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EXPLANATORY NOTES TO THE MAP: METAMORPHIC STRUCTURE OF THE ALPS TRANSITION FROM THE WESTERN TO THE CENTRAL ALPS

by

Romain Bousquet[1], Martin Engi[2], Guido Gosso[3], Roland Oberhänsli[4], Alfons Berger[2], Maria Iole Spalla[3], Michele Zucali[3] & Bruno Goffè[5]

[1]Department of Earth Sciences
University of Basel, Bernoullistrasse 30, CH-4056 Basel, Switzerland
[2]Institute of Geological Sciences
University of Bern, Baltzersstrasse 1-3, CH-3012 Bern, Switzerland
[3]Dipartimento di Scienze della Terra
Università di Milano, Via Manggiagalli 34, I-20133 Milano, Italy
[4]Institut für Geowissenschaften
Universität Potsdam, Karl-Liebknecht-Str. 25, 14476 Potsdam-Golm, Germany
[5]Laboratoire de Géologie
UMR 8538, CNRS, Ecole Normale Supérieure, 24 rue Lhomond, 75005 Paris, France

The northern-western Alps, located between two major tectonic structures, the Simplon and the Aosta-Ranzolla faults, represent a "transition" zone where all paleogeographic domains involved within the alpine orogenic wedge are present and clearly distinguishable on a map (e.g. BIGI et al., 1990; SCHMID et al., 2004). The structural style and metamorphic record in the area linking the West and South-West Lepontine to the Western Alps has particular characteristics, which warrant this separate chapter. This concerns the Lepontine zone from just East of Valle d'Ossola to the western limit set by the continental Bernhard nappe system in the North-West, the ocean-derived Piedmont-Ligurian zone and its prolongation to the west (Préalps), as well continental units issued either from the Adriatic continent domain (Sesia and Dent-Blanche massifs) or from the European margin (Mt Blanc massif).
All units will be described after that from east to west following Figure 1, while structural relationship between different units is described in details in SCHMID et al. (2004).

Sesia zone

The Sesia Zone (SZ) of the western Austroalpine is a huge portion of Alpine continental crust widely recording alpine eclogite-facies assemblages. For the very first time it was possible to demonstrate that even granites were brought outside the stability field of plagioclase and recrystallized under eclogite facies conditions (DAL PIAZ et al., 1972; COMPAGNONI & MAFFEO, 1976; COMPAGNONI et al., 1977; LARDEAUX et al., 1982; OBERHÄNSLI et al., 1982).

