Geological Field Trips

Società Geologica Italiana

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

SERVIZIO GEOLOGICO D'ITALIA
Organo Cartografico dello Stato (legge N°68 del 2-2-1960)
Dipartimento Difesa del Suolo

2014
Vol. 6 (1.2)

ISSN: 2038-4947

Valle d'Aosta section of the Sesia Zone: multi-stage HP metamorphism and assembly of a rifted continental margin

10th International Eclogite Conference - Courmayeur (Aosta, Italy), 2013

DOI: 10.3301/GFT.2014.02

GFT - Geological Field Trips

Periodico semestrale del Servizio Geologico d'Italia - ISPRA e della Società Geologica Italiana
Geol.F.Trips, Vol.**6** No.1.2 (2014), 44 pp., 9 figs, 5 tabs. (DOI 10.3301/GFT.2014.02)

Valle d'Aosta section of the Sesia Zone: multi-stage HP metamorphism and assembly of a rifted continental margin

10th International Eclogite Conference, Courmayeur (Aosta, Italy) - Pre-conference excursions: September 5, 2013

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ISSN: 2038-4947 [online]

http://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/geological-field-trips

Manuscript received 17 October 2013; accepted 17 December 2013

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Itinerary

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Safety

Mountain boots, sun glasses, and sun-tan lotion are strongly recommended, as well as warm, waterproof and wind resistant clothing.

Stop 1: Quincinetto-Pramotton
Altitude: ca. 300 m a.s.l.
Elevation change (on foot): none

Stop 2a: Settimo Vittone – Quarry of the jadeite-bearing orthogneiss
Altitude: from ca. 500 to ca. 350 m a.s.l.
Stop 2b: Glacial terrace above Montestrutto
Altitude: from c. 350 to ca. 300 m a.s.l.
Elevation change (on foot) for Stop 2a + 2b: ca. 200 m

Stop 3a: Val del Lys: Fointainemore - Guillemore Gorge
Note: Val de Lys is called Val de Gressoney on some maps
Altitude: ca. 900 m a.s.l.
Elevation change (on foot): none
Stop 3b: Val del Lys: Fointainemore at the bridge across the river
Altitude: c. 750 m a.s.l.
Elevation change (on foot): none

Stop 4: Donnas, Roman consular road
Altitude: c. 320 m a.s.l.
Elevation change (on foot): none

Stop 5: Hillock west of the Clapey house.
Altitude: c. 570 m a.s.l.
Elevation change (on foot): none

DOI: 10.3301/GFT.2014.02

Hospitals

Aosta
Ospedale Regionale
1, Viale Ginevra - 11100
Tel: (+39) 0165 543266, (+39) 0165 543315

C.R.I. (Italian Red Cross)
2, Via Grand'Eyvia -11100
Tel.: (+39) 0165 551566

Ivrea
Ospedale Civile di Ivrea
2, Piazza Credenza - 10015
Tel.: (+39) 0125 4141

C.R.I. (Italian Red Cross)
1, Piazza Croce Rossa - 10015
Via Dora Baltea, 3
Tel.: (+39) 0125 418111

Accomodation

Camping Mombarone
Fraz. Torre Daniele n° 54
10010 Settimo Vittone (Torino)
Tel.:(+39) 0125 757 907
info@campingmombarone.it
www.campingmombarone.it

Other useful addresses

Soccorso Alpino (Mountain Rescue) - Tel.: (+39) 800 800 319
Corpo Forestale (Forestry Corps) - Tel.: 1515
Pronto Soccorso (First Aid) - Tel.: 118
Corpo Vigili del Fuoco (Fire Brigade) –Tel.: 115

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IL GIARDINO DELLE ROCCE (rock garden with geological information)
Area attrezzata (Park area) "Grand Place" at Pollein, a few km downstream from Aosta.

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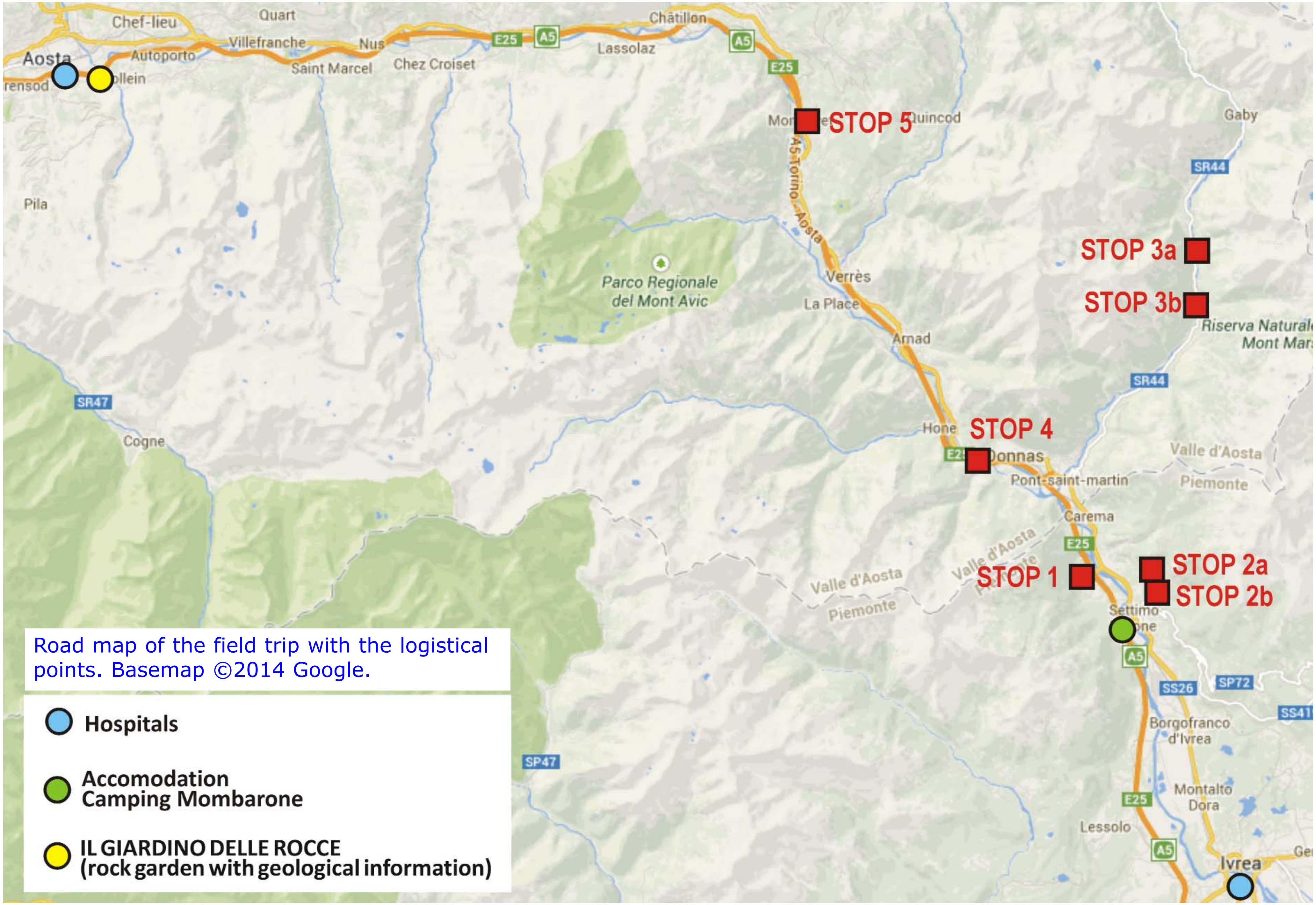

Road map of the field trip with the logistical points. Basemap ©2014 Google.

DOI: 10.3301/GFT.2014.02

Riassunto

Lo scopo principale di questa escursione, che attraversa le parti centrali della Zona Sesia, è la descrizione della geologia del **complesso dei micascisti eclogitici** (CME), in particolare delle caratteristiche petrografiche, strutturali e geocronologiche. Il CME è un corpo di crosta continentale polimetamorfica con una pervasiva impronta di alta pressione (HP) acquisita durante l'orogenesi Alpina. Gli affioramenti descritti ben illustrano i processi che si sono verificati ai margini di placche convergenti, coinvolgendo subduzione e collisione continentale, metamorfismo e deformazione in condizione della facies eclogitica, seguiti da rapida esumazione e parziale retrocessione. Altri argomenti di questa escursione riguardano il magmatismo associato al *rifting* pre-collisionale del margine continentale Adriatico e le relazioni della Zona Sesia con le adiacenti unità oceaniche della Zona Piemontese.

Gli affioramenti scelti si collocano in uno scenario spettacolare e forniscono un'opportunità ideale per esaminare rocce di HP. L'ampio spettro litologico caratteristico del CME varia dalle eclogiti (contenenti onfacite + granato ± fengite ± paragonite ± glaucofane ± zoisite + rutilo) a micascisti fengitici ± granato ± onfacite/giadeite ± cloritoide, calcescisti e marmi, e ortogneiss. Nonostante l'intensa deformazione polifasica e la ricristallizzazione metamorfica di HP, localmente è ancora possibile riconoscere caratteri del protolite pre-Alpino. Per esempio, due tipi di ortogneiss felsici possono essere riconosciuti in Valle d'Aosta: uno derivato da granitoidi permiani (con locale preservazione di contatti intrusivi, inclusioni cogenetiche, filoni aplitici, e altre strutture magmatiche: Stop 3), l'altro derivato da leucomonzograniti pre-varisici, tipo la pietra ornamentale estratta nella cava "Argentera" presso Settimo Vittone/Montestrutto (Stop 2; nota come "Verde Argento", che contiene giadeite, fengite, K-feldspato e quarzo).

Metasedimenti policiclici e più raramente monociclici mostrano evidenze di una complessa evoluzione P-T-D-t alpina, che localmente contiene relitti della storia prograda dagli scisti blu, a uno o più stadi in facies eclogitica. Recenti studi petrocronologici hanno datato in dettaglio questa evoluzione di HP della Zona Sesia. Nell'area dell'escursione, in una scaglia tettonica di dimensione chilometrica è stata identificata una chiara evidenza di ciclicità in condizioni di HP, indice di "*yo-yo tectonics*" (Stop 2), ma non in altre porzioni adiacenti del CME. In uno degli affioramenti descritti (Stop 4) è evidente una parziale retrocessione in facies scisti verdi delle paragenesi di HP associata ad una deformazione da duttile a fragile.

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Oltre ai quattro stop della Zona Sesia, un affioramento finale illustra le rocce di HP dell'adiacente unità oceanica della **Zona Piemontese**, costituita dai calcescisti e dai termini ofiolitici della Zona "Zermatt-Saas". L'affioramento sulla sommità della collinetta dello Stop 5 mostra una serpentinite antigoritica foliata con relitti peridotitici (clinopirosseno, spinello) che contiene *boudin* derivati da originari filoni doleritici. Queste meta-rodingiti a grana fine e le associate vene metamorfiche ripiegate nelle serpentiniti contengono Mg-clorite, forsterite e titanclinohumite che indicano una ri-equilibrazione metamorfica alpina in condizioni di facies eclogitica a quarzo. Tuttavia, queste unità hanno raggiunto il picco di HP oltre 20 Ma dopo la più recente impronta metamorfica in facies eclogitica della Zona Sesia.
Nonostante la Zona Sesia sia stata oggetto ormai da quasi mezzo secolo di numerosissimi studi di dettaglio, la complessa giustapposizione dei suoi terreni di HP e le sue relazioni con le parti più esterne delle Alpi Occidentali sono state solo in parte chiarite. Questa guida ha prevalentemente lo scopo di mostrare alcuni degli affioramenti più classici della Zona Sesia e discutere criticamente le evidenze in essi contenuti, e pertanto non contiene i dettagli di ciascun stadio della complessa evoluzione finora riconosciuta.

Parole chiave: Zona Sesia, Valle d'Aosta, eclogite, dinamica di zolle convergenti, polimetamorfismo, subduzione, collisione, cicli di pressione, esumazione.

