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Alpine metamorphism of the Southern Alps west of the Giudicarie Line

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Abstract

In the Southern Alps west of the Giudicarie Line data on the Alpine metamorphism are limited. The thermal event is recorded both in the basement and in the Permo-Mesozoic cover rocks. It is mainly related to the compressional tectonic phases ranging from Late Cretaceous up to Neogene. In the basement of the western part of the Southern Alps, the records are mainly localised along the major Alpine tectonic lineaments and associations of low to very low temperature are recognised, although a penetrative regional Alpine foliation is lacking. In the Orobic basement two main phases of deformation are recognised and are associated with low to very low temperature conditions. The same phases are reported for the pelitic layers of some Permian cover rocks where the cleavage planes are marked by white mica and chlorite. The Triassic rocks show assemblages of very low temperature metamorphism to high grade diagenesis, possibly due to the burial of the sequences overprinted by compressive Alpine phases. In the Orobic Alps the metamorphic overprint seems to be mainly related to the Late Cretaceous compressional tectonics, while in the western part it is attributed to the meso-Alpine and neo-Alpine phases. In the eastern part of the Orobic area, the youngest recorded event is the thermal metamorphism due to the emplacement of the Tertiary Adamello batholith. The assemblages described in the country rock point to temperatures around 850–900 °C at the contact with mafic rocks and 500 to 650 °C at the contact with tonalites and granodiorites.

Keywords: Alpine metamorphism, contact metamorphism, low T metamorphism, basement, Serie dei Laghi (Strona Ceneri Zone), Orobic basement.

1. Introduction

West of the Giudicarie Line, the pre-Alpine basement consists of two main metamorphic units (Fig. 1): (a) the Ivrea-Verbano Zone (IVZ), an amphibolite to granulite facies volcanic and sedimentary sequence (the Kinzigite Formation) with a large intrusive mafic body (the Mafic Complex) occurring in the westernmost area; and (b) a large unit including amphibolite to greenschist facies metapelites with large metagranitoid occurrences and minor amphibolite lenses. The second unit is subdivided, from west to east into: the Serie dei Laghi; the Val Colla Zone; and the Orobic Basement. The Serie dei Laghi is in turn subdivided into Scisti dei Laghi to the southeast and Strona Ceneri Zone to the northwest (see COLOMBO and TUNESI, 1999, this volume).

To the north and west, the Southern Alps are tectonically separated from the Alpine nappes by the Canavese Line and the Tonale Line (Periadriatic fault system, SCHMID et al., 1989). To the south, along the Orobic thrust in the central regions and the Cremosina fault system in the west, the basement is stacked upon the Permo-Mesozoic volcanic and sedimentary cover rocks. Within the crystalline basement, the Cossato–Mergozzo–Brissago Line (CMBL) and the Pogallo fault (PL) separate the Serie dei Laghi from the Ivrea-Verbano Zone. These two units are very different in composition and pre-Alpine metamorphic evolution. To the east, the Val Colla Line (VCL) separates the Strona Ceneri Zone from the Val Colla Zone. Conversely, these two units have a similar composition and pre-Alpine metamorphic evolution.

The present day structural setting of the Southern Alps west of the Giudicarie Line is, in the main, the result of Alpine compressional tectonic phases developed from Late Cretaceous to

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Neogene times (BRACK, 1981; LAUBSCHER, 1985; DOGLIONI and BOSELLINI, 1987; SCHÖNBORN, 1992; CASTELLARIN et al., 1992; MONTRASIO et al., 1994; CADEL et al., 1996; SCHUMACHER et al., 1997). These phases produced a complex system of south-verging folds and thrusts that involved both basement and Permo-Mesozoic cover rocks. The Alpine event took place under non to low grade metamorphic conditions and there is no evidence of pervasive regional foliation and recrystallizations. The only evidence that may be clearly attributed to the Alpine event is reported on the metamorphic map. It may be assumed that evidence of the Alpine event is more widespread, but specific studies are limited at present.

