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The Briançonnais margin units in the South-Western Alps (Italy- France)

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Cover page Figure: Panoramic view on the Aiguille de Chambeyron, looking south from the Marinet lake (Saint-Paul-sur-Ubaye, France).

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ABSTRACT

In the Cottian Alps, across the Italian-French boundary, several continental-derived tectonic units are stacked together with Alpine Tethys-derived units. The continental units derive from the passive European margin, particularly from its most distal part that was subducted and exhumed during the Alpine orogeny. These units are generally grouped as Briançonnais s.l. units (a term that includes the Classic Briançonnais Units of the Briançon area, the Acceglio-type, the Pre-Piemonte and the Internal Crystalline Massif Units), which comprise metasedimentary successions of Carboniferous to Eocene age and polycyclic crystalline basement units, experiencing various peak metamorphic conditions between lowermost greenschist and ultra-high pressure (UHP) conditions. In the study area, located well south of Briançon, oceanic and continental units are interleaved, resulting in a complex structural architecture dominated by large-scale structures. This field trip guide, organised in two days and 16 stops, proposes an itinerary of great interest between the Maira and Ubaye Valleys (the border area between Italy and France) where these different units can be observed. The proposed trip leads to the exploration of many interesting outcrops on the meso- and large-scale, offering the opportunity to observe the main aspects of the structural architecture of a tectonically complex area. Furthermore, some outcrops will reveal details about the paleogeographic and stratigraphic evolution of the European passive margin units. The itinerary is aimed at both specialists and those interested in the Alpine regional geology. This field trip also makes it possible to further enhance a less frequented part, rich in interesting geo-touristic sites, of the Maira and Ubaye Valleys.

Keywords: Cottian Alps, Briançonnais, Polyphase deformation, Tectonics, Field trip.

PROGRAM SUMMARY

The field trip lasts two days, during which the main aspects of the spectacular geology of the Briançonnais Units along the Ubaye-Maira valleys will be highlighted (Fig. 1). The first-day trip starts from San Damiano Macra (Maira Valley, Piemonte Region, Italy) while the second day's field trip starts from Saint-Paul-sur-Ubaye (Ubaye Valley, France). The itinerary of the first-day offers an overview of different types of tectonic units derived from the Briançonnais paleomargin. The first part of the day 1 trip, by car, allows for observing the most significant outcrops of the continental-derived Pre-Piemonte and Acceglio-type Units. This first-day trip ends with a short walk near a tectonic contact juxtaposing Classic Briançonnais and Acceglio-type Units. The second-day itinerary allows for a better observation of spectacular folding structures that characterize the Classic Briançonnais and Acceglio-type Units. It also presents interesting new features, not clearly outlined so far in the literature: (i) the mutual relationship between Helminthoid Flysch Units and the Briançonnais Units and (ii) the structure of recent faults. Only the first two stops of the second day can be reached directly by car, all the others will be visited walking along mountain paths. Finally, one stop will also be dedicated to show the differences between the ocean-derived breccias that are part of the Queyras Schistes Lustrés and those of the Briançonnais-derived continental units.

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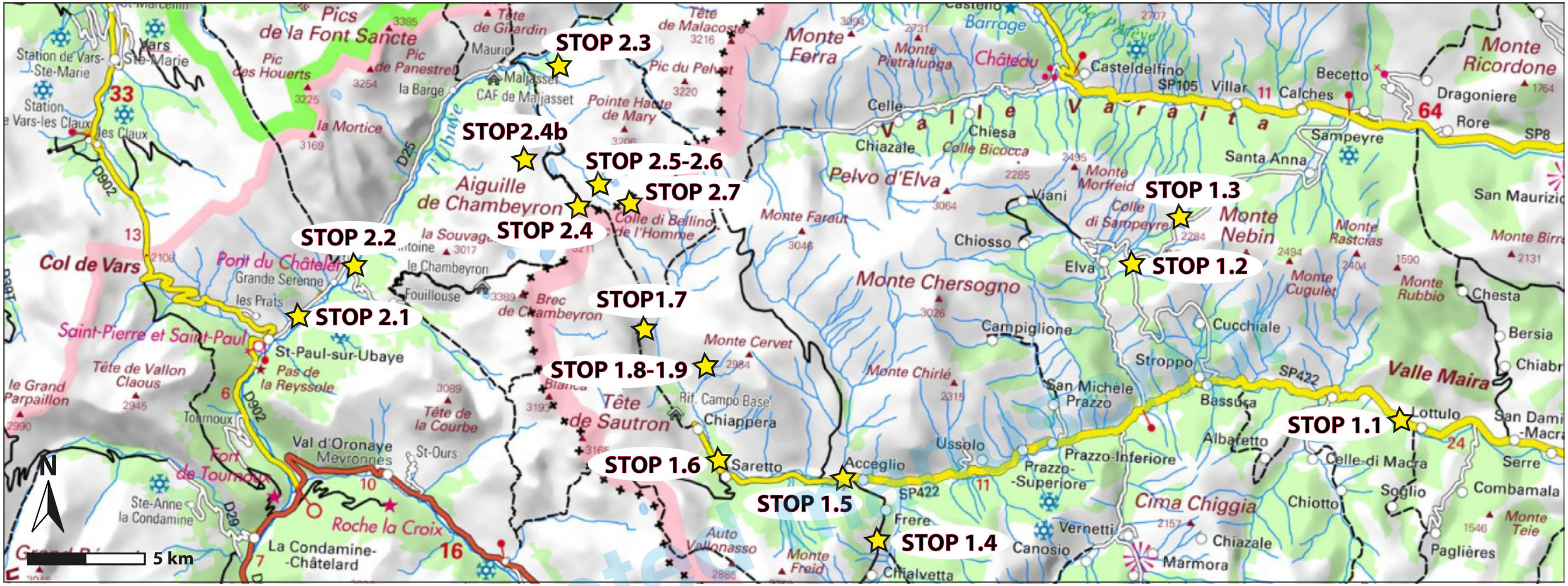

Fig. 1 - Itinerary of the proposed fieldtrip, the topographic map is available from IGN website (https://www.geoportail.gouv.fr/donnees/carte-topographique-ign).

SAFETY

The field trip is structured along traced paths and narrow roads through rough mountain terrains, and it reaches heights of about 3000 metres. Therefore, adequate technical personal equipment and preparation are required. Water can be found along the itinerary, but it is recommended to bring at least two litres of water per person. In some of the areas visited, there is no mobile telephone signal. In some places, the paths are very exposed and not recommended for those suffering from vertigo. The best time for the visit is between summer and early autumn. In case of bad weather (rain, snow, thunderstorm or fog) the itinerary of day 2 should be cancelled.

EMERGENCY PHONE NUMBERS:

Mountain Rescue (Italy and France) – 112.

HOSPITALS

Italy - Via Coppino Michele 26, 12100, Cuneo, Italy. Ph. +39 0171641111.
France - Quartier, 04000, Digne-les-Bains, France. Ph. +33 492301515.

ACCOMMODATIONS

There are several hotels, B&B, etc. in the villages of the Ubaye – Maira valleys. According to the field trip program, it is suggested to book accommodation in Acceglio (Italy) or in Maljasset (France).

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A SHORT INTRODUCTION TO THE WESTERN ALPS

The Alpine belt, originated from the tectonic inversion of major Mesozoic paleogeographical domains, linked to the Pangea breakup and Alpine Tethys opening (Handy et al., 2010; Pfiffner, 2014; Schmid et al., 2004, 2017). These domains are the European passive margin, the Briançonnais microcontinent, the Alpine Tethys Ocean and the Adria passive margin (Kissling and Schlunegger, 2018; Agard and Handy, 2021; Le Breton et al., 2021). This paleogeographical configuration was deeply reworked starting with Cretaceous convergence followed by collision between Europe and Adria during the Cenozoic. Various tectono-metamorphic units, representative of the different paleogeographic domains, were subducted, metamorphosed and deformed, at different times and by different mechanisms (Schmid et al., 2004; Rosenbaum and Lister, 2005; Froitzheim et al., 2008; Beltrando et al., 2010; Handy et al., 2010). Based on the original paleogeographical features and tectono-metamorphic history, the Western Alps can be divided into several first-order tectonic domains (Fig. 2) (Dal Piaz et al., 2003, 2010; Schmid et al., 2004, 2017; Handy et al., 2010; Pfiffner, 2014; Agard and Handy, 2021; Handy et al., 2021; Brunsmann et al., 2024).

The South Alpine domain consists of a fold and thrust belt, facing towards S/SE, thrusting the undeformed part of the Adriatic plate. A complete crustal section is exposed in this domain in form of the Ivrea Zone, down to the exhumed continental upper mantle (Pfiffner, 2014). This domain is limited to the N by the Insubric Line, an important dextral strike-slip tectonic contact (Schmid et al., 1987). The Southern Alps are generally considered lacking a strong Alpine metamorphic overprint, but greenschist and sub-greenschist facies conditions were probably reached in the westernmost part (Canavaese Zone) and in proximity of the Insubric Line (Beltrando et al., 2010; Schmid et al, 2017).

The Sesia–Dent Blanche Units (also referred to as Salassic domain, e.g., Marthaler et al., 2020) are generally interpreted as derived from Adria extensional allochthons detached from Adria during Latest Triassic – Lower Jurassic rifting (Schmid et al., 2004; Manzotti et al., 2014; Fig. 3). This tectonic domain records a high-pressure Alpine metamorphism of blueschist to eclogitic facies conditions (Compagnoni et al., 1977; Beltrando et al., 2010; Manzotti et al., 2014, 2018), which is the oldest one documented in the Western Alps (85 – 60 Ma; Rubatto et al., 1999, 2011; Dal Piaz et al., 2001). The Piemonte–Ligurian units include rocks derived from the Piemonte-Liguria Ocean and are grouped based on their Alpine metamorphic peak (Agard, 2021, Herviou et al., 2022). The ocean-derived units, closer to the ones observed during this field trip, are represented by the Monviso, Orsiera-Rocciavrè, Chenaillet, Queyras Schistes Lustrés and the Helminthoid Flysch units. The Monviso (e.g., Lombardo et al., 1978; Agard et al., 2001) and Orsiera-Rocciavrè (Pognante, 1979) units are part of the so-called Zermatt-type units, exhibiting an eclogitic facies Alpine metamorphic peak. They are mainly made up of ophiolite bodies and minor metasedimentary cover (Herviou et al., 2022). The overlying Queyras Schistes Lustrés are mainly represented by a metasedimentary sequence associated with subordinate ophiolite bodies (Tricart and Lemoine, 1986; Deville et al., 1992; Lagabrielle et al., 2015), their metamorphic peak remaining within the blueschist facies (Agard et al., 2001; Bousquet et al., 2008, Herviou et al., 2022). The Chenaillet Unit is an oceanic crust klippe (above the Queyras Schistes Lustrés) lacking any significant sign of Alpine metamorphism (e.g., Cordey and Bailly, 2007; Schmid et al., 2017). A fourth type of ocean-derived units is represented by the Helminthoid Flysch units, cropping out on the western margin of the area

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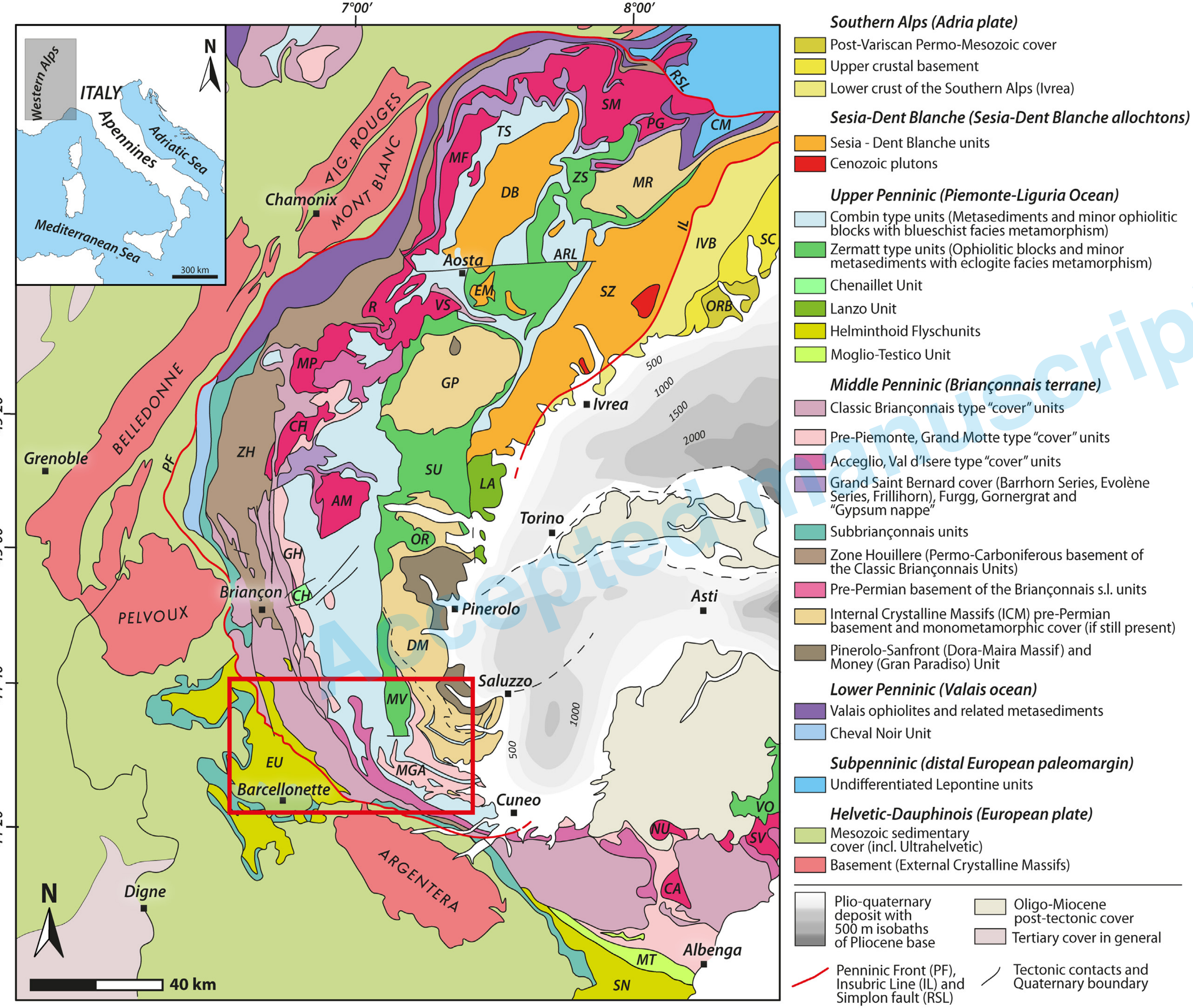

Fig. 2 - Tectonic sketch of the Western Alps (modified from Schmid et al., 2004 and Bigi et al. 1990, implemented with the data from Decarlis et al., 2013; Ballèvre et al., 2020; Michard et al., 2022; Pantet et al., 2023; Dana et al., 2023; Sanità et al., 2022a). Tectonic subdivision of the Western Alps is mainly based on Schmid et al. (2004, 2017). The red box highlights the position of Fig. 5. Abbreviations of tectonic boundaries and first order faults: ARL = Aosta-Ranzola Line, IL = Insubric Line, PF = Penninic Front, RSL = Rhone-Simplon Line. Abbreviations of main tectonic units: AM = Ambin Massif, CA = Calizzano Massif, CFI = Arpont-Chasseforêt (Vanoise Sud), CH = Chenaillet, CM = Camughera-Moncucco, DB = Dent Blanche, DM = Dora-Maira, EM = Emilius, EU = Embrunais-Ubaye, GH = Chaberton-Grand Hoche, GP = Gran Paradiso, IVB = Ivrea-Verbano, LA = Lanzo Massif, MF = Mont Fort, MP = Mont Pourri (Vanoise Nord), MR = Monte Rosa, MT = Moglio-Testico, MV = Monviso, NU = Nucetto, OR = Orsiera-Rocciavrè, ORB = Alpi Orobie, PG = Portjengrat, R = Ruitor, SC = Strona-Ceneri, SG = Serenne-Guillestre, SM = Siviez-Mischabel, SN = Sanremo, SU = Susa, SV = Savona, SZ = Sesia Zone, TS = Tsaté, VO = Voltri, VS = Valsavarenche – Zona Interna, ZH = Zone Houillère, ZS = Zermatt-Saas.

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described in this field trip guide (Kerckhove et al., 1984; Merle and Brun, 1984; Kerckhove et al., 2005). These latter units are almost entirely constituted by turbiditic sequences and are also considered as non-metamorphic (Kerckhove, 1969; Mueller et al., 2020).

The Briançonnais units are derived from the Briançonnais microcontinent that became separated from the European margin s.str. (Dauphinois), at least in parts of the Alps, by the Valaisan oceanic units (Schmid et al., 2004; Handy et al., 2010). This Briançonnais domain has been a long-debated area for understanding paleogeography and rift dynamics; it is characterized by a distinctive stratigraphic evolution that enables to distinguish it from the European s.str. and Adria units (e.g., Lemoine et al., 1986; Michard et al., 2022). Stampfli (1993) proposed that the Briançonnais terrane was a former part of the Tethys margin belonging to the Iberian Plate. According to him, it became detached from it and the European plate by the formation of another oceanic branch, the Valais domain, during the Cretaceous (Loprieno et al., 2011; Beltrando et al., 2012; De Broucker et al., 2021; see further information below). Another model proposed by Lavier and Manatschal (2006) and Mohn et al. (2010) interpreted the Briançonnais as a "hanging-wall block" formed between Europe and Adria during the Jurassic rifting. In other reconstructions, the Briançonnais is even interpreted as a portion of the Adria paleomargin (Hunziker and Martinotti, 1984; Polino , 1990). In this guide, the interpretation proposed by Stampfli (1993) and subsequently adopted by several other authors (e.g., Schmid et al., 2004; Ballèvre et al., 2018, 2020; Michard et al., 2022; Dumont et al., 2022) is followed.

On the larger scale, the Briançonnais-derived Units include the Grand Saint Bernard nappe system (e.g., Sartori, 1990; Thélin et al., 1993; Malusà et al., 2005; Sartori et al., 2006; Scheiber et al., 2013; Pantet et al., 2020, 2023), a multitude of mostly detached cover units of the French-Italian Alps (e.g., Ellenberger, 1958; Debelmas and Gidon, 1958; Michard et al., 2004; Dana et al., 2023) and closer basement complexes such as the Ambin Massif (Ganne et al., 2005, 2007), the pre-Alpine basement units of the Ligurian Alps with their preserved Mesozoic covers (Seno et al., 2005; Maino and Seno, 2016; Decarlis et al., 2017; Maino et al., 2019; Sanità et al., 2021, 2022a), and finally the Internal Crystalline Massifs lacking substantial volumes of Mesozoic cover (Schmid et al., 2004; Gasco et al., 2013; Ballèvre et al., 2020). These Internal Crystalline Massifs, namely the Dora-Maira, Gran Paradiso and Monte Rosa, are exposed as tectonic windows below-ocean-derived units. They are generally considered as representing the pre-Triassic basement from which the Briançonnais domain mostly sedimentary units became detached (Michard, 1967; Ballèvre et al., 2018, 2020; Michard et al., 2022), but other ideas have also been proposed in the literature (e.g., Froitzheim et al., 2001). The Dora-Maira Massif, cropping out east of the field trip area, is mainly made up of a Variscan metamorphic basement (represented by micaschist, paragneiss, orthogneiss, metabasite and minor marble) intruded by Permian granitic-dioritic intrusive, a monometamorphic Upper Carboniferous – Lower Triassic metasedimentary sequence of graphite-bearing micaschist and paragneiss with minor metaconglomerates (Pinerolo-Sanfront Unit) and discontinuous outcrops of marble and dolostones interpreted as remnants of a Mesozoic sedimentary cover (Sandrone et al., 1993; Ballèvre et al., 2020; Michard et al., 2022). The Briançonnais-derived units have a variable Alpine metamorphic overprint, ranging from eclogitic facies, widespread in the Internal Crystalline Massifs, over blueschist to greenschist or even sub-greenschist facies overprint in the more external detached units of the Briançonnais (e.g., Borghi et al., 1985; Ganne et al., 2003; Michard et al., 2004; Malusà et al., 2005; Bucher et al., 2007; Bousquet et al., 2008; Strzerzynski et al., 2012; Michard et al., 2022; Sanità et al., 2022b). Ultra-high pressure (UHP) peak conditions were reached in the Brossasco-Isasca (Southern Dora-Maira) and in the Chasteiran (Northern Dora-Maira) units (Chopin, 1984; Manzotti et al., 2022).

The Valais units represent the remnants of a paleogeographic domain whose nature (oceanic or continental crust) is rather debated in the literature (e.g., Fügenschuh et al., 1999; Masson et al., 2008; Loprieno et al., 2011; Beltrando et al., 2012; De Broucker et al., 2021). Valais-derived Units (e.g., *Sion-Courmayeur Unit*) predominantly consist of monotonous calcschist and sandstone, whose sedimentation probably started at the Jurassic-Cretaceous boundary (Jeanbourquin and Burri, 1991; Steinmann, 1994). According to some authors parts of these sediments were deposited on oceanic crust (e.g., *"Versoyen Unit"*), including exhumed sub-continental mantle (e.g., Florineth and Froitzheim, 1994; Fügenschuh et al., 1999; Loprieno et al., 2011). The Subbriançonnais units are represented by basin sequences deposited on continental crust, probably representing the southern continuation of the presumably oceanic parts of the Valais basin.