Abstract

The main focus of this field trip through central parts of the Sesia Zone is laid on the geology of the **Eclogitic Micaschist Complex** (EMC), notably on its petrographic, structural, and geochronological characteristics. The EMC is an impressive mass of polymetamorphic continental crust with a pervasive high-pressure (HP) imprint acquired during the Alpine orogeny. The outcrops visited offer insights into the processes at a convergent plate margin, involving continental subduction and collision, metamorphism and deformation under eclogite facies conditions, followed by rapid exhumation and partial retrogression. Additional topics of this field trip address the magmatism associated with pre-collisional rifting of the Adriatic continental margin and the relation of the Sesia Zone to the adjacent Piemonte oceanic units.
The outcrops selected are set in a spectacular scenery and provide ample opportunities to examine HP rocks.

The spectrum characteristic of the EMC ranges from eclogites (containing omphacite and/or jadeite, garnet, phengite, glaucophane, zoisite, chloritoid, rutile) to phengite schists, calcschists, and marbles, as well as a variety of orthogneisses. Despite the intense polyphase deformation and HP-metamorphic recrystallization, it is possible in some locations to recognize pre-Alpine characteristics in some of the protoliths. For instance, two types of felsic orthogneiss can be distinguished in the Aosta Valley, one derived from Permian granitoids (with local preservation of intrusive contacts, magmatic inclusions, leucocratic veins and other magmatic structures; Stop 3), the other derived from pre-Variscan leuco-monzogranite, such as the building stone mined at the "Argentera" quarry near Settimo Vittone / Montestrutto (Stop 2; so-called "Verde Argento" contains jadeite, phengite, K-feldspar, quartz).

Polycyclic and more rarely monocyclic metasediments contain evidence of a complex Alpine PTDt-evolution, locally including relics of their prograde history from blueschist, one or more stages at eclogite facies. Recent petrochronological studies have dated this HP-evolution of the Sesia Zone in some detail. In the area visited, clear evidence of HP-cycling has been identified in one km-size tectonic slice (Stop 1), but not in adjacent parts of the EMC, indicating "yo-yo tectonics". Partial retrogression and attendant ductile to brittle deformation of the HP-rocks is evident in one of the outcrops (Stop 4).

Apart from the four localities in the Sesia Zone, a final outcrop introduces HP-rocks of the adjacent **Piemonte oceanic unit**, specifically calc-schists and ophiolite members of the "Zermatt-Saas" zone. The hilltop outcrop (Stop 5) displays foliated antigorite schist with peridotite relics (clinopyroxene, spinel) containing lenses derived from doleritic dykes. These fine-grained metarodingites and the folded veins containing Mg-chlorite and titanoclinohumite within serpentinite once again indicate equilibration under low-temperature eclogite facies conditions. However, these units reached that HP stage more than 20 Ma after the youngest eclogite facies imprint recognized in the Sesia Zone.

Despite nearly half a century of intense study in the Sesia Zone, the complex assembly of its HP-terranes and their relation to more external parts of the Western Alps remains incompletely understood. This field guide merely introduces a few of the classic outcrops and discusses some of the critical evidence they contain, but it could not incorporate details on each stage of the evolution recognized so far.

Key-words: Sesia Zone, Aosta Valley, eclogite, convergent dynamics, polymetamorphism, subduction, collision, pressure cycling, exhumation.

Program summary

The starting point of this one-day field trip is located at Quincinetto, a small town located near the entrance of the Aosta Valley (Fig. 1). Quincinetto can be reached from Torino along the A5 Highway (ca. 45 minutes travel time). Immediately after you exit from the highway, at the south end of the bridge, enter the village on your left, then after 100 meters take a right and follow the road skirting upstream, with the river on your right; parking after 700 meters. **Stop 1** is reached walking a few hundred meters further on, to the end of the road. The gate to the powerstation is locked. To visit the outcrops beyond, you may need to make arrangements. Alternatively, giant blocks on the riverbank, some 200 meters before the end of the road, show many of the same features and can be visited freely.

To reach Stop 2 from Quincinetto, drive to Borgofranco and then to Nomaglio along the Provincial Road (SP72) up to the junction (at elevation of c. 575 m a.s.l.) with the country road leading to the Argentera quarry. Consider that the road is narrow and the place for parking is limited. Walk down the steep gravel road, a few hundred meters into the large quarry (**Stop 2a**). Leaving the quarry along a dirt road down to a paved minor road (10 minutes' walk), a glacial terrace is reached (**Stop 2b**). Then, walk back to the Argentera quarry and to the parking. An alternative way to reach Stop 2 is to drive from Quincinetto to the hamlet of Montestrutto along the National Road (SS26) (15 minutes' drive). From the village of Montestrutto a paved path leads up to the glacial terrace (Stop 2b) and from there to the Argentera quarry (Stop 2a), following the same route explained above, but in the reverse sense. Either way, the elevation change (on foot) is some 200 m.

The transfer from Nomaglio/Montestrutto to Fontainemore (Stop 3) requires a 40-45 minutes' drive along the Val del Lys (i.e. Gressoney valley). The Guillemore Gorges (**Stop 3a**) are located between the hamlets of Fontainemore and Issime, immediately below the small dam on the Lys stream. **Stop 3b** can be reached driving downstream from Stop 3a to the small bridge that crosses the Lys River at Fontainemore, locality Espaz.

Then, drive back down the valley (Val del Lys) to Pont St. Martin, and take the National Road SS26 up to Donnas (**Stop 4**) (ca. 35 minutes' drive). Use the sizeable parking lot right next to the Roman Road.

The transfer from Stop 4 to **Stop 5** requires a 40 minutes' drive along the National Road SS26 up to the top of the Montjovet hillslope; then take the small road to Saint Germain and the Château de Montjovet, and drive c. 500 m southward up to the path to Clapey (Sappé) house. After two minutes' walk to the Clapey house, in front of which a portion of the Roman road is preserved, climb the small hill to your right up to the top.

DOI: 10.3301/GFT.2014.02

1. Introduction

This day field trip runs through the Valle d'Aosta (Fig. 1), one of the major valleys of the Italian Western Alps, c. 100 km long. The excursion starts at Quincinetto, a small village located at the entrance of the Valle d'Aosta near the town of Ivrea, which is nestled in an amphitheatre of Pleistocene glacial moraines. Most of the excursion stops are within continental basement units of the Sesia Zone. Further up the Aosta valley, starting near the town of Verres, ophiolitic units of the Piemonte Zone dominate, and the last stop of the field trip is in this zone. Even further upstream, the Valle d'Aosta traverses mostly Paleozoic basement rocks of the Briançonnais domain, which originated from a continental ribbon located along the distal European margin; these units are not visited on this field trip.

The discovery of widespread eclogites in the continental basement rocks of the Sesia Zone some 35 years ago sparked an era of intense investigation of HP rocks. Owing to spectacular assemblages and metamorphic textures, many of the initial studies focussed on petrological aspects (see Table 1 for references). It was discovered that most of the rock types studied are polycyclic: a strong Paleozoic imprint (under upper amphibolite- to granulite-facies grade) is common (Lardeaux & Spalla, 1991). Pre-Alpine HT relics are particularly common in dry and weakly deformed rock types. On the other hand, many of the eclogites show partial retrogression to greenschist-facies assemblages.

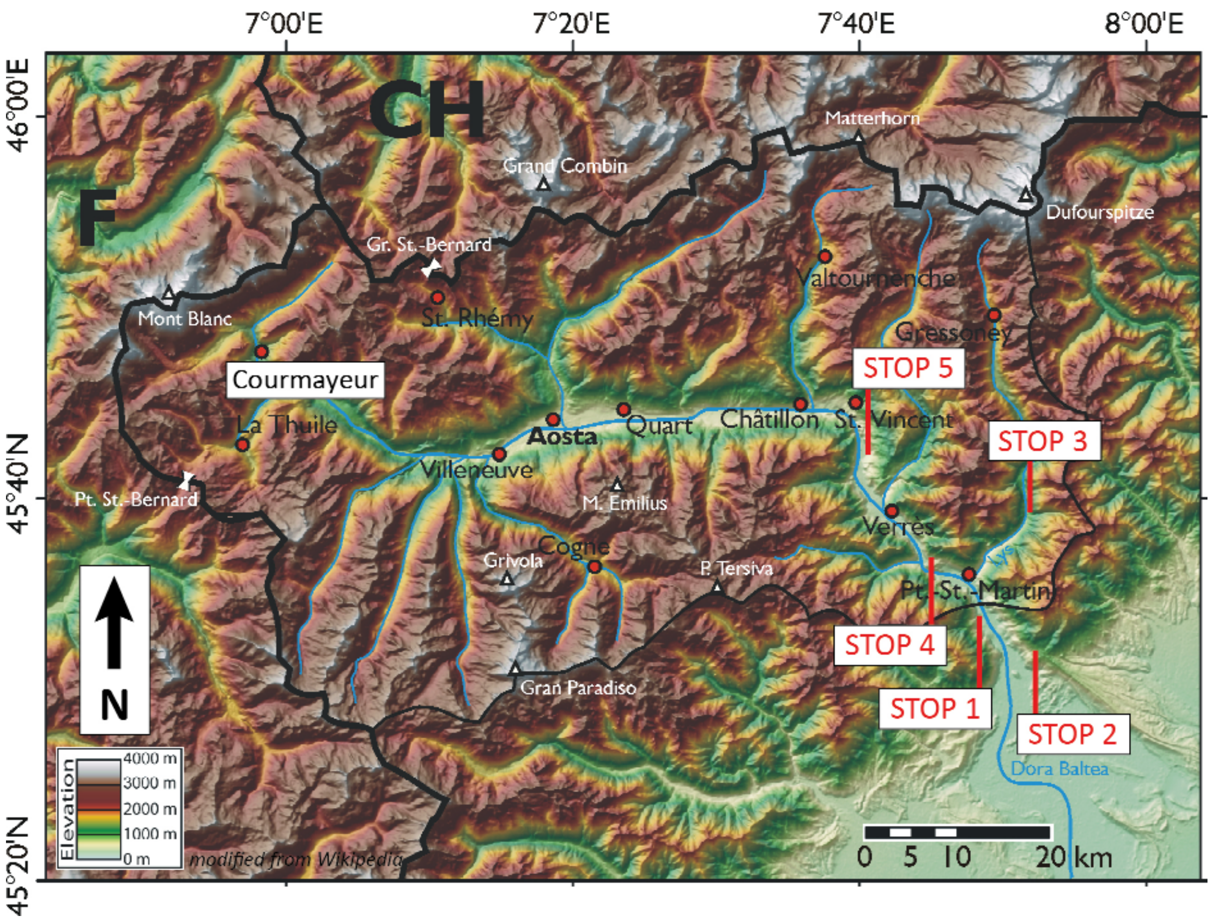

Fig. 1 – Geographical location of the field trip area and stops.

DOI: 10.3301/GFT.2014.02

No evidence of UHP-conditions has been reported from the Sesia Zone, but UHP-relics have been found in tectonized metasediments of the Piemonte Zone: coesite (Reinecke, 1991) and quite recently microdiamonds (Frezzotti et al., 2011) have been reported from the Lago di Cignana area (to be visited during the pre-conference field trip).

1.1 Sesia Zone

The Sesia Zone (also known as the Sesia-Lanzo Zone) is the most easterly unit of the axial belt of the Western Alps. It is bounded by the Insubric Line (locally called External Canavese Line) to the east, the Piemonte Zone to the west, and the Lanzo ultramafic Massif to the south (Fig. 2).