2. Records on Alpine metamorphism

2.1. REGIONAL METAMORPHISM

In the Ivrea-Verbano Zone (Fig. 1) pseudotachylite veins and lenses, ductile low-temperature shear zones and cataclastic faults developed during Alpine deformation. However, evidence of a widespread penetrative Alpine overprint is lacking (see SCHMID et al., 1987; SCHMID et al., 1989; ZINGG et al., 1990; RUTTER et al., 1993; and references therein). The ductile low-temperature shear zones are concentrated in the western areas close to the Canavese Line and become less frequent to the east. They range in width from a few millimetres to metres and crosscut the regional pre-Alpine foliation at a low angle. In these zones, the pre-Alpine high-temperature assemblage is replaced by a low-temperature greenschist facies assemblage. In the Mafic Complex and the Kinzigite Formation (Fig. 1) the Alpine assemblage is given by Ab + Act + Chl + Czo + Ttn in the metabasites and Qtz + Ab + Czo + WM + Chl + Ttn in the metapelites. The peridotites are locally serpentinised (ZINGG et al., 1990).

In the granulite rocks of the Ivrea-Verbano Zone, large-scale folding affected the regional pre-Alpine foliation as seen in the Proman antiform (SCHMID et al., 1987; BRODIE and RUTTER, 1987). This phase of deformation, developed under greenschist facies conditions, is considered to be coeval with the mylonites linked to the late Oligocene, early Miocene, Insubric back-thrusting event (SCHMID et al., 1987) and is responsible for the present vertical orientation of the Ivrea-Verbano Zone. The Proman antiform was subsequently truncated by later strike-slip movements along the Canavese Line.

Low-temperature conditions are also reported by SCHMID et al. (1989) and by ZINGG and HUNZIKER (1990) along the Canavese Line. SCHMID et al. (1989) recognise two mylonite belts in the western rim of the Ivrea-Verbano Zone. The first (mylonite belt 1) predates the emplacement of the Oligocene mafic dykes and is tentatively attributed to the meso-Alpine event. The second (mylonite belt 2) is post-Oligocene in age because it affected Oligocene magmatic rocks. This represents the continuation of the back-thrusting phase along the Canavese Line.

In the crystalline .basement of the Strona Ceneri Zone (Fig. 1) many Alpine south-verging thrusts have been mapped around Lago Maggiore (BORIANI et al., 1990), e.g. Cannero (west of Lago Maggiore), Indemini-Monte Tamaro (east of Lago Maggiore), or Germagno (west of Lago d'Orta); all of them are reported in the metamorphic map and in figure 1. They produce cataclastic effects and small displacements. Also, the Alpine event possibly reactivated Permian lineaments, e.g. the Cremosina-Val Colla and Pogallo faults (BORIANI and SACCHI, 1973).

In the basement rocks east of Lago Maggiore, very low to low grade assemblages are described by BORGHI (1989). A Prh + Ab + Chl + Act assemblage is observed in veins crosscutting the regional foliation. Actinolite and prehnite also occur in orthogneisses and in garnet-bearing amphibolites, (former eclogites ?), close to the veins. Corona structures of actinolite and albite surrounding tschermakitic hornblende and plagioclase (An 70%) are found in appinitic dykes. The exact age of these metamorphic assemblages is uncertain, but they are younger than the intrusion of the appinites (285 Ma; CUMMING et al., 1987) and according to BORGHI (1989) may be related to Permian fluid activity or to an unidentified Alpine event.

In the area between Locarno and Lago di Como (Val Colla Zone p.p.) the Alpine metamorphic overprint is developed along the Tonale Line, but no data on the diaphthoretic assemblage is reported. FUMASOLI (1974) describes "diaphthoretic and cataclastically deformed" schists dipping steeply and parallel to the Tonale Line, but the author points out that the distinction between pre-Alpine and Alpine diaphthoresis is difficult to evaluate. The occurrence of younger muscovite/sericite in metapelites and Ab + Chl in metabasites indicates a weak Alpine metamorphic overprint, but reported assemblages are not very diagnostic of a specific grade.