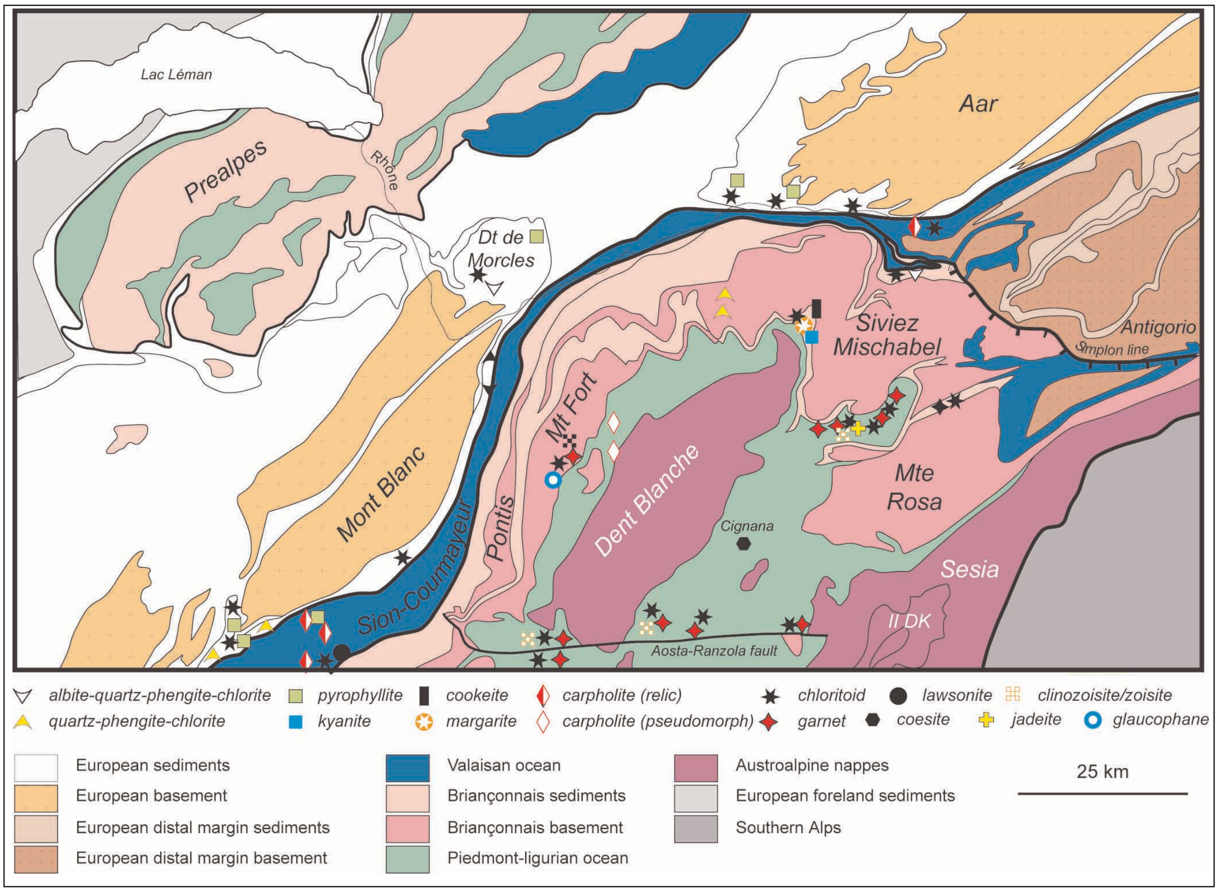

Figure 1

Structural map of the "transition" area between the Simplon line and the Aosta-Ranzola fault (after BIGI et al., 1990; SCHMID et al., 2004) displaying occurrences of metamorphic index mineral indicating greenschist, blueschist and eclogites metamorphic conditions observed in Mesozoic Alpine metasediments.

The Sesia Lanzo zone consists of an upper and a lower unit: the lower unit comprises the Gneiss Minuti Complex (GMC) and the Eclogitic Micaschists Complex (EMC), whereas the upper unit is constituted by the II Dioritic-Kinzigitic Zone (IIDK and Vasaro units; e.g. COMPAGNONI et al., 1977; POGNANTE et al., 1987). The upper unit is characterised by high-pressure blueschist mineral assemblages and its contact with the lower unit is marked by mylonitic belts, developed under eclogite or blueschist facies conditions (LARDEAUX et al., 1982; POGNANTE et al., 1987) and later overprinted by greenschist facies mylonites (RIDLEY, 1989; STÜNITZ, 1989). In the central and southern part of the lower unit, the alpine evolution is characterised by a LT eclogite imprint, following by a blueschist re-equilibration during the decompression (e.g. CASTELLI, 1991; POGNANTE, 1991 and references therein), and then by a low-pressure greenschist facies overprint (OBERHÄNSLI et al., 1985). Gneiss Minuti Complex and Eclogitic Micaschists Complex, both pervasively eclogitized, strongly differ in the volume percentage of greenschist retrogression. The Gneiss Minuti Complex, is widely re-equilibrated under greenschist facies conditions. This greenschist imprint is generally associated to mylonitic textures (STUENITZ, 1989; SPALLA et al., 1991). On the other hand, in the Eclogitic Micaschists Complex, which constitutes the innermost part of the Sesia Zone, the greenschist facies overprint is confined to discrete shear zones, more pervasively developed towards its inner boundary with the Southern Alps.

The Alpine structures are crosscuting by calc-alkaline and ultrapotassic dykes during Oligocene (DAL PIAZ et al., 1972, 1979). In the southernmost part of the massif, some thrust sheets, the metamorphic complex of Rocca Canavese thrust sheets, display mineral assemblages indicating blueschist facies conditions (POGNANTE, 1989a; 1989b). These thin tectonic slices are separated from each other by alpine blueschist mylonitic horizons. These differences in mineralogical occurrences could be interpreted either as an effect of the chemical composition of the rocks (RUBIE, 1986; RIDLEY, 1986) or by different metamorphic evolution. In this latter case, the coupling of EMC, GMC and RCT units is interpreted to have occurred in blueschist facies conditions, synchronous with the early exhumation stages of the Eclogitic Micaschists Complex (POGNANTE, 1989b). In the northern part of the Sesia zone SLZ, the lower unit display mineral assemblages indicating upper blueschist facies conditions similar to those of the upper (IIDK) unit.

