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Swiss Tectonic Studies Group Field Excursion – 2016

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Tectonic history of the Dent Blanche

Swiss Tectonic Studies Group Field Excursion – August, 26th-28th 2016

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Riassunto

Il sistema tettonico della Dent Blanche (DBTS), un frammento di crosta continentale di origine adriatica, costituisce l'elemento tettonico più elevato nella pila delle falde delle Alpi occidentali e si colloca a cavallo del confine italo-svizzero. Questa escursione vuole discutere la storia tettonica della Dent Blanche. A questo scopo, saranno descritte alcune località chiave che permetteranno di esaminare tre punti principali. In primo luogo, le rocce con metamorfismo pre-Alpino di alto grado, preservate nella serie di Valpelline daranno l'occasione di discutere la struttura e l'evoluzione della crosta inferiore durante il Permiano. In secondo luogo, durante il secondo giorno, sarà visitato il contatto frontale tra le rocce continentali della Dent Blanche e le sottostanti rocce di origine oceanica (oceano liguro-piemontese), al fine di discutere la natura di questo contatto. Infine, il terzo giorno è dedicato alla visita della Roisan-Cignana Shear Zone, un contatto tettonico principale all'interno della DBTS, che permetterà di comprendere la geometria interna di questo sistema tettonico.

Parole chiave: *Dent Blanche, serie di Valpelline, Roisan-Cignana Shear Zone, Berrio gabbro, Valle d'Aosta, evoluzione policiclica.*

Abstract

The Dent Blanche Tectonic System (DBTS), a stack of continental slices of Adriatic origin, is the highest tectonic element of the collisional wedge in the Western Alps, and it straddles the Italian-Swiss border. This excursion is intended to discuss its tectonic history. For this purpose, it describes key localities, allowing the examination of three main points. Firstly, the well-preserved pre-Alpine rocks of the Valpelline series will allow a statement about the structure and evolution of the lower crust during the Permian. Secondly, the frontal contact of the DBTS continental rocks with the underlying ocean-derived rocks (Piemonte-Liguria ocean) will be visited during the second day, in order to discuss the nature of this contact. Thirdly, the Roisan-Cignana Shear Zone, a major boundary inside the DBTS, will be visited during the third day, allowing a better interpretation of the internal geometry of the DBTS.

Key words: *Dent Blanche, Valpelline series, Roisan-Cignana Shear Zone, Berrio gabbro, Aosta Valley, polycyclic evolution.*

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Program summary

The Geological Field Trip in the Dent Blanche covers the Valpelline, the Ollomont and the St. Barthelemy valleys, north of Aosta. The starting point of this three-days field trip is located at Valpelline, a small town north of Aosta (Fig. 1). It is possible to park your car in the central square, in front of the tourist office.

From Switzerland, Valpelline can be reached crossing the border at the tunnel of the Grand St-Bernard along the E27 road. After the tunnel, follow the indications for Etroubles, then to the left to Allein, and then to Doues. If you have enough time, park the car at the entrance of the village Le Martinet (half way between Allein and Doues) and walk up for one hundred metres (electric pole). To the south, a nice view on the Aosta Valley and the surrounding mountains can be seen (Fig. 1). To the north, you can appreciate a nice view on the Valpelline. At the end of the valley, on a second line, the top most part of the M. Cervino (4478 m) is visible. On the west of Valpelline, the Grand Combin (4314 m) and the M. Berrio appear.

From Italy, Valpelline can be reached from Milano along the A4 and then A5 Highway (c. 2h 30' travel time). Immediately after your exit from the highway (exit "Aosta Est"), follow the road E27 for Grand St-Bernard. In Arliod, proceed to the right and follow the road SR28 to Valpelline.

Fig. 1 – Panorama on the Aosta Valley, from the road to Allein.

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The **first day** of the excursion is dedicated to **(i)** the granulite to amphibolite facies rocks of the Valpelline series (Fig. 2) and **(ii)** the tectonic contact between the Valpelline series and the Arolla series. In the Valpelline series, melting reactions and extensional structures associated with the Permian evolution will be observed. The first day ends with a panorama on the south-west termination of the Roisan-Cignana Shear Zone, a 25 km long Alpine shear zone, now separating the Dent Blanche s.s. and the Mont Mary-Cervino nappes. This shear zone contains pre-Alpine rocks sheared and folded together with Mesozoic meta-sediments.

The **second day** is dedicated to the geometry and kinematics of the frontal contact between the Dent Blanche and the remnants of the Piemonte-Liguria ocean. The contact is exposed in the Ollomont Valley (Fig. 2). Along this contact, in the Dent Blanche, the participants will observe a newly discovered Permian gabbro complex (i.e. the Berrio gabbro).

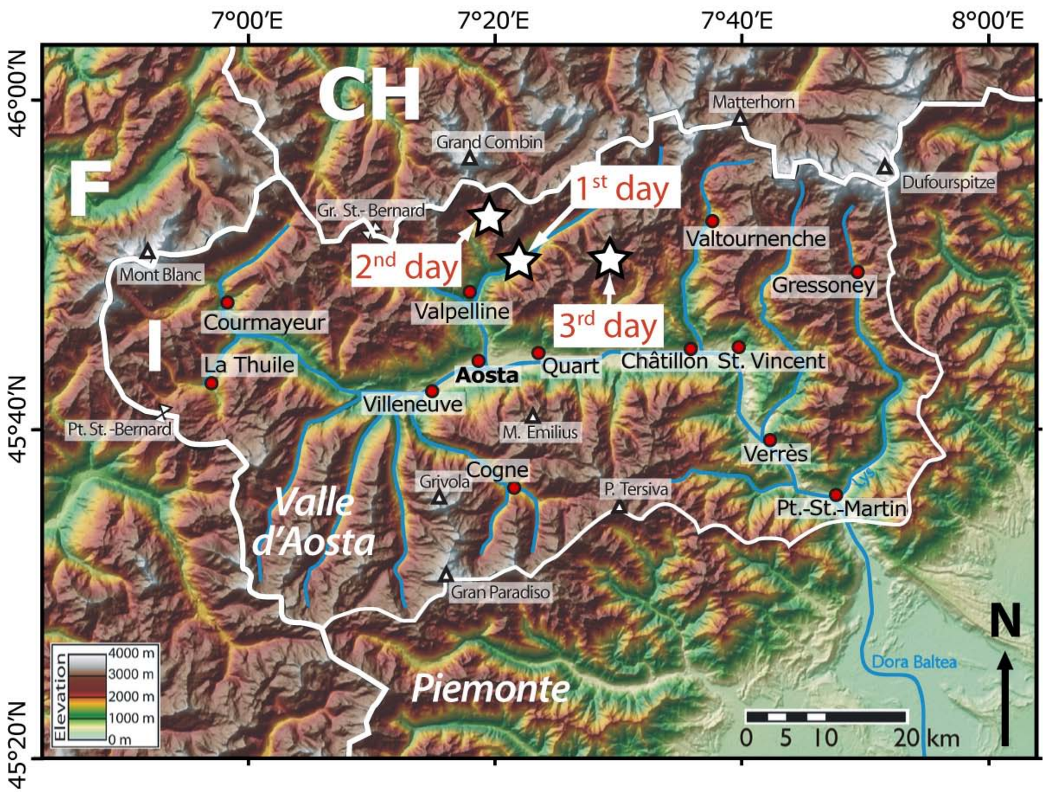

Fig. 2 – Geographical location of the Field Trip area.

The **third day** is spent in the St. Barthelemy Valley (Fig. 2) and is focused on the Roisan-Cignana Shear Zone. This area gives the opportunity **(i)** to observe the different rock types involved in the Roisan-Cignana Shear Zone and **(ii)** to discuss the geometry and kinematics of this Alpine structure.

Safety

The excursion takes place at relatively high altitude (between 960 and 2700 metres above sea level). Most of the outcrops are along paths. Comfortable mountain boots, water and windproof jacket as well as sun glasses and sunscreen are strongly recommended.

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Day 1

Stop 1.1: Oyace
Altitude: c. 1370 m a.s.l.
Elevation change (on foot): none
Stop 1.2: Bionaz (Lac Lexert)
Altitude: c. 1580 m a.s.l.
Elevation change (on foot): none
Stop 1.3: Bionaz (Moulin)
Altitude: c. 1600 m a.s.l.
Elevation change (on foot): none
Stop 1.4: Valpelline
Altitude: c. 990 m a.s.l.
Elevation change (on foot): none
Stop 1.5: Gignod
Altitude: c. 800 m a.s.l.
Elevation change (on foot): none
Stop 1.6: Rhins to Allein
Altitude: c. 910 m a.s.l.
Elevation change (on foot): none

Day 2

Stop 2.1: Plan Debat
Altitude: c. 2076 m a.s.l.
Elevation change (on foot): none
Stop 2.2: Balme de Bal
Altitude: c. 2130 m a.s.l.
Elevation change (on foot): none
Stop 2.3: Pointe Cornet
Altitude: c. 2354 m a.s.l.
Elevation change (on foot): c. 220 m
Stop 2.4: East of the Col Cornet
Altitude: c. 2440 m a.s.l.
Elevation change (on foot): c. 100 m
Stop 2.5: Basal contact of the Dent Blanche
Altitude: c. 2483 m a.s.l.
Elevation change (on foot): c. 40 m
Stop 2.6: The Berrio gabbro
Altitude: c. 2520 m a.s.l.
Elevation change (on foot): c. 40 m
Stop 2.7: Lago de La Clusa
Altitude: c. 2418 m a.s.l.
Elevation change (on foot): c. 100 m
Stop 2.8: Plan Debat
Altitude: c. 2076 m a.s.l.
Elevation change (on foot): none

Day 3

Stop 3.1: Unsealed road for Cuney area
Altitude: c. 2238 m a.s.l.
Elevation change (on foot): none
Stop 3.2: Sarrioles
Altitude: c. 2385 m a.s.l.
Elevation change (on foot): none

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Stop 3.3: Cuney area
Altitude: c. 2406 m sa.s.l.
Elevation change (on foot): none
Stop 3.4: Path for the Col de Chaléby
Altitude: c. 2683 m a.s.l.
Elevation change (on foot): c. 300 m
Stop 3.5: Crest above Col de Chaléby
Altitude: c. 2695 m a.s.l.
Elevation change (on foot): c. 20 m

Recommended geological maps

From 1/10^6 to 1/200,000 scale
- Structural Model of Italy scale 1:500.000, sheet 1. (Bigi et al., 1990).
- Metamorphic structure of the Alps. Transition from the Western to the Central Alps (Bousquet et al., 2004).
- Carta geologica delle Alpi nord-occidentali alla scala 1:200.000 (Hermann, 1938).

1/100,000 scale
- Carta Geotettonica della Valle d'Aosta, 1:150.000. (De Giusti et al., 2003)
- Carte Géologique de la Vallée d'Aoste (Elter, 1987).
- Carta Geologica d'Italia, Foglio Aosta n. 28; Foglio Monte Rosa n. 29 (Mattirolo et al., 2012).
- Carte géologique des Alpes de Suisse occidentale, Carte géologique spéciale N°123 (Steck, 1999).

1/50,000 scale
- Carte géologique du Massif de la Dent Blanche (moitié septentrionale), carte spéciale n° 52 (Argand, 1908).
- Carta Geologica d'Italia, Foglio 091 Châtillon (Bonetto et al., 2010); Foglio 070 Monte Cervino e Note Illustrative (Bonetto et al., 2015; Dal Piaz et al., 2015).

1/25,000 scale
- Atlas géologique de la Suisse, feuille 1346 Chanrion et Notice explicative avec partie nord de la feuille 1366 Mont Vélan (Burri et al., 1998; 1999).
- Blatt 1347 Matterhorn - Geologischer Atlas der Schweiz, Karte 107 (Bucher et al., 2003).
- Carta dei sentieri, Valpelline Saint-Bathélemy, n°6 (Blatto & Zavatta, 2009). Gran San Bernardo, Valle di Ollomont, n°5 (Blatto & Zavatta, 2011).
- Carta geologico-petrografica della Valpelline inferiore e della valle d'Ollomont (Diehl et al., 1952).

1/20,000 scale
- Petrostructural map of the Dent Blanche tectonic system between Valpelline and Valtournenche valleys, Western Italian Alps, scale 1:20.000, 1:10.000; 1:2.500 (Manzotti, 2011).

1/10,000 scale
- Tectono-metamorphic map of the Mont Morion Permian metaintrusives (Roda & Zucali, 2011).

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Hospitals

Aosta

- Ospedale Regionale. 1, Viale Ginevra – 11100, Aosta. Ph: +39 0165 543266, +39 0165 543315.
- C.R.I. (Italian Red Cross). 2, Via Grand'Eyvia - 11100, Aosta. Ph: +39 0165 551566.

Accomodation

Hostellerie Le Lievre Amoureux
Loc. Chozod 12 - 11010, Valpelline (AO).
Ph: +39 0165 713966
Email: info@lievre.it

Necessary permits

A permit is needed to take the road by car for the Stops of the second and third day. The permit can be obtained by the Corpo Forestale in Aosta.

Other useful addresses

Tourist Office - Ph: +39 0165 713502.
Informazione e Accoglienza Turistica (I.A.T.) Località Capoluogo n°1 - 11010, Valpelline (AO).

Soccorso Alpino (Mountain Rescue) -
Ph: +39 800 800 319

Corpo Forestale (Forestry Corps) - Ph: 1515
Loc. Grand Charrière 6/a. 11020 Saint-Christophe (Aosta)

Pronto Soccorso (First Aid) - Ph: 112

Corpo Vigili del Fuoco (Fire Brigade) – Ph: 115

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1. Introduction

The main tectonic units in the area visited during the excursion will be the remnants of the Mesozoic Piemonte-Liguria ocean, on top of which slices of pre-Alpine continental basements (the Sesia-Dent Blanche nappes) are thrusted. The excursion will focus on the contact between the Piemonte-Liguria ocean and the Dent Blanche on the one hand, and on a major shear zone (i.e. the Roisan-Cignana Shear Zone: Manzotti et al., 2014a) inside the Dent Blanche on the other hand.

1.1 The Piemonte-Liguria ocean

The Zermatt-Saas Zone and a large part of the Combin Zone (in South-Western Switzerland and in the Aosta region, Italy) represent remains of the Piemonte-Liguria Ocean (Figs 3 and 4, cf. Bearth, 1967; Dal Piaz & Ernst 1978; Cartwright & Barnicoat, 2002). The underlying **Zermatt-Saas Zone**, a dismembered ophiolite sequence, comprises mantle peridotites (now serpentinites) intruded by gabbros, and covered by basalts (with preserved pillow lavas), and sediments (including manganiferous cherts, pelites and marls, now quartzites, micaschists and calc-schists) (Bearth, 1967; Barnicoat & Fry, 1986; Barnicoat et al., 1995). This unit experienced eclogite facies conditions during the Alpine orogeny (Ernst & Dal Piaz, 1978; Bucher et al., 2005; Groppo et al., 2009; Rebay et al., 2012). Blueschist facies assemblages locally overprint earlier eclogite facies minerals, and later greenschist facies assemblages are commonly found along tectonic contacts (Cartwright & Barnicoat, 2002).

The **Combin Zone** comprises two types of units. Most are derived from an oceanic domain, and they consist of ophiolitic rocks, a few manganiferous cherts and calc-schists (Dal Piaz et al., 1979a; Caby, 1981; Baldelli et al., 1983). These are also referred to as the Tsaté nappe (Sartori, 1987). Other units are made of Permo-Mesozoic sequences, namely the quartzites and dolomitic marbles of presumed Permo-Mesozoic age of the Cime Bianche – Pancherot Unit (Dal Piaz 1965, 1988, 1999; Vannay & Allemann, 1990). These sequences were deposited on top of a lost continental basement (possibly a Briançonnais basement), from which they have been detached during the Alpine orogeny. The Combin Zone shows an Alpine pervasive greenschist-facies metamorphism, with scarce relicts of an earlier blueschist facies event during the Alpine evolution (Dal Piaz et al., 1979a; Caby, 1981; Baldelli et al., 1983; Sperlich, 1988; Martin & Cortiana, 2001).

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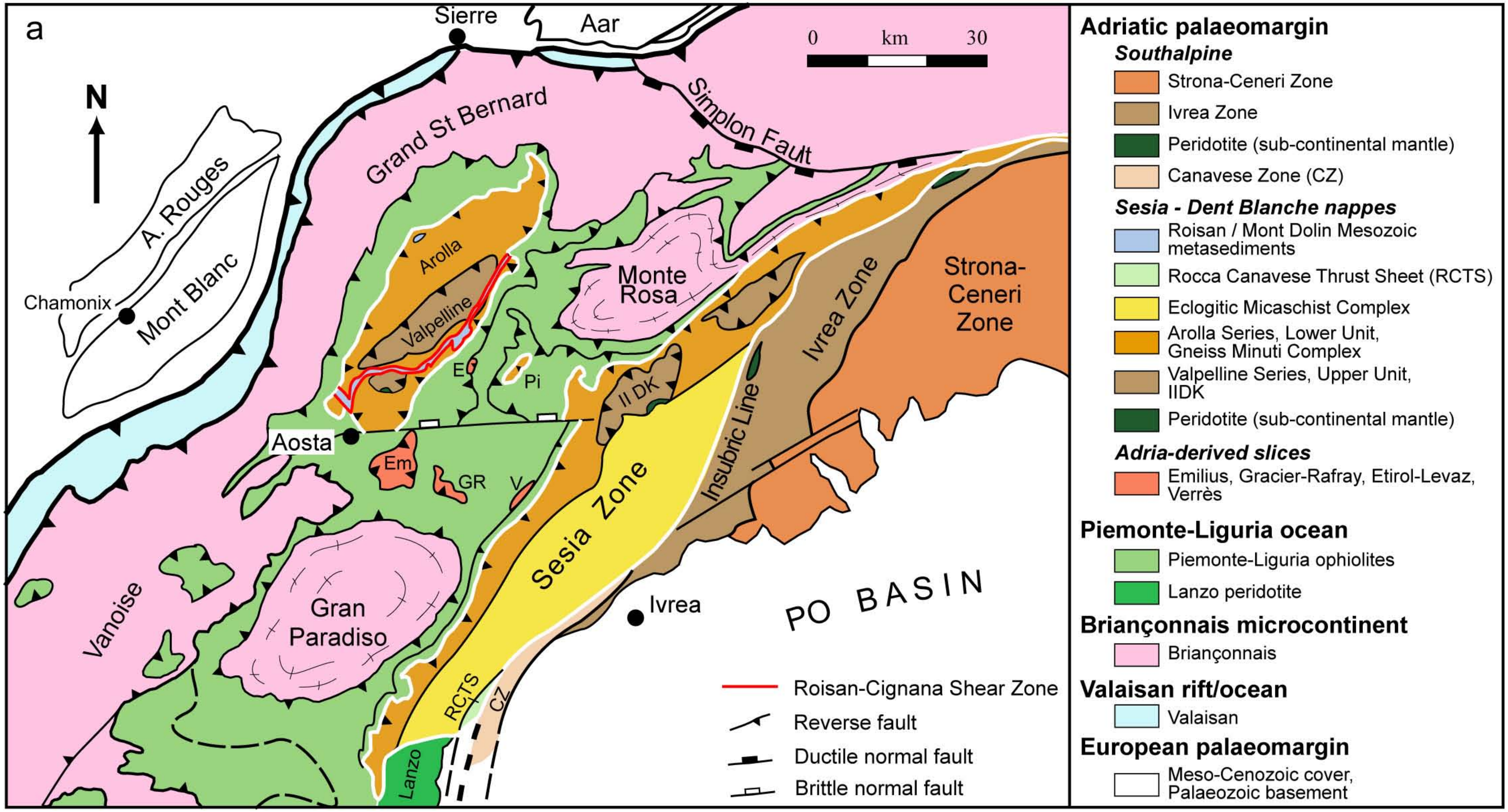

Fig. 3 – Simplified tectonic map of the north-western part of the Western Alps. **E** = Etirol Levaz; **Em** = Emilius; **GR** = Glacier-Rafray; **Pi** = Pillonet; **V** = Verrès. Because of their small sizes, other basement slices are not shown in the map. The outlines of the Dent Blanche Tectonic System, the Pillonet klippe, and the Sesia Zone (together referred to as the Sesia - Dent Blanche nappes) are marked by white lines (from Manzotti et al., 2014b and refs therein).

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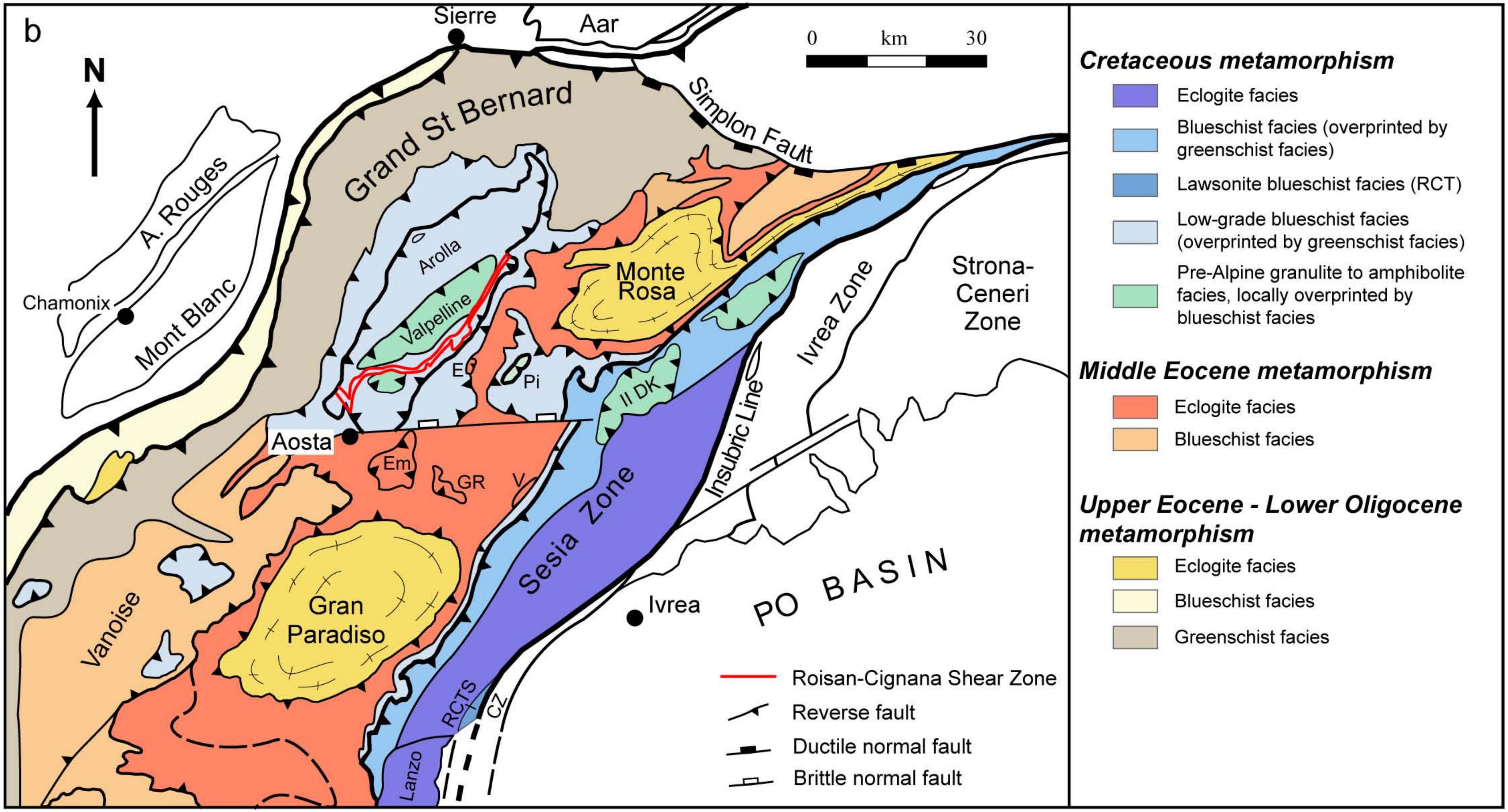

Fig. 4 – Metamorphic map of the same area. The map combines the age and the grade (i.e. the metamorphic facies) of the Alpine metamorphism (from Manzotti et al., 2014b and refs therein).

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1.2 The Sesia-Dent Blanche nappes

The Sesia-Dent Blanche nappes (Fig. 3) consist of slices of pre-Alpine basement derived from the distal continental margin of Adria. Such fragments have often been referred to as “Austroalpine” of the Western Alps in the literature, but their metamorphic history and tectonic position are different from those of the Austroalpine units of Eastern Switzerland and Austria (see Froitzheim et al., 1996; Schmid et al., 2004; Manzotti et al., 2014b).
Two major complexes are recognized within the Sesia-Dent Blanche nappes. Firstly, the more internal Sesia Zone stretches from the Insubric line to the eastern margin of the Piemonte-Liguria unit (Compagnoni, 1977; Compagnoni et al., 1977). Secondly, the more external Dent Blanche Tectonic System forms a giant outlier (>4000 km^2), and it has long been recognized to root in the Sesia Zone (Argand 1911; Stutz & Masson 1938; Diehl et al., 1952; Elter, 1960; Dal Piaz et al., 1972; Compagnoni et al., 1977).
Smaller pre-Alpine continental units (e.g. Etirol-Levaz, Emilius, Glacier-Rafray, etc.) also attributed to the “Austroalpine”, occupy a different tectonic position, at the boundary between the Zermatt and Combin Zones (Ballèvre et al., 1986; Dal Piaz, 1999; Dal Piaz et al., 2015). These will not be visited during the excursion.