BOCCHIO et al. (1980) describe a very low grade assemblage (Chl + Ms + Ab + Qtz) in the basement rocks between the Tonale Line and the Musso Line, which overprints the main Variscan metamorphic amphibolite facies assemblage. A

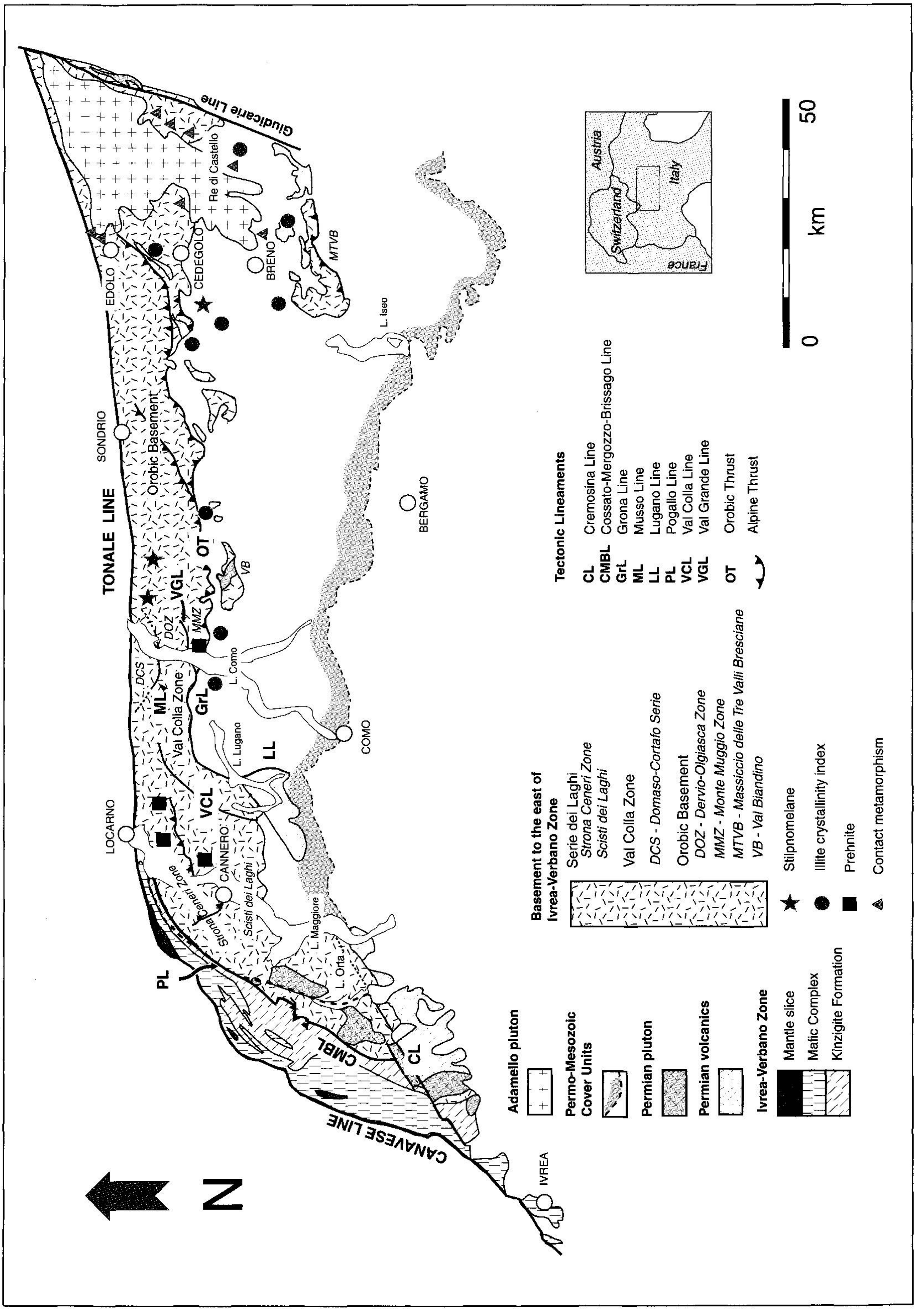

Fig. 1 Sketch map of the Southern Alps west of the Giudicarie Line showing Alpine metamorphic features.

similar assemblage with Chl + Sericite + Saussurite ± Mrg ± Prl replacing biotite, garnet, kyanite, staurolite, plagioclase, muscovite is also reported by SCHÖNBORN (1992) in basement rocks of the central Orobic area.

