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EXPLANATORY NOTES TO THE MAP:
METAMORPHIC STRUCTURE OF THE ALPS
CENTRAL ALPS

by

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The area of the Central Alps (Fig. 1) is delimited by the Subalpine Swiss Molasse to the north, the Austroalpine nappes in the Grisons and the Bergell in the east, and the Insubric Line to the south. The western limit is geologically less evident and is somewhat arbitrarily set in the Simplon area. Within the core portion of the Alpine orogen, some 72% of the (pre-Quarternary) units exposed have witnessed at least one pre-Alpine orogeny. Evidence of polymetamorphism is thus widespread in the basement; relics from the Variscan (Hercynian), Caledonian, and even Precambrian orogenies have been recognized. The intensity of the Alpine overprint is quite variable, and this had plagued early efforts of documenting regional metamorphic patterns (NIGGLI, 1974). Over the past thirty years it has become possible, despite the poly-orogenic metamorphic record, to decipher the Alpine cycle in considerable detail, by combining tectonic and seismic studies with petrology and geochronology.

The Central Alps comprise units attibuted to four paleogeographic domains, from N to S:

	Domain	*Original setting*
-	Helvetic shelf	Distal continental margin of the European craton
-	North-Pennine (= Valais)	Small oceanic basin (opening: Early Cretaceous)
-	Middle Penninic (= Briançonnais)	Microcontinental platform
-	South Pennine (= Piemont-Liguria)	Oceanic basin (opening: Middle Jurassic)

The Austroalpine orogenic lid has been entirely removed, by erosion and tectonic unroofing, in the area of the Central Alps. Whereas their external parts (Helvetic nappes and Penninic Prealps; Fig. 1) are almost entirely composed of post-Variscan shelf sediments, the imbricate thrust sheets in the Lepontine area are dominated by pre-Triassic crystalline cores. These basement units (of the European and Briançonnais domains) comprise largely supracrustal rock types, with abundant granitoid gneiss and clastic schist, subordinate amphibolite, and only minor other rock types. Relics of pre-Alpine orogenic reworking are more abundant in the External Massifs and in the northern parts of the Lepontine area, where the Alpine overprint is modest, but even in units which during the mid-Tertiary reached upper amphibolite facies, traces of a polycyclic history are not uncommon.

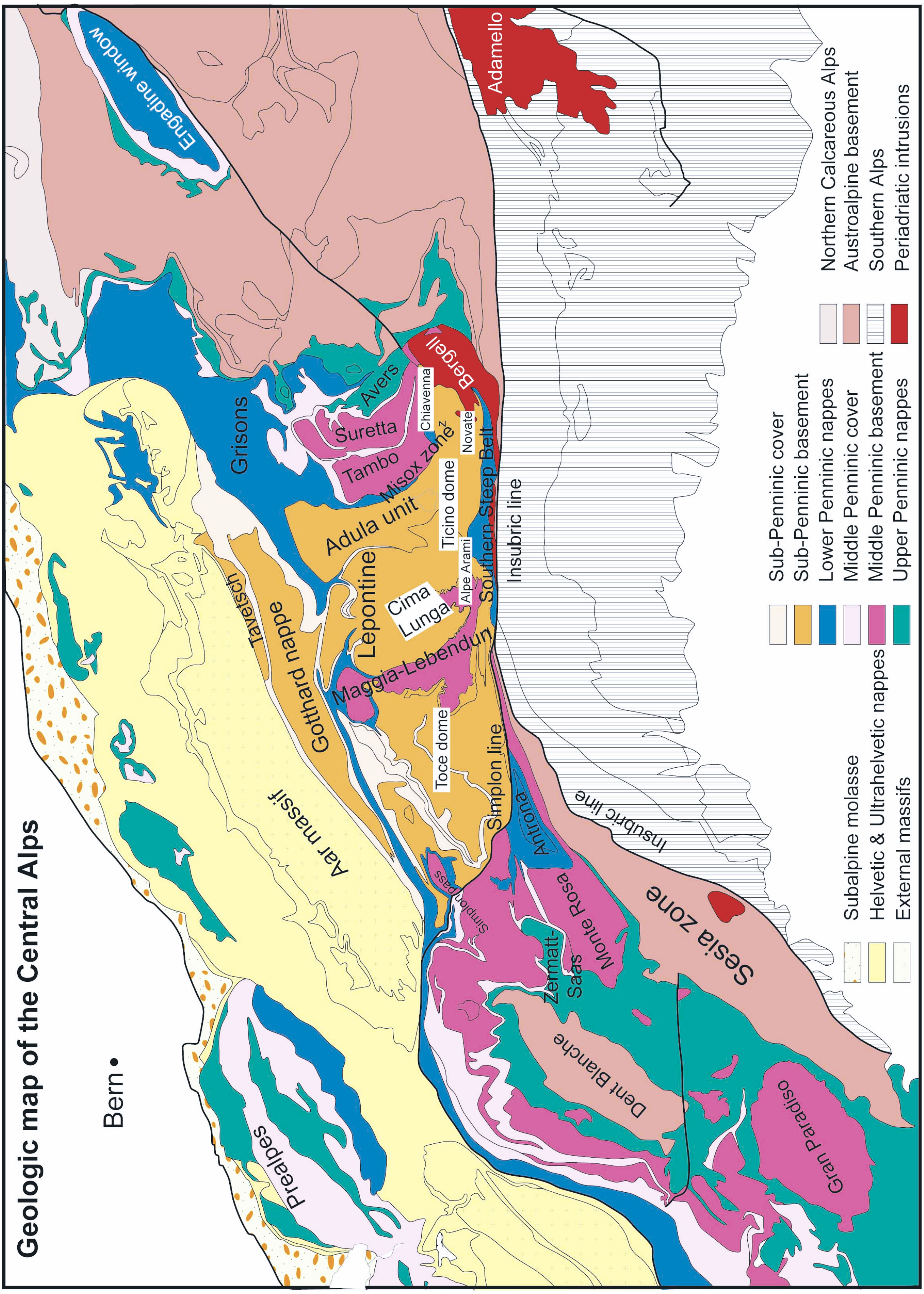


Fig. 1

Map showing locations and tectonic units to which the text refers.

