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GARNET PERIDOTITES, PYROXENITES AND MIGMATITES FROM THE ULTEN ZONE: A TRIBUTE TO LAURO MORTEN

by

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1. Introduction

The Ulten Zone (UZ) is an Alpine area where crust-mantle interaction can be observed because of the exhumation of subducted crust incorporating slices of mantle wedge. For this reason, in the last decade the UZ has been the subject of several petrologic studies with the aim to unravel its metamorphic and geodynamic evolution; particular attention has been paid to crust-to-mantle mass transfer.
The location of this field trip (Fig. 1) is "Le Maddalene" mountain range that marks the boundary between the Ulten and the Non valleys (Trentino Alto Adige/South Tyrol district, northern Italy).

The aim is to show the field relations between crustal and mantle rocks of the northeastern UZ. This guide has been subdivided into two parts: the first part (sections 2 to 5) summarizes the current petrological knowledge on the UZ, and the second part (section 6) presents the field trip focused on the Seefeld Alm area. This field trip can be considered the updated re-proposal of a field excursion entitled "Garnet-websterites and Garnet-pyroxenite lenses within garnet peridotites and country rocks from Seefeld Alm area (Ultental)" (MARTIN et al., 1993) performed in the framework of the IV International Eclogite Conference held in 1993 and convened by Lauro Morten (1941-2006). One of the reasons of this 2007 edition of the field trip is a tribute to his memory and to his remarkable research activity in this area.

2. Geological Overview

The UZ (ANDREATTA, 1935, 1948) forms the uppermost unit of the Upper Austroalpine domain, a nappe pile of Cretaceous age (THÖNI, 1981) consisting of metasedimentary cover and upper to lower crust units. These units derived from the Mesozoic passive margin of the Adria microplate (paleo-Africa; DAL PIAZ, 1993).

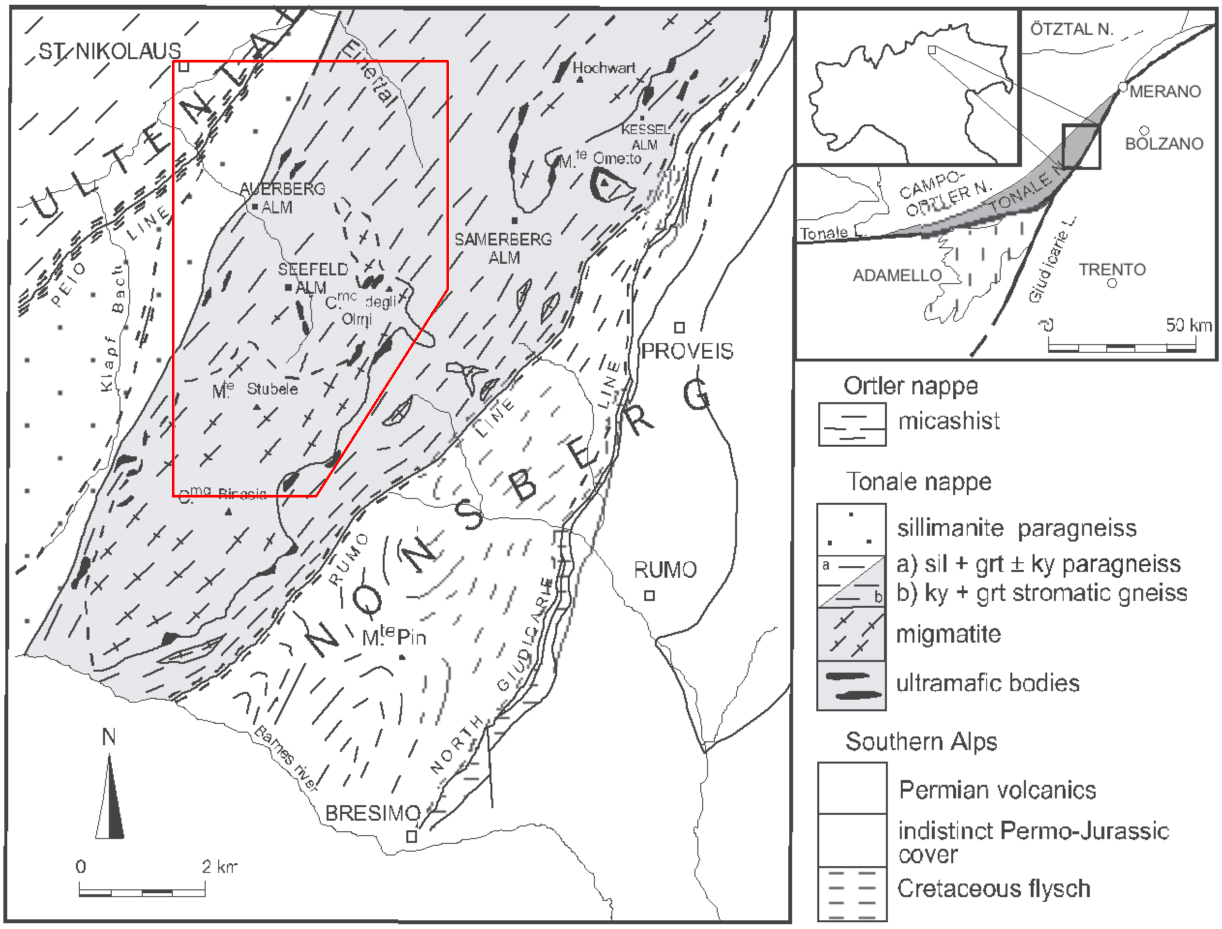


Fig. 1

Geological sketch map of the Ulten Zone (modified after DEL MORO et al., 1999). The red area refers to the portion of the Ulten Zone visited during the field trip.

The UZ belongs to the Tonale nappe that is separated to the North from the Ortler-Campo nappe by the Peio Line (ANDREATTA, 1948), a Late Cretaceous sinistral transtensive fault (MARTIN et al., 1991; MÜLLER et al., 2001). To the South the portion of the Periadriatic fault system known as Giudicarie Line marks the tectonic contact between the Tonale nappe and the South-alpine domain. The Tonale nappe is traditionally subdivided into the Tonale Zone and the UZ, which are separated by the Val Clapa Line and Rumo Line (MORTEN et al., 1976), a NE-trending extensional fault of Paleocene age (MÜLLER et al., 2001). The Tonale Zone is formed mainly of sillimanite-bearing metasediments, metagranitoids and minor marbles, calc-silicates and mafic intercalations affected by retrograde metamorphism during the late stages of the Variscan orogeny. In addition, records of Alpine greenschist facies signature are locally recognizable (THÖNI, 1981). The UZ is mainly composed of migmatites, garnet-kyanite gneisses and subordinate meta-granitoids. Barrel-shaped lenses (metric to hectometric in length) of amphibolitised spinel ± garnet peridotites are generally located between the garnet-kyanite gneiss and the overlying migmatites. Boudins of mafic amphibolites and rare retrogressed eclogites also occur. Unlike the Tonale Zone, the UZ shows well-preserved pre-Alpine high-grade metamorphic signatures, only weakly over-printed by Alpine metamorphism (OBATA & MORTEN, 1987; MARTIN et al., 1994, 1998; GODARD et al., 1996).

3. Rock types and metamorphic evolution of the Ulten Zone

Both crustal and mantle rocks from UZ have been widely described in several papers. Here we report the relevant petrographic and geochemical features and the reader interested in more petrographic details can refer to the papers reported below.

3.1 Peridotites

The UZ ultramafics are peridotites of harzburgitic to lherzolitic composition (BONDI et al., 1992). On the basis of grain size they have been subdivided into two groups: coarse and fine types, with the former considered as the protolith of the latter (see section 3.4; OBATA & MORTEN, 1987; MORTEN & TROMMSDORFF, 2003).

The (uncommon) coarse type peridotites show protogranular texture (sensu MERCIER & NICOLAS, 1975) with a grain size up to 5 mm (Fig. 2a). The assemblage consists of large (up to 5 mm), kinked olivine and enstatite and smaller diopside and Cr-Al-spinel. The latter occurs disseminated in the rock matrix, as exsolutions in pyroxenes and intergrowth with enstatite. In few coarse samples with porphyroclastic texture, pyrope-rich garnet surrounds brown to reddish brown spinel (Fig. 2c-d). In addition, garnet may appear also as exsolution lamellae in pyroxenes.