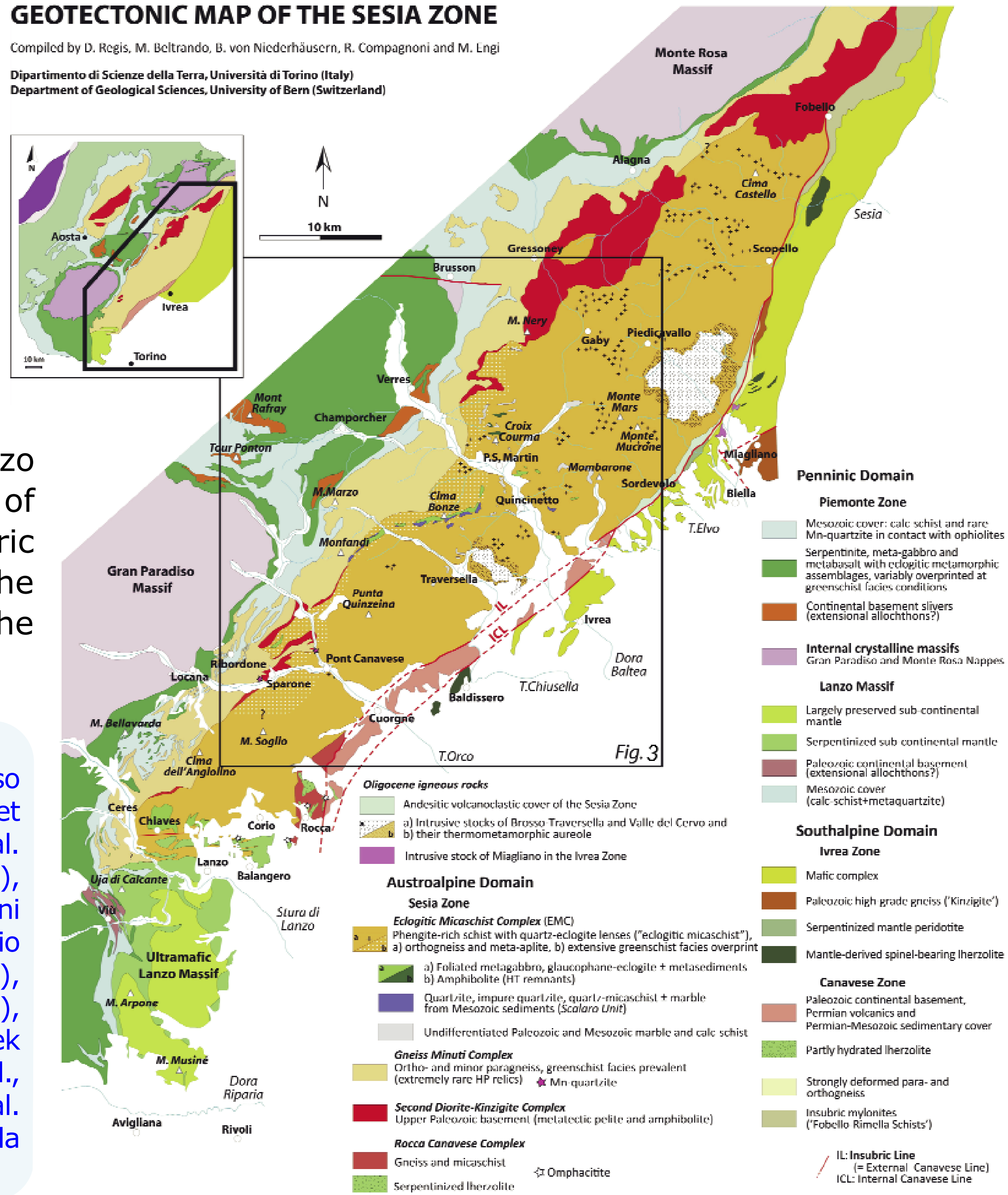

Fig. 2 - Geotectonic map of the Sesia Zone and the adjoining units, based on maps by Hermann (1937), Gosso (1977), Pognante (1989a), Passchier et al. (1981), Gosso et al. (1982), Williams & Compagnoni (1983), Pognante et al. (1987), Biino & Compagnoni (1988), Castelli (1991), Lardeaux & Spalla (1991), Venturini et al. (1994), Venturini (1995), Steck et al. (1999), Rebay & Spalla (2001), Servizio Geologico d'Italia/APAT (2002, 2006), Zucali (2002), Ferraris & Compagnoni (2003), Spalla & Zulbati (2003), Ferrando et al. (2004), Rebay & Messiga (2007), Kaczmarek & Muntener (2008), Zanoni et al. (2008), Gasco et al., (2009), Delleani et al. (2013), Zanoni (2010), Zanoni et al. (2010), Dal Piaz (2010), Dal Piaz (2011), Zucali & Spalla (2011), Kapferer et al. (2012), Regis et al. (2012).

DOI: 10.3301/GFT.2014.02

The Sesia Zone is a composite unit that consists predominantly of Palaeozoic continental basement similar to the Ivrea Zone, which is an equivalent block in the Southern Alps. The Ivrea zone is characterized by Permian amphibolite- to granulite-facies metamorphism and lacks Alpine overprint. Within the Sesia Zone, a Mesozoic sedimentary cover is locally found (Venturini et al., 1994); it underwent Alpine metamorphism together with the basement rocks.
A post-metamorphic volcano-sedimentary cover of Oligocene age crops out close to the Insubric Line (Ahrendt, 1969). Various subdivisions of the Sesia Zone have been suggested (e.g. Venturini et al., 1994; Babist et al., 2006), but the classical three sub-units, as defined by Compagnoni et al. (1977) on the grounds of metamorphic grade and prevalent rock types, are used below: Eclogitic Micaschists Complex (EMC), Gneiss Minuti Complex (GMC), and Second Diorite-Kinzigit Complex (2DK) (see Section 2).

1.2 Piemonte Zone

The Piemonte Zone, which crops out along the whole length of the Western Alps, has been referred to under different names, including Piemonte–Liguria Zone, Ligurian–Piemonte Zone, Ligurian–Piemontese Zone, Schistes Lustrés Zone and "Zona dei calcescisti con pietre verdi". It is bounded by the Sesia Zone and by the Po Plain to the southeast and by the Briançonnais units to the west (Fig. 2).
The Piemonte Zone samples remnants of the Piemonte–Liguria Ocean and of the sedimentary cover that was deposited along its margins (e.g. Bearth, 1967; Lemoine, 1985; Deville et al., 1992). On the base of the lithological associations and metamorphic imprints two main ensembles, first described in the northwestern Alps by Bearth (1967), can be distinguished all along the arc of the Western Alps: an eclogite facies Zermatt–Saas Zone and a blueschist facies Combin Zone (Fig. 2; from north to south, see Servizio Geologico d'Italia, 2006; Beltrando et al., 2008; Perotto et al., 1983; Servizio Geologico d'Italia, 2002; Agard et al., 2001; Lombardo & Pognante, 1982; Schwartz, 2002).

DOI: 10.3301/GFT.2014.02

2. The internal sub-units of the Sesia Zone

2.1 Eclogitic Micaschist Complex

The Eclogitic Micaschists Complex (EMC) consists of a polycyclic basement comprising paragneisses, minor metamafic rocks, orthogneisses and impure marbles. This basement is intruded by abundant Carboniferous to Permian granitoids and minor gabbros (Bussy et al., 1998; Rubatto, 1998). Granitoids are dominant in the northeastern part of the Sesia Zone; they are traditionally labelled "Sesia Gneiss" (Dal Piaz et al., 1972). A probably Mesozoic sedimentary cover, with monometamorphic paragneiss, carbonate schist and locally manganiferous impure quartzite, is found in the central part of the EMC (Venturini et al., 1994). The EMC reached maximum pressures less than 2 GPa at temperatures lower than 600 °C (Tropper & Essene, 2002; Zucali et al., 2002). In the proximity of the Gneiss Minuti Complex, a pervasive greenschist-facies assemblage overprints the eclogite-facies parageneses of the EMC (e.g. Dal Piaz et al., 1972, Compagnoni et al., 1977) (Fig. 2).

2.2 Gneiss Minuti Complex

The Gneiss Minuti Complex (GMC) mainly consists of orthogneisses interbedded with more mafic layers rich in albite, white mica, chlorite, epidote, and actinolite. In several exposures, such as in the lower Aosta Valley, the orthogneisses appear to have derived from granitoids of probable Permian age with associated aplitic dyke swarms, which intruded into a locally preserved polycyclic basement. In contrast, in other locations, such as the Orco Valley and the southern Sesia Zone, the Gneiss Minuti Complex does not show any trace of pre-Alpine metamorphism and probably developed at the expense of a Mesozoic sedimentary sequence comprising predominant meta-arkose and rare marble, calcschist, and metachert (Zambonini, 1922; Gennaro, 1925; Dal Piaz et al., 1971; Minnigh, 1977; Pognante, 1989b).

Table 1 - Select references to studies on HP/UHP metamorphism in the internal Western Alps.

Select* studies on the Sesia Zone (formerly Sesia-Lanzo Zone)	
A. Emphasis on HP-petrology	**B. Emphasis on structural geology and evolution**
Dal Piaz et al. (1971, 1972)	Pognante et al. (1980)
Compagnoni & Maffeo (1973)	Passchier et al. (1981)
Compagnoni (1977)	Lardeaux et al. (1982)
Dal Piaz et al. (1978)	Williams & Compagnoni (1983)
Minnigh (1977)	Rubie (1984)
Minnigh (1979)	Pognante (1989b)
Reinsch (1979)	Avigad et al. (1994)
Hy (1984)	Ridley (1989a)
Oberhänsli et al. (1985)	Ridley (1989b)
Stöckhert (1985)	Stünitz (1989)
Koons (1986)	Wheeler & Butler (1993)
Vuichard & Ballèvre (1987, 1988)	Spalla et al. (1996)
Pognante et al. (1988)	Inger & Ramsbotham (1997)
Pognante (1989a)	Rebay (1997)
Castelli (1991)	Tropper et al. (1999)
Lardeaux & Spalla (1991)	Rebay & Spalla (2001)
Spalla et al. (1991, 1996)	Zucali (2002)
Ferraris & Compagnoni (2003)	Zucali et al. (2002)
Zucali et al. (2004)	Babist et al. (2006)
Konrad-Schmolke et al. (2006)	Konrad-Schmolke (2006)
Pelletier & Müntener (2006)	Gosso et al. (2010)
Konrad-Schmolke et al. (2011a, b)	Meda et al. (2010)
Rubatto et al. (2011)	Zanoni et al. (2010)
Zucali & Spalla (2011)	Zucali & Spalla (2011)
Regis et al. (2012, 2013)	

* Includes articles in English only, no abstracts

2.3 Second diorito-kinzigitic zone

The second diorito-kinzigitic zone (2DK) consists of slivers of well-preserved pre-Alpine amphibolite-facies garnet–sillimanite–biotite micaschists with local migmatitic leucosomes, minor amphibolite, marble, and a small harzburgite body (Dal Piaz et al., 1971). Alpine re-equilibration under blueschist-facies conditions is restricted to the margins of the slivers or to narrow shear zones (Dal Piaz et al., 1971; Gosso et al., 1979; Passchier et al., 1981; Williams & Compagnoni, 1983). The 2DK crops out discontinuously along the contact between the EMC and the GMC (Fig. 2).

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3. Aim of the excursion

An intriguing aspect of the Valle d'Aosta transect across the Piemonte Zone concerns the relative timing of Alpine imprint. Geochronology of the HP-rocks indicates that the largely continental units now exposed in the Sesia Zone were subducted in the Upper Cretaceous, some 25-30 Ma earlier than the HP-imprint in oceanic units in the Piemonte Zone, which is Eocene in age (e.g. Rubatto et al., 1998). Plate-tectonic evolutions at convergent margins normally show the opposite temporal sequence, i.e. oceanic lithosphere is typically subducted first and accretion of continental slices may follow subsequently. In the Western Alps, despite some confusing age data, the gap in HP-age between the continental and the more external oceanic units is very clearly established (see Table 2 for references). It is interpreted to reflect the convergent evolution at a previously rifted and thinned continental margin (e.g. Dal Piaz et al., 2001), leading to the subduction of an ocean-continent transition (OCT) zone (Dal Piaz, 1999; Beltrando et al., 2010a,b).

