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Eclogite facies metamorphism and deformation of the middle Adula nappe (Central Alps, Switzerland): Excursion to Trescolmen

by *Christian Meyre*[1] and *Martin Frey*[1]

Abstract

The Penninic Adula nappe (Central Alps, Switzerland) experienced a regional high-pressure metamorphism of Eocene age. This high-pressure metamorphism reached blueschist facies conditions in the northern part and eclogite facies conditions in the middle and the southern part of the nappe. The Alpine history of the Adula nappe is characterized by five deformation phases that can be especially well observed in the northern and the middle Adula nappe. The locality of Trescolmen (middle Adula nappe) is best suited to investigate this tectono-metamorphic evolution: An impressive number of beautiful outcrops of mafic lenses and metapelites reveals eclogite facies assemblages and their relationship to Alpine deformation.

Keywords: blueschist facies, eclogite facies, tectono-metamorphic evolution, field excursion, Trescolmen, Adula nappe, Central Alps.

Introduction

For a general introduction of the Central Alps and the Adula/Cima Lunga complex, the reader is referred to the excursion guide of PFIFFNER and TROMMSDORFF (this issue).

The geology of Trescolmen

The locality Trescolmen is situated in the structurally upper part of the middle Adula nappe (Fig. 1). The cirque of Trescolmen is mainly embedded in a zone of metapelitic schists with a thickness of about 500 m. Within this zone, stretched layers (boudinage) of metabasaltic rocks are abundant. The metapelitic zone is surrounded by phengite-bearing orthogneisses (sometimes with augen) and paragneisses with a well developed foliation. Rare quartzitic and dolomitic metasediments ("internal Mesozoic" of FRISCHKNECHT, 1923) occur as lenses. A simplified geological map of Trescolmen is shown in figure 2.

The metamorphic and tectonic evolution of the middle Adula nappe at Trescolmen

The high-pressure metamorphism in the Adula nappe / Cima Lunga unit (Fig. 1) is characterized by a general increase in grade from the north (blueschist facies conditions, i.e. 450–550 °C, 10–13 kbar at Vals) to the south (very high-P conditions, i.e. 750–900 °C, 18–35 kbar at Alpe Arami, HEINRICH, 1986) and was followed by exhumation under amphibolite and greenschist facies conditions. This second metamorphic event caused a severe overprint in all lithologies except for the mafic lenses, which locally show fresh eclogite assemblages (i.e. Grt + Omp ± Ky ± Am ± Pg + Qtz) in their cores. Geochemical investigations on metabasic lenses of the Adula nappe (SANTINI, 1991) coherently reveal basaltic protoliths with oceanic origin and tholeiitic affinity. Some samples of SANTINI (1991) can be classified as MORB, while others show a trend from transitional to enriched MORB. Radiometric age dating (e.g. BECKER, 1993; GEBAUER, 1996) and structural in-