In the Orobic basement (Fig. 1) the ductile Variscan phases of deformation (D_1–D_2) are locally overprinted by the Alpine phases of deformation (D_3–D_4). The Alpine phases are associated with very low grade metamorphic conditions and relate mainly to Alpine thrust tectonics. On the eastern shore of Lago di Como in the Monte Muggio Zone (Fig. 1) GOSSO et al. (1997) recognised conjugated kinks, chevron folds and open folds created undulation in the Variscan fabrics. These folds present an axial plane foliation defined by chlorite and white mica. Close to the Val Grande Line and Tonale Line (Fig. 1) CRESPI et al. (1981; 1982) report the occurrence of stilpnomelane in gneissic rocks composed mainly of Qtz + Kfs + Bt (possibly orthogneisses: Gneiss di Mantello; Monte Legnone gneisses; and lenses within Gneiss di Morbegno). Stilpnomelane is found in blastomilonites and grows at the expense of chlorite that in turn replaces biotite, or may grow in veins and cracks that are related to movement along the Tonale Line (Upper Oligocene). BOCCHIO and DE CAPITANI (1998) also find prehnite-bearing veins in amphibolites of the Orobic Alps. The static growth of stilpnomelane under very low pressures and temperatures and the prehnite veins could be related to the final stages of decompression connected to the exhumation of the Orobic basement (CRESPI et al., 1982; MOTTANA et al., 1985; BOCCHIO and DE CAPITANI, 1998).

Chlorite, white mica and stilpnomelane were described by ALBINI et al. (1994) in some north-eastern Orobic areas. The assemblage grew in cleavage planes and fractures in the cover rocks (Collio Formation – Permian). These planes are related to D_3 deformation that produced pervasive foliation and folds in fine-grained Collio sediments and chevron folds or kink-bands in the basement metapelites (CADEL et al., 1996). The foliation in the cover rocks is defined by white mica, fine-grained carbonates and opaques (MARONI et al., 1995). The D_3 structures are associated with the south-verging thrusts that affected the pre-Alpine framework (MARONI et al., 1995; CARMINATI et al., 1997). This deformation predates the Adamello intrusion (42–29 Ma; DEL MORO et al., 1983) because andesitic dykes ascribed to the Adamello magmatism crosscut D_3 structures (ALBINI et al., 1994; CADEL et al., 1996; CARMINATI et al., 1997). According to ZANCHI et al. (1990) dykes cross-cutting the Triassic carbonaceous Presolana stack show mineral and whole rock K/Ar ages ranging from 50 to 65 Ma, therefore, D_3 would be older than Paleocene.

Pervasive D_4 deformation is also described in basement and cover rocks (ALBINI et al., 1994; CARMINATI et al., 1997). It gently folds pre-existing structures and develops crenulation cleavage in fine-grained sediments (e.g. Collio Formation) or fracture cleavage in conglomeratic rocks. D_4 planes in the Permian sequence of the north-eastern Orobic area (ALBINI et al., 1994) are defined by sericite, carbonates and opaques. The age of the D_4 phase is possibly younger than the Adamello intrusives (CARMINATI et al., 1997).