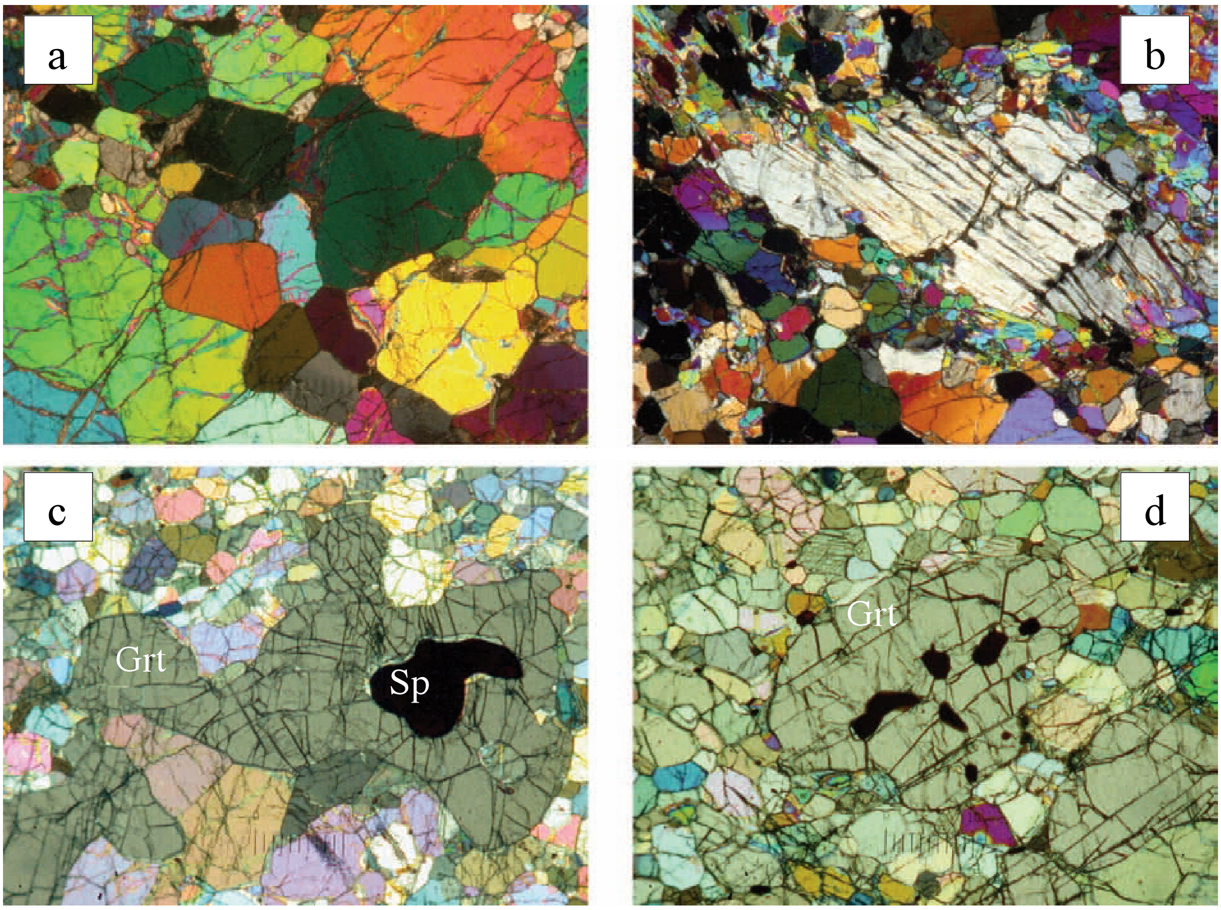


Fig. 2

Textural features of the Ulten Zone peridotites. Field of view: 4 mm. (a) Coarse-grained, protogranular texture of spinel-peridotite; crossed nicols. (b) Large exsolved orthopyroxene in an inequigranular matrix; crossed nicols. (c) Anhedral garnet (Grt) porphyroclast with an inclusion of dark-brown spinel (Sp); partly crossed nicols. (d) Garnet porphyroclast, with spinel inclusions, set in a polygonal matrix composed of olivine, orthopyroxene and amphibole; Partly crossed nicols.

The (common) fine type peridotites show porphyroclastic (Fig. 2b-d) to tabular or mosaic granoblastic textures and have grain size less than 1 mm. They are mainly spinel ± garnet harzburgites characterised by high modal amounts of amphibole (up to 23 vol%, RAMPONE & MORTEN, 2001). Olivine and orthopyroxene grains in the granoblastic aggregates do not show signs of deformation such as undulating extinction. Amphibole is colourless or pale to brownish green. Generally, amphibole shows an evident zonation: cores are generally pargasite or Mg-hornblende, whereas rims are tremolite-rich. Large dolomite grains rarely occur (OBATA & MORTEN, 1987; MORTEN & TROMMSDORFF, 2003; SAPIENZA et al., in prep.).
Among the fine type peridotites there are also chlorite- and phlogopite-bearing peridotites. Chlorite-bearing peridotites (Fig. 3a) consist of olivine, orthopyroxene, amphibole, chlorite and spinel relics included in chlorite porphyroblasts. Olivine is present as porphyroclast relics or as medium-sized crystals, sometimes arranged in mosaic polygonal textures. Orthopyroxene occurs either as smaller crystals or as kinked porphyroclast relics. Two amphibole types have been recognised: euhedral pargasite in textural equilibrium with olivine and orthopyroxene, and elongated crystals of tremolite, often associated to chlorite to form aggregates. Chlorite has been found in different textural sites, either as isolated and oriented crystals in the matrix or as medium-sized (3-4 mm) porphyroblasts including spinel relics (MAROCCHI & HERMANN, 2007).
Phlogopite-rich layers (Fig. 3b) occur at the peridotite-migmatite and peridotite-pyroxenite contacts. In both cases, phlogopite extends to few tens of centimetres into the peridotite. The orientation of the phlogopite flakes is concordant to the lithological contacts.

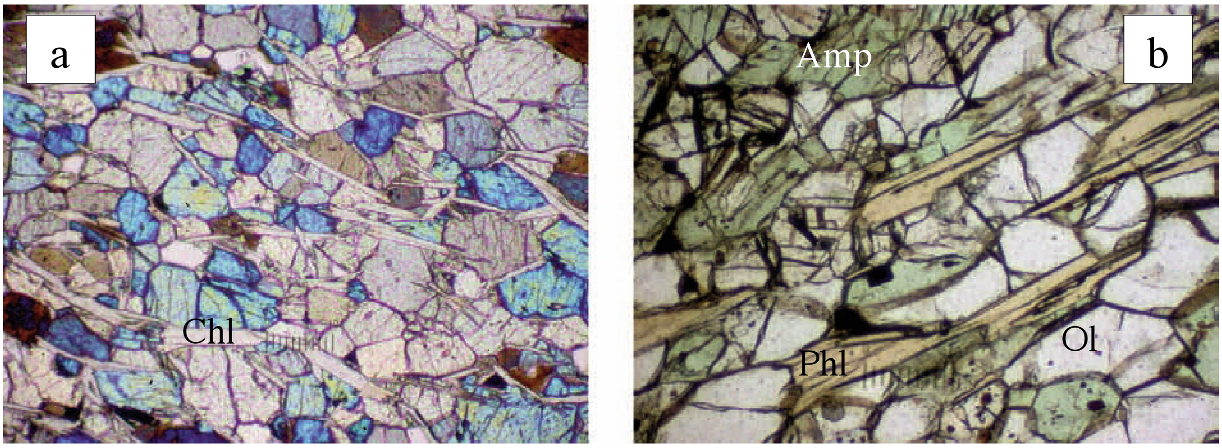


Fig. 3
Textural features of hydrated, fine-grained peridotites. Field of view: 1.25 mm. (a) Chlorite (Chl) lamellae, showing a preferred orientation, in a granoblastic matric consisting of amphibole and olivine; partly crossed nicols. (b) Fine-grained peridotite sampled at the contact with migmatitic country rocks. The foliation is outlined by the preferred orientation of light-brown phlogopite (Phl). Green-amphibole (Amp) and colourless olivine form the rock matrix; plane polarised light.

3.2 Pyroxenites
Dykes and dykelets of garnet-amphibole websterite and garnet-amphibole clinopyroxenite locally cut the peridotite lenses (MORTEN & OBATA, 1983). The mineral assemblage of the websterite consists of clinopyroxene, orthopyroxene and garnet megacrysts (up to 6 cm; Fig. 4a), dispersed in an equigranular mosaic matrix composed of orthopyroxene, clinopyroxene, tschermakitic amphibole, garnet and brown Cr-Al-spinel.

The assemblage of clinopyroxenite consists of diopside, Mg-hornblende, pyrope-rich garnet and accessory amounts of ilmenite. According to MORTEN & OBATA (1983) and NIMIS & MORTEN (2000), the UZ pyroxenites originated as intrusion of hydrous mantle-derived magmas into the mantle wedge spinel peridotites. These igneous intrusions eventually underwent a metamorphic equilibration into garnet-facies conditions together with the host peridotites.