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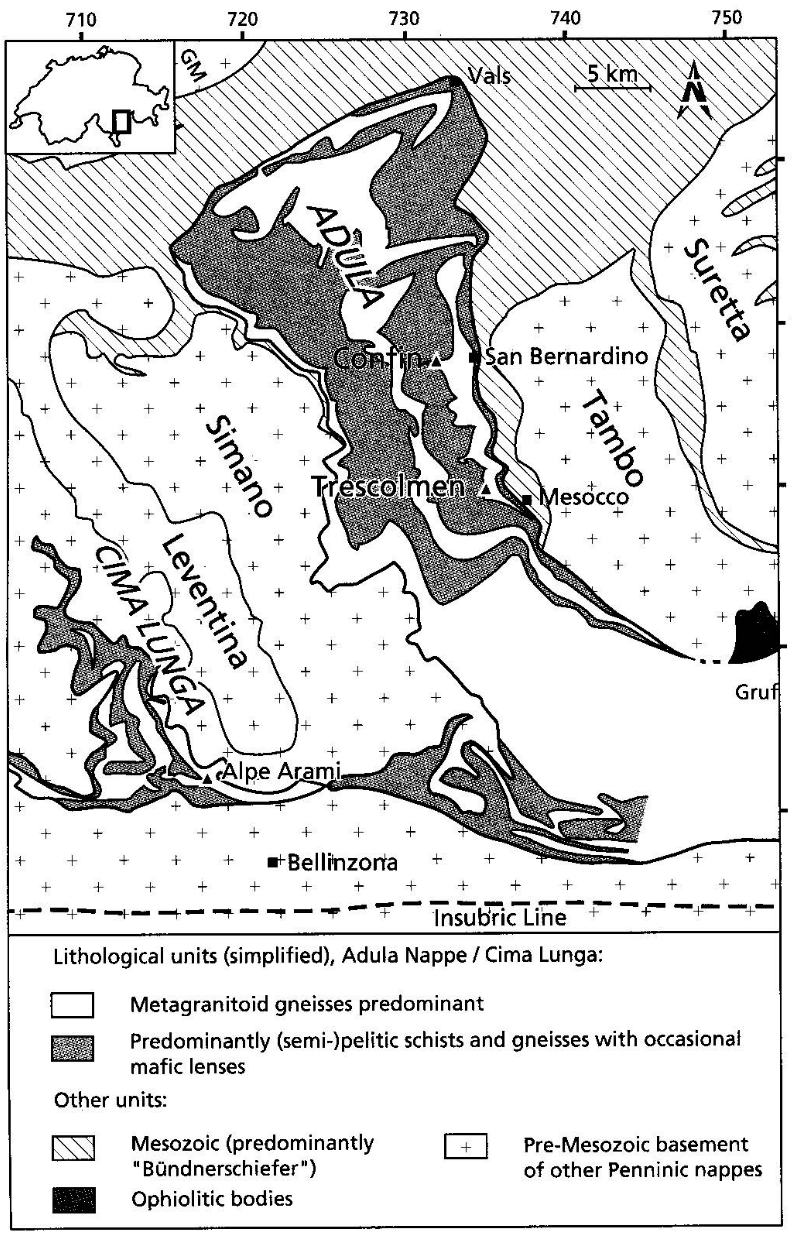


Fig. 1 Simplified tectonic map of the Adula nappe / Cima Lunga unit (modified after HEINRICH, 1982).