The Helvetic-Dauphinois domain (Fig. 2), nowadays placed in the footwall of the Penninic Front, is represented by the External Crystalline Massifs and their detached and folded, non-metamorphic (except for a very local greenschist to sub-greenschist metamorphism) sedimentary cover (Dumont et al., 2008; Bellahsen et al., 2014). The Helvetic-Dauphinois domain corresponds to the proximal part of the European passive margin (Lemoine et al., 1986; Schmid et al., 2004).

INTRODUCTION TO THE BRIANÇONNAIS DERIVED UNITS

During Alpine orogeny, the sedimentary covers of the original Briançonnais paleomargin often became detached from their pre-Permian basement (Ballèvre et al., 2020; Dana et al., 2023) forming tectonic units mainly made up of cover sequences (the units described in this field trip guide) or dominated by Variscan or even older basement (for example the Ambin or the Dora-Maira Massifs). Detached cover units and units representing their former basement outcrop in two different areas of the Western Alps. Detached sedimentary units correspond to, for example, the Briançonnais s.s. of the French authors (e.g., Termier, 1903), while the Internal Crystalline Massifs are made up of different basement dominated slices stacked together (e.g., Vialon, 1966; Sandrone et al., 1993; Ballèvre et al., 2020; Nosenzo et al., 2024).

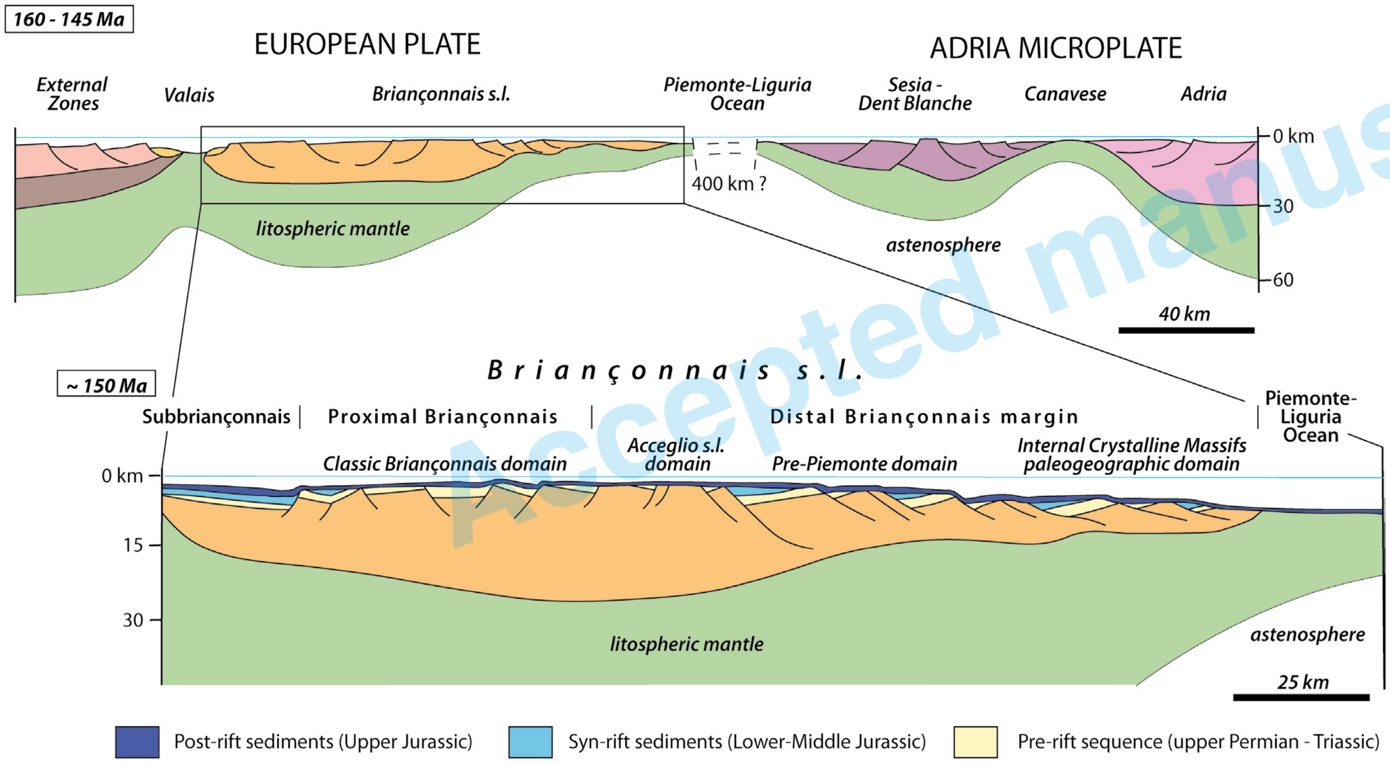

Fig. 3 - Restoration of the Alpine domain in cross-section before plate convergence. Upper panel after Manzotti et al. (2014), Ballèvre et al. (2020); and Michard et al. (2022). Lower panel: Kimmeridgian-Tithonian (~ 150 Ma) stage following the rifting and necking processes, based on Pantet et al. (2020) for the overall aspect and Michard et al. (2022) for the width and thickness of the Briançonnais crust and location of the Briançonnais s.l. paleogeographic domains of the southern Western Alps.

THE MESOZOIC COVER

During the Mesozoic, the Briançonnais domain has evolved from a stable platform environment (Mégard-Galli and Baud, 1977), corresponding to the deposition of the shallow-water sediments of the Lower – Middle Triassic (the future *St. Triphon* and *Champcella* Formations of the Classic Brianconnais units), to a period characterised by extension and rifting (Lower Jurassic) responsible for the formation of normal faults and tilted blocks (Lemoine et al., 1986) with local emersion. During the Upper Jurassic, several paleogeographic domains (Lemoine et al., 1986; De Graciansky et al., 1989) can be recognised along the European paleomargin (Fig. 3).
In the more proximal Classic Briançonnais and more distal Acceglio and Pre-Piemonte paleogeographic domains, as testified in

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tectonic units derived from these domains (Michard et al., 2022), the rifting and emersion phase was followed by the deposition of Upper Cretaceous to lower Paleogene detrital calcschists. These lithologies (labelled in the literature as "*Marbres en Plaquettes*" or "*Calcschist Planctonique*") are frequently associated with "*hard ground*" levels (Debelmas et al., 1983) and were deposited during a new and still enigmatic extensional event clearly post-dating rifting associated with the opening of the Alpine Tethys (Michard and Martinotti, 2002; Michard et al., 2022). The deposition of the "*Flysch Noir*" turbidites marks the end of sedimentation (lower Bartonian, Kerckhove et al., 2005), followed by the arrival of the ocean-derived Helminthoid Flysch units.

For the different domains located along the paleomargin, more or less typical stratigraphic sequences are recognised. Hence, different types of stratigraphic sequences are commonly used to group the detached cover units according to their paleogeographic provenance. The tectonic units, described in this field trip, derive from both the distal (Acceglio and Pre-Piemonte domains) and proximal Briançonnais (Classic Briançonnais domain) paleogeographic domains. These tectonic units, often referred to as "nappes", can be grouped according to their suspected original paleogeographic homeland (e.g., Michard et al., 2022):

- **Classic Briançonnais units**: these units are characterised by hundreds of metres thick Triassic carbonates (Mégard-Galli, 1972a, b; Baud and Mégard-Galli, 1975; Bourbon et al., 1977; Lualdi, 1985; Lemoine et al., 1986; Costamagna, 2013), often seen to have been deposited above a thick and also detached Carboniferous – upper Permian siliciclastic/volcanoclastic sole (*Zone Houillère*), and a nearly complete Middle Jurassic – Eocene sequence (Mégard-Galli, 1974; Fig. 4). In other cases, these units are detached at the base of Lower Triassic *cargneules* while the original Paleozoic basement is unknown or only preserved in very thin slices. In the study area, these units have experienced variable metamorphic peak conditions ranging from greenschist to blueschist facies going from west to east (Michard et al., 2004; Bousquet et al., 2008).
- **Acceglio-type units**: these units are characterised by a considerable reduction in the thickness of Triassic deposits. Frequently, Upper Jurassic marbles lie in unconformity directly on Lower Triassic quartzites or conglomerates/metavolcanites of Permian age (Gidon, 1958; Lemoine, 1961; Le Guernic, 1967; Michard et al., 2004; Fig. 4). This is interpreted as a consequence of major and deep erosion of pre-Middle Upper Jurassic deposits during the emersion phase in the Lower Jurassic linked to rifting dynamics (Faure and Megard-Galli, 1988). These units are often closed upwards by a sequence of continental breccias and olistoliths of Upper Cretaceous – Eocene age (Le Guernic, 1966; Lemoine, 1967). In our study area, the Acceglio-type units generally have Alpine metamorphic peak conditions in blueschist facies.
- **Pre-Piemonte units**: this type of units originates from a paleogeographic domain located east of the Acceglio-type units, hence closer to the Piemonte-Liguria ("*Schistes Lustrés*") units. They exhibit more basinal sequences compared to the Classic Briançonnais and Acceglio-type units (Franceschetti, 1961; Lemoine, 1964, 1971; Michard, 1967; Lemoine et al., 1978; Dumont, 1984, 1985; Dumont et al., 1984; Michard et al., 2022; Fig. 4) and are again characterised by thick Middle-Upper Triassic carbonates (Michard and Sturani, 1963; Megard-Galli, 1974) followed by abundant syn-rift series consisting of chaotic and bedded carbonate breccias, dated by Sinemurian

and Pliensbachian ammonites (e.g., Michard, 1967). In the study area these units generally have metamorphic peak conditions in the blueschist facies.

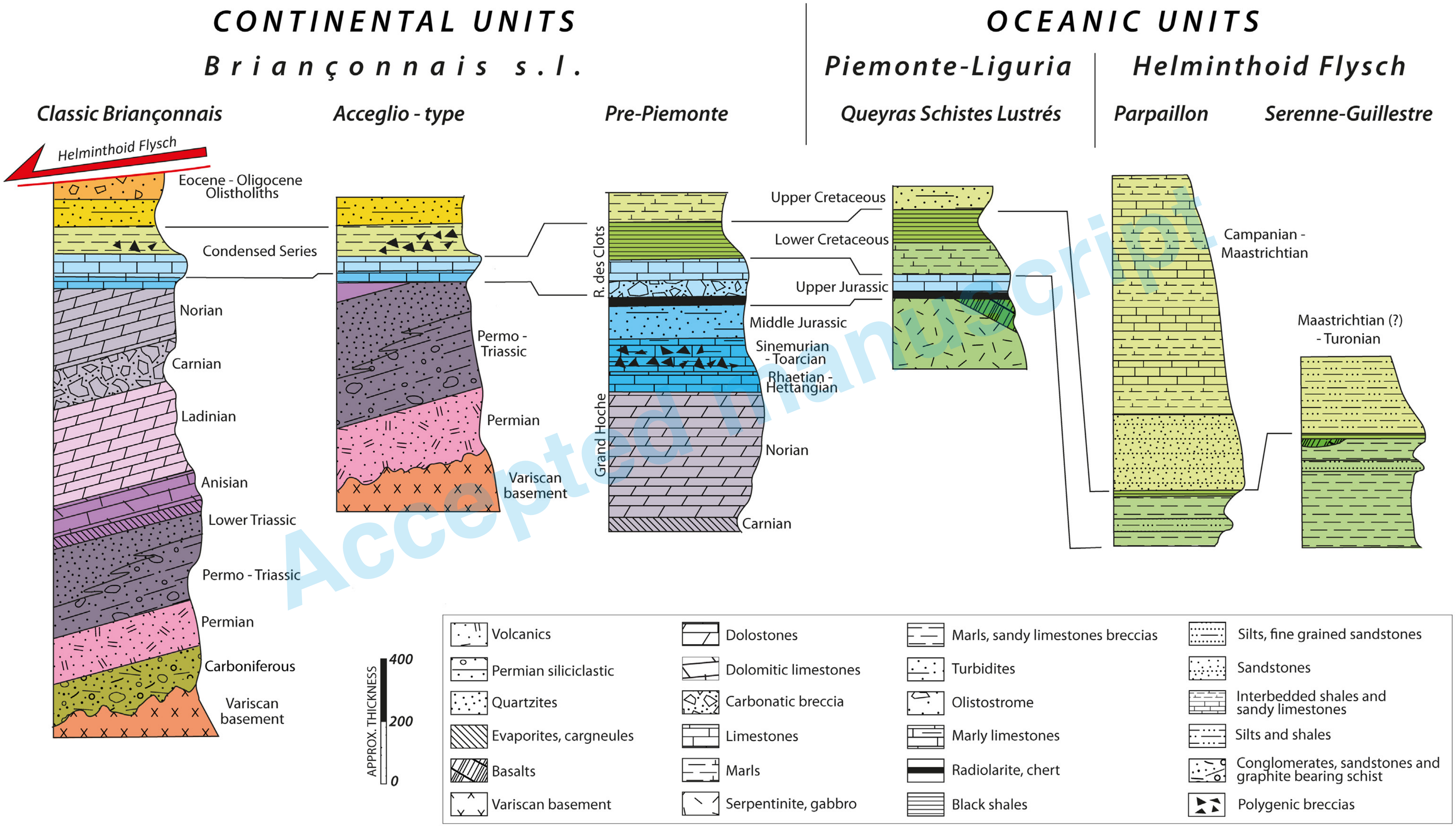

Fig. 4 - Stratigraphic columns of the main tectonic units exposed in the field trip area: Classic Briançonnais, Acceglio s.l., Pre-Piemonte, Queyras Schistes Lustrés and Helminthoid Flysch units (modified from Michard et al., 2022 and Dana et al. (2023), with addictions from Barbier (1948), Sturani (1963), Malaroda et al. (1970) and Kerckhove et al. (2005)).

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An additional type of cover sequences crops out at the margin of the Dora-Maira Massif; these covers are not detached in the northern portion of the Massif (Susa Valley) where they have been deformed and metamorphosed together with the basement (Gasco et al., 2011). Further south, the Dora-Maira cover sequence is rarely preserved and strongly dismembered by deformation (Franchi, 1898a; Vialon, 1966; Marthaler et al., 1986; Michard et al., 2022; Nosenzo et al., 2024). This cover sequence generally consists of quartzites and dolomitic marbles (attributed to the Triassic following the findings of crinoids by Franchi, 1898a), whitish marbles and calcschists (the latter containing Cretaceous microfossils described by Marthaler et al., 1986). A comparable detached cover sequence is also observed at the border of the Gran Paradiso Massif (“*Série de l'Agnel*”, Robert, 1979; Polino and Dal Piaz, 1977; Vearncombe, 1982).

THE PRE-ALPINE BASEMENT

The pre-Alpine basement of the Mesozoic cover sequences is preserved in various basement units (e.g., Grand Saint Bernard nappe system, Gran Paradiso, Dora-Maira, Savona, etc.; Fig. 2) and in the *Zone Houillère* (predominantly made of Carboniferous metasediments, detached from their former Variscan basement). An unequivocal attribution of these basement units to the Briançonnais s.l. domain can be done strictly for those basement units that preserved at least some diagnostic Mesozoic cover (e.g., Sartori, 1990; Pantet et al., 2020, 2023), whereas such an attribution could be potentially controversial if no remnants of a diagnostic cover are preserved (e.g., the Monte Rosa Unit; Froitzheim, 2001; Schmid et al., 2004).

The Briançonnais s.l. basement units represent polycyclic basement (i.e., showing relics of a pre-Alpine metamorphism). In different units, going from the Ligurian to the Swiss Alps, there is evidence of a protracted pre-alpine lithostratigraphic, tectonic and metamorphic evolution (e.g., Desmons, 1992; Borghi et al., 1999; Ganne et al., 2003; Ballèvre et al., 2018; Maino et al., 2019). Although there is no widespread geochronological data in all of these units, in some cases, it is suggested that the oldest rocks cropping out may be of Ediacarian age (e.g., Thiéblemont et al., 2023).

In the Calizzano, Siviez-Mischabel Unit, as well as in the Ambin Massif (Fig. 2), Middle-Late Cambrian basalts and acidic calc-alkaline volcanites associated with pelitic and arenitic sediments are recognized (Bertrand et al., 2000; Gaggero et al., 2004; Sartori et al., 2006; Decarlis et al., 2017). These rocks are intruded by Late Cambrian-Early Ordovician granitoids well documented in the Grand Saint Bernard nappe system (e.g., *Metagranite de Mont Rogneux* of the Siviez Mischabel Unit, Bussy et al., 1996; Sartori et al., 2006) and in the Ligurian Alps (commonly labelled “Orthogneiss I”; e.g., Decarlis et al., 2017). In the Ligurian Alps, the Briançonnais basement underwent Early Ordovician metamorphic re-equilibration under eclogite to amphibolite facies conditions (e.g., Cortesogno et al., 1993; Desmons et al., 1999; Gaggero et al., 2004; Decarlis et al., 2017). The intrusion of large granitic bodies and minor gabbro during Middle to Late Ordovician, followed by the Variscan medium to low-P amphibolite facies metamorphism has been recognised in many crystalline basement units, from the Grand Saint Bernard to the Ligurian Alps (e.g., by Bertrand and Leterrier, 1997 in the Arpont-Chasseforêt Unit; by Guillot et al., 2002 in the Ruitor Unit and by Maino et al., 2019 in the Calizzano and Nucetto units in Liguria). These two events are also widely witnessed in the Dora-Maira Massif.

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Indeed, in this area, Upper Ordovician – Early Silurian granitoids have been dated by Bussy and Cadoppi (1996) and by Nosenzo et al. (2022, 2024). Variscan P-T metamorphic conditions of 6-7 kbar and 650°C have been estimated by Nosenzo et al. (2022) for the northern Dora-Maira Massif in the Muret Unit.

During the Permian, large masses of granitic magma intruded the older basement rocks in the case of the Internal Crystalline Massif and the Grand Saint Bernard nappe system (e.g., Bussy and Cadoppi, 1996; Liati et al., 2001; Bertrand et al., 2005). In the Ligurian Alps (Nucetto and Savona units), abundant Permian magmatism is documented as well, with the local occurrence of Permian lava flows resting directly on the lower Paleozoic metamorphic basement (Dallagiovanna et al., 2009; Maino et al., 2012; Decarlis et al., 2017). Similar Permian magmatism, with the occurrence of rhyolitic lava flows and tuff have been also documented in several Briançonnais derived units (e.g., Ballèvre et al., 2018, 2020). Often these sequences of volcanic rocks have been detached from their original pre-Alpine basement along with the Mesozoic covers described previously (Gidon et al., 1994; Dana et al., 2023).

These data demonstrate that despite a similar evolution, there are many local variations between the different basement units. Some of these units were overprinted by Alpine high-pressure metamorphism (e.g., the famous Brossasco-Isasca Unit in the Southern Dora-Maira; Chopin, 1984), whereas in others, the Alpine metamorphic overprint does not exceed the greenschist facies (e.g., in the Savona Unit; Cortesogno et al., 1997)

The itinerary described in this guide does not visit outcrops of pre-Alpine polycyclic basement. In the field trip area, the Briançonnais-derived units are all made of detached cover sequences (with the local preservation of Permian and Carboniferous formations). The only exception is represented by the Pelvo d'Elva Unit, which preserves a pre-Alpine polycyclic basement slice at its base (e.g., Michard et al., 2022).

STRUCTURAL ARCHITECTURE AND TECTONO-METAMORPHIC EVOLUTION OF THE UBAYE, MAIRA AND VARAITA VALLEYS

The current structural architecture of the area described in this fieldtrip, represented in Fig. 5, results from a complex Alpine tectonic evolution. Sandwiched between the ocean-derived units (Helminthoid Flysch units to the W and Monviso – Queyras Schistes Lustrés to the E), a stack of Briançonnais-derived units is present. Each unit of this stack shows different stratigraphical and metamorphic imprints. The latter increases from sub-greenschist to blueschist facies going towards E (Gidon et al., 1994; Michard et al., 2004; Kerckhove et al., 2005; Dana et al., 2023). These units were deformed during a polyphase structural evolution.

During the Eocene, the Briançonnais domain was affected by Alpine deformation with an outward, i.e. foreland-directed transport direction towards the N or NW (typically referred to the D1-D2 deformation phases, in the literature), which caused the original stacking of the various units (Debelmas and Gidon, 1958; Ellenberger, 1958; Lemoine et al., 1986; Ricou and Siddans, 1986; Platt et al., 1989; Michard et al., 2004; Schmid et al., 2017). From the Oligocene onward this original stack was affected by a severe deformation event D3 showing an opposite transport direction, i.e., back-thrusting and –folding toward the interior of the chain (the so-called retrovergence or "*rétrocharriage*"; Tricart, 1975). Deformation of the already stacked units is testified by large-scale folds (backfolds or "*pli en retour*" in the early French literature, e.g., Termier, 1903; Blanchard, 1915; Gignoux, 1939) and thrusts (backthrusts), with top-to-the-E tectonic transport direction (Tricart, 1975; Lefèvre, 1982; Debelmas et al., 1983; Platt et al., 1989; Caby, 1996; Tricart and Schwartz, 2006; Tricart and Sue, 2006; Michard et al., 2004, 2022; Dumont et al., 2022; Dana et al., 2023). The backfolding, in some parts of the visited area (for example the High Ubaye Valley; Michard and Henry, 1988), was so penetrative that it almost completely obliterated the previous structures related to the outward stacking of nappes. At the Western Alps scale, the combined effect of the D1-D2 and D3 deformation phases was to produce a "fan-like" architecture for the Briançonnais units outcropping west of the Schistes Lustrés (Tricart, 1975; Caby, 1996; Bucher et al., 2003). This structure, known as "*Briançonnais fan, Auct*." or "*'éventail Briançonnais*" (Termier, 1903) has been extensively described, particularly along the Briançon and Guil Valley transects (e.g., Termier, 1903; Gignoux and Moret, 1938; Goguel, 1950).