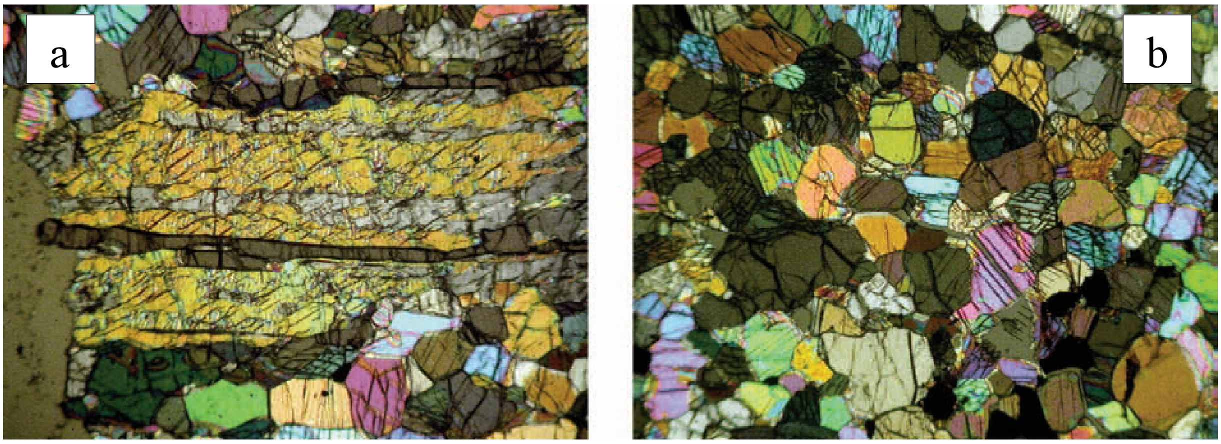


Fig. 4
Textural features of a garnet-websterite sample. Field of view: 4 mm. (a) porphyroclast consisting of clinopyroxene (yellow), orthopyroxene (light-grey) and garnet (dark-grey) in a polygonal amphibole-bearing matrix; partly crossed nicols. (b) View of a fine-grained portion of the garnet-websterite. Crossed nicols.

3.3 Garnet-kyanite gneiss, migmatite and orthogneiss

The garnet-kyanite gneisses (Fig. 5a-b), which underlie the peridotite level, generally display large garnet and kyanite grains (up to several centimetres) set in a foliated matrix defined by the alternation of millimetre-to-centimetre thick quartz-feldspatic layers with mica-rich films. The quartz-feldspatic layers consist of aggregates of quartz + albitic plagioclase ± orthoclase-rich alkali feldspar. Aggregates of biotite ± white mica form the mica-rich foliation. The more deformed samples display the finer grain size, lower white mica modal amounts and quartz ribbons with undulose extinction. Rutile may be found as inclusion in all the major rock-forming minerals as well as disseminated in the quartz-feldspatic matrix. Apatite, monazite, zircon and graphite are present in trace modal amounts.

Migmatites (DEL MORO et al., 1999), which overlie the peridotite layer, are mainly diatexites (i.e. a variety of migmatite with schlieren and nebulitic structures where the pre-migmatization features are not visible). Observations at the microscope reveal that the texture of the migmatite consists of fine-grained, inequigranular aggregates of quartz + plagioclase ± alkali-feldpar (all with irregular grain boundaries) alternating with biotite layers containing anhedral garnet and kyanite. Locally, quartz ribbons with undulose extinction are present. Figure 5c shows a melanocratic diatexite: the leucocratic domains consist of aggregates of quartz + albitic plagioclase + (minor) orthoclase-rich alkali-feldspar, whereas biotite, garnet, kyanite, white mica and rutile form the melanocratic portions. Zircon, apatite and monazite are in accessory amounts. Within the migmatites, rare melanocratic garnet-rich rocks (garnet ~ 90 vol%) with minor amounts of interstitial kyanite quartz and biotite occur (Fig. 5d). Accessory minerals such as plagioclase, rutile, amphibole and sulphides are also present (BARGOSSI et al., 2003). These rock have been interpreted as residua after the extraction of partial melts that gave origin to the migmatites.

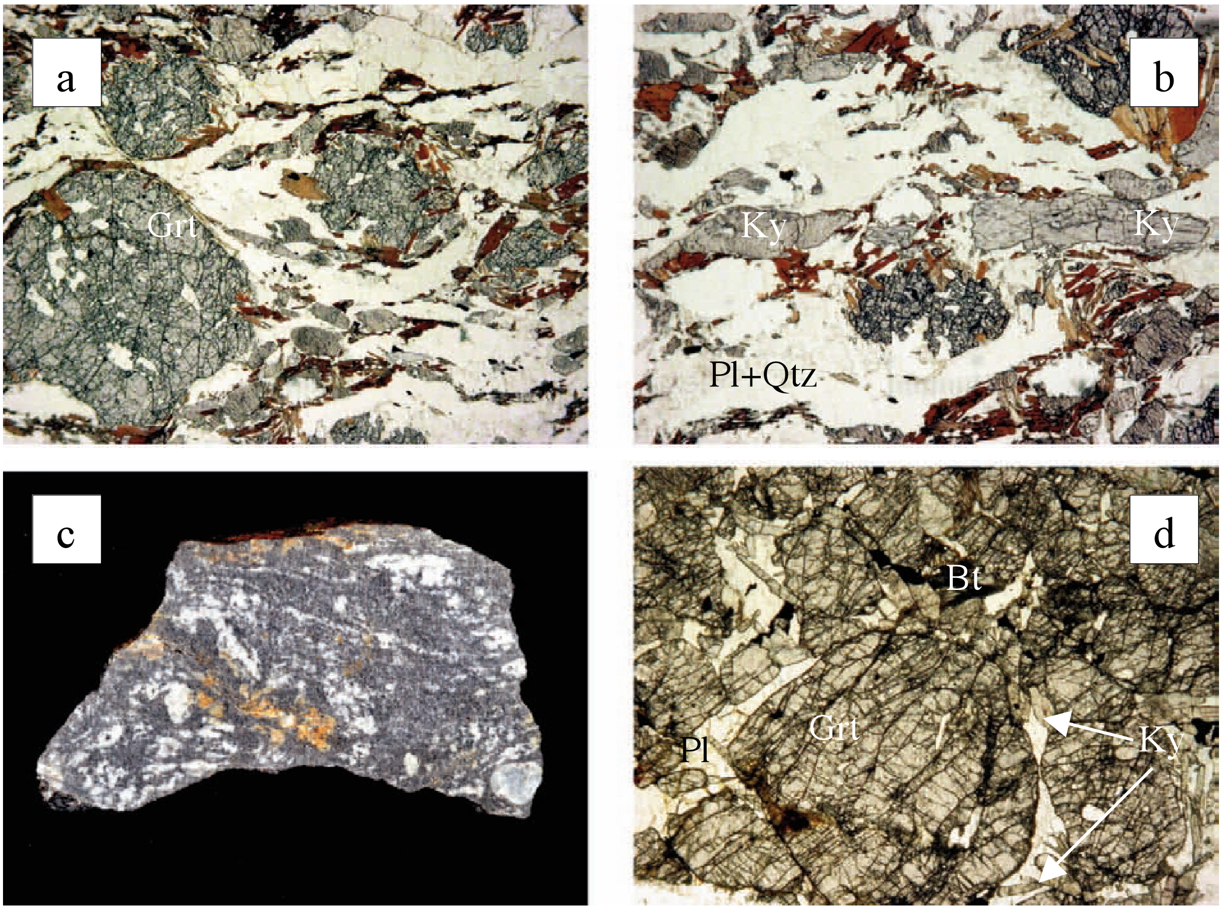


Fig. 5
(a) Large rounded garnets with quartz inclusions from a garnet-kyanite gneiss. Field of view: 4 mm. (b) Deformed kyanite aligned along the foliation. Field of view: 4 mm. (c) Scan of a polished saw cut of a melanocratic diatexite. Field of view: about 20 cm. (d) Large garnets and interstitial plagioclase, kyanite and biotite form a restitic gneiss. Field of view: 4 mm.