This chapter presents the metamorphic evolution recognized in the Central Alps in chronological sequence, outlining the present state of understanding and indicating some of the limits. To keep the text concise, references to the essential primary data are far from exhaustive. Recent reviews are cited where available, and progress due to studies not treated in these is summarized in more detail. Still, it is not possible here to refer to all relevant studies produced in this classic orogen.

Pre-Alpine metamorphism in the Central Alps

At least two pre-Alpine cycles of orogenic metamorphism and deformation have been recognized in the External massifs and in the northernmost thrust sheets, all belonging to paleo-Europe. Following Proterozoic magmatism in a rift setting, Ordovician (Caledonian) high grade metamorphism and magmatism is well established, notably in the External Massifs, and the Permian (Variscan) magmatic and metamorphic imprint affected all of the basement units.

Caledonian orogeny: Case studies in the Central Alps (ABRECHT et al., 1991; ABRECHT & BIINO, 1994; BIINO, G., 1994; 1995; BIINO, G. G. et al., 1997) show eclogite facies and ± coeval granulite facies conditions. In the Gotthard and Tavetsch nappes for example, lawsonite grew on the prograde path, and eclogite formation peaked at $P_{max} \sim 2.4 \pm 0.3$ GPa and $T \sim 680 \pm 30$°C; the subsequent granulite and migmatite stages occurred at at 0.9-0.7 and 0.7-0.5 GPa, respectively, all at about the same temperature. This evolution reflects a collisional orogeny dated at ~460-464 Ma (OBERLI et al., 1994; GEBAUER et al., 1988). However, several stages of migmatite formation have been dated between 470 and 445 Ma, a period for which larger magmatic intrusions, both basic and granitic, are known from various units (as reviewed by SCHALTEGGER & GEBAUER, 1999). Amphibolite facies grade metamorphism and migmatites are widespread in the late Ordovician, as are large granitoid intrusives (MERCOLLI et al., 1994). To account for the tectono-metamorphic imprint during the Caledonian cycle, an active margin setting of a peri-Gondwana micro-continent has been invoked (VON RAUMER, 1998; VON RAUMER et al., 1999).

Variscan continent-continent collision: This cycle left its imprint both in the sedimentary record (Early Carboniferous synorogenic flysch: MATTE, 1986; FLÜGEL, 1990) and in widespread syn- and late-orogenic magmatism (360-320 Ma and 320-260 Ma, respectively). The metamorphic grade reached (low- to medium-P) amphibolite facies in the Central Alps. The overprint was thus less pronounced than in the Caledonian orogeny, but the effects of the two cycles are often difficult to distinguish. The spatial distribution of the Variscan phenomena suggests that continental terranes were accreted between the Silurian and the Devonian to the upper plate, now exposed e.g. in the External Massifs of the northern Central Alps. No such accretion is known from the (Variscan) lower plate, i.e. in Austroalpine and Southern Alpine units.

Alpine metamorphism in the Central Alps

Metamorphic assemblages in post-Variscan units, notably in post-Permian sedimentary sequences, are definitely attributable to the Tertiary Alpine cycles (NIGGLI, 1960). Yet even in such samples, evidence of a plurifacial Alpine metamorphism is fairly common in the Central Alps.

Similarly, this part of the Alpine orogen shows several generations of structural overprint (MILNES, 1974b; 1974a). Both the tectonic and metamorphic patterns in the Lepontine appear rather simple at first sight, concealing much of the complexity of their evolution. The nappe stack as a whole shows a central part which is relatively flat lying, despite two young, regional culminations (Ticino and Toce domes), whereas two steep belts delimit this central part both to the north and south. However, detailed studies of the structural evolution in several parts of the Lepontine nappe stack (e.g. northern Maggia-Lebendun: GRUJIC & MANCKTELOW, 1996; southern Simano-Adula: NAGEL et al., 2002b) indicate at least four phases of deformation, from early nappe-forming (D_1 and D_2; main schistosity and tight folds) to exhumation-related deformation, including the late-orogenic back-folding. Efforts to decipher the concomitant metamorphic evolution have recognized three discrete phases based on petrologic analysis and geochronology: (1) High-pressure assemblages of Eocene age are restricted to certain tectonic units; (2) a pervasive medium-pressure (Barrovian) overprint, connected with Oligocene nappe stacking, affected the Lepontine as a whole, postdates D_2 and either outlasted or was (locally) affected by D_3; (3) a far less pervasive, late-orogenic phase attained lower metamorphic grades, but was locally quite effective, notably related with hydrothermal fluids.