Not all the units represented in Fig. 5 will be dealt with here; for a more detailed description the interested readers can refer to Gidon (1958), Michard and Henry (1988), Michard et al. (2004, 2022) and Dana et al. (2023). Regarding the area covered by this field trip, we will first briefly describe the tectonic structure of the Classic Briançonnais units cropping out in the Ubaye-Maira valleys, then the Acceglio-type and Pre-Piemonte units.

The structurally highest, in terms of the present-day stacking order, Classic Briançonnais Unit in the Ubaye-Maira valleys is a composite thrust sheet consisting of the Châtelet Unit s.s. and its equivalents: the Font Sancte Unit (an independent slice thrusted towards NE; Blanchet, 1934; Michard and Henry, 1988; Claudel and Dumont, 1999), the Brec de Chambeyron klippe (Gidon et al., 1994; Kerckhove et al., 2005; Dana et al., 2023; Fig. 5) and two minor klippe (not represented in Fig. 5 due to the small size). To the north, these units are overlain by

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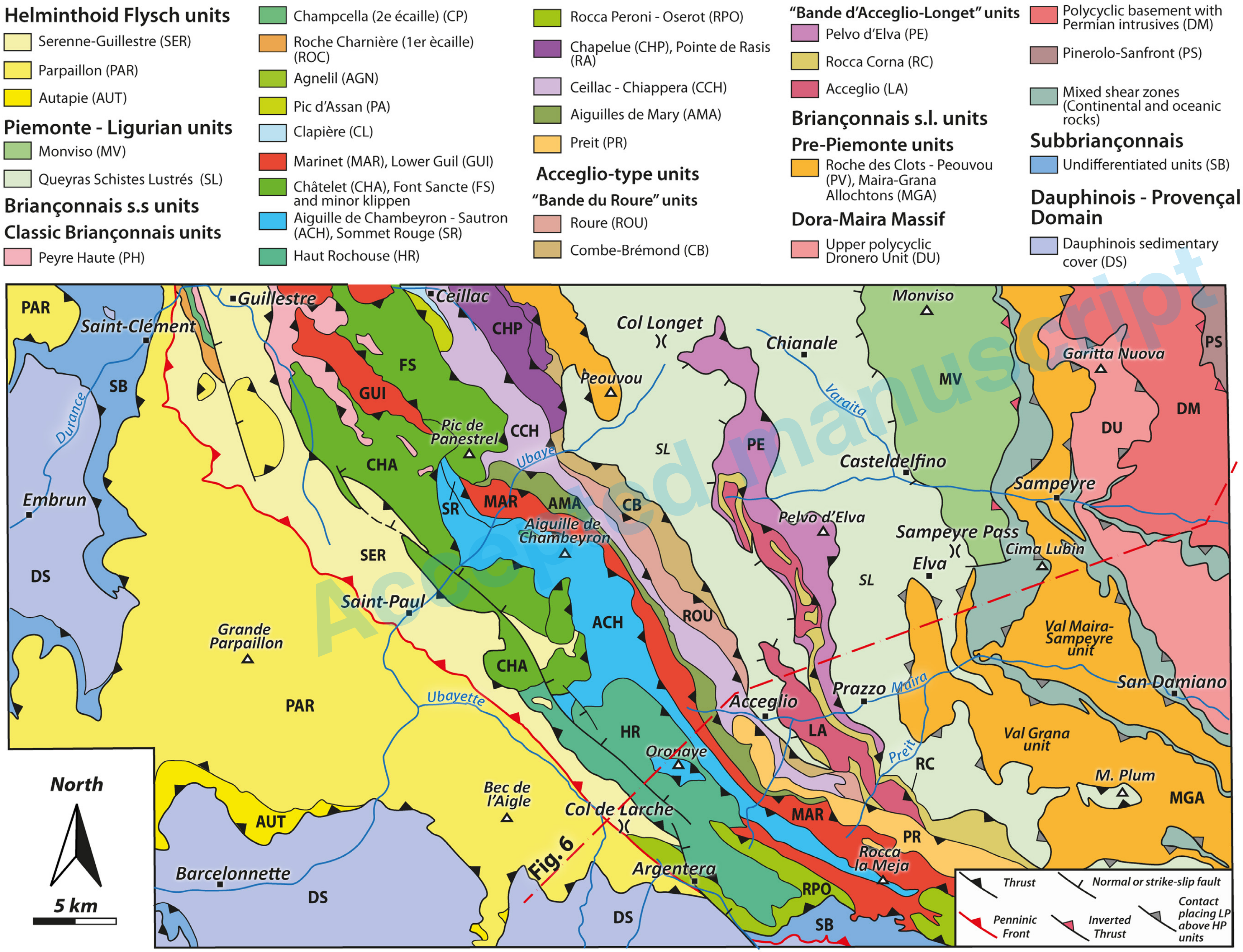

Fig. 5. Tectonic sketch of the southern Western Alps, centred on the Italy and France border area. Figure 6 cross-section trace is drawn with the dashed red line. This figure is a compilation of data from Tricart (1980), Bigi et al. (1990), Gidon et al. (1994), Claudel (1999), Kerckhove et al. (2005), Michard et al. (2022), and Dana et al. (2023). The "Inverted Thrust" in the figure, represents tectonic contacts active as former thrust placing high-pressure above lower-pressure rocks, later reactivated as extensional shear zones (Michard et al., 2022).

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the Peyre Haute Unit, which is the tectonically highest Briançonnais unit south of the Guil River (Ortolland, 1955; Debelmas and Lemoine, 1957; Tricart et al., 1988). Towards W the Châtelet Unit is tectonically overlain by the Serenne-Guillestre Unit, part of the Helminthoid Flysch units, emplaced in mid-to-latest Eocene times by top-west movement (in present coordinates) over the Briançonnais, Subbriançonnais and Dauphinois (Kerckhove et al., 2005; Dana et al., 2023). The Serenne-Guillestre Unit will be discussed in detail at a dedicated stop (see stop 2.1). This unit represents a Helminthoid Flysch-type Unit located in a particular tectonic position, i.e., to the E of the Penninic Front. The main part of the Helminthoid Flysch units, on the other hand, crop out W of the Penninic Front, in the form of two large tectonic units named the Parpaillon Unit (the structurally higher one) and the Autapie Unit (the structurally lower unit). Along the Upper Ubaye valley transect the Châtelet Unit s.l. (Fig. 5), is clearly backthrusted towards the northeast above a SW-dipping nappe pile that includes the Aiguille de Chambeyron – Sautron Unit, the isoclinally folded stratigraphic sequence of the Marinet Unit as well as the Aiguilles de Mary and the Ceillac-Chiappera Unit for at least 7 km (Gidon et al., 1994; Michard and Henry, 1988). The Châtelet, Aiguille de Chambeyron – Sautron and Ceillac-Chiappera Units present a typical Classic Briançonnais sequence detached along the Lower Triassic *cargneules* level.

Other minor differences (absence or presence of specific formations) allow an easy distinction of the three units. The Marinet and Aiguilles de Mary Units, on the other hand, include a reduced carbonate cover and a thick siliciclastic sole. In the Marinet Unit, the oldest formation is represented by Upper Carboniferous metaconglomerates (“*Assise de la Blachière*”, Gidon, 1958) whereas in the Aiguilles de Mary Unit is represented by upper Permian metandesites (Lonchampt, 1962). The Marinet Unit and the equivalent Lower Guil Unit are considered as the southern continuation of the *Zone Houillère* (Feys, 1954, Fabre, 1982), which crops out extensively from Briançon up to the Grand Saint Bernard pass (Fig. 2 and 5). To the south, structurally below the Aiguille de Chambeyron – Sautron Unit, the two structurally lowermost Classic Briançonnais units of the study area crop out; the Haut Rochouze and Rocca Peroni – Oserot Units (Gidon, 1958; Gidon, 1977). These units are not detached from the Permian siliciclastic/volcanoclastic sequence and have a nearly complete Classic Briançonnais carbonate cover from Middle Triassic to Eocene (Gidon, 1977). The lowermost Rocca Peroni – Oserot Unit tectonically overlies the Subbriançonnais units (Carraro, 1961; Malaroda et al., 1970; Gidon, 1971; Sturani, 1975) exposed in the Stura Valley southeast of Argentera village (Fig. 5). Alpine metamorphism reaches low-grade greenschist facies conditions in the Châtelet and Aiguille de Chambeyron – Sautron units whereas HP greenschist conditions are registered in the Marinet Unit and blueschist facies conditions in the Aiguilles de Mary and Ceillac-Chiappera units (Michard et al., 2004; Dana et al., 2023).

The Acceglio-type units, in the South-Western Alps give rise to two bands of outcrops (Fig. 5), known as the *Bande d’Acceglio-Longet* (Franchi, 1898b; Debelmas and Lemoine, 1957; Lefèvre, 1966; Michard, 1959) and the *Bande du Roure* (Le Guernic, 1967). Since Franchi (1898b), in agreement with Le Guernic (1967), the *Bande du Roure* is interpreted as the western prosecution of the *Bande d’Acceglio-Longet*, separated by a post-nappe D3 syncline within the Queyras Schistes Lustrés (Franchi, 1898b; Lefèvre, 1966; Michard et al., 2004; Figgs. 5, 6). The *Bande du Roure* is made up of two different unit, the *Roure* and *Combe-Brémond Units*, both internally folded with a vergence that indicates their position at the southwestern margin of the above-mentioned syncline of Queyras Schistes Lustrés (Dana et al., 2023; Mendes et al., 2023). The Roure Unit consists of a single upper Permian – Lower Triassic siliciclastic sequence, while the Combe-Brémond Unit has an Acceglio-

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type cover sequence consisting of a relict Middle Triassic followed by Upper Jurassic marble transgressive on Lower Triassic quartzites and an Upper Cretaceous – Paleocene polygenic breccias sequence (Lemoine, 1961; Gidon et al., 1994). Both these units reached blueschist facies conditions during the Alpine metamorphism.

At the eastern margin of the post-nappe D3 syncline the "*Bande d'Acceglio-Longet*" crops out (Fig. 6). From WSW to ENE the *Bande of Acceglio-Longet* consists of three different units (Fig. 5, Michard, 1959; Lefèvre, 1966; Gidon et al., 1994): Acceglio, Rocca Corna and Pelvo d'Elva units. Two of these units (Acceglio and Rocca Corna) are folded together into a D3 anticline (known as "*Acceglio Anticline*") while the third (Pelvo d'Elva) forms another independent D3 anticline in a higher structural position. The Pelvo d'Elva Unit (*Zona anticlinale du Pelvo d'Elva*; Franchi, 1898b) is made of an upper Permian – Lower Triassic siliciclastic sequence and a reduced carbonate cover mainly represented by Upper Jurassic and Upper Cretaceous rocks. This Unit is frequently truncated into minor tectonic slices only made of "*socle siliceux, Auct.*" (the siliciclastic/volcanic portion of the metasedimentary sequence, Lefèvre, 1966; Fig. 5). At the base of the siliciclastic sequence, the Pelvo d'Elva Unit contains a basement slice consisting of polymetamorphic micaschist (Michard, 1959; Lefèvre and Michard, 1976; Schwartz et al., 2000) and jadeite-bearing orthogneiss (Lefèvre and Michard, 1965; Michard et al., 2022). According to Michard et al. (2004) this unit reached peak alpine P-T conditions at about 13 kbar and 430°C whereas slightly more higher values are reported by Schwartz et al. (2000). However, this latter estimate is controversial since the studied garnet could be inherited from pre-Alpine metamorphism (Lefèvre and Michard, 1976). In the Rocca Corna Unit, the carbonate cover, mainly represented by Upper Jurassic marble and Cretaceous calcschist is in direct stratigraphic contact with Lower Triassic or Permian quartzites. The lowermost Acceglio s.s. Unit, comparable to the Roure Unit, is mainly composed by a Permian – Lower Triassic siliciclastic sequence and lacking Triassic carbonates, with minor Jurassic and Cretaceous rocks (the calcareous-dolomitic Triassic cover is only locally preserved in tectonic slices, e.g., *Grange Serri sliver* of Lefèvre, 1982). This unit forms the core of the Acceglio nappe anticline (Fig. 5).

A second post-nappe emplacement (post-D1-D2) syncline with Queyras Schistes Lustrés in the core separates the "*Bande d'Acceglio-Longet*" from the Maira-Grana Allochthons (Fig. 6). The Maira-Grana Allochthons (MGA) are two large cover units, detached from their former basement. In the Val Maira – Sampeyre Unit, Lower and Middle Triassic formations are observable whereas the Val Grana Unit is made of Middle-Upper Triassic and Lower-Middle Jurassic formations (Michard, 1967; Michard et al., 2022). Both these units are Pre-Piemonte units, derived from the distal Briançonnais paleomargin. The Alpine metamorphic peak conditions of these units are in blueschist facies with peak temperatures around 400 – 500 °C (Lahfid et al., 2022; Michard et al., 2022).

The *Cima Lubin shear zone (CLSZ)* separates the Val Maira – Sampeyre Unit from the overlying Val Grana Unit (Fig. 6). CLSZ is a heterogeneous shear zone (including both oceanic and continental material, Michard et al., 2022) mainly made of calcschists involving tectonic lenses of micaschists (Permian?), quartzites (Lower Triassic), *cargneules* and dolostones (Middle-Upper Triassic), and metabasites. This shear zone continues northward separating the overlying Monviso Unit from the Val Maira-Sampeyre Unit (known as Sea Bianca Unit in the Po Valley; Balestro et al., 2011). The MGA are overlain by tectonic units derived from the Piemonte-Liguria Ocean: the Monviso Unit and the Queyras

Schistes Lustrés. The *Monviso (MV)* Unit, consisting of several eclogitic units (locally up to UHP, Ghignone et al., 2023) is mainly made up by meta-ophiolites and rare oceanic metasediments, underlain by a basal sole of serpentinites (Lombardo et al., 1978; Agard et al., 2001; Angiboust et al., 2012; Balestro et al., 2013; Locatelli et al., 2019). The *Queyras Schistes Lustrés (SL)* consist of different units (not separated in Fig. 5) made up of blueschist-facies oceanic metasediments bearing boudinaged meta-ophiolite bodies (Deville et al., 1992; Lemoine and Tricart, 1993; Tricart and Schwartz, 2006; Herviou et al., 2022).

A second heterogeneous shear zone, referred to as *San Damiano shear zone (SDSZ*), separates the Val Maira-Sampeyre Unit from the Dora-Maira Massif upper unit, known as Dronero Unit (Michard et al.,1993, 2022; Bonnet et al., 2022).

Structures referred to three or four deformation phases, depending on the authors, are recognised in the South-Western Alps metamorphic wedge (Tricart, 1980; Platt, 1989; Michard et al., 2022). The first deformation phase (D1) produced an S1 foliation that is subparallel to the original bedding (S0). F1 folds are rare. The S1//S0 foliation is folded by F2 folds, frequently observed at the western margin of the Classic Briançonnais units. The D1 phase is associated with the metamorphic peak pressure conditions in the Maira – Grana Allochthons (MGA) and in the Queyras Schistes Lustrés (Michard et al., 2022). In the underlying Dora-Maira eclogitic units, according to Henry et al. (1993), an early (S1?) foliation developed under peak-pressure conditions and is deformed by syn-greenschist facies folds (D2?). In the MGA the D2 phase is probably formed during the exhumation; it is occasionally well-defined by isoclinal to tight folds, transposing the previous S1 foliation into the main S2 foliation. Distinguishing F2 from subsequent F3 folds in the MGA is not an easy task. The equivalent structures in the southern Dora-Maira Massif units are represented by syn-greenschists facies mylonites (Henry et al., 1993; Michard et al., 1993). In the Classic Briançonnais and Acceglio-type units the first two phases (D1-D2) of deformation are related to the original top-to-the-W to NW nappe piling (e.g., Platt, 1989; Dumont et al., 2022; Dana et al., 2023). They are associated with foliations developed under conditions close to the Alpine metamorphic peak, as suggested by the occurrence of lawsonite- and carpholite-bearing parageneses (Goffé and Velde, 1984; Goffé and Bousquet, 2004; Michard et al., 2004). The D3 phase is associated with backfolding and subsequent backthrusting clearly visible at the larger scale (Fig. 6). In the MGA, Classic Briançonnais and Acceglio-type units these D3 structures are observed at all scales. The D3 deformation phase represents the most intensive deformation phase in the Classic Briançonnais and Acceglio type units of the Ubaye-Maira valleys. In these units all the previous tectonic surfaces are transposed by the D3 event, developed under retrograde–decompression metamorphic conditions. The S3 foliation is a crenulation or disjunctive cleavage mainly developed in incompetent lithologies and associated with scarce greenschist-facies recrystallisation (white mica and chlorite assemblages) more prominent in the Acceglio-type and MGA units. Apparently, D3 retro-structures are not observed in the southern Dora-Maira Massif, instead the Dora-Maira Massif and related shear zones (SDSZ, VMSZ, CLSZ) underwent a top-to-the-SW extensional phase in greenschist-facies conditions (Henry et al., 1993; Michard et al., 1993, 2022). Note that the D3 phase significantly dominates the area of interest with intense backfolding and backthrusting at all scales. A D4 phase has only been observed by some authors in the Classic Briançonnais and Acceglio-type units (Michard et al., 2004). According to some authors, this phase is developed under late, retrograde metamorphic conditions and is mainly associated with small upright folds probably connected to the Western Alps oroclinal bending or to late-stage faulting and extension.

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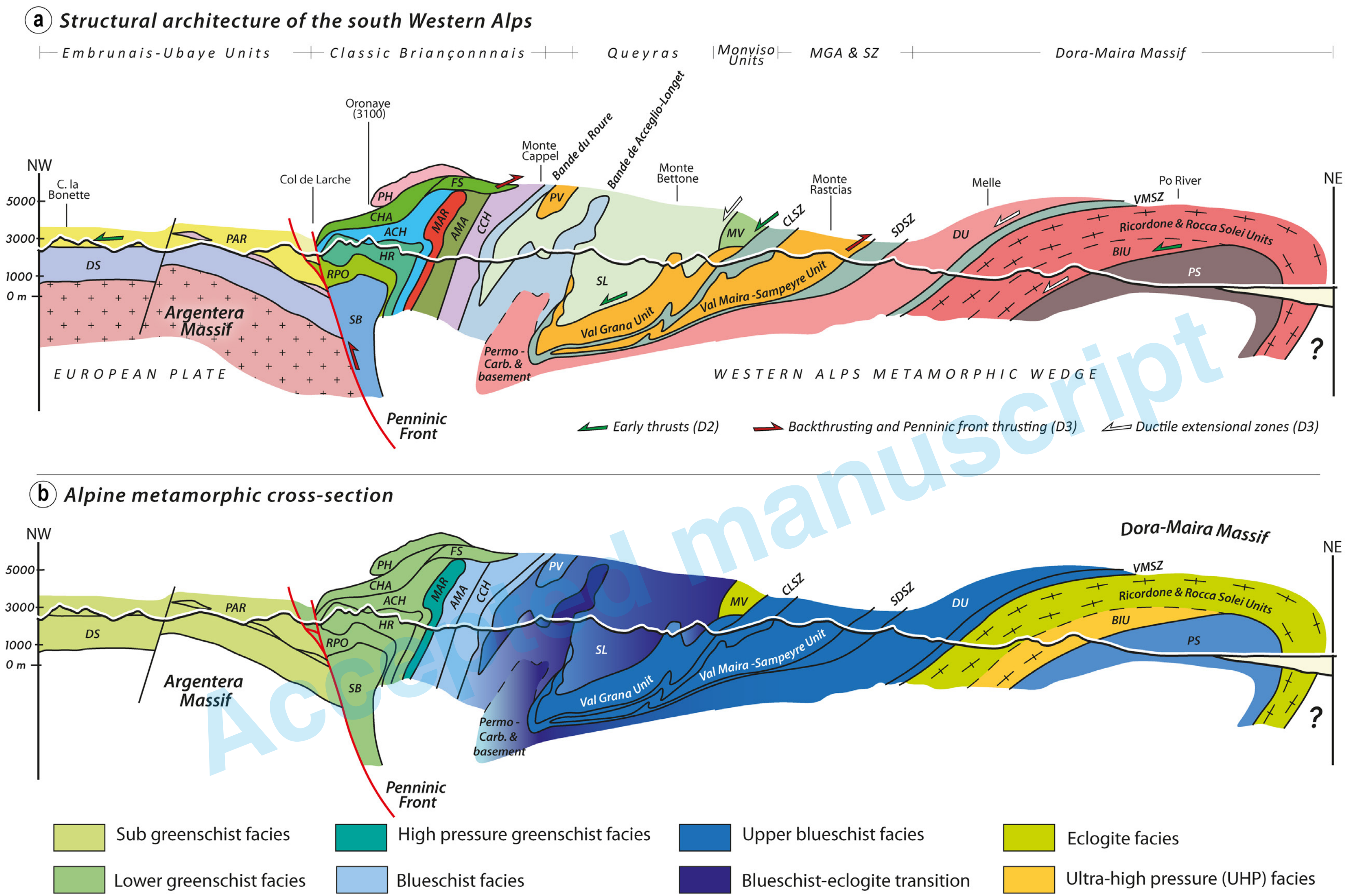

Fig. 6 - Schematic orogen-scale cross sections across the southwestern Alps (modified from Michard et al., 2022). See Fig. 5 for the cross-section trace. a) Tectonic cross section (colours are the same of Fig. 5) based on Michard et al., 2022. b) Alpine metamorphic cross-section. Metamorphic data are from Bousquet et al. (2008), Michard et al. (2022), and Dana et al. (2023). Abbreviations: PAR = Parpaillon Unit, DS = Dauphinois sedimentary cover, SB = Subbriançonnais Units, RPO = Rocca Peroni-Oserot Unit, HR = Haut Rochouse Unit, ACH = Aiguille de Chambeyron-Sautron Unit, CHA = Chatelet Unit, FS = Font Sancte Unit, PH = Peyre Haute Unit, MAR = Marinet Unit, AMA = Aiguilles de Mary Unit, CCH = Ceillac-Chiappera Unit, PV = Roche des Clots-Peouvou Unit, SL = Queyras Schistes Lustrés, MV = Monviso Unit, CLSZ = Cima Lubin Shear Zone, SDSZ = San Damiano Shear Zone, DU = Dronero Unit, VMSZ = Valmala Shear Zone, BIU = Brossasco-Isasca unit, PS = Pinerolo-Sanfront Units.