The very low T/P ratio, characterising the SLZ Alpine metamorphic history, favours preservation of pre-Alpine relic assemblages in spite of several a strong greenschist overprint. This ancient granulite to amphibolite evolution could be interpreted as consequent to a lithospheric extension-related uplift of the pre-Alpine lower crust, during Permo-Triassic times (DAL PIAZ, 1993; LARDEAUX & SPALLA, 1991; REBAY & SPALLA, 2001).

Piedmont-Ligurian unit

The Piedmont-Ligurian zone in the north of the Western Alps is classically divided into two units, the Tsaté nappe (or Combin zone) and the Zermatt-Saas nappe (e.g SARTORI & THÉLIN, 1987; DAL PIAZ, 1999 and references therein), separated by a major extensional fault (BALLÈVRE & MERLE, 1993; REDDY et al., 2003). The distinction between both units was based both on lithostratigraphic (BEARTH, 1962; MARTHALER, 1984; MARTHALER & STAMPFLI, 1989) and on metamorphic differences (DAL PIAZ, 1965; KIENAST, 1973; CABY et al., 1978).
The lowermost unit, the Zermatt-Saas nappe, is composed mainly of mafic and ultramafic ophiolites, displaying an oceanic affinity. Since the famous BEARTH'S work, this nappe is well known for its high-pressure mineral assemblages (BEARTH, 1967; ERNST & DAL PIAZ, 1978; CHINNER & DIXON, 1973). The discovery of coesite inclusions within garnet in some Mn-bearing metasediments in Lago di Cignana suggests that some piece of the Piedmont-Ligurian were deeply subducted up to 28 kbar at 600°C (REINECKE, 1991). The most eclogites of the Zermatt-Saas nappe display high-pressure mineral assemblages formed by omphacite-garnet-chloritoid-talc-zoisite or omphacite-garnet-kyanite-clinozoisite ± talc (OBERHÄNSLI, 1980; BARNICOAT & FRY, 1986; GANGUIN, 1988). The eclogites are strongly retrogressed into epidote amphibolites ± garnet toward the contact with the uppermost unit in the West.

The uppermost unit, the Tsaté nappe, is an ophiolitic unit dominated by carbonate and terrigeneous calcschists, alternating with tholeiitic metabasalts. The lack of eclogites and relics of sodic amphiboles in metabasites (DAL PIAZ & ERNST, 1978; AYRTON et al., 1982; SPERLICH, 1988) as well in Mn-rich quartzitic schists associated with Mn-rich garnets (DAL PIAZ, 1979b; CABY, 1981) have been led to consider the Tsaté nappe to have overall the same metamorphic evolution, both western and eastern of the Dent-Blanche. However the ground of metasediments shows a metamorphic gradient from west to east (Fig. 1).

Calcschists and other terrigeneous sediments display pseudomorphs after carpholite (PFEIFFER et al., 1991) in the west and relics of garnet, Mg-rich chloritoid and phengite assemblages in strongly retrogressed albite-rich metapelites in the east at the contact with eclogites of the Zermatt-Saas nappe.
At the base of the Tsaté nappe occur discontinuous exotic sheets of continental origin (Cime Bianche and Frilihorn units) displaying jadeite-quartz-phengite mineral assemblages (SCHAUB, pers. com.).