This field trip through Valle d'Aosta presents an opportunity to appreciate the progress made in understanding this evolution by integrating structural, petrological and geochronological work – spanning some forty years of intense study. Polyphase deformation related to the Alpine tectonic evolution has been documented in detail, both in the external and internal parts of the Western Alps (e.g. Passchier et al., 1981; Zucali, 2002; Babist et al., 2006). The Sesia Zone was exhumed as a coherent HP-terrain, but it comprises at least three continental nappes. The evidence gathered strongly suggests that the pre-orogenic structure at lithospheric scale fundamentally affects where, when and how HP-rocks are formed. Recent studies have discovered unexpected complexities in the kinematic evolution of the Sesia Zone (Rubatto et al., 2011; Regis, 2012), with some tectonic slices having experienced substantial pressure cycles ("yo-yo tectonics"). The scales, rates and duration of tectonic mixing by differential movements within the Sesia Zone are targets of ongoing studies. Characterizing and quantifying the internal dynamics at convergent margins remains a challenge, and type examples such as the HP-terrains of the internal Western Alps are a critical reality check for numerical modelers who aim to understand Earth dynamics (e.g. Roda et al. 2010 and references therein).

DOI: 10.3301/GFT.2014.02

Table 2 - Select references to geochronological studies of HP/UHP metamorphism in the Internal Western Alps.

Tectonic domain	Reference	Rock type	Method	Mineral	Age/Ma	Interpretation and conditions	
Eclogitic Micaschist Complex (localities grouped approximately from E to W, i.e. from internal to external units)							
EMC: Druer slice Mombarone	Regis et al. (2013)	micaschist	U-Th-Pb SHRIMP	allanite	85.8±1.0	Prograde HP1 stage: 540-550 °C 1.9-2.0 GPa	HP-max
		micaschist	U-Th-Pb SHRIMP	zircon	74.1±0.9	HP	
Montestrutto	Rubatto et al. (1999)	jadeite-vein	U-Th-Pb SHRIMP	zircon	76±1	HP	
Monte Mucrone	Rubatto et al. (1999)	micaschist eclogite	U-Th-Pb SHRIMP	zircon zircon rims	65±3 65±5	D3 stage?	
Monte Mucrone Monte Mars	Inger et al. (1996)	Metaquartz-diorite eclogite metapelite	Rb-Sr	white mica – whole rock	63±1.3 63±1.4 63±1.5		
EMC: Fondo slice Quincinetto	Rubatto et al. (2011)	eclogitic micaschist	U-Th-Pb SHRIMP	zircon rim1 zircon rim2 zircon rim3	78.6±0.9 76.8±0.9 73.7±0.9	HP1 (prograde) LP (decompression) HP2 (retrograde?)	YoYo
Cima Bonze	Regis et al. (2013)	monocyclic phengite-quartzite	U-Th-Pb SHRIMP	allanite core allanite rim1 allanite rim2	75.6±0.8 69.8±0.8 65-62	HP1: ~540 °C, 1.7 GPa (D1/D2) Decompression to MP HP2: ~550 °C, 1.4-2.0 GPa (D3)	YoYo
Cima Bonze	Rubatto et al. (1999)	metabasic rocks	U-Th-Pb SHRIMP	zircon rims	68±7		YoYo
Marine (Pont St. Martin)	Dal Piaz et al. (2001)	marble	Rb-Sr	phengite – whole rock	71.0±0.8	Decompression?	
Lillianes-Fontainemore	Duchêne et al. (1997)	meta-intrusive / eclogite	Lu-Hf	garnet and pyroxene	69.2±2.7		
Quinseina	Inger et al. (1996)	monocyclic marble	U-Pb	titanite	66.3±0.4		
Marine (Pont St. Martin)	Ruffet et al. (1995)	micaschist (garnet-glaucophane bearing) +meta-lamprophyre	Rb-Sr & Ar-Ar	phengite – whole rock	64.2±2.5	D3 stage?	
Val Chiusella	Babist et al. (2006)	HP gneiss: phengite-sodic amph-garnet	Rb-Sr	phengite – albite	63.6±0.7	min. age of D2	

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Table 2 (continued) - Select references to geochronological studies of HP/UHP metamorphism in the Internal Western Alps.

Tectonic domain	Reference	Rock type	Method	Mineral	Age/Ma	Interpretation and conditions
Gneiss Minuti Complex						
Val d'Ayas – Val Soana – Val d'Orco	Inger et al. (1996)	gneiss minuti	Rb-Sr	phengite – whole rock	39-38	Greenschist facies overprint
Val Sesia	Reddy et al. (1999)				46.2±0.4	
Klippen, outliers a top Piemonte-Liguria units						
Pillonet	Cortiana et al. (1998)		Rb-Sr & Ar-Ar	phengite	75-73	Blueschist facies imprint
Mont Emilius	Dal Piaz et al. (2001)	HP gneiss, eclogite	Rb-Sr	phengite – whole rock	49-40	Eclogite facies imprint
Etirol-Levaz		HP gneiss			47-45	
Glacier-Rafray		glaucophane-eclogite			47-45	
Etirol-Levaz	Beltrando et al. (2010)	eclogite	U-Pb SHRIMP	zircon rims	47.5±1.0	Eclogite facies imprint
Piemonte-Liguria units						
Combin Zone	Reddy et al. (1999)	calc-schist	Rb-Sr		45-37	Greenschist facies
Zermatt-Saas Zone		calc-schist			47±1	Eclogite facies
		eclogite			~44	
	Lapen et al. (2003)	eclogite	Lu-Hf	garnet	48.8±2.1	Prograde
Lago Cignana	Rubatto et al. (1998)	eclogite	U-Pb SHRIMP	zircon	44.1±0.7	
	Amato et al. (1999)	eclogite	Sm-Nd		40.6±2.6	P max?

Note - Argon ages are shown only for studies that reported comparable results from other isotopic systems, e.g. Rb-Sr.

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Itinerary

The lower Valle d'Aosta exposes a complete section (about 20 km long) across the continental Sesia Zone and adjoining ophiolitic Piemonte zone. Albeit the rather low elevation, exposures are very good due to extensive erosion and polishing by the Quaternary Valle d'Aosta glacier.

Locations of the outcrops visited are shown in Fig. 1 and 3. Stops 1 to 4 are within the Eclogitic Micaschist Complex. With respect to the subsequent greenschist-facies overprint, Stops 1 to 3 are in the Eclogitic Micaschist Complex where the eclogite-facies mineral assemblages are well preserved (key minerals: garnet, Na-pyroxene omphacite/jadeite and glaucophane), whereas Stop 4 is close to the tectonic contact with the Gneiss Minuti Complex, in an area with significant greenschist-facies overprint, where jadeite has been completely replaced, but glaucophane is still locally preserved. Stop 5 is within the meta-ophiolites of the eclogite-facies Zermatt-Saas zone of the Piemonte zone (Fig. 3).

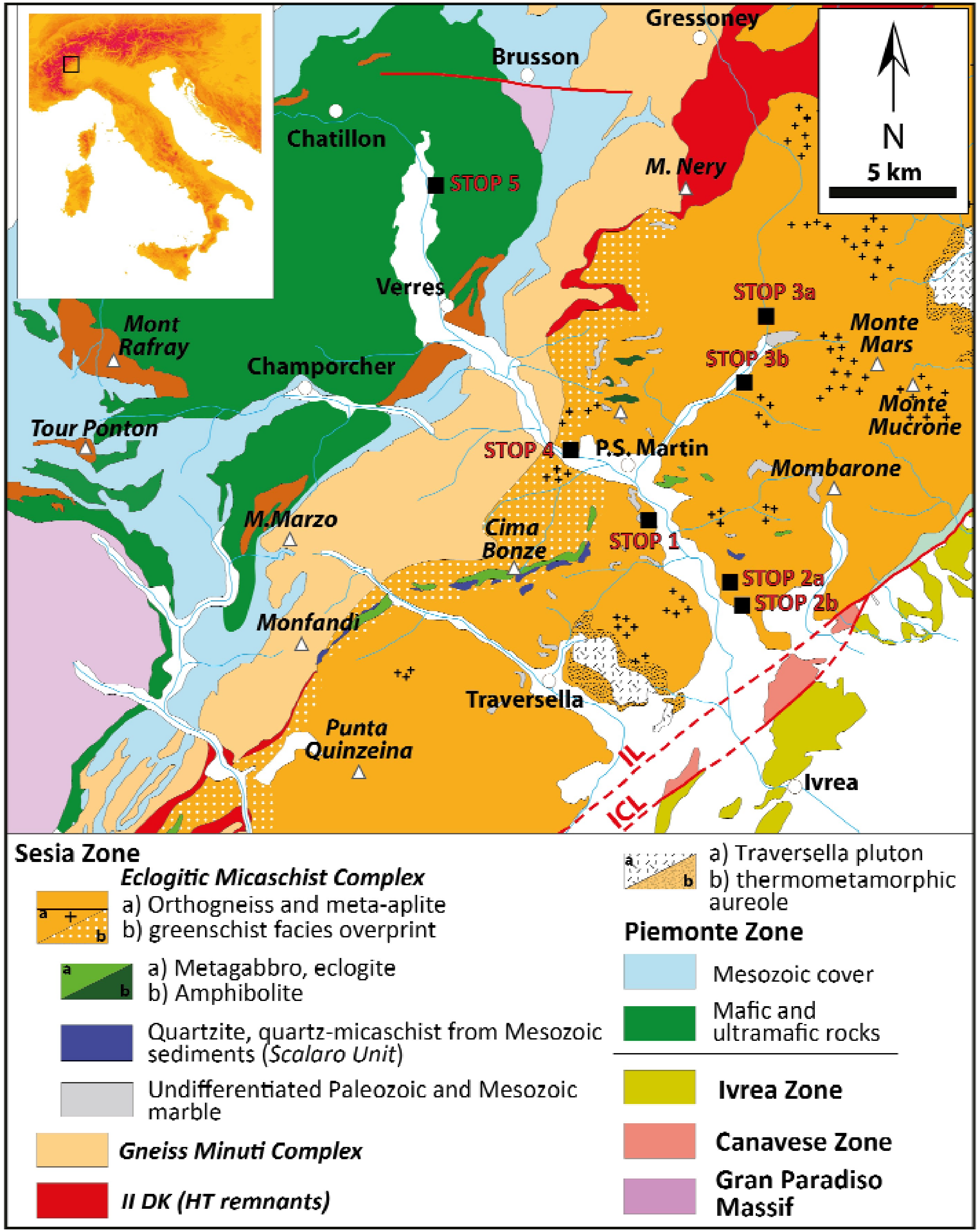

Fig. 3 - Enlargement of the central part of Fig. 2 with location of Stops 1 to 5 described in the text.

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STOP 1: Variscan amphibolite-facies continental crust recrystallized under quartz eclogite facies

Quincinetto – Bric Vert to Pramotton

(Coord. 45°33'47.52" N, 7°48'29.34" E, elev. c. 300 m a.s.l.)

Most lithologies typical of the Eclogitic Micaschist Complex can be collected from large blocks that fell from the towering face of Bric Vert. Along the path leading from Chiapetti to Pramotton, locals have used such large blocks as outside walls in their cabin constructions.

Early-Alpine minerals are very coarse-grained (Fig. 4b); euhedral crystals of omphacite (up to 1 cm long) were recently found in HP-veins. Retrogression is minor.