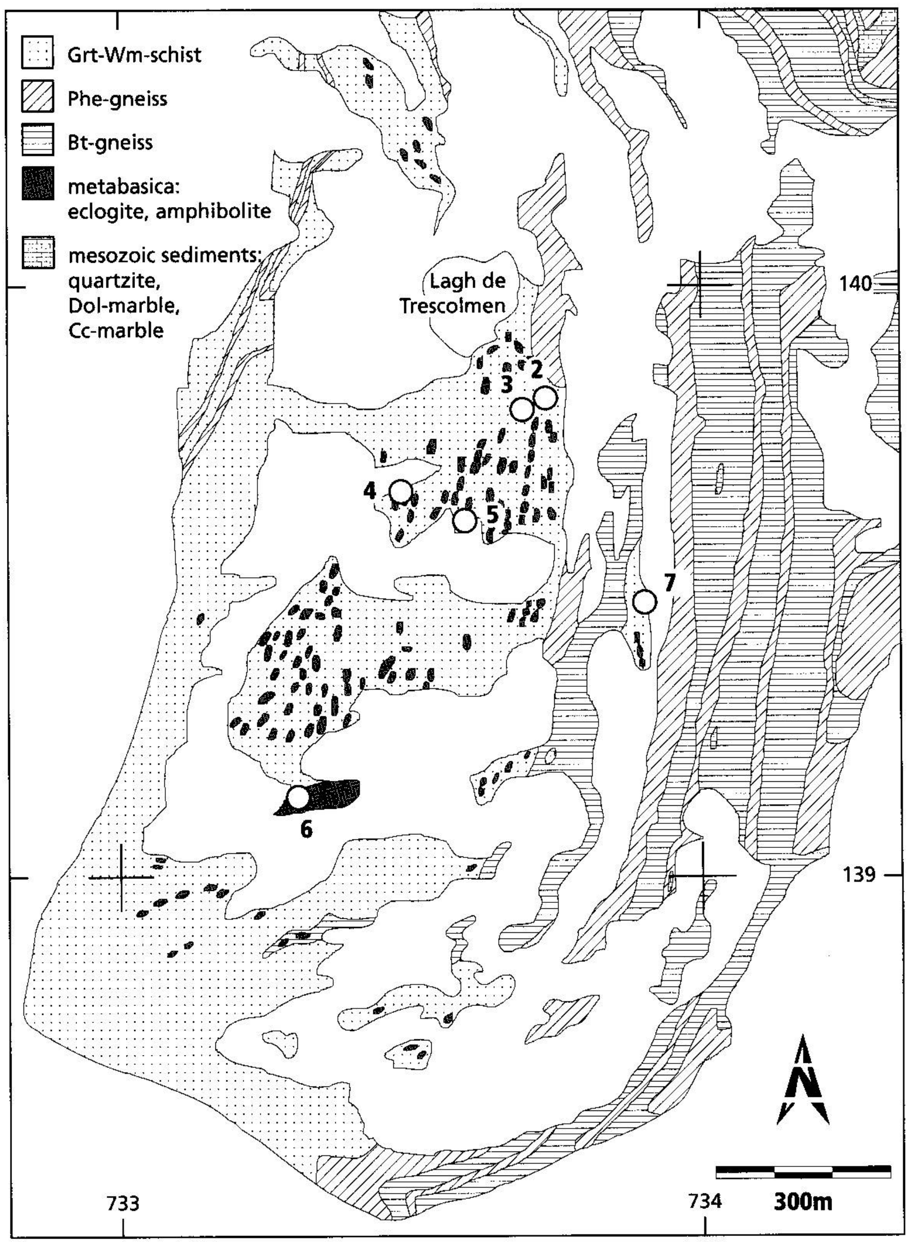


Fig. 2 Simplified geological map of the locality Trescolmen (after PUSCHNIG, 1992 and MEYRE, 1993). Localities of stops 2–7 are indicated on the map. Stop 1 is outwith the area shown.