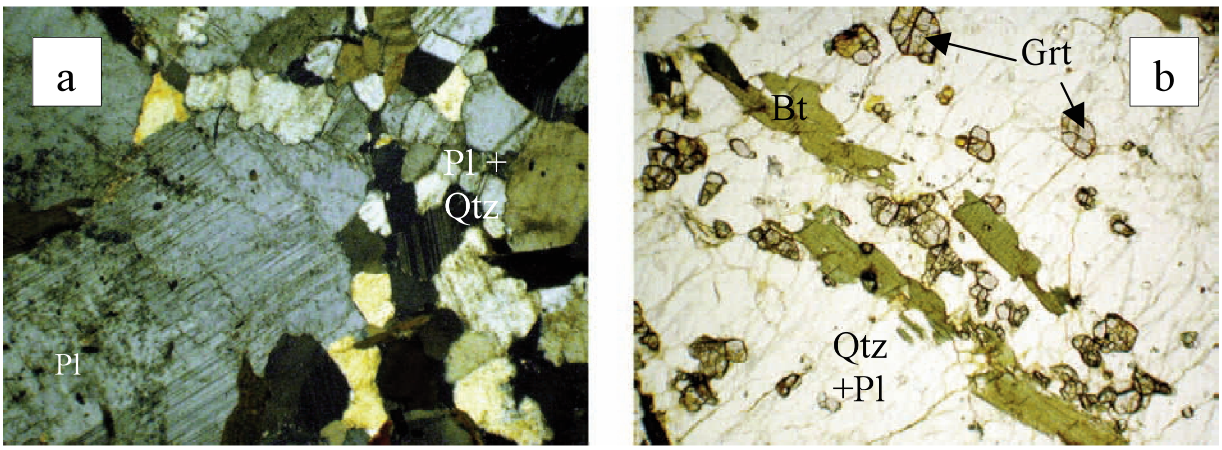


Fig. 6
(a) Garnet-free orthogneiss: plagioclase porphyroclast in a quartzo-feldpsatic matrix consisting of inequigranular grains with irregular boundaries. Crossed nicols. Field of view: 2 mm. (b) Garnet-bearing orthogneiss: aligned green biotite (Bt) and rounded garnet in a quartz-rich matrix. Plain polarised light. Field of view: 2 mm.

Orthogneisses are present as concordant intercalations within gneisses and migmatites. They show a variety of textures, mineral paragenesis and grain sizes. On textural and mineralogical grounds, we define two orthogneiss types: the first type is garnet-free and shows a porphyroclastic texture characterised by the presence of large (several mm across) anhedral quartz and plagioclase (Fig. 6a) set in an inequigranular matrix composed mainly of quartz and plagioclase. Interstitial brown biotite occurs in minor modal amounts. Rutile and white mica are accessory phases. The second orthogneiss type is garnet-bearing (Fig. 6b) and aggregates of quartz, plagioclase and alkali-feldspar (both perthitic/antiperthitic and microcline) form a granoblastic texture. Biotite, zircon and white mica are accessory phases.

3.4 Pressure-temperature-time evolution

Figure 7 shows the pressure(P)-temperature(T)-time(t) path of the UZ basement. Several P-T estimates are available for the peridotites (OBATA & MORTEN, 1987; GODARD et al., 1996; NIMIS & MORTEN, 2000; TUMIATI et al., 2003) that are believed to record the whole (i.e. prograde and retrograde evolution) metamorphic history of the UZ basement. By contrast, the P-T estimates of the crustal rocks (GODARD et al., 1996; HAUZENBERGER et al., 1996; TUMIATI et al., 2003) are thought to record only retrograde metamorphic stages. Recently, preliminary investigations by BRAGA et al. (2006) argues for the presence of mineralogical relics of an early (prograde) amphibolite-facies stage preserved in large kyanite and garnet grains from the gneisses.

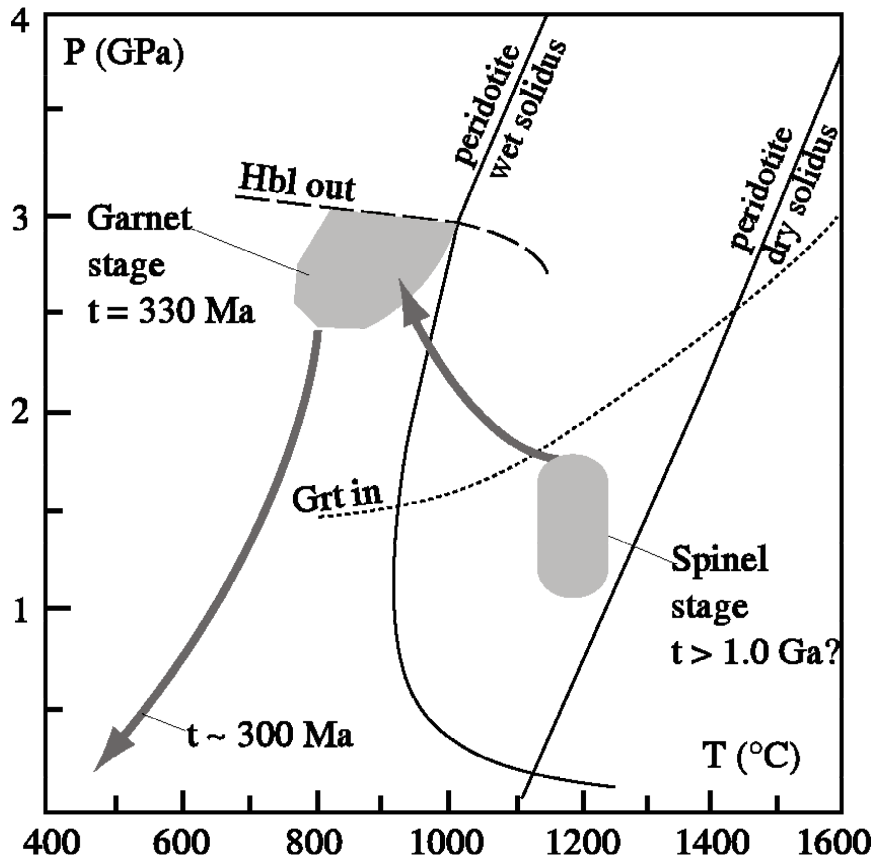


Fig. 7
Summary of the pressure-temperature-time evolution of the Ulten Zone peridotites (modified form SCAMBELLURI et al. 2006). The inferred age of 1.0 Ga is from PETRINI & MORTEN (1993). Radiometric data for the garnet-stage equilibration (330 Ma, Sm-Nd) and the retrogression under amphibole-facies conditions (300 Ma, Rb/Sr white mica age) are from TUMIATI et al (2003) and HAUZENBERGER et al (1993), respectively.

The oldest metamorphic stage is represented by the coarse-grained, protogranular spinel peridotites that equilibrated under high-T conditions (~ 1200°C). The age of this early metamorphic stage is not well constrained; however, Sm/Nd dating of coarse type peridotites (and minerals thereof) led PETRINI & MORTEN (1993) to propose a Mesoproterozoic age of ~ 1.0 Ga.
The transition from spinel- to garnet-facies (through the intermediate stage characterised by the coexistence of garnet + spinel) follows a path consisting of pressure increase (up to 2.5-2.8 GPa) and concomitant temperature decrease (800-1000°C). The pressure peak under garnet-facies conditions occurred at ~ 330 Ma (TUMIATI et al., 2003). According to these Authors, the crustal anatexis (producing the UZ diatexites) and, possibly, the insertion of peridotite blobs into the crust, occurred simultaneously at the Carboniferous pressure peak. The age of the retrogression towards amphibolite-facies conditions is constrained at ~ 300 Ma by Rb-Sr cooling ages of white micas separated from the UZ gneisses (HAUZENBERGER et al., 1993).

4. Metasomatic history of the Ulten Zone peridotites

The transformation from coarse type spinel peridotite to fine type garnet peridotite was accompanied by abundant crystallisation of amphibole, chlorite and, locally, of dolomite and apatite (OBATA &MORTEN, 1987; SAPIENZA et al., in prep.). In addition, field observations show the presence of phlogopite-rich layers in the peridotite lenses in contact with enclosing crustal rocks and pyroxenitic dykes. These observations coupled with whole-rock enrichment of Light Rare Earth Elements (LREE) and some Large Ion Lithophile Element (LILE) (e.g. K and Sr) relative to the primitive mantle indicate that the UZ peridotites record significant metasomatic processes (MORTEN & OBATA, 1990).
Recent studies of the trace element composition of minerals revealed that the Ulten peridotites underwent a complex multi-stage metasomatic history. An early metasomatic event led to LREE and LILE enrichment in spinel-peridotites and in the porphyroclastic orthopyroxene of the chlorite-peridotite (SCAMBELLURI et al., 2006; MAROCCHI & HERMANN, 2007). However, its age (pre-Variscan?) is still matter of debate. This old metasomatism has been interpreted to reflect interaction of percolating melts (possibly slab-derived) with the overlying wedge peridotites at temperatures of ~1200°C and P ~1.5 GPa (SCAMBELLURI et al., 2006). A second metasomatic event occurred at much lower temperatures (~850°C) but higher pressures (~2.7 GPa) as documented by the onset of amphibole crystallisation at the transition from anhydrous spinel peridotites to hydrous garnet-amphibole peridotites. The metasomatic agent was likely an aqueous fluid related to the partial melting of the subducted continental crust (SCAMBELLURI et al., 2006). Slab-derived melts interacted with the ambient peridotite and evolved through orthopyroxene fractionations. The residual liquid after the orthopyroxene fractionation, now enriched in H_2O, LREE and LILE components, moved upward and interacted with the overhanging mantle wedge, triggering the crystallisation of hydrous minerals.
A mineral trace-element study of the chlorite-amphibole peridotites reveals the evolution of the metasomatic fluid. The trace element characteristics of early formed hornblende (i.e. LREE and LILE enrichment, marked Ba and Pb positive anomalies) indicate that the metasomatic agent contained high amounts of fluid-mobile elements. Conversely, late tremolite shows significantly lower LILE and LREE contents than the hornblende. Thus, tremolite most likely formed from a "diluted" aqueous fluid (MAROCCHI & HERMANN, 2007).