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2. The internal sub-units of the Dent Blanche

The Dent Blanche Tectonic System (DBTS; Manzotti et al., 2014a and refs therein) (~52 x 15 km) constitutes the largest continental klippe now exposed above the surrounding oceanic units (Fig. 5). It comprises two main basement nappes, i.e. the Dent Blanche nappe to the northwest and the Mont Mary-Cervino nappe to the southeast

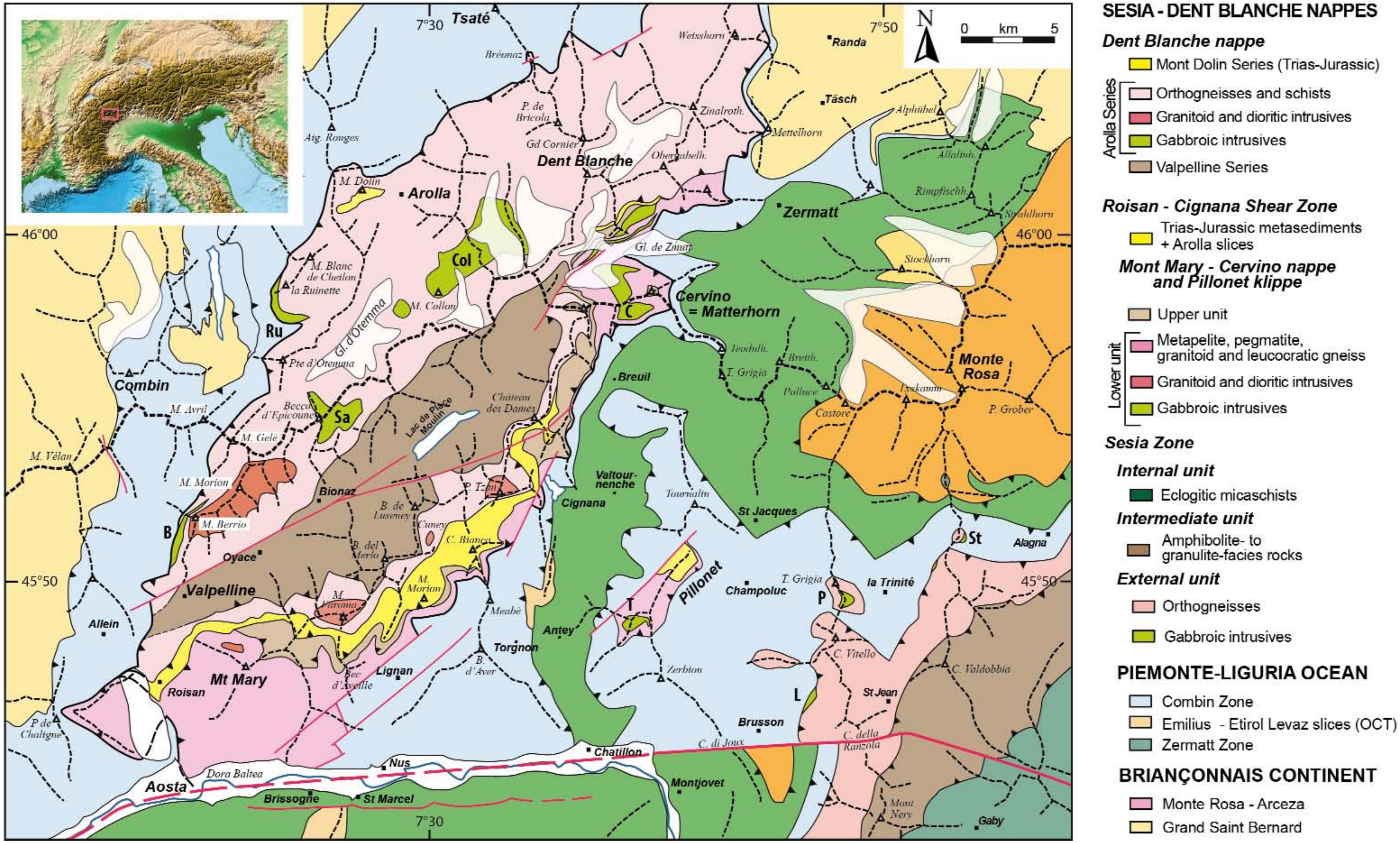

Fig. 5 - Simplified geological map of the Dent Blanche Tectonic System in the Western Alps.

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(Fig. 5). The former is made up of two superimposed lithological associations, i.e. the Valpelline and the Arolla series (Argand, 1906, 1908; Diehl et al., 1952). The Mont Mary-Cervino nappe also includes two different lithological units, simply termed the upper and lower units (Canepa et al., 1990; Dal Piaz et al., 2010). The Dent Blanche and Mont Mary-Cervino nappes are separated by a 25 km long shear zone, defined as the Roisan-Cignana Shear Zone (RCSZ) (Manzotti, 2011; Manzotti et al., 2014a). This shear zone contains pre-Alpine rocks sheared and folded together with Mesozoic meta-sediments. The Pillonet klippe (Fig. 5) is by far smaller (~5 x 2 km) compared to the DBTS and crops out at about midway between the DBTS and the Sesia Zone (Dal Piaz, 1976).

2.1 Valpelline series (Dent Blanche nappe)

The Valpelline series is made of pre-Alpine amphibolite to granulite facies meta-pelites, mafic and carbonate rocks (Nicot, 1977; Gardien et al., 1994; Manzotti & Zucali, 2013). This unit experienced an early stage of metamorphism at 4.5-6.5 kbar followed by migmatite formation. The most penetrative fabric affecting all lithotypes developed at amphibolite to granulite facies conditions (~7-8 kbar, 800-850 °C, Manzotti & Zucali, 2013). This high-temperature event is now dated at Permian times (Zucali et al., 2011; Manzotti, 2012; Kunz et al., 2017) (Fig. 6). Following cooling and exhumation of the Valpelline series, a local mineral-chemical re-equilibration under greenschist facies (~4 kbar, 450 °C) is observed, but its age is uncertain. A localized Alpine blueschist to greenschist facies overprint is recognizable (Diehl et al., 1952; Kiénast & Nicot, 1971; De Leo et al., 1987).

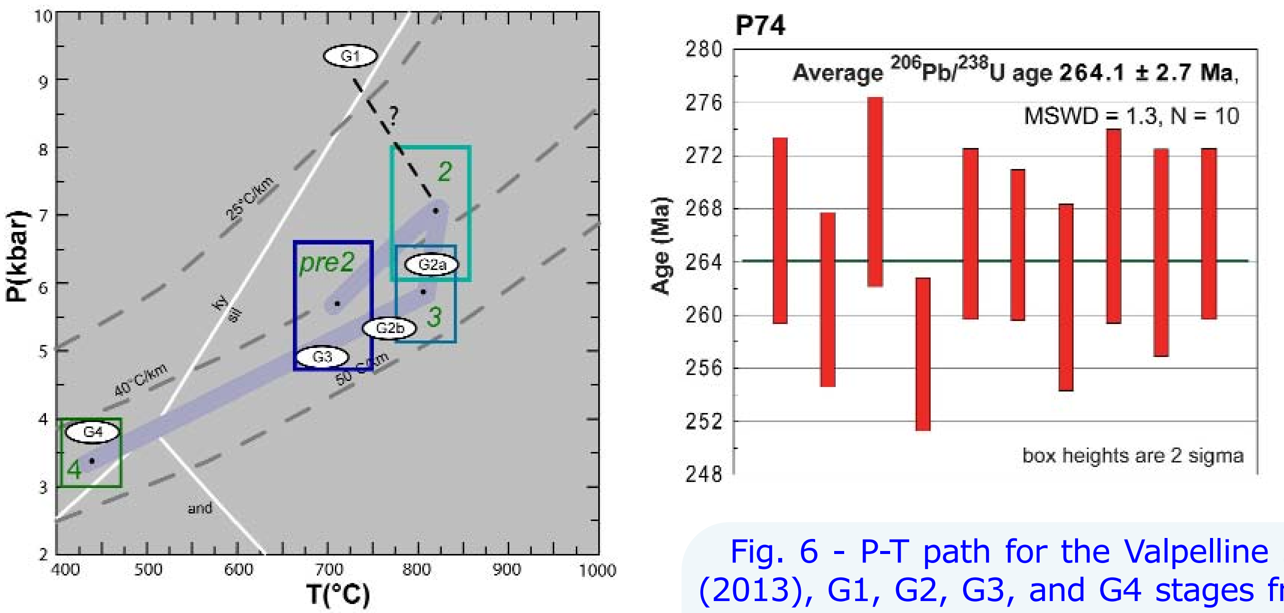

Fig. 6 - P-T path for the Valpelline series. Stage pre2 to 4 from Manzotti & Zucali (2013), G1, G2, G3, and G4 stages from Gardien et al. (1994). Diagram summarizing the zircon concordia age data obtained for a garnet-biotite-sillimanite meta-pelite.

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2.2 Arolla series (Dent Blanche nappe)

The Arolla series mostly comprises three types of lithologies (from the commonest to the rarest):
1. Large intrusive bodies of granitoids (Fig. 5) were metamorphosed and deformed in orthogneisses and locally converted to mylonitic schists during the Alpine evolution (De Leo et al., 1987; Pennacchioni & Guermani, 1993; De Giusti et al., 2003; Roda & Zucali, 2008). The age of the igneous protoliths of the granitoid bodies is Permian (Bussy et al., 1998; Manzotti, 2012).
2. Mafic to ultramafic layered igneous bodies occur in the Matterhorn (Cervino) and Mt. Collon – Dent de Bertol areas (Dal Piaz et al., 1977; Monjoie et al., 2005) (Fig. 5). They also show Permian age (Dal Piaz et al., 1977; Monjoie et al., 2005).
3. Pre-Alpine high temperature–low pressure assemblages are only locally preserved in pods of biotite-sillimanite-bearing gneiss and amphibolites (Diehl et al., 1952; Pennacchioni & Guermani, 1993; Roda & Zucali, 2008). These pods are interpreted either as roof-pendants within the undeformed granites (Roda & Zucali, 2008) or as large-scale septa of country-rocks (Burri et al., 1998; Dal Piaz et al., 2015).

Following the pre-Alpine evolution, the rocks of the Arolla series were subsequently transformed to orthogneiss. Most of them show "greenschist-facies" parageneses (quartz-albite-phengite-chlorite), but some of them record "blueschist-facies" parageneses characterised by the occurrence of sodic pyroxene and/or sodic amphibole (Diehl et al., 1952; Hunziker et al., 1974; Ayrton et al., 1982, Menegon et al., 2008; Roda & Zucali, 2008; Malaspina et al., 2011; Angiboust et al., 2014, 2015; Dal Piaz et al., 2015). Both types of parageneses can have crystallized at the same P-T conditions as a function of the bulk-rock chemistry. Estimated P-T conditions are at 400-500°C, 12 kbar (Roda & Zucali, 2008) and c. 450°C, 12 kbar (Angiboust et al., 2014).
The age of the high pressure Alpine stage remains uncertain. K-Ar data (Hunziker, 1974) for sodic amphibole (from glaucophane schists near Ollomont close to the Combin-Dent Blanche contact) have provided an age of 48 ± 15 Ma, interpreted as recording the high pressure metamorphism in the Arolla series. Ayrton et al. (1982) reported a range of K-Ar ages (between 55 and 30 Ma, with a peak at 45-47 Ma) and Rb-Sr ages in the Arolla-Mont Dolin area. More recently, a larger dataset of Rb-Sr ages has been provided by Angiboust et al. (2014). The ages display a range from 58 to 43 Ma and they have been interpreted as recording a protracted evolution of the deformation under high pressure metamorphic conditions. The oldest age (58 Ma) has been found in

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mylonites along the Arolla-Valpelline contact, while younger ages (48-43 Ma) stem from gneisses of the Arolla series. At present, these ages are considered preliminary because of their large uncertainties (the MSWD, i.e. the mean square weighted deviation, of all dated samples range from 19 to 1003, and of those retained by the authors between 19 and 928). Some of these ages may reflect a deformation event, but this will require further clarification with respect to the structural history of the area studied by Angiboust et al. (2014). The age of the high-pressure imprint on rocks in the Dent-Blanche nappe thus remains poorly constrained.

2.3 Upper unit (Mont Mary-Cervino nappe)

The upper unit consists of pre-Alpine amphibolite- to granulite-facies meta-pelites, mafic and carbonate rocks, and small slices of amphibole-bearing spinel-harzburgite (Cesare et al., 1989; Canepa et al., 1990; Bonetto et al., 2010). Locally the pre-Alpine high-grade assemblages have been partly retrogressed to greenschist facies conditions during the Alpine evolution. The main pre-Alpine amphibolite-facies schistosity is deformed along mylonitic horizons that developed at relatively low pressure. The upper unit also comprises a meta-gabbro body, cropping out at Becca d'Aveille and characterized by a well-developed Alpine greenschist overprint (Dal Piaz et al., 2010).

2.4 Lower unit (Mont Mary-Cervino nappe)

The lower unit mainly consists of pre-Alpine amphibolite-facies meta-pelites and minor amphibolite, pegmatite, granitoid and leucocratic gneiss. All lithotypes show a heterogeneous Alpine greenschist-facies overprint. A few assemblages with sodic amphiboles have been reported (Canepa et al., 1990; Dal Piaz et al., 2010; Manzotti et al., 2014a).

2.5 Mesozoic sediments (Mont Dolin, Roisan Zone)

In the DBTS, Mesozoic meta-sediments are preserved in the Mont Dolin series and in the Roisan Zone.
The **Mt. Dolin series** crops out in Val d'Hérens (Fig. 5). It consists of cargneules, Triassic and Liassic carbonates, and both mono- and polygenic breccias (Hagen, 1948; Weidmann & Zaninetti, 1974; Ayrton et al., 1982). The polygenic breccias have been considered Dogger in age by Weidmann & Zaninetti (1974) and by

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Ayrton et al. (1982). Ayrton et al. (1982) described blue amphibole from the Mont Dolin Mesozoic cover sequence.

The **Roisan Zone** (Diehl et al., 1952; Elter, 1960; Ciarapica et al., 2016) consists of remnants of Mesozoic sediments, folded and sheared together with pre-Alpine sediments and mylonitized basement rocks derived from the adjacent Arolla series and lower unit (Fig. 5). The meta-sediments of the Roisan Zone contain a variety of lithologies.

1. Dolomite marbles (derived from thick-bedded dolostones) are classically attributed to the Triassic on the basis of lithology and poorly-preserved fossils like diploporacean algae (Ballèvre et al., 1986). Recently, Ciarapica et al. (2010, 2016) identified diploporacean algae and a rich association of foraminifera preserved in dolomite marble that was attributed to the Late Triassic (Norian). Some of the dolomite marbles nicely preserve primary sedimentary structures (e.g. at Grand Pays, see Ciarapica et al., 2016), like breccias and algal mats.

2. Calcite marbles comprise tabular marbles and marbles with quartzarenites, as well as thin-bedded white marbles with calcirudites.

3. Calc-schists are sometimes abundant, and in a few cases display dolomite clasts (e.g. Col de Chaléby, Bivacco Tzan-Cima Bianca area) indicating a post-Triassic age.

4. Carbonaceous matter-rich quartz-micaschists are also observed, recording sedimentation in an anoxic environment of probable Jurassic or mid-Cretaceous age.
The sedimentary sequences of the Roisan Zone are devoid of mafic and ultramafic rocks, and were deposited on top of the continental basement following rifting of the Adriatic crust.

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3. The Roisan-Cignana Shear Zone (RCSZ)

3.1 Geometry and kinematics of the Roisan-Cignana Shear Zone

The Roisan-Cignana Shear Zone (RCSZ) consists of a 25 km long high strain zone, trending SW-NE. It has been mapped from the right side of the Buthier Valley (Gignod) to the Cignana area. It is best exposed along the ridge between the Valpelline and Valtournenche valleys (Figs 5 and 7). North of the Cignana Lake, the exact location of the RCSZ is difficult to ascertain (e.g. Elter, 1960). However, based on detailed mapping of the Matterhorn (= Cervino) area (Bucher et al., 2003), Dal Piaz (1997, 1999) proposed a new geometry for the RCSZ, as depicted in Figure 5. According to these studies, the Arolla and the Valpelline series from the "Monte Cervino subunit" represent the northern extension of the Mont Mary-Cervino nappe (lower and upper unit respectively). Dal Piaz (1976, 1999) described yet another part of the RCSZ located in the Pillonet klippe (Fig. 5).
The RCSZ records several Alpine deformation phases and is characterized by tectonites and mylonites derived from protoliths of the Dent Blanche nappe (Arolla series) and of the Mont Mary-Cervino nappe (lower and upper units) basements, from pre-Alpine meta-sediments (Cuney and Becca di Salé slices) and from the Mesozoic cover of the Roisan Zone.
The Roisan Zone occurs within the RCSZ and its thickness ranges from 30-50 m to 400-500 m. It is dismembered into bands and pods from metres up to 100 m in lateral extent, embedded within mylonites derived from the Arolla series (Dent Blanche nappe) and from the lower unit (Mont Mary-Cervino nappe). The Triassic dolomites are best preserved as small pods (1-10 m) at the Col de St. Barthélémy and Roisan village, and as large lenses (10-400 m) at Cima Bianca (Fig. 7).

The deformation history of the RCSZ comprises a few relicts of pre-Alpine deformations in some lithologies (**stages 1** and **2**) and the following Alpine stages (Manzotti et al., 2014a). **Stage 3** is the oldest foliation (S_3) recognized in the field or at the microscale. **Stage 4** displays the most pervasive foliation seen in the field, and metre-to decametre-scale folds with axes trending NW-SE. During stage 4, a prominent NW–SE stretching lineation L_4 developed. L_4 is displayed by most of the rocks along the RCSZ, with the exception of the boudinaged Triassic dolomites. Kinematic indicators related to L_4 reflect a top to-NW sense of movement.

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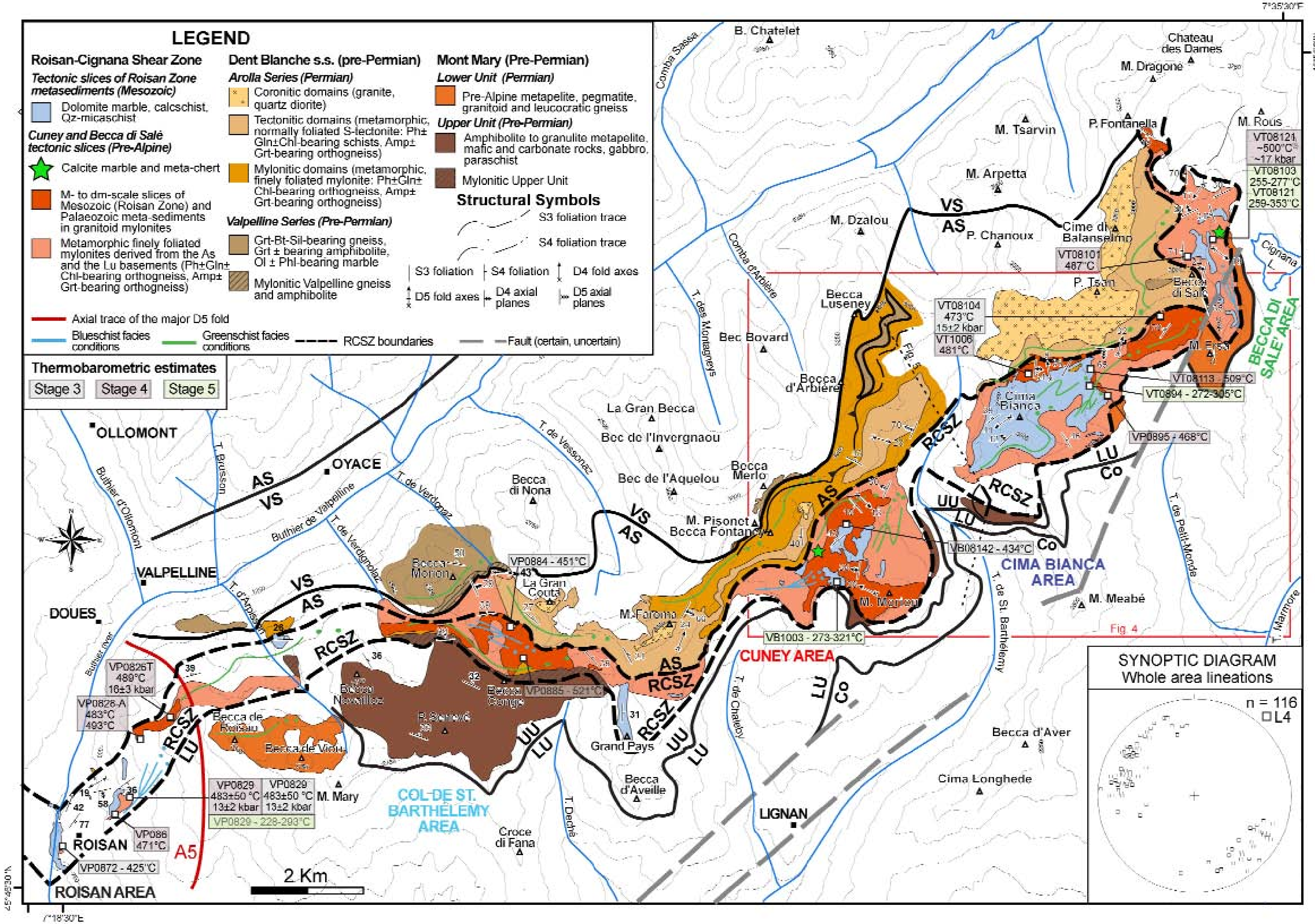

Fig. 7 – Simplified structural and geological map of the Roisan-Cignana Shear Zone (RCSZ) (from Manzotti et al., 2014a). The map also shows the distribution of samples used in the RSCM study and for P-T estimations. The axial trace of the major D5 fold (Verney fold) at Becca di Roisan is depicted in red. The inset shows lower hemisphere Schmidt (equal area) projection of the stretching lineations developed during D4. AS Arolla Series, VS Valpelline Series, RSCZ Roisan-Cignana Shear Zone, UU Upper Unit, LU Lower Unit, Co Combin Zone.

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Stage 5 occurred at greenschist facies, producing large-scale open folds (hundreds of metres in amplitude; Fig. 11) and moderate to pervasive crenulation or chevron folding. The D5 fold axes generally trend NE-SW, with axial planes dipping moderately to the NW. When this folding event becomes more intense, the L_4 stretching lineation is no more recognizable.

A kilometre-scale fold (named in the following **Verney fold**) is associated to stage 5 and it is responsible of the regional attitude of the main S_4 foliation (Fig. 9). The geometry of this fold is frequently overlooked in the literature, although it has previously been drawn by Hermann (1927) (Fig. 10) and Elter (1960) (Fig. 11). Specifically, one can define three structural domains with respect to this fold:

- In the Buthier Valley, the main foliation (D4) dips to the SE, as nicely shown by the Roisan sediments in the type locality, because we are located in the lower limb of the Verney fold.

- The hinge of the Verney fold is located in the Comba d'Arpisson area, a densely wooded place, and is relatively remote and difficult to access, but some views can be seen from a distance (Fig. 9).

- From the divide between the Valpelline and the St. Barthélémy valleys, all structures are dipping to the NW, because we are now located in the upper limb of the Verney fold.

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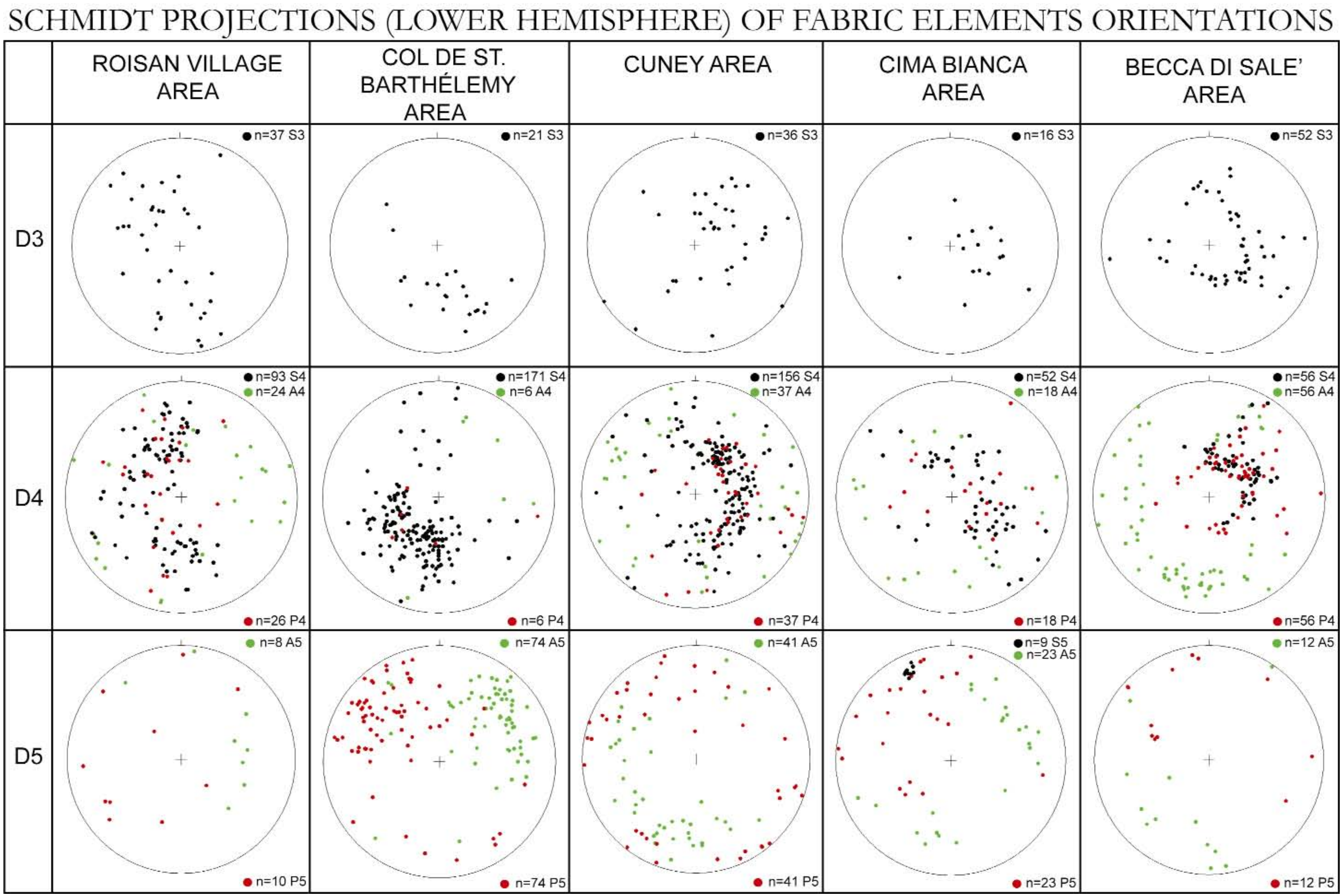

Fig. 8 – Lower hemisphere Schmidt (equal-area) projections of structures in the Dent Blanche Tectonic System (lower unit, upper unit, Roisan Zone, pre-Alpine meta-sediments). Black dots poles to syn-metamorphic surface; red dots poles to axial surface of folds; green dots fold axes (from Manzotti et al., 2014a).