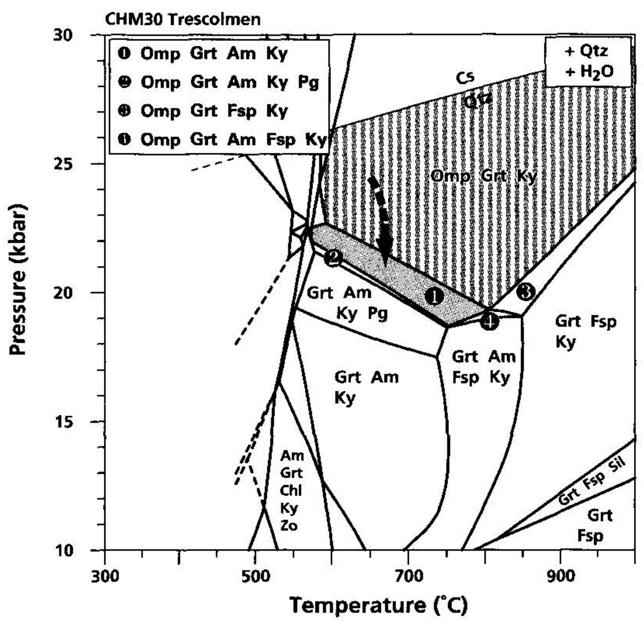


Fig. 3 Equilibrium phase diagram for the sample CHM30 from Trescolmen (middle Adula nappe), calculated with the computer program DOMINO (DE CAPITANI, 1994). The diagram is constructed for a specific bulk composition through computation of equilibrium assemblages by Gibbs free energy minimization. Each field encloses a single mineral assemblage. The boundaries represent one or more reactions. In general, neither the composition of any solution phase nor the activity of any endmember are constant along these boundaries. Below 500–600 °C the calculated assemblages include chlorite, mica and amphibole with compositions outside the defined solution models (see text). These assemblages are omitted from consideration in the present discussion. The gray shaded areas correspond to the observed assemblages. The striped region indicates the assemblage of presumed peak pressure conditions. The arrow represents the assumed retrograde path (cf. Fig. 5). The measured endmember composition is $Jd_{0.36}Di_{0.53}Hd_{0.11}$ for omphacite and $Grs_{0.19}$ $Prp_{0.40}Alm_{0.41}$ for garnet.

formation indicate that the exhumation from peak pressure conditions to amphibolite facies conditions was a short-living process, nevertheless re-equilibration during the early stages of the decompression – still under eclogite facies conditions – can locally be observed. The localities Confin and Trescolmen (Fig. 1) show peak-pressure assemblages that are partly overprinted by retrograde eclogite assemblages:

Confin:

Grt + Omp ± Ky + Qtz –>

Grt + Omp + Am + Qtz ± Pg.

Trescolmen:

Grt + Omp + Ky + Qtz –>

Grt + Omp + Am + Ky + Qtz.

The PT-conditions of the peak-pressure assemblage and the re-equilibration assemblage can be determined by calculation of equilibrium phase diagrams (Fig. 3, MEYRE et al., 1997). These calculations were performed with the computer-code DOMINO (DE CAPITANI, 1994) and solution models for the following minerals: Omphacite (MEYRE et al., 1997), garnet (BERMAN, 1990), feldspar (FUHRMAN and LINDSLEY, 1988), white mica (CHATTERJEE and FROESE, 1975) and amphibole (MEYRE et al., 1997).

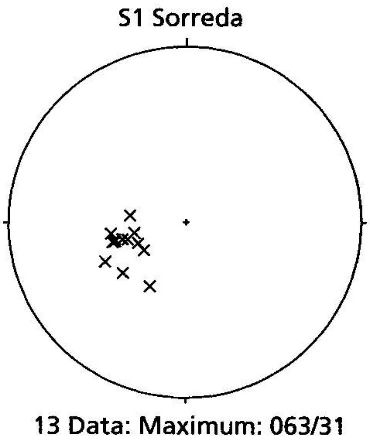
In the middle Adula nappe and especially at the locality Trescolmen, five deformation phases (Fig. 4) related to the Alpine evolution can be observed (LÖW, 1987; MEYRE and PUSCHNIG, 1993; PARTZSCH, 1996; PARTZSCH and MEYRE, 1995).

Sorreda phase (D1): The first deformation phase caused the imbrication of pre-Mesozoic continental basement rocks, Mesozoic sedimentary rocks and mafic rocks of unknown formation age. The D1 contacts are completely overprinted by the later Zapport deformation phase (D3, see below) in the middle part of the Adula nappe, whereas in the northern Adula nappe Sorreda fabrics are preserved (LÖW, 1987). LÖW (1987) suggests increasing temperatures and pressures for this deformation event.

Trescolmen phase (D2): The second deformation phase can only be observed in eclogite lenses. Recrystallized omphacite grains and elongated garnet aggregates define a distinct foliation and stretching mineral lineation associated with isoclinal folds. This deformation event coincides with the re-equilibration of the eclogite assemblage mentioned above (MEYRE et al., 1997) and therefore, the Trescolmen deformation phase took place during the first stages of decompression (ca. 19–21 kbar, ca. 650–700 °C). The peak-pressure conditions cannot be determined precisely, but are assumed to be below the quartz/coesite transition (ca. 25–26 kbar at this temperature).