High-Pressure Relics in the Central Alps

a. Low- to medium-temperature HP rocks are found in several Middle- and South-Pennine units outside the Lepontine (amphibolite facies) belt, notably in the following:

- Several nappes, with different metamorphic patterns due to different tectonic histories, represent the Piemont-Ligurian domain in eastern part of the Central Alps. Regional metamorphic grade in these units was classically viewed (NABHOLZ, 1945) to increase from anchizonal conditions in the North (near Arosa, FERREIRO-MÄHLMANN, 1995) to biotite-greenschist facies to the south (Val Malenco, TROMMSDORFF & NIEVERGELT, 1983). However recent studies have recognized more complexity in the regional metamorphic distribution. In units mainly composed of mafic and ultramafic rocks (Arosa, Platta, Malenco), which have a thin Jurassic cover, overprinting under greenschist facies conditions only has been reported for the Alpine metamorphism dated between 70 and 100 Ma (PHILIPP, 1982; HANDY et al., 1996). On the other hand in the Avers unit, where the Piemont-Ligurian domain is mainly composed of Jurassic marbles and Cretaceous calcschists (equivalents to the Schistes Lustés in the Western Alps) with some MORB-type metabasalts, abundant evidence of HP metamorphism has been documented. Mineral assemblages such as Gln-Gt ± Ctd in metabasalts (OBERHÄNSLI, 1978), Gln-phengite in marbles, and Gt-Ctd in calcschists (WIDERKEHR, pers. com.) indicate Tertiary metamorphic conditions around 12 kbar and 400°C (RING, 1992a; 1992b). A major shear zone (Turba mylonite zone) separates Avers Bündnerschiefer from the Platta nappe (NIEVERGELT et al., 1996).
- To the East of the Lepontine, the Briançonnais microcontinent is reduced to two basement units (Tambo and Suretta nappes) and a metasedimentary nappe (Schams). The Tambo and Suretta nappes comprise polycyclic gneisses (NUSSBAUM et al., 1998) with Permian intrusives (Truzzo granite, Roffna porphyr) and monocyclic metasediments (strongly deformed and reduced Mesozoic series) – show Alpine assemblages which range from HP-greenschist / blueschist facies (in the N) to high-P amphibolite facies (in the S). Mineral assemblage data of blueschist facies conditions are scarce.

Phengite barometry yields P_{max} ~10-13 kbar (at T ~400°C in the N, ~550°C in the central part, BAUDIN & MARQUER, 1993; RING, 1992a) for the Tambo nappe, and 9-12 kbar (at 400-450°C, CHALLANDES, 1996; NUSSBAUM et al., 1998) for the Suretta nappe. However newly "rediscovered" occurrences of porphyroblasts of Ctd and Gt (STAUB, 1926, WIDERKEHR pers. com.) in Carbonifero-Permian cover of the Suretta nappe seem indicate that the previous estimates are only minimum conditions. In the Schams nappes, consisting mainly of limestones and breccias, the characteristic assemblage Phe-Chl-Qtz-Ab-Cal-Stp-Ep indicates lower greenschist facies metamorphism, with temperatures around 300-400°C (SCHREURS, 1995). However, according to their structural position (SCHMID et al., 1996), the Schams is likely to have experienced metamorphic conditions similar to those of the Tambo and Suretta nappes, i.e. blueschist facies between 45 and 50 Ma (CHALLANDES et al., 2003).

- Valaisan units (North Pennine Bündnerschiefer) to the NE and NW of the central Lepontine belt: A large volume shaly-calcareous-terrigenous sediments, is outcropping in northern Graubünden, i.e. at the northeastern border of the Lepontine dome. Here the Bündnerschiefer can be separated into two nappes, the Grava nappe below and the Tomül nappe above (STEINMANN, 1994). The main body of Bündnerschiefer was deposited in Cretaceous times (STEINMANN & STILLE, 1999) until the late Eocene (BAGNOUD et al., 1998). Basaltic intercalations of MORB composition (DÜRR et al., 1993; STEINMANN & STILLE, 1999) within Bündnerschiefer metasediments indicate that the Valaisan is floored by oceanic crust (TRÜMPY, 1980).

Bündnerschiefer north and south of Thusis contain the typical mineral assemblage Ms + Pg + Na, K-mica + Chl + Qtz + Cal + organic matter ± Alb ± Dol (THUM & NABHOLZ, 1972). The same assemblage is also predominant in the Piz Aul area in front of the Adula nappe (KUPFERSCHMID, 1977) as well in Grava and Tomül nappes (STEINMANN, 1994; RAHN et al., 2002). Based on this, the metamorphic conditions experienced by Bündnerschiefer of northern Graubünden were generally interpreted as greenschist conditions. Rather than a metamorphic climax, these occurrences represent a strong retrograde overprint. Indeed, indications of an earlier high-pressure and low-temperature metamorphism have been found within the Bündnerschiefer as well within metabasaltic rocks. (Fe, Mg)-carpholite occurs as relic hair-like micro-fibres, included in quartz of quartz-carbonate segregations (GOFFÉ & OBERHÄNSLI, 1992) and chloritoid occurs within the rocks (OBERHÄNSLI et al., 1995). Glaucophane occurrences in the ophiolites are well known (OBERHÄNSLI, 1978; HEIM & SCHMIDT, 1891; NABHOLZ, 1945), but in contrast to the Engadine window, the Na-amphibole (OBERHÄNSLI, 1986) is richer in Mg and Fe^{3+} (Vals valley).

For carpholite-bearing rocks devoid of chloritoid, calculated pressures range from 10 to 12 kbar and temperatures from 350 to 375°C, whereas for carpholite + chloritoid-bearing rocks, temperatures estimated from the Fe-Mg partitioning between chloritoid and chlorite range from 360 to 400°C, and pressures estimated range from 12 and 14 kbar (BOUSQUET et al., 2002). In the HP metamorphic unit, two types of P-T paths are observed. In the (Fe, Mg)-carpholite zone without chloritoid where the carpholite fibers are well preserved, maximum P-T conditions are ~11-12 kbar and 350°C (BOUSQUET et al., 1998). The preservation of carpholite and the absence of imply a decompression path that did not cross the equilibrium.