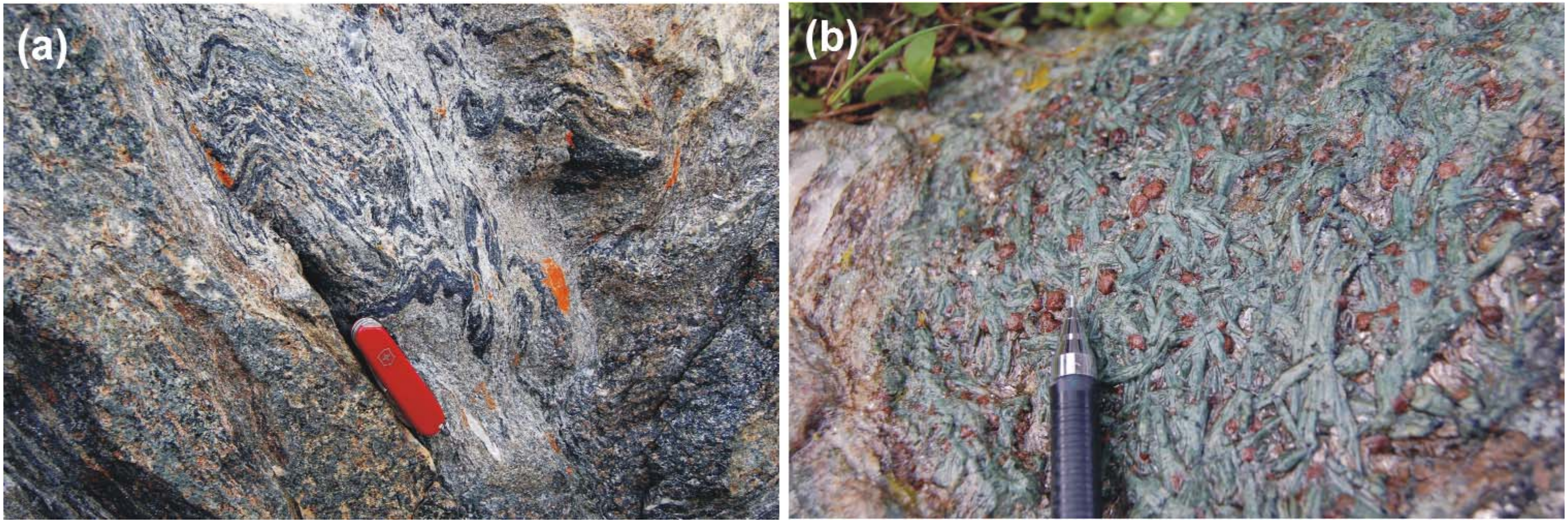

Fig. 4 – Outcrop appearance of representative lithologies of Stop 1. **(a)** Folded glaucophane-garnet micaschist. Scalaro above Quincinetto. **(b)** Omphacite-garnet rock. Mombarone area.

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Main lithologies

The most frequent lithologies are:
- Phengite micaschist (with garnet ± Na-pyroxenes ± glaucophane ± rutile);
- Glaucophane eclogite, omphacitite (with phengite ± ferroan dolomite ± zoisite), and garnet glaucophanite (± phengite);
- Calcite - dolomite ± ankerite marble (with phengite, zoisite, omphacite ± garnet);
- Quartz-phengite-carbonate (calcite and dolomite) schists with accessory glaucophane, Fe-sulphide, titanite, apatite and graphite. Characteristic, a few cm wide, nodules of columnar white calcite are interpreted as pseudomorphic after HP aragonite.

Dolomite appears to be in equilibrium with the other high-pressure minerals; some eclogites are relatively rich in carbonate, suggesting that they are para-eclogites derived from marly sediments.

Blocks of a post-metamorphic minette dyke crosscutting the eclogitic micaschists in the face above Case Chiapetti can also be sampled. The minette consists of phenocrysts of augite, phlogopite, and apatite in a groundmass of orthoclase with minor quartz and small needles of arfvedsonitic amphibole (De Marco, 1958).

The road cuts a small body of banded and deformed eclogite, which is one of several metabasics exposed in the paraschists most likely deriving from a dismembered layered complex. A similar megaboudin, c. 800 m long, exposed at Ivozio on the other side of the Valle d'Aosta, was mapped in detail by Zucali & Spalla (2011). These rocks probably derive from pre-Alpine amphibolites; this is suggested by the occurrence of colourless amphibole porphyroclasts replacing brown hornblende, which is rarely preserved as brown patches. The magmatic protolith age of such metabasics was determined to be Early Carboniferous (352 ± 8 Ma SHRIMP U–Pb zircon at Cima di Bonze; Rubatto et al. 1999); the earlier hypothesis (Venturini et al. 1994, 1996) that these metabasics are monometamorphic is thus refuted.

Interesting eclogitized rocks of a different type are exposed some hundred meters up along the road south of the river Dora Baltea. The dominant lithology is here an omphacite-glaucophane-garnet micaschist containing small eclogite boudins and layers of polycyclic marbles (Castelli, 1991; Castelli & Rubatto, 2002). Skeletal garnet and less abundant glaucophane, both of Alpine age, overgrow the hornblende. This stage of initial eclogitization in metabasics is common all over the Sesia Zone; the large amphibolite body of the Croix Corma ridge above Donnas being a clear example (Williams & Compagnoni, 1983).

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In the same outcrop (where this peculiar amphibolite to eclogite stage occurs) other rock types are found like quartz - carbonate micaschists containing small eclogitic boudins. A metamorphic leucocratic dyke, with relict igneous biotite, unconformably cuts these lithologies.
Boudins of amphibolite also occur in the marbles exposed further to the north along the suspended path, now collapsed, originally skirting the spur on which the ancient tower of Pramotton is built. Dykes of metagranitoid rocks and eclogitic micaschists are interlayered and repeatedly folded with marbles. In folded calcschist, boudins containing coarse white aggregates of columnar calcite (aragonite pseudomorphs) occur again; they may derive from veins and appear to have been in equilibrium with omphacite.

Evidence of fluid-rock interactions

In several lithotypes of this outcrop sequence, effects of fluid-rock interaction at eclogite facies conditions are prominently visible. Hydrothermal reaction fronts attesting to the infiltration of reactive HP-fluid are observed. For instance, omphacite-rich bands in calcschist are commonly rimmed by a reaction front of siderite. Glaucophane appears to have formed in several generations, and at least one common type is linked to vein formation; glaucophane replacing omphacite and the converse reaction can be observed, probably reflecting variations in the fluid composition (activity of H_2O). The localization of deformation, e.g. mylonite bands in orthogneiss layers or mineral growth in brittle/ductile mixing zones of metasediments riddled with eclogite clasts, appears to reflect variations in fluid abundance or composition (CO_2-H_2O ratio, salinity).

"Yo-Yo-tectonics"

For the part of the Sesia Zone exposed at this locality near Quincinetto, recent studies (Rubatto et al., 2011; Regis, 2012) have reported evidence of pressure cycling at eclogite-facies conditions (cf. Table 2). In these studies much emphasis was placed on samples from monocyclic rocks, but it is noteworthy that polycyclic samples from the Quincinetto locality were found to contain key evidence as well. For instance, two stages of high-pressure metamorphism interrupted by a lower pressure stage were identified petrographically and from the trace-element signatures of distinct growth-zones within zircon in a sample of eclogitic micaschist (Rubatto et al., 2011). Detailed analysis in a larger suite of samples allowed these stages to be quantified in terms of P-T conditions and to be dated by SHRIMP (U-Th-Pb spot analysis of allanite and zircon overgrowths). When integrated with the meso- and micro-structural evidence of several stages of deformation (Regis et al., 2013),

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these petrochronological results provide a very detailed account of the internal tectono-metamorphic dynamics. The present location is part of the Fondo slice (Regis et al., 2013), for which the most recent data indicate that pressure cycling involved subduction (to ~55 km, ~80-75 Ma), followed by exhumation (to ~40 km, ~75-70 Ma), and again subduction (to ~50 km, ~65 Ma ago). Thus Yo-Yo appears to have operated for at least 15 Ma (from ~80 to 65 Ma) and involved an average (vertical) rate of 2-3 mm/a. While the Fondo slice cannot at present be well delimited in the field, it should be stressed that samples showing a similar P-T-t-evolution and local evidence of cycling span an area of several km, from Valle d’Aosta to Valchiusella.

By contrast, no evidence of pressure cycling has been found in a sample suite analyzed from more internal parts of the Sesia Zone (e.g. near Mombarone: Regis, 2012). There, the onset of subduction was earlier, pressures (and temperatures) were a bit higher. Samples consistently indicate that a depth of at least 60 km was reached as early as ~85 Ma ago. Based on these data and observations, this more internal portion of the Sesia Zone is now regarded as a different tectono-metamorphic slice, termed the Druer slice (Regis et al., 2013); note that both slices are part of the Eclogitic Micaschist Complex (or, in terms of the subdivision of Babist et al., 2006, the Mombarone nappe).

Ongoing work is aiming to refine the “details” of such tectono-metamorphic slices in the Sesia Zone, in order to constrain their shape and size. Comparing the P-T-t paths for the Druer and Fondo slices with the record reported by previous studies for different areas of the EMC (e.g. Ivozio and southern Sesia Zone, Pognante 1989b; Zucali & Spalla, 2011), it is increasingly evident that the Sesia terrane as a whole is characterized by several tectonic fragments, which were independently mobile (in space and time) during the Cretaceous convergence. While many details of the kinematics in the subduction channel are still missing, the scale of tectonic mobility (at least its vertical component) and the rates of such mixing processes have been partially documented.

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STOP 2: Jadeite-bearing leucocratic orthogneiss quarry (Stop 2a) and glacial terrace with a variety of basement rocks (Stop 2b)

East of Montestrutto

Stop 2a: Jadeite-bearing leucocratic orthogneiss (trade name: "Verde Argento")

Settimo Vittone – "Argentera" Quarry

(Coord.: 45°32'25.70'' N, 7°50'40.27' E', 450 m a.s.l.)

This quarry has been opened in a ca. 10 m thick leucocratic orthogneiss layer that is thickened by m-scale parasitic folds, which are part of a large scale fold structure with a flat-lying axial plane. The fold axis trends SW across the valley, and thus the same structure is evident on the opposite flank of the valley, where a similar quarry has been opened above Tavagnasco.

These orthogneiss layers had long been considered coeval with orthogneiss bodies derived from Permian granitoids. Intrusives such as the well-known Monte Mucrone metagranitoids (Compagnoni & Maffeo, 1973; Oberhänsli et al., 1985) are widespread in the EMC (e.g. Zucali, 2011), as are the related orthogneisses. However, the orthogneisses quarried here are leucomonzogranitic in composition (see Table 3), whereas the Permian metagranitoids are granodiorites (see Table 4), and they differ in age. Liermann et al. (2002) dated two samples collected from the two mentioned quarries and obtained well-defined single zircon U-Pb discordia with upper intercepts at 435 ± 8 Ma for the Settimo Vittone sample and 396 ± 21 Ma for the Tavagnasco sample; both ages refer to the magmatic protolith.

The excavation technique and processing of "Verde Argento" are described in Fiora et al. (1999).

The leucocratic orthogneiss (Fig. 5a) consists of quartz, jadeite, K-feldspar, phengite ± minor garnet and glaucophane, with accessory Al-rich titanite, metamictic allanite, zircon, apatite, and local fluorite, Fe-sulphide and carbonate. Locally, the jadeite is surrounded by a thin retrogression corona mainly consisting of albite. This rock has been used by Tropper et al. (1999) to calibrate the jadeite- K-feldspar- quartz (KJQ) geobarometer used to determine pressure in eclogite-facies granitoids and pelites.

The orthogneiss in the quarry locally hosts narrow (mm to cm) shear bands of dark ultramylonite, with orientations parallel to the main foliation (S1/S2 composite) (Fig. 5b). These bands contain ultra-fine-grained

DOI: 10.3301/GFT.2014.02

quartz+jadeite and local pseudotachylite; the bands may reflect rapid post-seismic stress release features, as TEM studies in this high yield strength material indicate differential stresses of 0.3-0.5 GPa (Küster & Stöckhert, 1999; Trepmann & Stöckhert, 2003).

Table 3 - Major element composition (wt. %) of jadeite-bearing leucocratic orthogneiss samples from the Settimo Vittone (HPG1) and Tavagnasco quarries (HPG2) (Liermann, 1994), and from a roadside outcrop between Quincinetto and Santa Maria (SL664: Lombardo et al., 1977).

Sample	HPG1	HPG2	SL664
SiO_2	73,82	76,11	74,43
TiO_2	0,17	0,12	0,13
Al_2O_3	13,24	13,01	13,44
Fe_2O_3	0,71	0,68	0,16
FeO	0,99	0,89	1,36
MnO	0,03	0,03	0,05
MgO	0,28	0,24	0,93
CaO	0,83	0,52	0,56
Na_2O	3,22	3,31	3,38
K_2O	4,87	4,39	4,67
CO_2	0,1	0,14	n.d.
P_2O_5	0,2	0,2	0,26
H_2O	0,9	0,86	0,98
Total	99,36	100,5	100,35

Table 4 - Major element composition (wt. %) of orthogneiss and metagranitoid samples from Lilianes/Fontainemore (MEC 84) (Callegari et al., 1976, Table 1) and from Monte Mucrone (MEC97, MEC188).

