Penninic Alpine ophiolites, would be missing. Note, however, that radiolarites are not expected if this ophiolite complex is, as we propose, part of the N-Penninic ocean from which no radiolarite has been described so far. Associations of ultramafic and mafic rocks with marble, but without radiolarites, are also known from the N-Penninic Aul marble unit, one of the slices within the Valais Bündnerschiefer which roots in the Misox zone (STEINMANN, 1994).

3.3. TAMBO NAPPE

Our map only covers the southernmost, presently north-dipping part of this nappe. Paleogeographically, this nappe was part of the middle Penninic (Briançonnais) realm (SCHMID et al., 1990). Our compilation is based on maps provided by STAUB (1921); WEBER (1966); BLANC (1965); WENK and CORNELIUS (1977); MONTRASIO and SCIESA (1988), and recent mapping (S. Schmid) south of the Engadine line. An overview of the entire nappe is found in BAUDIN et al. (1993).

Gneisses and schists in general: This unit encompasses various polymetamorphic basement units which pre-date the intrusion of the Truzzo granite which only underwent Alpine metamorphism. The mesocratic biotite-rich gneisses and schists are found on top of the Chiavenna ophiolite and contain intercalations of amphibolite (SCHMUTZ, 1976). Staurolite attributed to the Alpine metamorphism is found within metapelitic rocks. Sillimanite is confined to the southernmost outcrops near the Adula-Gruf nappe, whereas andalusite only appears further to the east (south of Castasegna: SCHMUTZ, 1976; Val Bondasca: WENK et al., 1974; WENK and CORNELIUS, 1977), where regional metamorphism gradually gives way to contact metamorphism in the vicinity of the Bergell pluton. WENK et al. (1974) also report kyanite west of Val Bondasca. Similar rock types are found north of the Mera river. However, due to the lack of recent studies, the position of the E–W running staurolite-in isograd can only be approximately located immediately north of the river Mera between Chiavenna and the Swiss border. For a map showing the distribution of alumosilicates in metapelites around the Bergell pluton see WENK et al. (1974), WENK (1982) and WENK (1986).

Truzzo granite and gneiss: This granite intruded at 293 ± 14 Ma according to Rb/Sr whole rock dating (GULSON, 1973). The Truzzo granite contains K-feldspar megacrysts and, when undeformed, strongly resembles the Bergell granodiorite (e.g., at excursion stop 61 of excursion 4 in TRÜMPY and TROMMSDORFF, 1980; north of Chiavenna, just outside our map). Shear zones within the Truzzo granite transform the granite into a two-mica augen gneiss that is locally mylonitic (MARQUER, 1991). South of the Mera river, the granite is homogeneously and strongly deformed, and exhibits a pronounced E–W lineation.

Permo-Mesozoic cover: Within the area of our map, this sequence of rocks predominantly consists of a volcano-detrital Permo-Carboniferous cover at the base, overlain by white quartzite (STAUB, 1921; MONTRASIO and SCIESA, 1988). BAUDIN et al. (1993, 1995) have recently re-investigated the cover sequence including younger formations, preserved in an area north of our map.

3.4. SURETTA NAPPE

The Suretta nappe, together with the Tambo nappe and the Schams nappes, paleogeographically represents the Briançonnais realm (SCHMID et al., 1990). The Suretta nappe was mapped by STAUB (1921, 1946) north of and along the eastern margin of the Bergell pluton. The southernmost part of this nappe, north of the Engadine line (TRÜMPY, 1977; SCHMID and FROITZHEIM, 1993), is north-dipping. A coherent southeast-dipping remnant of this nappe, however, is still preserved immediately south of the Engadine line which displaced it (see profiles in WENK, 1973, 1986). In this northeastern corner of the Bergell pluton, the last coherent part of the Suretta nappe, attached to the Avers Bündnerschiefer unit and the Forno unit on top, is discordantly cut by the intrusion of the granodiorite in the Lavinair Crusc area, as mapped by STAUB (1921) and GYR (1967). Isolated xenoliths of various sizes (10 cm to 100 m) derived from the Suretta nappe, the Avers Bündnerschiefer, and the Forno unit can be found within the granodiorite (STAUB, 1921, 1946; DRESCHER and STORZ, 1926; GYR, 1967; GIERÉ, 1985; PERETTI, 1985). The spacial arrangement of these xenoliths within the granodiorite is systematic

(DRESCHER and STORZ, 1926; GYR, 1967; PUSCHNIG, 1996). This indicates only minor displacement of the xenoliths during magma intrusion.

A km-sized mappable block of Suretta basement and cover is again preserved at Cima di Vazzeda at the eastern margin of the pluton, mostly enclosed by tonalite and granodiorite (GIERÉ, 1984, 1985; BERGER and GIERÉ, 1995). Judging from the geometry of the country rocks around the intrusion, this huge block must have been displaced upwards a considerable distance with respect to its original position during magma emplacement (BERGER and GIERÉ, 1995). Further to the south, from Monte Disgrazia to Valle di Preda Rossa, only a very thin band of the Suretta nappe is preserved along the contact between the Bergell tonalite and the Malenco ultramafic rocks (GIERÉ, 1985; PFIFFNER and WEISS, 1994). This attenuated band runs parallel to a major synmagmatic shear zone which follows and deforms the pluton margin: the Preda Rossa shear zone (geometrically and kinematically a normal fault; BERGER and GIERÉ, 1995; BERGER et al., 1996). According to NIEVERGELT et al. (1996) and PUSCHNIG (1996) the contact between the Suretta nappe and the overlying Malenco and Forno units represents the southern continuation of the Turba mylonite zone, a low angle extensional detachment overprinting former nappe contacts (LINIGER and NIEVERGELT, 1990; NIEVERGELT et al., 1996). In map view the Turba mylonite zone cuts out the Avers Bündnerschiefer which are no more present along the SE margin of the pluton. Both fault zones are considered to be roughly contemporaneous by BERGER et al. (1996). Since both exhibit top to the east to south-east normal faulting, they are probably kinematically linked.

Basement: Analogous to the Tambo basement, the Suretta basement also consists of a polymetamorphic sequence (referred to as the Timun complex) and younger Permo-Carboniferous intrusions, subvolcanic and volcanic rocks (Roffna porphyroids) described by STAUB (1918), GRÜNENFELDER (1956), BLANC (1965), GYR (1967), WENK (1974), and GIERÉ (1985). Within the area of our map, biotite schist and gneiss, metapelite, and some amphibolite of alkalibasaltic composition are the predominant rock types in the polymetamorphic Suretta basement. Thin layers of quartzo-feldspathic gneiss and augen gneiss, interleaved with this polymetamorphic basement, have been mapped by STAUB (1921) and GYR (1967) but are not discriminated on our map. The affiliation of these gneisses to either the polymetamorphic basement or the Permo-Carboniferous intrusions remains uncertain. The polymetamorphic character of the metapelites has been studied by WENK (1974), WENK et al. (1974), and GIERÉ (1985). Pre-Alpine amphibolite facies metapelites contain kyanite, staurolite, garnet and chloritoid. Near the Bergell pluton, the contact metamorphic overprint is clearly recognizable by the growth of new biotite in gneisses, and of cordierite, sillimanite, andalusite and garnet in metapelites, respectively.

Quartzite: The oldest sedimentary rocks above the basement are quartz conglomerates, overlain by fine-grained platy quartzites, usually with white mica and up to several meters thick. Both rock types are assigned to the Permo-Triassic (STAUB, 1918, 1921). Close to the Bergell pluton, the quartzites are coarse-grained and contain biotite and fibrolitic sillimanite, the latter overgrowing white mica (GIERÉ, 1985). The conglomeratic base, typical for the Tambo and Suretta nappes, is observed near lake Cam north of Vicosoprano and in Valle di Preda Rossa (PFIFFNER and WEISS, 1994).

Marble: The stratigraphy of the carbonate sequence of Triassic and younger age is best preserved near lake Cam north of Vicosoprano and outside the Bergell contact aureole (STAUB, 1918, 1921). The dominant rock types are dolomite, limestone, cargneule and carbonate breccia. A characteristic alternation of dolomite and dark limestone is reminescent of the Streifenserie of Ladinian age (STREIFF et al., 1971/76), found in parts of the Tambo, Suretta and Schams nappes (BAUDIN et al., 1995). Above the marble-rich section, calcareous schists with carbonate breccias contain siliceous marbles and grade into more sandy and pelitic calcareous schists. This sequence, which also includes greenschists, exhibits complex thrusting and folding (STAUB, 1921). At least some of the greenschist layers may represent original Triassic basaltic rocks.

The mineralogy of the pure and impure calcite and dolomite marbles near the northeastern margin of the Bergell pluton is described in detail by GYR (1967), WENK and MAURIZIO (1970), BUCHER-NURMINEN (1977), GIERÉ (1985), and PFIFFNER and WEISS (1994). A characteristic feature of these (presumably) Triassic carbonate rocks is the occurrence of stratigraphic markers near the base of the sequence. These markers, a reddish carbonate schist and a dark magnetite-amphibole-marble, can be traced around the Bergell pluton from outcrops in Val Bregaglia (regional metamorphic) to localities in Valle di Preda Rossa (overprinted by contact metamorphism; GIERÉ, 1985). The marble sequence also contains

20 to 40 cm thick intercalations of green amphibolite, which probably represents former tuffs, tuffites or sills. Textural relationships, observed in calc-silicate layers within the Suretta carbonate sequence, suggest that the contact metamorphism can be subdivided into two stages: an older static event followed by a younger syn-kinematic stage (BERGER and GIERÉ, 1995). Near the contact with the intrusive rocks, the carbonate rocks are intensely affected by metasomatism. This is documented by the occurrence of composite veins and complex skarns with olivine, titanian clinohumite, spinel and minor brucite, tremolite and xanthophyllite (BUCHER-NURMINEN, 1977, 1981; GIERÉ, 1986; RIED, 1994). These veins are often folded and boudinaged (CONFORTO-GALLI et al., 1988; RIED, 1994; PUSCHNIG, 1996).

3.5. AVERS BÜNDNERSCHIEFER UNIT

This tectonic unit mainly consists of Mesozoic metasediments and intercalated ophiolitic greenschists. Following MILNES and SCHMUTZ (1978) we consider the basal contact with the Suretta cover to be tectonic. Paleogeographically, the Avers Bündnerschiefer unit is of south-Penninic origin (SCHMID et al., 1990). It probably represents an accretionary wedge emplaced onto the Suretta nappe during an early phase of Tertiary subduction (SCHMID et al., 1996 a, b). The thickness of this unit rapidly decreases southward toward the area depicted in our map because of tectonic attenuation in connection with normal faulting along the Turba mylonite zone (NIEVERGELT et al., 1996). The Avers Bündnerschiefer, including the Turba normal fault, can be traced into the Lavinair Crusc, where they are displaced by the Engadine line. The Bergell granodiorite discordantly cuts the Turba normal fault but pre-dates the Engadine line. Hence it provides an excellent time marker for dating different orogenic stages in the transition area from Central to Eastern Alps (SCHMID et al., 1996a).

Early studies of this area (STAUB, 1918, 1921) assigned the Avers Bündnerschiefer and its ophiolitic intercalations to an "ophiolitic" cover sequence belonging to the Suretta nappe. This sequence also encompassed the Lizun greenschists, some amphibolite at the eastern margin of the Bergell pluton, and the Malenco ultramafics. One has to distinguish, however, between the Mesozoic cover of the Suretta nappe, the truly ophiolitic Avers Bündnerschiefer and calcareous as well as sandy and pelitic successions of unknown age. Furthermore, the Malenco-Forno-Lizun complex (see below) represents a separate ophiolitic zone within the orogenic lid above the Avers Bündnerschiefer unit. This orogenic lid, also encompassing the Austroalpine nappe stack, is characterized by predominantly Cretaceous deformation (LINIGER and NIEVERGELT 1990; LINIGER, 1992; FROITZHEIM et al., 1994; NIEVERGELT et al., 1996) and metamorphism (DEUTSCH, 1983).

Greenschist: Metabasaltic ophiolitic rocks predominate over serpentinite (STAUB, 1921). Rock types with porphyroblastic albite (prasinite) as well as alkali amphibole-bearing (glaucophane, Mg-riebeckite) greenschist are common (OBERHÄNSLI, 1978). Metachert with magnetite and occasionally manganese mineralizations (WENK and MAURIZIO, 1976) are commonly associated with greenschist, especially in the Val Cam and Pizzi di Maroz area. These are overlain by marbles and calcschists. From point 2369 (west of Pizzi di Maroz) towards southwest into Val di Cam this sequence is well exposed. This succession is analogous to that known from the Platta ophiolites (DIETRICH, 1969, 1970) and the Forno unit (FERRARIO and MONTRASIO, 1976; PERETTI, 1985; WEISSERT and BERNOULLI, 1985). At the Pizzi di Maroz, metagabbro fragments also occur. These are commonly transformed to white mica-zoisite-albite schist. White mica is chromium-bearing, and thus, these rocks were called "Fuchsitschiefer" by STAUB (1921).

Calcareous schist and marble: The Avers metasedimentary rocks contain a wide spectrum of rock types (STAUB, 1918; 1921). In the area of the map, calcareous schist and marble predominate over quartz-rich and pelitic rocks. They form part of the ophiolitic sequence typical for the southern part of the Avers Bündnerschiefer unit.

3.6. MALENCO-FORNO-LIZUN COMPLEX

This complex merges with the Platta nappe further to the north and represents the classical South-Penninic ophiolitic suture (STAUB, 1946) in southern Graubünden and northern Italy. The tectonically higher ophiolites of the southern part of the Platta nappe (overlying the Margna nappe) remain outside the map. The greenschists of the Lizun unit lack metasedimentary rocks but contain metagabbro (STAUB, 1921). The Forno unit south of the Engadine line is mainly composed of mafic volcanic rocks and their sedimentary cover (MONTRASIO, 1973; FERRARIO and MONTRASIO, 1976; GAUTSCHI, 1980; PERETTI, 1985; PERETTI and KÖPPEL, 1986) and is overprinted by contact metamorphism.

The Malenco unit was paleogeographically positioned between the ocean floor sequence of the Forno unit and the continental margin represented by the Margna nappe. It includes denudated serpentinized mantle-derived rocks, lower crustal rocks, slivers of upper crustal rocks, ophicarbonates, and MORB-type dikes (HERMANN and MÜNTENER, 1996). A special feature of the Malenco unit is the preservation of an exhumed crust-mantle boundary with pelitic granulites welded to the mantle rocks by the intrusion of the Fedoz gabbro (MÜNTENER and HERMANN, 1996; HERMANN et al., subm.). Therefore the Malenco unit does not represent a typical ophiolite suite (TROMMSDORFF et al., 1993). The Fedoz gabbro and lower crustal rocks are lithologically identical with the Fedoz gabbro and Fedoz series of the Margna nappe. However, in terms of their Alpine tectonic position, we consider these lower crustal rocks to be part of the Malenco unit (HERMANN and MÜNTENER, 1996). Intrusive relationships between the Forno mafics and the Malenco ultramafic rocks indicate that the Forno unit laterally replaces the Malenco unit (TROMMSDORFF et al., 1993).