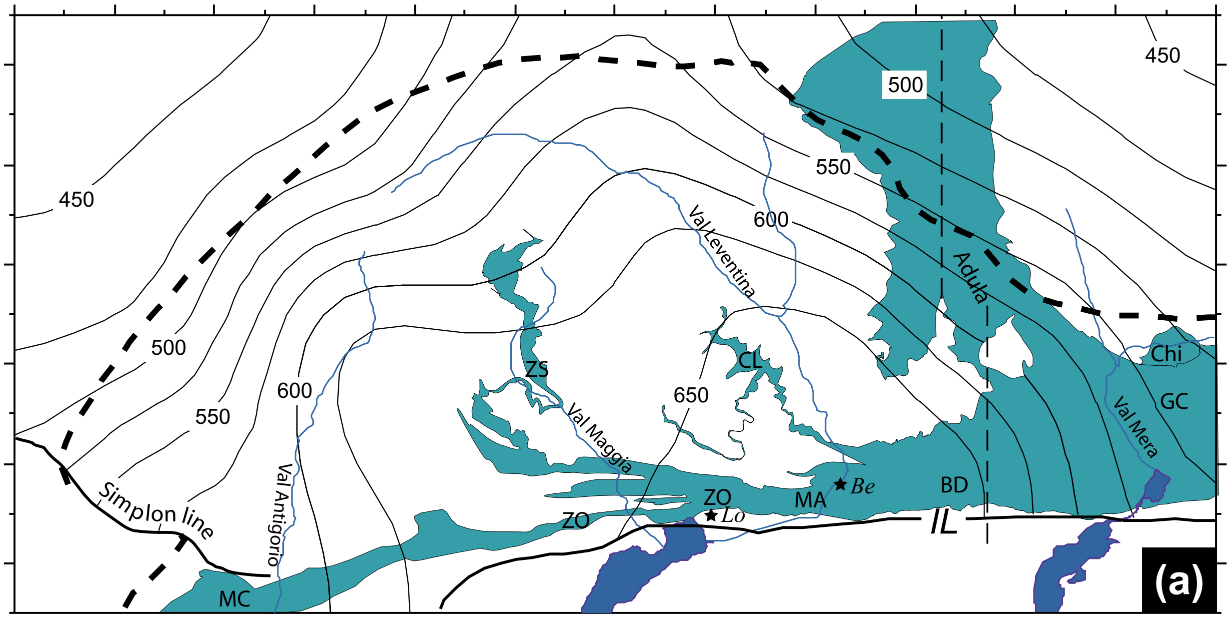
The retrograde P-T path must have been cold and fast enough to metastably preserve carpholite but not aragonite (GILLET & GOFFÉ, 1988). In addition, partially replaced carpholite occurs in association with chloritoid, implying a warmer decompressional P-T path. Associated with these blueschists, eclogite (with P > 12 kbar at T ~510 ± 50°C) is known from a single locality in the (southernmost) Misox Zone (OBERHÄNSLI, 1994).

These calculated P-T conditions confirm an increase in metamorphic grade from the northeast to the southwest, as reported by NABHOLZ (1945).

- Where these accretionary wedge sequences attained amphibolite facies conditions, i.e. in the central Lepontine area, HP-assemblages have not been found so far. However, such assemblages ((Fe, Mg)-carpholite – chloritoid) have recently been discovered both to the east (OBERHÄNSLI et al., 2004) and west of the Lepontine amphibolite facies region, hence it seems likely that these had existed also in the central portion prior to the strong Barrovian overprint.

b. Alpine eclogite facies remnants in the central Lepontine area appear to be restricted to tectonic mélange units. They are isolated occurrences in a belt that includes relics of variegated high grade metamorphism, from granulite facies to eclogite to (typically HP) amphibolite facies. Collectively these are thought to represent remnants of a tectonic accretion channel (TAC: ENGI et al., 2001), which had developed along the convergent plate boundary during Alpine subduction, collision, and extrusion. Classic eclogite (and garnet peridotite) localities (TROMMSDORFF, 1990) are in the Adula nappe (e.g. Trescolmen) and the Cima Lunga unit (e.g. Gagnone), but we have recently found eclogite relics in several additional units, including the Mergoscia-Arbedo zone and the Someo-Orselina zone. All of these TAC units (Fig. 2) constitute tectonic mélanges, i.e. highly deformed and imbricated slices of various gneiss types, trails of clastic metasediments with lenses of marble, sparse ultramafic rocks, and dismembered mafic rocks. The metamorphic grade varies greatly within and between the different TAC units, and the patterns are far from fully understood. For example, a regional PT-gradient (HEINRICH, 1986; MEYRE et al., 1997; 1999) is evident in the Adula nappe, with eclogite stage conditions increasing from the north (1.0-1.5 GPa at 500 ± 50°C) to the south (3.0-3.6 GPa at 800-900°C). Although the Adula nappe is made up of an imbricated series of thin slices, at least the northern and central parts shows a consistent metamorphic field gradient of 20 ± 5 MPa/km and 9.6 ± 2.0°/km over the frontal 25 km of the nappe (DALE & HOLLAND, 2003). This field gradient links Eocene HP-assemblages formed within the TAC, which was dipping ~45°S, and this terrane apparently behaved as a coherent tectonic unit along the exhumation path.

Metagabbroic kyanite eclogite and metabasaltic eclogite fragments occur in other TAC units as well, and PT-conditions show substantial variation among individual HP-fragments (Fig. 3), both in their P_{max} and the decompression-cooling paths they experienced (ENGI et al., 2001; BROUWER & ENGI, 2004). Internal mobility within the TAC during its extrusion is also evident in the southern parts of the Adula nappe, based on structural and petrological data (NAGEL et al., 2002b; DALE & HOLLAND, 2003). Most prominent among the HP-fragments are the classical localities of Cima di Gagnone and Alpe Arami which belong, respectively, to the Cima Lunga unit and the Mergoscia-Arbedo zone. Whereas metarodingites show a serpentinization stage prior to the HP-metamorphism for the former (EVANS & TROMMSDORFF, 1978; PFIFFNER & TROMMSDORFF, 1997), this is not the case for any of the HP-bodies known within the latter.