The western end of the Lepontine dome and the Monte Rosa

The western culmination of the Lepontine Alps (i.e. the Toce dome) emparts a westerly axial plunge to the Pennine nappe stack. This results in successively higher thrust sheets being visible at today's erosional level, from the lowest Penninic gneiss units (e.g. Antigorio nappe) up to the Austroalpine Dent Blanche nappe appearing at the top, some 50 km further west. The nappe system is polydeformed and cut by the late orogenic (D4) Simplon fault, running to the NW from Valle d'Ossola to Simplon Pass. Tectonic unroofing by this major ductile/brittle normal fault (MANCKTELOW, 1985) brought the high grade Lepontine belt into a position opposite the greenschist facies Grand St-Bernard nappe system. The NW-part of the Simplon line marks the western limit of the Central Alpine amphibolite facies. In the Simplon area this Barrovian overprint has been dated at ~30 Ma (garnet growth in metaclastics, VANCE & O'NIONS, 1992). By contrast, in the area W and SW of Domodossola the Barrovian amphibolite facies/greenschist facies boundary crosscuts all major tectonic boundaries, and the medium pressure overprint is the sequel of an earlier (Eocene) HP-history. Decompression stages dated between 38 and 32 Ma in the western Monte Rosa nappe, but as young as 26 Ma in its eastern section (ENGI et al., 2001b), can be linked with the evolution in the Moncucco-Camughera unit, where KELLER (2004) showed the Barrovian reequilibration to be associated with D3 backthrusting (top-WSW) and dextral shearing at amphibolite facies conditions. These are responsible for the sillimanite and staurolite zone boundaries shown in (Fig. 2); as in the eastern TAC units (NAGEL et al., 2002; ENGI et al., 2004) these Al-phases were formed at the expense of paragonite and phengite during decompression (at P ~ 1.1-0.8 MPa), but with no evidence of a heating spike (KELLER, 2004). In the upper parts of the Monte Rosa nappe and westerly adjacent units, the decompressional Barrovian overprint reached only greenschist facies, as shown already by BEARTH (1958) who mapped the albite/oligoclase isograd (Fig. 2).

The geometry of the metamorphic zone boundaries in the westernmost Lepontine and southerly adjacent nappes is remarkable, as it reflects (a) the rapid exhumation of the Pennine nappe stack of the Central Alps, and (b) the strong dextral transpression at their southern contacts. This lead to a far more rapid thermal quench in the eastern part of the Central Alps (in ENGI et al., 2004), with closely spaced isotherms as compared to the western part, where they are more widely spaced. The successive transfer of heat from the Central Alpine block is also reflected in the succession of isograds extending to the south of the Centovalli line, a ductile-brittle fault running from Locarno to Valle d'Ossola (Fig. 1), which evidently served as a major truncation surface in the late-Alpine exhumation history of the Central Alps.