Confusion may arise when comparing the older maps of STAUB (1921, 1946) and WENK (1977, tectonic inset map) with our tectonic classification at the eastern margin of the Bergell pluton. This is because we adopt the stratigraphy of this area as described by FERRARIO and MONTRASIO (1976), who first established the existence of the ophiolitic succession described later (see Rossi series).

Garnet-mica-schist (former granulite): Within the mapped area, garnet-mica-schists represent pelitic granulites of the Malenco unit. Garnet, up to 1.5 cm in diameter, is the only preserved granulite facies mineral within this schist. Intercalated grossular-epidote-diopside calc-silicates show minor retrogression only. These granulitic rocks represent a meta-sedimentary sequence originally consisting of kyanite-biotite-plagioclase-garnet granulites (MÜNTENER and HERMANN, 1996), with intercalations of both calc-silicate rocks that occasionally contain wollastonite (SCHUMACHER, 1975) and spinel-olivine marbles (WENK, 1963; BANGERTER, 1978). The formation of partial melts, crosscutting the metamorphic banding, and migmatization of the pelitic granulites are due to contact metamorphism caused by the Permian Fedoz gabbro intrusion (MÜNTENER and HERMANN, 1996). Metamorphic conditions of granulite facies metamorphism are approximately 800 °C and 10 kbar (MÜNTENER and HERMANN, 1996). Exhumation of mantle rocks, together with gabbro and granulites from the crust-mantle interface to the seafloor during the early Mesozoic is indicated by retrograde metamorphism and associated overprinting structures. Hence, a Permian event of extension and magmatic underplating is followed by Jurassic rifting (HERMANN and MÜNTENER, 1996).

Previously, these granulitic rocks of the Malenco unit were regarded as part of the Margna nappe (CORNELIUS, 1925; STAUB, 1946; MONTRASIO and TROMMSDORFF, 1983), where similar rock types are observed (the Fedoz series). Because the Permian Fedoz gabbro links the granulitic rocks to the Malenco ultramafic rocks, they are now considered to be part of the Malenco unit (HERMANN and MÜNTENER, 1996).

Fedoz gabbro (Malenco unit): This gabbro, together with the granulites, was mapped on both sides of the Val Ventina by SCHUMACHER (1975), ULRICH (1995) and BORSIEN (1995). It is strongly deformed during the Alpine orogeny and completely transformed into banded amphibolite. Black garnet-bearing fine-grained amphibolites represent higher differentiated gabbros enriched in iron and titanium. Within the mapped area, they are hardly distinguishable from the Forno metabasalts (ULRICH and BORSIEN, 1996). At Alpe Zocca the gabbros display rodingitized contacts to the ultramafic rocks. Where the Fedoz gabbro is mostly unaffected by Alpine deformation and metamorphism it mainly contains clinopyroxene, orthopyroxene and plagioclase. It displays a penetrative deformation that was subsequently annealed under pre-Alpine granulite facies conditions (GAUTSCHI, 1980; HERMANN and MÜNTENER, 1996). A detailed description of non-altered gabbros and their occurrence within the Malenco nappe is given by MÜNTENER and HERMANN (1996). The tholeiitic Fedoz gabbro displays a magmatic evolution from magnesian gabbro to ferro-gabbro (GAUTSCHI, 1980) and to highly differentiated quartz diorites and ilmenite-pyroxene-amphibole gabbros (ULRICH and BORSIEN, 1996). The gabbro exhibits primary contacts with the pelitic granulites and the ultramafic rocks (HERMANN et al., subm.). U–Pb dating of zircon yields a maximum intrusion age of 280 Ma for the Fedoz gabbro (HANSMANN et al., 1995) and indicates magmatic underplating in Permian times, an event also described in the Ivrea zone (SCHMID, 1993).

Ultramafic rock: The Malenco ultramafic rocks predominantly consist of magnetite-diopside-antigorite serpentinites and are often strongly foliated. Titanian clinohumite-bearing veins are common in the serpentinites (TROMMSDORFF and EVANS, 1980). In the uppermost Valle Airale and east of Rifugio Porro/Gerli in Val Ventina, Alpine metamorphism was static and pre-Alpine mantle structures are preserved. Near Mt. Braccia, along the eastern continuation of the Malenco ultramafics, non-hydrated layered spinel peridotites crop out. They are associated with harzburgites, dunites, spinel-websterites and garnet-pyroxenites and exhibit a complex mantle evolution (MÜNTENER and HERMANN, 1996). All these rock types also occur, with different degrees of serpentinization, within the mapped area.

The western border of the serpentinites is overprinted by contact metamorphism. This offers an excellent opportunity to map isograds in the same rock type over 10 km distance parallel to the contact with the Bergell pluton (TROMMSDORFF and EVANS, 1972, 1977, and 1980; PFIFFNER and WEISS, 1994; TROMMSDORFF and CONOLLY, 1996). At first, the regional metamorphic diopside-antigorite serpentinites are transformed into tremolite-olivine-antigorite serpentinites. The best visible isograd is associated with the break-down of antigorite nearer to the intrusion: the foliated antigorite serpentinites abruptly change to olivine-talk fels. In the direct vicinity of the tonalite contact, the stable parageneses in the ultramafic rocks is olivine + enstatite.

Ophicarbonate: In Val Ventina, a 5 km long zone of ophicarbonates within the ultramafic rocks strikes perpendicular to the tonalite contact. Serpentinite fragments predominate over the carbonate matrix. The carbon isotope signature of calcite and dolomite indicates formation in an oceanic environment. Therefore, POZZORINI (1996) interpreted this kind of ophicarbonate as the filling of a former fracture zone. Contact metamorphism of these ophicarbonates has been studied by TROMMSDORFF and EVANS (1977) and FERRY (1995). Matrix supported ophicarbonates occur in Val Scermendone (PFIFFNER and WEISS, 1994) and represent the sedimentary cover of the exhumed mantle rocks (POZZORINI, 1996; POZZORINI and FRÜH-GREEN, 1996).

Mafic rocks: At Piz Lizun, north of the Engadine line and outside the Bergell contact aureole, Mesozoic meta-basaltic rocks of the Lizun unit are overprinted by Alpine greenschist facies regional metamorphism. Most likely, the Lizun greenschists represent mainly meta-pillow lavas (NIEVERGELT and DIETRICH, 1977) accompanied by pillow breccias and dikes. Primary porphyritic feldspars are still preserved. Furthermore, these rock types compare well with those of the Forno unit found northeast of Piz Salacina, just south of the Engadine line. No serpentinite is associated with the Lizun greenschist. Hornblende gabbro, showing all stages of transformation to the "Fuchsitschiefer" (see above), is found near Piz Lizun (STAUB, 1921).

The mafic rocks of the Forno unit, now present as amphibolites, locally exhibit pillow lava structures (see "pillow structures" under "Various rock types" in map legend), pillow breccias (MONTRASIO, 1973), and swarms of parallel dikes with porphyritic feldspar (KUBLI, 1983; GIERÉ, 1984; DIETHELM, 1984). A MORB character is indicated for these rocks by chemical analyses (RIKLIN, 1977; GAUTSCHI, 1980; KUBLI, 1983) as well as by Pb-isotopic studies (PERETTI and KÖPPEL, 1986). A Fe–Cu–Zn sulphide mineralization occurring within a zone of several km length is interpreted to have formed from hydrothermally altered mafic rocks (PERETTI and KÖPPEL, 1986). Ultramafic lenses are embedded within porphyritic amphibolites at Alp da Cavloc. An amphibolite body south of Piz Cassandra (PIKA, 1976) is chemically equivalent to the Forno metabasalts (GAUTSCHI, 1980) and displays intrusive contacts to the surrounding ultramafic rocks as well as rodingitized borders (TROMMSDORFF et al., 1993).

Rossi series (mostly And-Grt-Bt-schist, Mesozoic): This sedimentary cover of the Forno mafic rocks has been mapped by KUBLI (1983), PERETTI (1983, 1985), MÜTZENBERG (1986) and RIKLIN (1977, 1978). The age of the cover (including the younger Muretto series) is assumed to be Mid-Jurassic to Cretaceous (PERETTI, 1985; WEISSERT and BERNOULLI, 1985). A basal quartzite, up to 2 m thick, usually contains magnetite and locally manganese ore deposits (PETERS et al., 1973; FERRARIO and MONTRASIO, 1976). Most likely it represents metaradiolarites. This quartzite is overlain by calc-silicates and calcite marbles, interpreted to represent former Aptychus limestone. Andalusite-garnet-biotite-schist is the predominant metapelitic rock type of the Rossi series. In several places it contains graphite-bearing layers which possibly represent Cretaceous black shales (WEISSERT and BERNOULLI, 1985).

Muretto series (meta-arkose, Mesozoic): This meta-arkose (PERETTI, 1985) was referred to as the "Muretto quartzite" by STAUB (1946) and as diopside-plagioclase-quartz-schist by DRESCHER-KADEN (1940) and GYR (1967). These former sediments mark the change from pelagic to clastic sedimentation of continent-derived material (TROMMSDORFF and NIEVERGELT, 1983), and they are probably of late Cretaceous age.

All rock types of the Forno unit are overprinted by contact metamorphism caused by the Bergell granodiorite (WENK et al., 1974; TROMMS-

DORFF and NIEVERGELT, 1983; PERETTI, 1985). This contact metamorphic overprint provides an excellent time marker for inferring the age of the deformation structures in these rocks (PUSCHNIG, 1996). Contact metamorphism in the few relics of ultramafic rocks of the Forno series increases from antigorite-olivine to olivine-talc-tremolite, olivine-anthophyllite-tremolite, and olivine-enstatite (the latter is observed in xenoliths within granodiorite only). Isograds in the metapelites of the Rossi series are defined by the first occurrence of andalusite (approx. 2 km away from the intrusion) and sillimanite (approx. 600 m away from the granodiorite contact). The highest grade in the metapelites is documented by the local occurrences of K-feldspar and corundum (TROMMSDORFF and NIEVERGELT, 1983). In the metabasalt no isograds are mappable, but contact metamorphism leads to pargasite and plagioclase blastesis (GAUTSCHI, 1980). The only mappable isograd in the Muretto series is the first occurrence of diopside (approx. 2.3 km away from the intrusion).

4. Lower Austroalpine units

The Lower Austroalpine units are derived from the distal Apulian continental margin (HANDY et al., 1993; FROITZHEIM et al., 1994). Within the area of the map, the flat-lying part of the Margna nappe is found north of the Passo d'Ur antiform, its root within the Southern Steep Belt. Occurrences of the Sella-Bernina nappe are restricted to the Southern Steep Belt (SPILLMANN, 1993). For an overview of Lower Austroalpine units immediately adjacent to the map the reader is referred to SPILLMANN (1993) and SPILLMANN and BÜCHI (1993).

4.1. MARGNA NAPPE

The paleogeographic and tectonic position of this nappe is controversial because of its present structural position between two ophiolitic units: the Platta nappe and the Malenco-Forno-Lizun complex. Although all authors now agree that the Margna nappe is derived from the Apulian margin, as suggested by MONTRASIO and TROMMSDORFF (1983) and MONTRASIO (1984), the Margna nappe may also be regarded as a Penninic (STAUB, 1946; TRÜMPY, 1975) or Ultra-Penninic (TRÜMPY, 1992) unit in the sense that it is paleogeographically surrounded by oceanic domains. LINIGER (1992) provided evidence that its present position between the two ophiolitic units is inherited from paleogeographical complications. FROITZHEIM and MANATSCHAL (1996) and FROITZHEIM et al. (1996) postulate that this nappe separated from the Apulian margin as an extensional allochthon between two oceanic domains during Mesozoic rifting. Furthermore, this nappe differs from the rest of the Austroalpine nappes in that it comprises a slice of continental lower crust (Fedoz series of SPILLMANN, 1993), which exhibits close similarities to former granulites found in the Penninic Malenco unit (see above). On the other hand, HERMANN and MÜNTENER (1992) showed that the Margna nappe is connected to the Austroalpine Sella nappe by a syncline of Mesozoic sediments. SPILLMANN (1993) found no evidence for a separation between Sella- and Bernina nappes further to the east.

The Margna nappe has recently been re-investigated by LINIGER (1992), LINIGER and GUNTLI (1988), GUNTLI and LINIGER (1989), and HERMANN and MÜNTENER (1992). For compiling the map, we used SPILLMANN (1993) and the following diploma theses from ETH Zürich covering different parts of the Margna nappe: GUNTLI (1987), LINIGER (1987), MÜTZENBERG (1986), and SPILLMANN (1988, 1989). For mapping the Scermendone zone, we used the maps of PFIFFNER and WEISS (1994) and VENZO et al. (1971). Recent structural and petrographic investigations (BAY, 1996; FORNERA, 1996) indicate a correlation of this zone with the Margna nappe, as proposed by STAUB (1946). Previously, the Scermendone zone was linked with the window of Lanzada situated to the east of our map, and this "Lanzada-Scermendone zone" was considered as an equivalent of the Suretta nappe (MONTRASIO, 1984).

The terminology used for subdividing different units within the Margna nappe s.str., exposed north of the Malenco serpentinites, follows that given by SPILLMANN (1993). The basement of the Margna nappe is composed of lower- and upper crustal rock associations, separated by a Jurassic normal fault (HERMANN and MÜNTENER, 1996). The lower crustal rocks comprise granulites, referred to as the Fedoz series in the Margna nappe, intruded by the Fedoz gabbro. This piece of lower crust is similar to that found in the Malenco unit, but the Alpine greenschist facies overprint is stronger in the Margna nappe. The upper crustal rocks consist of paragneiss metamorphosed during the Variscan (Maloja series) and intruded by late Variscan granitoids (SPILLMANN and BÜCHI, 1993). In the area of our map, a prominent band of Permo-Mesozoic cover separates a higher tectonic unit (the Maloja unit), preserved as klippen at Piz da la Margna and Piz Fora, from a lower one (the Fora unit) according to LINIGER and GUNTLI (1988) and SPILLMANN (1993).

Gneisses of the Scermendone zone: The basement of this zone consists of micaschist, quartz-rich schist, amphibolite, and thin layers of quartzo-feldspatic augen gneiss (PFIFFNER and WEISS, 1994). Intercalated marble (see "various rock types" in legend) mostly represent Mesozoic cover (PFIFFNER and WEISS, 1994). Garnet-rich paragneisses with lenses of blue quartz and intercalations of calc-silicate rocks have been found in Valle Airale. These probably represent the Fedoz series in the verticalized part of the Margna nappe.

Micaschist, marble and calc-silicate (Fedoz and Maloja series): The Fedoz and Maloja metasedimentary series are described by STAUB (1917) and CORNELIUS (1925) and were re-investigated by GUNTLI and LINIGER (1989) and SPILLMANN (1993). Garnet micaschist, calc-silicate, marble and occasional lenses of serpentinite, talc and actinolite fels are found within the Fedoz series. Granulite facies relics document the derivation of the Fedoz series from lower continental crust (SPILLMANN, 1993). Hence the Fedoz series is the equivalent of the granulites in the Malenco unit. STAUB (1917) pointed out the similarities of the Fedoz series with the Valpelline series in the Dent Blanche nappe. In areas with a strong Alpine overprint, the Fedoz series is hardly distinguishable from the paragneisses and schists of the upper crustal Maloja series (SPILLMANN, 1993).