Based on the illite crystallinity index, newly formed phyllosilicates in the recrystallized matrix of the Collio Formation shales suggest thermal conditions between epizone for basal beds and anchizone for the upper detritic beds (CASSINIS et al., 1978). According to CASSINIS et al. (1978), these conditions resulted from an anomalous thermal gradient due to pre-Alpine burial of the sequence, or alternatively, to Triassic or Alpine magmatic activity. Anchimetamorphic conditions are also reported by KELLER (1986) for the Collio Formation and the Lower Triassic Servino sandstones, while epizonal conditions were reached in the marbles of Middle Triassic Calcare di Prezzo. These conditions indicate temperatures between 200 and 300 °C according to SCHÖNBORN (1992). Similar temperatures between 250 and 300 °C (vitrinite reflectance) are reported in the east by BERSEZIO et al. (1997) from stacked Lower Triassic units close to the Cedegolo anticline.

The illite crystallinity index and the occurrence of corrensite in the Upper Triassic to Liassic sedimentary rocks of the Monte Generoso basin (west of Lago di Como) indicate transformation of the original clay minerals to a high-grade diagenetic assemblage close to anchizonal temperatures. These temperatures were estimated at about 210 ± 30 °C by isotopic thermometry on syntectonic calcite-quartz veins (SOMMARUGA, 1991). These conditions are evidence for the burial of the Mesozoic rocks and an important N-S compression during the Tertiary period (SOMMARUGA, 1991).

2.2. CONTACT METAMORPHISM

Both basement and cover rocks have a thermal overprint due to emplacement of the Adamello batholith (Fig. 1) between Eocene and Oligocene (DEL MORO et al., 1983). For detailed studies about the contact metamorphism see CALLEGARI (1983) and BRACK et al. (1983) and the references therein. The contact metamorphism produced strong textural and mineralogical changes in an irregularly shaped aureole (extending up to 6 km in the Val Daone area, according to RIKLIN, 1983). In the matrix of the Verrucano Lombardo red sandstones (Permian), from the outer aureole zones to the contact with the granodiorites and tonalites, RIKLIN (1983) describes, using illite crystallinity data, an initial mineralogical assemblage typical of anchimetamorphism. Biotite first appears in the external part of the aureole, at around 2 km from the contact. It has been locally replaced by cordierite in zones closer to the intrusives. Cordierite is responsible for the typical mottled appearance of the sandstones. Close to the contact, the thermal metamorphism developed And + Kfs + fibrolitic Sil. The estimated temperatures and pressures close to the contact are 600–650 °C and lower than 2 kbar ($P_{H_2O} = P_{tot}$; RIKLIN, 1983).

In the Triassic successions of the southern areas (e.g. Bazena, southeast of Breno, Val Camonica) the contact aureoles of the tonalites and granodiorites have the following paragenesis: Fo + Spl + Di in the dolomites; Cal + Wo in limestones; Scp + Crn + Kfs in marls; and Crd + Bt + And + Kfs in pelites. The estimated temperatures at the contact are around 500–600 °C and the derived pressures are always lower than 2 kbar (BRACK et al., 1983 and references therein). More spectacular effects of contact metamorphism are seen in the aureoles of the mafic intrusions. Close to the contact with the intruded gabbros, Mtc + Spl + clintonite developed in impure dolomites and Cal + Per (now transformed into brucite) in purer dolomites. The assemblage monticellite forsterite-clintonite-pleonast-calcite indicates temperatures around 850–900 °C and a fluid composition dominated by CO_2 (BRACK et al., 1983).

In the north-western part of the Adamello massif a well developed contact aureole is observed (MOTTANA and SCHIAVINATO, 1973). The country rocks are mainly basement metapelites with some Permo-Triassic cover rocks. The contact metamorphism is more highly developed in the former. The resulting hornfels show the following mineralogical neoformations, from the furthest extent of the aureole to the contact with the tonalites: biotite-garnet-andalusite-cordierite-sillimanite-spinel-(orthorhombic amphibole-Kfs). Similar mineralogical successions are described for metapelites in the north-eastern part of the Adamello massif (Rendena Valley, close to the Giudicarie Valleys; BORIANI and GIOBBI ORIGONI, 1982/83). With increasing temperature towards the tonalites and granodiorites (Re di Castello, Corno Alto, Sostino), the newly formed contact minerals are: biotite, andalusite locally associated with cordierite and sillimanite. Close to the contact, the temperature was estimated to have reached approximately 650 °C with pressures lower than 2 kbar (BORIANI and GIOBBI ORIGONI, 1982/83).