Zapport phase (D3): Foliations and lineations of the Zapport deformation phase are widespread throughout the structurally upper part of the Adula nappe, where they define the dominant structural fabric. Thrust planes of the Sorreda phase and the locally preserved pre-Zapport cleavage (D2?) are folded by isoclinal folds related to the Zapport phase (D3). The subhorizontal fold axes of these isoclinal folds plunge to the north and their fold axial planes dip ca. 30° to the north-east. The stretching lineation (LS3) is subparallel to the D3 fold axes and the penetrative foliation (S3) represents the axial plane cleavage of isoclinal folds (F3). During the Zapport phase mafic rocks were deformed and recrystallized from eclogite facies assemblages to amphibolite facies assemblages. Pressure and temperature calculations (PARTZSCH et al., 1998) yield conditions of ca. 6.5–8.5 kbar and ca. 640–700 °C. Structural and petrological observations in the northern and the middle Adula nappe, such as for example the preservation of high-pressure minerals in Zapport structures (e.g. LÖW, 1987), suggest continuous decompression from eclogite to amphibolite facies conditions during northward exhumation. However, shear sense indicators (rotated clasts, shearbands) throughout the entire Adula nappe indicate incompatible shear sense (i.e. southward thrusting of the Adula nappe relative to the Tambo nappe in the hangingwall).

Leis phase (D4): During the fourth deformation phase the main schistosity (S3) was refolded by open folds or by crenulation in lithologies enriched in sheet silicates, respectively. The fold axes dip ca. 35° towards the east-north-east to east in the structurally upper part of the Adula nappe. In the lower part the Leis phase can be correlated with the thrusting of the Adula nappe onto the Simano nappe (PARTZSCH et al., 1995). The Leis phase takes place under lower amphibolite to upper greenschist facies conditions.