Fedoz gabbro (Margna nappe): The Fedoz gabbro crosscuts the metasedimentary banding in the Fedoz series (SPILLMANN, 1988). Only a few relics of the primary mineral assemblage are preserved within the gabbro. Usually this metagabbro contains a greenschist facies metamorphic paragenesis with albite + epidote + chlorite + amphibole. Sometimes the metagabbro grades into a black amphibolite representing a more highly differentiated iron-rich gabbro. In the region of Dosso Calvo, magmatic gabbro textures are still preserved (RIKLIN, 1977). The granulite facies flaser structure, typical for the deformed Fedoz gabbro in the Malenco unit, is also preserved in this region (HERMANN and MÜNTENER, 1996). The name "Fedoz gabbro" was introduced by STAUB (1917) for the occurrence of this metagabbro in the Margna nappe.

Granodioritic to granitic augen gneiss: Magmatic textures are not preserved in these rocks. However, large K-feldspar crystals, probably representing former phenocrysts, can be recognized locally. Xenoliths of the surrounding basement demonstrate that these rocks do indeed represent former igneous rocks. Moreover, the lack of pre-Alpine metamorphism points to a Late (or post-) Variscan age of these rocks (SPILLMANN, 1993). Geochemical analyses (GUNTLI, 1987) reveal a granodioritic to granitic composition. An increase of the Alpine regional metamorphism from NE to SW is documented by the occurrence of the index minerals stilpnomelane and biotite (BUCHER and PFEIFFER; 1973; GUNTLI and LINIGER, 1989).

Permo-Mesozoic cover: This cover sequence stratigraphically overlies the Maloja series and/or the Late Variscan augen gneisses. It is best exposed in the Tremoggia syncline between the Margna and Sella nappes outside our map and described in detail by HERMANN and MÜNTENER (1992). A detrital base (correlated with the Fuorn formation) is overlain by Triassic marble, siliceous calc-schist (Allgäu formation), metaradiolarite, and a younger marble (Aptychus limestone) and calcschist. This typically Austroalpine cover (FURRER, 1985) documents the derivation of the Margna nappe from the Apulian passive margin.

4.2. SELLA-BERNINA NAPPE

The Sella and Bernina nappes are separated from each other by two intermediate tectonic units, the Platta and Corvatsch nappes, in the western Bernina massif only (outside our map). No distinct separation between Sella and Bernina nappes can be found further east in the Bernina massif according to SPILLMANN (1993). The wedging out of the Platta and Corvatsch nappes (and possibly also the Sella nappe) is due to Late Cretaceous normal faulting along the Corvatsch normal fault (LINIGER, 1992; SPILLMANN, 1993; FROITZHEIM et al., 1994). Since a clear subdivision cannot be made within the part of the Sella-Bernina nappe covered by our map either (i.e. within the Southern Steep Belt, south of the Passo d'Ur antiform), the two nappes are taken together. Our compilation follows the detailed map by VENZO et al. (1971). These authors propose that the Sella nappe wedges out east of our map and attribute the rock types described below to the Bernina nappe. However, west of Sondrio, the assignment of gneisses to the Margna, Sella-Bernina, and Campo-Languard nappes is difficult. Therefore, other authors (STAUB, 1946; WENK and CORNELIUS, 1977) chose different correlations from those of VENZO et al. (1971).

Gneiss and micaschist: These rocks were mapped as "Gneiss del Monte Canale" by VENZO et al. (1971). Muscovite-epidote-bearing micaschist and gneiss, often grading into augen gneiss, are locally interlayered with amphibolites. Lenses of calcite and dolomite marbles of unknown age are mapped separately (see "marble" under "various rock types").

Granitic gneiss: This biotite-bearing granite gneiss (the "granitic gneiss of Pizzo Mercantelli" of VENZO et al., 1971) is granitic to granodioritic in composition and intensely deformed in most places, locally preserving a massive texture. Following SPILLMANN (1993) we interpret this rock type to represent a Late Variscan intrusion.

Marble (Permo-Mesozoic cover): Calcite and dolomite marbles (including cargneules) of presumably Permo-Mesozoic age (STAUB, 1946) are preserved in a large lens at Sasso Bianco just east of our map. This occurrence represents a synclinorium preserved immediately adjacent to the boundary with the Margna nappe (see profiles in VENZO et al., 1971).

5. Upper Austroalpine units

In the area of the map, occurrences of Upper Austroalpine units are restricted to the Southern Steep Belt immediately north of the Insubric line (see FROITZHEIM et al., 1994, for an overview of the Upper Austroalpine units further north). No distinction can be made between Campo and Languard nappes within the area of the map. The Tonale series is commonly regarded as part of the Campo nappe, but it is lithologically and tectonically distinct from the rest of the Campo nappe.

5.1. CAMPO-LANGUARD NAPPE

This tectonic unit corresponds to the "Cristallino di Petra Rossa" of VENZO et al. (1971). Its southern limit is discussed under "Tonale series".

Gneiss and micaschist: Fine-grained muscovite (± biotite) gneiss, micaschist grading into quartzitic layers, and gneiss with large biotite aggregates are the predominant rock types. Intercalations of muscovite (± biotite, ± chlorite) augen gneiss, amphibolite and marble, as well as pegmatites, are also present (VENZO et al., 1971).

M. Rolla granitic gneiss: This granitic to granodioritic augen gneiss locally preserves a porphyritic texture with K-feldspar megacrysts (VENZO et al., 1971). A Late Variscan age is probable (SPILLMANN, 1993).

5.2. THE TONALE SERIES

A distinct association of various amphibolite grade rocks (schist and gneiss, amphibolite, calcsilicate, marble, pegmatites, and occasionally ultramafics) accompanies the Tonale line (the eastern segment of the Insubric line) all the way from Bellinzona to beyond Passo Tonale in the east (CORNELIUS and CORNELIUS-FURLANI, 1931; LARDELLI, 1981; FUMASOLI, 1974; WERLING, 1992). In the east the contact between the Tonale series, characterized by Variscan high-grade metamorphism, and the lower grade Campo nappe s.str. is defined by the Pejo and Mortirolo lines (WERLING, 1992). West of Tirano, however, the boundary between Campo-Languard nappe and Tonale series is difficult to draw on purely lithological criteria. In the area of our map, the Tonale series corresponds to the mylonites related to movements along the Insubric line (LARDELLI, 1981; WIEDENBECK, 1986; BERGER, 1995; BERGER et al., 1996).

5.3. INSUBRIC MYLONITES

The protoliths of these mylonites are identical to the non-mylonitic rocks of the Tonale Series, only preserved east of the map area. Amphibolite grade metamorphism (Variscan in the east, Alpine south of the Bergell pluton) is preserved locally, evidenced by garnet and sillimanite in pelitic schists (LARDELLI, 1981). A retrograde greenschist facies metamorphic overprint during mylonitization is strong, particularly in the southern parts of the mylonite belt.

West of Val Mera, lineations in the mylonites pitch to the west and steepen from south to north (HEITZMANN, 1987b; FISCH, 1989; BERGER et al., 1996). Almost horizontal lineations are observed further east (BERGER, 1995; BERGER et al., 1996; WIEDENBECK, 1986). Senses of shear indicate backthrusting, combined with dextral strike slip motion during retrograde mylonitization. This gradually gives way to pure dextral strike slip motion east of the Bergell pluton (SCHMID et al., 1989; WERLING, 1992). A cataclastic late overprint is restricted to the immediate contact with the Southern Alps (the "Tonale fault", spectacularly exposed in a gorge east of Livo, FUMASOLI, 1974). This dextral overprint post-dates mylonitization (SCHMID et al., 1989).

6. Southern Alps

Unmetamorphic (to anchimetamorphic?) cover of the Southern Alps is preserved just south of the

Tonale line. Hence the vertical throw across the Insubric mylonite belt amounts to at least 20 km in the western part of the map, but rapidly decreases eastwards (BERGER et al., 1996). The compilation of the Southern Alpine units is based on the maps of FUMASOLI (1974), LARDELLI (1981), VENZO et al. (1971), and MONTRASIO and SCIESA (1988).

Biotite-gneiss, micaschist and phyllonite: Garnet- and staurolite-bearing gneiss grades into micaschist and is interlayered with amphibolites, as mapped by FUMASOLI (1974) west of Lake Como. East of this lake, the so-called "Morbegno gneiss or schist" (LARDELLI, 1981) also contains garnet, staurolite, and (typically) poikiloblastic albite. Phyllonites are widespread and a product of pre-Alpine deformation under retrograde metamorphic conditions. This basement is part of the Gravedona zone (BOCCHIO et al., 1980; or northern phyllonite zone of EL TAHLAWI, 1965) and resembles the Stabiello Gneiss of the Val Colla zone further to the west (REINHARD, 1953).

Granitic gneiss (Dazio granite, Mantello gneiss): Granitic to dioritic augen gneiss of igneous origin, mapped by VENZO et al. (1971), is exposed south of Dazio and forms an isolated stock within the surrounding Morbegno gneiss and schist. The Mantello "granite", mapped by LARDELLI (1981) and MONTRASIO and SCIESA (1988) is part of the so-called "Gneiss Chiari" (EL TAHLAWI, 1965), consisting of leucocratic gneisses composed of quartz, albite, K-feldspar and muscovite. The nature of the protolith is debated and ranges from arkose (EL TAHLAWI, 1965) to Carboniferous plutonites (KÖPPEL and GRÜNENFELDER, 1971). Typically, the Gneiss Chiari are directly overlain by the Mesozoic cover, as is shown on our map.

Permo-Mesozoic cover: Remnants of this cover are preserved just south of the Insubric line where they dip steeply to the north, i.e. towards the Central Alps. This indicates a component of relative uplift of the Southern Alps during cataclastic overprint of the Insubric mylonites by the dextral Tonale fault. Litho-stratigraphy and structure of this cover have been described and mapped in detail by FUMASOLI (1974) and LARDELLI (1981). Permo-Triassic Verrucano and Servino are overlain by dolomite and occasionally limestone of Triassic age, but younger stratigraphic levels are not preserved here.

7. Tertiary Igneous Rocks

7.1. BERGELL PLUTON

The Bergell pluton is composed primarily of tonalite and granodiorite, with minor amounts of gabbro, hornblendite, diorite, and aplitic and pegmatitic granites (WENK, 1973 and 1986; WENK et al., 1977; TROMMSDORFF and NIEVERGELT, 1983; REUSSER, 1987; DIETHELM, 1989). It is a composite pluton in that mafic rocks (predominantly tonalite and minor amounts of gabbro and other mafic rock types) form the margins of the pluton with granodiorite occupying the core and northwestern margin. A zone where mingling and mixing occurred, the "Übergangszone" of MOTICSKA (1970) and WENK and CORNELIUS (1977), is always present between the granodiorite and tonalite, except in the eastern part of the pluton. In the east, cross-cutting relationships between tonalite and granodiorite demonstrate the slightly younger crystallization age of the granodiorite in this part of the pluton (GYR, 1967; TROMMSDORFF and NIEVERGELT, 1983; BERGER and GIERÉ, 1995), consistent with radiometric dating. VON BLANCKENBURG (1992) showed that the tonalite and granodiorite at the eastern margin cooled through their solidus at 32 and 30 Ma, respectively (see review by HANSMANN, 1996).

The margin of the Bergell pluton was re-mapped in three areas. Its position significantly differs from that given in the map of WENK and CORNELIUS (1977) in the area of Val Bondasca. According to our own mapping (C. Davidson and S. Schmid), as well as according to detailed maps found in DIETHELM (1989), parts of the Adula-Gruf nappe were erroneously interpreted as plutonic rocks belonging to the Bergell pluton by WENK and CORNELIUS (1977). The southeastern margin in Val Masino south of Bagni del Masino (lower Val Spluga) was re-mapped by BERGER (1995). Finally, ROSENBERG (1996) and BERGER (1995) re-mapped the contact zone in Valle dei Ratti, and also newly mapped the boundary between tonalite and "Übergangszone" south of Valle dei Ratti. Individual dikes within the Bergell pluton have not been mapped but will also be briefly described below.

Gabbro and hornblendite: Sporadic occurrences of basic rocks, which are part of the calc-alkaline Bergell suite, were studied in detail by DIETHELM (1985, 1989). They are commonly associated with tonalite near the contact to the country rocks. Several different types can be distinguished in the field: coarse-grained orthopyroxene-bearing olivine-clinopyroxene hornblendite;

fine-grained and medium-grained clinopyroxene-hornblende gabbro; and a pegmatitic hornblende gabbro with hornblende crystals up to 30 cm long (DIETHELM, 1985). These rocks are considered to represent an early phase of the Bergell intrusion, as suggested by field relationships, e.g., gabbroic enclaves in tonalite, intrusive contacts to Mesozoic country rocks and chemistry (DIETHELM, 1985, 1989).

Tonalite: The tonalite is predominantly composed of plagioclase, quartz, hornblende, biotite, and small amounts of epidote and K-feldspar (REUSSER, 1987). It is often altered at the contact with marble country rocks due to intense metasomatism. It has a well-developed foliation defined by the preferred orientation of biotite and plagioclase laths, and/or a lineation defined by the alignment of elongate hornblende crystals. Structural observations at the eastern, western and southern margin of the pluton revealed a continuous transition from magmatic flow to high-temperature solid-state syn-intrusive deformation (BERGER and GIERÉ, 1995; DAVIDSON et al., 1996; BERGER et al., 1994; ROSENBERG et al., 1994; BERGER et al., 1996; BERGER and STÜNITZ, 1996). Foliations and lineations along the western margin of the pluton are always concordant with those of the surrounding rocks. To the west of the main body of the pluton, a steeply inclined tabular body of tonalite (the Jorio tonalite) extends almost to Giubiasco near Bellinzona. Geobarometry based on the Al content in hornblende indicates that the pressure of final crystallization of the tonalite decreases from greater than 8 kbars in the west to less than 5 kbars in the northeast (REUSSER, 1987; DAVIDSON et al., 1996).

A solid-state overprint is particularly strong at the southern margin of the pluton and is associated with metamorphic reactions taking place under amphibolite grade conditions. These reactions promote growth of biotite and epidote at the expense of hornblende (BERGER and STÜNITZ, 1996). Gradual transitions into tonalite gneisses and high-temperature mylonites are observed in the Southern Steep Belt.

Melirolo augen gneiss: The Melirolo augen gneiss (AGM) is an intensely solid-state deformed and occasionally mylonitic (FISCH, 1989) epidote-bearing granodiorite (REUSSER, 1987). The augen, usually 1–2 cm in length, are primarily plagioclase, but K-feldspar and quartz augen are also found. According to VOGLER (1980) and VOGLER and VOLL (1976, 1981) this gneiss, which occurs only in the western part of the Bergell pluton, has a sharp contact with the tonalite and represents an independent intrusion. However, according to FISCH (1989) and our own observations, there is a gradual transition from the tonalite into the AGM. The AGM everywhere follows the southern margin of the Jorio tonalite and it locally intrudes the Tonale series as individual thin dikes. These dikes are situated south of the main intrusive body, and are interpreted to be of subvolcanic nature by VOGLER and VOLL (1981). In the area of Bellinzona, the AGM extends further to the west with respect to the Jorio tonalite (WEBER, 1957). Porphyritic dikes of very similar composition are also reported from the Sesia zone exposed west of Locarno and are found all the way to the Val d'Ossola, where some of these dikes are mylonitized within the Insubric mylonite belt (REINHARDT, 1966; KRUHL and VOLL, 1976; SCHMID et al., 1987). While we agree with VOGLER and VOLL (1981) that the AGM represents a separate intrusion locally, we regard this intrusion to be roughly contemporaneous with and part of the Bergell pluton because of the gradational transitions observed at its northern boundary with the tonalite. Also, post-emplacement mylonitization started under amphibolite facies conditions (FISCH, 1989) and therefore we cannot accept a subvolcanic origin for the AGM.