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Fig. 9 – Hinge of the Verney fold (stage 5) seen from Verney farm (Comba d'Arpisson).

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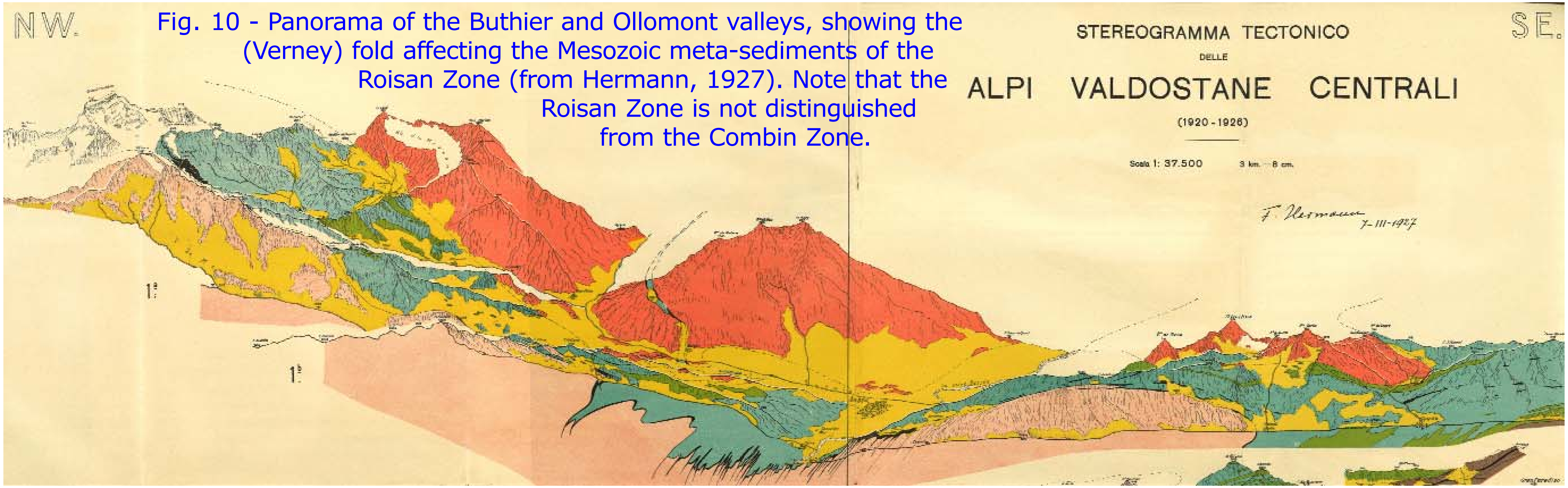

Fig. 10 - Panorama of the Buthier and Ollomont valleys, showing the (Verney) fold affecting the Mesozoic meta-sediments of the Roisan Zone (from Hermann, 1927). Note that the Roisan Zone is not distinguished from the Combin Zone.

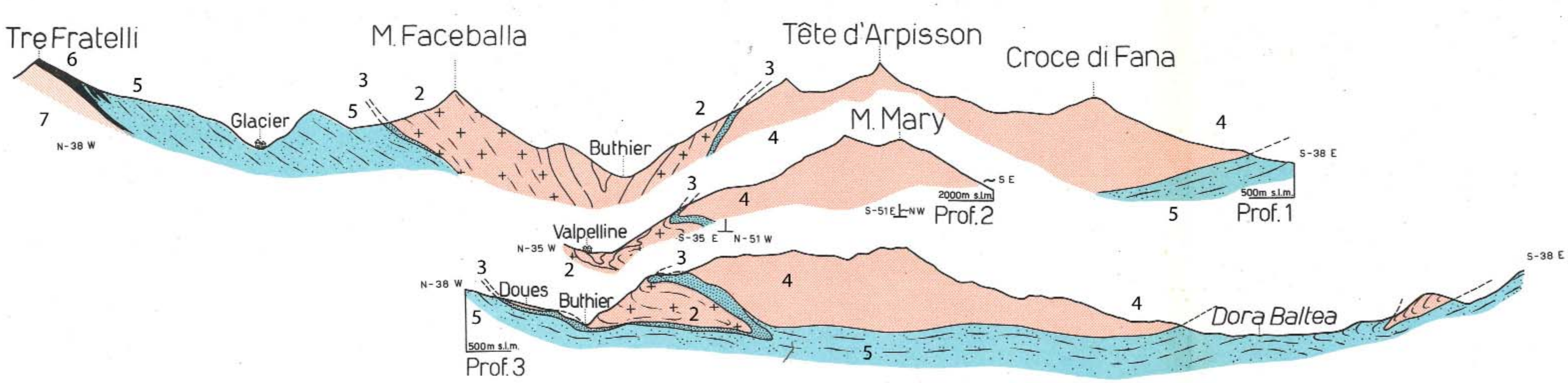

Fig. 11 – Cross-section through the Buthier and Ollomont valleys, showing the (Verney) fold affecting the Mesozoic meta-sediments of the Roisan Zone (n° 3) (from Elter, 1960). Note that the Roisan Zone is also depicted below the Dent Blanche nappe.

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3.2 Metamorphism of the Roisan-Cignana Shear Zone

Due to the lack of appropriate bulk-rock chemistries, it is difficult to characterize the Alpine metamorphism (stages 3 and 4) in the RCSZ.

1. In the meta-sediments of the Roisan Zone, T estimates have been made on carbonaceous micaschists and calc-schists using the RSCM method (Beyssac et al., 2002, 2003). Out of the 14 samples studied by Manzotti et al. (2014a), an average T of 473 ± 17°C and of 451 ± 11°C were derived in graphitic micaschist and calc-schist that display stage 3 microstructures. Temperatures between 470 and 521 °C and between 467 and 509 °C have been obtained for stage 4 microstructures. Because the RSCM method allows access to maximum temperatures, these values indicate T at around 450-500 °C. Another sample (calc-schist, #03a) from the Roisan Zone has been studied by the same method by Angiboust et al. (2014), providing a T of 482 ± 15°C, consistent with the estimates of Manzotti et al. (2014a).

2. Another indicator for the metamorphic evolution of the Roisan Zone includes the phengite-quartz-H_2O equilibrium as calibrated by Dubacq et al. (2010), providing values of c. 15-16 kbar. As discussed by Manzotti et al. (2014a), these values may overestimate the P.

3. In the orthogneisses from the RCSZ, garnet-phengite mineral pairs indicate 483 ± 50 °C for stages 3 and 4. The phengite-quartz-H_2O method of Dubacq et al. (2010) indicates pressure of 13 ± 2 kbar.

4. In the pre-Alpine marbles and meta-cherts, the same method yields (maximum) pressure of about 17 kbar for a nominal T of 500 °C (Manzotti et al., 2014a).

For stage 5 the following temperatures (± 25 °C) have been estimated using the chlorite-quartz-water method of Vidal et al. (2005, 2006) for a fixed pressure of 4 kbar:
- 272-321°C in the carbonaceous micaschists of the Roisan Zone;
- 228-293°C in the blue amphibole bearing orthogneiss of the Arolla series and lower unit;
- 255-277°C in the pre-Alpine meta-chert;
- 259-353°C in the pre-Alpine impure marble.

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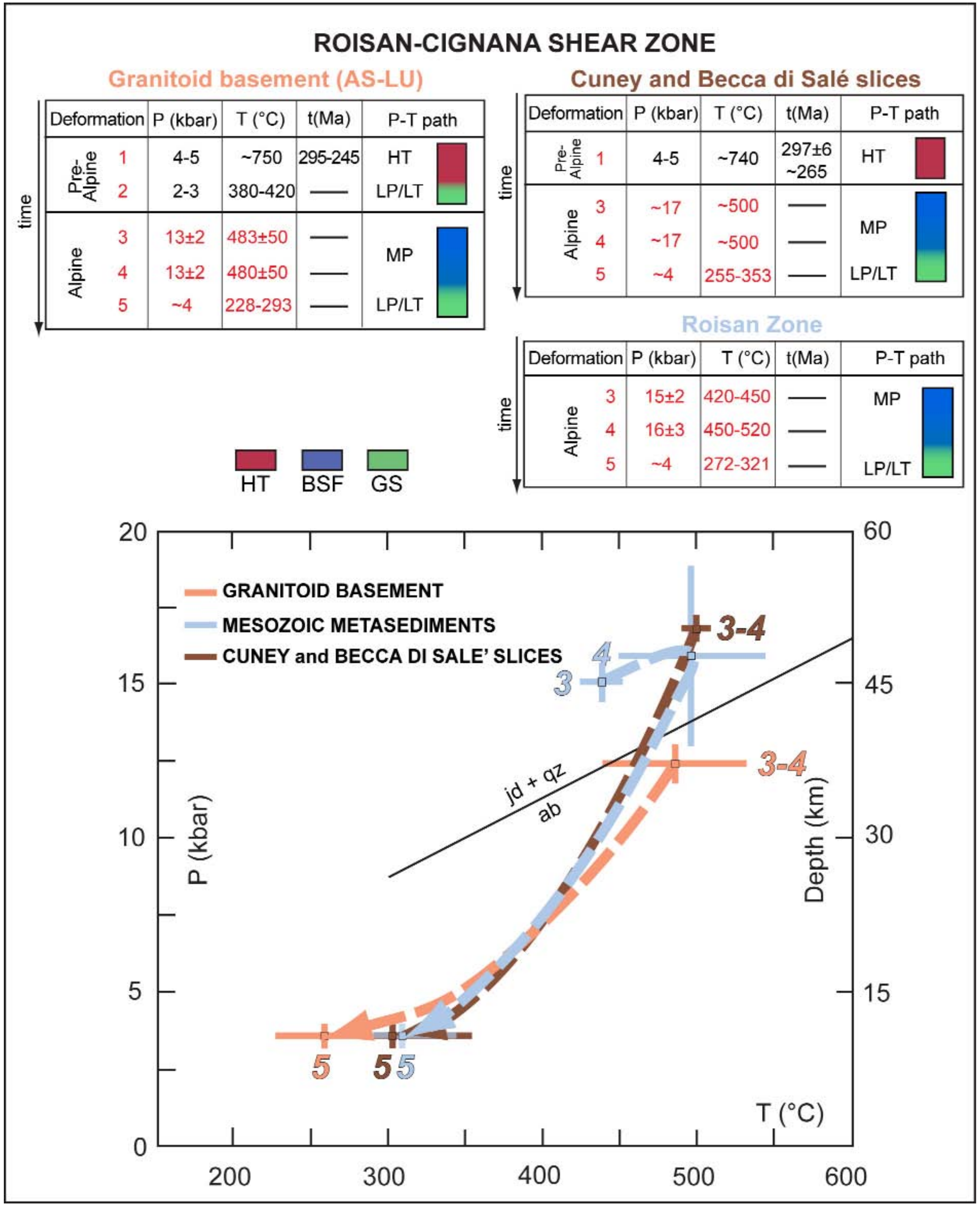

To sum up, the rocks from the DBTS undoubtedly record an early Alpine evolution at c. 500°C, at relatively high pressure (13 ± 2 kbar), although accurate estimates are still in progress. Structural and metamorphic evidence suggests that a tectonic incorporation of the Cuney and Becca di Salé slices (Fig. 7) in the polydeformed basement of the Arolla series (Dent Blanche nappe) and of the lower unit (Mont Mary-Cervino nappe) occurred prior to or during stage 3, at relatively high pressure conditions (~13 ± 2 kbar) (Fig. 12).

Fig. 12 – Summary of P–T–d–t table for the studied tectonic slices (Arolla series, lower unit of the Mont Mary-Cervino nappe, Roisan Zone, pre-Alpine meta-sediments, all belonging to the DBTS) involved in the RCSZ (from Manzotti et al., 2014a). Data obtained from Manzotti et al. (2014a) are in red. Literature data are reported in black (Roda & Zucali, 2008; Manzotti et al., 2012). A coloured column indicates the metamorphic conditions estimated for the different stages of the evolution (HT high temperature—amphibolite/granulite facies, BSF blueschist facies, GSF greenschist facies). The graph shows the Alpine P–T evolution for the basement units (Arolla series of the Dent Blanche nappe and lower unit of the Mont Mary-Cervino nappe), the Roisan Zone and the Cuney and Becca di Salé slices, along the RCSZ (from Manzotti et al., 2014). The Ab = Jd + Qz equilibrium is calculated according to Holland (1980).

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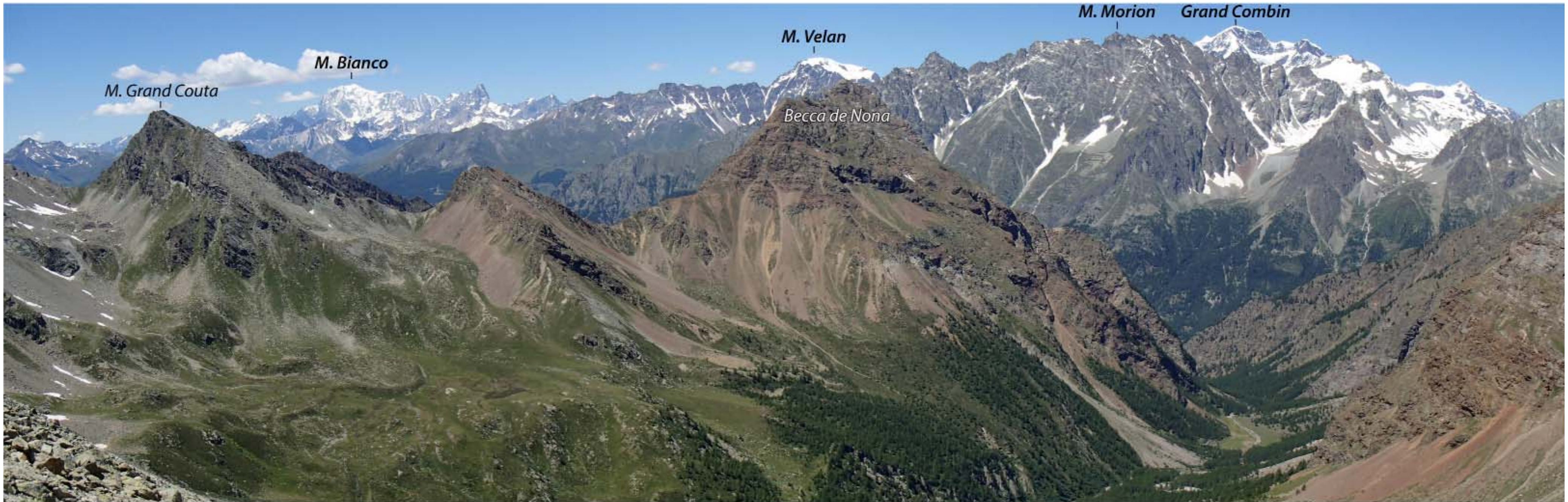
Day 1: The Valpelline series

This half journey is dedicated to the Valpelline series, a slice of Permian lower crust derived from the Adriatic continent. The Valpelline series crops out along the Valpelline Valley, from the Valpelline village (about 950 m) to the head of the valley, at the Col de Valpelline 3559 m, along the Swiss-Italian border. The valley is surrounded by a large number of high summits, including Mont Morion (3505 m), Dent d'Hérens (4171 m), Becca di Luseney (3504 m), Monte Redessau (3253 m), Becca del Merlo (3237 m), Monte Faroma (3070 m), Mont Mary (2815 m). Please note the odd orientation (NE-SW) of the valley with respect to the general orientation of the Alpine belt, with the Buthier river going downstream towards the SW, i.e. towards the core of the Alpine belt. This may be explained by the fact that the Buthier river follows a late brittle fault (the Valpelline fault), whose importance has only been recently acknowledged (e.g. Dal Piaz et al., 2015).



A view of the Valpelline from the Col de Vessona, showing the contact between the greenish orthogneisses of the Arolla Series (M. Grand Couta) and the reddish paragneisses of the Valpelline Series (Becca de Nona).

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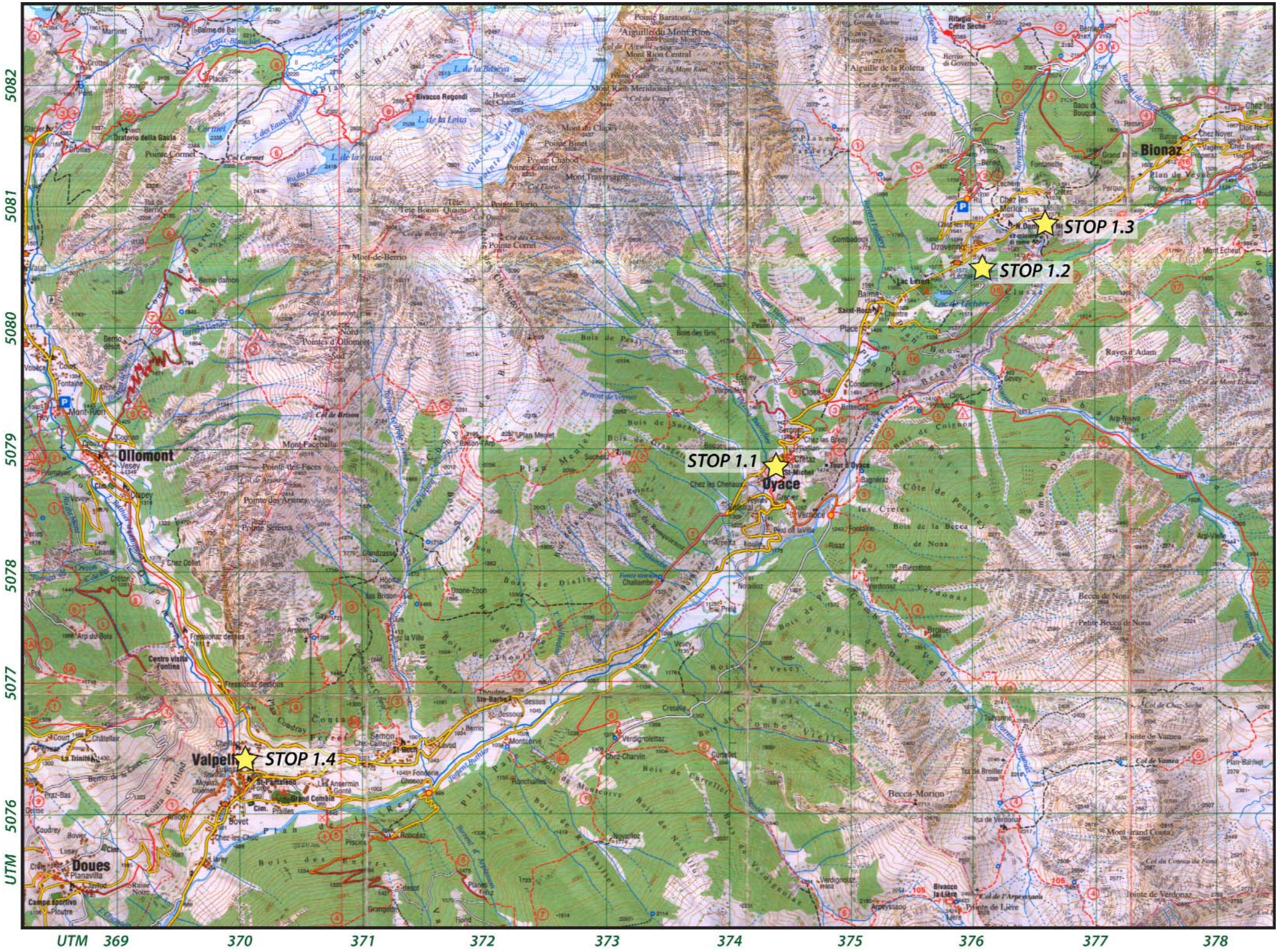

Fig. 1.1 – Location of the first day Stops (1-4), from Blatto & Zavatta, 2009.

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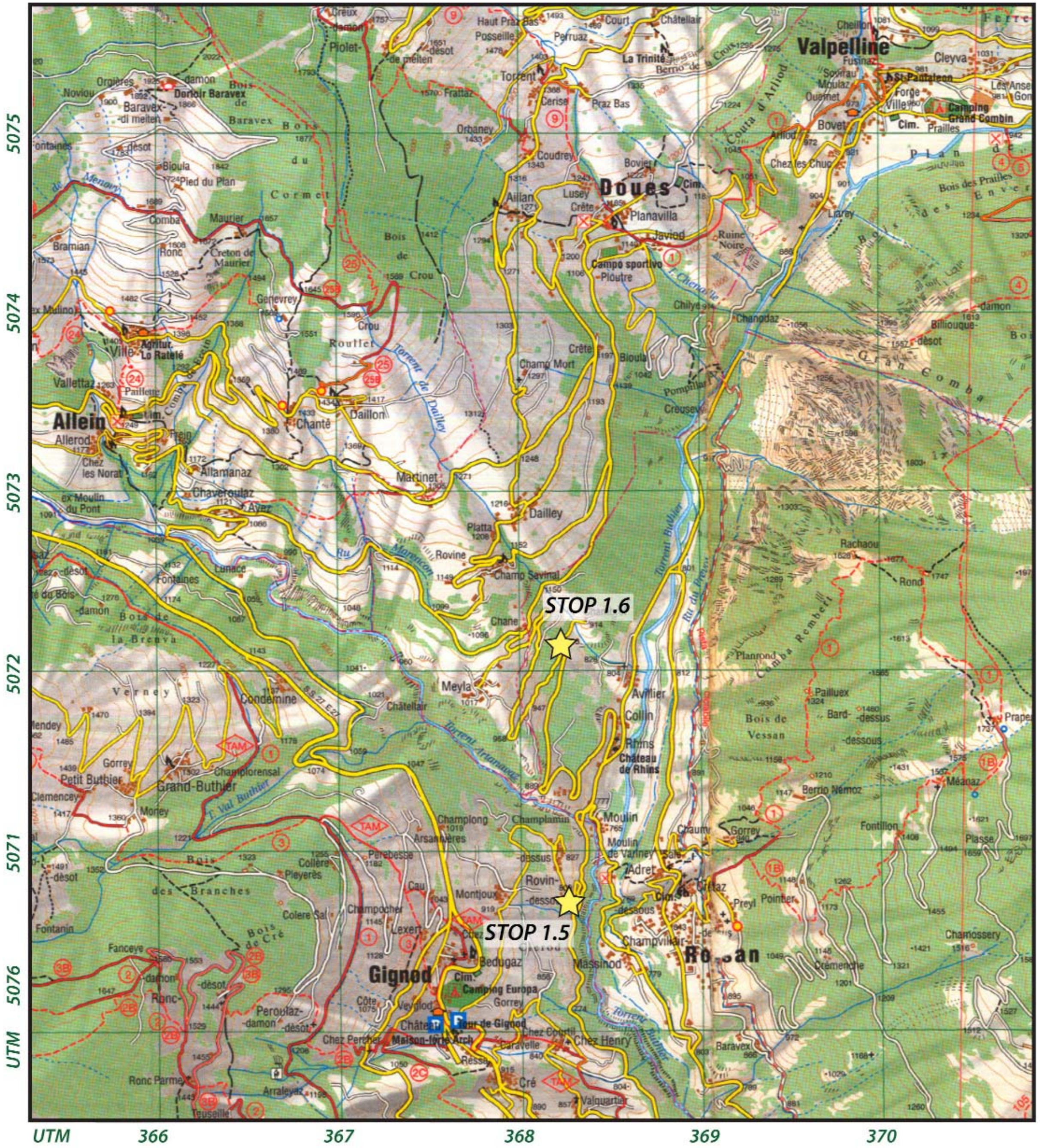

Fig. 1.2 – Location of the first day Stops (5-7), from Blatto & Zavatta, 2011.

STOP 1.1 - Oyace (Cretaz hamlet, S. Michele church): high grade meta-pelite

Valpelline – Main road to the Place Moulin dam (45°51’01.19” N, 7°22’53.82” E, elev. c. 1362 m a.s.l.)

Take the road to the Place Moulin dam and stop in the sporting area in Cretaz hamlet (Oyace), close to the S. Michele church.

In the outcrop (Fig. 1.3), the following lithologies are observed:

- Meta-pelites, consisting of metatexites in which leucosomes may occur as mm- to cm-sized layers. Granoblastic aggregates of quartz, K-feldspar, plagioclase, and garnet are oriented parallel to the main foliation. Melanosomes consist of biotite-garnet-sillimanite. Locally, pinkish garnet-rich restites occur (Fig. 1.4).
- Amphibolites occur as decametre-size bodies interlayered with meta-pelites. They consist of plagioclase, amphibole, ± garnet, ± clinopyroxene. The foliation is marked by plagioclase-rich layers and by the shape preferred orientation of amphibole (hornblende).
- Pegmatitic veins frequently cut cross the main foliation.

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- In the left part of the outcrop, a few cataclasites occur (Fig. 1.3) along fault planes moderately dipping to the SE. Shear criteria indicate a top-to-the NW displacement of the hangingwall with respect to the footwall.