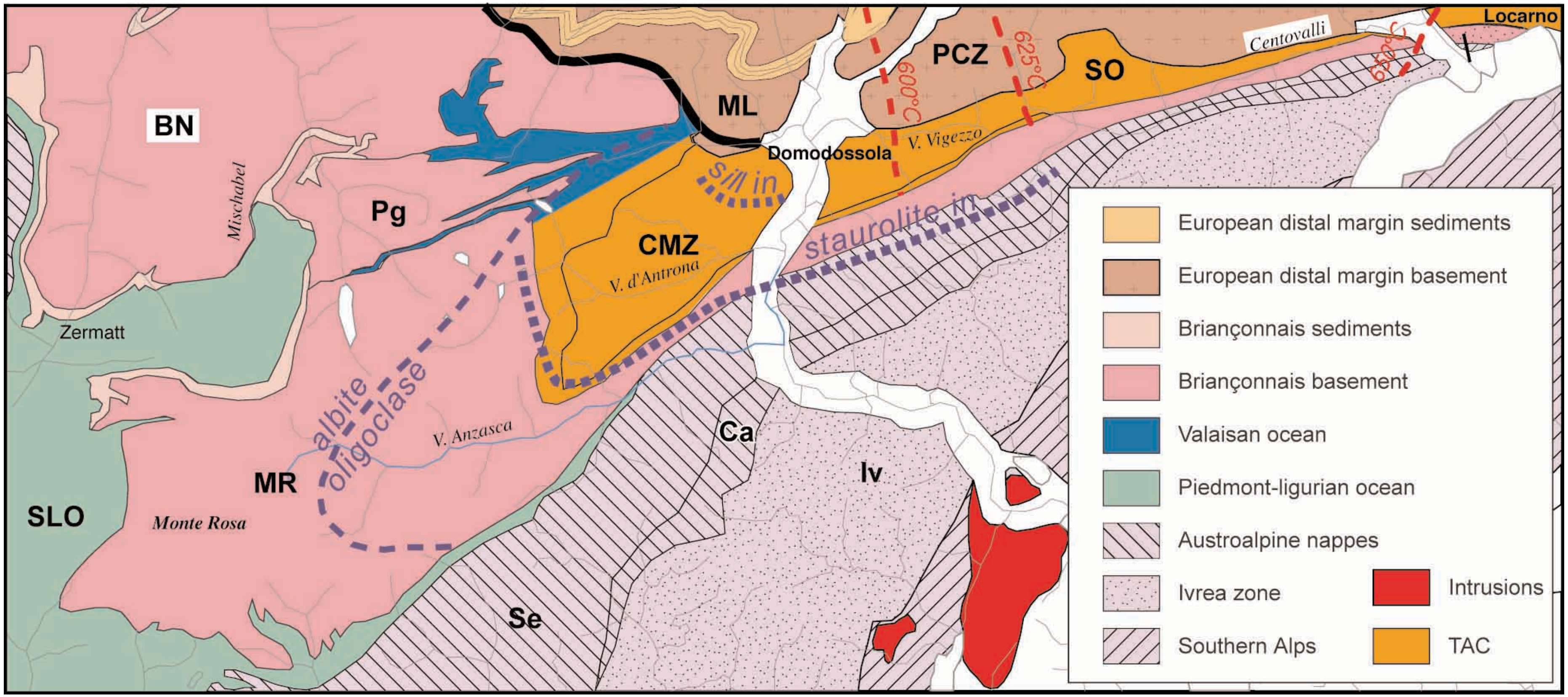

Fig. 2

Metamorphic elements in the transition zone from the Central Alps to the Western Alps, updated from ENGI et al. (2001b) using data from KELLER (2004).

Iv: Ivrea Zone, ML: Monte Leone nappe, MR: Monte Rosa nappe, Se: Sesia zone.

The Monte Rosa nappe and in its footwall neighbors (Camughera-Moncucco and Antrona unit) are tentatively considered to be part of the tectonic accretion channel (TAC, ENGI et al., 2001a). These TAC units reveal evidence of an ealier collisional HP phase which reached eclogite facies during D_1/D_2 decompressional deformation, with top to N or NW thrusting (KELLER, 2004). HP metamorphism has also been extensively documented from units further to the SW and W. Recent geochronological results, however, challenge the earlier views of a common eclogite stage for these two groups (e.g discussion in HANDY et al., 2004). It appears now that the classic "Eoalpine" stage (DAL PIAZ et al., 1972; HUNZIKER, 1974), which is Late Cretaceous according to more recent data (reviewd by DAL PIAZ, 1999) is restricted to units such as the Sesia-Lanzo zone (as well as units of the Western Alps s.s.), whereas the the Saas-Zermatt zone, Monte Rosa nappe, and underlying units reached eclogite facies during the Eocene (CHOPIN & MONIÉ, 1984 and summary in DAL PIAZ, 1999), with maximum pressures of 1.4-1.6 GPa at 500-550°C (BORGHI et al., 1996; ENGI et al., 2001b; KELLER, 2004). The last pre-Tertiary metamorphic imprint in the Monte Rosa nappe is not Cretaceous but Permian and yielded widespread low-P assemblages (BEARTH, 1952, PAWLIG & BAUMGARTNER, 2001).

Dent Blanche

The alpine metamorphic events in the Dent Blanche rocks are polyphase. The last major phase of metamorphism affecting all rocks of this unit produced mineral assemblages of the lower to upper greenschist facies. This greenschist facies event was preceded by subduction related high-pressure metamorphism. The rocks of the Dent Blanche nappe have been affected in various degrees by this event and the preservation of high-pressure indications is variable. Contrarily to the underlying eclogite facies rocks of the Zermatt-Saas Fee unit (BEARTH 1959, 1967), the Dent Blanche rocks only experienced epidote-blueschist facies or transitional alkali-amphibole greenschist facies conditions (BALLÈVRE & MERLE, 1993; CORTIANA et al., 1998). Sodic amphiboles were found in mylonites along the contacts of Permian Gabbros (STRØN, 1990) and in the northernmost part of the nappe (AYRTON et al., 1982). The gneisses of the Arolla series also contain relics of the Eo-alpine event. Thermobarometry with phengite+Kfsp+biotite+chlorite yields P-T conditions of 0.10 to 0.12 GPa and 350-400°C (OBERHÄNSLI & BUCHER, 1987; BUCHER et al., 2004). The rocks of the Valpelline series contain chloritoid and kyanite replacing sillimanite as indicators of a high-pressure phase (KIENAST & NICOT, 1971; DE LEO et al., 1987; CANEPA et al., 1990; PENNACCHIONI & GUERMANI, 1993). An early Alpine assemblage of glaucophane-crossite and aegirine-augite coexisting with phengite yielded an age of 75 Ma in the Pillonet klippe (CORTIANA et al. 1998).