5. Geodynamic interpretations

During the decades of research on the UZ, various geodynamic models have been put forward to explain the occurrence of mantle peridotites into crustal rocks. Recently, two geodynamic models have been proposed by NIMIS & MORTEN (2000) (successively modified by TUMIATI et al., 2003 and SCAMBELLURI et al., 2006) and by RANALLI et al. (2005).

NIMIS & MORTEN (2000) reconstructed the P-T path of the UZ peridotites, proposing that mantle domains, belonging to the innermost portion of a mantle wedge overlying a subducting continental slab (Fig. 8), produced hydrous melts that percolated into the overlying, high-T spinel lherzolites (~ 1200°C, 1.3-1.6 GPa). These melts gave origin to the pyroxenites segregates. Convection induced by the movement of the subducting plate caused wedge peridotites to cool, while flowing towards the slab at essentially constant depth (isobaric cooling path). Then, the mantle material was driven to greater depth by the downward flow near the wedge-slab interface (T-decrease and P-increase path) and was eventually incorporated in the crust as tectonic slices or as sinking blobs. The depth of the insertion of mantle material into the crustal slab is a matter of debate. The radiometric work by TUMIATI et al. (2003) demonstrates that the HP metamorphism of the peridotites is coeval with the crustal anatexis, supporting the idea that peridotite slivers were entrained into the crustal slab at peak conditions or during the first stage of exhumation.

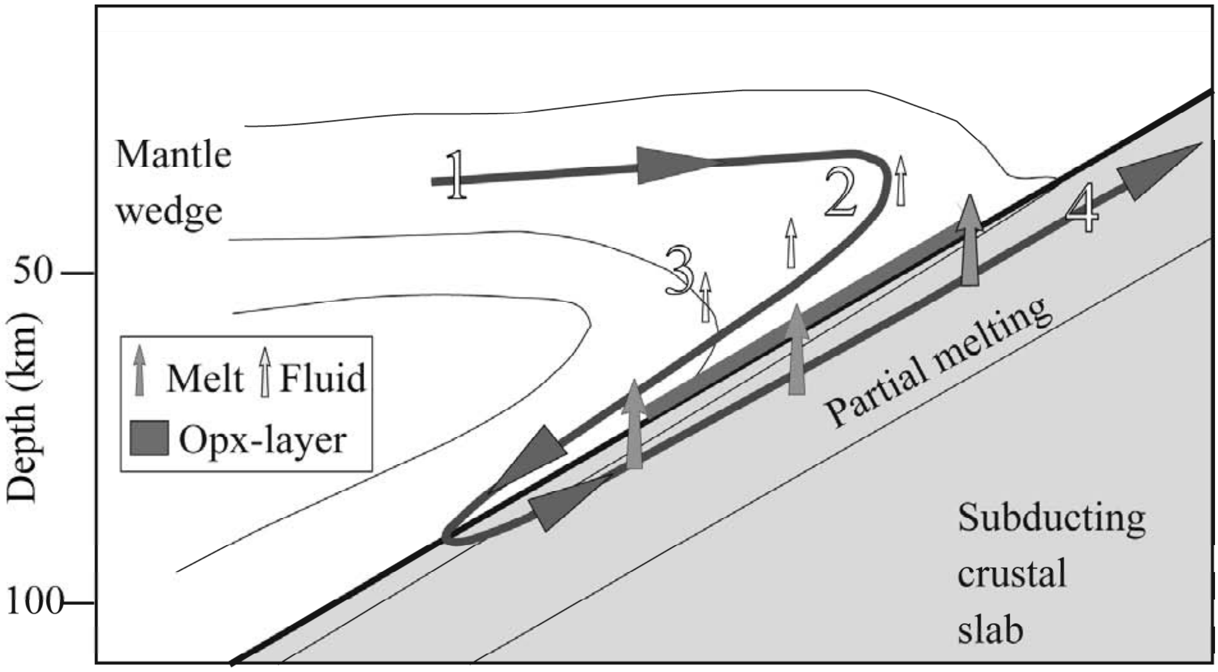


Fig. 8

Geodynamic model modified from SCAMBELLURI et al (2006). Spinel-facies mantle wedge peridotites (1) were intruded by mantle-derived melts that gave origin to the pyroxenite dykes. These mantle portions were entrained into wedge corner flow that buried the peridotites at depths consistent with garnet stability (2). Crustal melts emanated from the subducting slab interacted with the adiacent mantle. This interaction produced the crystallisation of an orthopyroxene-rich layer (dark grey box). Large orthopyroxene porphyroclasts are considered as relics of this layer. The orthopyroxene crystallisation left a residual liquid enriched in LILE and H_2O. This liquid infiltrated and enriched the garnet-peridotite still residing in the mantle wedge (3). The metasomatised garnet-peridotites were finally entrained into the crustal slab dduring the exhumation process (4).

This implies that garnet-facies peridotite interacted with siliceous, crustal-derived melts. SCAMBELLURI et al. (2006), however, argued that the mantle-siliceous melt interaction would have promoted - within the peridotite - abundant orthopyroxene crystallisation at garnet-facies conditions. Rather, slab-derived fluids percolating the overhanging mantle wedge better explain the widespread presence of hydrous minerals. Therefore, SCAMBELLURI et al. (2006) suggested that the insertion of mantle material occurred during crustal exhumation and not during peak metamorphism.
The model proposed by RANALLI et al. (2005) is based on petrological and geophysical calculations. These Authors suggests that, after the emplacement of peridotites into the crust as envisaged by NIMIS & MORTEN (2000), the exhumation and cooling of the garnet peridotites were due to two-stage extrusion of the Ulten crustal slice along the subduction channel during ongoing subduction of the slab (Fig. 9). A first (fast) stage was driven by the upward buoyancy of crustal material, a second (slow) stage was related to slab break-off with consequent lithospheric extension. The model favors the entrapment of the peridotites into the crust at peak metamorphic conditions but does not account for any further incorporation of mantle rocks slices during exhumation.

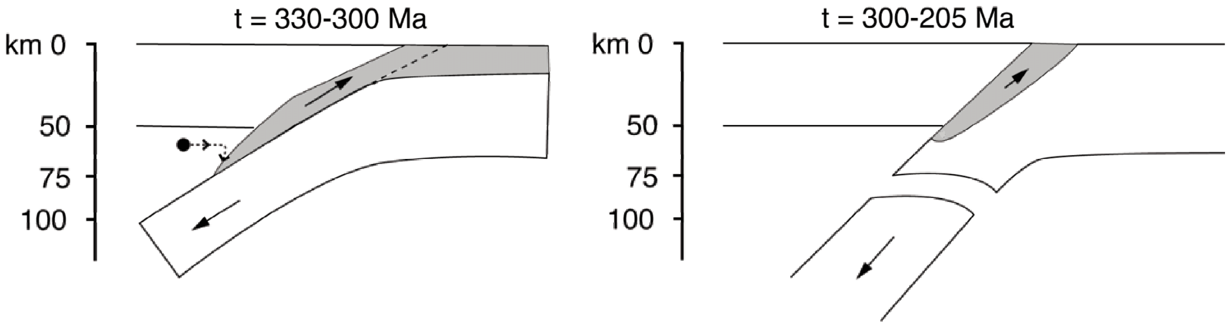


Fig. 9
Geodynamic model modified from RANALLI et al (2005). Mantle wedge peridotites (black dot) were entrained into the crustal slab at 330 Ma under peak metamorphic conditions. Between 330 and 300 Ma a first stage of fast, buoyancy-driven exhumation of a crustal slice occurred during continuing subduction. The second exhumation stage (t < 300 Ma) was slow, probably as a response of slab break-off and the end of subduction.

6. Field trip itinerary

Figure 10 shows the field trip itinerary. The excursion will follow both marked footpath and unmarked track on debris deposits (especially around the Seefeldjoch/Passo Lavazzè area). The height gain during the trip is about 500 m, similar as the height loss. Thus, the field trip may be physically demanding. Proper training and equipment (mountains boots are compulsory, warm and waterproof clothes, gloves, sunglasses and solar protection) for alpine conditions are required. The Tabacco topographic map 1:25000 “Val d’Ultimo/Ultental” (sheet 042) may be useful.
Departure from Meran to Sankt Nikolaus (Ulten) and Auerberg Alm using the 4-wheeldrive vehicles provided by the Geological Survey of the Autonome Provinz Bozen Südtirol. We will take the forest road that climbs up the Auerbergtal, we will reach the Auerberg Alm. Here, we will start walking along the footpath n. 18 (red-white marks) up to the Seefeld Alm-Seefeldsee area (about 2100 m).