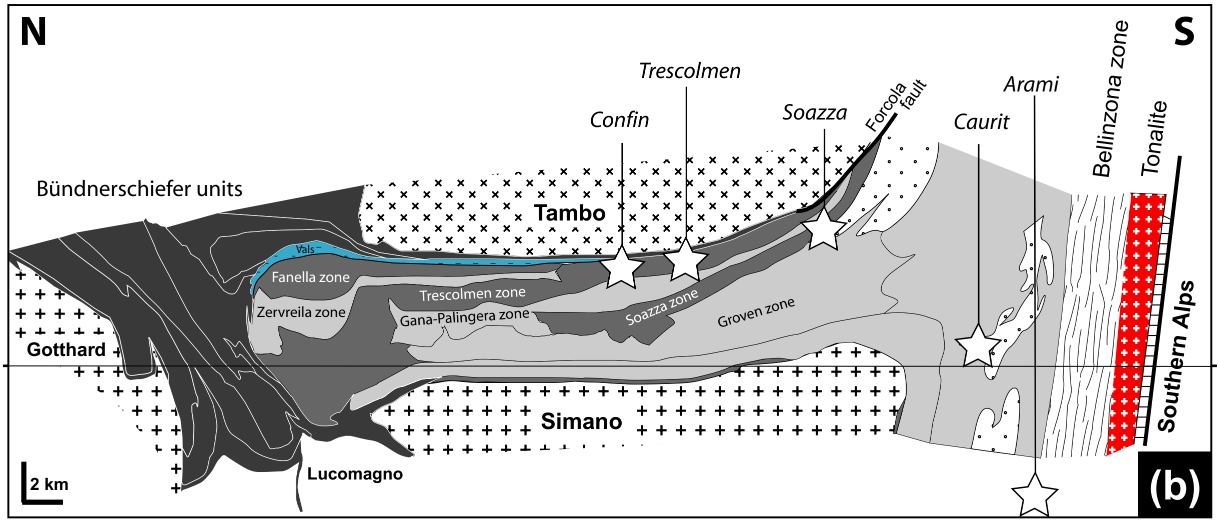


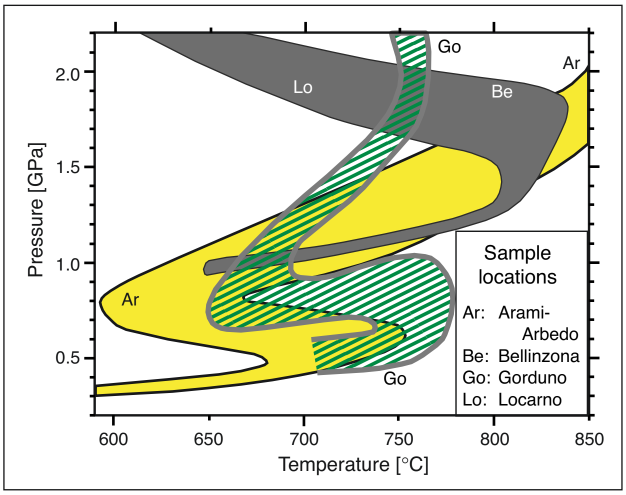
Fig. 2a

Map of the tectonic mélange belt in the Central Alps interpreted to represent a portion of the tectonic accretion channel (TAC). Labels refer to some of the more prominent subunits of this belt classically mapped as individual "zones" (BD: Bellinzona-Dascio zone, CL: Cima Lunga unit, CM: Camughera-Moncucco unit, GC: Gruf complex, Chi: Chiavenna ophiolite, MA: Mergoscia-Arbedo zone, ZS: Someo zone, ZO: Orselina zone; stars mark some towns; Be: Bellinzona; Lo: Locarno). Trace of synthetic profile for Fig. 2b and isotherms from Fig. 4b are also shown.

Fig. 2b

Schematic Profile through the central Lepontine Alps. The classic Adula thrust sheet is a nappe-shaped body comprising a number of these zones (various shades of grey). Internal slices in the Adula nappe after JENNY et al. (1923), KÜNDIG (1926), and NAGEL et al. (2002). Occurrences of relic eclogites (stars indicate some of the localities) are restricted to the TAC. Its internal structure is outlined, with mapped zones representing slices of imbricated mélange sheets, each comprising a distinct spectrum of rock types. Eclogite relics are missing in the basal part of the Adula nappe, which is thus tentatively separated from the TAC zones in the upper part. Bündnerschiefer units comprise several slices (after LÖW, 1987) of the Alpine accretionary prism.

Fig. 3
P-T paths documented for various lenses within the TAC (BROUWER, 2000; TÓTH et al., 2000; ENGI et al., 2001; GRANDJEAN, 2001; NIMIS & TROMMSDORFF, 2001; BROUWER & ENGI, 2004). The HP-route documented for each body may differ substantially from those of nearby lenses, but their P-T paths converge at mid-crustal levels, indicating a fairly uniform (coherent ?) exhumation of the TAC during its final emplacement.