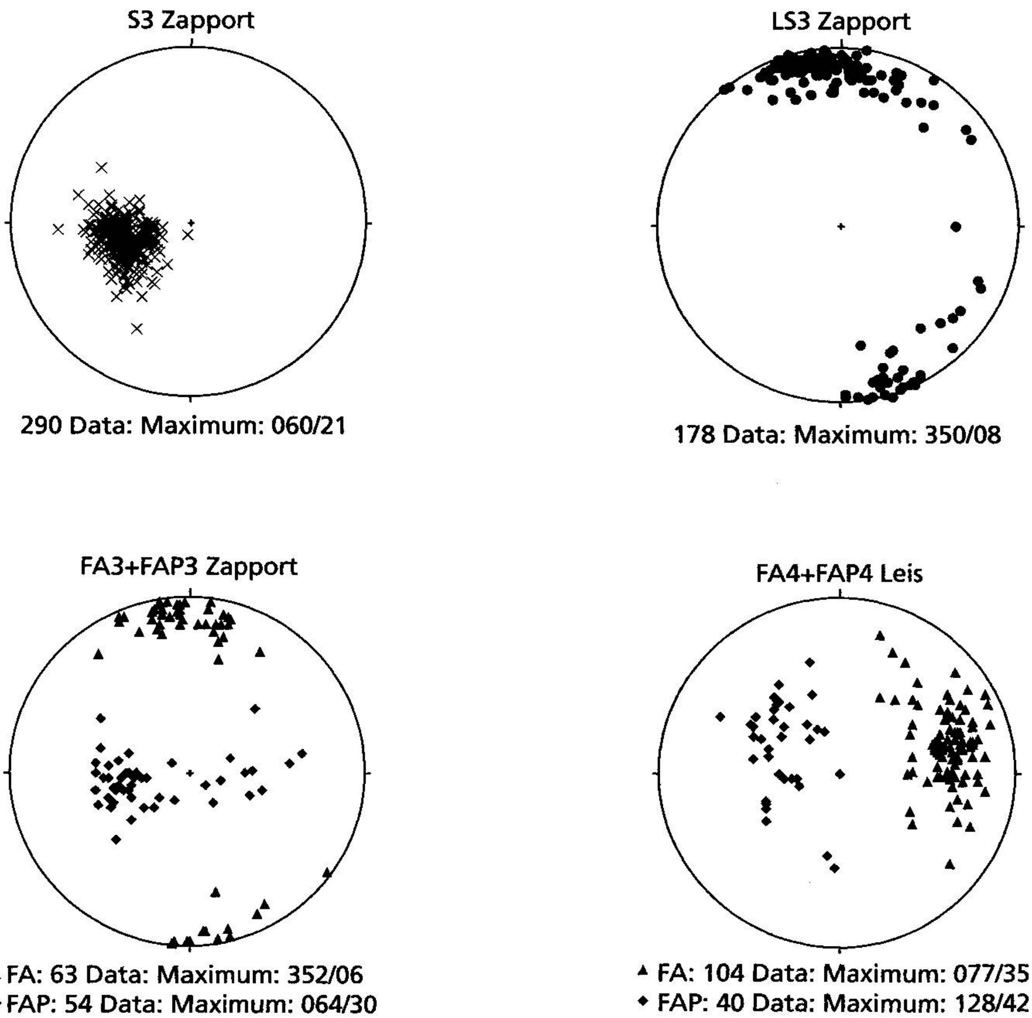


Fig. 4 Lower hemisphere equal-area projections of structural elements (top of Adula nappe). Data from PARTZSCH (1996) and MEYRE (unpub.). S = schistosity; LS = stretching lineation; FA = fold axes; FAP = Fold axial plane.

Carassino phase (D5): During the fifth deformation phase the northern and the middle Adula nappe was affected by undulation and kinking in the ductile/brittle transition. Undulation axes dip to the east with ca. 35°.

The metamorphic and structural data are portrayed in a PT-loop for the middle Adula nappe (Fig. 5).

Itinerary

On the Swiss national highway A2 (Basel–San Gottardo–Chiasso) take exit "Bellinzona Nord/ San Bernardino". Then take the San Bernardino highway until exit Roveredo. From there go north towards Grono. Just before the village of Grono turn left following the sign showing "Calanca". Follow this road to the village of Rossa and continue 3 km to Valbella. 300 m beyond the village of Valbella use a small parking lot. From there take the small foot-path to Trescolmen. The stops are indicated in figure 2.

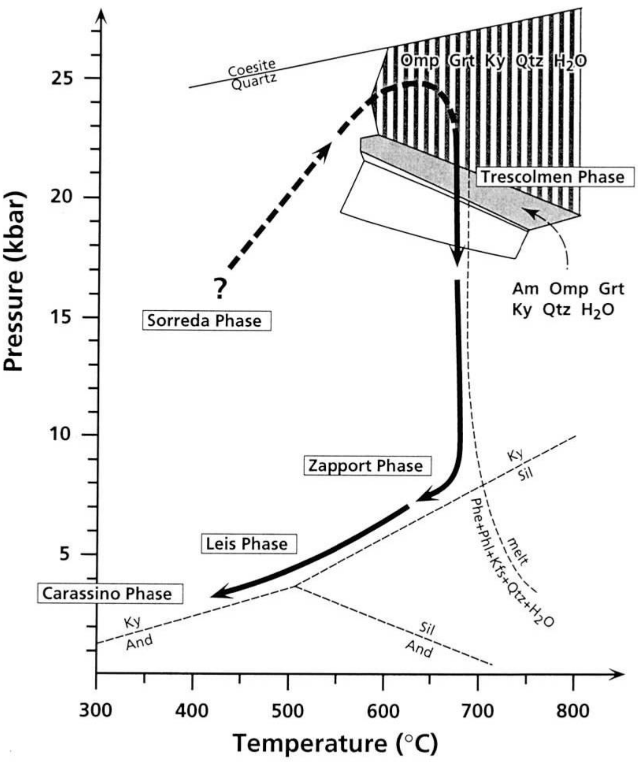


Fig. 5 P-T path of the structurally upper part of the middle Adula nappe. The peak pressures were reached in the stability field of Omp + Grt + Ky + Qtz + H_2O around 25 kbar and 600–650 °C (striped region). The shaded area represents the stability field of Am + Omp + Grt + Ky + Qtz + H_2O where the Trescolmen-deformation phase took place and the eclogites recrystallized during early stages of decompression (21 kbar, 650–700 °C). The approximate positions of the other deformation phases are indicated by the text boxes.