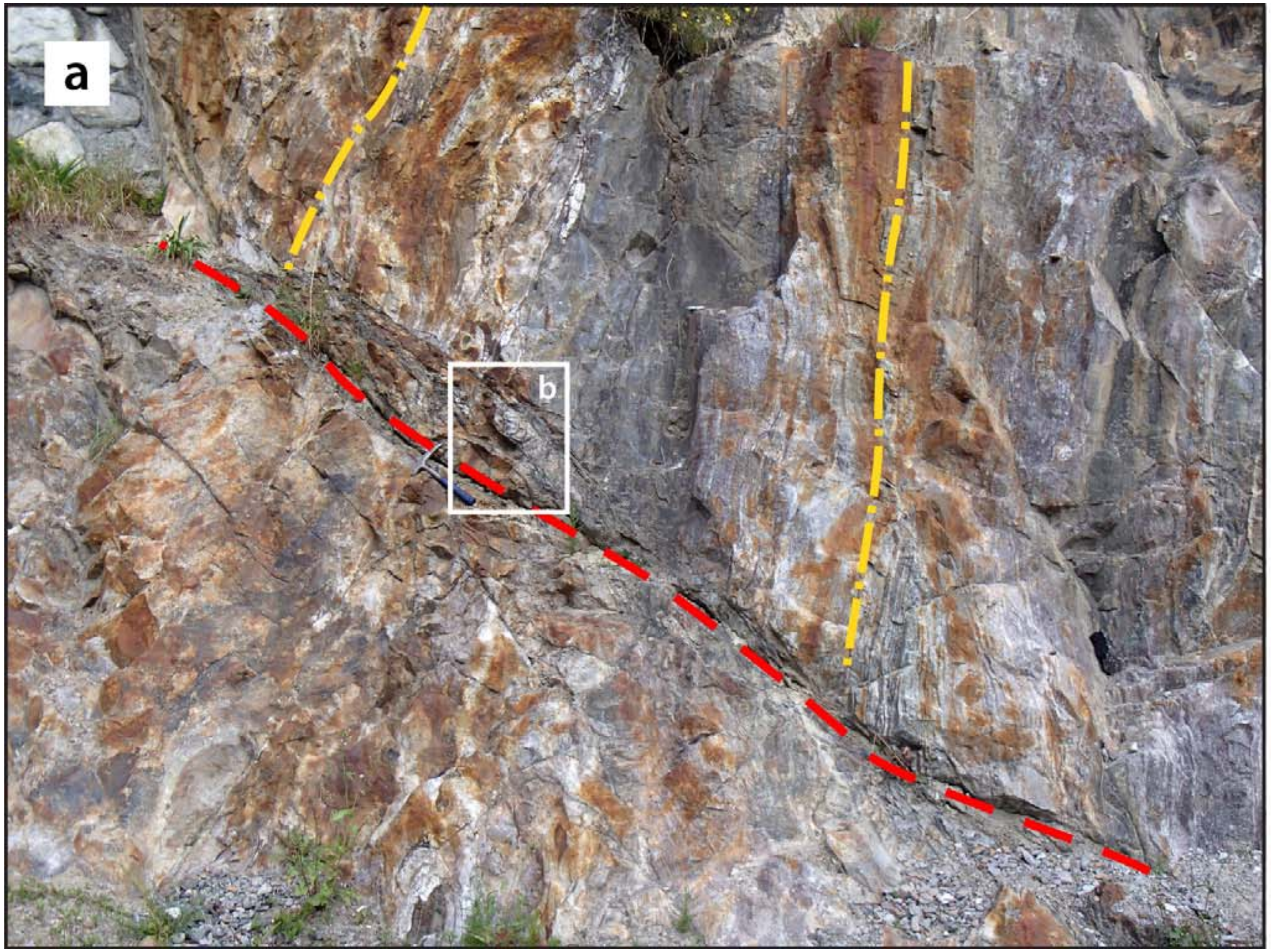

Fig. 1.3 – **a)** Typical appearance of the reddish meta-pelites from the Valpelline series. **b)** Detail of cataclasites cutting the layering and the foliation in the meta-pelite.

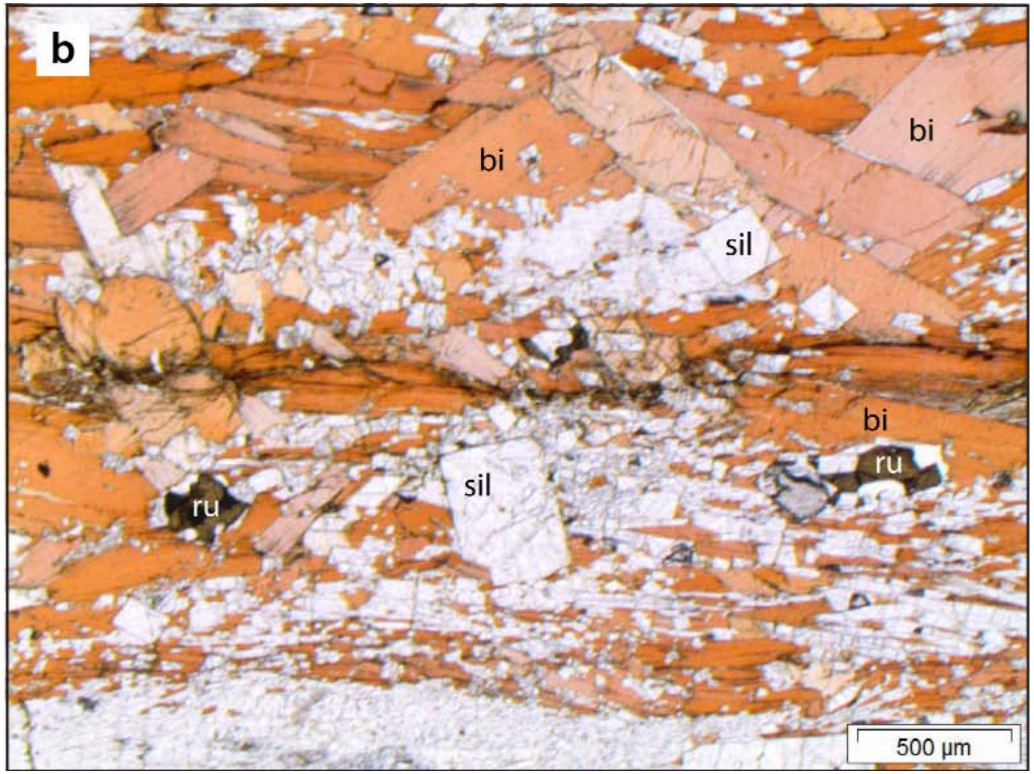

Fig. 1.4 - **a)** Detail of partially melted meta-pelites from the Valpelline series: foliation is marked by the alternation of quartz-plagioclase and garnet-biotite±sillimanite layers. **b)** Foliation defined by biotite and sillimanite layers in a meta-pelite (Photomicrograph in plane polarized light).

STOP 1.2 - Bionaz (Lac Lexert)

Valpelline – Main road to the Place Moulin dam (45°52′00.70″ N, 7°24′20.73″ E, elev. c. 1584 m a.s.l.)

Proceed along the same road for a few kilometres and stop on the right side of the road, by Lac Lexert. Take the cross-country ski run. Fine-grained amphibolites (Fig. 1.5) with coarse-grained veins occur, resulting from partial melting. The veins are generally parallel to the main pre-Alpine foliation (S=310/80, trend 50) and contain plagioclase+quartz+pyroxene±garnet. The fine-grained amphibolites display a stretching lineation dipping to the N-NE.

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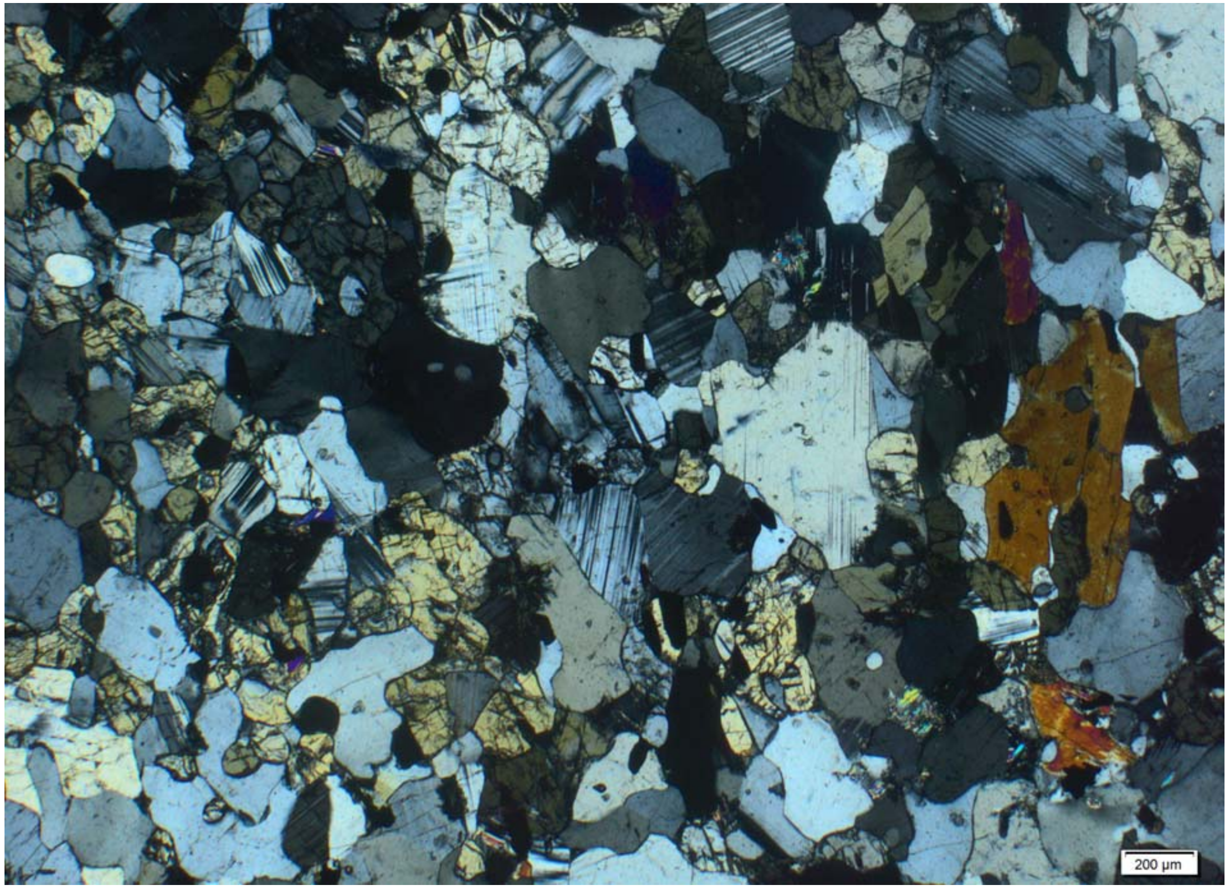


Proceeding along the path to the S-SE, layers of meta-pelites occur, characterised by garnet ± orthopyroxene leucosomes.

Fig. 1.5 – Hornblende, plagioclase and clinopyroxene in an amphibolite (Photomicrograph in crossed polarized light).

STOP 1.3 - Bionaz (Moulin hamlet): high grade mafic rocks

Valpelline – Main road to the Place Moulin dam (45°52'07.53" N, 7°24'38.67" E, elev. c. 1610 m a.s.l.)

Proceed on the same road for few hundred metres and stop in the car park on the right side of the road, situated in Moulin hamlet. Carefully cross the road.

The outcrop consists of garnet-bearing amphibolites interbedded with garnet-biotite gneisses. In the amphibolites, idioblastic garnet crystals are up to 5 cm in size and exceptionally up to 15 cm in size (**please do not hammer!**). Garnet is in most cases located into leucosomes (quartz-plagioclase), suggesting that it precipitates during partial melting as a peritectic phase (e.g. Pl + Amp + Qtz = Liq + Grt). The same is true for Cpx-bearing leucosomes (Fig. 1.6).

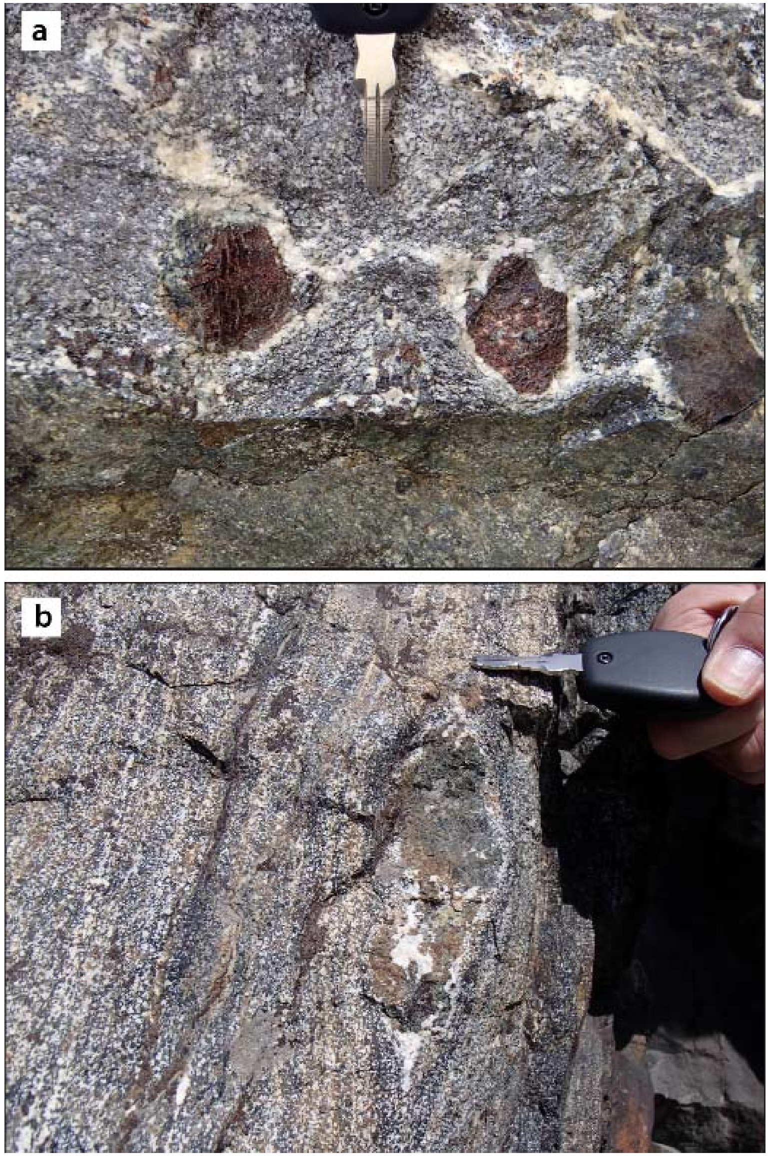
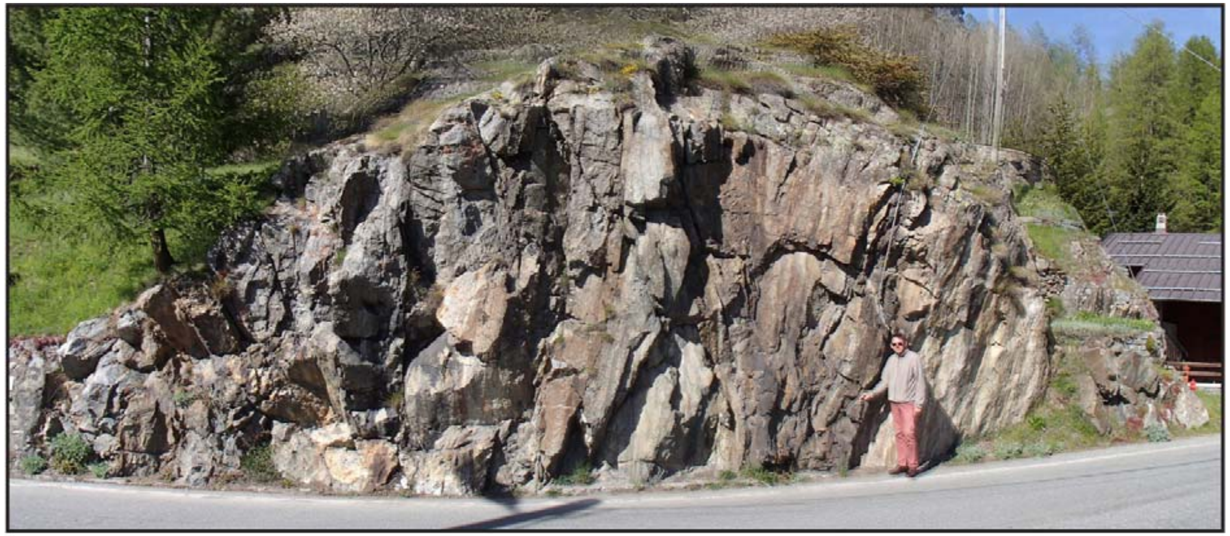


Fig. 1.6 – Evidence for partial melting in the Valpelline series. **A)** Idioblastic garnet porphyroblasts in a leucosome within an amphibolite. **B)** Clinopyroxene-bearing leucosome in an amphibolite.

Gently folded pegmatitic dykes cut the main foliation (S= 302/70, trend 50). The axial plane of the pegmatite folds is parallel to the main layering and to the foliation in the enclosing garnet-biotite gneisses (Fig. 1.7).



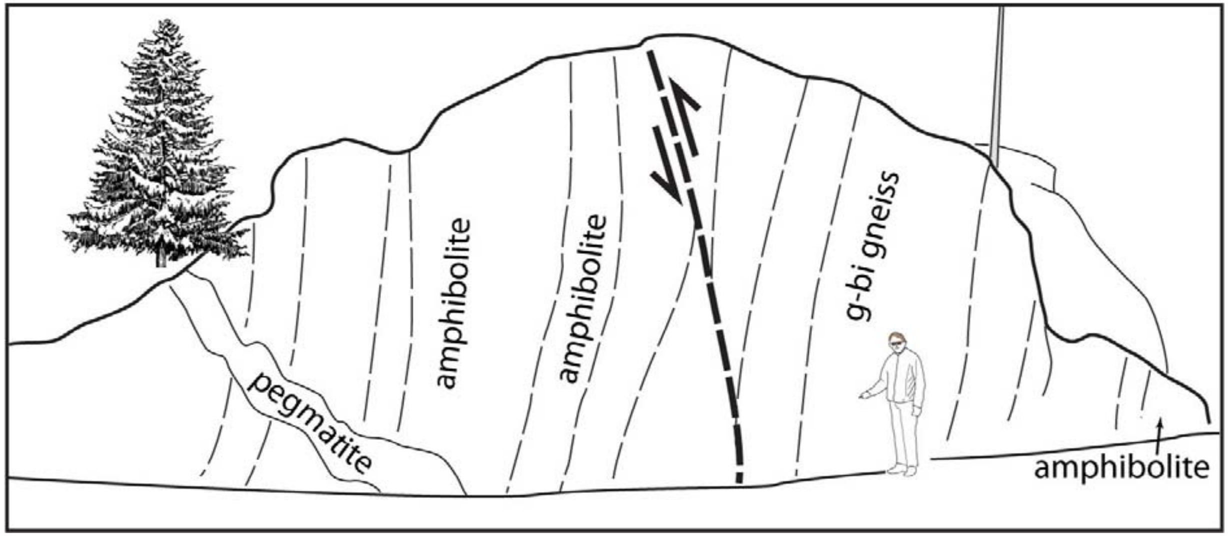


Fig. 1.7 – Photograph and hand-drawing of the outcrop of Stop 1.3. Metre- to decametre-scale ductile shear zone and cross-cutting pegmatites occur.

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A low-angle ductile shear zone is also seen in this outcrop (Fig. 1.7). This shear zone is undoubtedly of pre-Alpine age, because the HT mineral parageneses are stable within the shear zone. Its present orientation is the result of the Alpine deformation, the Valpelline series being rotated as a whole (without much internal strain).

Assuming that the main foliation in the Valpelline Series was subhorizontal during the pre-Alpine time, it follows that the displacement observed along the shear zone and the folding of the pegmatite dykes are compatible with vertical shortening, in line with all models assuming a crustal-scale extensional regime during the Permian.

STOP 1.4 - Valpelline (hydroelectric plant): mylonites at the boundary between Arolla and Valpelline series

Valpelline – Behind the hydroelectric plant (45°49'38.44" N, 7°19'25.29" E, elev. c. 989 m a.s.l.)

Following the same road, return to Valpelline village and park the car close to the municipal hall. Take the small road to the right of the town hall and walk for one hundred metre towards the hydroelectric plant. Behind the hydroelectric plant, two outcrops occur. The first one consists of partially melted garnet-rich amphibolites belonging to the Valpelline series (Fig. 1.8). The second one is made of mylonites and ultramylonites and represents the contact between the Valpelline series and the Arolla series (S=162/67). The contact develops for 1 m in the Valpelline series and for ~10 m in the Arolla series (i.e. strongly deformed Arolla chlorite-muscovite orthogneiss). A stretching

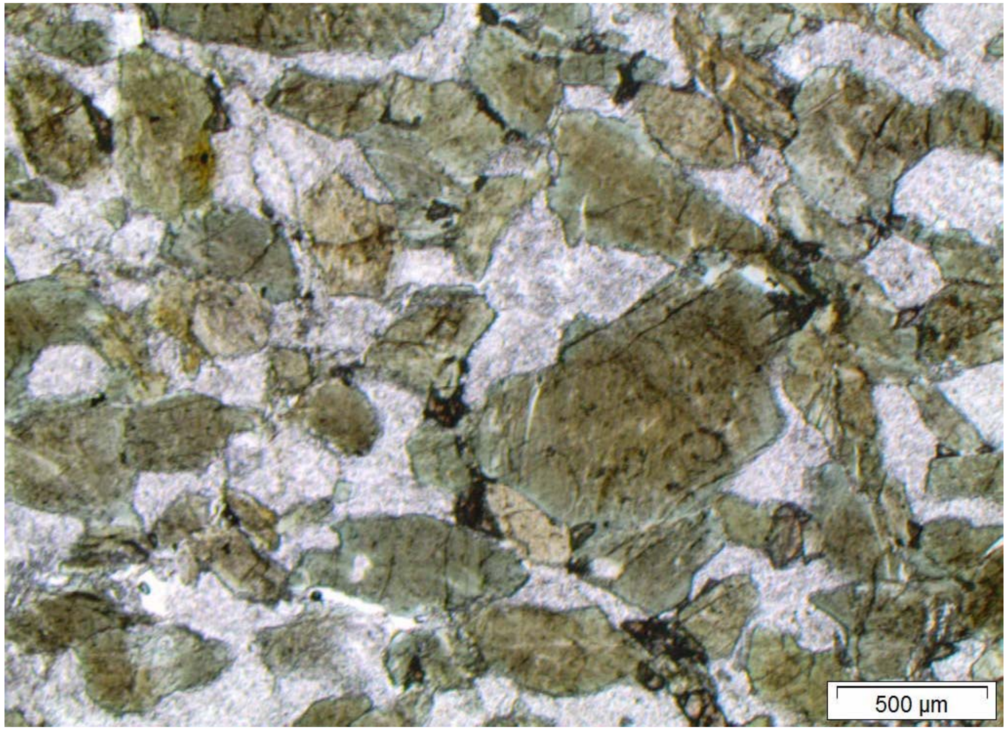

Fig. 1.8 – Plagioclase and hornblende from an amphibolite from the Valpelline series, close to the contact with the Arolla series. Brown hornblende is decoloured and mainly green at the rim, whereas plagioclase is partially replaced by fine-grained aggregates of muscovite (photomicrograph in plane polarized light).

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lineation (L=160/75) is visible, particularly in the Valpelline ultramylonites.
In the Arolla orthogneisses, some cm-scale folds are visible. Shear criteria (e.g. cm-spaced shear bands and asymmetric folds in quartz-veins) indicate a displacement of Valpelline rocks towards the NNW with respect to the Arolla series. In its present geometry, the contact is therefore a thrust.

STOP 1.5 - Gignod: Mesozoic meta-sediments from the Roisan Zone

Gignod – Along the road from Valpelline to Aosta, crossroad for Rovin (45°47'05.80" N, 7°18'18.17" E, elev. c. 797 m a.s.l.)

A section across the Roisan Zone can be made along the road from Valpelline to Aosta, close to the cross for Rovin, a small village north-east of Gignod. Care must be taken along the road because of the traffic.
From north to south (i.e. from bottom to top), one can see:
- Orthogneiss of the Arolla series (S_4 = 170/58; L_4 = 85/32).
- Graphitic micaschist with quartz-calcite veins. Ankerite is locally present. (S_4 = 155/50). Grey marble layers, 5 to 10 cm thick, occur inside the micaschist. A sample (#VP0872) from this locality has been used for determining the maximum T of metamorphism using the RSCM method (425 ± 7 °C) (Manzotti et al., 2014a).
- Whitish dolomite pods (up to 20 x 10 m in size) occur within the graphitic micaschist (Fig. 1.9). The dolomite pods are not foliated. The foliation in the graphitic micaschists wraps the dolomite pods. This foliation (S_4 = 129/30) may be locally crenulated.
- The graphitic micaschists crop out up to a small river (a tributary of the Buthier).

Fig. 1.9 – Dolomite pods within graphitic micaschists of the Roisan Zone.

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STOP 1.6 - Panorama between Valpelline and Roisan

Hairpin turn – Along the road from Rhins to Allein (45°47'49.82" N, 7°18'12.48" E, elev. c. 912 m a.s.l.)

This panorama displays a view on the rigth side of the Buthier Valley, dominated by summits (Becca de Roisan, Becca de Viou, and Mont Mary) belonging to the Mont Mary nappe. The Roisan-Cignana Shear Zone is not easily recognizable in the panorama, except for the outcrops of white- to yellow patches of Triassic dolomites in the slopes below the Becca de Roisan. These are located on top of strongly deformed Arolla orthogneisses, making the bulk of the cliffs on the left of the panorama (Fig. 1.10). The main foliation (S4), which is parallel to the lithological boundaries, is deformed by an open kilometre-scale fold (D5, Verney fold), whose hinge is located close to the sky line. Note that the change in apparent thickness from the hinge to the lower limb of the fold is largely due to topographic effects. In the lower slopes of the Buthier Valley, the Alpine rocks and structures are covered by Quaternary glacial and fluvio-glacial deposits, on top of which is built the Roisan village. However, the Roisan dolomites and associated rocks also outcrop on the rigth side of the Buthier Valley (Stop 1.5), where they display the same strike and dip than on the panorama. It follows that the Roisan-Cignana Shear Zone displays on the maps a "vee" in the Buthier Valley (e.g. Figures 5 and 7).