Sample	MEC 84	MEC 97	MEC 188
SiO_2	64,83	66,6	66,6
TiO_2	0,76	0,58	0,56
Al_2O_3	15,81	16,31	16,4
Fe_2O_3	1,35	0,36	0,4
FeO	3,54	3,99	4,2
MnO	0,07	0,07	0,07
MgO	2,1	1,22	1,4
CaO	4,65	3,93	3,7
Na_2O	3,06	3,54	3,5
K_2O	1,51	2,15	2,7
CO_2	n.d.	n.d.	0,05
P_2O_5	0,2	0,18	0,19
H_2O	1,77	1,02	0,7
Total	99,56	99,95	100,5

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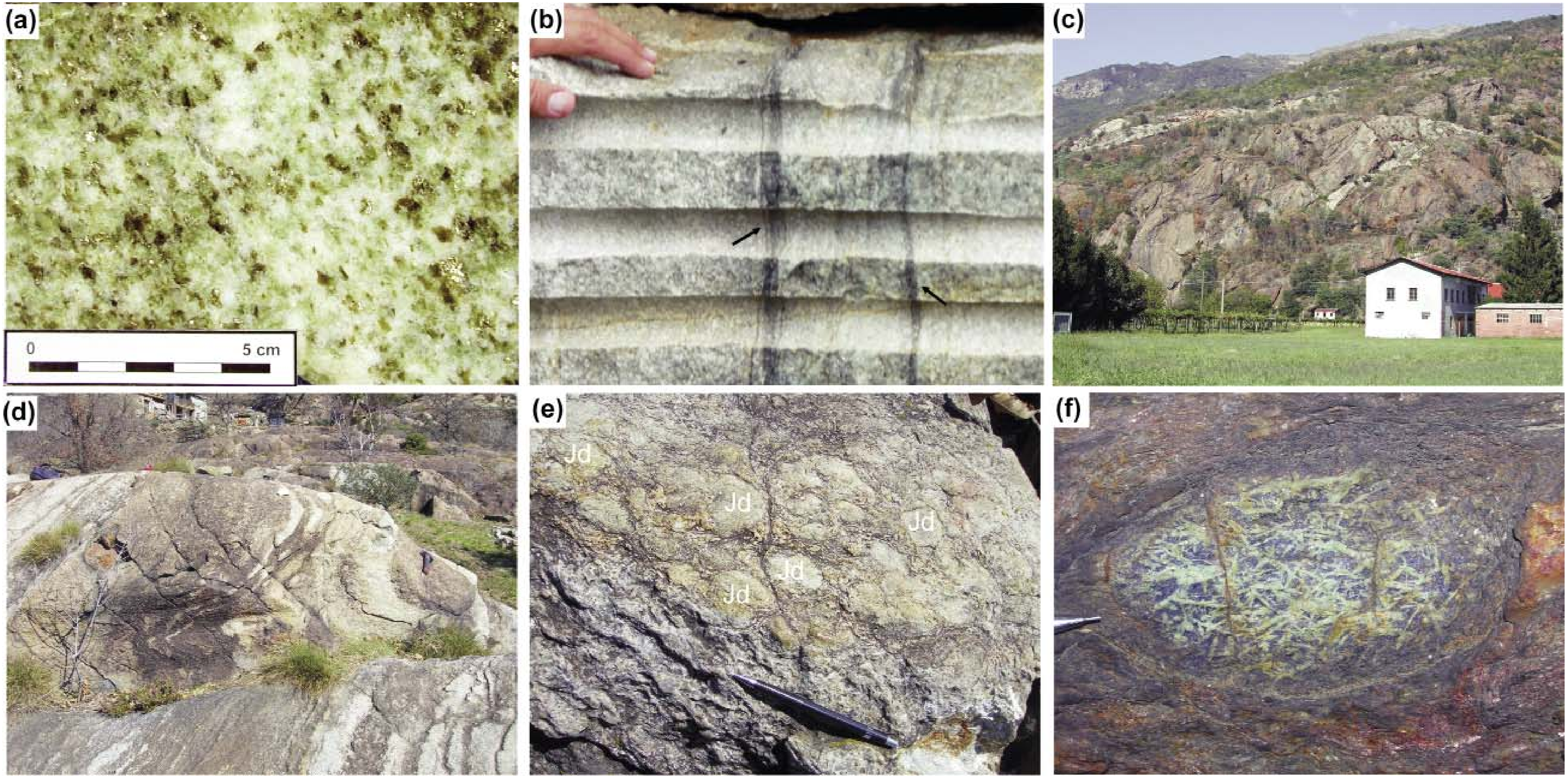

Fig. 5 – **(a, b)** Stop 2a: Jadeite-bearing leucocratic orthogneiss: **(a)** Photograph showing the typical appearance of the polished jadeite-bearing leucocratic orthogneiss; **(b)** Ultramylonite/pseudotachylite veins in the leucocratic jadeite-bearing orthogneiss. "Argentera" Quarry, Settimo Vittone; **(c, d, e, f)** Stop 2b: **(c, d)** Layers of leucocratic orthogneiss (whitish) within eclogite-facies paraschists at Montestrutto; **(e)** Detail of roundish megablasts of jadeite (Jd) in the leucocratic orthogneiss at the contact with the paraschist; **(f)** Small boudin of glaucophane eclogite within the paraschist.

DOI: 10.3301/GFT.2014.02

Stop 2b: A variety of paraschists, layers of leucocratic orthogneiss and metamorphic veins

Glacial terrace above Montestrutto
(Coord.: 45°32'17.18'' N, 7°50'38.27'' E, c. 300 m a.s.l.)

The outcrops are located near a vantage point, c. 500 m east of the village of Montestrutto. Looking west, the Fort of Bard stands prominently in the middle of the valley. To the south, the Po plain is visible in the distance; and in a few points the "roches moutonnées" of the Ivrea Zone surface at the foot of the Quaternary moraine cover (Fig. 6).

On the glacial terrace, banded lithologies prevail, consisting of eclogite-facies assemblages with garnet, Na-pyroxene (omphacite/jadeite) ± quartz ± glaucophane ± white mica (phengite and/or paragonite) ± zoisite ± carbonate and accessory rutile, apatite and zircon. The bands reflect a wide range of relative modal proportions and grain sizes. The overall lithology, which includes paraschist with small boudins of garnet omphacitite and glaucophane eclogite (Fig. 5f), dips gently westward. Isoclinal folding and transposition are responsible for the nearly parallel association of layers of leucocratic orthogneiss with darker paraschists (Fig. 5c,d). The leucocratic orthogneiss is similar in chemical composition to those described in Stop 2a. Within the thickest leucocratic orthogneiss layer, roundish megablasts of jadeite (~ Jd_{95}, ca. 5 cm across) occur, particularly close to the clear-cut contact with the paraschist (Fig. 5e). These unusual rocks resemble "metaconglomerates" because of the roundish jadeite porphyroblasts standing out on the surface. The best examples were described by Andreoli et al. (1976) from Monte Le Colme on the opposite side of the Valley, along the Valchiusella - Valle d'Aosta ridge.

A few dm-thick layers of a boudinaged jadeite + quartz + phengite rock (possibly eclogite-facies veins) with asymmetric quartz-filled pressure shadows indicate not only the sense of shear but also the amount of the finite strain. Refolded quartz veins with minor phengite, cm-long rutile prisms and local carbonate rhombohedra (several dm thick) are common, especially on the northern side of the terrace.

The paved path connecting the glacial terrace (Stop 2b) to the hamlet of Montestrutto meets the "Francigena of Sigerico Way". Since the early Middle Ages the Francigena Way has represented the route followed by pilgrims of central and northern Europe aiming to reach Rome, the seat of the Papacy. What today is known as "The Francigena of Sigerico Way" is a route some 1600 km in length. The Archbishop Sigerico in the year 990 covered 80 legs in 79 days to return to Canterbury from Rome after the investiture of the Archiepiscopal Pallium from Pope John (Giovanni) XV. In 2004 this way was declared a "Great European Cultural Itinerary" by the Council of Europe, similar to the "Walk of Santiago de Compostela" in Spain.

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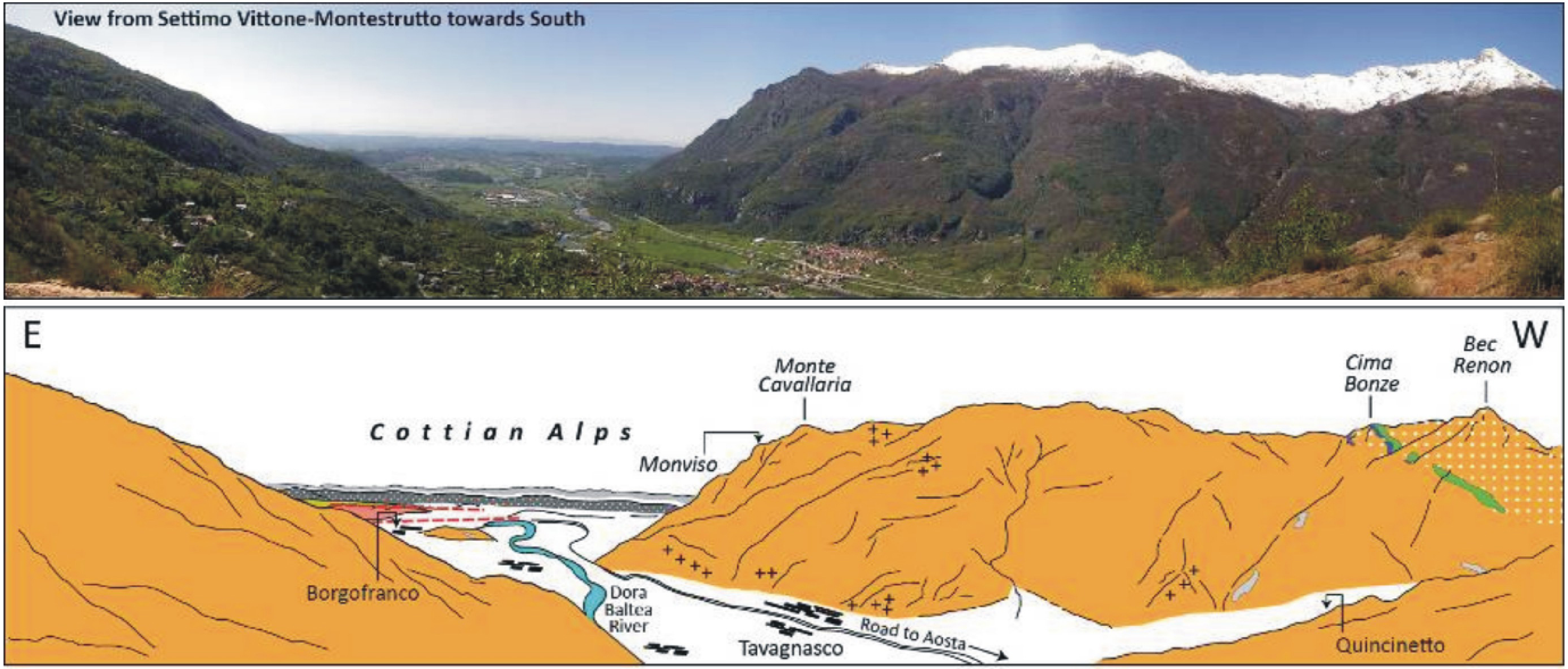

Sesia Zone

Eclogitic Micaschist Complex (EMC)
Phengite-rich schist with quartz-eclogite lenses ("eclogitic micaschist"), with major bodies of a) Orthogneiss (omp-phe-grt) and meta-aplite; b) with pervasive greenschist facies overprint

Metabasic rocks
Foliated metagabbro, glaucophane-eclogite and associated metasediments

Mesozoic metasedimentary cover (Scalaro Unit)
a) Quartzite, impure quartzite, quartz-micaschist, graphitic micaschist ± marble
b) Marble (Calcite and/or dolomite), graphite-bearing calcschist

Ivrea Zone

Canavese Zone

Piemonte Zone
(with Monviso meta-ophiolite)

Moraine (Quarternary Val d'Aosta glacier)

Insubric Line (= External/Internal Canavese Line)

Fig. 6 – Geologic view from Stop 2b towards the Valle d'Aosta outlet with the Quaternary moraine, the city of Ivrea, and the Cottian Alps in the background.