Some authors have suggested UHP (ultra-high pressures) for the early evolution of garnet peridotite from Alpe Arami (DOBRZHINETSKAYA et al., 1996: > 300 km; BRENKER & BREY, 1997: > 5 GPa; BOZHILOV et al., 1999: > 8 GPa; OLKER et al., 2003: 5.9 GPa, 1180°C), whereas others derived conditions (e.g. NIMIS & TROMMSDORFF, 2001: 3.2 GPa, 840°C) much more in line with those found for other Alpine garnet lherzolite and associated eclogite lenses from the southern parts of the TAC (e.g. NIMIS et al., 1999: 3.0-3.2 GPa, 740-840°C). The controversy regarding the highest pressures is unresolved at this time. It is possible (but not clear) that the reported UHP conditions may document an early stage within the Mantle. Since comparable pressures have neither been reported for associated eclogites nor metapelites (and no coesite or diamond relics have been found to date), Arami may not be a relevant constraint the esimate the maximum depth reached by the TAC.

The central portion of the mélange unit interpreted to represent an Alpine TAC (shown as a variegated facies unit on the Map of Alpine Metamorphism), is definitely delimited from the Pennine nappes adjacent to the north. Towards the eastern and western boundary of this belt, the separation is more tentative at this time. The TAC does not appear to extend beyond the Bergell intrusive sheet in the E, but the Gruf unit (with Alpine granulite facies relics) and Chiavenna ophiolite are interpreted as belonging to the TAC. Similarly, in the W the Monte Rosa nappe is a definite limit, but the Antrona and Moncucco-Camughera units are tentatively considered to be part of the TAC.

c. Age constraints for the HP-stage in the Central Alps show that Early Tertiary closure of the Piemont-Ligurian basin lead to accretion of a sedimentary wedge (South Pennine Bündnerschiefer) during the Paleocene, with subduction of the Briançonnais microcontinent following by early Eocene. The Tambo and Suretta terranes were welded to Apulia, and a coherent TAC formed in their footwall during the subsequent closure (50-47 Ma, SCHMID et al., 1996) of the Valais basin, where sedimentation continued into the Eocene (LIHOU, 1995; 1996). Eclogite formation (FROITZHEIM et al., 1996) in TAC units was initially dated between ~43-36 Ma for fragments from both Arami and Gagnone (BECKER, 1993; GEBAUER, 1996; 1999), but recent data for other fragments in the Central Alpine TAC indicates eclogite facies conditions in an age range from ~55 to 35 Ma (BROUWER et al., 2003a; 2003b). Exhumation from depths of >100 km to the Barrovian overprint (25-15 km) by 32 Ma implies a short time interval for the very rapid extrusion of parts of the TAC to mid-crustal levels.

The Oligo-/Miocene Lepontine Belt

A relatively simple zonal pattern in the metamorphic field gradient (Fig. 4a) has long been recognized in the Lepontine Alps. Mineral zone boundaries and metamorphic reaction isograds (see recent review by FREY & FERREIRO MÄHLMANN, 1999) outline a classical Barrovian belt. Conditions range from anchimetamorphic – in the northern, most external parts of the orogen – to sillimanite-Kfsp / grade in the southern, most internal portion of the dome. Abundant late-orogenic migmatites occur within the Southern Steep Belt. Immediately to the South of this shear belt, the core part of the Alpine orogen is truncated by the Insubric Line, separating the Central Alps from the Southern Alps. The latter show but incipient Alpine metamorphism.