Transition zone between granodiorite and tonalite: This "Übergangszone" (MOTICSKA, 1970; WENK and CORNELIUS, 1977; HANSMANN, 1981), found only in the southern and southwestern parts of the intrusion, is an inhomogeneous zone characterized by alternating layers of tonalitic and granodioritic rocks, probably due to mingling between the tonalite and granodiorite magmas. Magmatic mixing is also indicated in the "Übergangszone" by the presence of rocks with intermediate chemical compositions between the tonalite and granodiorite (REUSSER, 1987). Contacts between the "Übergangszone" and tonalite, mapped by BERGER (1995) and ROSENBERG (1996), are delineated by the first occurrence of K-feldspar megacrysts. The "Übergangszone"-granodiorite contact was mainly taken from the map of WENK and CORNELIUS (1977). However, this contact is less clear and often gradational. When present, fabrics within the "Übergangszone" are concordant with the sourounding rocks. These observations suggest that tonalite and granodiorite had a common magmatic stage, at least in the southern and southwestern parts of the pluton.

Granodiorite: The granodiorite mainly contains plagioclase, quartz, K-feldspar and biotite, and (in some places) hornblende (GYR, 1967;

REUSSER, 1987). K-feldspar occurs both as megacrysts (3–5 cm, but sometimes > 10 cm) and in the matrix. Near the tonalite contact in the west, the granodiorite (and "Übergangszone") usually has a well-developed foliation marked by the preferred orientation of biotite, whereas the alignment of K-feldspar megacrysts defines a mineral lineation. In the east, and center of the pluton, foliations and lineations are usually subtle or not present, except close to the contact with the country rocks (DRESCHER-KADEN and STORZ, 1926; BERGER and GIERÉ, 1995). In some areas (e.g., near Rifugio Omio), the granodiorite exhibits a distinct magmatic layering, documented by accumulation of K-feldspars that are oriented parallel to the layers. A solid-state overprint is sporadically observed in quartz domains (WENK, 1973). However, this overprint is very much weaker than that observed in the tonalite and does not define a pervasive solid-state foliation.

Both the granodiorite and tonalite contain abundant homogeneous enclaves of dioritic to monzonitic composition ("endogene Xenolithe" of GANSSER and GYR, 1964; see also MOTICSKA, 1970; HANSMANN, 1981; MORAND, 1981; DIETHELM, 1989, 1990). These inclusions are more common in the granodiorite, where they are typically oval to round in shape and often occur concentrated in large numbers (e.g. north of the Fornohütte or east of the Cima di Vazzeda). In the tonalite, the enclaves are usually present as schlieren. Based on observations of disintegrated mafic dikes in Val Porcellizzo, DIETHELM (1990) concluded that these enclaves represent products of mingling between injected basic magmas and the slowly cooling tonalite and granodiorite magmas. In the eastern part of the intrusion, the shapes of mafic enclaves reveal a strain concentration towards the contact of the pluton (BERGER and GIERÉ, 1995).

Granodiorite of Alpe Cameraggio: This homogeneous rock is a fine grained, equigranular variety of the Bergell granodiorite. It occurs at the border between the typical Bergell granodiorite and the tonalite near Alpe Cameraccio (WENK and CORNELIUS, 1977). The contact between the two granodiorites is usually sharp (WENK, 1986, 1992). The granodiorite of Alpe Cameraccio has not yet been studied in detail.

Andesitic-basaltic dikes: At Piz Lizun, northeast of lake Cavloc, and in Val Malenco, basaltic dikes crosscutting nappe boundaries are found at the eastern Bergell margin (NIEVERGELT and DIETRICH, 1976; GAUTSCHI and MONTRASIO, 1978; WENK, 1980). They are younger than the regional Alpine deformation but older than the emplacement of the Bergell tonalite and granodiorite as revealed by their contact metamorphic overprint (GAUTSCHI and MONTRASIO, 1978; WENK, 1980; TROMMSDORFF and NIEVERGELT, 1983). A magmatic texture is documented by an ophitic intergrowth of anorthite and hastingsitic amphibole. A possible connection with the Bergell calc-alkaline intrusive seems possible in view of their geochemical characteristics (DIETHELM, 1989).

Microgranite and aplitic granite (not mapped), orbicular granite: Microgranites and aplitic granites are associated with the central granodiorite body and occur as small stocks or lenses, and dikes respectively, both within the pluton and in the country rocks. The aplitic granites contain abundant K-feldpar as well as plagioclase, quartz, biotite and muscovite (GYR, 1967; MOTICSKA, 1970; WENK, 1986). Occasionally, garnet is present, typically as small euhedral crystals. Aplites are finer grained and richer in white mica (WENK, 1986). Near Monte Rosso, a muscovite-rich aplitic granite stock ("orbicular granite" in map legend) is characterized by the occurrence of numerous dark spherical inclusions (GYR, 1967). The spherical inclusions are biotite-rich, contain strongly zoned euhedral garnet, and are surrounded by a biotite-free zone which has no clear border with the surrounding aplite (GIERÉ, 1984). The aplitic granites often occur, as do the pegmatitic dikes, in swarms of parallel, generally N-dipping (WENK, 1986, his Fig. 11) dikes (very prominent at Mte. Sissone, REUSSER, 1987). In many places microgranites and aplitic granites resemble the Novate granite and they often cross-cut contacts between tonalite and granodiorite. Therefore, many of them are probably related to the Novate intrusion (see below). However, REUSSER (1987) also describes post-tonalitic aplitic dikes that pre-date the granodiorite.

Pegmatites (not mapped): Pegmatites are found throughout the entire pluton as well as in the country rocks. These rocks are characterized by a graphic texture and coarse perthite exsolution, and contain various amounts of muscovite and biotite and often garnet, beryl and tourmaline (GYR, 1967; MOTICSKA, 1970; WENGER and ARMBRUSTER, 1991). A classification of the pegmatites into various types is given by WENGER and ARMBRUSTER (1991). A typical feature of the Bergell pegmatites is the occurrence of graphic intergrowths of garnet and quartz (GIERÉ, 1984; depicted in GIERÉ, 1987); recent fieldwork by R. Gieré revealed that these garnet-quartz intergrowths are found both in the eastern (e.g., near

Monte Rosso) and western part (e.g., upper Val Codera) of the intrusion. The Bergell pegmatites are further known for containing a plethora of rare and accessory minerals (WENK, 1986) including molybdenite, uranophan, monazite, xenotime, allanite, columbite and niobite (e.g. GRAMACCIOLI, 1978; WENGER and ARMBRUSTER, 1991; BEDOGNÉ et al., 1993 and 1995). Good mineral collections are found in the museums at Stampa, Morbegno and Chiesa.

7.2. NOVATE GRANITE

The two-mica Novate (San Fedelino) granite stock crops out in Val Mera south of Chiavenna. Mapping of the Novate stock, which has an extremely irregular margin in detail, follows REPOSSI (1915). Several Novate dikes have been taken from the map of MOTICSKA (1970). Generally, the Novate granite is fine-grained and consists of quartz, plagioclase, K-feldspar, biotite, muscovite, and in many places garnet (REPOSSI, 1915; PICCOLI, 1961; MOTICSKA, 1970). The granite is commonly foliated, defined by the preferred orientation of the micas. However, the granite cross-cuts fabrics found in all the surounding rocks, including tonalite from the Bergell pluton. Hence, the intrusion of this granite is clearly younger than final emplacement and synmagmatic folding of the Bergell pluton (DAVIDSON et al., 1996, BERGER et al., 1996). Its probable age of around 26 Ma is not yet well constrained by radiometric data (KÖPPEL and GRÜNENFELDER, 1975).

HAFNER (1993) describes in detail the fabrics present in the Novate Granite and associated aplite and pegmatite dikes west of Lago di Mezzola. Early Novate-related dikes observed at M. Peschiera are contemporaneous with the late stages of synmagmatic folding and migmatization. However, the majority of dikes and stocks postdates folding and migmatization (HAFNER, 1993). The peraluminous chemical composition of the Novate granite (CALLEGARI and MONESE, 1961; GULSON, 1973; WENK et al., 1977; MOTTANA et al., 1978; MOTICSKA, 1970; HAFNER, 1993) suggests that this granite is not related to the calc-alkaline Bergell suite, and was probably derived from partial melting of crustal rocks. Magma formation, due to decompression melting, and intrusion of the Novate granite stock probably occurred during exhumation of the Bergell pluton in connection with backthrusting along the Insubric line (SCHMID et al., 1987, 1989; HEITZMANN, 1987b) which sets in at around 28 Ma according to BERGER et al. (1996), and hence before the intrusion of the main stock of Novate granite.

7.3. HORNBLENDE PORPHYRITE
(see "Various rock types" in legend)

Hornblende-bearing subvolcanic dikes have been found within the Insubric mylonites near Val Masino (BERGER, 1995). Porphyritic crystals of hornblende, plagioclase and quartz are embedded in a fine-grained micaceous matrix. Similar dikes are also known from other regions within the Austroalpine (GATTO et al., 1976; BECCALUVA et al., 1983).

8. Summary of structural and petrological relationships between pluton and surrounding rocks

The relationship of the Bergell pluton to its surounding rocks (Fig. 1) has a long history of controversy (see TROMMSDORFF and NIEVERGELT, 1983 for an excellent review). The controversy can be viewed as two separate, but related questions:

(1) Does the Bergell pluton represent a classical post-tectonic intrusion (e.g. STAUB, 1946, 1958), or was it "emplaced as a nappe concordantly in the stack of higher Pennine nappes" (WENK, 1973, 1982)? What was the mechanism of ascent and final emplacement?

(2) Where have the magmas been generated (mantle or crustal origin, in situ granitization?), and what are the relationships in time and space between regional Lepontine metamorphism and intrusion?

We briefly address the second (petrologically oriented) questions before concentrating on the first (structural) questions, which are directly addressed by the enclosed map (BERGER, 1996).

8.1. SOME PETROLOGIC ASPECTS

The observations of DRESCHER-KADEN (1940) are extremely valuable in a structural sense. However, the in situ granitization postulated by this author for the fomation of the Bergell pluton is untenable in the light of modern petrologic concepts (see discussion in TROMMSORFF and NIEVERGELT, 1983). More moderate transformistic ideas were published by ARTUS (1959), WENK (1973, 1982), and WENK et al. (1977), who regarded amphibolite and gneiss at the border of the pluton as source materials for the tonalite. A careful petrologic and geochemical study by DIETHELM (1989) demonstrated that many mafic rocks preserved at the margin of the pluton are the basic parts of the calc-alkaline Bergell suite, and he clearly distinguished these from the ultramafic or tholeiitic mafic rocks present in the country rocks. In addition, VON BLANCKENBURG (1992) and VON BLANCKENBURG et al. (1992) demonstrated, on the base of stable isotope analyses, that the Bergell suite originates from the lithospheric mantle. This requires a particular mechanism of ascent and emplacement into the crust (VON BLANCKENBURG and DAVIES, 1995).

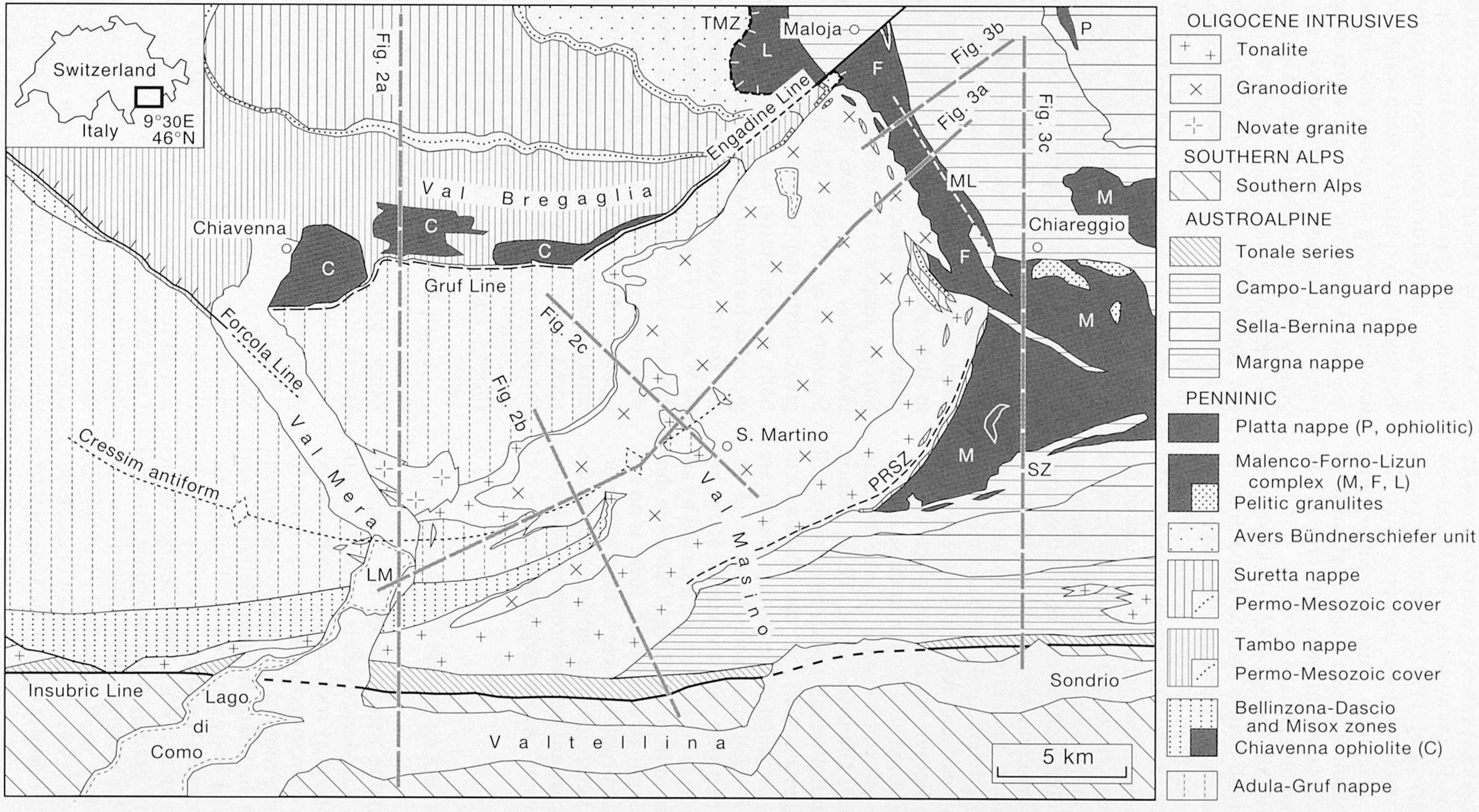
An extensive discussion of the relationship between the Bergell pluton and the Lepontine regional metamorphism is beyound the scope of this contribution, except to say that Tertiary regional metamorphism (35–40 Ma) partly pre-dates the Bergell intrusion in the northeastern part of the Lepontine area (HURFORD et al., 1989), while temperatures in the country rocks adjacent to the pluton, and probably all through the southern part of the Lepontine dome remained high, up to and (probably) after the intrusion (VANCE and O'NIONS, 1992). Final equilibration of metamorphic minerals near and adjacent to the western margin of the Bergell pluton took place at pressures lower (ENGI et al., 1995) than those derived for the time of solidification of the tonalite (REUSSER, 1987; DAVIDSON et al., 1996). Hence, this final equilibration must post-date the Bergell intrusion. Migmatization in the Adula-Gruf nappe and the intrusion of the Novate granite are syn- to post-Bergell intrusion (BERGER et al., 1996), suggesting that the late stages of the regional metamorphic evolution are affected by advective heat input from the Bergell intrusion during decompression. In conclusion, there is no Lepontine metamorphic "event", this metamorphism being heterogeneous in time and space. Mapped isograds are heterochroneous and unrelated to an "event", as also suggested by ENGI et al. (1995).