After the stop n. 3, we will take an ill-marked track and go up to the Seefeldjoch/Passo Lavazzè (2344 m, the field trip's highest point) where we will be at the boundary between the Ulten (South Tyrol district) and Non valleys (Trentino district). We will start to go down the southern slopes of the Seefeldspitz/Cima della Siromba mount. Loose blocks on the track require attention. The track will intersect the footpath n. 133 where we will go westward to Malga Masa Murada (2046 m) and then southward on the footpath n. 134. After the last stop (few hundreds meters south of Malga Masa Murada) we will follow the footpath n. 134 to Malga Lavazzè (1639 m). Here, a car service will take the participants back to Meran, end of the field trip.

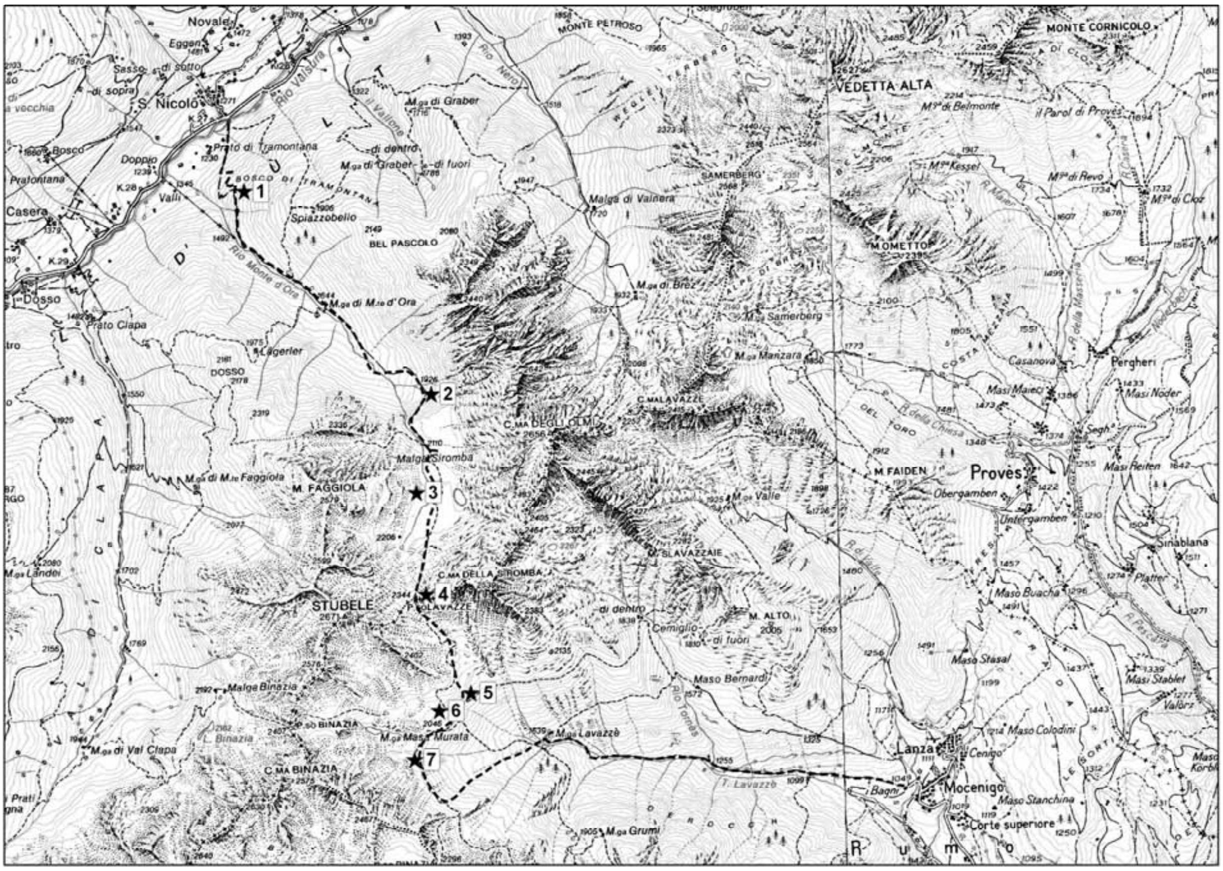


Fig. 10
Field trip itinerary (dashed black line) with stop locations.

Stop1 – Along the forest road from Sankt Nikolaus to Auerberg Alm (1400 m)
Target: Tectonic contact, relative to the Peio fault, between the Ortler and Tonale nappes.
In this area, the Ortler basement consists of mylonitic paragneiss (Fig. 11a), locally intercalated with quartzites (Fig. 11b, not visible at the stop) and leucocratic mylonitic orthogneiss (Fig. 11c), with a sub-horizontal foliation. This foliation is verticalized and dismembered by several sets of fractures. Locally, subvertical dm-width shear zones (badly exposed) and fault drags (Fig. 11d) reveal the tectonic movements along the Peio fault.

Stop2 – Along the footpath from Auerberg Alm to Seefeld Alm (N46°29'09 E10°56'90, 1990 m)
Target: Ulten Zone Gneiss

Massive, fine- to medium-grained gneiss outcrops along the footpath n.18 displaying the characteristic reddish alteration colour. These rocks represent the Ulten Zone country rocks geometrically below the peridotite-bearing zone. On a fresh surface the gneiss shows a high modal amounts of biotite that forms mm-thick layers alternating with quartz-feldspatic levels. Garnet porphyroclasts also occur.

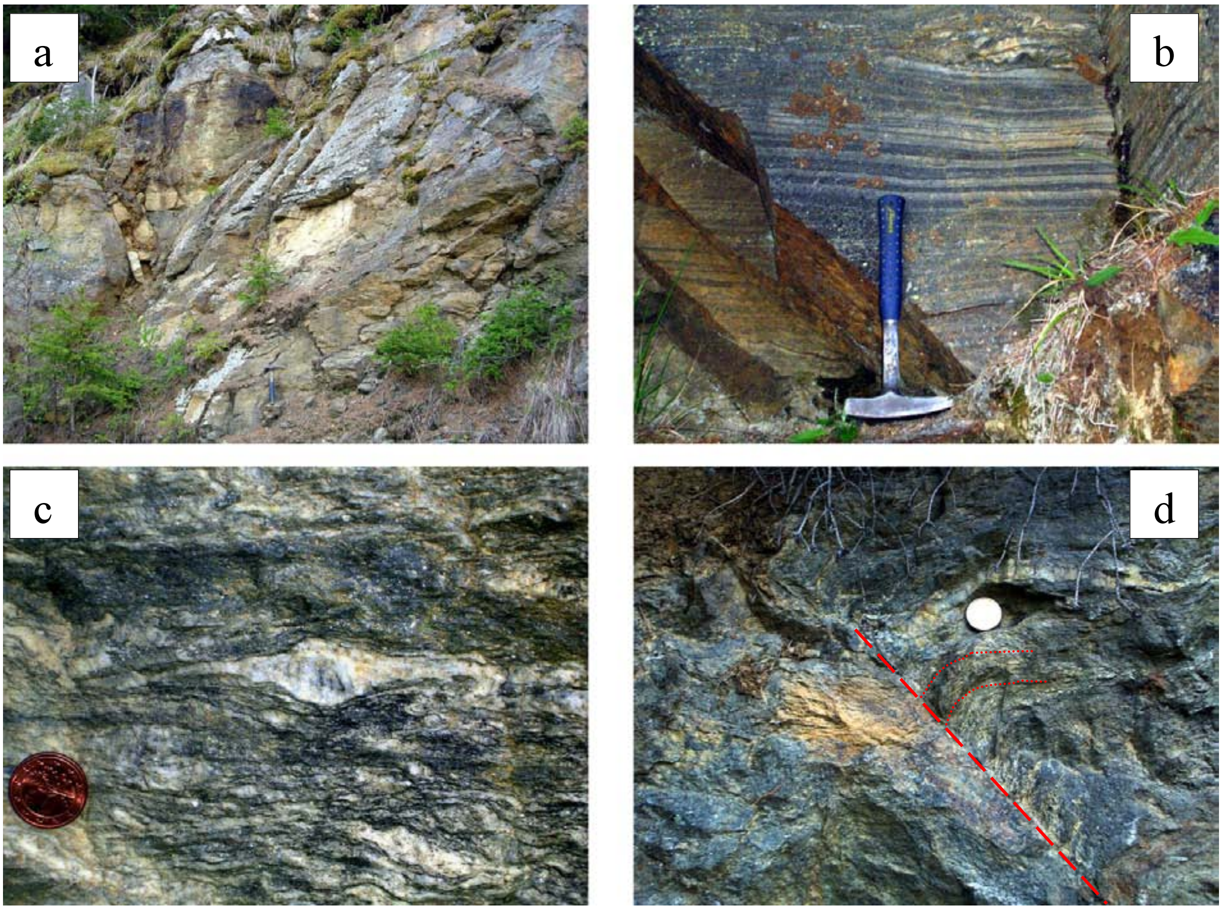


Fig. 11
(a) Mylonitic paragneiss of the Ortler nappe. The deformation is associated with the activity of the late-Cretaceous Peio fault. (b) Foliation defined by alternating quartzite and micascist layers (observable along the foothpath n.18, which cut the forest road, at 1470 m). (c) porphyroclast consisting of aggregate of alkali-feldspar and mafic minerals in mylonitic gneiss intercalated within the micaschists. (d) Fault drag in micaschist: deflection of mineralogical layering adjacent to a fault.