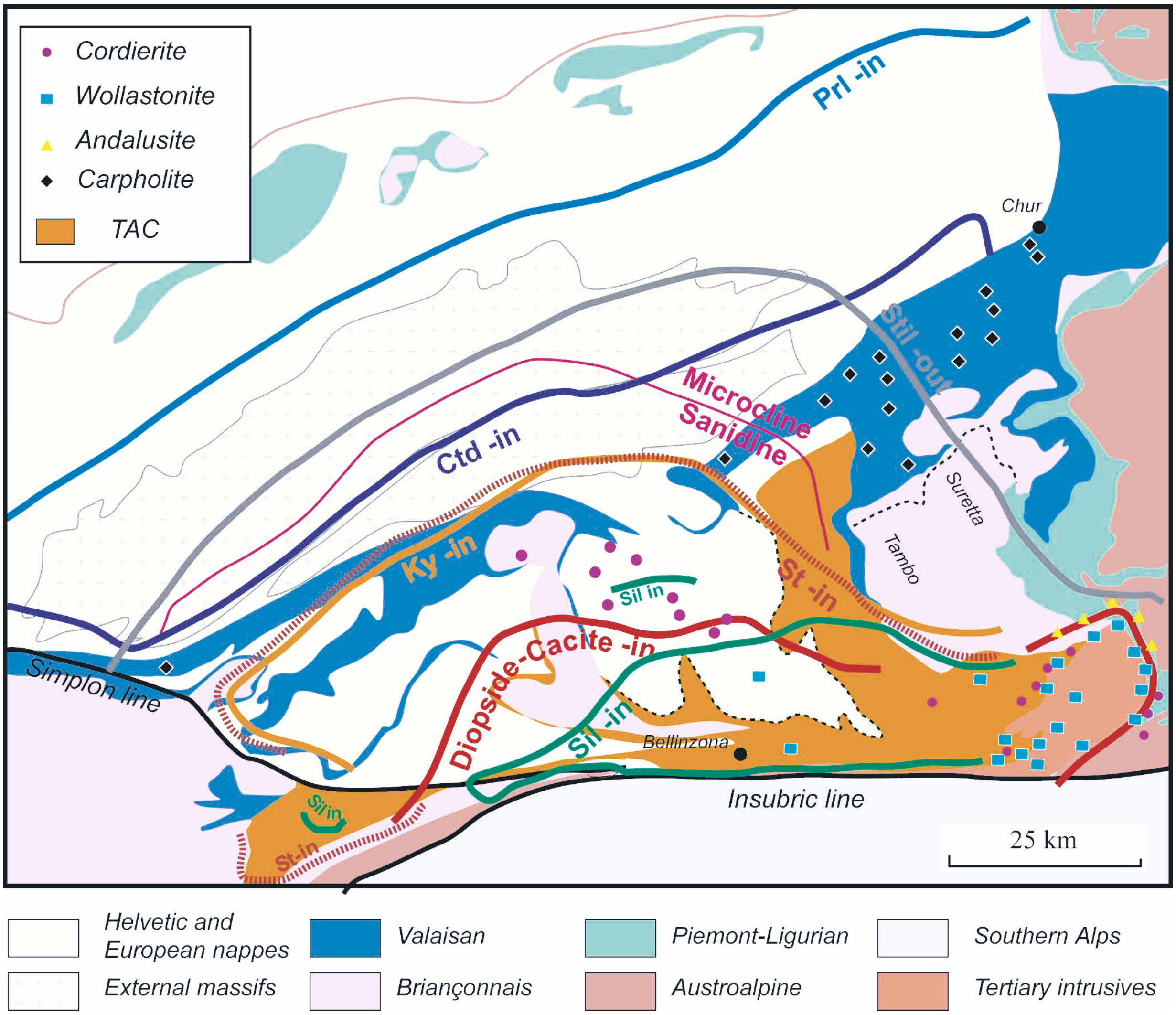


Fig. 4a
Select isograds (solid curves) and mineral zone boundaries (dashed curves) of Alpine metamorphism in the Central Alps. Updated from FREY & FERREIRO MÄHLMANN (1999), based on NIGGLI & NIGGLI (1965), TROMMSDORFF (1980), BERNOTAT & BAMBAUER (1982), IROUSCHEK (1983) and FREY (1987); with additions from KELLER (2004) and data on Mg-Fe carpholite from GOFFÉ & OBERHÄNSLI (1992) and BOUSQUET (unpubl.). SF: Simplon fault, CF: Centovalli fault.

A wealth of detail has been established regarding the metamorphic overprint in the Central Alps, manifested by Barrovian mineral zones of stilpnomelane, chloritoid, staurolite and kyanite, as well as (fibrolitic) sillimanite (NIGGLI & NIGGLI, 1965; FREY & FERREIRO MÄHLMANN, 1999). It should be noted that the first appearance of any one of these aluminous phases does not reflect one specific irreversible reaction, and such a mineral zone boundary thus does not constitute a metamorphic isograd sensu stricto.

For example, in the Adula and Simano nappe, NAGEL et al. (2002a) showed that several paragonite breakdown reactions lead to the appearance of staurolite (as well as kyanite and sillimanite), whereas in the Lucomagno area, FREY (1974) found staurolite to grow at the expense of chloritoid. The former reactions took place during (±isothermal) decompression, the latter along a prograde burial path. Nevertheless, at least the medium and upper amphibolite facies, mineral zone boundaries for metapelites and ultramafic rocks (TROMMSDORFF & EVANS, 1969; 1974; NAGEL et al., 2002a) do outline a zonal pattern which corresponds rather closely to proper mineral (reaction) isograds, such as tremolite-calcite and diopside-calcite mapped for siliceous dolomite marbles by TROMMSDORFF (1966).