Main conclusions of the first day

1. The Valpelline series is made of a suite of pelitic, carbonate and mafic protoliths with high-grade amphibolite to granulite facies metamorphism (c. 7-8 kbar, 800-850°C), of Permian age. The pre-Alpine structures in the Valpelline series are well preserved (along strike, for at least 10 km; across strike, for about 1-2 km). Some structural evidence for crustal-scale extension during high-grade metamorphism is preserved in the Valpelline rocks.

2. Inside the Valpelline series, the Alpine metamorphism is very weak or absent, and the tectonic overprint is reduced to discrete shear zones. No clear evidence in favour of a synformal fold is found. The Valpelline series cannot represent the full thickness of the lower crust during the Permian. Therefore, the Valpelline series may be considered as a coherent piece of lower crustal rocks, extracted from the lower Adriatic crust either during the Mesozoic rifting, and/or during the Alpine convergence.

3. The contact Arolla-Valpelline is a first-order ductile (thrust) shear zone. Mylonites along the shear zone essentially develop at the expense of the Arolla series.

4. The Roisan-Cignana Shear Zone (to be described in detail during Day 3) displays a D5 km-scale fold (Verney fold), with a NW-vergence (Figs 1.10 and 1.11).

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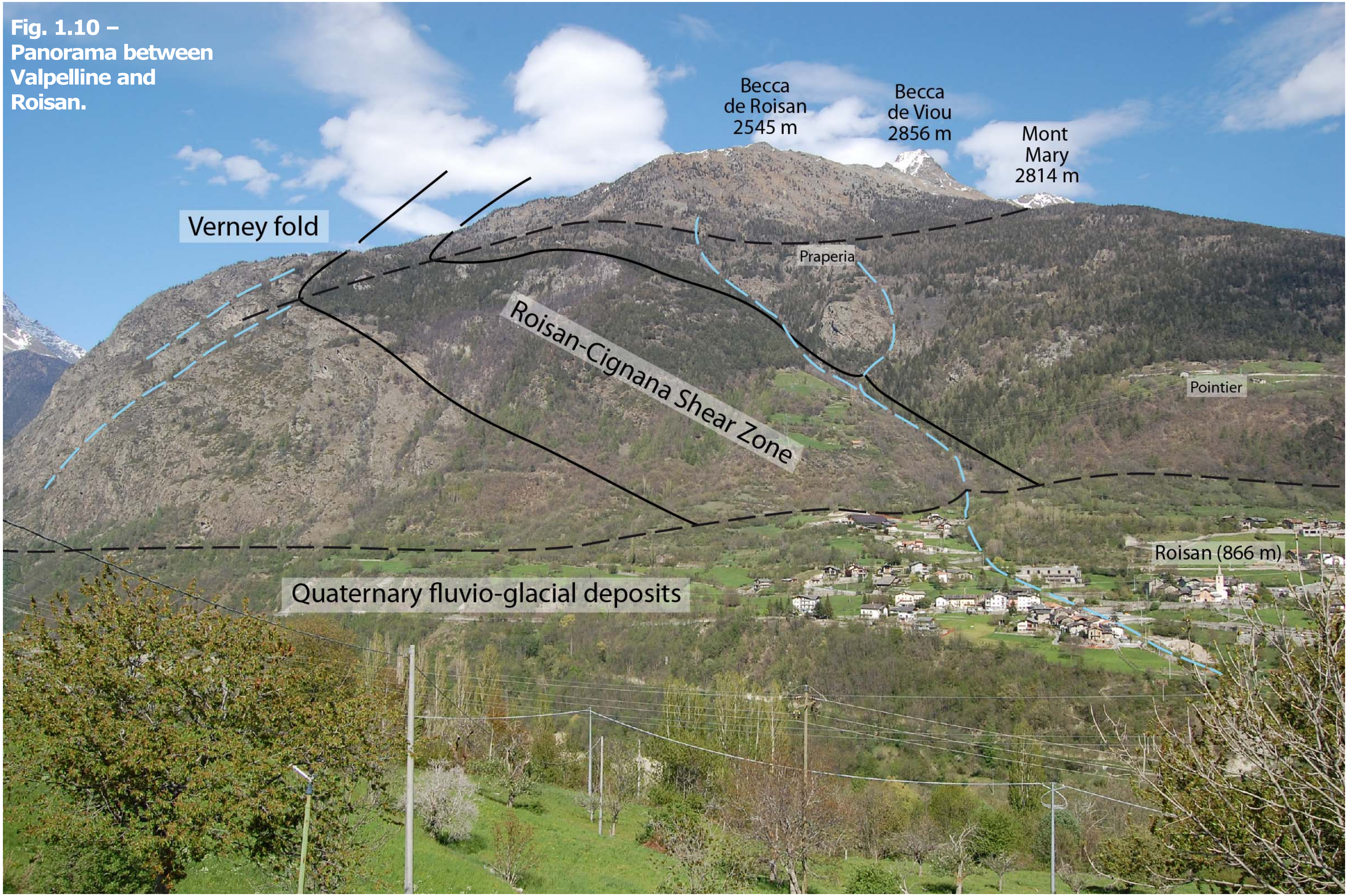

Fig. 1.10 – Panorama between Valpelline and Roisan.

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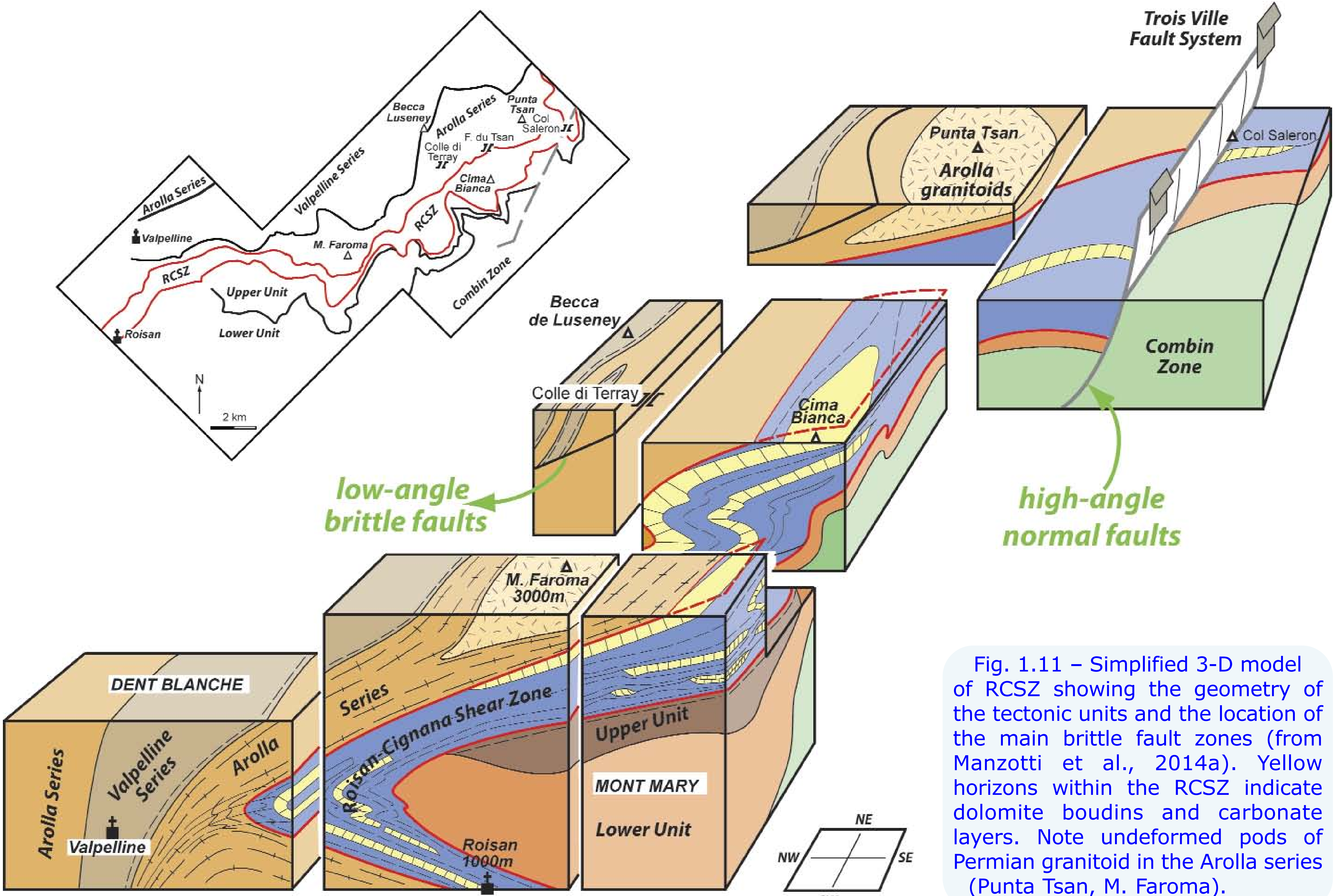

Fig. 1.11 – Simplified 3-D model of RCSZ showing the geometry of the tectonic units and the location of the main brittle fault zones (from Manzotti et al., 2014a). Yellow horizons within the RCSZ indicate dolomite boudins and carbonate layers. Note undeformed pods of Permian granitoid in the Arolla series (Punta Tsan, M. Faroma).

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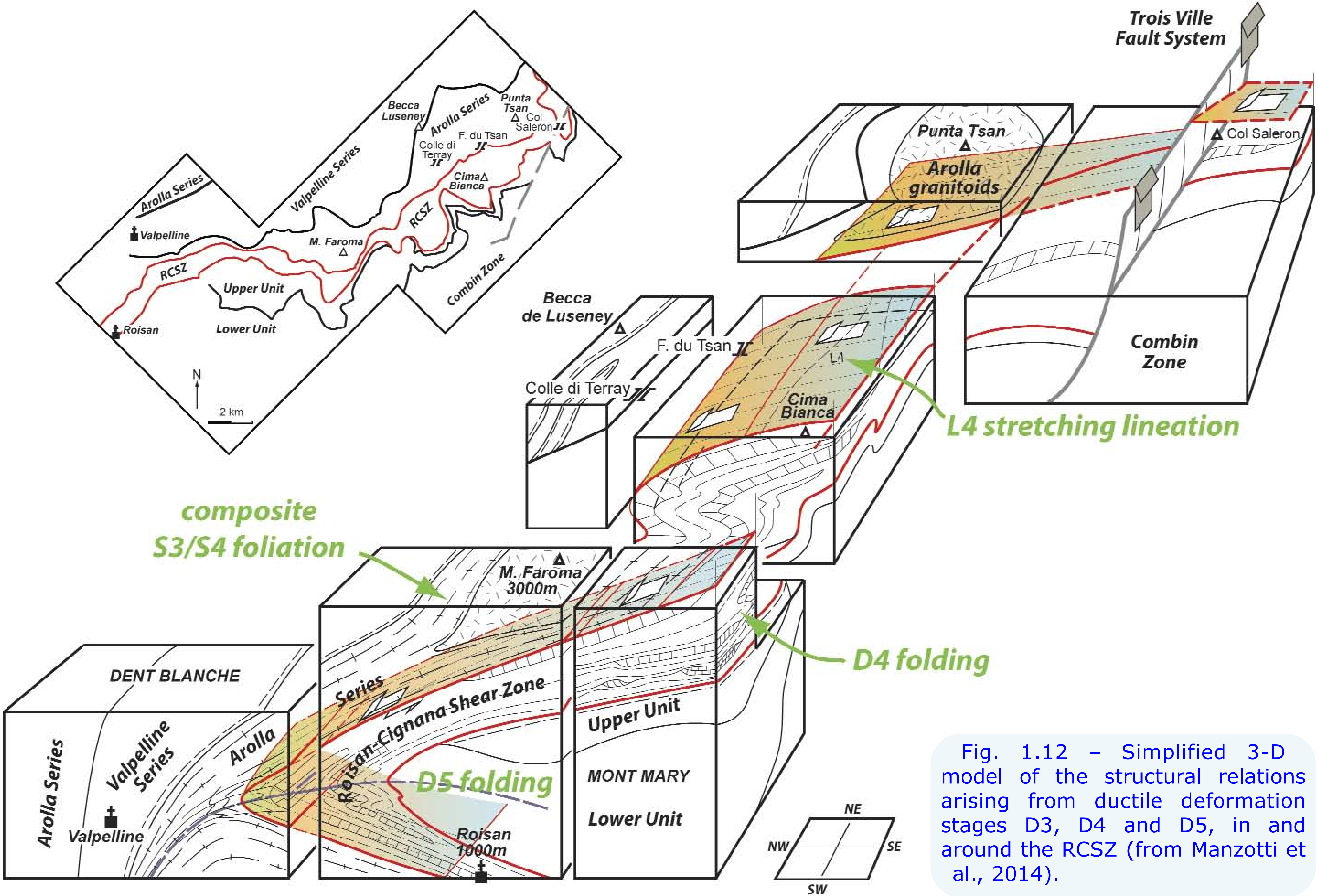

Fig. 1.12 – Simplified 3-D model of the structural relations arising from ductile deformation stages D3, D4 and D5, in and around the RCSZ (from Manzotti et al., 2014).

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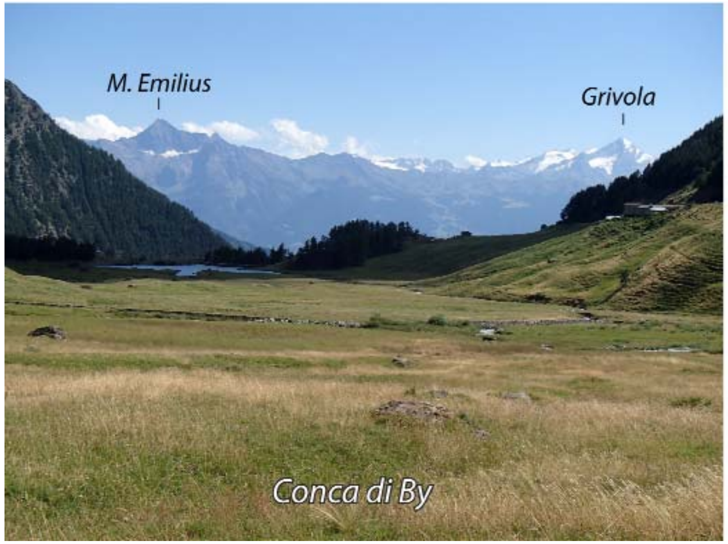
Day 2: The contact between the Arolla series and the Tsaté unit

Ollomont Valley and Conca di By

The second day is dedicated to the geometry and kinematics of the contact between the Dent Blanche and the Tsaté unit (Piemonte-Liguria ocean).

Main mountains:
Mont Vélan (3708 m); Grande Tête de By (3587 m); Mont Avril (3347 m); Mont Gelé (3519 m).

Places of interest:
Copper mine, now transformed in a "cheese mine" (Fontina Museum).



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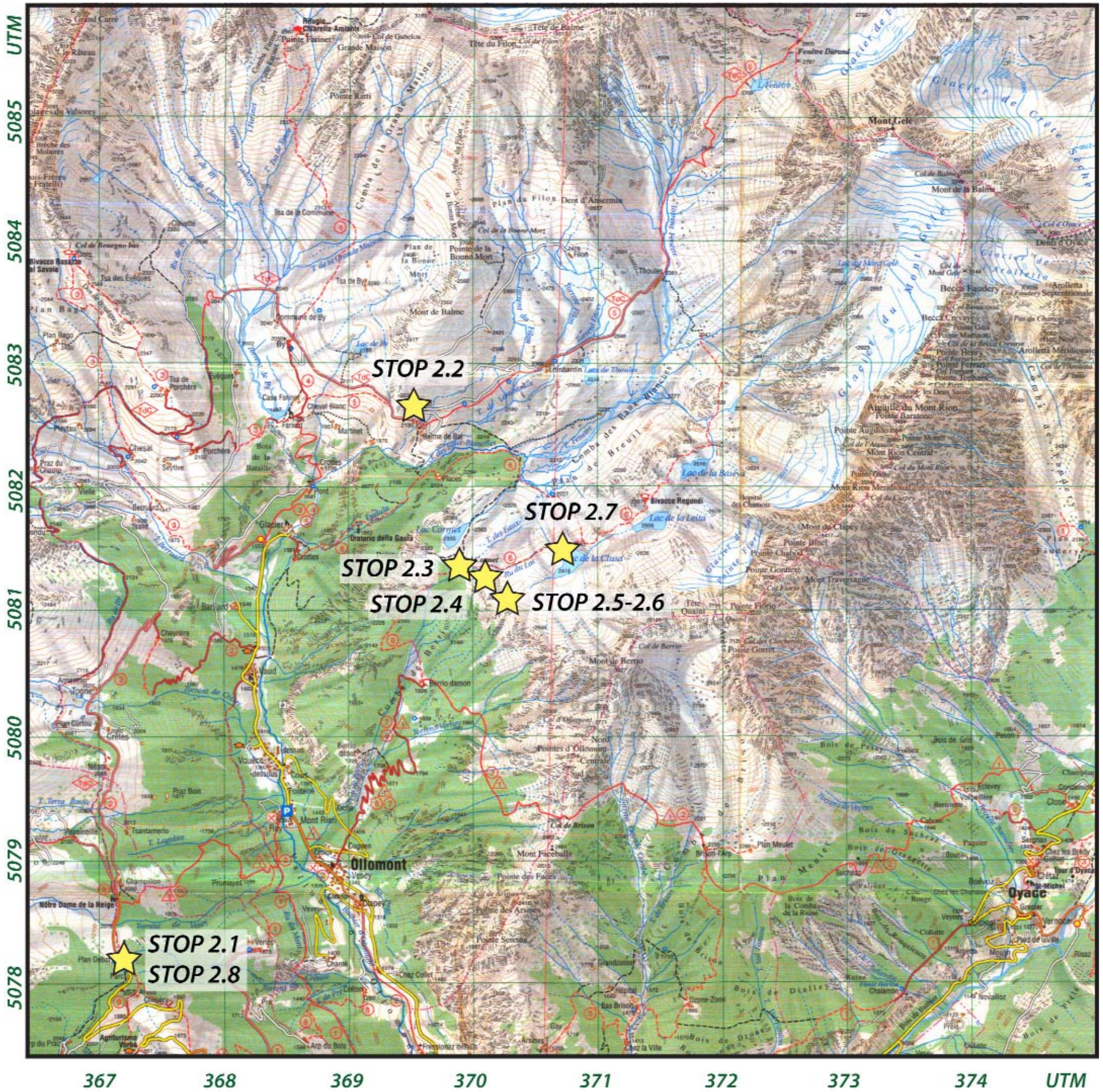

Fig. 2.1 – Location of the second day Stops (from Blatto & Zavatta, 2009).

STOP 2.1 - Panorama from Plan Debat (2076 m): introduction of the main units

Valpelline – Road for Plan Debat (45°50’36.30” N, 7°17’16.10” E, elev. c. 2098 m a.s.l.)

Take the road from Valpelline to Doues and continue on the same road for 15 kilometres up to Plan Debat, at the entrance of the Conca di By (20-25 minutes). From left to right, the main summits and passes surrounding the Conca di By are M. Vélan, Grand Combin, M. Avril, Fenêtre de Durand (contact between Tsaté unit and Dent Blanche nappe), M. Gelé, M. Morion and M. Berrio. Inside the Conca di By, there is a prominent ridge, extending from the M. Berrio to the Punta Cornet. This ridge represents the best section in the area to observe the contact between the Combin unit (Tsaté unit) and the Dent Blanche nappe (Fig. 2.2). On the left side of Valpelline, there is a high altitude ridge that goes from the Becca di Viou, Becca di Fana to the Becca dell’Aquelou.

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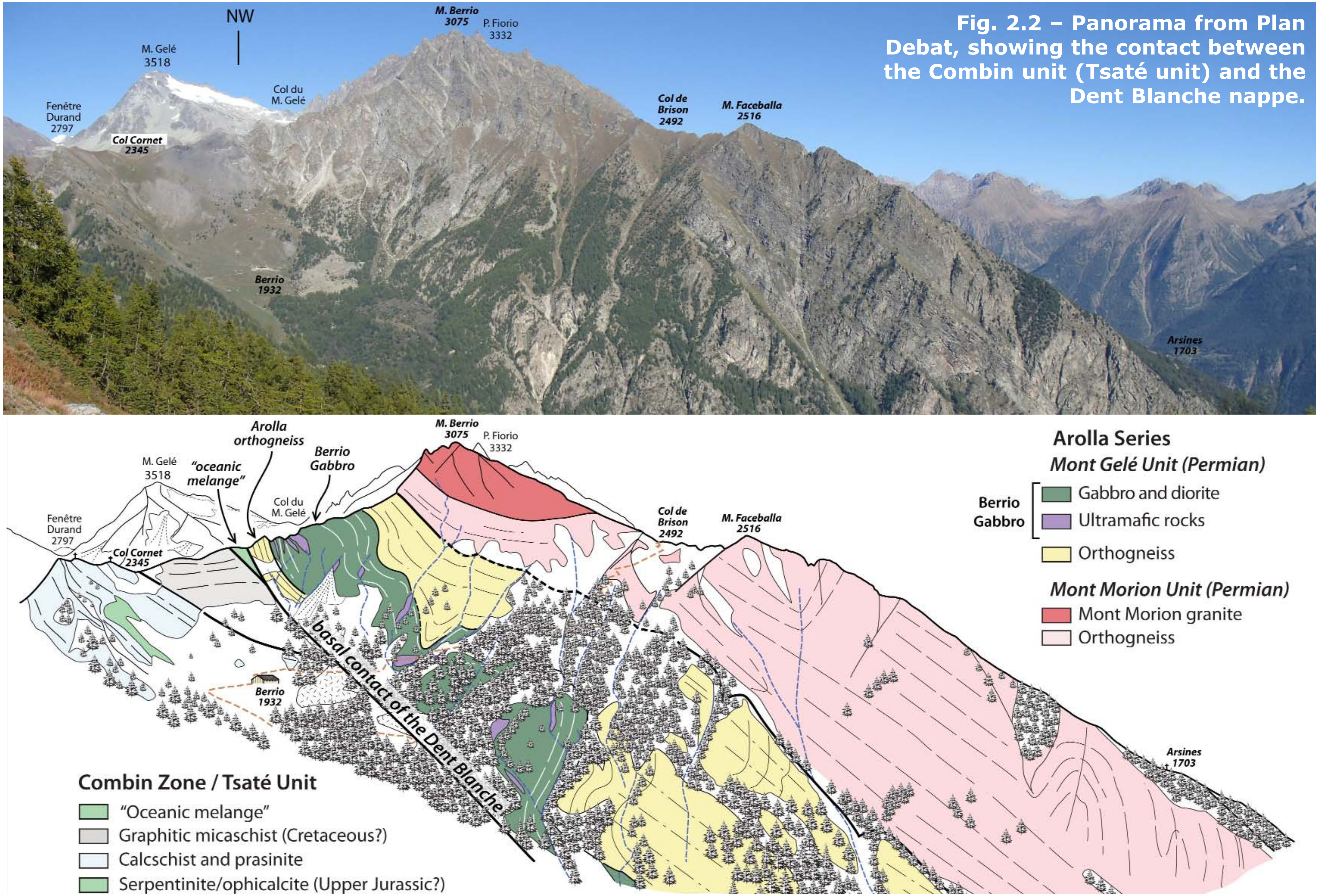

Fig. 2.2 – Panorama from Plan Debat, showing the contact between the Combin unit (Tsaté unit) and the Dent Blanche nappe.

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STOP 2.2 - Balme de Bal (2130 m) to Col Cornet (2355 m): calc-schists of the Tsaté unit

Conca di By – Unsealed road for the Fenêtre de Durand. Car Park at Balme de Bal (45°52’53.54” N, 7°19’10.51” E, elev. c. 2174 m a.s.l.)

From Plan Debat (2076 m), take the unsealed road to Balme de Bal (2174 m). This is an easy, but long road (c. 10 km, 45’) without steep sections. To take the road by car, a permit is needed. This can be obtained by the Corpo Forestale in Aosta. Park the car in Balme de Bal. Brownish calc-schists, containing quartz, calcite, muscovite, and graphite crop out. Numerous veins of quartz and calcite occur. Disseminated copper hydroxides are visible (Fig. 2.3). Calc-schists display a pervasive foliation (S = 182/25; trace of the foliation = 45) and a prominent stretching lineation (L = 135/20).

Fig. 2.3 – An example of copper hydroxides from the calcschist of the Tsaté unit.

From Balme de Bal, take a small path indicated with red signs. Cross a small river and move slightly up on a small pass for about 15 minutes (Coord. 45°52’52.37’’N, 7°19’34.44’’E, elev. c. 2213 m a.s.l.). On the left of the pass, an outcrop of greyish calc-schist occurs (S = 138/32; trace of the foliation = 148). Note that in the area there are now many erratic blocks of Arolla granitoids and orthogneisses.

Cross the main river in the Comba of the Acque Bianche, close to the outlet for the hydroelectric power plant. Take the path n°6, proceeding up along the Lago Cornet, up to the large and flat surface of Col Cornet (2355 m). From this point, we can go directly to the foot of the M. Berrio ridge (the main interest of the excursion) or make a brief detour at the Pointe Cornet, to examine mantle peridotites from the Piemonte-Liguria ocean.

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STOP 2.3 - Pointe Cornet (2354 m): ophiolites and calc-schists of the Tsaté unit

Conca di By– Path n°6 for the Col Cornet-Pointe Cornet (45°52'20.96" N, 7°19'05.09" E, elev. c. 2354 m a.s.l.)

At the Pointe Cornet, a section across the Tsaté unit can be observed. From base to top, one can see (Fig. 2.4):
- Interbedded greenschists (prasinites) and calc-schists, forming a prominent cliff below P. Cornet. Prasinites

Fig. 2.4 – Ophicalcites outcrop on top of the greenschists, close to the Pointe Cornet.

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display green amphibole, chlorite, epidote, albite, titanite ± muscovite.
- Brecciated and sheared serpentinites (ophicalcites) displaying a 20 to 50 cm-thick layer of impure marbles. Serpentinites show abundant calcite veins, and are cross-cut by an anastomosed set of cm-thick shear zones. Undeformed volumes between the shear zones still display relics of coarse-grained granoblastic texture, interpreted to represent the former mantle fabric.
- Calc-schists (dominantly carbonate) with some mylonitic leucocratic metabasites, most probably deriving from Mg-rich gabbros.