DAY 1

The first-day itinerary will be done partly by car and partly by walking. It is recommended to plan the trip in the way that the first four stops are made in the morning and the following ones in the afternoon. The first two stops (Stop 1.1 – 1.2) allow us to observe part of the Pre-Piemonte type sequences of the Maira – Grana Allochthons and associated folding structures at meso- and mega-scale. Stop 1.3 and 1.4 is devoted to get an overview of the "*Acceglio-Longet Band*" Units and their structures. The nearby Stop 1.5 will allow the observation of one of the rare ophiolite bodies scattered within the Queyras Schistes Lustrés calcschists. Stops 1.6 to 1.9 offer an overview of the main Classic Briançonnais units in the field trip area, culminating at the Ceillac backthrust outcrop. It is important to drive carefully along the unpaved road leading to the Grange Collet, here a high-seated car (e.g., pick-up) is more suitable. It is also possible to carry out, walking, this part of the field trip (from Stop 1.6 to 1.7), but an additional hour of walking will result.

Starting from Cuneo (Italy), drive towards Valle Maira, following the road signs leading to Acceglio. Continue on the SP422 road until the village of San Damiano Macra. This village gives the name to the large shear zone that separates the southern part of the Dora-Maira Massif from the Pre-Piemonte Units of the Maira-Grana Allochthons. After the main residential area, a large parking area can be found at the road turn indicated by the coordinates.

Stop 1.1 - Mesoscale folding in the Pre-Piemonte units

Coordinates: Lat. 44°29'47.501' N, - Long. 7°12'7.235'' E – Altitude: 798 m

A wide outcrop of Anisian-Ladinian dolomitic metalimestones and associated metapelites (Michard, 1967) of the Val Maira-Sampeyre Unit overlooks the car park. The attention immediately shifts to the complex and irregular large folds in the outcrop (Fig. 7). The folded surface is represented by an early metamorphic foliation (S1-S2) parallel or subparallel to the original bedding (S0). S2 represents the main foliation in the most competent lithologies part of the Val Maira-Sampeyre Unit and is generally defined by white mica and chlorite (Michard et al., 2022). This surface is folded by F3 folds whose axial planes show different orientations (from sub-horizontal to nearly vertical). F3 sometimes develops box fold hinges. Locally, at the small scale in the metapelitic levels, it is possible to observe the development of an S3 crenulation cleavage.

Continue driving past the village of Macra, after a few kilometres at a crossroad, take the road on the right leading towards Elva village. Upon arriving at the "La Sousto du Col" restaurant (c. 30 minutes from the previous Stop), it is possible to park in the available free space. A c. 10-minute walk takes you to a panoramic viewpoint known as "Fremo Cuncunà".

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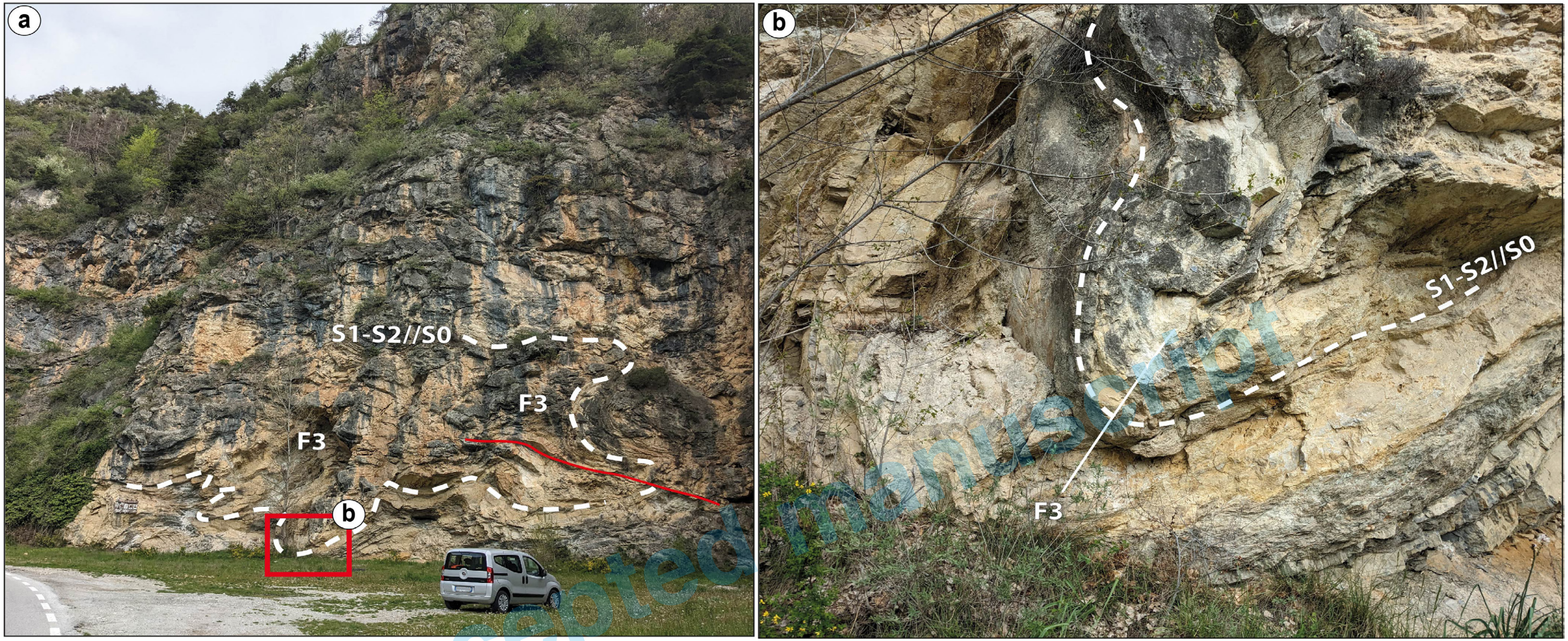

Fig. 7 - Stop 1.1. Folding of an early metamorphic foliation (S1-S2) by F3 folds. Anisian-Ladinian dolomitic metalimestones and metapelites associated with *cargneules* of the Val Maira-Sampeyre Unit. a) The outcrop seen from the main road towards Acceglio. The red line is a local décollement trace and the box highlights the position of panel b detail. b) Meso-scale detail of one F3 fold hinge.

Stop 1.2 - Panoramic view of the Monte Bettone anticline

Coordinates: Lat. 44° 31’ 29’’ N, – Long. 7° 5’ 30’’ E – Altitude: 1783 m

In this stop the Monte Bettone F3 anticline (Fig 8a), first described by Franchi (1898b) and later by Michard (1967), represents one of the most spectacular folding structures in the MGA. The greyish lithologies, describing the fold, are mainly Norian bedded dolostones and marbles, black schists and breccias of Rhaetian – Sinemurian age. This structure, clearly visible from this point of view, also folds the tectonic contact between the Val Grana Unit and the overlying Queyras Schistes Lustrés. The D3 fold is oriented approximately NW-SE, with an axis

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dipping weakly to the NW and facing to the E. The fold is truncated by a late brittle fault dipping W. The folded surface is represented by an S2 foliation subparallel to the original bedding. The S3 foliation only develops poorly in the most competent levels (i.e., dolostones) where it can only be observed rarely. Due to the high competence of the Norian dolostone and the presence of a low-strain domains, locally, an angular unconformity between the Norian and Lower Jurassic formations is preserved (Michard, 1967; Michard et al., 2022). The local preservation of primary structures despite the polyphase deformation is well known throughout the Briançonnais area; indeed, another similar unconformity was described in the Rochebrune Unit (south of the Briançon city) by Dumont (1984).

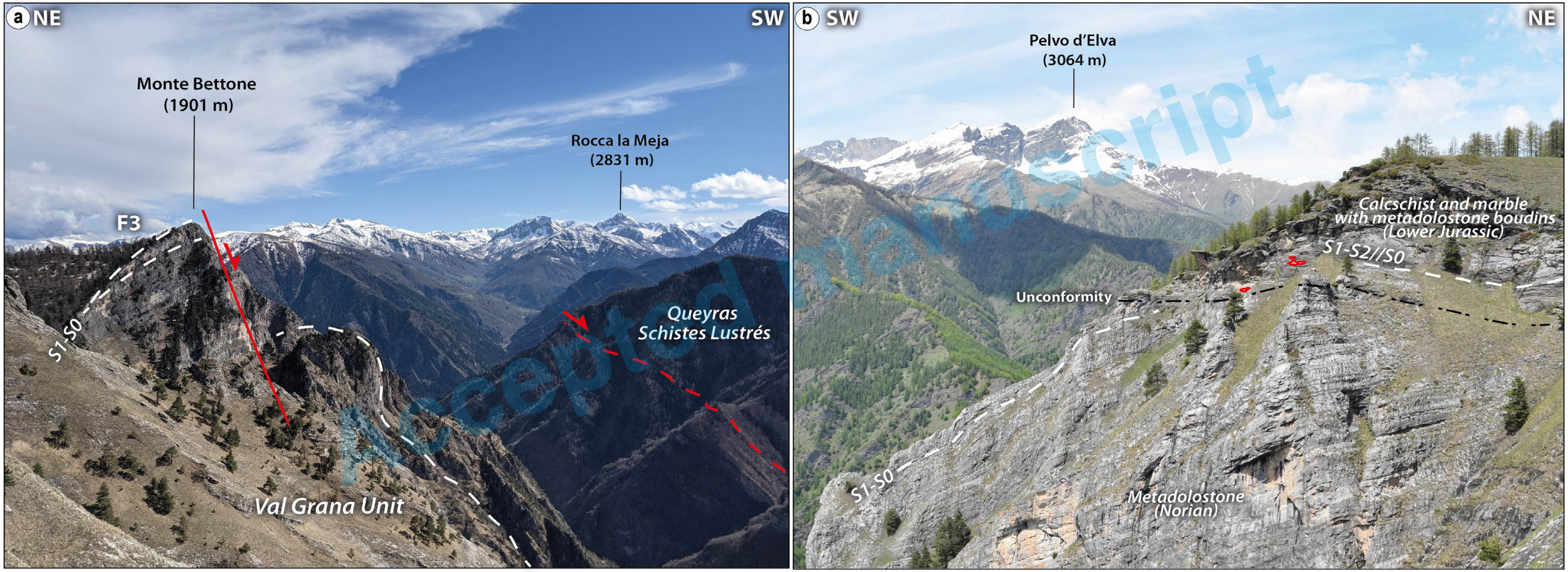

Fig. 8 - Stop 1.2. a) Monte Bettone F3 anticline seen from the Fremo Cuncunà panoramic viewpoint. The folded lithologies in the picture are mainly Norian dolostones, calcschist and impure marbles with dolostone boudins of Rhaetian – Sinemurian (Early Jurassic) age. b) Locally preserved angular unconformity between Norian metadolostone and Lower Jurassic formations (seen from Fremo Cuncunà). Metadolostone boudins are enclosed by a red line (Fig. 8b). The main surface visible in the metadolostone is interpreted as the original stratigraphic surface (Michard et al., 2022).

A possible, interesting, variation to the planned route is the nearby Sampeyre pass (about 10 minutes by car from Stop 1.2 continuing along the same road).

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Stop 1.3 - Panoramic view on the Pelvo d'Elva Unit

Coordinates: Lat. 44° 33' 10.714'' N, – Long. 7° 6' 44.906' E – Altitude: 2.284 m

The wonderful panorama visible from the Sampeyre pass allows to observe a glimpse of the relationship between the "*Bande d'Acceglio-Longet*" units and the Piemonte-Ligurian units. In the panorama (Fig. 9), observed from the Sampeyre Pass looking in the direction of the unpaved road going towards W, the backthrust that carries the Pelvo d'Elva Unit (referred as "*Zona anticlinale del Pelvo d'Elva*" in Franchi, 1898b) above the Queyras Schistes Lustrés is visible. The Pelvo d'Elva Unit (Gidon et al., 1994) is structured as a big km-scale fold nappe, overturned towards NE. From this observation point, only the inverted limb is observed. The trace of the backthrust is highlighted by a clear colour contrast between the dark grey calcschists of the Queyras Schistes Lustrés and the thin whitish Upper Jurassic marbles of the Pelvo d'Elva Unit. The whitish marbles are overlain by thick Lower Triassic quartzites and upper Permian "*Verrucano Alpino*" that make up most of the Pelvo d'Elva and Monte Chersogno summit.

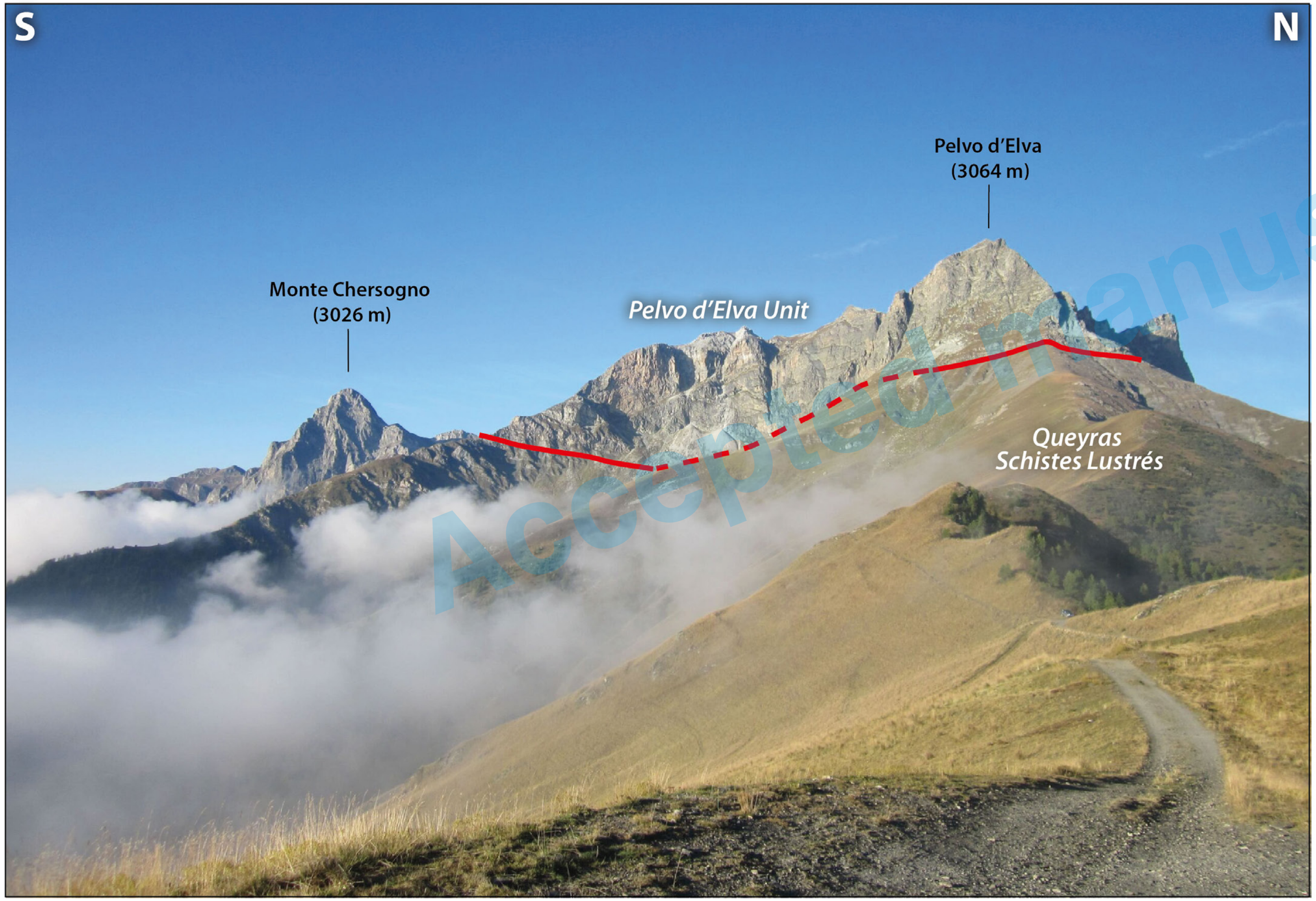

Fig. 9 - Stop 1.3. Panorama from the road between Colle di Sampeyre and Colle della Bicocca. The backthrust contact between the upper Pelvo d'Elva Unit (part of the Bande d'Acceglio-Longet Units) and the lower Queyras Schistes Lustrés is traced in red (dashed portion indicates where the tectonic contact is not directly visible.

From the previous stop, descend back to the Maira valley and proceed on the *SP 422 road in the direction of the Acceglio village. At the road sign turn left towards the Chialvetta locality (c. 40 minutes). Stop in the parking lot in front of the Chialvetta hamlet (N 44° 27' 1.732'', E 7° 0' 4.432''). This stop is one of the few places along the Maira Valley where the wide Acceglio anticline is clearly visible.*

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Stop 1.4 - The Acceglio Anticline

Coordinates: Lat. 44° 27' 1.732'' N, – Long. 7° 0' 4.432'' E – Altitude: 1370 m

This structure was described for the first time by Franchi (1898b) and later studied in detail by Lefèvre (1982). The *Acceglio anticline* is a large D3 phase structure that deforms all the "*Bande d' Acceglio-Longet*" units and the overlying Queyras Schistes Lustrés units (Fig. 10). The Acceglio Unit s.s crops out in the core of the anticline. This Acceglio Unit s.s. sequence is made of Permian volcanoclastites (historically known as "*porphyroids*"; Franchi, 1898b; Lefèvre, 1982) followed by upper Permian metaconglomerates and metarkoses of the "*Verrucano Alpino*" Formation and by upper Permian - Lower Triassic "*Werfenien*" quartzites. The volcanoclastites derive from a volcanic and volcanoclastic sequence deposited as a result of intense Permian volcanic activity (Lefèvre and Michard, 1976; Lefèvre, 1982). The *Acceglio anticline* has a closed-to-open geometry, the western limb dips nearly 60° to the W and the eastern limb dips more steeply towards E. The structurally higher Rocca Corna and Pelvo d'Elva units lie on the eastern limb of the Acceglio anticline. The tectonic contact with the Queyras Schistes Lustrés, belonging to the ocean-derived Piemonte-Ligurian units (Stop 15), is also folded around the anticline. Along this contact, few tectonic slices of Upper Jurassic detrital marble belonging to the Acceglio Unit are observed (e.g., *Grange Serri sliver*; Lefèvre, 1982)
Go back on the SP 422 road and proceed towards the Acceglio village (c. 5 minutes from the previous Stop). After crossing the main residential area, stop in a large parking area located near the Maira Valley Visitor Center.

Stop 1.5 - Queyras Schistes Lustrés metaophiolite bodies

Coordinates: Lat. N 44° 28' 29.726'', – Long. E 6° 59' 19.446'' – Altitude: 1230 m

The outcrops bordering the parking area show that our field trip has entered the oceanic units of the Queyras Schistes Lustrés. The large outcrop in front of the car park is entirely made up of glaucophane-bearing metabasites (Fig. 11) and basaltic metabreccias. Serpentinite blocks, rich in carbonate veins, are also visible along the Maira river. These serpentinites were used as an ornamental stone and building material with the name "*Marmo Verde di Acceglio*" (Barale et al., 2020). All these blocks belong to a large meta-ophiolite body packed in a Lower Jurassic-Cretaceous sequence of oceanic metasediments represented by calcite rich schists, known as "*Schistes Lustrés*". The outcrop of this stop is located very close to the hinge of a large synform that separates the "*Bande d'Acceglio-Longet*" to the east from the "*Bande du Roure*" to the W (Fig. 5 and Fig. 6).

From the previous stop continue driving on the SP 422 in the direction of Chiappera (c. 10 minutes). After passing the Saretto Lake, stop near the bridge (limited parking space available both before and after the bridge).