8.2. STRUCTURE OF THE PLUTON MARGIN

The Jorio tonalite extends from the vicinity of Bellinzona to Val Mera, exhibits concordant contacts with the country rocks, and occupies a structural position corresponding to that expected for the non-existing roots of the Tambo and Suretta nappes within the Southern Steep Belt (Fig. 1 and 2a). This tabular body, between the Tonale series and the Bellinzona-Dascio zone, was intensely deformed (VOGLER and VOLL, 1981) during a deformational event grading from magmatic to solid state flow (ROSENBERG, 1996; BERGER et al., 1996). According to ROSENBERG et al. (1995), DAVIDSON et al. (1996) and BERGER et al. (1996), it represents the feeder dike of the Bergell intrusion .

Across Val Mera the northern contact of the Jorio tonalite can be followed into Valle dei Ratti, where its foliation continuously changes from dipping steeply north, to a steep south-dip, and ultimately flattening to a gently east-dipping orientation, characteristic for the western margin of the pluton (Figs 2a and 2b). In addition, a window is present at Bagni del Masino (see Fig. 2c and structure contours in DAVIDSON et al., 1996). This western contact follows a former nappe boundary along the top of the Adula-Gruf nappe and is mostly concordant with the structures of the country rocks exposed below the former floor of the pluton. DAVIDSON et al. (1996) show that the pluton was syntectonically (with respect to post-nappe refolding) emplaced into the country rocks while the pluton was partially molten. Geometrically, the shape of the pluton is, in fact, similar to that of a nappe (WENK, 1973), with a root and a flat-lying part (Fig. 2). However, this nappe-like emplacement did not occur during nappe stacking as suggested by WENK (1973, 1982), but during differential displacements of the Tambo and Suretta nappes to the north after nappe-stacking (DAVIDSON et al., 1996; BERGER et al., 1996; SCHMID et al., 1996b). This demonstrates that, at great crustal depth, final emplacement of a partially molten pluton was an integral part of regional deformation which affected both the pluton and the country rocks, as previously suggested by WENK (1973). Additionally, differential north-directed escape of the Tambo and Suretta nappes with respect to lower and higher tectonic units elegantly solves the space problem without advocating assimilation of huge amounts of country rocks. After nappe-like emplacement, but while the pluton was still partially molten, the floor of the pluton was tightly folded into a series of antiforms and synforms (Fig. 2; DAVIDSON et al., 1996).

A post-Bergell normal fault marked by greenschist facies mylonites (the Forcola line; MARQUER, 1991) reaches the map near Gordona (south of Chiavenna), cutting through the former western continuation of the Chiavenna ophiolite. Along the northern contact, the structural relationships abruptly change east of Vicosoprano. West of Vicosoprano the subvertical contact of the Bergell pluton is still concordant to the foliation in the Adula-Gruf nappe and runs parallel to a high-temperature fault zone between Adula-Gruf nappe and Chiavenna ophiolite (the Gruf line, BERGER et al., 1996). The Gruf line is the deep-seated equivalent of the cataclastic Engadine line according to BERGER et al. (1996). Both are responsible for the rapid exhumation of the Bergell pluton and Adula-Gruf nappe with re-



LM: Lago di Mezzola ML: Muretto Line PRSZ: Preda Rossa Shear Zone SZ: Scermendone Zone TMZ: Turba Mylonite Zone

Fig. 1 Tectonic map of the Bergell pluton and surrounding tectonic units. Traces of profiles presented in figures 2 and 3 are indicated.

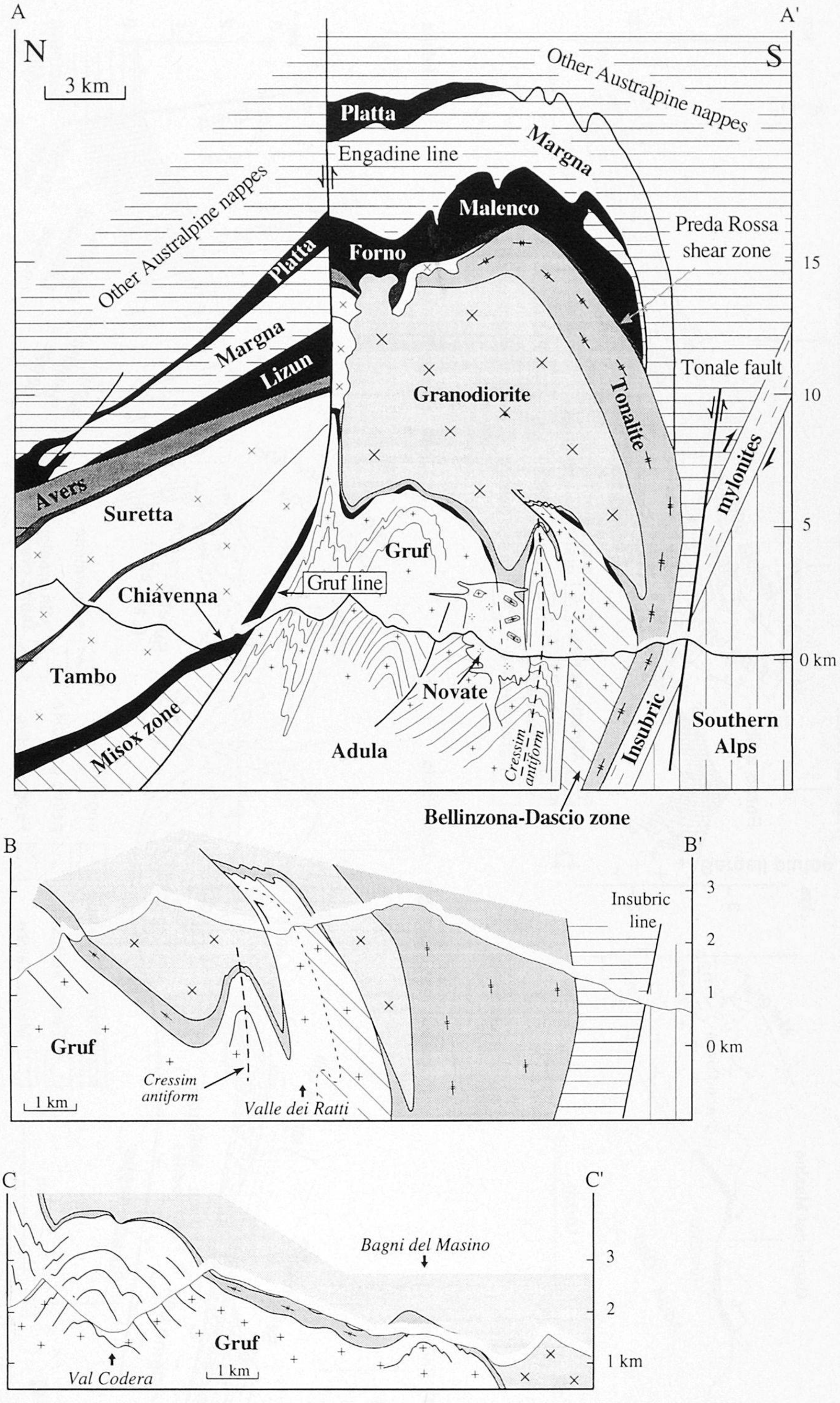


Fig. 2 (a) Synthetic N–S section through the Bergell pluton, after SCHMID et al. (1996b).
(b, c) Detailed sections through the western margin of the Bergell pluton, after DAVIDSON et al. (1996).

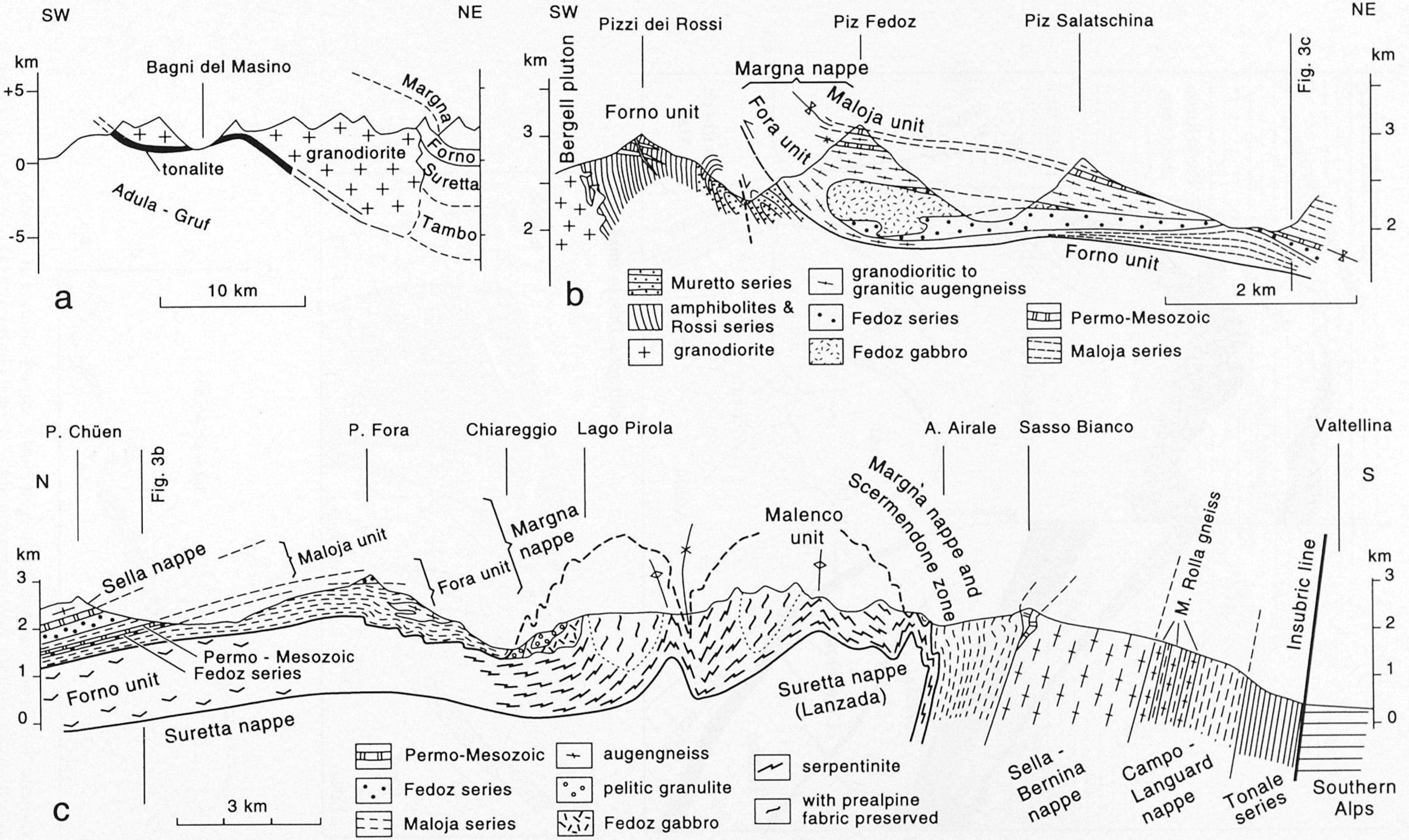


Fig. 3 (a) Synthetic SW–NE section through the Bergell pluton, after BERGER and GIERÉ (1995).
(b) Detailed SW–NE section through the eastern margin of the Bergell pluton, after SPILLMANN (1993).
(c) N–S section through the tectonic units exposed east of the Bergell pluton, running along the eastern margin of the attached map (BERGER, 1996).

spect to the country rocks to the north. East of Vicosoprano, however, the Bergell granodiorite starts to discordantly cut up-section through the Tambo and Suretta nappes, including the Avers Bündnerschiefer. This change coincides with the location where the granodiorite also cuts through its tonalitic rim (still preserved until south of Vicosoprano, but too thin to show on the map). This points to late stage mobilization of the granodiorite, possibly due to folding at the base of the pluton and simultaneous ballooning at the higher structural levels exposed at the northeastern margin of the pluton (ROSENBERG et al., 1995).

The above observations explain some of the controversy regarding syn- versus post-tectonic emplacement. It is simply an expression of the fact that we cross an original depth interval of about 10 km by following the northern contact of the pluton from Passo Trubinasca eastwards to the vicinity of Maloja, where the pluton intruded the base of the orogenic lid which was at moderate temperatures (corresponding to greenschist facies conditions) at the time of the intrusion. Around the northeastern margin the contact is discordant to the main (predominantly Cretaceous) fabrics in the adjacent units. However, subsequent deformation of the country rocks, related to ballooning, can be very intense (CONFORTO-GALLI et al., 1988). Contact metamorphic minerals are pre- to syn-kinematic with respect to these later deformations (BERGER and GIERÉ, 1995; PUSCHNIG, 1996). This forceful emplacement of the intrusives probably caused flexuring of the country rocks along a NNW–SSE axis (Figs 3a and 3b), parallel to the contact (SPILLMANN, 1993; PUSCHNIG, 1996) into a subvertical to steeply east-dipping orientation. BERGER and GIERÉ (1995) relate this flexuring to late-stage ballooning within the granodiorite, PUSCHNIG (1996) attributes it to the emplacement of the tonalite. In spite of the discordances observed locally, the contact always follows the Forno unit around the northeastern corner. The Muretto line is a discrete fault running parallel to the eastern border of the Bergell pluton (RING, 1994). It is associated with minor relative uplift (about 200 m, SPILLMANN, 1993) of the western block and post-dates flexuring and intrusion.

Another structural change along the contact occurs further south along the eastern margin, south of Cima di Vazzeda. Here, tonalite is again present along the contact of the intrusion, and granodiorite is seen to intrude both tonalite and country rocks (BERGER and GIERÉ, 1995). The fabrics of the tonalite are concordant to those in the country rocks (the attenuated remnants of the Suretta nappe) all the way to Val Masino. The contact is marked by the Preda Rossa shear zone (BERGER et al., 1996), a synmagmatic normal fault with top-to-the-south to -southeast sense of shear, exhuming the still partially molten pluton. Note that this fault is synmagmatic with respect to the tonalite, but is itself intruded by the granodiorite.