Useful topographic maps (National maps of Switzerland): 1 : 100'000 N° 43 "Sopra Ceneri"; 1:25'000 N° 1274 "Mesocco".

STOP 1
ECLOGITE BOULDER (732.760/140.100; 1800 m)

Suggested reading: Becker (1992).

Large eclogite bodies are lying in the creekbed. The bodies are relatively inhomogeneous: Garnet appears as aggregates, omphacite is apparent with its light green color.

STOP 2
ECLOGITE LENSES (733.740/139.810; 2110 m)

Beside the creekbed just at the top of the waterfall, several eclogite lenses can be observed. The rims of the lenses are overprinted by a fine-grained, dark symplectite, which mainly consists of diopsidic pyroxene, tschermakitic amphibole and albite. In the core of the lenses fresh eclogite can be seen. Within the eclogite abundant amphibole porphyroblasts are alined in the foliation. This amphibole belongs therefore to the Trescol-

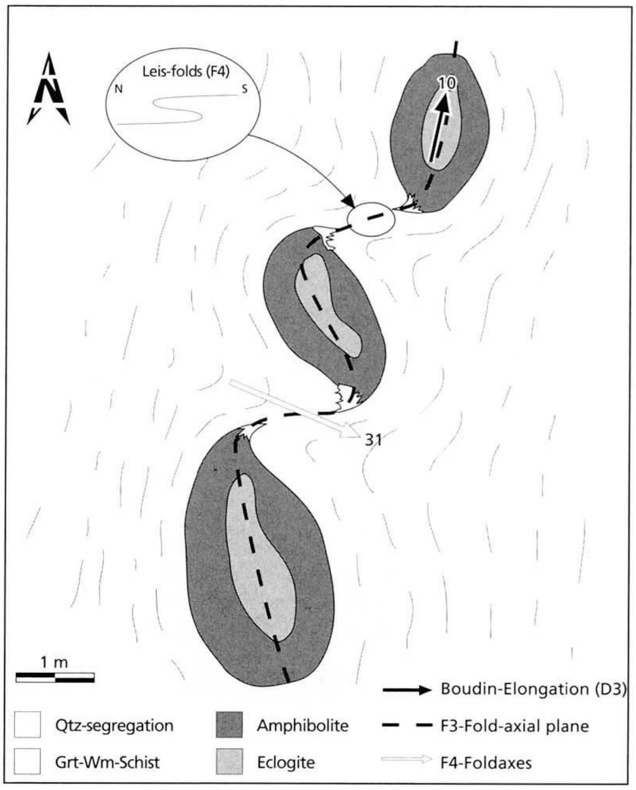


Fig. 6 The metabasic lenses are aligned to "string of pearls" (Stop 2). During the D4 deformation phase (Leis) the strings are folded. The fold axes dip towards E.

men deformation phase, which was developed under eclogite facies conditions. The equilibrated assemblage is Grt + Omp + Am ± Ky + Qtz (cf. Fig. 3). Conjugated joints crosscut the eclogite lenses. The "string of pearls" of metabasic lenses are folded by F4-folds (Leis) (Fig. 6).

STOP 3
FOLDED METABASITE LAYER
(733.700/139.790; 2110 m)

A re-folded metabasite layer (retrograde eclogite) within metapelitic countryrock shows overprinting features of two deformation phases.

1) isoclinal folding during Trescolmen deformation phase (under eclogite facies conditions).

2) refolding during Zapport deformation phase (under amphibolite facies conditions).

In this outcrop no relics of the eclogite assemblages are preserved because of complete overprint during decompression.

STOP 4
ECLOGITE LENS (733.490/139.650; 2135 m)

Suggested reading: HEINRICH (1982, 1983, 1986).