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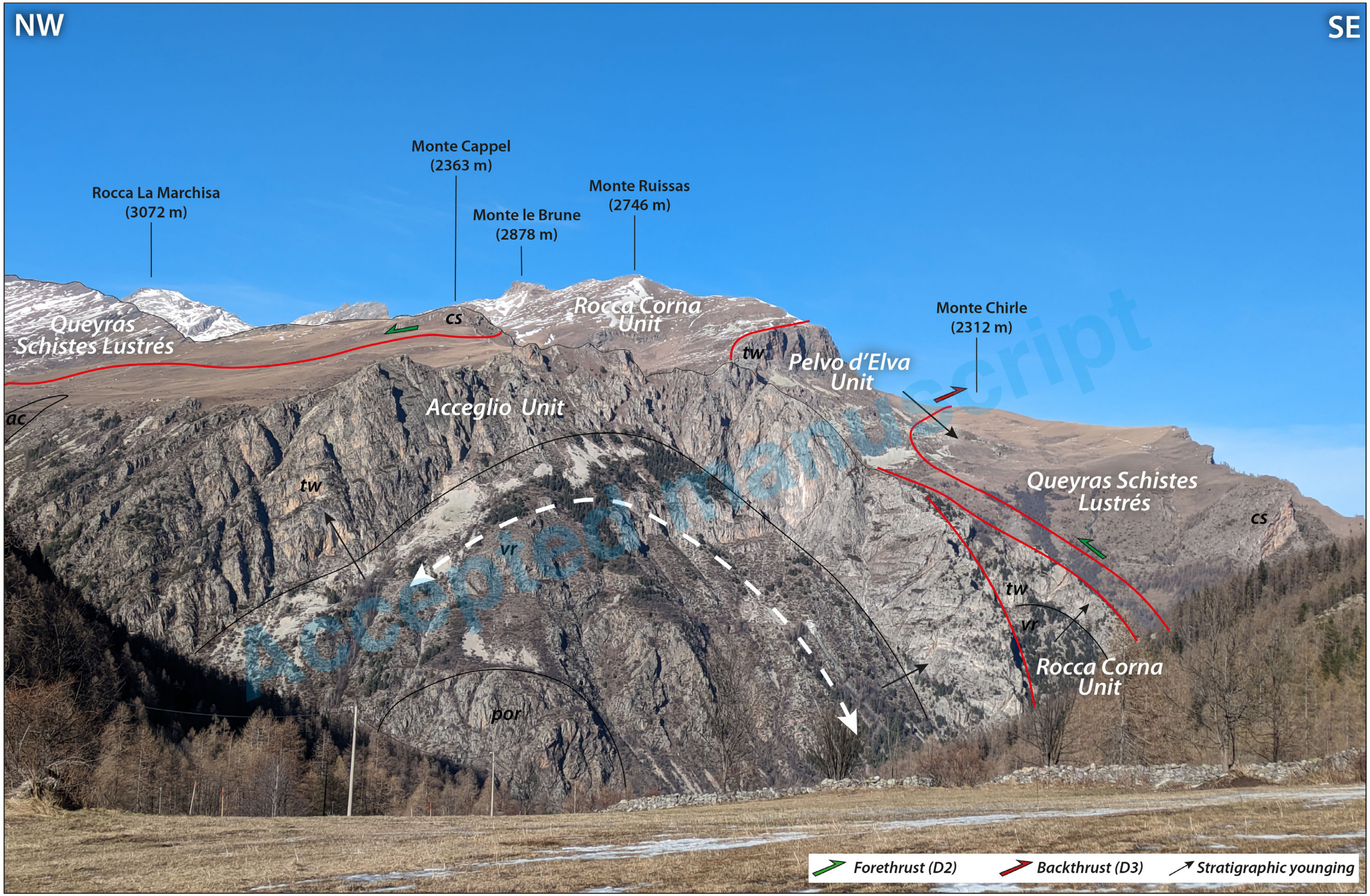

Fig. 10 - Stop 1.4. The Acceglio Anticline. View of the Acceglio Anticline from Chialvetta northwards over the different units of the "Bande d'Acceglio-Longet". The Acceglio anticline hinge is drawn with the white dotted line. Abbreviations: cs = calcschist and ophiolitic boudins (Jurassic – Upper Cretaceous), ac = Grange Serri marbles (Upper Jurassic?), tw = white quartzites and conglomeratic quartzites (Permian – Lower Triassic), vr = "Verrucano Alpino" (upper Permian), por = "Acceglio porphyroids" (Permian?).

Fig. 11 - Stop 1.5. House-sized block of metabasites located in the Acceglio village car park. This block is part of one of the various ophiolites boudins scattered in the Queyras Schistes Lustrés Units. A visible intense folding affected the main foliation of the metabasite block.

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Stop 1.6 - Panoramic view on the Classic Briançonnais units

Coordinates: Lat. 44° 29' 3.97'' N, – Long. 6° 55' 42.423'' E – Altitude: 1544 m

The panoramic view depicted in Fig. 12 is now visible. In front of us, we can observe four different tectonic units and their relationships. All these units are part of the Classic Briançonnais. The upper unit is represented by the Aiguille de Chambeyron – Sautron Unit, which is backthrusted above the underlying units through the Col des Houerts thrust. Mylonites are well developed along the tectonic contact and testify a *top-to-the-NE* sense of shear. Large F3 parasitic folds are visible in the backthrust hanging wall on the Monte Pertusà cliffs. If observed closely, they reveal that the folded surface is already a crenulation cleavage (S2), clearly distinguishable in the hinge zones. The Col des Houerts backthrust is associated with the late D3 phase because crosscut the upper part of the underlying Marinet nappe anticline, an early D3 backfold. The Marinet nappe anticline (already described by Franchi, 1898b) is one of the most important structures of the southern Western Alps area and its axial plane trace can be followed from the upper Ubaye valley to the lower Maira valley for more than 40 km (Debelmas and Gidon, 1958).

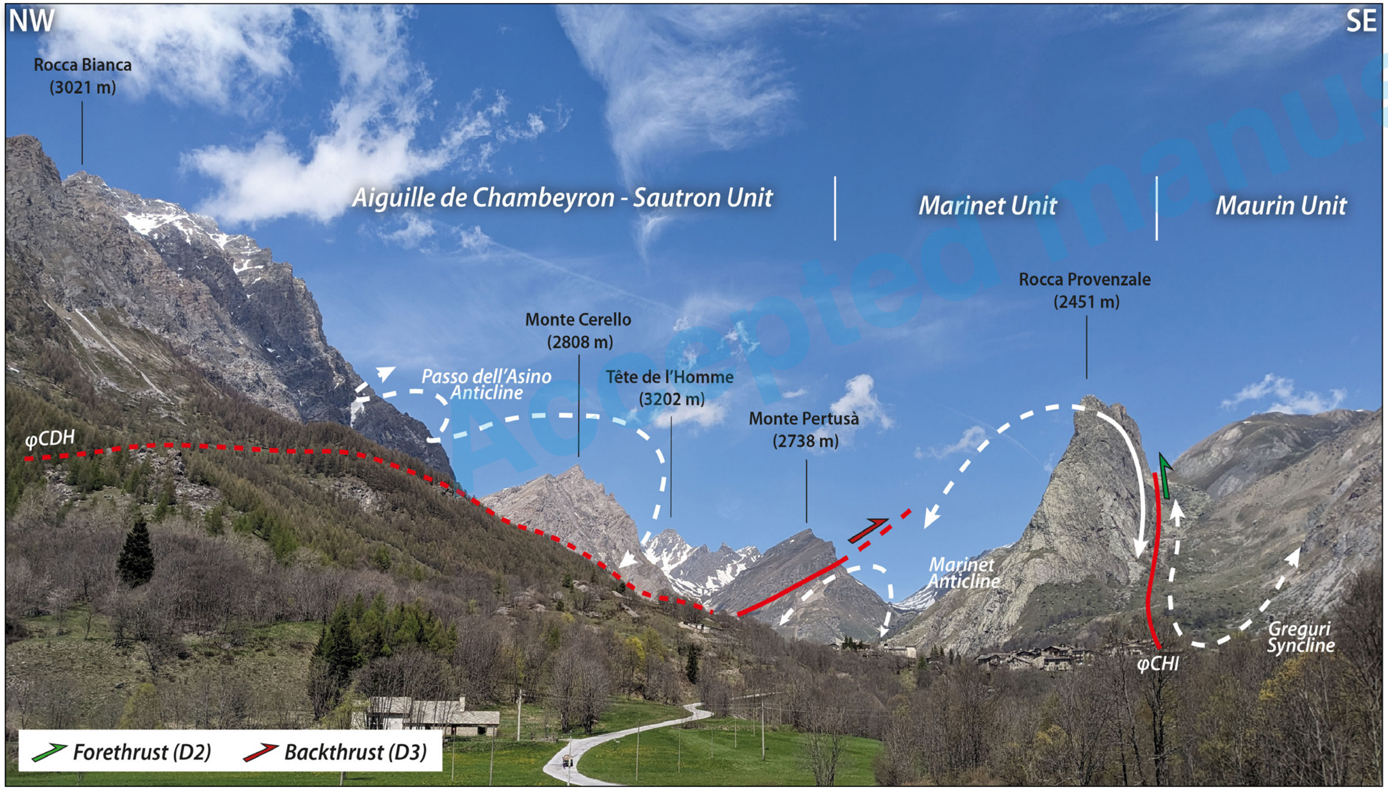

Fig. 12 - Stop 1.6. Panorama on the Classic Briançonnais Units as seen from Stop 1.6. Major D3 folds traces are drawn with the white dashed lines. Tectonic contacts are depicted in red. Abbreviations: ϕCDH = Col des Houerts backthrust (D3), ϕCHI = Chillol thrust (D2).

The Marinet nappe anticline folds together three different units; from the bottom to the top in the present-day setting, they are: the Marinet, Aiguilles de Mary and Ceillac-Chiappera units. The two Aiguilles de Mary and Ceillac-Chiappera units as depicted in Fig. 12 are not well distinguished from each other and grouped together in the Maurin unit..

The basal tectonic contact of the Aiguille de Mary Unit is represented by an original D2 thrust, folded around the Marinet Anticline. This observation is supported by the discovery of folded D2 mylonites along the tectonic boundary (Dana et al., 2023).

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Starting from the previous stop continue along the SP 422 road. After Chiappera village at the crossroad take the road on the right. This road becomes unpaved after a couple of hairpin bends (it is best to avoid driving low-slung cars) and arrives after crossing a wooden bridge at Grange Collet locality (c. 10-15 minutes from the previous Stop). Here, it is possible to park the car and continue the rest of the field trip by walking.

Stop 1.7 - Grange Collet

Coordinates: Lat. 44° 31’ 21.425’’ N, – Long. 6° 54’ 27.161’’ E – Altitude: 1999 m

The panoramic view from Grange Collet allows us to observe several significant structures in the mountains around us (Fig. 13). Looking to the SW, in the direction of the Rocca Bianca cliff and Stroppia Waterfalls (the highest waterfalls in Italy, with a 500 m drop), it is possible to

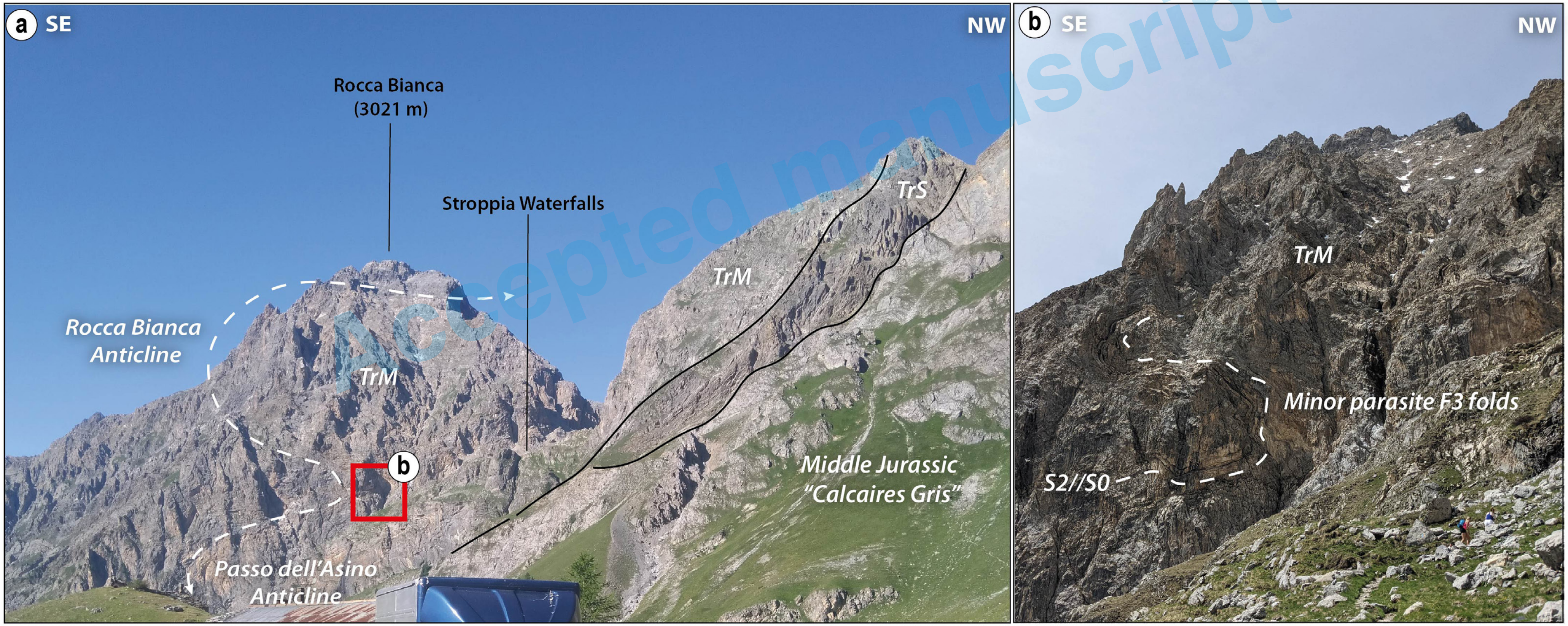

Fig. 13 - Stop 1.7. F3 km-scale backfolding in the Aiguille de Chambeyron – Sautron Unit. a) Interpreted panorama from Grange Collet, the fold axis is subparallel to the cliff walls. The black lines represent stratigraphic contacts, white lines represent folded surfaces. Note that also the angular unconformity between Upper Triassic (TrS) and Middle Jurassic carbonates is folded. TrM = Middle Triassic metalimestone and metadolostones. b) Detail on a minor parasitic fold close to a syncline hinge (seen from Stroppia Waterfalls path).

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observe some large-scale folding structures that affect this portion of the Aiguille de Chambeyron – Sautron Unit. The deformed rocks are a Middle Triassic – Upper Cretaceous Classic Briançonnais sequence, mainly made of metadolostone, metalimestone and calcschist. A series of large F3 folds, facing towards NE and oriented approximately NW-SE is visible in Fig. 13a. Part of the large anticline hinge, closer to our observation point is eroded, but looking in the background on the Rocca Bianca cliffs it is possible to observe its southern prolongation. The folds are strongly disharmonic due to the rheological contrast between the different lithologies (Fig. 13b).

From the Grange Collet locality proceed SE and take the path named "Sentiero Gioiele" (red-white marks and signs) in the direction of Colle Greguri (1.10 h, +310 m).

Stop 1.8 - Colle Greguri

Coordinates: Lat. 44° 30' 48.918'', – Long. 6° 55' 23.291'' E – Altitude: 2319 m

Reaching the "Colle Greguri" pass, we observe the panoramic view depicted in Fig. 14a. Rocca Castello and Rocca Provenzale cliffs are made of strong Lower Triassic "*Werfenien*" quartzites of the Marinet Unit. The shape of these mountains is dominated by the geological structure, in fact the two cliffs are an exceptional outcrop of the great Marinet anticline (Fig. 14a, b). The eastern limb of the fold, i.e., the overturned one, is exposed in the cliffs above Colle Greguri. A reduced metacarbonate cover, mainly represented by Anisian – Ladinian metadolostone, crops out at the base of the quartzite cliffs at Colle Greguri (Fig. 14b). A badly exposed folded tectonic contact separates this reduced cover from greenish metavolcanites part of the Aiguille de Mary Unit. Metandesites of the Aiguilles de Mary (AMA) Unit are here in contact with Upper Cretaceous detrital calcschists classically part of the Ceillac-Chiappera (CCH) Unit. Dana et al. (2023) documented the presence of marked andesitic detritus at the base of the calcschists highlighting that this contact has to be considered as stratigraphic, and as a consequence the two, previously defined, Aiguilles de Mary and Ceillac-Chiappera units are actually separated by a paleofault (more details will be showed at Stop 2.5) and have to be considered as part of one large tectonic unit called Maurin Unit.

From the Colle Greguri pass continue walking on the "Sentiero Gioiele" path in the direction of La Colletta (0.30 h, +257 m). This is the last stop of Day 1. Follow the same trail to return to Grange Collet.

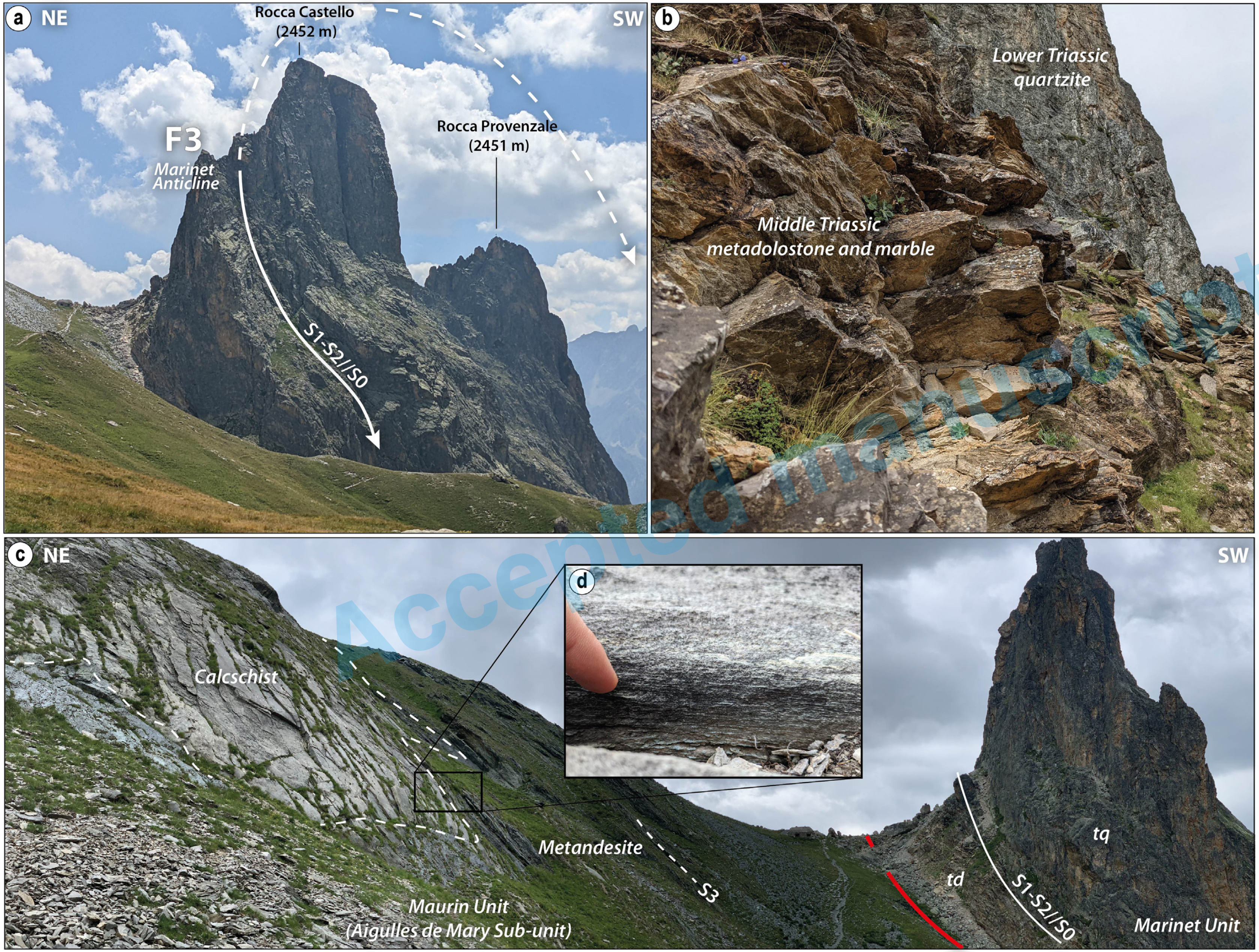

Fig. 14 - Stop 1.8. Rocca Castello – Provenzale group at Colle Greguri. a) Interpreted panorama, the reverse limb of the Marinet Anticline is traced with a continuous white line, the dashed line indicates the eroded portion. b) The overturned Middle Triassic cover of the Marinet unit cropping out near the Greguri Pass. c) Panorama showing the contact between Aiguilles de Mary sub-unit metandesite and Ceillac-Chiappera sub-unit calcschist. d) Detail of the contact between andesite and calcschist is shown; a fine intercalation between andesite layer and calcite layers is visible. This intercalation is the result of the dismantling caused by erosion of the metandesites during the deposition of the Upper Cretaceous calcschist. Abbreviations: tq = quartzites (Lower Triassic), td = "*Dolomies grises et noires*" formation (Ladinian). The red line in picture c represents the folded tectonic contact separating the Marinet Unit and Aiguille de Mary sub-unit.