Stop3 – West of Seefeld Lake (N46°28'66 E10°56'85, 2200 m)
Target: Garnet-pyroxenites intruded in garnet+spinel peridotites
The outcrop (Fig. 12), a few meters-high cliffs west of the Seefeld Lake, shows light-brown peridotite cut by a 10 to 40 cm-thick green websterite dyke (Fig. 13a), which shows a late fracture cleavage oriented at high angle with respect to the lithological contact. The peridotite is medium-grained (grain size ~ 1 mm) and the preferred orientation of mineral defines the foliation. On a fresh cut the peridotite is dark-coloured: dull-green olivine (± light-brown orthopyroxene) is visible in a dark grey matrix composed of amphibole. Green clinopyroxene and dark red garnet may be found as isolated coarse grains or forming rounded aggregates of 1-2 cm diameter (Fig.

13b). Phlogopite flakes (Fig. 13c) form a 40 cm-thick band occurring at 50 cm below the websterite-peridotite contact. The green websterite shows megacrysts (several centimetres across, Fig. 13d) made of an intergrowth of clinopyroxene, orthopyroxene and garnet set in a medium- to coarse-grained matrix of orthopyroxene + clinopyroxene II + pargasitic amphibole + garnet ± spinel. On a fresh surface it is easy to recognise green emerald clinopyroxene, light brown orthopyroxene, dark green amphibole and red garnet. With the aid of a hand lens it is possible to observe that the matrix minerals are equigranular and form a mosaic texture.
Another decametric peridotite lens crops out some 50 m N of the above site. Here a leucocratic, igneous-textured dyke (possibly a trondhjemitic dyke) is located between the overlying peridotite and the stromatic gneiss. In the dyke, the modal abundance of biotite increases toward the contact with the stromatic gneiss.

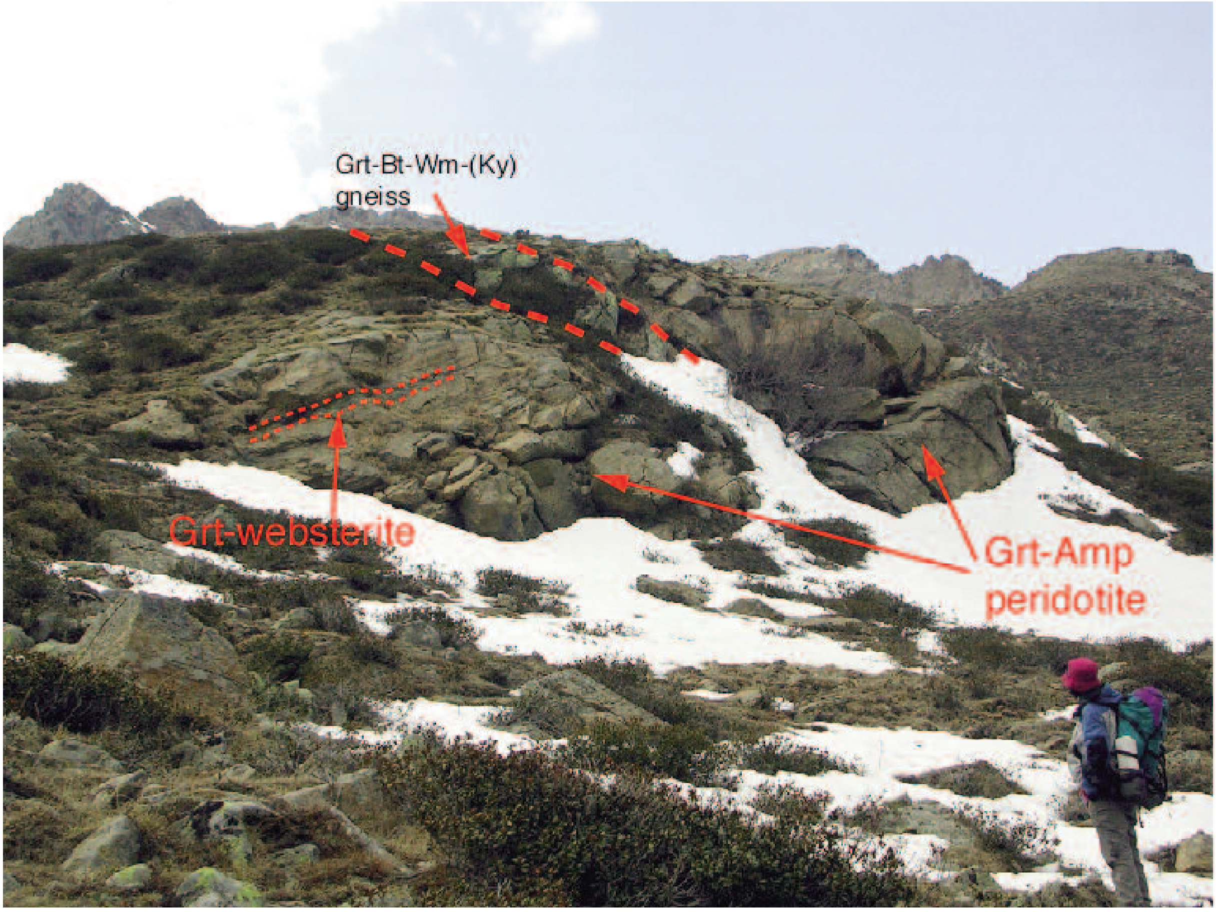
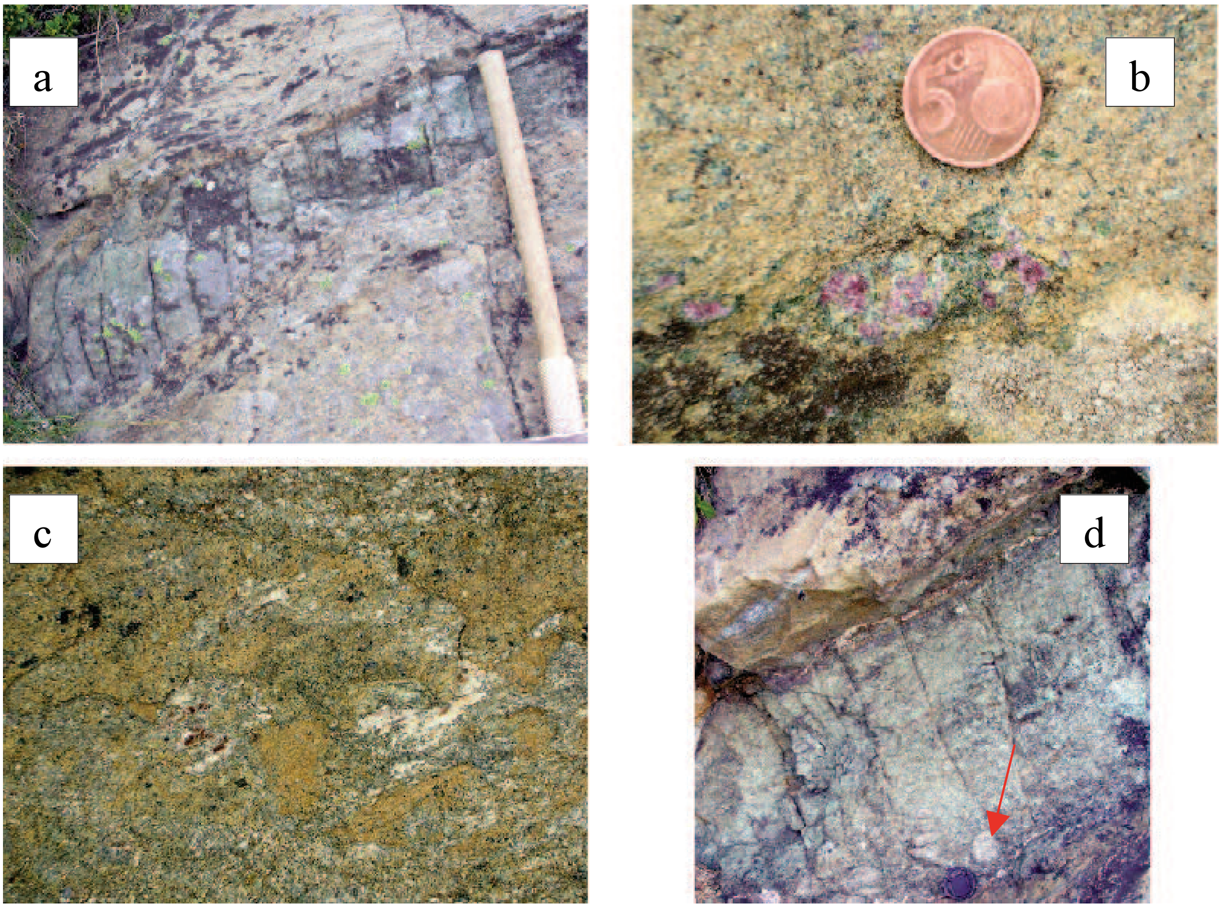