3. Conclusions

The reported data document the scarce knowledge of the Alpine event in the Southern Alps west of the Giudicarie Line. Deformation phases and mineralogical associations of Alpine age were recognised by different authors, both in the western and central regions, but the data set suffers from several gaps. Moreover, the published data do not always give good correlation with the metamorphic assemblages and the recognised deformation phases in the different areas of the Southern Alps.

However, the mineral assemblages seem to define a zoneographic arrangement from north to south. In the basement rocks, mainly close to the Periadriatic fault system, the assemblages show low to very low temperature conditions. Southwards, the mineralogical associations and vitrinite reflectance data from the Permian to Triassic cover rocks indicate a decreasing thermal regime from very low metamorphic to high grade diagenetic conditions (SCHÖNBORN, 1992; BERSEZIO, personal communication).

The most difficult task is to link the metamorphic assemblages to the recognised tectonic phases. These phases are post-Permian in age, because they involved older cover rocks and locally affected the Permian mafic plutons (270–280 Ma). In the Ivrea-Verbano Zone, the low to very low temperature assemblages are associated with compressional movements possibly attributed to the meso-Alpine collisional event (see belt 1, SCHMID et al., 1989) and to a post-Oligocene back-thrusting event (belt 2). In the western Orobic basement, according to CRESPI et al. (1982), only the occurrence of stilpnomelane in veins and cracks seems to be connected with the youngest strike-slip movements along the Tonale Line (post-Oligocene Insubric phase). In all the other Orobic Alps, based on evidence from stratigraphy (BERSEZIO and FORNACIARI, 1987), structural data (BRACK, 1981; DOGLIONI and BOSELLINI, 1987; SCHÖNBORN, 1992; CASTELLARIN et al., 1992; MONTRASIO et al., 1994; CADEL et al., 1996) and radiometric data (ZANCHI et al., 1990), Alpine associations are related to the compressional eo-Alpine tectonics starting at the beginning of the Upper Cretaceous. Also, the published data present evidence for the presence of stilpnomelane in the Permian Collio Formation shales, connected with a pre-Paleocene D_3 phase of deformation (ALBINI et al., 1994). In this case, two generations of stilpnomelane should be present in the Orobic sector: the first linked to the oldest Cretaceous events; the second to the youngest tectonic movements. In the Permian Collio Formation the recognised metamorphic Alpine evolution is similar to that of the basement rocks (ALBINI et al., 1994). For the Triassic cover rocks, the high grade diagenetic assemblages are characteristic of a sedimentary burial followed by the compressive phases of Tertiary age (SOMMARUGA, 1991).

The reconstruction in the crystalline basement seems to be in agreement with the few fission track data available on zircons (HUNZIKER et al., 1992). Along the Periadriatic Line, the rocks reached temperatures below 250 °C mainly between 30–15 Ma , coeval with the development of the low temperature mylonites of belt 2 in the Ivrea-Verbano Zone (SCHMID et al., 1989) and to the static growth of stilpnomelane in the Orobic sector (CRESPI et al., 1982). To the south, the fission track blocking temperature of the zircons are mainly between 85 and 60 Ma, in agreement with the inferred pre-Paleocene age of the D_3 deformation phase (ALBINI et al., 1994) which is associated with the very low temperature metamorphic assemblages in the Orobic sector.

The most significant Alpine metamorphic event is the contact metamorphism developed in the eastern area of the Orobic sector, where the Eocene-Oligocene Adamello batholith intruded both basement and Permo-Triassic cover rocks. The contact aureole shows high temperature assemblages (850–900 °C) close to mafic intrusions, and medium temperature associations (around 600 °C) in contact with granodiorites and tonalites.

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