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Stop 3a: Transposed intrusive contact

Val del Lys: Fointainemore - Guillemore Gorge («Gouffre de Guillemore»)
(Coord.: 45°40'4.43'' N, 7°51'31.01'' E, c. 900 m a.s.l.)

The Gouffre de Guillemore within the Regional Nature Reserve of Mont Mars has been carved by the waters of the Lys stream into rocks of the Eclogitic Micaschist Complex of the Sesia Zone.

The polished rocks, exposed on both sides of the riverbed, show an outstanding example of a deformed intrusive contact between a most likely Permian granitoid, now a weakly foliated fine grained orthogneiss, and a polymetamorphic basement mainly consisting of paragneiss with boudins (Fig. 7a). The orthogneiss is crowded with rounded xenoliths of metabasics (Fig. 7b), now converted to fresh eclogite, most likely due to the more refractory character of mafic bodies relative to the paragneiss. A post-metamorphic Oligocene, dm-thick, andesite dyke cuts across the deformed paragneiss-granitoid contact.

Stop 3b: Deformed Permian granitoid and aplite dykes with mafic autoliths recrystallized at quartz eclogite-facies conditions, cut by post-metamorphic Oligocene andesite dykes

Val del Lys: Fontainemore - bridge across the River
(Coord: 45°38'35.78'' N, 7°51'20.63'' E, c. 730 m a.s.l.)

This outcrop, on the western side of the Lys stream, exposes a nice example of a deformed metagranodiorite, crowded with mafic autoliths (or cognate inclusions) and aplitic dykes (Figs. 7c,d). The metagranodiorite consists of the eclogite-facies assemblage quartz + omphacite + phengite aggregates + zoisite + small garnets + minor glaucophane + accessory rutile, zircon, apatite and local relict igneous allanite. The greenschist-facies retrogression is limited.

The eclogite-facies rocks are cut by undeformed andesite dykes with small plagioclase phenocrysts and visible chilled margins (Fig. 7e). In the Western Alps, such post-metamorphic intrusions, consisting of andesite and lamprophyre, crosscut the Alpine nappe pile (Dal Piaz et al., 1979). This ultrapotassic and related magmatism was probably generated by partial melting of a metasomatised mantle with some crustal contamination (see e.g. Dal Piaz et al., 1979; Venturelli et al., 1984). The age is 34-30 Ma (Krummenacher & Evernden, 1960; Carraro & Ferrara, 1968; Hunziker, 1974; Venturelli et al., 1984; Pettke et al., 1999; Owen, 2008 with ref. therein) and thus coeval with the peak of post-collisional late-Oligocene magmatism in the southern parts of the Alps (von Blanckenburg et al., 1998). Minor hydrothermal imprint with albite, chlorite and epidote replacing the eclogite assemblage is localized along sparse brittle fractures.

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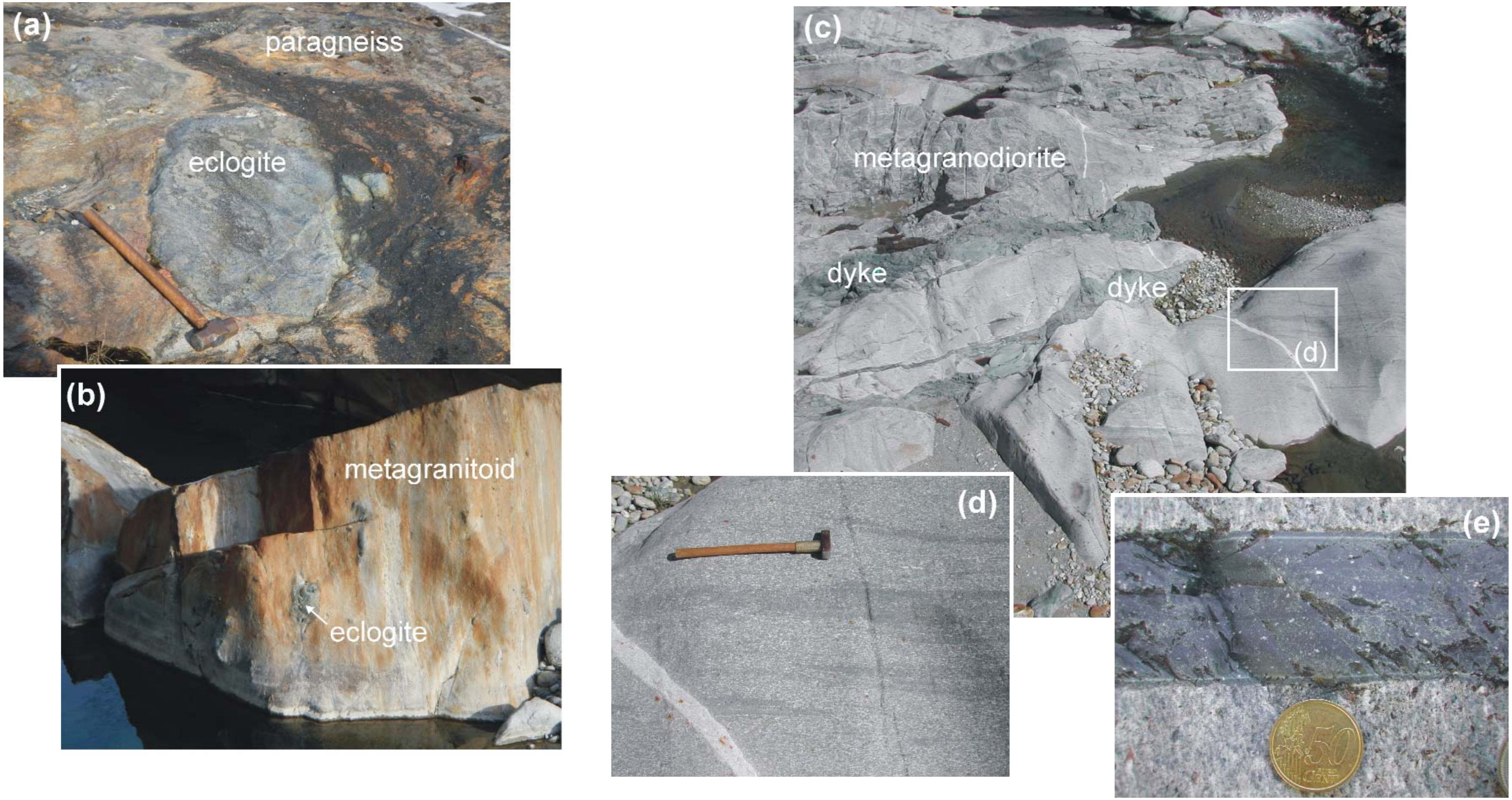

Fig. 7 – **(a, b)** Stop 3a: deformed intrusive contact between a most likely Permian granitoid, now a weakly foliated fine grained orthogneiss, and a polycyclic basement consisting of paragneiss with eclogite boudins **(a)**. The orthogneiss is crowded with rounded xenoliths of metabasics **(b)**, now converted to fresh eclogite. **(c,d,e)** Stop 3b: **(c)** Deformed metagranodiorite, crowded with eclogitized mafic autoliths and aplitic dykes. The metagranodiorite consists of the eclogite-facies assemblage quartz + omphacite + phengite. The eclogite-facies rocks are cut by undeformed post-metamorphic andesite dykes. **(d)** Detail of (c), showing the eclogitized and deformed mafic autoliths and an aplitic dyke. **(e)** Detail of an undeformed andesite dyke cutting the metagranodiorite, with small plagioclase phenocrysts and evident chilled margins.

DOI: 10.3301/GFT.2014.02

STOP 4: Pervasive late-Alpine greenschist-facies metamorphism overprinting the earlier eclogite-facies mineral assemblages

Donnas, Roman consular road to the Galliae
(Coord: 45°36’8.03” N, 7°45’40.91” E, c.320 m a.s.l.)

The excursion will stop at a famous archaeological site, where a 221 m long portion of the Roman consular road is exposed. This Cyclopean work was built to link Rome to the Rhone Valley on the northern side of the Western Alps, the Galliae (i.e. present-day France). The relic Roman road was carved out by slaves; it preserves an impressive arch, 4 metres in width and 4 metres in height, which was left to prevent a rock fall. The arch also served as a milestone on which the number 36 in Roman characters (XXXVI) indicates the distance in miles (ca. 50 km) between Donnas and Augusta Praetoria, the present-day city of Aosta. On the road pavement the furrows left by the carriages are evident. The stone bridge in the nearby Village of Pont Saint Martin, whose depressed arch spans 31 m across, is part of this Roman road and was used during the Middle Ages to cross the Lys mountain stream.

The Roman road has been dug into the most external portion of the Eclogitic Micaschist Complex of the Sesia Zone (Fig. 3), where the late Alpine greenschist-facies overprint extensively obliterated the previous eclogite-facies mineral assemblages. Among the HP mineral relics, several-cm long rutile crystals, typical of the Eclogitic Micaschist Complex, are locally preserved in quartz veins. Occasional garnet relics are preserved at the core of very Fe-rich chlorite masses, the outline of which indicates they are pseudomorphs after garnet porphyroblasts. Green amphibole laths locally retain a bluish core visible under the hand-lens.

Looking northwest, the Fortress of Bard is visible. Built in 25 BC after the Romans defeated the local Celtic population, the fortress was destroyed in 1800 by the French troops under the command of Napoleon, but rebuilt in 1827 by Carlo Felice of Savoy and remained almost intact till now as one of the best examples of early 1800 military strongholds.

At present the Fortress of Bard houses the permanent Museum of the Alps that illustrates the mountain through an interactive, multimedia and multidisciplinary journey, and temporary exhibitions and conferences. From a geological point of view, the fortress is built in the narrowest place of the Aosta Valley, on a spur corresponding to a complex fold structure (Williams & Compagnoni, 1983) where the three main complexes of the Sesia Zone join (Fig. 8b).

N.B. Collecting rock samples is not allowed at the archaeological site!