STOP 2.4 - Calc-schists along the ridge Pointe Cornet – Monte Berrio

(45°52’15.22” N, 7°19’35.65” E, elev. c. 2441 m a.s.l.)

Fig. 2.5 – Folded layers of meta-cherts within greyish schists.

From Col Cornet proceed up and follow the ridge to Monte Berrio. This ridge will provide a nice section across the contact between the Tsaté unit and the basal part of the Dent Blanche.
The Tsaté unit is made of greyish schists and less abundant brownish calcschists (S = 340/10). In the greyish schists, thin mm- to cm-thick layers of meta-cherts occur. The latter are isoclinally folded with thickened hinges and thinner limbs, giving rise to rootless folds (Fig. 2.5). The axial planes of these folds are sub-horizontal. Another noticeable feature of this formation is the abundance of folded quartz-carbonate veins, the fold hinges being preserved in cm- to dm-thick microlithons. In addition, a few Cr-rich phengite layers are observable in this formation.
This suggests deposition of the sedimentary sequence in a deep-sea environment, characterized by anoxia, at a time where pieces of the oceanic

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crust were still cropping out, providing chromite grains to the sediments. It is therefore quite probable that these schists derive from Cretaceous black shales. A sample (#27a) from these schists has been used for determining the maximum T of metamorphism using the RSCM method (396 ± 15 °C) and it has provided a Rb-Sr isochron of 41.3 ± 0.4 Ma (MSWD = 1.1) (Angiboust et al., 2014).

STOP 2.5 - Basal contact of the Dent Blanche nappe

(45°52'09.49" N, 7°19'40.04" E, elev. c. 2483 m a.s.l.)

On top of the grassy ridge towards Monte Berrio, stop at the foot of a rocky ridge for examining the basal contact of the Dent Blanche nappe (Fig. 2.6). Proceeding up from the black calc-schist, a zone, 5 m-thick, with brecciated serpentinite (ophicalcite) and several types of pale green to bright green (due to the presence of Cr) mafic rocks occur. The latter possibly derive from gabbroic rocks. Approaching the tectonic contact with the Arolla orthogneisses, a few m-thick layers of greyish marbles containing albite porphyroblasts or aggregates occur. These marbles are separated from the Arolla orthogneisses by 2 m-thick band of brecciated serpentinite. The Arolla orthogneisses display a mylonitic foliation (S = 315/35) and a cm- to dm-scale crenulation folds (P = 282/15; A = 29/2). The contact between the Dent Blanche and the Tsaté unit is cut by a high angle transcurrent fault.

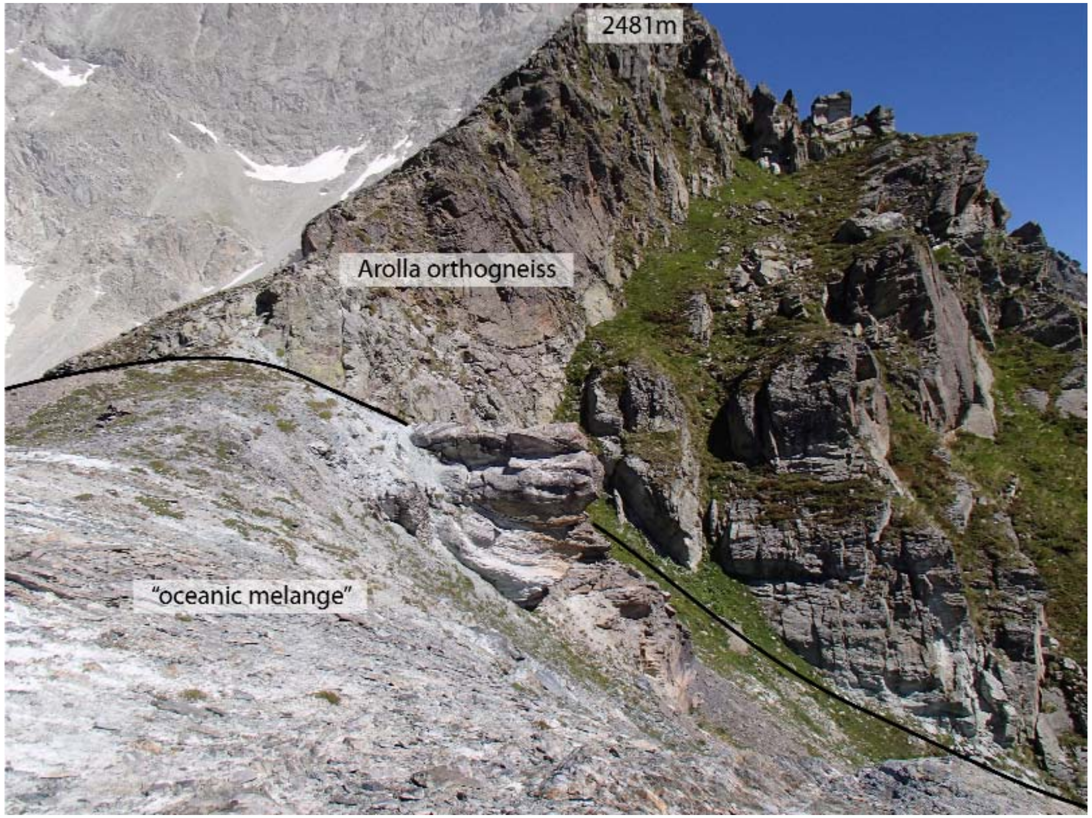

Fig. 2.6 – Below of the basal contact of the Dent Blanche nappe, a narrow zone with varied lithologies may be interpreted as an "oceanic melange".

Due to outcrop conditions, the basal contact of the Dent Blanche cannot be characterised with accuracy along the Berrio ridge (the same situation is unfortunately also found in the Fenêtre de Durand, where the contact itself is

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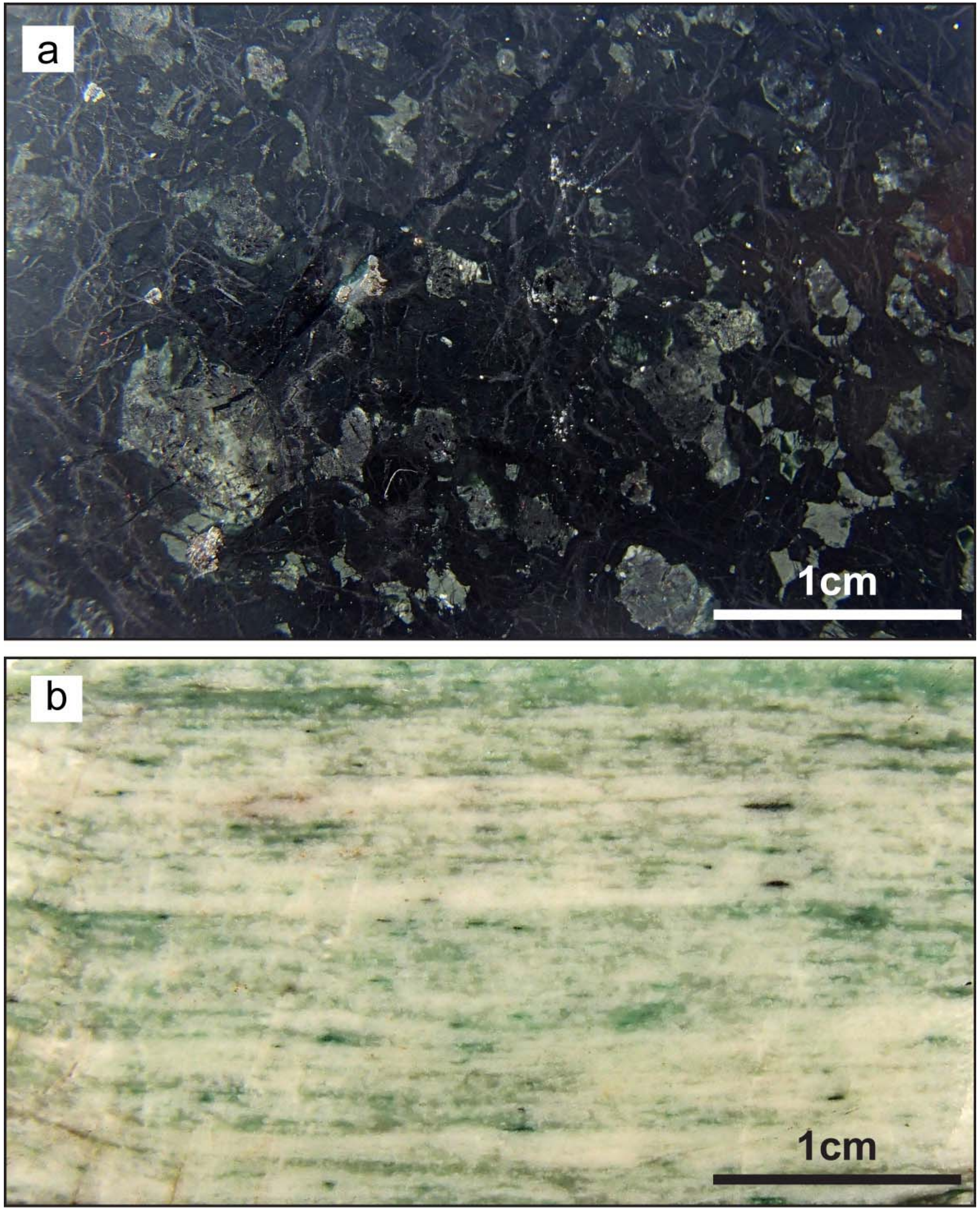

covered by scree). However, we have done a detailed map of the area from Ollomont to the Fenêtre de Durand, which will allow us presenting serial cross-sections and geological panoramas. These display several fold generations, whose relative age and kinematics with respect to the basal contact of the Dent Blanche will be discussed.

STOP 2.6 - The Berrio gabbro

(45°52′13.83″ N, 7°19′46.87″ E, elev. c. 2520 m a.s.l.)

Proceed now along the northern slope of the ridge up to the base of a gully allowing an easy access to the ridge, south-east of the quote 2481 m. Caution is required on this section, because stone falls may occur due to steinbocks (and geologists!) moving above you. All rock types (and indeed the best samples!) may be seen easily in the scree, and the complete section will be seen from a distance in the next Stop.
Two main rock types are seen in the scree (Fig. 2.7), namely **(i)** dark ultramafic rocks deriving

Fig. 2.7 – Representative rock slabs. **a)** Preserved cumulate texture in an ultramafic rock of the Berrio gabbro. **b)** Mylonitic Cr-rich Mg-gabbro from the Berrio gabbro.

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from pyroxene cumulates, and preserving igneous structures (i.e. no Alpine deformation!), and **(ii)** strongly foliated leucocratic mafic rocks, some of them displaying nice bright green patches (Cr-bearing phengite, i.e. fuchsite), and deriving from Cr- and Mg-rich gabbroic cumulates. Details about these rocks will be provided on the Stop, following an extensive geochemical study (Manzotti et al., 2017).

Please note also how different are the ultramafic rocks from the Berrio gabbros with respect to those seen in the Tsaté unit (Stops 2.3 and 2.5), the former lacking calcite veins and serpentine shear veins.

Previous authors have recognized the peridotite bodies, but interpreted them as ophiolites belonging to the Combin Zone (Diehl et al., 1952; Roda & Zucali, 2011), or as resulting from a tectonic mélange along the subduction interface (Angiboust et al., 2014). Following detailed mapping associated with a geochemical study, we favour an alternative interpretation of this section, and we recognize that the peridotites are part of a layered gabbro complex, of continental origin (Manzotti et al., 2017).

STOP 2.7 - Lago de La Clusa (2418 m): panorama and summary

(45°52’28.88” N, 7°20’02.98” E, elev. c. 2410 m a.s.l.)

Walk to Lago de La Clusa. From this point, a nice panorama on the Berrio gabbro and the Dent Blanche-Tsaté contact can be seen (Fig. 2.8).

From Lago de La Clusa join again path n°6 and come back to Balme de Bal.

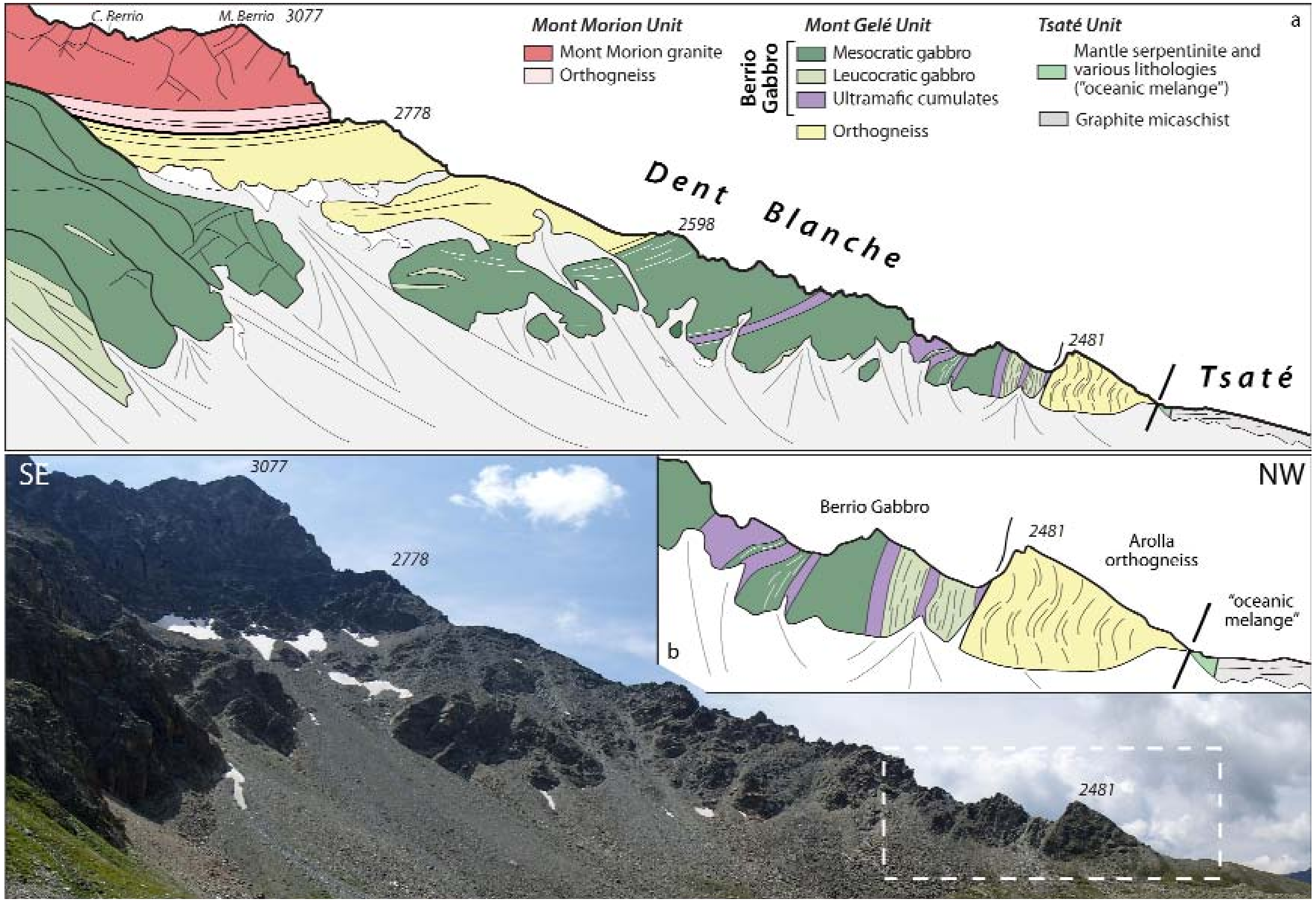

Fig. 2.8 – Panorama on the Berrio gabbro and the Dent Blanche-Tsaté contact (from Manzotti et al., 2017).

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STOP 2.8 - Panorama from Plan Debat (2076 m): geometry of the main units

(45°50′36.30″ N, 7°17′16.10″ E, elev. c. 2098 m a.s.l.)

Take the car and return to Plan Debat (Fig. 2.2). The late afternoon (in summer) sun light offers a wonderful panorama on Col Cornet – Monte Berrio ridge where the Dent Blanche – Tsaté contact and the Berrio gabbro are exposed.

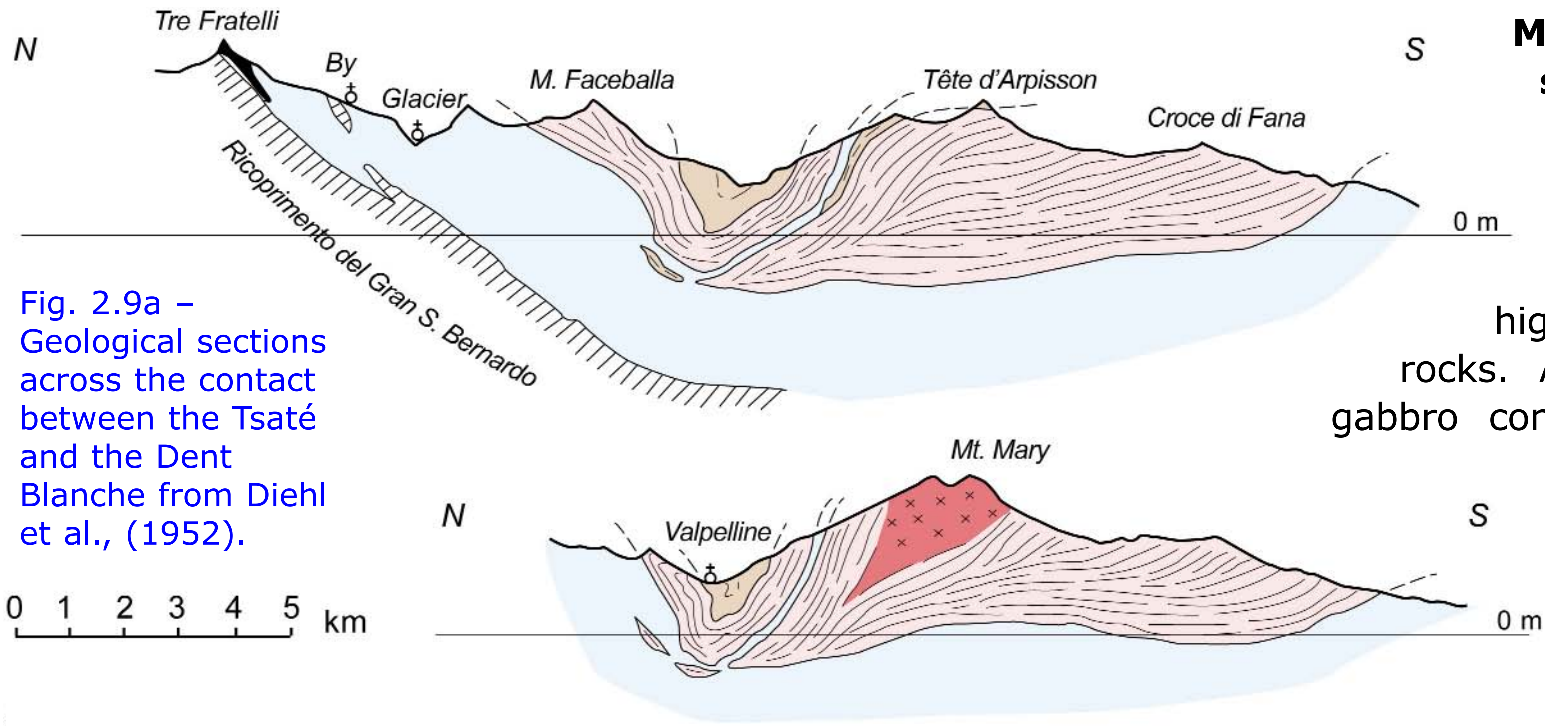

Fig. 2.9a – Geological sections across the contact between the Tsaté and the Dent Blanche from Diehl et al., (1952).

Main conclusions of the second day

1. The Arolla series is made of granitoids of Permian age, intruding high-grade amphibolite facies rocks. A nicely preserved layered gabbro complex (the Berrio gabbro), with a chemistry similar to other Permian gabbro complexes from the Dent Blanche, is found close to the basal contact of the Dent Blanche.

2. The Alpine deformation in the Arolla series is highly heterogeneous. Several stacked units are recognized. In the highest unit, large undeformed volumes of granitoids are preserved (Mont Morion unit). In the lower units, essentially made of orthogneisses and meta-gabbros, several episodes of ductile deformation can be seen from sample- to landscape-scale. Late brittle faults with cataclasites are also found.

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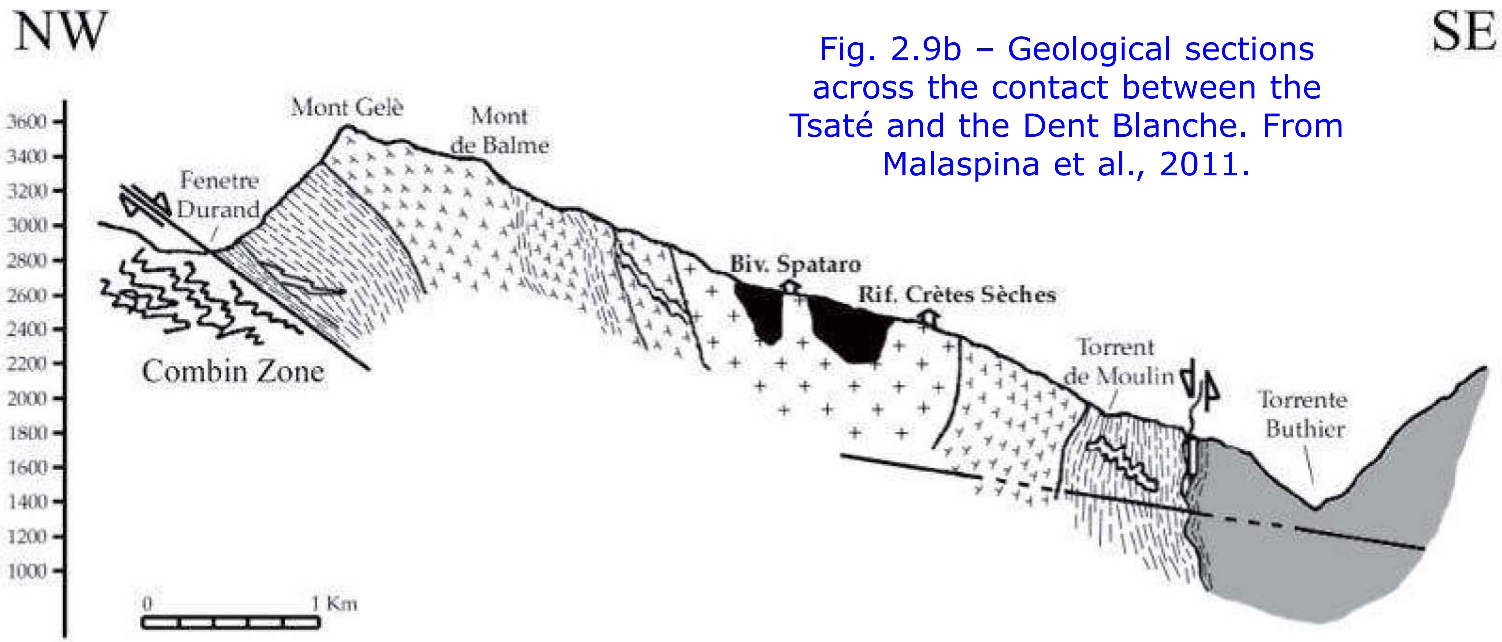

Fig. 2.9b – Geological sections across the contact between the Tsaté and the Dent Blanche. From Malaspina et al., 2011.

3. The Combin (Tsaté) Zone is made of ocean-derived sediments associated with minor ophiolitic bodies. They are pervasively foliated (except the mantle peridotites), and display a NW-SE trending stretching lineation.

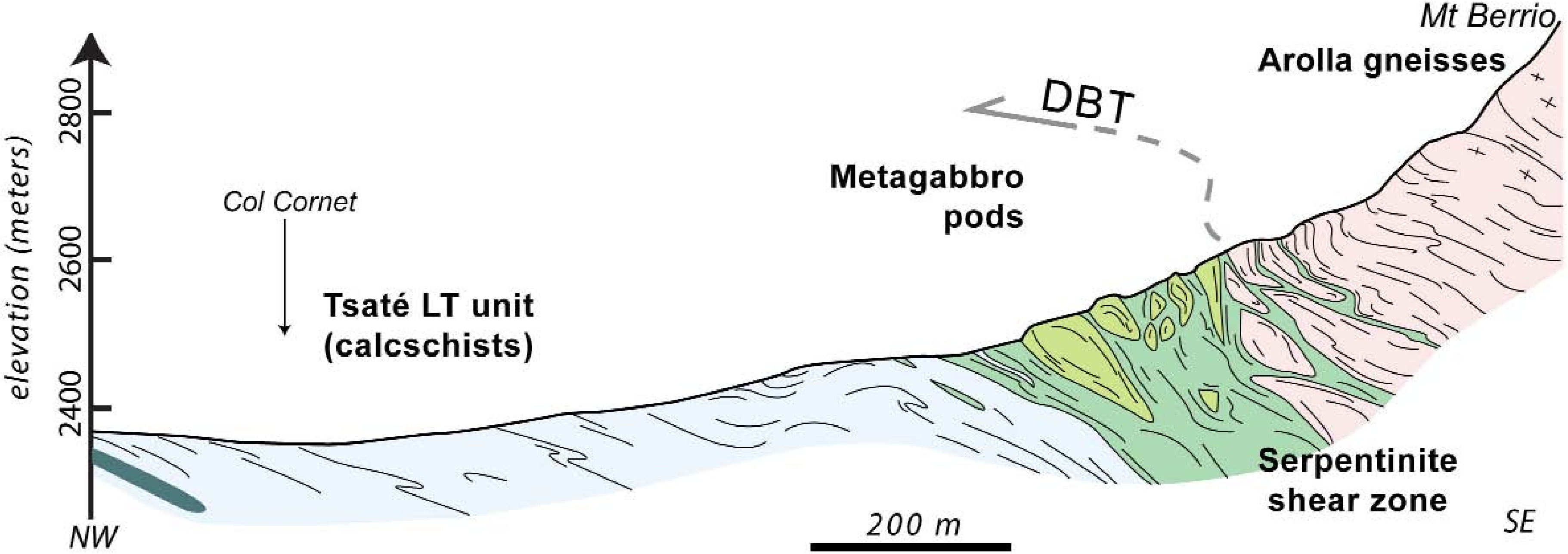

Fig. 2.9c – Geological sections across the contact between the Tsaté and the Dent Blanche. From Angiboust et al., 2014.