Fig. 12
Overview of the outcrop relative to the Stop 3.

next page:
Fig. 13
(a) Garnet-websterite dyke (greenish) intruded in the garnet-amphibole peridotite. The dyke is concordant to the peridotite foliation. (b) Rounded aggregate of green clinopyroxene and garnet in the peridotite. (c) Phlogopite-bearing domain of the peridotite. Field of view: about 25 cm. (d) Large porphyroclast (arrow) in garnet-websterite.



Stop4 – Lavazzè/Seefeld Pass (2344 m)
Target: Garnet-kyanite stromatic migmatites
At Lavazzè/Seefeld Pass (2344 m) we have the panoramic view of the Ulten Valley (to the north) and the Non Valley (to the south). The mountain peaks at both side of the pass (Stubele and Siromba/Seefeld Spitz) consist of migmatites that can be observed at the pass where stromatic structures are clearly visible. During the way down, loose blocks throughout the area and along the track provide evidence of migmatite structures such the melanocratic stromatic-textured diatexites (Fig. 14b).

Stop5 – Along the footpath n. 133 toward Masa Murada (N46°27'55 E10°57'32, 2040 m)
Target: Contact between amphibole peridotite and mylonitic migmatite
The decametre-long outcrop shows the contact between peridotite (rocks at the footpath level with a light-brown altered surface) and the overlying migmatite (with a reddish altered surface). At hand sample the medium-grained (~ 1mm on average) peridotite shows a modal composition dominated by olivine (dull green), orthopyroxene (light brown) and amphibole (dark grey). A phlogopite-rich layer occurs in the peridotite towards the contact with the overlying migmatite. Very rare dark-red garnet and green clinopyroxene are present. The evident sampling traces indicate the site where a large orthopyroxene porphyroclast occurred. The peridotite foliation is outlined by the shape-preferred orientation of olivine and orthopyroxene grains. This foliation is parallel to that of the surroundings migmatites. The overlying mylonitic migmatite shows a foliation defined by alternating leucocratic and biotite-rich mm-thick layers.

Fig. 14
(a) Panoramic view from the Passo Lavazzè/Seefeldjoch towards the Aubergtal. The loose blocks of the debris covering the slope provide the opportunity to observe the mesoscopic structures of migmatites. (b) Example of stromatic diatexite.

This layering is locally folded and cut by late pegmatoid dykelets. Dull-red garnet porphyroclasts (generally with diameter < 1 mm) occur within the mica-rich layers of the migmatite.

Stop6 – Along the footpath n. 133 near Masa Murada (N 46°27'55 E 10° 57'09, 2070 m)
Target: Contact between garnet amphibolite and leucocratic diatexite.
Melanocratic mafic amphibolite shows a paragenesis consisting of black amphibole + plagioclase + biotite + garnet ± quartz (Fig. 16a). Ilmenite, titanite and epidote minerals are in accessory amounts. Locally, a mineralogical layering defined by alternating mafic- and plagioclase-rich

levels is observable. The leucocratic diatexites are massive and displays biotite- and quartz-feldspatic-rich domains. The amphibolite-diatexite contact is irregular: leucocratic quartz-feldspatic pockets intrude the amphibolite along the mineralogical layering (Fig. 16b). In addition, amphibolite enclaves may be found within the leucocratic pockets.

Fig. 15
Contact between amphibole-bearing peridotite and migmatite at Stop 5 along the footpath n. 133.

Stop7 – Along the footpath from Masa Murada to Malga Lavazzè (2020 m)
Target: Volcanic porphyritic dyke intruding the garnet-kyanite gneiss.
Following the footpath n.134 down to Malga Lavazzè, a m-width light grey, EW trending dyke cut at low angle the foliation of the garnet-kyanite gneiss cropping out at ground level. The dyke is a medium- to fine-grained rock with hornblende and plagioclase phenocrysts. No chilled margins have been observed. Major-element data reveals a basaltic-andesite composition. To the W, near the Poinella lake at about 2180 m, dykes of similar composition contains gabbroic and granodioritic xenoliths (several cm in diameter) as well as rare garnet-bearing ultramafic xenoliths. No radiometric age is available for this igneous event. However, on the basis of similarities with andesitic dykes of the Ortlel nappe, MARTIN et al. (1993) inferred an Oligocene igneous age.

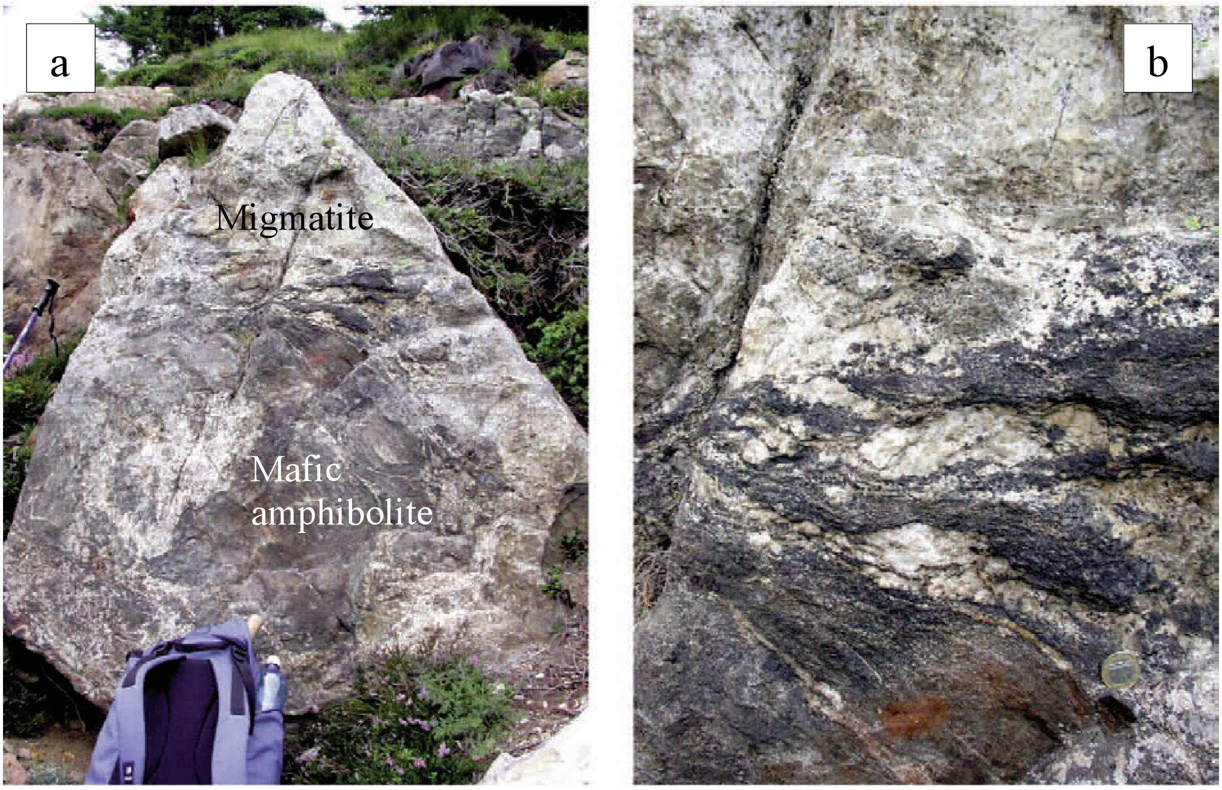


Fig. 16
(a) Contact between mafic amphibolite (dark grey) and leucocratic migmatite. (b) Particular of the lithological contact with leucocratic pockets intruding the mafic amphibolite along foliation planes.

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