DOI: 10.3301/GFT.2014.02

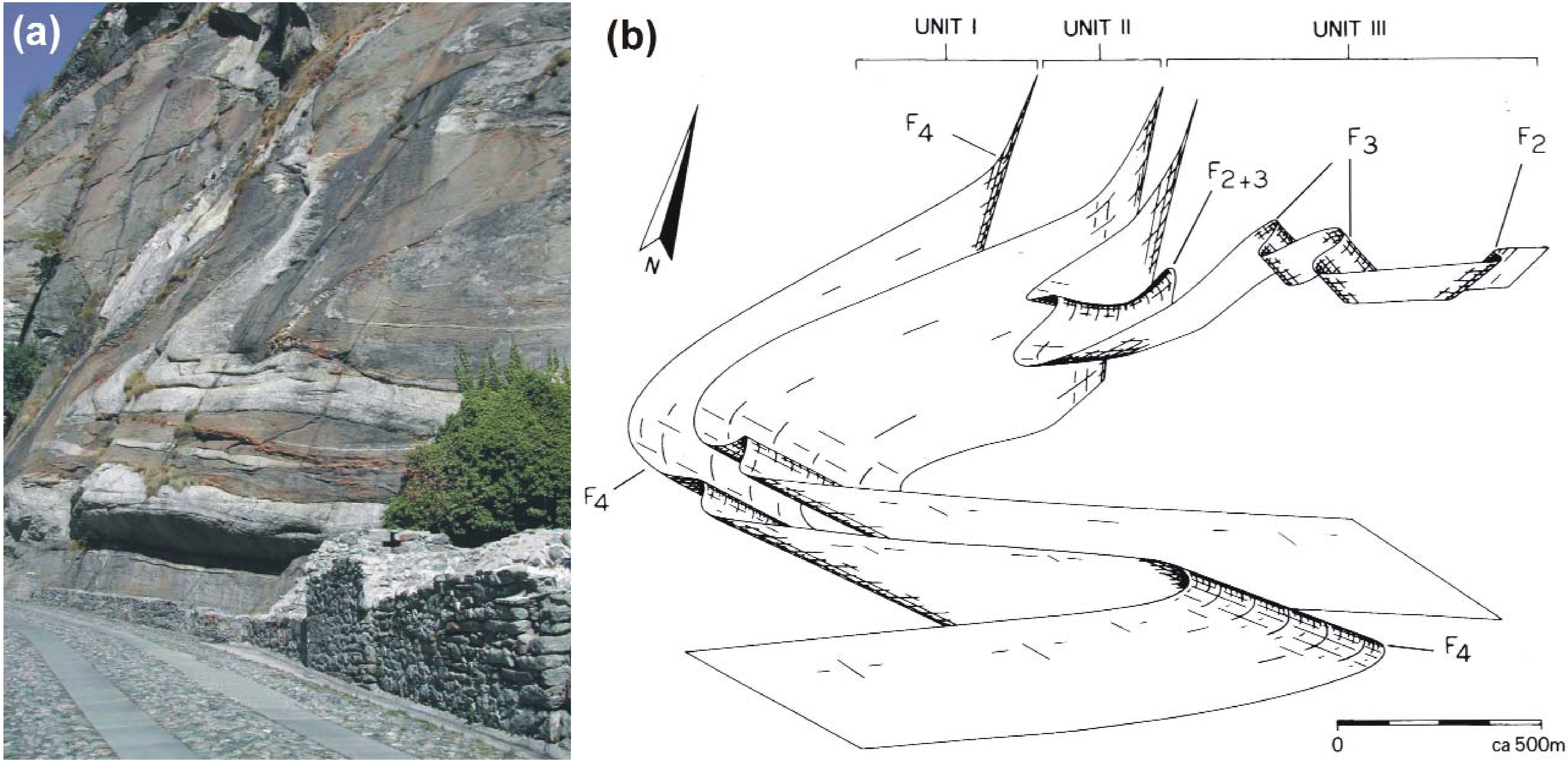

Fig. 8 – **(a)** View of the outcrops exposed along the Roman consular road at Bard, not far from Stop 4. The Roman road has been dug into the most external portion of the Eclogitic Micaschist Complex of the Sesia Zone. **(b)** Block diagram of the area of Bard, showing the F4 folds in the contacts between units I, II and III, and F2 and F3 folds within unit III (from Williams & Compagnoni, 1983, their Fig. 5). Units I, II and III correspond to the GMC, IIDK and EMC, respectively.

DOI: 10.3301/GFT.2014.02

STOP 5: Foliated serpentinite with metarodingite and forsterite + Ti-clinohumite + Mg-chlorite veins

Hillock west of the Clapey (Sappé) house
(Coord: 45°43'37.78" N, 7°40'2.56" E, c.570 m a.s.l.)

The outcrop consists of a "roche moutonnée", i.e. a roundish hill polished by the Quaternary Valle d'Aosta glacier. Upon retreat of the ice mass, a number of erratic boulders of porphyritic granites from the Mont Blanc massif remained on top.

The hillock is the northeastern tip of the large body of the Mont Avic (3006 m a.s.l.) ultramafics (see Panseri et al., 2008) that are cut by a E-W trending fault, known as the Aosta-Col de Joux-Col della Ranzola fault system (Fig. 2).

The Clapey serpentinite is a strongly foliated and crenulated antigorite rock with accessory magnetite. It contains thin layers of fine grained metamorphic olivine and diopside that includes cm- to dm-thick folded and boudinaged chloritites veins consisting of Mg-chlorite + minor magnetite ± antigorite ± forsterite ± Ti-clinohumite ± diopside ± Ni-Fe alloys ± apatite. This mineral assemblage formed during Alpine eclogite-facies metamorphism. Microscopic examination of these veins indicates that at least two olivine and Ti-clinohumite generations may be recognized: (i) porphyroclasts up to several cm across with wavy extinction, subgrain and mortar microstructure (Figs. 9a,b), and (ii) fine grained granoblasts derived from porphyroclast recrystallization (Figs. 9a,b). Olivine and Ti-clinohumite porphyroclasts show dusty patches rich in fluid inclusions and opaque phases. Locally olivine porphyroclasts include an internal foliation (Si) that is defined by diopside needles.

On the top of the hillock, a folded and boudinaged rodingite, 20-30 cm thick, is discontinuously exposed within the hosting serpentinites. The rodingite formed by metasomatism of an original basaltic dyke during peridotite serpentinization. The rodingite is fine grained and mainly contains a pinkish grossular-rich garnet and diopside with Mg-chlorite concentrated at the dyke selvages. From a careful examination of the outcrop it is evident that, where the metasomatic process completely dissolved the rodingite, only selvages of Mg-chlorite ± forsterite and Ti-clinohumite are preserved. Since the fresh lherzolites contain only a small amount of titanium (c. 0.2 wt.%), the Ti necessary for the growth of the abundant Ti-clinohumite must derive from basaltic (or gabbroic) dykes originally intruding the peridotite. A similar scenario has been proposed by Scambelluri et al. (1991) for the olivine-Ti-clinohumite bearing chloritite veins of the Ligurian Voltri Group.

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DOI: 10.3301/GFT.2014.02

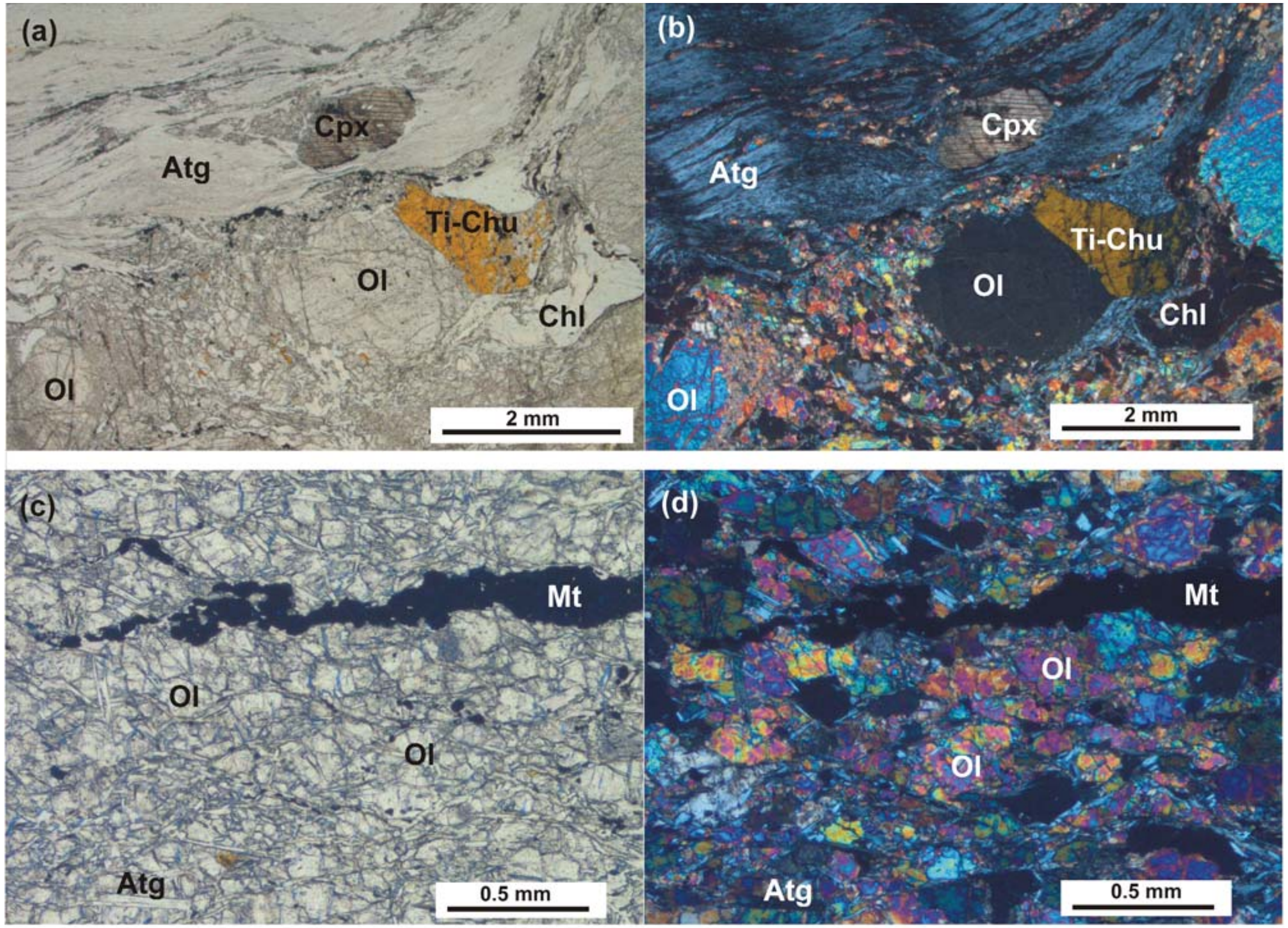

Fig. 9 – **(a,b)** Sheared antigorite serpentinite with transposed vein of coarse-grained forsterite + Ti-clinohumite (+ diopside + magnetite + Mg-chlorite + antigorite ± Fe-Ni alloys). Note in the top center a relict of the peridotitic clinopyroxene. **(a)** PPL, **(b)** XPL (Sample OF 270).
(c,d) Ultramafic rock interlayered with the antigorite serpentinite consisting of forsterite, magnetite and antigorite ± Ti-clinohumite. The rock foliation is marked by the alignments of the magnetite aggregates and the olivine preferred dimensional orientation. **(c)** PPL, **(d)** XPL (Sample OF 272).

Going back to the Clapey house and following southward the Roman road, serpentinites show a sub-vertical banding with more massive layers of "dunitic" composition. They consist of fine-grained olivine, minor antigorite and magnetite, and rare Ti-clinohumite. The foliation is defined by antigorite flakes, magnetite aggregates (Fig. 9c), and by the dimensional preferred orientation of fine-grained olivine derived from recrystallization of porphyroclasts (Fig. 9d). Relics of the original peridotite are rare and consist of small clinopyroxene porphyroclasts and lens-like magnetite + chlorite pseudomorphs after the original Cr-spinel. The preservation of these relics indicates that the rock derives from an original mantle lherzolite. Furthermore, the occurrence of the "dunitic" layers and in particular the inclusions of magnetite in the metamorphic olivine indicates that the lherzolite was in part at least already serpentinized prior to the Alpine eclogite-facies metamorphism.

DOI: 10.3301/GFT.2014.02

The contact with metabasic rocks is exposed a few tens of m southwards along the Roman road. These metabasics, on which the Saint Germain (or Montjovet) castle is built, derive from metamorphic recrystallization of original ophiolitic basalts. The banded, dark green albite-epidote amphibolites are partly re-equilibrated eclogites, consisting of omphacite + garnet, and accessory interstitial quartz, rutile and apatite. The amphibolite main foliation is defined by lineated relict of pale glaucophane that is rimmed with dark green amphibole, clinozoisite, minor chlorite and accessory titanite. Albite only occurs with green amphibole as medium grained symplectites after omphacite, indicating a static Na-pyroxene replacement. On the basis of the mineral microstructural relationships three Alpine metamorphic stages may be recognized, as summarized in Table 5.

Minerals	Stage I	Stage II	Stage III	Vein stage
Omphacite	▬▬▬			
Garnet	▬▬▬			
Rutile	▬▬▬	▬▬▬		
Quartz	▬▬▬			
Apatite	▬▬▬			
Glaucophane		▬▬▬		
White mica		▬▬▬		
Clinozoisite		▬▬▬		
Green amphibole			▬▬▬	
Albite			▬▬▬	▬▬▬
Titanite			▬▬▬	
Chlorite			▬▬▬	▬▬▬
Carbonate				▬▬▬
Opaque ores (Ilm and/or Mt)			▬▬▬	

Table 5 - Alpine metamorphic stages recorded in the Saint Germain albite-epidote amphibolite with relict eclogite-facies assemblages.

Please, do not collect samples on the top of the hillock where ice polished rocks were exposed about 10'000 years ago at the end of the last glaciation!

Acknowledgements

The Authors are very grateful to Gisella Rebay and Chiara Groppo for their careful editing and expert advice.

DOI: 10.3301/GFT.2014.02

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