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Stop 1.9 - Ceillac backthrust at La Colletta

Coordinates: Lat. N 44° 31’ 9.253’’, – Long. E 6° 55’ 47.4’’ – Altitude: 2576 m)

Near La Colletta, on the Italian side of the area of interest, the tectonic contact between the Ceillac-Chiappera Unit and the underlying Roure Unit, known as Ceillac Fault or Ceillac Backthrust is exposed (Fig. 15a). This tectonic contact is represented by an area of high strain domains characterised by kinematic indicators with a *top-to-the-NE* sense of shear that can be seen developed in the hangingwall calc-mylonites (Fig. 15b) (Ceillac-Chiappera Unit). An approximately 1-2 m thick zone of *cargneules* and tectonic breccias separates the two units and represent the basal part of the thrust contact.
The footwall is represented by the Roure Unit, part of the Acceglio-type units. In the footwall a penetrative foliation is developed in the “*Verrucano Alpino*” conglomeratic quartzite closer to the tectonic contact. The volcanic clasts inside the conglomeratic quartzites are stretched along the shear direction (approximately SW-NE). The Ceillac backthrust dips about 30-35° towards WSW at La Colletta outcrop. Moving northward along the Maurin valley, the fault plane becomes steeper (about 60-65°, Fig. 15c). The fault trace is highlighted by the boundary between the *cargneules* lens and “*Verrucano Alpino*” outcrops of the Roure Unit.

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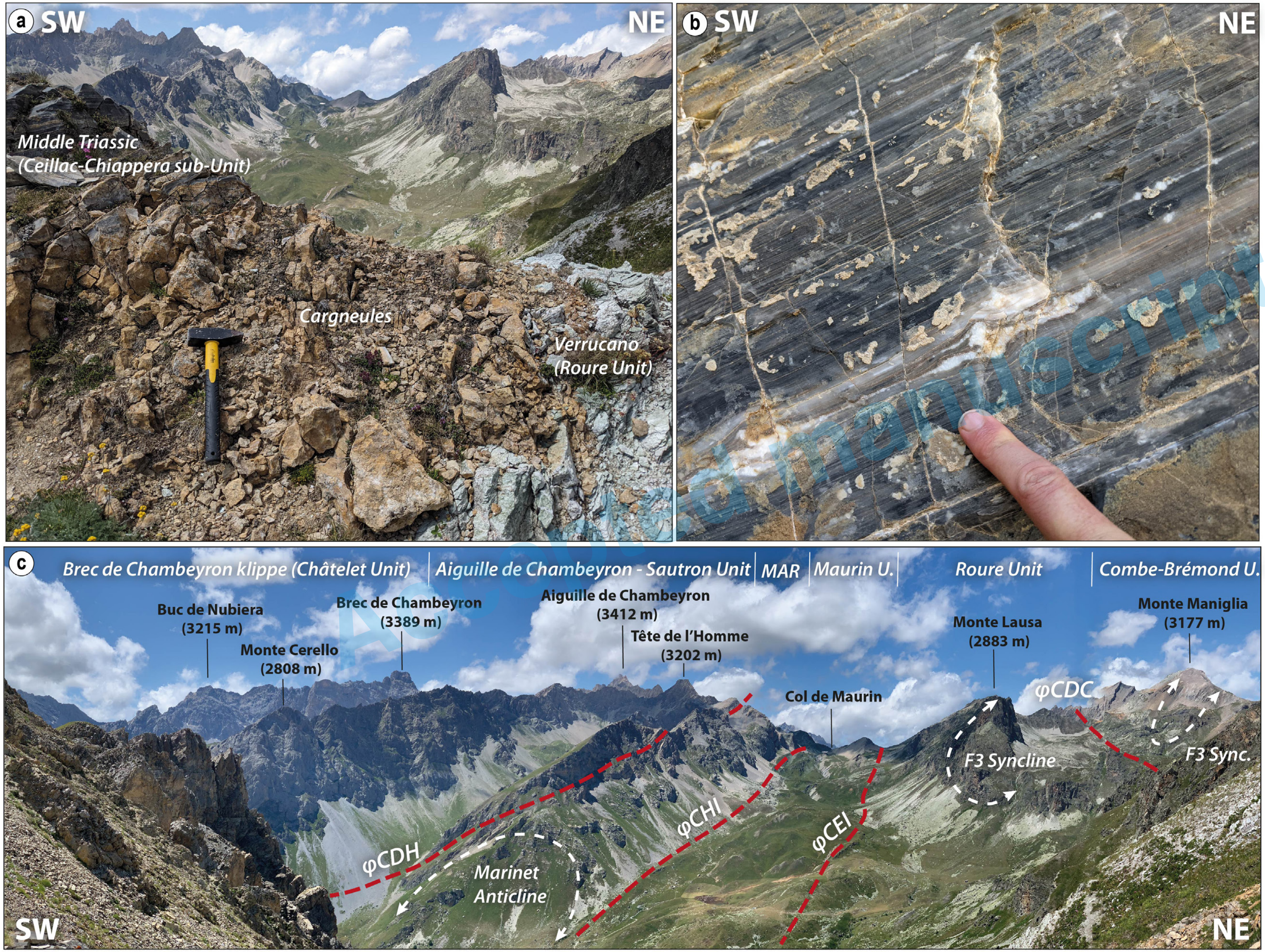

Fig. 15 - Stop 1.9. Geological features visible at La Colletta. a) Ceillac backthrust: the tectonic contact base is represented by 1-2 m thick *cargneules* and tectonic breccias level underlying the hangingwall calc-mylonites. b) An example of the calc-mylonites appearance in the field, a photo taken a few metres from the previous one. c) Interpret panorama towards the Col de Maurin as seen from the Stop 1.8 point of view. Dashed white lines represent folded surfaces and red lines tectonic contacts. Abbreviations: ϕCDH = Col des Houerts backthrust, ϕCHI = Chillol thrust, ϕCEI = Ceillac backthrust, ϕCDC = Col de Ciabriera backthrust.

DAY 2

The itinerary of the second day must be done entirely by walking, except the first two stops on the road going from Saint-Paul-sur-Ubaye to the small Maljasset hamlet. The followed paths climb towards the maximum altitude of the Colle di Ciabriera pass (2821 m). The starting point is located at the Maljasset village (Saint-Paul-sur-Ubaye, France), on the French side, along the Upper Ubaye Valley. Maljasset can be reached either by car (3 hours from Acceglio) or by walking in about three hours (17 km, +1050 m) from Grange Collet (Stop 1.6).
The purpose of this itinerary is to take a closer look at the Classic Briançonnais and Acceglio-type units introduced in the final part of Day 1. Stop 2.1 will be dedicated to the observation of tectonic and sedimentary breccias derived from the Piemonte-Liguria Ocean and Briançonnais domain. Stop 2.5 will be dedicated to the Maurin paleofault outcrop. The rest of the field trip will be dedicated to show spectacular examples of the polyphase deformation history of the Briançonnais-derived units.

Starting from Saint-Paul-sur-Ubaye village center drive towards Maljasset/Maurin (follow road signs). After 5-10 minutes, reaching Le Grande Serenne locality stop on the roadside. There is space for a few vehicles. This stop offers a chance to observe some examples of rocks that are part of the Serenne-Guillestre Unit.

Stop 2.1 - The Serenne-Guillestre Unit and the "Schistes à bloc": their structural relationships and tectonic meaning

Coordinates: Lat. 44° 31' 7.962'' N, – Long. 6° 45' 31.411'' E – Altitude: 1500 m

The Serenne-Guillestre Unit (a part of the Helminthoid Flysch units) mainly consists of the Albian-Cenomanian black schist referred as "*Schistes noirs du Col de Vars*" and the overlying undated "*Schistes de Serenne*" (Fig. 16a and b). Occasional ophiolite-bearing mélanges, proving the oceanic derivation of these sediments, are reported ("*opholites de Serenne*"; Kerckhove, 1961; Kerckhove et al., 2005). However, the Serenne-Guillestre tectonic Unit does not represent the basal complex of the Parpaillon Unit, as interpreted by some previous authors (Kerckhove, 1969; Bigi et al., 1990) but represents a separate tectonic unit. This concept can be better understood by looking at the interpreted panorama reported in Figure 16c. Structurally, large portions of the NE parts of the Serenne-Guillestre tectonic Unit are overturned and form a kind of pseudo-cover over the Eocene metasediments ("*Schistes à blocs*") of the Châtelet Unit (in the south) or over the Peyre Haute Unit (in the north). The contact with the Briançonnais units is, however, a tectonic one related to a first phase of the emplacement of the Helminthoid Flysch units over the Briançonnais in latest Eocene times (Kerckhove, 1963; Kerckhove et al., 2005). The Eocene metasediments of the Châtelet Unit, the so-called "*Schistes à blocs*" (Gidon, 1958; Kerckhove, 1969; Kerckhove et al., 2005), are represented by a wildflysch (tectono-sedimentary mélange) with ophiolitic blocks formed during this early emplacement (Kerckhove, 1969; Caron et al., 1981). The SW margin of the Serenne-Guillestre Unit is represented by a west-directed thrust, referred to as Penninic Front (Trullenque, 2005; or Front

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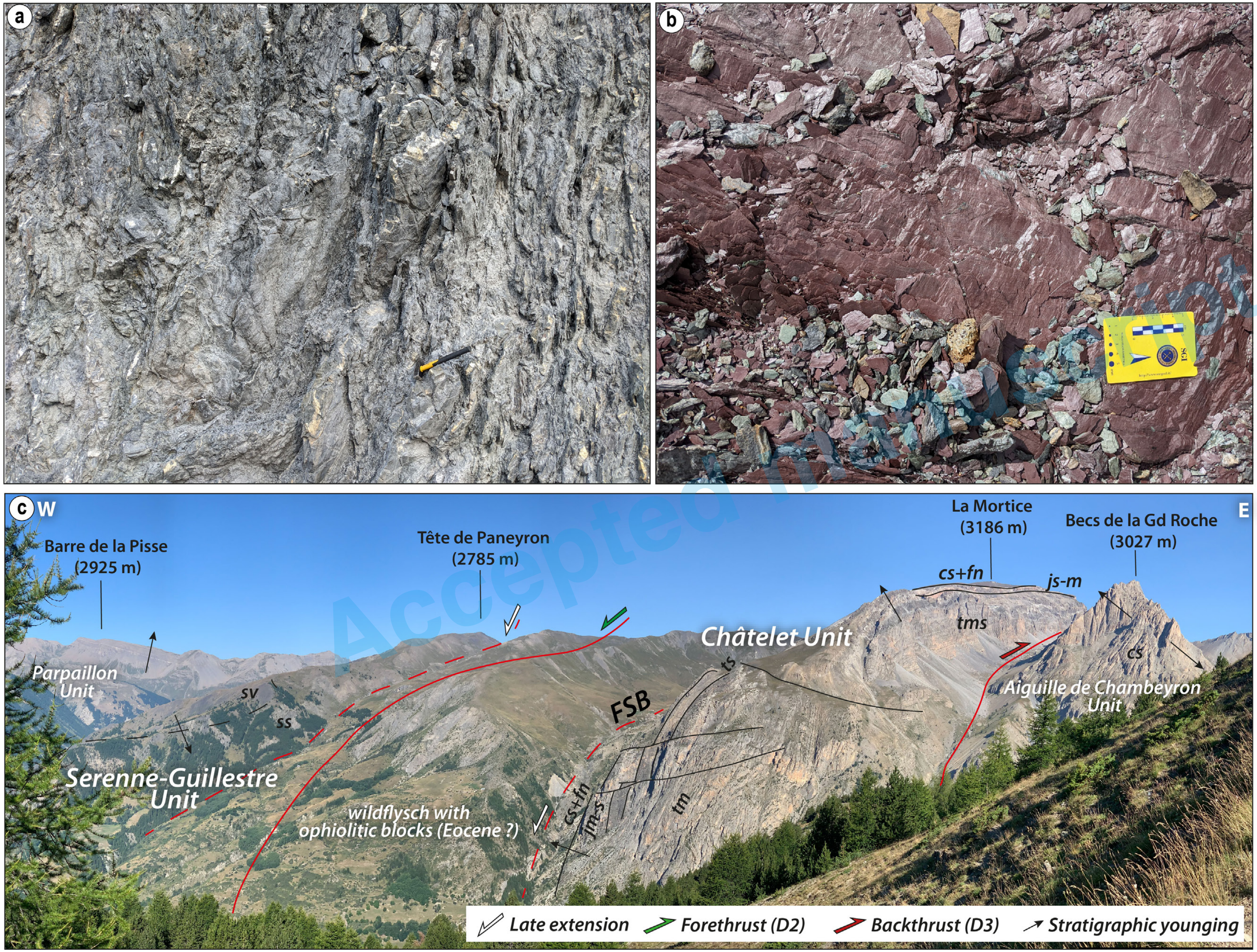

Fig. 16 - Stop 2.1. The Serenne-Guillestre Unit. a) Highly deformed and verticalized S2 foliation in the "*Schistes de Serenne*". This outcrop is located in the core of the "*Briançonnais fan*", hence the steep, almost vertical dipping. b) Rare reddish pelites, part of the "*Schistes noir de Vars*" formation (Col de Nubiera); c) Interpreted panoramic view as seen from the path climbing towards Refuge du Chambeyron. Abbreviations: tm = metalimestone an metadolostone (Middle Triassic), ts = "*Roche des Clots*" formation (Upper Triassic), jm-s = "*Calcaires Gris*" (Middle Jurassic), "*Marbres de Guillestre*" and "*Calcaires Blancs*" (Upper Jurassic), cs = detrital calcschist (Upper Cretaceous – Paleocene), fn = "*Flysch Noir*" (Lutetian ? – lower Priabonian). FSB = Serenne-Bersezio fault.

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Briançonnais, by Tricart, 1980) over the Parpaillon nappe (Fig. 5, Fig. 6). Hence the tectonic position of the Serenne Unit is in the hangingwall of the Penninic Front and forms the core of the "*Briançonnais Fan*" in the Ubaye section. It represents that part of the Helminthoid Flysch Units that has been affected by backfolding and backthrusting (Dana et al., 2023).

From the previous stop start driving again towards Maljasset. After 3-4 minutes the road begins to climb with a few hairpin bends. It is possible to park in the designated spaces *provided after the hairpin bends and then reach the orientation board (10 metres from the car park). The stop is located at the Pont du Châtelet orientation table.*

Stop 2.2 - The Serenne fault system at Pont du Châtelet

Coordinates: Lat. N 44° 32' 9.94'', – Long. E 6° 46' 59.765'' – Altitude: 1550 m

The Ubaye region stands out as the most seismically active area in the Western Alps, experiencing a recurrent pattern of mainshock-aftershock sequences and numerous earthquake swarms (Baques et al., 2021; Larroque et al., 2021; Jomard et al., 2022). Despite its significant seismic activity, this region has remained predominantly rural, resulting in limited historical seismic data availability. St-Paul-sur-Ubaye village has encountered numerous earthquakes throughout its relatively recent history, albeit few have caused substantial damage. For instance, the earliest documented earthquake in the Ubaye Valley dates back to 1844 (Jomard et al., 2022). Several events with epicentral intensities exceeding VII on the MSK-64 scale have occurred, notably in 1935, 1938, and 1959, with estimated magnitudes ranging between 5 and 5.5 (Manchuel et al., 2018; Jomard et al., 2022).

"*Pont du Châtelet*" is a classic stop for earthquake geologist and has been proposed also in other fieldtrip guides (e.g., Jomard et al., 2022). The bridge was built to facilitate permanent access to the hamlet of Fouillouse. Before the bridge was built, access to Fouillouse was via a path crossing the Ubaye at Grande Serenne. The municipal council of Saint-Paul-sur-Ubaye decided in 1879 to build a durable masonry bridge. Two years later, a 28-metre-long tunnel was completed, along with the new link. The bridge sits at the top of a narrow 27-metre gorge incised in the Jurassic metalimestone, overhanging the Ubaye River by 108 metres. The mountainous setting, the ochre-grey rock, the narrowness, and the immediate connection with a small, single-track rock tunnel make this a truly striking site.

The rock wall of the gorge, well visible from our stop (Fig. 17), is formed by the Jurassic metalimestone of the Châtelet Unit, which dips almost vertically here. The bridge supports are formed by nodular Oxfordian-Kimmeridgian marble ("*Marbre de Guillestre*"), which here is rather green in colour. The Jurassic marble bar is overlain at the front by Upper Cretaceous – Eocene detrital calcschist ("*Marbles en Plaquettes*"), crossed by the road climbing to Fouillouse. In the slopes that follow downstream, particularly at the lookout point downstream from the gorge, these layers give way to the "*Schistes à blocs*" (i.e. Châtelet Unit wildflysch cover). This, high and steep rock wall, where the bridge has been built, marks the passage of a segment of the Serenne-Roburent fault, which continues in the landscape on both sides of the valley (Sue et

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al., 2007). This fault is part of the so-called Serenne-Bersezio fault system, which, together with the Durance fault system, represents the structures responsible for the seismicity of the area (Sue et al., 2007; Baques et al., 2021; Jomard et al., 2022). According to Jomard et al. (2022), the long-term activity of the fault is well-marked in the morphology, but no evidence of Holocene activity has yet been observed in the field. The instrumental seismicity in the vicinity of the Serenne-Roburent fault appears mostly diffuse (Baques et al., 2021), with focal mechanisms showing a major normal tectonic regime with a slight dextral motion (Ménard, 1988). Nodal planes are compatible with the orientation of the fault (Sue et al., 2007). Looking at the outcrops near the bridge, it is possible to observe many smaller fault planes. These structures exhibit predominantly extensional or transtensional kinematic indicators (Fig. 17b).

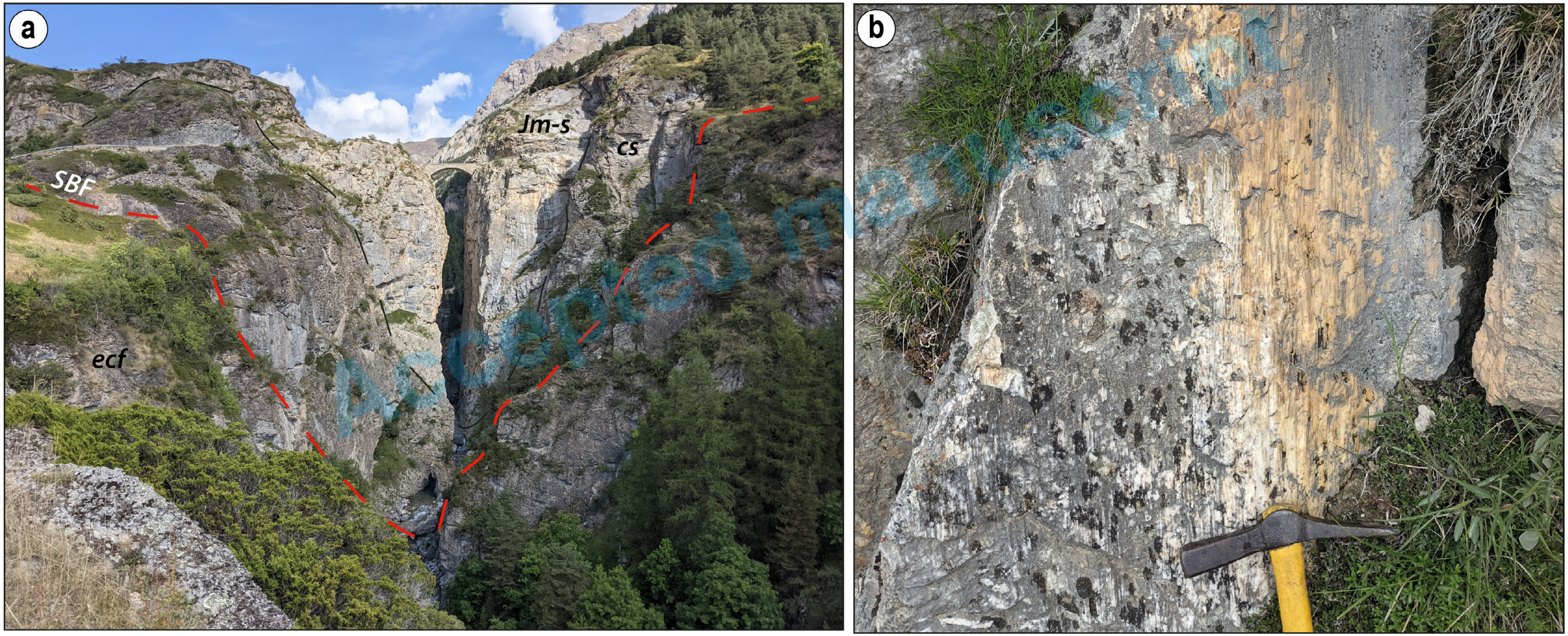

Fig. 17 - Stop 2.2. Pont du Châtelet seen from the orientation table. a) Interpreted panorama. Abbreviations: Jm-s = "*Calcaires Gris*" (Middle Jurassic), "*Marbres de Guillestre*" and "*Calcaires Blancs*" (Upper Jurassic), cs = detrital calcschist (Upper Cretaceous – Paleocene), SBF = Serenne-Bersezio fault. b) Fault kinematic indicators showing a "normal" sense of shear (the photo is taken near the bridge).