Across Val Masino, the displacement along the Preda Rossa shear zone is absorbed by magmatic flow within the tonalite, while the contact itself becomes discordant again in lower Valle Spluga, with xenoliths of country rocks in tonalite that lacks a pronounced foliation (BERGER, 1995; BERGER et al., 1996). This discordance is also apparent in map view where the pluton contact structurally climbs up and across the subvertical roots of the Sella-Bernina and the Campo-Languard nappes. This, together with the findings of SPILLMANN (1993), clearly demonstrates that the formation of the Southern Steep Belt pre-dates the Bergell pluton, as already proposed by STAUB (1918). The pre-existing steeply inclined anisotropy was probably instrumental for the ascent of the Bergell pluton as a vertical dike (the Jorio tonalite) in an overall compressional environment (see discussion in BERGER et al., 1996).

Toward the southern contact, the pluton margin merges with the mylonitized Tonale series and becomes concordant with the country rocks once again. Steeply north-dipping, this contact runs back to the west where we started our journey around the pluton. At first sight, parallelism between this southern contact and the Insubric mylonites suggests a genetic link between the intrusion and the Insubric mylonite zone. Note however, that the greenschist facies mylonites along the Insubric line postdate the intrusion of the Bergell pluton (BERGER et al., 1996). Backthrusting across the Insubric mylonite belt, related to rapid exhumation of the pluton, leads to the most outstanding structural feature of the Bergell pluton; namely, the present-day west to east exposure of the pluton is a distorted crustal profile from the floor of the pluton to near its roof.

9. Summary of the structural evolution

The western margin of a Cretaceous orogen, characterized by west-directed folding and thrusting (HANDY et al., 1993; FROITZHEIM et al., 1994) and re-deformed during the Tertiary, is exposed near the eastern margin of the Bergell pluton (Fig. 3; SPILLMANN, 1993). Because the pluton intrudes the rocks at the base of the orogenic lid (the Malenco-Forno-Lizun complex), the intrusion must have also crossed the Tertiary-aged basal thrust of this orogenic lid (also comprising the Austroalpine nappes) situated above the viscously deforming Penninic units (SCHMID et al., 1996b). Hence, the Bergell intrusion post-dates Paleocene to Eocene north-directed stacking of nappes during Tertiary orogeny.

VON BLANCKENBURG and DAVIES (1995) suggest that the ascent of the Bergell pluton was triggered by detachment of the European lithospheric mantle during collision with the Briançonnais realm, starting at the end of the Eocene. Continued convergence probably caused post-nappe refolding, backfolding, and backthrusting north of the Insubric line (SCHMID et al., 1996b). Final ascent of the pluton, parallel to the pre-existing Southern Steep Belt, probably began about 35 Ma ago. Syntectonic emplacement took place over a long interval in time (between 33 and 28 Ma according to OBERLI et al., 1996) and is related to vertical extrusion within the Southern Steep Belt (BERGER et al., 1996). Ascent and emplacement of the pluton occurred during transpressive regional north-south shortening, accompanied by east-west extension (BERGER et al., 1996; DAVIDSON et al., 1996).

Extremely rapid post-emplacement exhumation, linked to ongoing transpression and east-west extension, immediately starts after solidification of the western part of the pluton at about 28 Ma, according to the results of OBERLI et al. (1996). This allows for rapid exhumation, erosion, and transport of Bergell boulders into Tertiary sediments of the Southern Alps (GIGER and HURFORD, 1989). Rapid exhumation lasts until shortly after the intrusion of the Novate granite (HURFORD, 1986). Differential exhumation of the Bergell intrusion and immediately surrounding units in respect to other parts of the Alpine orogen is accommodated across the Engadine and Gruf lines in the north (BERGER et al., 1996) and the Insubric line in the south (SCHMID et al., 1989). This forms the characteristic and unusally narrow eastern appendix of the Lepontine dome, defined by very steep metamorphic field gradients which are not coeval with those found further west.

In conclusion, the Bergell area offers an excellent and in many respects unique opportunity to study the interplay between deformation, metamorphism and pluton emplacement. The area is extremely well exposed, and, as can be seen from the extensive although still incomplete list of references, an impressive amount of work has been carried our over the years. The authors hope that the map by BERGER (1996), together with this text, will stimulate further work on problems related to pluton emplacement, in the Bergell area and elsewhere.

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References

ARTUS, F. (1959): Über metamorphe Breccien basischer Gesteine im Granit des Bergeller Massivs. Hamb. Beitr. Miner. Kristallphys. Petrogen. 2, 1–39.

BANGERTER, G.C. (1978): Strukturen und Metamorphose im Grenzbereich des Malenco–Serpentins und der Margna-Decke im Gebiet um den Monte Braccia. Unpublished diploma thesis Univ. Zürich.

BAUDIN, T., MARQUER, D. and PERSOZ, F. (1993): Basement-cover relationships in the Tambo nappe (Central Alps, Switzerland): Geometry, structure and kinematics. J. Struct. Geology 15, 543–553.

BAUDIN, T., MARQUER, D., BARFÉTY, J.-C., KERCKHOVE, C. and PERSOZ, F. (1995): Nouvelle interprétation stratigraphique de la couverture mésozoïque des nappes de Tambo et de Suretta: mise en évidence d'une nappe de décollement précoce (Alpes centrales suisses). C.R. Acad. Sci. Paris, 321, série IIa, 401–408.

BAY, F. (1996): Strukturelle und petrographische Untersuchungen an der Südseite des Malenco-Körpers, Teil 1 (Valle Airale, N-Italien). Unpublished diploma thesis University Zürich.

BECCALUVA, L., BIGIOGGERO, B., CHIESA, S., COLOMBO, A., FANTI, G., GATTO, G.O., GREGNANIN, A., MONTRASIO, A., PICCIRILLO, E.M. and TUNESI, A. (1983): Post collisional orogenic dyke magmatism in the Alps. Mem. Soc. Geol. It. 26, 341–360.

BEDOGNÉ, F., MAURIZIO, R., MONTRASIO, A. and SCIESA, E. (1995): I Minerali della Provincia di Sondrio e della Bregaglia Grigionese. Val Bregaglia, Val Masino, Val Codera e Valle Spluga. Bettini, Sondrio.

BEDOGNÉ, F., MONTRASIO, A. and SCIESA, E. (1993): I Minerali della Provincia di Sondrio. Valmalenco. Bettini, Sondrio.

BERGER, A. (1995): Magmatic and solid state flow during the syntectonic emplacement of the Bergell pluton (southeastern part): field studies and microstructural analysis. Ph. D. Thesis Geol.-Paläont. Institut Univ. Basel 7.

BERGER, A. (1996): Geological-tectonic map of the Bergell pluton and surrounding country rocks (Southern Switzerland, Northern Italy). Supplemento to Schweiz. Mineral. Petrogr. Mitt., 76/3.

BERGER, A. and GIERÉ, R. (1995): Structural observations at the eastern contact of the Bergell Pluton. Schweiz. Mineral. Petrogr. Mitt. 75, 241–258.

BERGER, A. and STÜNITZ, H. (1996): Deformation mechanisms and reaction of hornblende: examples from the Bergell tonalite (Central Alps). Tectonophysics 257, 149–174.

BERGER, A., ROSENBERG, C. and HEILBRONNER, R. (1994): Deformation of polyphase rocks at different temperature conditions (II): microstructural and textural development of biotite in the Bergell tonalite. Annales Geophysicae 12, C90.

BERGER, A., ROSENBERG, C. and SCHMID, S.M. (1996): Ascent, emplacement and exhumation of the Bergell pluton within the Southern Steep Belt of the Central Alps. Schweiz. Mineral. Petrogr. Mitt., 76, 357–382.

BLANC, B.L. (1965): Zur Geologie zwischen Madesimo und Chiavenna (Provinz Sondrio, Italien). Ph. D. Thesis ETH Zürich.

BLATTNER, P. (1965): Ein anatektisches Gneismassiv zwischen Valle Bodengo und Valle di Livo (Prov. Sondrio und Como). Schweiz. Mineral. Petrogr. Mitt. 45, 973–1071.

BOCCHIO, R., CRESPI, R., LIBORIO, G. and MOTTANA, A. (1980): Variazioni composizionali delle miche chiare nel metamorfismo progrado degli scisti sudalpini dell'alto lago di Como. Mem. Sci. Geol. Padova 34, 153–176.

BORSIEN, G.R. (1995): Petrographische Untersuchungen im oberen Val Malenco (Val Ventina, Provinz Sondrio, N-Italien) Teil 2. Alpe Zocca. Unpublished diploma thesis ETH Zürich.

BRUGGMANN, H.O. (1965): Geologie und Petrographie des südlichen Misox. Ph. D. Thesis Univ. Zürich.

BUCHER-NURMINEN, K. (1977): Die Beziehung zwischen Deformation, Metamorphose und Magmatismus im Gebiet der Bergeller Alpen. Schweiz. Mineral. Petrogr. Mitt. 57, 414–434.

BUCHER-NURMINEN, K. (1981): The formation of metasomatic reaction veins in dolomitic marble roof pendants in the Bergell intrusion (Province Sondrio, Northern Italy). Amer. J. Sci. 281, 1197–1222.

BUCHER, K. and PFEIFER, H.R. (1973): Über Metamorphose und Deformation der östlichen Malenco-Ultramafitite und deren Rahmengesteine (Prov. Sondrio, N-Italien). Schweiz. Mineral. Petrogr. Mitt. 53, 231–241.

BUCHER-NURMINEN, K. and DROOP, G. (1983): The metamorphic evolution of garnet-cordierite-sillimanite-gneisses of the Gruf-Complex, Eastern Pennine Alps. Contr. Mineral. Petrol. 84, 215–227.

CALLEGARI, E. and MONESE, A. (1961): Studio petrogenetico dei bordi di reazione metamorfico-metasomatici attorno a lenti ultrafemici incluse nel granito di San Fedelino (Sondrio). Rend. Soc. Mineral. It. 17, 147–192.

CONFORTI-GALLI, C., SPALLA, M., GOSSO, G. and MONTRASIO, A. (1988): Syn-intrusive foliation of the Masino-Bregaglia Tonalite and its roof pendants in Val Sissone (Val-Malenco, Central Alps, Italy). Rend. Soc. It. Mineral. Petro. 43, 509–516.

CORNELIUS, H.P. (1925): Über einige Gesteine der "Fedozserie" aus dem Disgraziagebiet (Rhätische Alpen). Neues Jb. Mineral. Geol. Paläont. Beilage 52/A, 1–50.

CORNELIUS, H.P. and CORNELIUS-FURLANI, M. (1930): Die Insubrische Linie vom Tessin bis zum Tonale-Pass. Denkschr. Akad. Wiss. Math. Klasse 102, 208–301.

DAVIDSON, C., ROSENBERG, C. and SCHMID, S.M. (1996): Evidence for syntectonic intrusion from the western margin of the Bergell pluton, Central Alps. Tectonophysics, in press.

DEUTSCH, A. (1983): Datierungen an Alkaliamphibolen und Stilpnomelan aus der südlichen Platta-Decke. Eclogae geol. Helv. 76, 295–308.

DIETHELM, K.H. (1984): Geologie und Petrographie des Bergell-Ostrandes. II. Unpubl. Diploma thesis ETH Zürich.

DIETHELM, K.H. (1985): Hornblendite und Gabbros im östlichen Bergell (Val Sissone, Prov. Sondrio, Italien). Schweiz. Mineral. Petrogr. Mitt. 65, 223–246.

DIETHELM, K.H. (1989): Petrographische und geochemische Untersuchungen an basischen Gesteinen der Bergeller Intrusion. Ph. D. Thesis ETH Zürich Nr. 8855.

DIETHELM, K.H. (1990): Synintrusive basische Gänge und "endogene" Xenolithe: Magma-Mingling in der Bergeller Intrusion. Schweiz. Mineral. Petrogr. Mitt. 70, 247–264.

DIETRICH, V. (1969): Die Ophiolithe des Oberhalbsteins (Graubünden) und das Ophiolithmaterial der ostschweizerischen Molasseablagerungen, ein petrographischer Vergleich. Europ. Hochschulschr. 17/1. Lang & Cie., Bern, 179 pp.

DIETRICH, V. (1970): Die Stratigraphie der Platta-Decke. Eclogae geol. Helv. 63, 631–671.

DRESCHER-KADEN, F.K. (1940): Beiträge zur Kenntnis der Migmatit- und Assimilationsbildungen sowie der synanatektischen Reaktionsformen 1. Über Schollenassimilation und Kristallisationsverlauf im Bergeller Granit. Chemie der Erde 12, 304–417.

DRESCHER, F.K. and STORZ, M. (1926): Ergebnisse petrographisch-tektonischer Untersuchungen im Bergeller Granit (mit tektonischer Karte). N. Jb. Mineral. B.B. 54, Abt. A, 284–291.

DROOP, G. and BUCHER-NURMINEN, K. (1984): Reaction textures and metamorphic evolution of sapphirine-bearing granulites from the Gruf Complex, Italian Central Alps. J. Petrology 25, 766–803.

EL TAHLAWI, M.R. (1965): Geologie und Petrographie des nordöstlichen Comerseegebietes (Provinz Como, Italien). Ph. D. Thesis ETH Zürich.

ENGI, M., TODD, C.S. and SCHMUTZ, D.R. (1995): Tertiary metamorphic conditions in the eastern Lepontine Alps. Schweiz. Mineral. Petrogr. Mitt. 75, 347–369.

FERRARIO, A. and MONTRASIO, A. (1976): Manganese ore deposits of Monte del Forno. Its stratigraphic and structural implications. Schweiz. Mineral. Petrogr. Mitt. 56, 377–386.

FERRY, J.M. (1995): Fluid flow during contact metamorphism of ophicarbonate rocks in the Bergell aureole, Val Malenco, Italian Alps. J. Petrology 36, 1039–1053.

FISCH, H.R. (1989): Zur Kinematik der südlichen Steilzone der Zentralalpen, E von Bellinzona. Schweiz. Mineral. Petrogr. Mitt. 69, 377–392.

FORNERA, T. (1996): Ricerche strutturali e petrografiche lungo il margine meridionale del corpo ultramafico del Malenco. 2: zona "Mastabia" (Valle Airale). Unpublished diploma thesis ETH Zürich.

FROITZHEIM, N. and MANATSCHAL, G. (1996): Kinematics of Jurassic rifting, mantle exhumation, and passive-margin formation in the Autroalpine and Penninic nappes (Eastern Switzerland). Bull. geol. Soc. America, 108, 1120–1133.

FROITZHEIM, N., SCHMID, S.M. and CONTI, P. (1994): Repeated change from crustal shortening to orogen-parallel extension in the Austroalpine units of Graubünden. Eclogae geol. Helv. 87, 559–612.

FROITZHEIM, N., SCHMID, S.M. and FREY, M. (1996): Mesozoic paleogeography and the timing of eclogite-facies metamorphism in the Alps: A working hypothesis. Eclogae geol. Helv. 89, 81–110.