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4. The tectonic nature of the basal contact of the Dent Blanche is recognized since Stutz & Masson (1938) and Diehl et al., 1952 (Fig. 2.9a). Because the continental rocks of the Dent Blanche lay structurally over the oceanic rocks of the Tsaté, the basal contact is generally interpreted either as a normal thrust (Fig. 2.9b) or as a ductile thrust (Fig. 2.9c). A recent model for this thrust (Fig. 2.9c) envisions it as a serpentinite shear zone where blocks of ocean-derived and continental-derived material are mixed, developed along the subduction interface (Angiboust et al., 2014, 2015). However, this model is not compatible with field observations in the area visited during Day 2 (Fig. 2.9d), which suggest a sharp discontinuity between ocean-derived material in the footwall and continent-derived material in the hangingwall (the Berrio gabbro is continental in origin, and the ultramafic rocks from the Berrio gabbro are more resistant than their enclosing meta-gabbros).

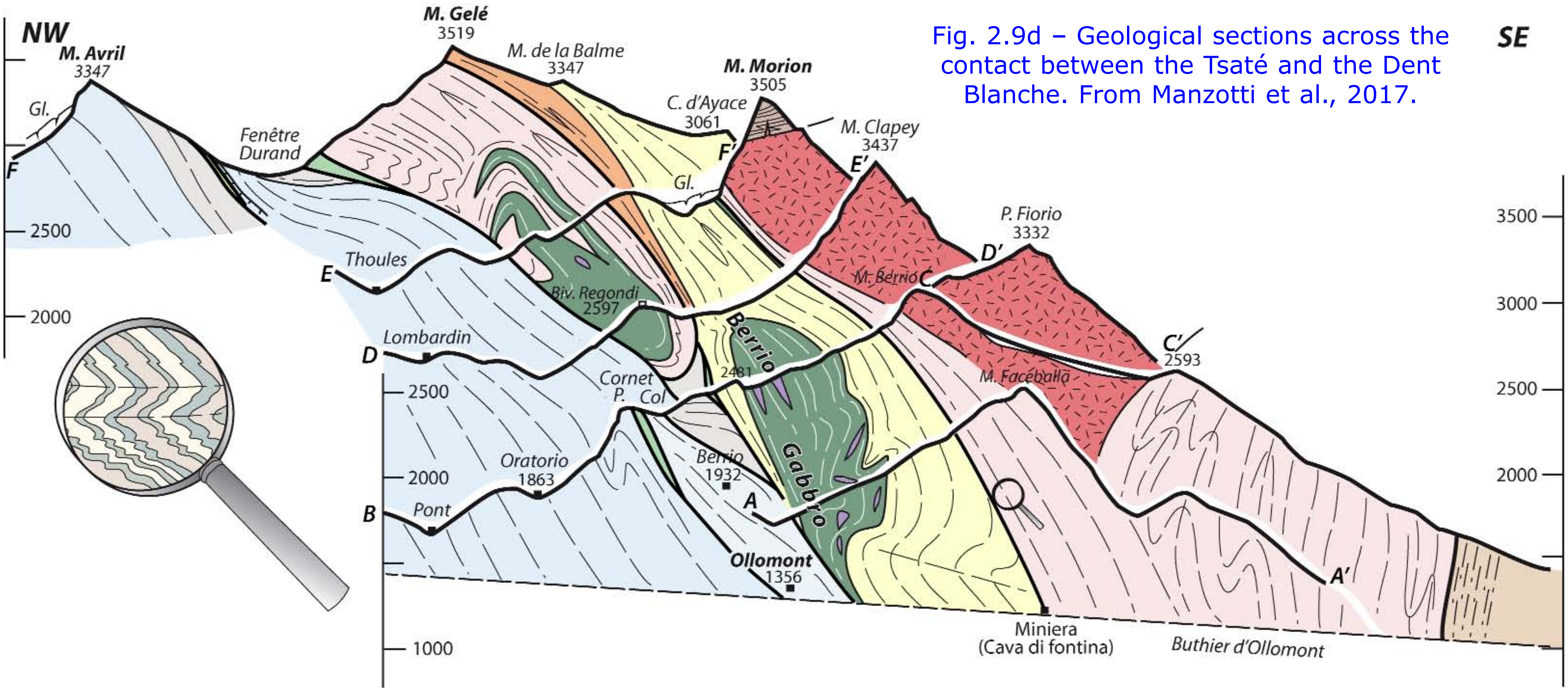

Fig. 2.9d – Geological sections across the contact between the Tsaté and the Dent Blanche. From Manzotti et al., 2017.

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Day 3: The Roisan-Cignana Shear Zone

The **St. Barthélémy Valley** is one of the less touristic places in the Valle d'Aosta region. It is divided into two main branches, and closes to the north towards summits that belong to the Dent Blanche Tectonic System (Monte Faroma (3072 m), Becca del Merlo (2961 m), Becca di Luseney (3504 m), Cima Bianca (3008 m)), and to the Tsaté unit (Monte Meabé (2616 m) and Becca d'Aver (2469 m)).

Places of interest:

· Varenche manganese mine (Les Fabriques), exploited until 1904 (Baldelli et al., 1983; Barresi et al., 2005).
· Astronomy observatory (Lignan), opened in 2003.
· Cuney sanctuary (first sacred in 1659) and refuge (2656 m).

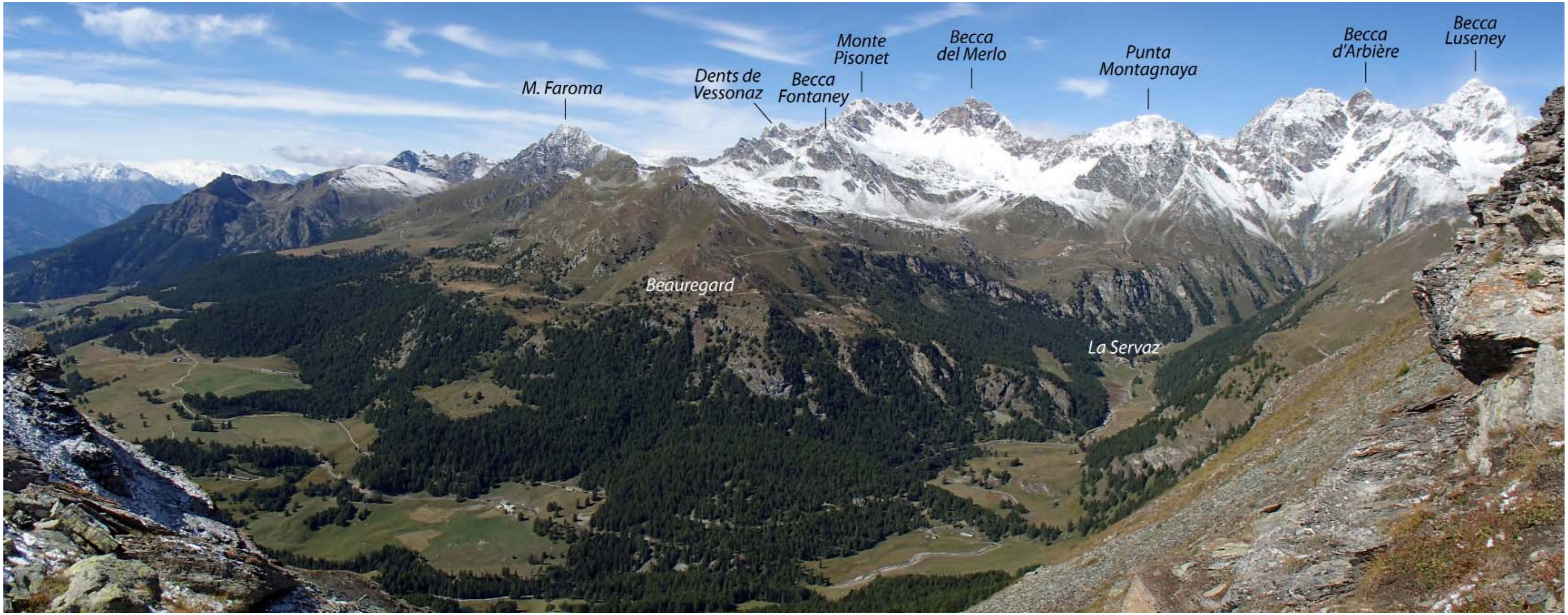

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Fig. 3.1 - Location of the third day Stops (from Blatto & Zavatta, 2009).

The third day is spent in the St. Barthélémy Valley and it focuses on the Roisan-Cignana Shear Zone (Figs 3.1, 3.2). From Valpelline, take the road SR28 and then the E27 to Aosta. Turn to the left on the SS26 and enter in Nus. In Nus take the road SR36 to Lignan. Proceed through Saquignod, Venoz, and Le Cret to the end of the sealed road (car park and water at the picnic area Porliod c. 1900 m). The following road will take place on an unsealed road, with a few steep sections, up to a small car park at the foot of the Colle di Chaléby (~2500 m). To take the road by car, a permit is needed. This can be obtained by the Corpo Forestale in Aosta. From there, we will proceed along well traced footpaths.

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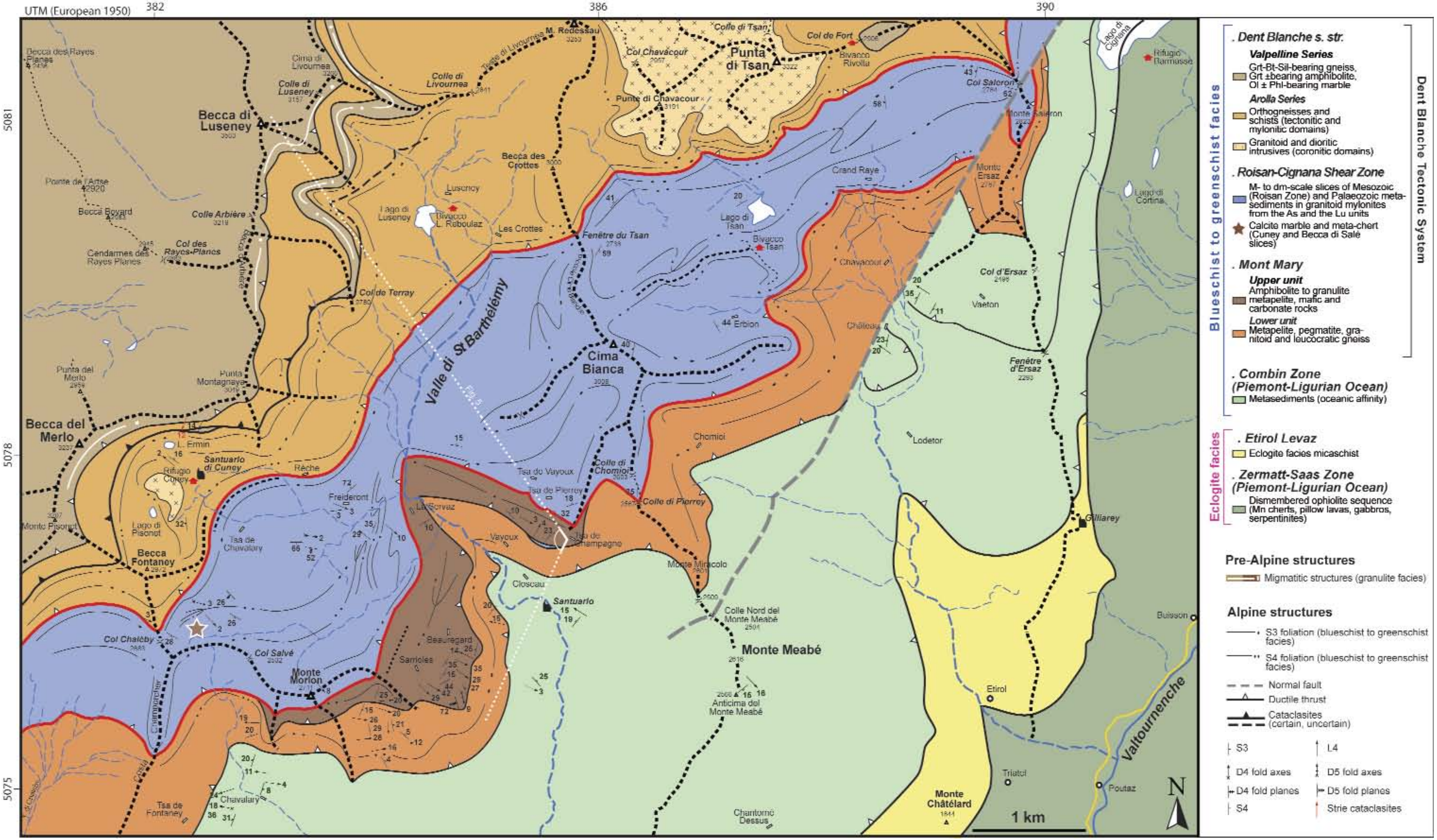

Fig. 3.2 – Structural and geological map of the Cuney area, showing the position of the RCSZ with respect to the other units (from Manzotti et al., 2014a). In the RCSZ, the location of the pre-Alpine meta-sediments is indicated by a brown star (north-east of the Col de Chaléby). In the Arolla series, pods of variable size (from metre to hundreds of metres), preserving a Permian undeformed granitoid, are found southwest of Rifugio Cuney and in the Punta di Tsan – Punta di Chavacour area. Foliation traces associated with stages 3 and 4 are drawn as lines with one or two dots, respectively. Foliations in the Valpelline series, represented as white traces, are related to the pre-Alpine evolution.

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STOP 3.1 - Lower unit of the Mont Mary-Cervino nappe

Unsealed road for Cuney area (45°49’11.27” N, 7°30’30.05” E, elev. c. 2238 m a.s.l.)

Mylonitic orthogneisses consisting of muscovite, chlorite, quartz and some K-feldspar clasts crop out. They display a penetrative foliation, moderately dipping to the N (S_4 = 15/37) and a well-developed stretching lineation (L_4 = 99/20).
From this Stop it is possible to see a nice panoramic view on the Mont Morion (Fig. 3.3). From bottom to top the following lithologies are recognisable:

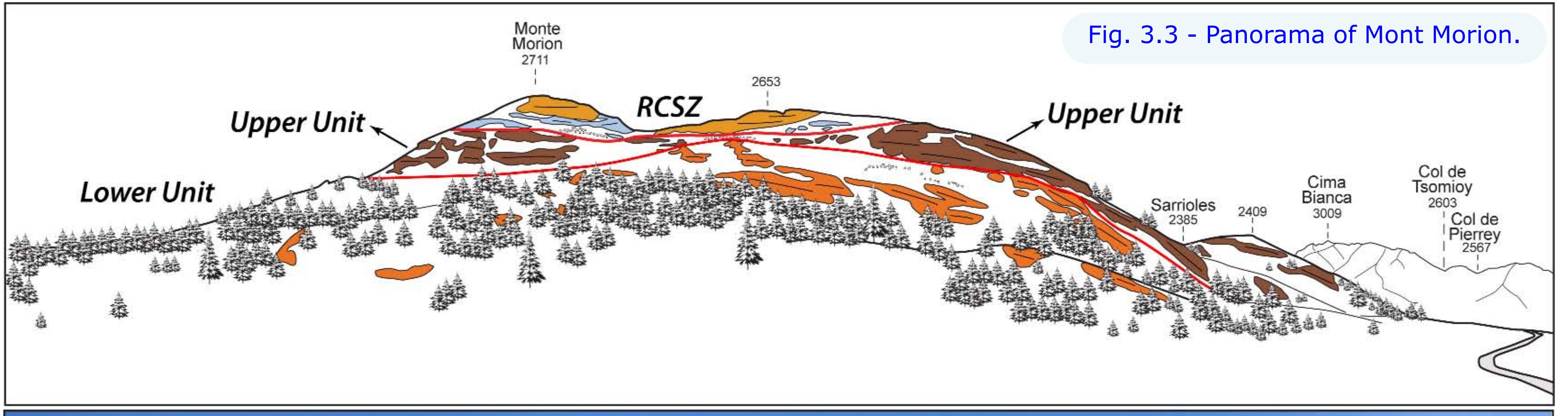

Fig. 3.3 - Panorama of Mont Morion.

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- Leucocratic mylonitic orthogneisses (**lower unit**).
- Red schists with impure marbles. Lenses of meta-chert, up to 10 cm thick, are locally found in the impure marbles. They contain quartz, garnet, ± pale green amphibole, ± chlorite, ± magnetite, ± titanite, ± stipnomelane. The impure marbles consist of calcite, diopside, garnet, titanite, muscovite (**upper unit**).
- Calc-schist with few boudinaged calcite marbles. These calc-schists contain calcite, muscovite, chlorite, albite, quartz, titanite, graphite. Calcite marbles contain a few flakes of muscovite (**Roisan Zone**).
- Mylonitic granitic orthogneisses consist of muscovite, chlorite, quartz, K-feldspar, albite, titanite, allanite, epidote (**Arolla series** involved in the Roisan Cignana Shear Zone).

STOP 3.2 - Sarrioles (2385 m): the upper unit of the Mont Mary-Cervino

Unsealed road for Cuney (45°49’29.20” N, 7°30’48.76” E, elev. c. 2254 m a.s.l.)

Fine-grained micaschists consisting of quartz, muscovite, chlorite, epidote, and opaque, and impure marbles of the upper unit occur along the road. The marbles and the micaschists show a penetrative foliation (S_4 = 165/49) and stretching lineation (L_4 = 112/45) (Fig. 3.4). Silicate layers inside the marbles are stretched and boudinaged. The foliation is cut by high-angle brittle normal faults.

Along the road (where the slope on the road side is protected by nets) and along the footpath to Sarrioles (just above the road), fine-grained dark micaschists (S_4 = 320/20; L_4 = 312/12), sometimes containing ankerite, crop out. These micaschists show a rusty weathering and they are sometimes covered by green lichens (*Rhizocarpon geographicum*). For this reason, they can be confused with pre-Alpine basement rocks. However, they most probably derived from Mesozoic meta-sediments (black shales). This statement may be assessed using two observations:
- Relics of HT parageneses have never been observed in these schists (but this lack can be due to the Alpine deformation!).
- The RSCM method indicates maximum T of about 520°C, well below the expected T for the pre-Alpine metamorphism.

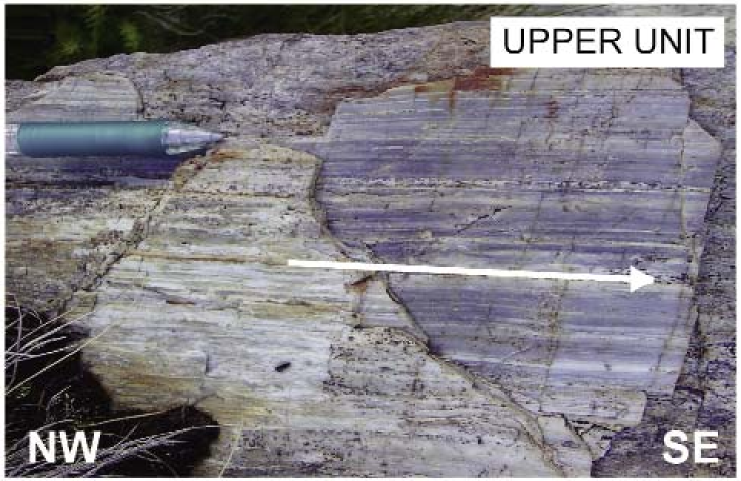

Fig. 3.4 - A well-developed lineation (L4), defined by calcite aggregates and plunging to the southeast in a marble of the upper unit.

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STOP 3.3 - Geological panorama of the Cuney area

Unsealed road for Cuney area (45°49'51.34" N, 7°30'19.48" E, elev. c. 2406 m a.s.l.)

A nice panorama can be seen from a small hill to the right of the road, and it will be commented from a geological point of view (Figs 3.5 and 3.6). From left to right the following mountains are recognisable: Mont Morion, Col du Salvé, Col de Chaléby, Becca Fontaney, Monte Pisonet, Becca del Merlo, Punta Montagnaya, Col Montagnaya, Becca d'Arbière, Becca Luseney, and, off-right of Fig. 3.6, Monte Redessau, Fenêtre du Tsan, Cima Bianca, etc.

Fig. 3.5 – Panorama of the Cuney area. Recognizable from top to bottom: the Valpelline series (M. Pisonet and Becca del Merlo) and the Arolla series (Becca Fontaney) of the Dent Blanche nappe, and the Roisan Cignana Shear Zone (Col de Chaléby). From this point, we will move to the Col de Chaléby to examine the rocks and the structure of the RCSZ. The geology of this panorama is explained on Figure 3.6, and the key section is described on Figure 3.10.

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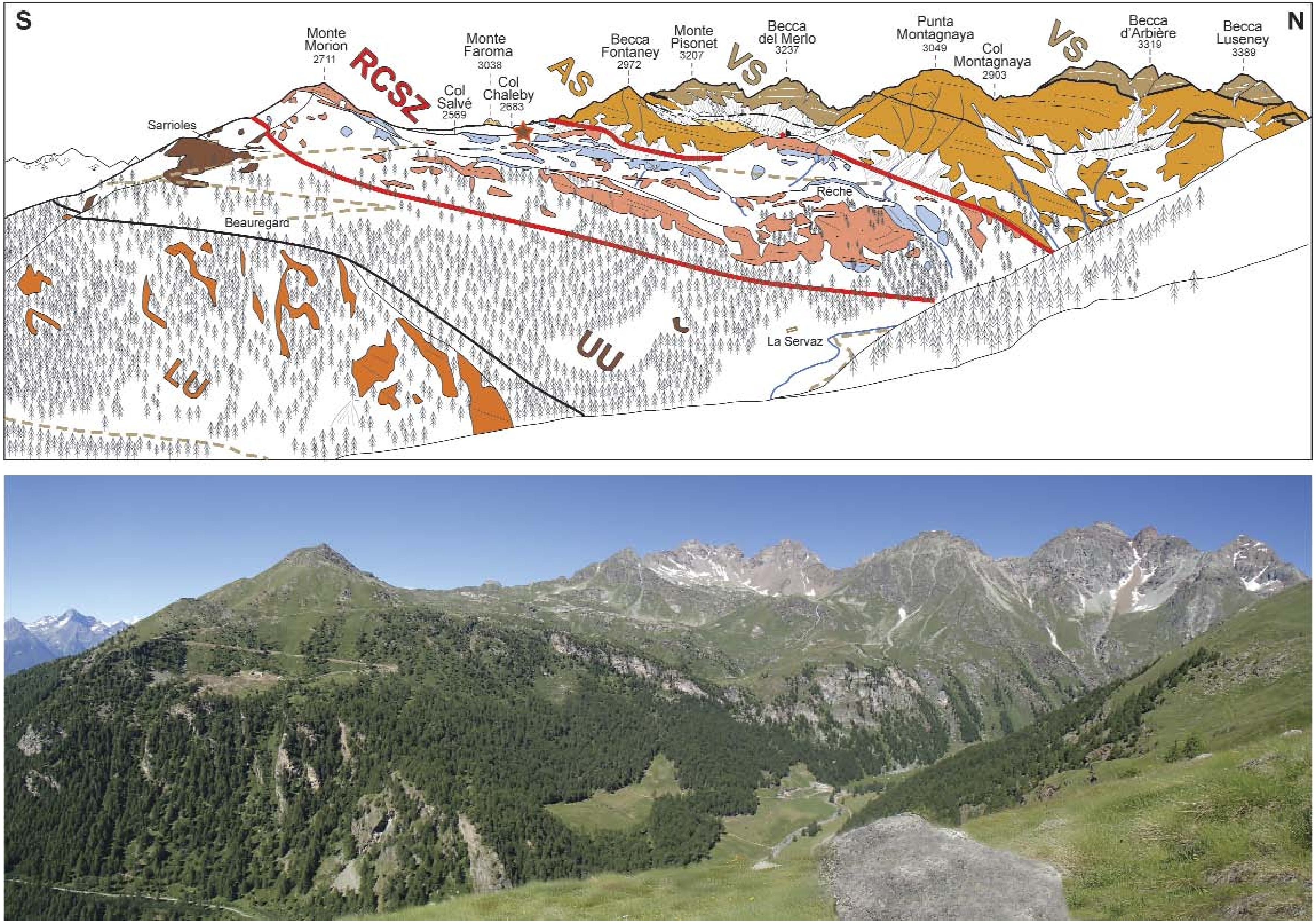


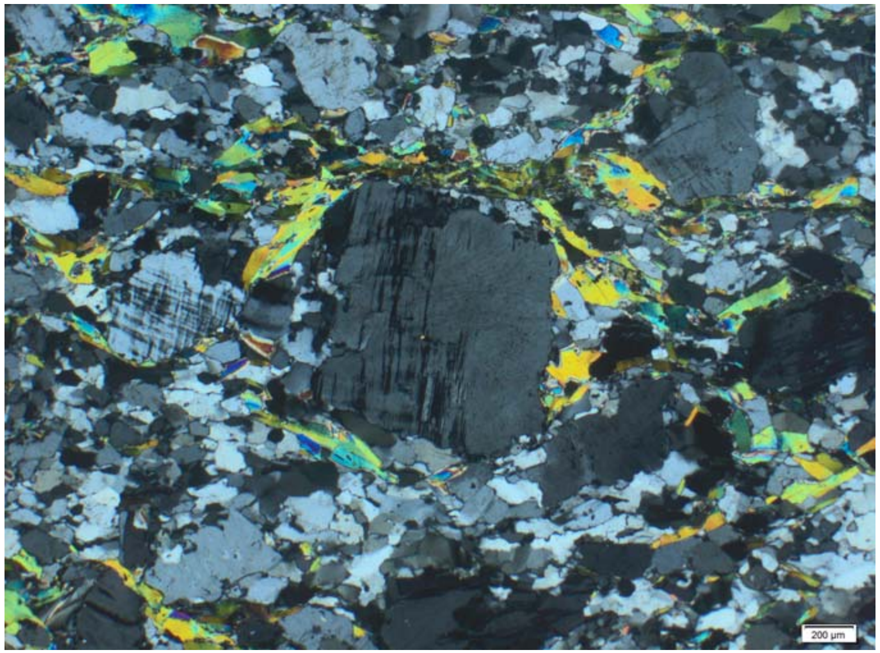
Fig. 3.6 – Panorama of the Cuney area (from Manzotti et al., 2014a). The distance from Monte Morion to Becca Luseney is about 5 km. Recognizable from bottom to top: the Lower Unit (LU) and Upper Unit (UU) of the Mont Mary-Cervino nappe, the Roisan-Cignana Shear Zone (RCSZ), the Arolla Series (AS) and the Valpelline Series (VS) of the Dent Blanche nappe. The brown star marks the next Stop, with pre-Alpine meta-cherts (Manzotti et al., 2012).