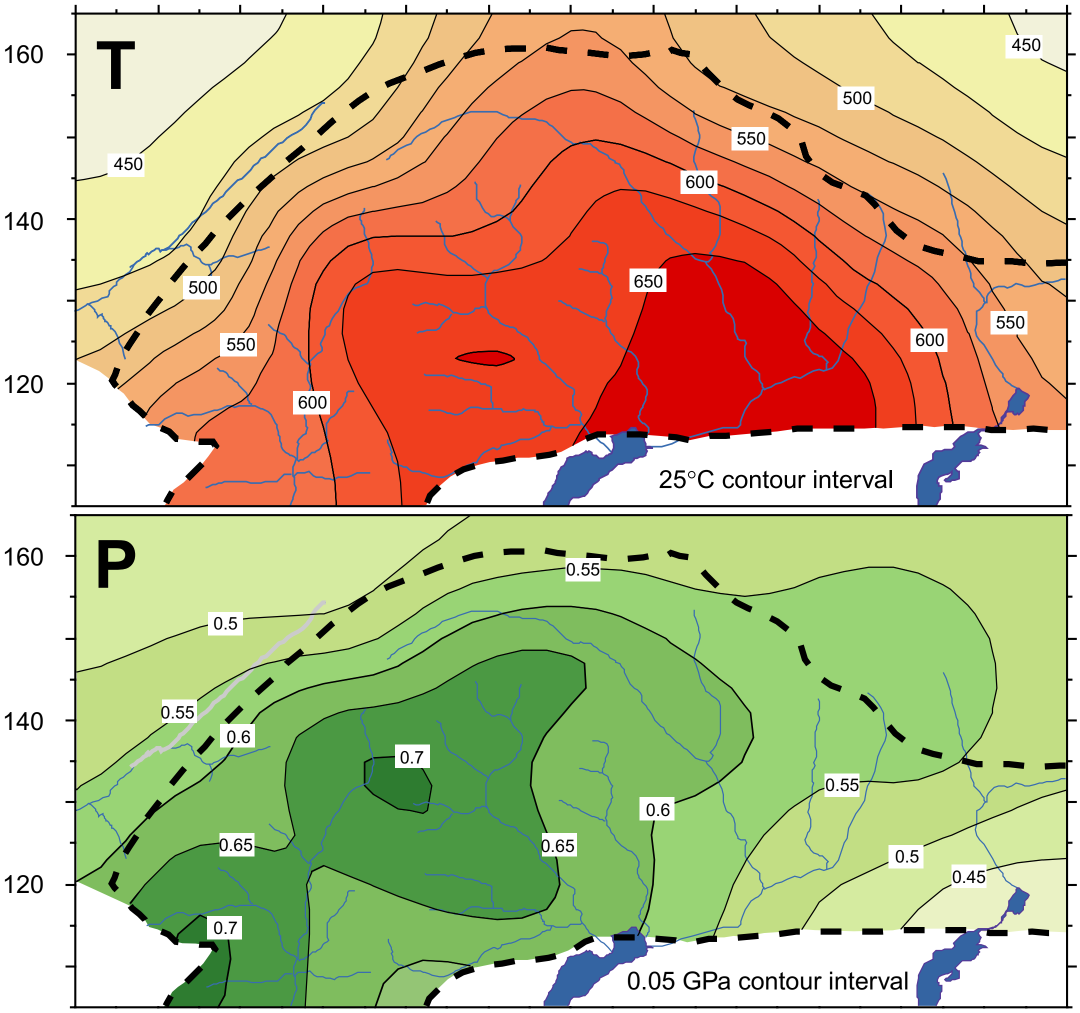


Fig. 4b/c

Map of isotherms and isobars for the Barrovian overprint in the Lepontine (updated from ENGI et al., 1995; TODD & ENGI, 1997), reflecting conditions near T_{max} and $P_{(T_{max})}$.

The regional thermal and baric structure of the Lepontine belt (Fig. 4b/c), combined with recently determined PTt-paths from several tectonic units and mineral age data, indicate that the mid-Tertiary overprint which produced the Barrovian structure was diachronous by about 7 My. The thermal peak was first reached in the Southern Steep Belt, about 28 Ma ago, at pressures of 0.5-0.55 GPa only. During this late stage of decompression, fluid-assisted partial melting occurred (BURRI, 2004), producing up to ~30 vol-% leucosomes, which are variably deformed (by D_3 backfolding). Intrusive ages for the Novate stock, a small S-type granite that segregated late-stage partial melts, provide another age constraint for the migmatisation (~24 Ma, LIATI et al., 2000). This magmatism is distinct from and clearly postdates the intrusion of the Bergell granodiorite and the associated tonalite sheet (VON BLANCKENBURG, 1992; OBERLI et al., 2004). In units further to the north, i.e. the central parts of the Lepontine, the thermal peak appears to have been reached at successively later times, between 26 and ~21 Ma ago, but here the thermal climax was reached at greater depths (P = 0.6-0.75 GPa). At the northern margin of the Lepontine amphibolite facies belt, T_{max} and P(at T_{max}) are lower (Fig. 2), but the age pattern remains unclear (HUNZIKER et al., 1992; ENGI et al., 1995). Ages between 42 and 16 Ma have been reported on the basis of different mineral chronometers, and it seems likely that these represent a mix of signals (and noise) recorded over 2-3 stages of evolution, i.e. the early HP phase (?), a prograde medium-pressure subduction phase, and the Barrovian overprint following emplacement of the TAC units and final exhumation of the nappe stack.

During this progressive exhumation process (NAGEL et al., 2002b) TAC-units with an ealier eclogite facies imprint were variably overprinted under amphibolite facies conditions (e.g. HEINRICH, 1982; MEYRE et al., 1999). The extent of this overprint was strongly dependent on the availability of hydrous fluids and localized deformation. Tectonic fragments now contained in the TAC-units in many cases show no early HP segment in their PT-paths, whereas nearby lenses differ strongly in the P_{max} and/or T(at P_{max}) they recorded (ENGI et al., 2001; NAGEL et al., 2002b), it is difficult to infer at what stage the accretion channel consolidated to a coherent tectonic unit. While much remains to be investigated, it certainly appears from the tectonic location and internal characteristics of this mélange unit that it played a crucial role in the tectono-metamorphic evolution of the Central Alps. Thermal modelling (ROSELLE et al., 2002) indicates that the relatively high temperatures reached during the regional Barrovian metamorphism can be explained by considering the dominantly upper crustal contents of the TAC, which in the Central Alps has an average heat production of 2.67 μW m^{-3}. Recent reports (ÁBALOS et al., 2003; LÓPEZ SÁNCHEZ-VIZCAÍNO et al., 2003) indicate that tectonic elements of similar character as the Alpine TAC are important in other collisional belts as well.

In the section of Lepontine between Valle Mera and Locarno, the Southern Steep Belt of the Central Alps is terminated to the south by the Insubric Line, and TAC units, in part intruded by the Bergell tonalite sheet, form the limit to the Southern Alps. To the West of Locarno, however, the Insubric Line swings SW, whereas the Steep Belt continues in a westward direction, being cut in part by the Centovalli Line, an important late-orogenic E-W lineament with largely brittle character. In between the southernmost TAC-units and the Insubric Line two thrust sheets emerge, the Monte Rosa and the Sesia nappe, gaining in thickness towards the west. The Barrovian overprint in units south of the Centovalli Line rapidly decays, and the transition from greenschist facies to amphibolite facies runs nearly E-W.

However, in contrast to areas in the SSB east of Locarno the tectonic units lying immediately south of the TAC units do show Barrovian overprint. Quenching of the heat advected by the Central Alpine belt was directly against the Southern Alps in the eastern section, but against the Sesia and Ivrea bodies in the western section of the SSB. The spacing of isotherms (Fig. 4b) gets notably much wider in the west. This is likely to reflect the dextral transpressional exhumation, during which the the southern block was successively heated by the hottest portion of the northern block and, as the transfer of heat from the hot Central Alpine block to the cool southern block was most effective initially, leading to rapid quenching in the eastern part of the Central Alps, whereas the thermal quench was less pronounced in their western portion. This topic is further elaborated in the chapter by BOUSQUET et al. (2004).

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