FUMASOLI, M.W. (1974): Geologie des Gebietes nördlich und südlich der Iorio-Tonale-Linie im Westen von Gravedona. Ph. D. Thesis Univ. Zürich.

FURRER, H. ed. (1985): Field workshop on Triassic and Jurassic sediments in the Eastern Alps of Switzerland. Mitt. Geol. Institut ETH und Univ. Zürich NF 248, 81 pp.

GANSSER, A. and GYR, T. (1964): Über Xenolithschwärme aus dem Bergeller Massiv und Probleme der Intrusion. Eclogae geol. Helv. 57, 577–598.

GATTO, G.O., GREGANIN, A., PICCIRILLO, E.M. and SCOLARI A. (1976): The "Andesitic" magmatism in the south-western Tyrol and its geodynamic significance. Geol. Rundsch. 65, 691–700.

GAUTSCHI, A. (1976): Geologisch-petrographische Untersuchungen am Südrand des Malencoserpentinites (Provinz Sondrio, Nord-Italien). Unpublished diploma thesis ETH Zürich.

GAUTSCHI, A. (1980): Metamorphose und Geochemie der basischen Gesteine des Bergeller Ostrands. Ph. D. Thesis ETH Zürich Nr. 6672.

GAUTSCHI, A. and MONTRASIO, A. (1978): Die andesitisch-basaltischen Gänge des Bergeller Ostrandes und ihre Beziehung zur Regional- und Kontaktmetamorphose. Schweiz. Mineral. Petrogr. Mitt. 58, 329–343.

GIERÉ, R. (1984): Geologie und Petrographie des Bergeller Ostrandes. Unpublished diploma thesis ETH Zürich.

GIERÉ, R. (1985): Metasedimente der Suretta-Decke am Ost- und Südostrand der Bergeller Intrusion: Lithostratigraphische Korrelation und Metamorphose. Schweiz. Mineral. Petrogr. Mitt. 65, 57–78.

GIERÉ, R. (1986): Zirconolite, allanite and hoegbomite in a marble skarn from the Bergell contact aureole: implications for the mobility of Ti, Zr and REE. Contrib. Mineral. Petrol. 93, 459–470.

GIERÉ, R. (1987): La geologia tra le valli Sissone e Muretto. Atti ufficiali del convegno Val Malenco Natura 1, 21–26.

GIGER, M. and HURFORD, A.J. (1989): Tertiary intrusives of the Central Alps: Their Tertiary uplift, erosion, redeposition and burial in the south-alpine foreland. Eclogae geol. Helv. 82, 857–866.

GRAMACCIOLI, C.M. (1978): Die Mineralien der Alpen, Vol. I and II, Ott Verlag, Thun.

GRÜNENFELDER, M. (1956): Petrographie des Roffnakristallins in Mittelbünden und seine Eisenvererzung. Beitr. Geol. Schweiz, geotechn. Ser. 35.

GULSON, B.L. (1973): Age relations in the Bergell region of the South-East Swiss Alps: with some geochemical comparisons. Eclogae geol. Helv. 66, 293–313.

GUNTLI, P. (1987): Geologische und petrographische Untersuchungen der Margna südlich des Silsersees, Oberengadin. 2. Fedoz. Unpublished diploma thesis Univ. Zürich.

GUNTLI, P. and LINIGER, M. (1989): Metamorphose in der Margna-Decke im Bereich Piz da la Margna und Piz Fedoz (Oberengadin). Schweiz. Mineral. Petrogr. Mitt. 69, 289–301.

GYR, T. (1967): Geologische und Petrographische Untersuchungen am Ostrande des Bergeller Massivs. Mitt. aus dem Geol. Institut der ETH Zürich und der Univ. Zürich N.F. 66.

HAFNER, M. (1993): Strukturgeologische und geochemische Untersuchungen von leukokraten Granit-Gängen und Migmatiten der südlichen Adula am Monte Peschiera (It). Unpublished diploma thesis Univ. Basel.

HANDY, M.R., HERWEGH, M. and REGLI, CH. (1993). Tektonische Entwicklung der westlichen Zone von Samedan (Oberhalbstein, Graubünden, Schweiz). Eclogae geol. Helv. 86, 785–817.

HANSMANN, W. (1981): Geologisch-petrographische Untersuchungen im südlichen Bergell: 2. Val Ligoncio. Unpublished diploma thesis ETH Zürich.

HANSMANN, W. (1996): Age determinations on the Tertiary Masino-Bregaglia (Bergell) intrusives (Italy, Switzerland): a review. Schweiz. Mineral. Petrogr. Mitt. 76, 421–451.

HANSMANN, W., HERMANN, J., MÜNTENER, O. and TROMMSDORFF, V. (1995): U–Pb dating of single zircons from a gabbroic intrusion at the crust-mantle boundary (Val Malenco, Italy). Terra Abstracts, suppl. No. 1 to Terra Nova 7, 352.

HEITZMANN, P. (1975): Zur Metamorphose und Tektonik im südostlichen Teil der Lepontinischen Alpen (Provincia di Como, Italia). Schweiz. Mineral. Petrogr. Mitt. 55, 467–522.

HEITZMANN, P. (1987a): Calcite mylonites in the central Alpine "root zone". Tectonophysics 135, 207–215.

HEITZMANN, P. (1987b): Evidence of late Oligocene/early Miocene backthrusting in the Central Alpine "root zone". Geodinamica Acta 1, 183–192.

HERMANN, J. and MÜNTENER, O. (1992): Strukturelle Entwicklung im Grenzbereich zwischen dem penninischen Malenco-Ultramafitit und dem Unterostalpin (Margna- und Sella-Decke). Schweiz. Mineral. Petrogr. Mitt. 72, 225–340.

HERMANN, J. and MÜNTENER, O. (1996): Extension-related structures in the Malenco-Margna system. Implications for paleogeography and consequences for rifting and Alpine tectonics. Schweiz. Mineral. Petrogr. Mitt., 76, 501–519.

HERMANN, J., MÜNTENER, O., TROMMSDORFF, V., PICCARDO, G.B. and HANSMANN, W. (in prep.): A fossil crust-mantle transition in the Alps. Subm. to Geophys. Res.

HURFORD, A.J. (1986): Cooling and uplift patterns in the Lepontine Alps, South Central Switzerland and an age of vertical movement on the Insubric fault line. Contr. Mineral. Petrol. 92, 413–429.

HURFORD, A.J., FLISCH, M. and JÄGER, E. (1989): Unravelling the thermo-tectonic evolution of the Alps: a contribution from fission track analysis and mica dating. In: COWARD, M.P., DIETRICH, D. and PARK, R.G. (eds): Alpine Tectonics. Geol. Soc. Spec. Publ. 45, 369–398.

HÄNNY, R. (1972): Das Migmatitgebiet der Valle Bodengo (östl. Lepontin). Beitr. geol. Karte Schweiz N.F. 145, 109 pp.

HÄNNY, R., GRAUERT, B. and SOPTRAJANOVA, G. (1975): Paleozoic migmatites affected by high-grade Tertiary metamorphism in the Central Alps (Valle Bodengo, Italy). A geochronological study. Contr. Mineral. Petrol. 51, 173–196.

KÖPPEL, V. and GRÜNENFELDER, M. (1971): A study of inherited and newly formed zircons from paragneisses and granitised sediments of the Strona-Ceneri zone (Southern Alps). Schweiz. Mineral. Petrogr. Mitt. 51, 385–409.

KÖPPEL, V. and GRÜNENFELDER, M. (1975): Concordant U–Pb ages of monazite and xenotime from the Central Alps and the timing of the high temperature Alpine metamorphism, a preliminary report. Schweiz. Mineral. Petrogr. Mitt. 55, 129–132.

KRUHL, J.H. and VOLL, G. (1976): Fabrics and metamorphism from the Monte Rosa Root Zone into the Ivrea Zone near Finero, southern margin of the Alps. Schweiz. Mineral. Petrogr. Mitt. 56, 627–633.

KUBLI, T. (1983): Geologie und Petrographie der Fornoserie im unteren Val Forno. Unpublished diploma thesis ETH Zürich.

LARDELLI, T. (1981): Die Tonalelinie im unteren Veltlin. Ph. D. Thesis Univ. Zürich.

LINIGER, M. (1987): Geologie und Petrographie der Margna südlich des Silsersees, Oberengadin (I). Unpublished diploma thesis ETH Zürich.

LINIGER, M. (1992): Der ostalpin-penninische Grenzbereich im Gebiet der nördlichen Margna-Decke (Graubünden, Schweiz). Ph. D. Thesis ETH Zürich Nr. 9769.

LINIGER, M. and GUNTLI, P. (1988): Bau und Geschichte des zentralen Teils der Margna-Decke. Schweiz. Mineral. Petrogr. Mitt. 68, 41–54.

LINIGER, M. and NIEVERGELT, P. (1990): Stockwerk-Tektonik im südlichen Graubünden. Schweiz. Mineral. Petrogr. Mitt. 70, 95–101.

MARQUER, D. (1991): Structures et cinématique des déformations alpines dans le granite de Truzzo (Nappe de Tambo: Alpes centrales suisses). Eclogae geol. Helv., 84, 107–123.

MILNES, A.G. (1974): Post-nappe folding in the Western Lepontine Alps. Eclogae geol. Helv. 67, 333–348.

MILNES, A.G. (1978): Structural zones and continental collision, Central Alps. Tectonophysics, 47, 369–392.

MILNES, A.G. and PFIFFNER, O.A. (1980): Tectonic evolution of the Central Alps in the cross section St. Gallen-Como. Eclogae geol. Helv. 73, 619–633.

MILNES, A.G. and SCHMUTZ, H.U. (1978): Structure and history of the Suretta nappe (Pennine zone, Central Alps) – a field study. Eclogae geol. Helv. 71, 19–33.

MONTRASIO, A. (1973): Strutture a pillow nelle amphiboliti del M. Forno (Pennidico medio-Alpi Retiche). Atti Accad. Naz. Lincei, Rend. Cl. Sci. fis. mat. nat. 54, 114–123.

MONTRASIO, A. (1984): The "Lanzada-Scermendone Zone": An ophiolitic unit of continental affinity in the Southern Rhaetic Alps (Prov. Sondrio-Italy). Schweiz. Mineral. Petrogr. Mitt. 66, 111–129.

MONTRASIO, A. and TROMMSDORFF, V. (1983): Guida all'escursione del massiccio di Val Masino-Bregaglia, Val Malenco occidentale, Sondrio. Mem. Soc. Geol. It. 26, 421–434.

MONTRASIO, A. and SCIESA, E. (1988): Carta Geologica della Valle Spluga ed area adiacenti. Consiglio Nazionale delle Ricerche, Centro di Studio per la Stratigrafia e Petrografia delle Alpi Centrali, Milano.

MORAND, P. (1981): Geologisch-petrographische Untersuchungen im südlichen Bergell: I. Val Porcellizzo. Unpublished diploma thesis ETH Zürich.

MOTICSKA, P. (1970): Petrographie und Strukturanalyse des westlichen Bergeller Massivs und seines Rahmens. Schweiz. Mineral. Petrogr. Mitt. 50, 355–443.

MOTTANA, A., MORTEN, L. and BRUNFELT, A.O. (1978): Distribuzione delle terre rare nel Massiccio Val Masino – Val Bregaglia (Alpi Centrali). Rend. Soc. Ital. Mineral. Petrol. 34, 485–497.

MÜNTENER, O. and HERMANN, J. (1996): The Val Malenco lower crust-mantle complex and its field relations (Italiens Alps). Schweiz. Mineral. Petrogr. Mitt., 76, 475–500.

MÜTZENBERG, S. (1986): Petrographische und strukturelle Untersuchung am Bergell-Nordostrand, südlich Maloja. Unpublished diploma thesis ETH Zürich.

NIEVERGELT, P. and DIETRICH, V. (1977): Die andesitisch-basaltischen Gänge des Piz Lizun (Bergell). Schweiz. Mineral. Petrogr. Mitt. 57, 267–280.

NIEVERGELT, P., LINIGER, M., FROITZHEIM, N. and FERREIRO–MÄHLMANN, R. (1996): Early to mid Tertiary crustal extension in the Central Alps: The Turba Mylonite Zone (Eastern Switzerland). Tectonics 15, 329–340.

OBERHÄNSLI, R. (1978): Chemische Untersuchungen an Glaukophan-führenden basischen Gesteinen aus den Bündnerschiefern Graubündens. Schweiz. Mineral. Petrogr. Mitt. 58, 139–156.

OBERLI, F., MEIER, M., BERGER, A., ROSENBERG, C. and GIERÉ, R. (1996): ^{230}Th/^{238}U disequilibrium systematics in U–Th–Pb dating: Nuisance or powerful tool in geochronometry? Abstract 6th V.M. Goldschmidt Conference, Heidelberg.

PARTZSCH, J.H., FREY, M., KRUSPAN, P., MEYRE, C. and SCHMID, S.M. (1994): Die tektono-metamorphe Entwicklung der mittleren Adula-Decke (Zentralalpen, Schweiz). Extended abstract in: 5. Symposium TSK, Göttingen, Göttinger Arb. Geol. Paläont. Sb1, 124–126.

PERETTI, A. (1983): Geologie und Petrographie der Fornoserie. Piz dei Rossi. Unpublished diploma thesis ETH Zürich.

PERETTI, A. (1985): Der Monte-del-Forno-Komplex am Bergell-Ostrand: Seine Lithostratigraphie, alpine Tektonik und Metamorphose. Eclogae geol. Helv. 78, 23–48.

PERETTI, A. and KÖPPEL, V. (1986): Geochemical and lead isotope evidence for a mid-ocean ridge type mineralization within a polymetamorphic ophiolite complex (Monte del Forno, North Italy/Switzerland). Earth Planet. Sci. Lett. 80, 252–264.

PETERS, T., SCHWANDER, H., TROMMSDORFF, V. (1973): Assemblages among Tephroite, Pyroxmangite, Rhodochrosite, Quartz: Experimental data and Occurrences in the Rhetic Alps. Contrib. Mineral. Petrol. 42, 325–332.

PFIFFNER, M. and WEISS, M. (1994): Strukturelle und petrographische Untersuchungen im Grenzbereich Penninikum-Unterostalpin am Südostrand des Bergell-Plutons (Val Masino, Italien). Schweiz. Mineral. Petrogr. Mitt. 74, 245–264.

PICCOLI, G. (1961): Metasomatismo e migmatiti nelle rocce verdi di Novate Mezzola (Sondrio, Alpi Lombarde). Rend. Soc. Mineral. Ital. 17, 427–454.

PIKA, J. (1976): Petrographie des Malenco-Serpentinites und seiner Kontakte im Valle Airale. Unpublished diploma thesis ETH Zürich.

POZZORINI, D. (1996): Stable isotope investigations of ophicarbonate rocks, Bergell aureole, Valmalenco: Constraints on fluid-rock interaction. Ph. D. Thesis ETH Zürich Nr. 11436.

POZZORINI, D. and FRÜH-GREEN, G. (1996): Stable isotope systematics of the Ventina Ophicarbonate zone, Bergell contact aureole. Schweiz. Mineral. Petrogr. Mitt., 76, 549–564.