In the Cuney area, from top to the bottom the following units occur:
- Paragneisses with a characteristic reddish color and interbedded impure marbles belonging to the **Valpelline series** (Monte Pisonet and Becca del Merlo).
- Mylonitic orthogneisses with a characteristic greenish color belonging to the **Arolla series** (Becca Fontaney). In a few cases, low strain volumes of granitoid rocks are still preserved (at the same altitude or slightly higher up than the Rifugio Cuney).
- A huge domain with mylonitic granitic orthogneisses and Mesozoic meta-sediments, collectively named **Roisan-Cignana Shear Zone**. The apparent chaotic distribution of orthogneisses and Mesozoic meta-sediments results from the imbrication of tectonic slices and the superposition of several folding episodes.

In the small hill of the panorama, Arolla type orthogneisses display a mylonitic foliation (S_4 = 258/19) and the same lineation seen in the Mesozoic graphitic micaschist (L_4 = 300/5).

STOP 3.4 - Path to the Col de Chaléby 2683 m: a section through the Roisan-Cignana Shear Zone

Cuney area – Path for the Col de Chaléby (45°49'53.24" N, 7°29'29.32" E, elev. c. 2490 m a.s.l.)



The following lithologies are observed along the foot path to the Col de Chaléby:
1- *Arolla orthogneisses*, consisting of quartz, feldspar, hornblende (rimmed by blue or green amphibole), garnet, epidote, phengite, chlorite, and titanite (Fig. 3.7).
2- *Roisan meta-sediments* (i.e. *quartz-micaschist*). Quartz-micaschist contains minor calcite, chlorite, graphite, ankerite, plagioclase, and pyrite (Fig. 3.8). Common feature of these rocks is a black phyllosilicate-rich thin mineral

Fig. 3.7 – Orthogneiss from the lower unit (photomicrograph in crossed polarized light). Note the presence of porphyroclasts of microcline, derived from the magmatic K-feldspar, in a foliated matrix essentially consisting of quartz, albite and muscovite (phengite).

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Fig. 3.8 – Microscopic aspect of a graphitic micaschist from the Roisan Zone. S3 foliation is defined by the alternation of quartz layers and graphite-phengite films. S3 is folded and a new axial plane foliation (S4) is locally visible in the hinge zone (photomicrograph in plane polarized light).

layering, due to organic carbonaceous matter (graphite), which results in a finely laminated appearance. Shape-preferred orientation of white-mica and graphite marks the main mylonitic foliation (S_3).

3- *Meta-cherts* (10-30 cm thick) interbedded with *impure marbles* (0.5 to 1 m thick) form discontinuous layers (metre- to ten metre long) (Fig. 3.9a). Shape preferred orientation of phengite and amphibole define the dominant Alpine foliation S_3. Meta-cherts occur as variably coloured layers, consisting of quartz, garnet, a range of amphiboles (Mn-cummingtonite and Mn-grunerite, riebeckite-crossite, winchite), magnetite, hematite, epidote, chlorite, stipnomelane, and pyrite. The Alpine foliation is marked by amphibole, which is parallel to garnet- and quartz-rich layers (Fig. 3.9d). Impure marbles are white, grey or pale green in colour and consist of calcite, plagioclase, phengite, calcic and sodic amphiboles, titanite, epidote, quartz, garnet, diopside, chlorite, and ilmenite.

The main foliation S_3 (230/25), well developed in all lithologies, is deformed by isoclinal folds (P_4 ~ 220/25; A_4 ~110/3) (Fig. 3.9b). In the Arolla orthogneiss is locally visible an axial plane foliation S_4 (~215/30).

The best outcrop of the meta-cherts is located to the left of the footpath to the Col de Chaléby, and comprises from bottom to top (Fig. 3.9a):

1) A level, 30-40 cm thick of whitish *impure marble*, consisting of calcite, plagioclase, phengite, actinolite, titanite, epidote, quartz, garnet, diopside, chlorite, and ilmenite. Garnet (4-5 mm in size) and clinopyroxene (1-3 mm in size) are observable with the lens, as small sub-rounded red and green dots, respectively. In the impure marbles, the oldest metamorphic assemblage comprises a first generation of garnet, with diopside, titanite, quartz, allanite, and calcite (Fig. 3.9c). Estimated T conditions for this event are 740°C (based on the Zr content in titanite, using the calibration of Hayden et al., 2008) (Manzotti et al., 2012), and refer to the pre-Alpine evolution indicating upper amphibolite-facies conditions.

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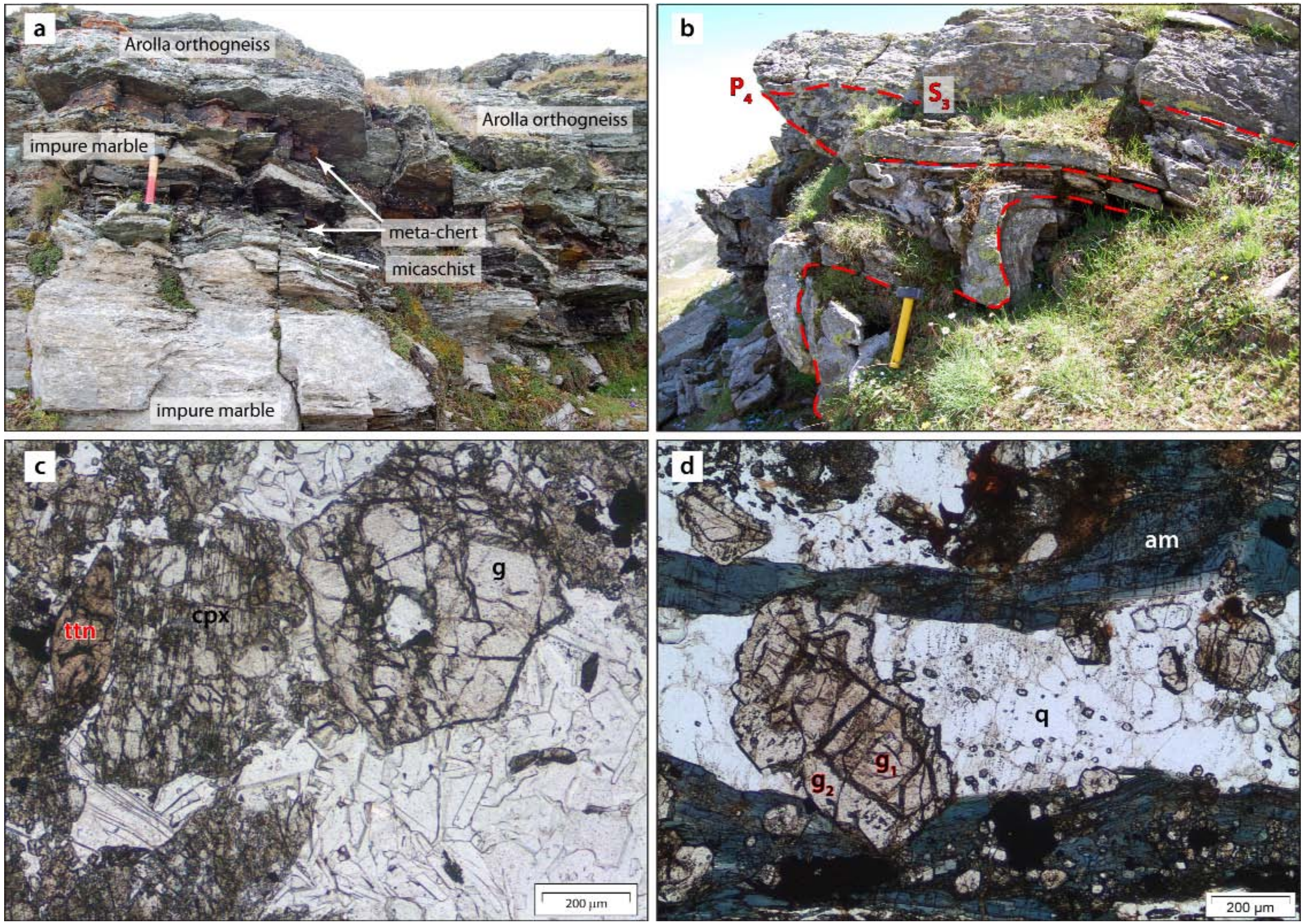

Fig. 3.9 – **a)** A photograph of the outcrop of Stop 3.6. Impure marble and meta-chert layers are in contact with orthogneiss of the Lower Unit. **b)** Same outcrop seen from W-NW: the orthogneiss of the Lower Unit and the marbles and meta-chert layers of the Upper Unit are folded together by folds of D4 stage. **c)** Garnet, clinopyroxene and titanite assemblage in impure marble (Photomicrograph in plane polarized light). **d)** Garnet1+quartz domains oriented at high angle to the Alpine foliation, marked by Mg-riebeckite (photomicrograph in plane polarized light).

2) A *micaschist* layer 5-10 cm thick, consisting of chlorite, phengite, epidote, titanite, and calcite.

3) A 5-15 cm-thick band of reddish to brownish *meta-chert*, consisting of quartz, garnet, sodic amphibole, magnetite, and zircon. In the meta-chert, the oldest metamorphic assemblage comprises garnet1, Mn-cummingtonite, quartz, allanite, zircon, magnetite, and apatite. This pre-Alpine stage may have occurred at amphibolite-facies conditions, at relatively low pressure. The S_1 foliation is marked by elongate garnet and allanite and by the planar preferred orientation of Mn-cummingtonite. S_1 is oriented at high angle to the dominant Alpine S_3 foliation. The latter is marked by sodic amphibole.

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Similar calcite marbles associated with discontinuous layers of meta-chert were reported by Ballèvre & Kienast (1987) in the Cignana-Becca di Salé area and interpreted a belonging to the Mesozoic sequences of the Roisan Zone. However, these meta-sediments record a Permian metamorphic imprint characterised by high temperature assemblages (e.g. diopside in the marbles and garnet1 in the cherts). In meta-cherts, microstructural relations indicate coeval growth of allanite and garnet at ~ 300 Ma (Manzotti et al., 2012). Microscopic features of zircon also indicate crystallization at high-temperature conditions; ages scatter from 263 to 294 Ma, with a major cluster of data at ~ 276 Ma (Manzotti et al., 2012). In impure marble, U-Pb analyses of titanite domains (with variable Al and F contents) yield apparent $^{206}Pb/^{238}U$ dates ranging from Permian to Jurassic (Manzotti et al., 2012). Chemical and isotopic data suggest that titanite formed at Permian times and was then affected by (extension-related?) fluid circulation during the Triassic and Jurassic, which redistributed major elements and partially opened the U-Pb system.
The calcite marbles and associated meta-cherts are separated from the dolomite marbles of the Roisan Zone by thin sheets (1-2 m) of mylonitic orthogneisses. They represent slices of pre-Alpine lithologies inserted within the RCSZ. Because marbles and cherts have been found in the paraschists of the upper unit (Mont Mary-Cervino nappe), we propose that these slices represent pieces of the upper unit of the Mont Mary-Cervino nappe, sheared into the RCSZ.

STOP 3.5 - Crest above the Col de Chaléby (2683 m): ductile shearing along the basal thrust of the Dent Blanche

Cuney area – Col de Chaléby (45°49’42.68” N, 7°29’18.23” E, elev. c. 2695 m a.s.l.)

Proceed to the Col de Chaléby following the footpath, and then follows cautiously the crest. Some difficulties may be more easily passed on the western side of the crest (a scree slope generally devoid of snow in summer).

The following lithologies are encountered from base to top (Fig. 3.10):
1) foliated Arolla orthogneisses, belonging to a basement slice inside the Roisan-Cignana Shear Zone.
2) A lower layer of whitish to pale greyish marbles, characterized by the occurrence of cm-thick layers of quartzites (marble with quartz of Ciarapica et al., 2016), and displaying nice isoclinal D4 folds of various dimensions.

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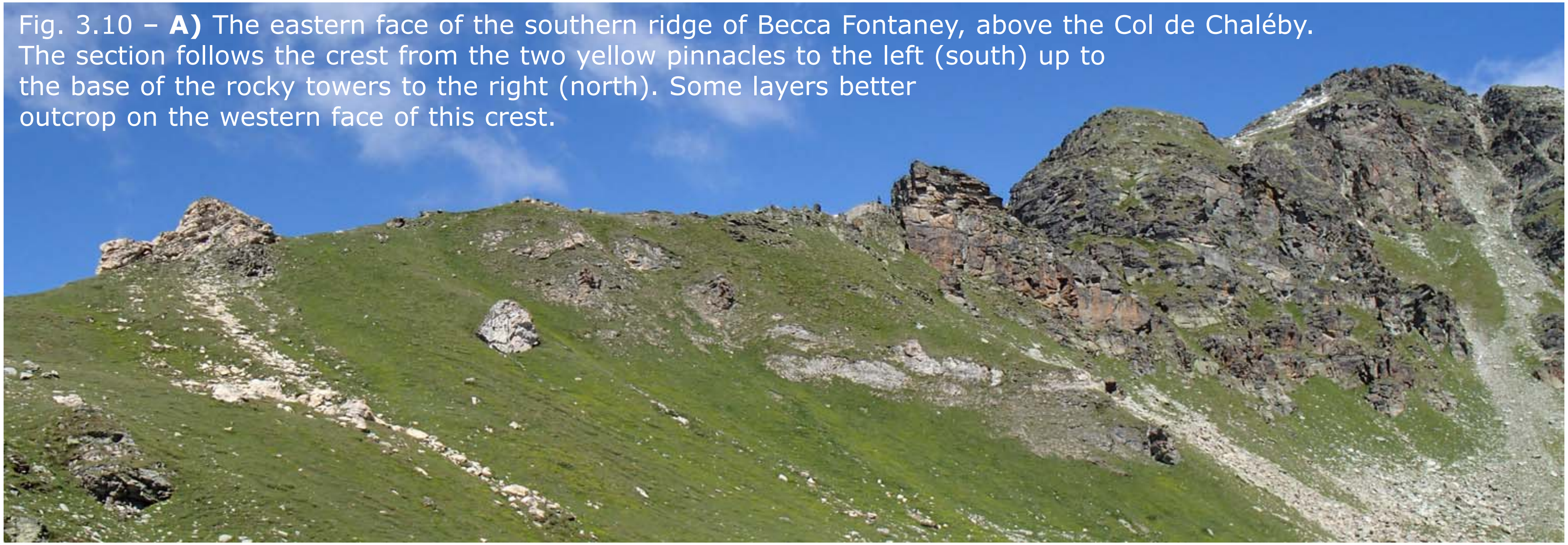
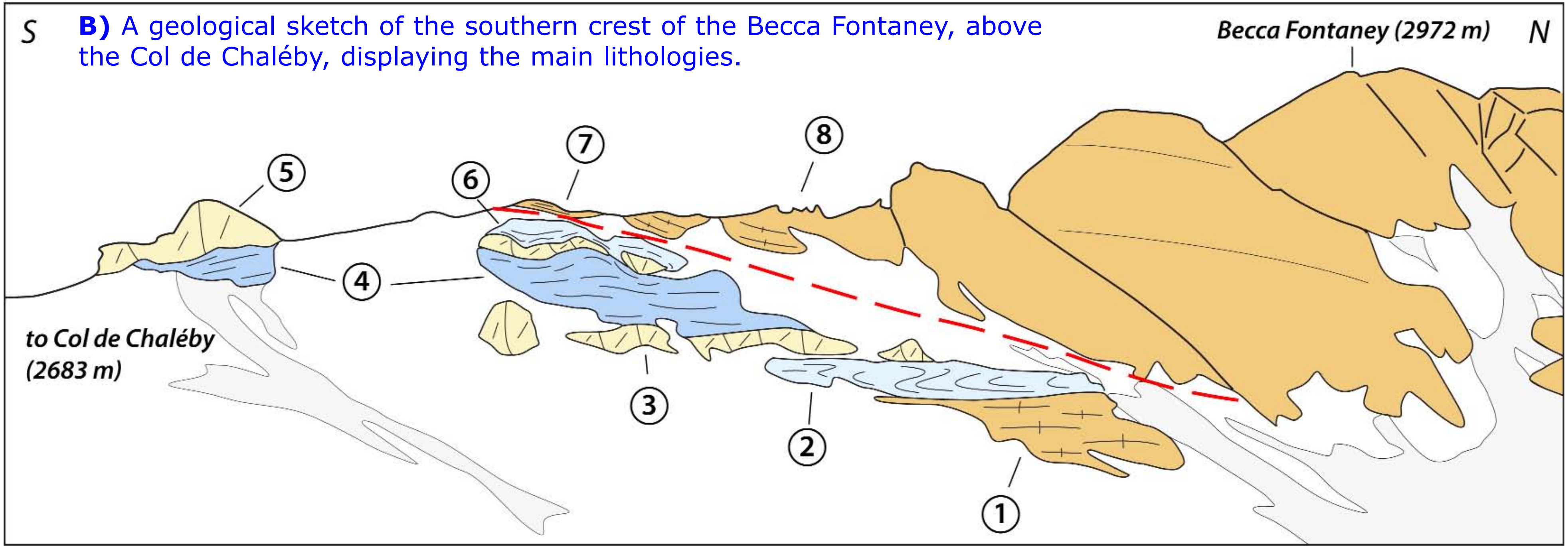


Fig. 3.10 – **A)** The eastern face of the southern ridge of Becca Fontaney, above the Col de Chaléby. The section follows the crest from the two yellow pinnacles to the left (south) up to the base of the rocky towers to the right (north). Some layers better outcrop on the western face of this crest.



B) A geological sketch of the southern crest of the Becca Fontaney, above the Col de Chaléby, displaying the main lithologies.

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3) A lower layer (up to 5 m thick) of boudinaged dolomite pods.
4) A layer, up to ten m thick, of foliated carbonate-rich calc-schists, displaying clasts of various sizes (from cm to m!). The clasts are made of carbonate sediments, including dolomites and calcite marbles (Fig. 3.11) Please note the lack of quartzites and basement-derived clasts. The dolomites show a brittle behavior, displaying veins and fractures, whereas the calcite marbles are flattened parallel to the main foliation. Some of the clasts display nice asymmetrical shapes in section parallel to the stretching lineation, indicating top-to-the-NW shear sense.
5) An upper layer of boudinaged dolomite pods (the two pinnacles to the left of Fig. 3.10 belong to this layer).
6) A thin layer of interbedded cm-scale marble-quartzite (similar lithology as layer 2), locally isoclinally folded with black schists.
7) Finely foliated schists with a reddish weathering (ultramylonites).
8) Foliated orthogneisses with abundant cm-sized K-feldspar clasts (Arolla orthogneisses), belonging to the basal part of the Dent Blanche nappe.

This outcrop displays a stratigraphic sequence recording two main events, namely (i) development of a carbonate (dolomite) platform during the Triassic, and (ii) rifting of the Adriatic continent during the Jurassic.
This sedimentary sequence has been detached from its basement, isoclinally folded during the Alpine orogeny, and overthrust by the Dent Blanche nappe.

Fig. 3.11 – Field aspect of carbonate-rich calc-schists with cm- to metre-long clasts. Western slope of the southern ridge of Becca Fontaney.

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Main conclusions of the third day

1) The Roisan Zone is made of meta-sediments of Late Triassic (Ciarapica et al., 2016) and post-Triassic age, recording the establishment of a Late Triassic carbonate platform followed by its disruption during Jurassic rifting. The best section for stratigraphy is preserved in the Col de Chaléby area.
2) The Roisan-Cignana Shear Zone (RSCZ) separates the DBTS into two minor nappes (Dent Blanche and Mont Mary-Cervino), and it involves three kinds of slices, namely Arolla orthogneisses, marbles and meta-cherts with pre-Alpine relics, and Mesozoic meta-sediments of the Roisan Zone. They were sheared and folded together during three main episodes, at decreasing pressure (from blueschist to greenschist facies).
3) The km-scale folding of the RCSZ (Verney fold) is associated with a flat-lying crenulation cleavage at greenschist-facies conditions. The kinematic meaning of this folding episode has been interpreted as recording post-nappe folding during westward shearing (Manzotti et al., 2014a).

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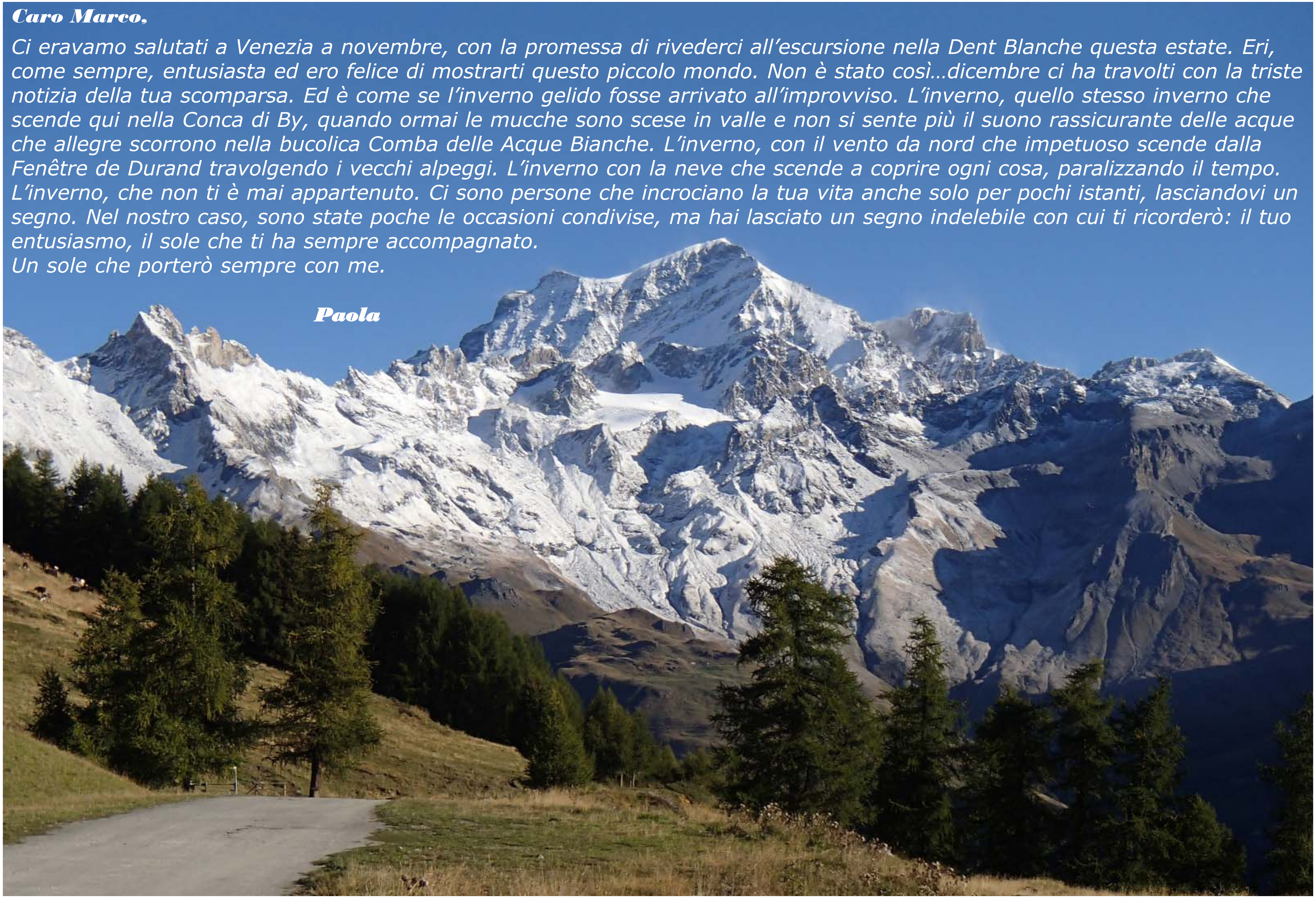
Caro Marco,

Ci eravamo salutati a Venezia a novembre, con la promessa di rivederci all'escursione nella Dent Blanche questa estate. Eri, come sempre, entusiasta ed ero felice di mostrarti questo piccolo mondo. Non è stato così…dicembre ci ha travolti con la triste notizia della tua scomparsa. Ed è come se l'inverno gelido fosse arrivato all'improvviso. L'inverno, quello stesso inverno che scende qui nella Conca di By, quando ormai le mucche sono scese in valle e non si sente più il suono rassicurante delle acque che allegre scorrono nella bucolica Comba delle Acque Bianche. L'inverno, con il vento da nord che impetuoso scende dalla Fenêtre de Durand travolgendo i vecchi alpeggi. L'inverno con la neve che scende a coprire ogni cosa, paralizzando il tempo. L'inverno, che non ti è mai appartenuto. Ci sono persone che incrociano la tua vita anche solo per pochi istanti, lasciandovi un segno. Nel nostro caso, sono state poche le occasioni condivise, ma hai lasciato un segno indelebile con cui ti ricorderò: il tuo entusiasmo, il sole che ti ha sempre accompagnato.
Un sole che porterò sempre con me.

Paola



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