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From the previous stop continue driving towards Maljasset (c. 15 minutes). Before reaching the village leave the car in the large parking area on the left and proceed by walking. From Maljasset church start walking following hiking signs towards Col de Mary (3.20 h, +800 m). After 30 minutes, at the end of the military road follow the path on the left (Carrière de marbre – L'Alpet direction). In about five minutes it is possible to reach the Stop, located inside an old historical quarry. Walking about 0.30 h, following the same path to the "L'Alpet", those who are interested can reach the summit of the quarry and the spectacular outcrop of the continental-derived breccias.

Stop 2.3 - The Maurin quarry: continental and oceanic breccias

Coordinates: Lat. N 44° 35' 25.357'', – Long. E 6° 51' 39.308'' – Altitude: 2100 m

Before looking at the quarry it is recommended to turn towards north and have a look to the panoramic view on the northern side of the valley. This panorama, interpreted in the Fig. 18, is extremely useful to understand the tectonic position of the quarry outcrop (i.e., structurally below the inverted limb of the Combe-Brémond Unit).

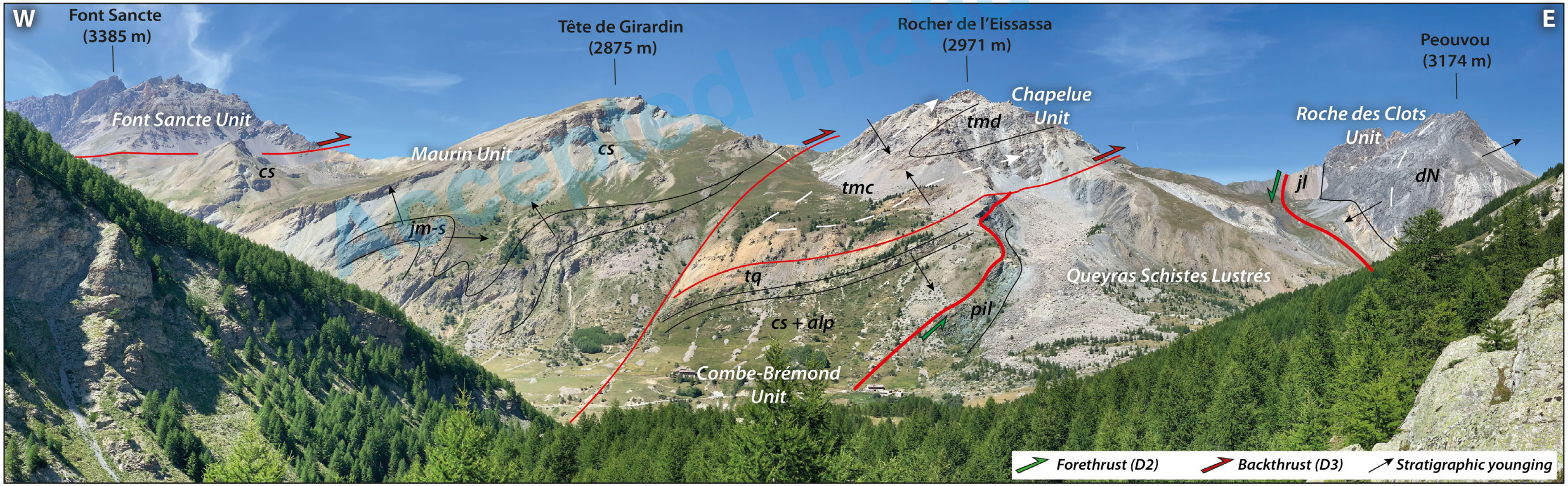

Fig. 18 - Stop 2.3. Interpreted panorama on the northern slope of the Ubaye valley from the Carrière de marbre path. Abbreviations: tmc = metalimestone (Middle Triassic), tmd = metadolostone (Middle Triassic), jm-s = und. marbles (mainly Middle – Upper Jurassic, locally preserved Lower Jurassic breccias in the Maljasset Anticline hinge), cs = detrital calcschist (Upper Cretaceous – Paleocene), alp = Alpet breccias (Upper Cretaceous – Paleocene), pil = pillow metabasalts (as boudins in the ocean-derived Schistes Lustrés), jl = calcschist "*Lias Prépiémontais*" (Lower Jurassic) of Pre-Piemonte units, dN = "*Hauptdolomit*" dolostone (Norian) of Pre-Piemonte units.

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An ornamental stone, known as the "*Marbre vert de Maurin*", was quarried here and used to make important monuments in Paris, like Napoleon's tomb and the Garnier Opera House. Despite its historical name, this rock is an ophicalcite, a serpentinite fragment breccia formed during the opening and spreading of the Piemonte-Liguria Ocean (Fig. 19a). The quarried ophiolitic rocks constitute a hectometre-sized body included within the Schistes Lustrés Jurassic – Upper Cretaceous calcschists. This ophiolitic body is located close to the tectonic contact between the Combe-Brémond and the Queyras Schistes Lustrés units, cropping out a few metres above. Ophiolites are present in isolated bodies of different sizes within the Queyras Schistes Lustrés (another ophiolite body has been visited in Stop 1.5). Some of these bodies are olistoliths whereas others originated from shearing of the oceanic lithosphere (e.g., Deville et al., 1992, Lemoine and Tricart, 1993; Lagabrielle et al., 2015). The Combe-Brémond Unit stratigraphic sequence is overturned due to D3 folding at the larger scale (Fig. 6); just above the tectonic contact, it is possible to observe an Upper Cretaceous-Paleocene sequence of continental-derived metabreccias and olistoliths ("*Bréches de l'Alpet*"; Le Guernic, 1967). These breccias are mainly made of dolostone and quartz clasts derived from Permian to Upper Jurassic formations. Similar

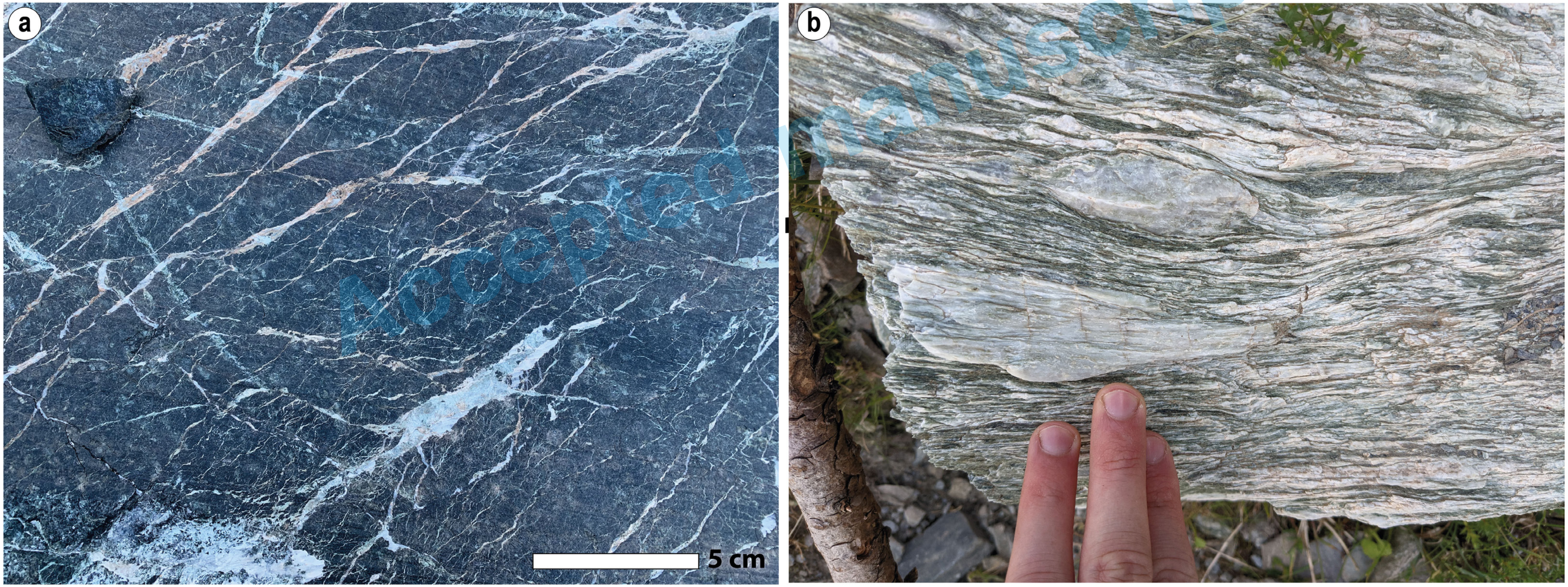

Fig. 19 - Stop 2.3. The breccias discussed in this Stop. a) "*Marbre vert de Maurin*", an ophicalcite in the abandoned quarry, and b) "*Bréches de la Bergerie de l'Alpet*", in this case in their richest portion of quartz clasts. The effect of the intense deformation and the nearly homogeneous clast petrography tends to make these rocks resemble certain "*Verrucano Alpino*" Permian siliciclastic facies. In fact, in the historical literature, these rocks were also called "reconstituted Permian" (*Permien reconstitué*; Lemoine, 1967).

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breccia sequences, typical of the Acceglio-type units and described for the first time by Lemoine (1951), are interpreted as the result of a late (Late Cretaceous and/or early Cenozoic) extensional event interpreted to be related to fore-bulge dynamics (Michard et al., 2022). The breccias closer to the tectonic contact have experienced significant deformation, causing the clasts to stretch and flatten extensively, thereby rendering the original breccia nature of these rocks nearly unrecognizable (Fig. 19b). Although both the "*Marbre vert de Maurin*" and *Bréches de l'Alpet*" are breccias and crop out close together their formation environments, tectonic significance and ages are very different.

From the previous stop, return to the military road and follow the path towards Col de Mary (2.30 h, +600 m). Follow the hiking signs and near a waterfall take the path in the direction of Col de Marinet. The trail passes through the Marinet lakes and the Marinet Glacier frontal moraines before reaching the Col de Marinet, allowing us to observe some truly spectacular landscapes.

Stop 2.4 - The Marinet Anticline and the Pas de Chillol klippe

Coordinates: Lat. N 44° 33' 7.888'', – Long. E 6° 52' 35.378'' – Altitude: 2787 m

This stop allows us to observe a spectacular outcrop of the Marinet Anticline. The mountain in front of us (Fig. 20a) is entirely made up of the siliciclastic upper Permian – Lower Triassic succession of the Marinet Unit ("*Verrucano Alpino*" and "*white quartzites*" formations). The older formation of the Marinet Unit stratigraphic sequence crops out slightly to the NW, in the core of the anticline. It corresponds to an Upper Carboniferous thick sequence of greenish-grey metaconglomerates interbedded with violet-coloured schists, probably of volcanoclastic origin. A folded surface, formed during D2, is recognizable in Fig. 20a. With a closer look (or maybe with the help of a binoculars) it is possible to distinguish an axial plane surface (S3) with a fan-like geometry in respect to the fold hinge. The NE limb of this major D3 anticline is topped by dark-greenish rocks. These rocks are metavolcanites, mainly of andesitic composition and of Late Permian age. In these rocks it is possible to recognize some lawsonite crystals of large size, firstly described by Lonchampt (1962). The metavolcanites represent the deepest formation of the Aiguilles de Mary Unit; the tectonic contact, placed at their base, separates this unit from the Marinet Unit. This tectonic contact is a D2 thrust folded by F3, generally known as Chillol thrust. The main foliation of the metandesites is represented by the S3 crenulation cleavage, developed during the metamorphic re-equilibration.
Another interesting feature of this panorama is the presence of a klippe made of carbonate rocks resting on top of the Aiguilles de Mary metandesites (Fig. 20b). The metacarbonatic rock klippe (known as Pas du Chillol klippe) was formed subsequent to the D3 folding and foliation development. A small slice of yellowish rocks consisting of tectonic breccias and *cargneules* forms the base of this tectonic contact, commonly interpreted as a backthrust (Gidon et al., 1994; Dana et al., 2023). The Middle Triassic rocks that make up the klippe come from further W, from the more external Classic Briançonnais units. Based on detailed stratigraphic correlations this klippe can be referred to the composite thrust sheet of the Châtelet- Font Sancte units.

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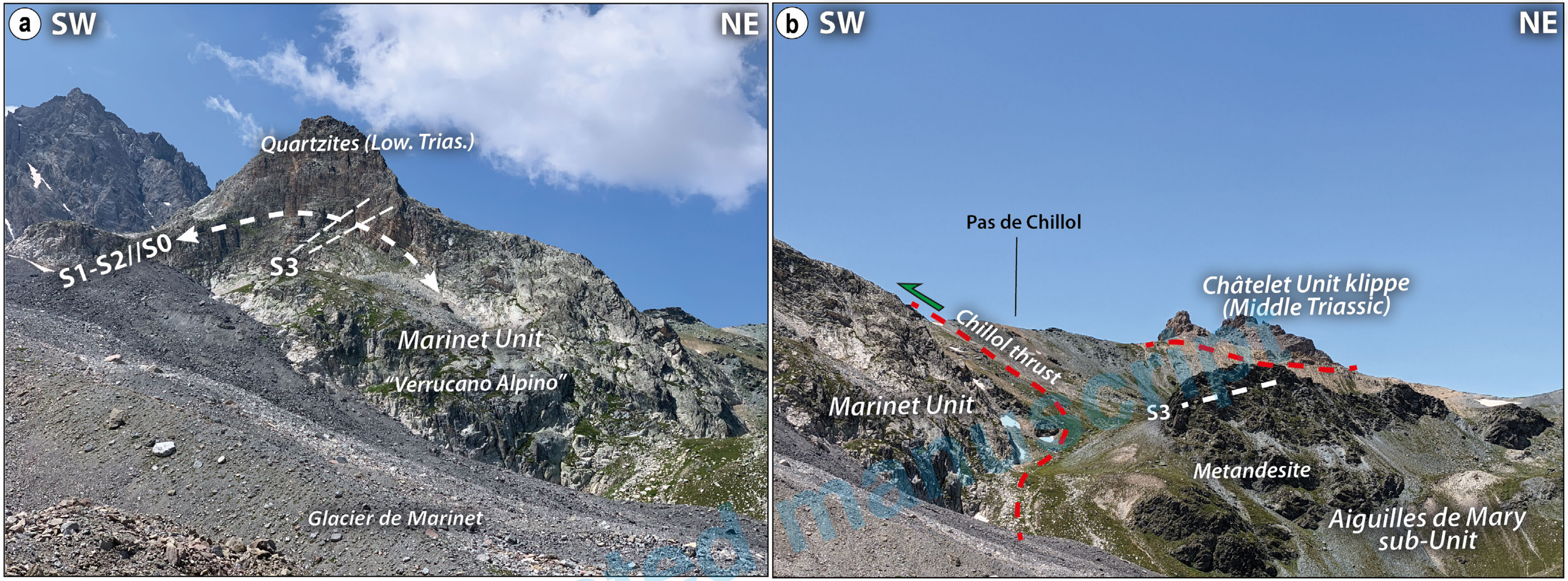

Fig. 20 - Stop 2.4. Interpreted panorama from Stop 2.2. a) The Marinet Anticline is visible from the path going downhill in the direction of Marinet Lakes. b) The contact between Marinet and Aiguilles de Mary units is represented by the folded Chillol thrust (red dashed line); a late-D3 backthrusted klippe of middle Triassic rocks is visible above the dark greenish metavolcanites.

The Pas de Chillol, where the eponymous klippe crops out, can be reached by taking the narrow path climbing west of the Marinet glacier lake (20 minutes of walking, Stop 2.4b in Fig. 1). Here, it is also possible to descend a bit in the Chillol valley to reach the Upper Carboniferous conglomerates. From the Chillol pass it is possible to have a good panoramic view on the northern side of the Ubaye Valley and the Font Sancte Massif (Fig. 21).

At this additional stop, it is also possible to observe (best with the use of binoculars) a series of deformed paleofaults, of suspected Cretaceous age, inside the Font Sancte Unit (Fig. 21). These structures have been described in detail by Claudel (1999).
From the previous stop, proceed along the trail leading from Col de Marinet towards Colle del Maurin pass (stone cairns mark the path, 0.30 h, -150 m). Stop in a meadow just before the descent to the Roure lakes.

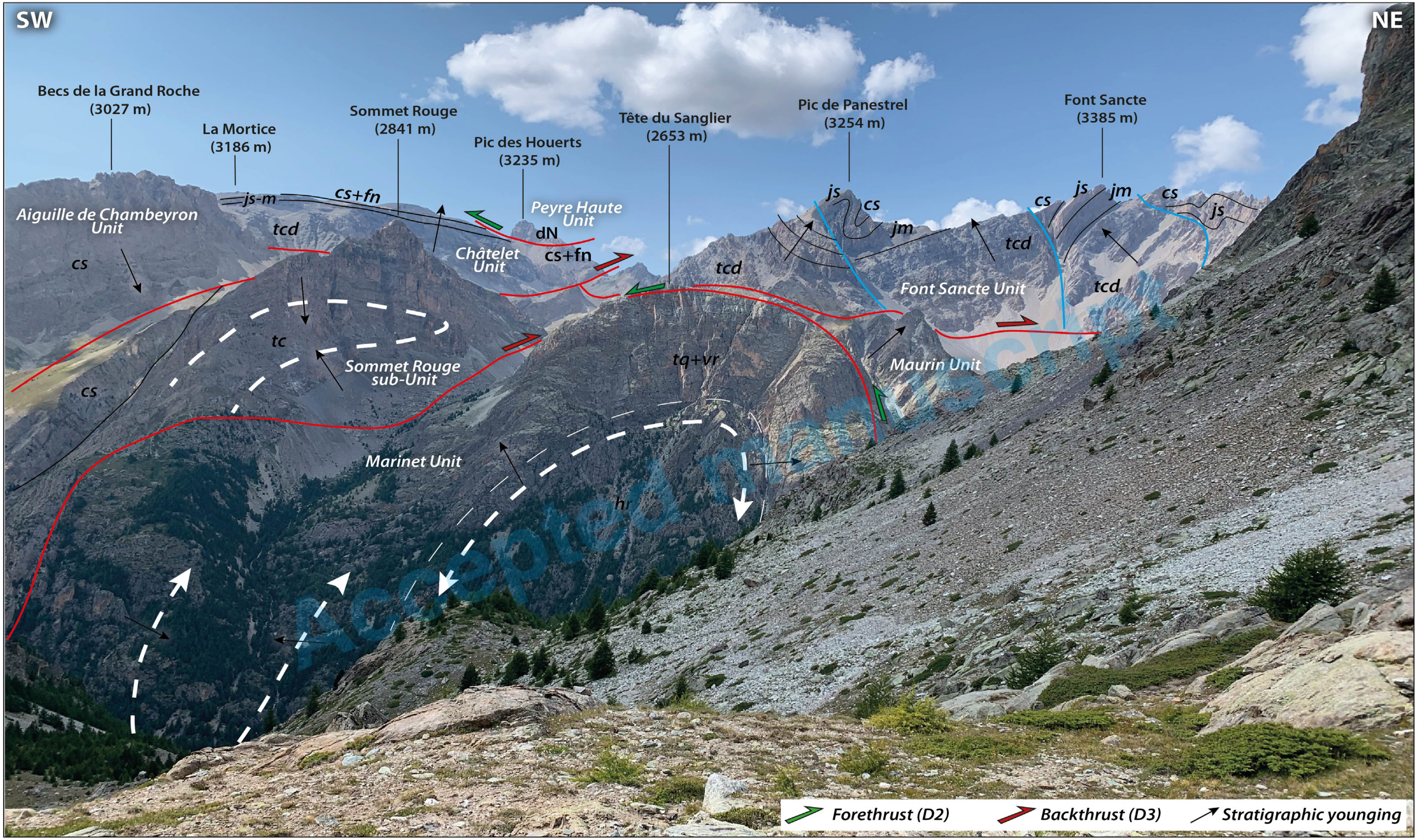

Fig. 21 - Stop 2.4 (suggested detour). Interpreted panorama on the northern slope of the Ubaye valley from the Pas de Chillol (red line = tectonic contact; black line = stratigraphic contact; blue line = paleofault). Note the three deformed paleofaults (drawn in blue) cropping out in the Font Sancte Unit (Claudel, 1999). Abbreviations: hr = "*Conglomérats de la Blachière*" (upper Carboniferous), vr = "*Verrucano Alpino*" (Permian), tq = quartzites (Lower Triassic), tmc = metalimestone (Middle Triassic), tcd = dolomitic metalimestone (Middle Triassic), tmd = metadolostone (Middle Triassic), dN = "*Hauptdolomit*" dolostone (Norian), jm = "*Calcaires Gris*" (Middle Jurassic), js = "*Marbres de Guillestre*" and "*Calcaires Blancs*" (Upper Jurassic), cs = detrital calcschist (Upper Cretaceous – Paleocene), fn = "*Flysch Noir*" (Lutetian ? – lower Priabonian).