PUSCHNIG, A.R. (1996): Regional and emplacement-related structures at the northeastern border of the Bergell intrusion (Monte del Forno, Rhetic Alps). Schweiz. Mineral. Petrogr. Mitt., 76, 399–420.

REINHARD, M. (1953): Über das Grundgebirge des Sottoceneri im südlichen Tessin. Eclogae geol. Helv. 46, 214–222.

REINHARDT, B. (1966): Geologie und Petrographie der Monte Rosa-Zone, der Sesia-Zone und des Canavese im Gebiet zwischen Valle d'Ossola und Valle Loana (Prov. di Novara, Italien). Schweiz. Mineral. Mitt. 46, 553–678.

REPOSSI, E. (1915). La bassa Valle della Mera. Studi petrografici e geologici II. Mem. Soc. Ital. Sci. Nat. Milano 8, 186 pp.

REUSSER, C.E. (1987): Phasenbeziehung im Tonalit der Bergeller Intrusion. Ph. D. Thesis ETH Zürich Nr. 8329.

RIED, F. (1994): Titanmobilität: Metasomatische, titanreiche Adern am Kontakt von Dolomitmarmoren zur Bergeller Intrusion. Ph. D. Thesis ETH Zürich Nr. 10637.

RIKLIN, K. (1977): Geologisch-petrographische Untersuchungen am Bergell-Ostrand, nördlich der Valle Sissone. Unpublished diploma thesis ETH Zürich.

RIKLIN, K. (1978): Strukturen und Metamorphose im Bereich der südlichen Muretto-Linie. Schweiz. Mineral. Petrogr. Mitt. 58, 345–356.

RING, U. (1994): The kinematics of the late Alpine Muretto fault and its relation to dextral transpression across the Periadriatic line. Eclogae geol. Helv. 87, 811–831.

ROSENBERG, C. (1996): Magmatic and solid state flow during the syntectonic emplacement of the western Bergell pluton: field studies and microstructural analysis. Ph. D. Thesis Geol.-Paläont. Institut Univ. Basel Nr. 8.

ROSENBERG, C., BERGER, A. and HEILBRONNER, R. (1994): Deformation of polyphase rocks at different temperature conditions (I): rheological versus mineralogical phases in the Bergell tonalite. Annales Geophysicae 12 (Abstract).

ROSENBERG, C., BERGER, A. and SCHMID, S.M. (1995): Observation from the floor of a granitoid pluton: Inferences on the driving force of final emplacement. Geology 23, 443–446.

SCHMID, S.M. (1993): Ivrea zone and adjacent Southern Alpine basement. In VON RAUMER, J.F. and NEUBAUER, F. (eds): Pre-Mesozoic Geology in the Alps, Springer Verlag, 567–583.

SCHMID, S.M., AEBLI, H.R., HELLER, F. and ZINGG, A. (1989): The role of the Periadriatic line in the tectonic evolution of the Alps. In: COWARD, M.P., DIETRICH, D. and PARK, R.G. (eds): Alpine Tectonics. Geol. Soc. Spec. Publ. 45, 153–171.

SCHMID, S.M. and FROITZHEIM, N. (1993): Oblique slip and block rotation along the Engadine line. Eclogae geol. Helv. 86, 569–593.

SCHMID, S.M., PFIFFNER, A. and SCHREURS, G. (1996a): The Penninic Zone. In: HEITZMANN, P. (ed.): Deep structure of the Swiss Alps – Results from NFP/PNR 20. Birkhäuser AG, Basel, in press.

SCHMID, S.M., PFIFFNER, O.A., FROITZHEIM, N., SCHÖNBORN, G. and KISSLING, E. (1996b): Geophysical-geological transect and tectonic evolution of the Swiss-Italian Alps. Tectonics, in press.

SCHMID, S.M., RÜCK, P. and SCHREURS, G. (1990): The significance of the Schams nappes for the reconstruction of the paleotectonic and orogenic evolution of the Penninic zone along the NFP 20 East Traverse (Grisons, eastern Switzerland). Mém. Soc. géol. France 156, 263–287.

SCHMID, S.M., ZINGG, A. and HANDY, M. (1987): The kinematics of movements along the Insubric Line and the emplacement of the Ivrea Zone. Tectonophysics 135, 47–66.

SCHMIDT, M.W. (1989): Petrography and structural evolution of ophiolitic remnants in the Bellinzona Zone, Southern Steep Belt, Central Alps. Schweiz. Mineral. Petrogr. Mitt. 69, 393–405.

SCHMUTZ, H.U. (1976): Der Mafitit-Ultramafitit-Komplex zwischen Chiavenna und Val Bondesca. Beitr. Geol. Karte Schweiz. (N.F.) 149, 73 pp.

SCHUMACHER, T. (1975): Geologisch-petrographische Untersuchungen des Malenco-Serpentinits und der Margnagesteine bei Chiareggio. Unpublished diploma thesis ETH Zürich.

SPILLMANN, P. (1988): Struktur und Metamorphose in der Margna-Decke und im Malenco-Serpentinit im oberen Val Malenco. Unpublished diploma thesis ETH Zürich.

SPILLMANN, P. (1989): Struktur und Metamorphose der Margna-Decke im obersten Valmalenco. Schweiz. Mineral. Petrogr. Mitt. 69, 147–150.

SPILLMANN, P. (1993): Die Geologie des penninisch-ostalpinen Grenzbereichs im südlichen Berninagebirge. Ph. D. Thesis ETH Zürich Nr. 10175.

SPILLMANN, P. and BÜCHI, H.J. (1993): The pre-Alpine Basement of the Lower Austroalpine nappes and the Bernina Massif (Grisons, Switzerland; Valtellina, Italy). In: VON RAUMER, J.F. and NEUBAUER, F. (eds): The pre-Mesozoic Geology in the Alps, Springer Verlag : 457–467.

STAUB, R. (1917): Das Äquivalent der Dentblanchedecke in Bünden. Vjschr. Natf. Ges. Zürich 62, 349–370.

STAUB, R. (1918): Geologische Beobachtungen am Bergeller Massiv. Vjschr. natf. Ges. Zürich, 63, 1–18.

STAUB, R. (1921): Geologische Karte der Val Bregaglia (Bergell). Geol. Spezialkarte 90, Schweiz. Geol. Kommission.

STAUB, R. (1946): Geologische Karte der Berninagruppe und ihrer Umgebung im Oberengadin, Bergell, Val Malenco, Puschlav und Livigno, 1:50'000. Geol. Spezialkarte 118, Schweiz. Geol. Kommission.

STAUB, R. (1958): Klippendecke und Zentralalpenbau. Beitr. geol. Karte Schweiz N.F. 103, 184 pp.

STEINMANN, M. (1994): Ein Beckenmodell für das Nordpenninikum. Jb. Geol. B.-A. Wien 137, 675–721.

STREIFF, V., JÄCKLI, H. and NEHER, J. (1971/76): Geologischer Atlas der Schweiz 1:25'000. Blatt 56 Andeer, mit Erläuterungen. Schweiz. Geol. Kommission.

TROMMSDORFF, V. (1990): Metamorphism and tectonics in the Central Alps: the Alpine lithospheric mélange of Cima Lunga and Adula. Mem. Soc. Geol. It. 45, 39–49.

TROMMSDORFF, V. and EVANS, B.W. (1972): Progressive metamorphism of antigorite schists in the Bergell tonalite aureole (Italy). Am. J. Sci. 272, 423–437.

TROMMSDORFF, V. and EVANS, B.W. (1977): Antigorite Ophicarbonates; Contact Metamorphism in Val Malenco, Italy. Contrib. Mineral. Petrol. 62, 301–312.

TROMMSDORFF, V. and EVANS, B.W. (1980): Titanian Hydroxyl-Clinohumite: Formation and breakdown in antigorite rocks (Malenco, Italy). Contrib. Mineral. Petrol. 72, 229–242.

TROMMSDORFF, V. and NIEVERGELT, P. (1983): The Bregaglia (Bergell) Iorio Intrusive and its field relations. Mem. Soc. Geol. It. 26, 55–68.

TROMMSDORFF, V., PICCARDO, G.B. and MONTRASIO, A. (1993): From magmatism through metamorphism to sea floor emplacement of subcontinental Adria lithosphere during pre-Alpine rifting (Malenco, Italy). Schweiz. Mineral. Petrogr. Mitt. 73, 191–203.

TROMMSDORFF, V. and CONNOLLY, J.A.D (1996): The ultramafic contact aureole about the Bregaglia (Bergell) tonalite: isograds and a thermal model. Schweiz. Mineral. Petrogr. Mitt., 76, 537–547.

TRÜMPY, R. (1975): Penninic-Austroalpine boundary in the Swiss Alps: a presumed former continental margin and its problems. Am. J. Sci. 275A, 209–238.

TRÜMPY, R. (1977): The Engadine Line: A sinistral wrench fault in the Central Alps. Mem. geol. Soc. China s2, 1–12.

TRÜMPY, R. (1992): Ostalpen und Westalpen – Verbindendes und Trennendes. Jb. geol. B.-A. Wien 135, 875–882.

TRÜMPY, R. and TROMMSDORFF, V. (1980): Excursion 4: Alps of Eastern Switzerland In: Geology of Switzerland, part B, Ed. Schweiz. Geol. Kommission, Wepf and Co., 246 pp.

ULRICH, T. (1995): Petrographische Untersuchungen im oberen Val Malenco (Val Ventina, Provin Sondrio, N-Italien), Teil 1. Lago Pirola. Unpublished diploma thesis ETH Zürich.

ULRICH, T. and BORSIEN, G.R. (1996): Fedozer Metagabbro und Forno Metabasalt (Val Malenco, Norditalien): Vergleichende petrographische und geochemische Untersuchungen. Schweiz. Mineral. Petrogr. Mitt. 76, 521–535.

VANCE, D. and O'NIONS, R.K. (1992): Prograde and retrograde thermal histories from the central Swiss Alps. Earth Plan. Sci. Letters 114, 113–129.

VENZO, S., CRESPI, R., SCHIAVINATO, G. and FAGNANI, G. (1971): Carta geologica – petrografica delle Alpi Insubriche Valtellinesi tra la Val Masino e la Val Malenco (Sondrio). In: Mem. della Soc. It. Scienze Nat. e del Museo di Storia Naturale – Milano 1; Vol. 19.

VOGLER, S. (1980): Art und Ausmass der Deformation in Tonalit, Augengneis von Melirolo und Tonale-Serie am Alpen-S-Rand östlich von Bellinzona. Ph. D. Thesis Univ. Bonn, 217 pp.

VOGLER, S. and VOLL, G. (1976): Fabrics and Metamorphism from Tonalite, Granitic Augen-Gneiss and Tonale Series at the S-margin of the Swiss Alps, E of Bellinzona. Schweiz. Mineral. Petrogr. Mitt. 56, 635–640.

VOGLER, S. and VOLL, G. (1981): Deformation and Metamorphism at the south-Margin of the Alps, East of Bellinzona. Geol. Rundschau 70, 1232–1262.

VON BLANCKENBURG, F. (1992): Combined high-precision chronometry and geochemical tracing using accessory minerals: applied to the Central-Alpine Bergell intrusion. Chem. Geol. 100, 19–40.

VON BLANCKENBURG, F. and DAVIES, J.H. (1995): Slab breakoff: A model for syncollisional magmatism and tectonics in the Alps. Tectonics 14, 120–131.

VON BLANCKENBURG, F., FRÜH-GREEN, G., DIETHELM, K.H. and STILLE, P. (1992): Nd-, Sr-, O-isotopic and chemical evidence for a two-stage contamination history of mantle magma in the Central-Alpine Bergell intrusion. Contr. Mineral. Petrol. 110, 33–45.

WEBER, J. (1957): Petrographische und geologische Untersuchungen des Tonalitzuges von Melirolo-Sorico zwischen Tessintal und Comersee. Schweiz. Mineral. Petrogr. Mitt. 37, 267–397.

WEBER, W. (1966): Zur Geologie zwischen Chiavenna und Mesocco. Ph. D. Thesis ETH Zürich.

WEISSERT, H. and BERNOULLI, D. (1985): A transform margin in the Mesozoic Tethys: evidence from the Swiss Alps. Geol. Rundschau 74, 665–679.

WENGER, M. and ARMBRUSTER, TH. (1991): Columbite $(Fe,Mn)(Nb,Ta)_2O_6$ in the pegmatites of the calc-alkaline Bergell intrusion (southeast Central Alps). Schweiz. Mineral. Petrogr. Mitt. 71, 349–369.

WENK, E. (1963): Klinohumit und Chondrodit in Marmoren der Tessiner Alpen und der Disgraziagruppe. Schweiz. Mineral. Petrogr. Mitt. 43, 287–293.

WENK, H.R. (1973): The structure of the Bergell Alps. Eclogae geol. Helv. 66, 255–291.

WENK, H.R. (1974): Two episodes of high grade metamorphism in the northern Bergell Alps. Schweiz. Mineral. Petrogr. Mitt. 54, 555–565.

WENK, H.R. (1980): More porphyritic dikes in the Bergell Alps. Schweiz. Mineral. Petrogr. Mitt. 60, 145–152.

WENK, H.R. (1982): A geological history of the Bergell granite and related rocks. In: Transformists petrology. Theophrastus publications Athens 1982, 113–148.

WENK, H.R. (1986): Introduction to the geology of the Bergell Alps with Guide for Excursions. Jber. Natf. Ges. Graubünden 103, 29–90.

WENK, H.R. (1992): Note esplicative. Foglio 70 Sciora. Servizio idrologico e geologico nationale, 61 pp.

WENK, H.R. and CORNELIUS, S.B. (1977): Geologischer Atlas der Schweiz. 1 : 25'000. Blatt 70 Sciora. Schweiz. Geol. Kommission.

WENK, H.R., HSIAU, J., FLOWERS, G., WEIBEL, M., AYRANCI, B. and FEJÉR, Z. (1977): A geochemical survey of granitic rocks in the Bergell Alps. Schweiz. Mineral. Petrogr. Mitt. 57, 233–265.

WENK, H.R. and MAURIZIO, R. (1970): Geological observation in the Bergell Area (SE Alps). II. Contact Minerals from Mt. Sissone-Cima de Vazzeda. Schweiz. Mineral. Petrogr. Mitt. 50, 349–354.

WENK, H.R. and MAURIZIO, R. (1978): Kutnahorite, a rare Mn Mineral from Piz Cam (Bergell Alps). Schweiz. Mineral. Petrogr. Mitt. 58, 97–100.

WENK, H.R., WENK, E. and WALLACE, J.H. (1974): Metamorphic mineral assemblages in pelitic rocks of the Bergell Alps. Schweiz. Mineral. Petrogr. Mitt. 54, 507–554.

WERLING, E. (1992): Tonale-, Pejo- und Judikarien-Linie: Kinematik, Mikrostrukturen und Metamorphose von Tektoniten aus räumlich interferierenden, aber verschiedenaltrigen Verwerfungszonen. Ph. D. Thesis ETH Zürich, Nr. 9923.

WIEDENBECK, M. (1986): Structural and isotopic age profile across the Insubric Line, Mello, Valtellina, N-Italy. Schweiz. Mineral. Petrogr. Mitt. 66, 211–227.

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