The Briançonnais domain

The Briançonnais microcontinent in this part of the Alps, classically called Grand St-Bernard nappe system (LUGEON & ARGAND, 1905), consists of several units (see details in ESCHER, 1988; GOUFFON, 1993) that display different metamorphic evolution (THÉLIN et al., 1994). The major part, of the called Grand St-Bernard nappe system, formed by the Houillère zone and the Siviez-Mischabel unit, displays a metamorphic evolution within greenschist facies conditions.

The Siviez-Mischabel unit is characterized by an augen-schist horizon with albite mega-porphyroblasts that extends for hundred kilometres along the contact with the basement. Texture and mineralogy vary little in this horizon and indicate a synkinematic crystallization of albite porphyroblasts (SARTORI & THÉLIN, 1987).
In two units, one in the north (the Barrhorn series), one in the south (the Pontis unit), high-pressure greenschist mineralogy has been described. The Barrhorn series, located on the top of the Siviez-Mischabel unit, contains pockets of. The rock-forming minerals of the metabaxites are phengite, Zn-staurolite, kyanite, margarite, chloritoid, diaspore, paragonite ± cookeite (SARTORI, 1990; CHOPIN et al., 2003). Southward in the Pontis unit, pinched between the Houillère zone and the Siviez-Mischabel unit, micaschists contain neocrystallization of chloritoid ± kyanite (OULIANOFF & TRÜMPY, 1958) parallel to the main foliation (GOUFFON & BURRI, 1997). Paradoxically this is the uppermost unit of the Grand St-Bernard nappe system, the Mont Fort unit that display the deepest evolution into high-pressure metamorphic conditions. The Alpine metamorphic evolution is characterized by extensive development of mineral assemblage of epidote-blueschist facies conditions: chloritoid, glaucophane, epidote, garnet, phengite (SCHAER, 1959; BEARTH, 1963).

The "external" units: Valaisan - Mt Blanc - Préalps

Pinched between two continental domains (the Briançonnais microcontinent and the European margin), metasediments of the Sion-Courmayeur zone represent a second oceanic domain, the Valaisan ocean, situated north to the Piedmont-Ligurian (FRISCH, 1979; STAMPFLI, 1993). Metamorphism of this area is characterized by high-pressure conditions (blueschist to eclogites, BOUSQUET et al., 2002; GOFFÉ et al., 2004).
The Mont Blanc massif is one of several Variscan "external crystalline massifs" of the European margin within western and central Alps. It is made of paragneisses, orthogneisses, migmatites and granites (BONIN et al., 1993). During the Tertiary, the Mont Blanc massif was affected by the Alpine orogeny and developed a non pervasive greenschist facies metamorphic assemblage that consists, in granites, of quartz, albite, muscovite, biotite, chlorite, epidote and stilpnomelane (VON RAUMER, 1974; BORGHI et al., 1987). The Mont Blanc Massif is also well known for its hydrothermal veins mainly filled by chlorite, quartz, muscovite, adularia and calcite (POTY et al., 1974). These veins have been dated at 13-18 Ma in the granite using K/Ar and Rb/Sr techniques on adularia and muscovite (LEUTWEIN et al., 1970) and are contemporaneous with shear zones containing biotite-muscovite-chlorite-epidote-quartz-albite assemblages.
The Préalps consist of cover nappes of Triassic to Eocene formations, derived from the Valais, Briançonnais and Piedmont-Ligurian domains. These nappes escaped of their original setting before that these later undergone in subduction. Thus the Préalps suffered only low metamorphic conditions. Occurrences of diaspore, pyrophyllite, paragonite, phengites and corrensite in the Préalps Médianes (JABOYEDOFF & THÉLIN, 1996, and references therein) and of prehnite, pumpellyite, epidote, actinolite, sodic amphibole, stilpnomelane in gabbro and diabase of the Gêts nappes are the main indicator of the low metamorphic conditions (BERTRAND, 1970; BILL et al., 2001). This main metamorphic event affected the Préalps during their Penninic origin, and the process responsible for the metamorphism was progressive burial by thrust stacking, probably during late Eocene (JABOYEDOFF & THÉLIN, 1996).

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