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Stop 2.5 - The Maurin pass paleofault

Coordinates: Lat. N 44° 33' 7.041'', – Long. E 6° 53' 12.344'' – Altitude: 2637 m

Another evidence of an Upper Cretaceous – Paleocene late extensional event is the presence of preserved paleofaults. The occurrence of stratigraphic gaps with breccias can be probably due to paleofault activity. These structures, often folded during Alpine deformation or in some cases reactivated, are extremely widespread within the Briançonnais units. Both paleostructures, those referable to the Jurassic rifting and those to the Late Cretaceous extensional event have been documented (e.g., Tissot, 1955; Lemoine et al., 1986; Jaillard, 1988; Michard and Henry, 1988; Claudel et al., 1997; Bertok et al., 2012; Pantet et al., 2020). Recently one of these structures has been reported at the Maurin Pass (Dana et al., 2023). Looking towards the rock wall above the Vallon de Mary, it is possible to observe the panoramic view reported in Fig. 22. According to Dana et al. (2023) the steep southwest-dipping contact between detrital calcschists and the Triassic marbles, Lower

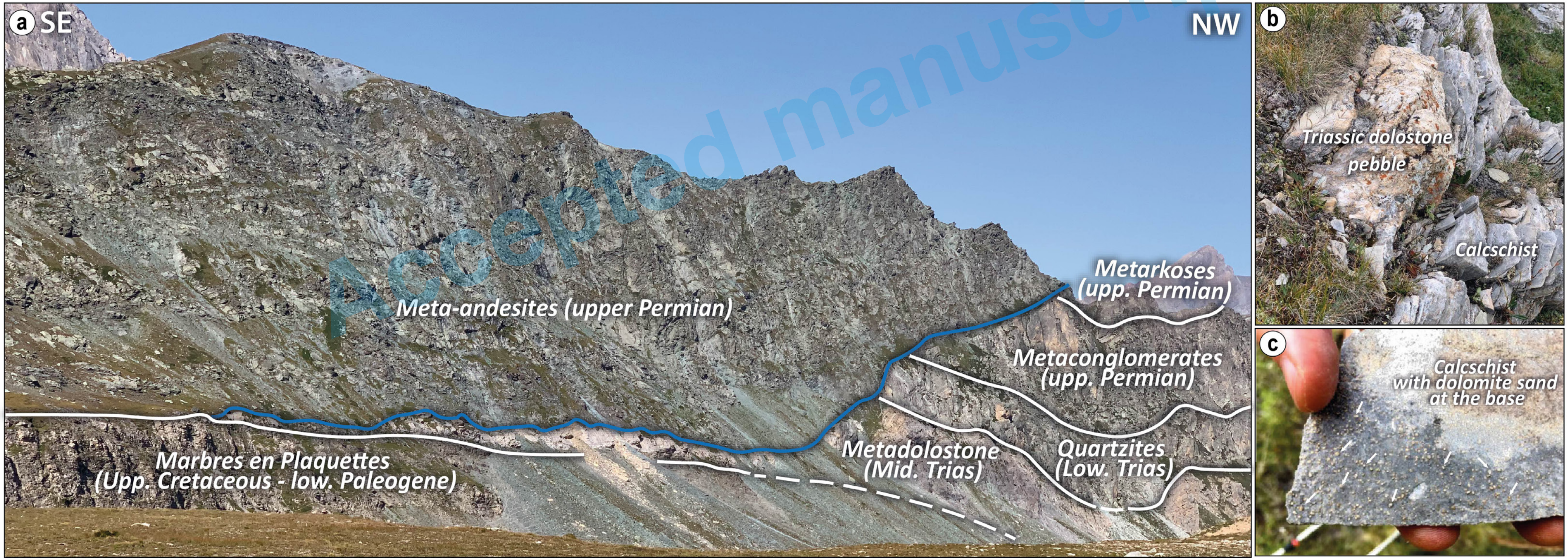

Fig. 22 - Stop 2.5. Col de Maurin paleofault (modified form Dana et al., 2023). a) Interpreted panorama, blue line marks the trace of the paleofault to be located between the steeply SW-dipping and overturned Permian meta-andesite and the younger formations (Lower Triassic – Upper Cretaceous). b) Triassic dolostone pebbles at the stratigraphic base of the Upper Cretaceous detrital calcschist. c) Dolostone clasts embedded in the fine-grained calcschist matrix.

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Triassic and Permian siliciclastic is interpreted as a paleofault that has been completely overturned during Alpine deformation. The presence of Triassic dolostone pebbles (Fig. 22b), quartz clasts and andesitic detritus at the base of the calcschist (Fig. 22c) would attest the activity of the fault, forming with its upper part a submarine scarp, source of the reworked clasts. The paleofault at the Maurin pass was previously interpreted as an Alpine tectonic contact, but meso- and microstructural evidence points toward an inherited structure from extensional tectonics prior to the subduction (Dana et al., 2023).

From the previous stop, follow the path that passes through the Roure lakes, heading towards Colle di Ciabriera pass (stone cairns along the path, 0.30 h, +150 m). Stop closer to the Lac Grand du Roure southern shore.

Stop 2.6 - Pointe Haute de Mary

Coordinates: Lat. N 44° 33' 31.964'', – Long. E 6° 53' 27.466'' – Altitude: 2658 m

The Pointe Haute de Mary massif represents an exceptional example of the many complex fold systems that dominate the Acceglio-type units. Already in 1898, S. Franchi described the structures observed on these mountains. As noted by Le Guernic (1967), these structures are profoundly disharmonic because of the strong competence contrast between the different lithologies. The Roure and Combe-Brémond units, cropping out in this massif, are separated by a tectonic contact (the Colle di Ciabriera thrust, CDC) frequently marked by lenses of *cargneules* and tectonic breccias. A strong increase of strain intensity is observed approaching the contact. In the Pointe Haute de Mary peak the S2 foliation describes an antiform; one limb dip towards WSW with an inclination of 60-70°, whereas the other one is folded by another synform (Fig. 23). The deepest terms of the Combe-Brémond Unit crop out at the core of the antiform. These lithologies are represented by "*Verrucano Alpino*" type siliciclastic sequences, coarser going towards the base (i.e., *Lac de Tuissier* area). In contrast, the core of the synform is made of Upper Jurassic – Cretaceous red and blue marble, in unconformity above the Lower Triassic white quartzites.

Continue walking from the previous stop and reach Colle di Ciabriera pass (0.30 h, +150 m). From the pass, it is possible to follow the path trace going downhill (stone cairns mark the path) in the Ciabriera Valley to return to Grange Collet (Italian side of the visited area, Stop 1.7) or follow back the signs to return at Maljasset (French side of the visited area). This is the last stop of Day 2 and is located in the area immediately closer to the pass.

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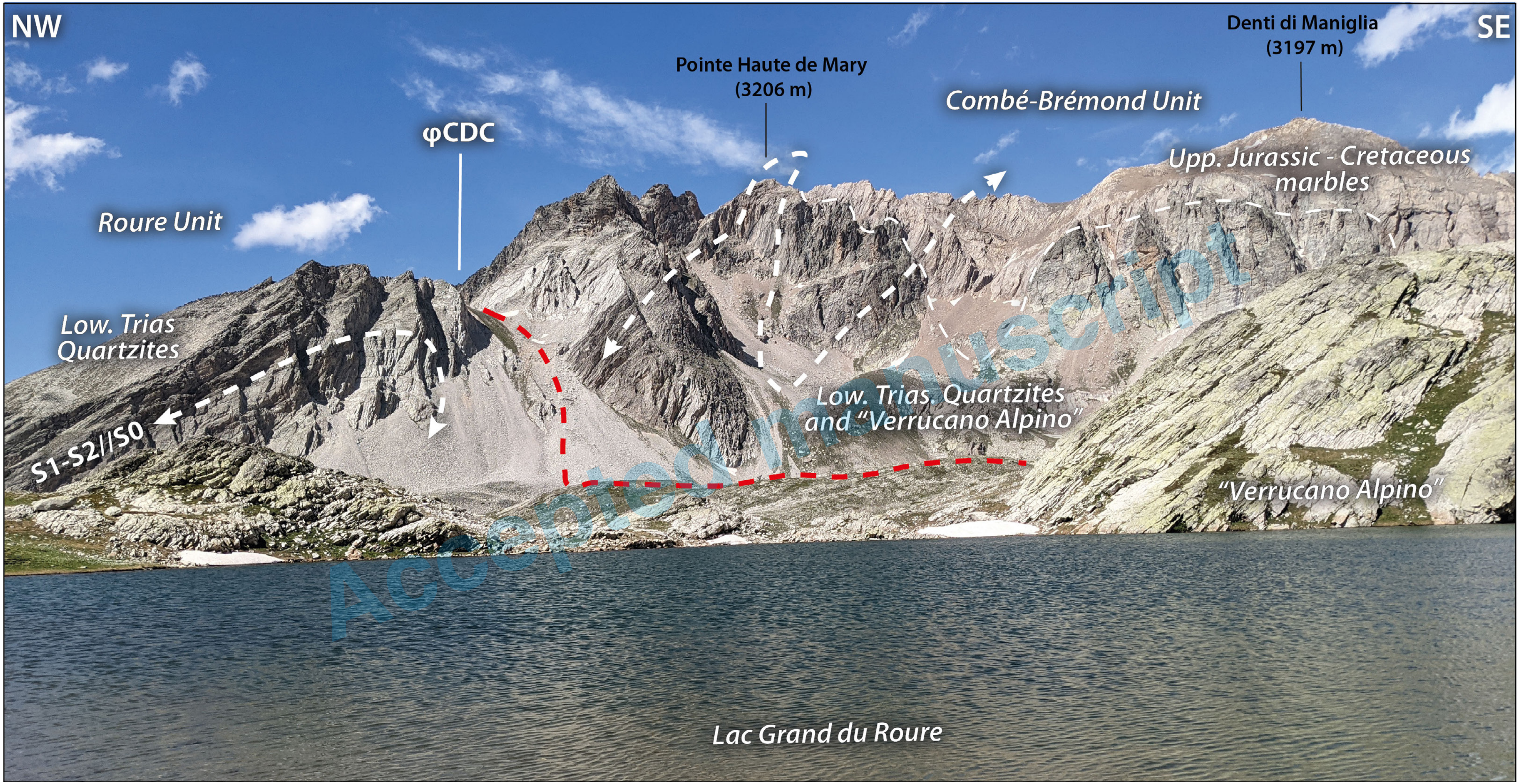

Fig. 23 - Stop 2.6. Panoramic view on the Pointe Haute de Mary group seen from the Lac Grand du Roure shore. The tectonic contact between the Roure and Combé-Brémond Units is traced in red (φCDC = Col de Ciabriera backthrust). Thick white dashed lines represent the folded surfaces.

Stop 2.7 - Folding in the Col de Ciabriera area

Coordinates: Lat. N 44° 33’ 29.25’’, – Long. E 6° 54’ 35.334’’ – Altitude: 2821 m

Near the Colle di Ciabriera pass some intensely deformed meta-dolostone and metapelites crop out. These rocks represent remnants of the Middle Triassic cover of the Combe-Brémond Unit (Le Guernic, 1967; Gidon et al., 1994). Major D3 phase folds, like the one observed in the previous stop, develop along their limbs several minor parasitic folds. While these minor folds are difficult to see clearly in the volcanoclastic or siliciclastic lithologies, they are very clearly visible in the carbonate cover. In the lithologies cropping out near this stop the F3 parasitic folds often become very irregular due to the high competence contrasts between metadolostone and metapelite. Some examples can be seen in Fig. 24. F2 folds fold a previous foliation, which along the limbs is parallelised to the S2 axial plane foliation (Fig. 24c). An S3 crenulation cleavage is clearly developed in the less competent rocks and frequently has a fan-like geometry respect to the D3 fold hinges (Fig. 24 b, c).

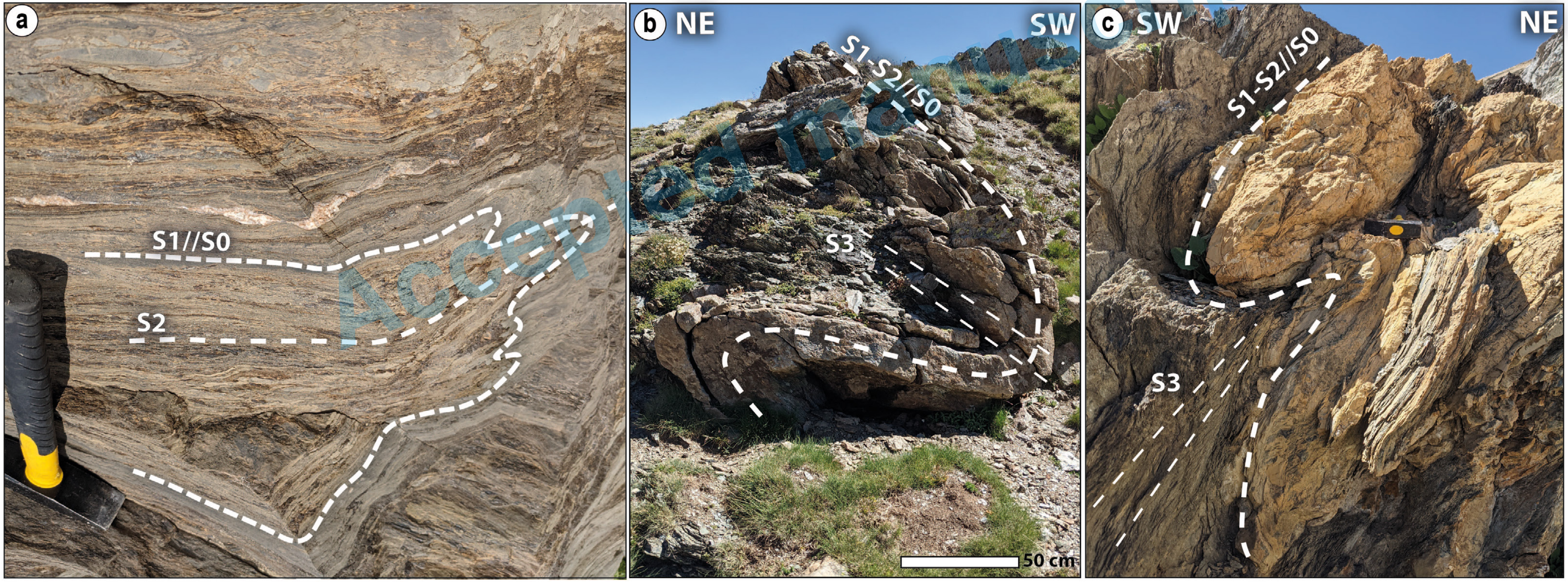

Fig. 24 - Stop 2.7. Different examples of mesoscale folds observed in the Colle di Ciabriera area. a) Rare F2 fold in Upper Cretaceous impure marbles/detrital calcschist, the folded surface is already a foliation. The development of an S2 surface sub-parallel to the folded one is visible. b) D3 minor parasitic folding in Anisian – Ladinian metadolostones and metapelites. c) Another example of D3 parasitic folding with a selective S3 cleavage development in the same lithologies.

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In Fig. 25, taken in the Ciabriera Valley looking at the pass, large D3 parasitic folds can be observed.

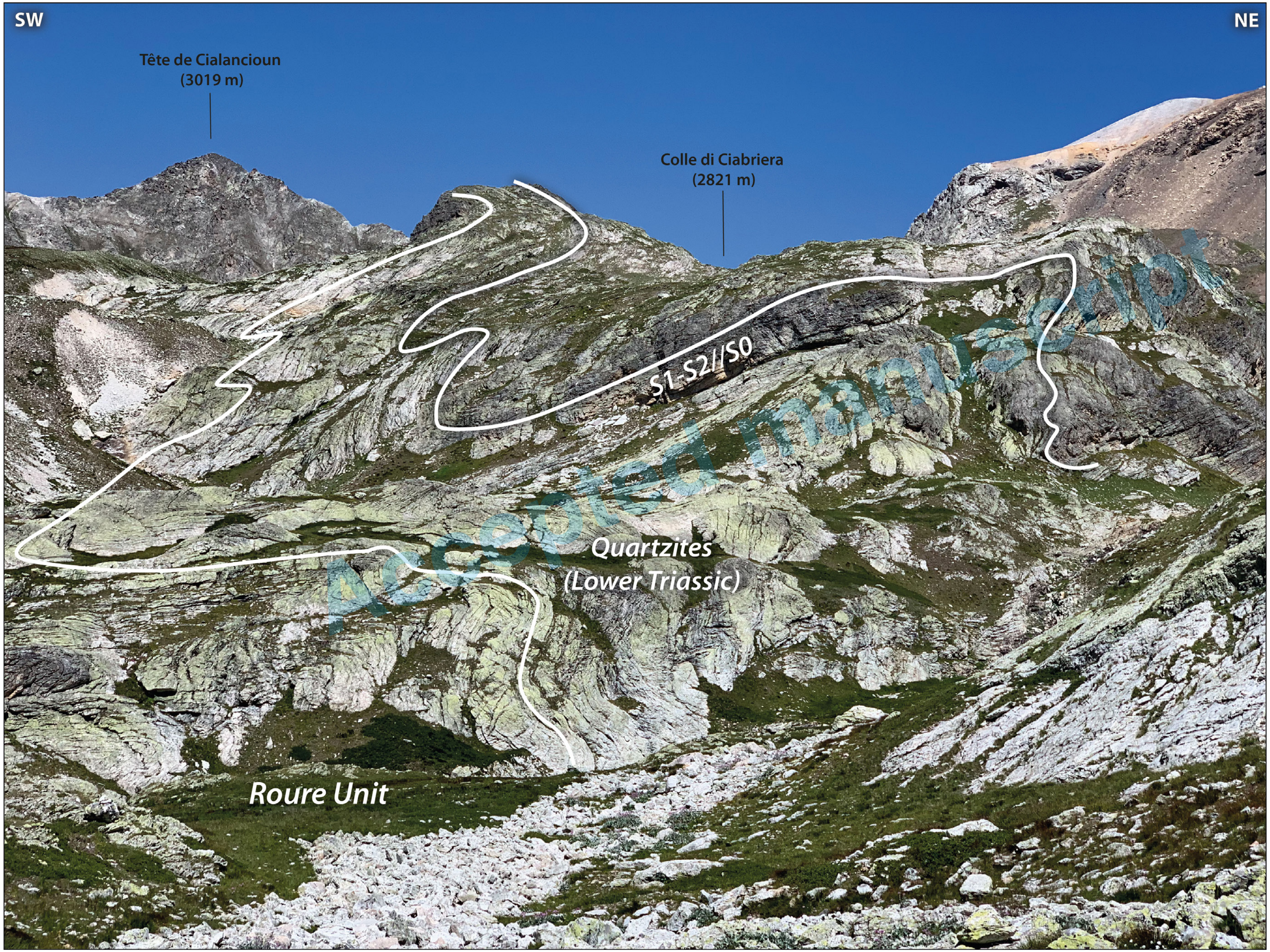

Fig. 25 - Stop 2.7. D3 folding in the "white quartzites" (Lower Triassic) of the Roure Unit, with locally disharmonic folds due to the strong rheological behaviour of the deformed rocks.

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CONCLUSIONS AND TAKE-HOME MESSAGE

During the field trip various continental- and ocean-derived tectonic units have been visited. The observed continental-derived units can be grouped into three main groups based on their stratigraphic, paleogeographic, and metamorphic features, which are: (i) Classic Briançonnais, (ii) Acceglio-type and (iii) Pre-Piemonte units. Evidence of polyphase deformation has been encountered across all these units. The structures observed during the field trip revealed that the continental-derived units underwent a common tectono-metamorphic evolution with part of the ocean-derived units only from a specific point onward. Notably, large-scale structures, associated with the D3 deformation phase, deform all these units together, and profoundly influenced/controlled the present mountain landscape. Older structures in the continental and oceanic-derived units have been developed at different times and metamorphic conditions for each specific tectonic unit. In the continental-derived Briançonnais units, presented in this field trip guide, the older structures (referred to the D1-D2 deformation event) often exhibit strong transposition due to backfolds and backthrusts (Stop 1.1, Stop 1.6, Stop 1.9, Stop 2.4, Stop 2.6 and 2.7) associated with an intense retro-vergent deformation phase (D3). While a portion of the oceanic-derived units, represented by the Queyras Schistes Lustrés, is intrinsically deformed with the continental margin units (Stop 1.2, Stop 1.3, Stop 1.4 and 1.5), a large part of the Helminthoid Flysch units is located further W of the Penninic Front and therefore not affected by the deformation phases described in this guide. A notable exception is the Serenne-Guillestre Unit (Stop 2.1), a portion of the Helminthoid Flysch units that remains in the hangingwall of the Penninic Front and, therefore, became involved in backthrusting and backfolding during D3.
During Day 2, the presence of Upper Cretaceous – Paleocene polygenic breccia (Stop 2.3) and paleofaults (Stop 1.8, Stop 2.4) was highlighted. These rocks and paleostructures witness an extensional event occurring during the early stages of the Alpine subduction. Different explanations about the causes of this extensional event have been proposed in the literature, but the most likely explanations should be related to the forebulge dynamic (e.g., Michard and Martinotti, 2002; Michard et al., 2022).
In summary:

1. structures referred to three deformation phases have been illustrated in the Briançonnais derived units. D1-D2 phases correspond to the original fore-thrusting and folding during nappe emplacement. These events were associated with different metamorphic peak conditions in all the visited units. D1-D2 structures are pervasively overprinted by intense D3 backfolding and backthrusting, linked to strong greenschist facies recrystallisation and the exhumation process in all the units (Michard et al., 2004, 2022).
2. Polygenic chaotic breccia (“*Série de la Bergerie de l’Alpet”* breccias) and recently observed paleofaults provide evidence of a significant extensional event during the Late Cretaceous to Paleocene period, associated with the deposition of the “Marbres en Plaquettes”. One of these Late Cretaceous paleofaults separated two former tectonic units: the Aiguilles de Mary and Ceillac-Chiappera Units (Gidon et al., 1994; Dana et al., 2023).

3. The D3 deformation phase, with backfolds and backthrust associated with a top-to-the-NE sense of shear, is the dominant deformation in the area, and their role was frequently underestimated.

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