A beautiful outcrop with a three-dimensional view of a metabasic lens (Fig. 7). This lens shows the overprinting features, described by HEINRICH (1982): During decompression (± isothermal) dehydration reactions (breakdown of muscovite to biotite in metapelites and leucocratic gneisses) produce a fluid phase, which retrogrades the basic lenses (Fig. 8). The eclogitic assemblage is preserved in the core of the lens. The pressure shadows of the lens are filled with segregated Qtz and Ky. **Please do not hammer this outcrop!**

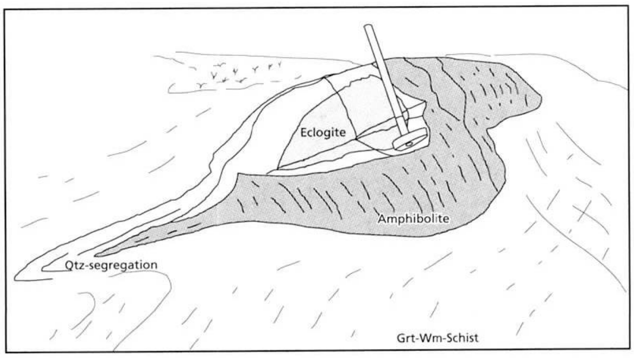


Fig. 7 Schematic view of a metabasic lens (Stop 4) with an eclogite core and an overprinted rim (amphibolite).

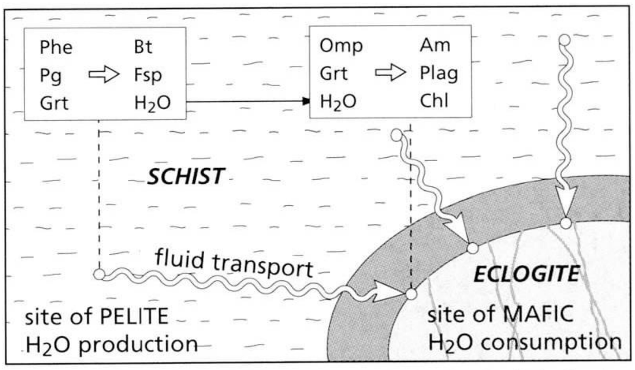


Fig. 8 Overprinting reactions of the basic lithologies induced by dehydration reactions of the pelitic lithologies (from HEINRICH, 1982).

STOP 5
ECLOGITE FOLD (733.600/139.600; 2165 m)

Suggested reading: HEINRICH (1982); MEYRE et al. (1998); MEYRE and PUSCHNIG (1993); PARTZSCH et al. (1998)

This metabasic fold is of special interest, because eclogite relics and their metamorphic overprinting features can be observed in relation to high-pressure deformation (schematic view in Fig. 9). The concentric overprint of the boudinaged fold implies that retrogression under amphibolite facies conditions took place after the folding of the lens (under eclogite facies conditions). Metapelite enclosed in the hinge of the fold contains the preserved high-pressure assemblage (Qtz + Ky + Grt + Phe). This metapelite has a distinct foliation defined by white mica flakes (phengite). Garnet and kyanite are abundant besides the major component quartz. Minor components are apatite, rutile and ilmenite. Rims of phengitic white mica are epitactically overgrown by biotite (cf. HEINRICH, 1982). Phengite is zoned in silica content from core (Si ≈ 3.4 p.f.u.) to rim (Si ≈ 3.3 p.f.u.) due to diffusion. This zonation can be systematically observed in metapelites of the upper Adula nappe and seems to be related to equilibration during decompression (HEINRICH, 1982; PARTZSCH et al., 1998). Garnet is essentially unzoned in the core (core composition: $Alm_{51}Prp_{33}Grs_{15}Sps_1$). A slight zonation in the rim with respect to pyrope and grossular ($Alm_{50}Prp_{28}Grs_{21}Sps_1$) can be observed. Symplectic pseudomorphs of albite and amphibole after omphacite occur interstitially between garnet and quartz.

At the same outcrop two little metabasic lenses are intensely deformed (fish-mouth structure; Fig. 10) and show the same concentric overprint feature as described above. The internal S2-foliation is well observable. **Please do not hammer this outcrop!**

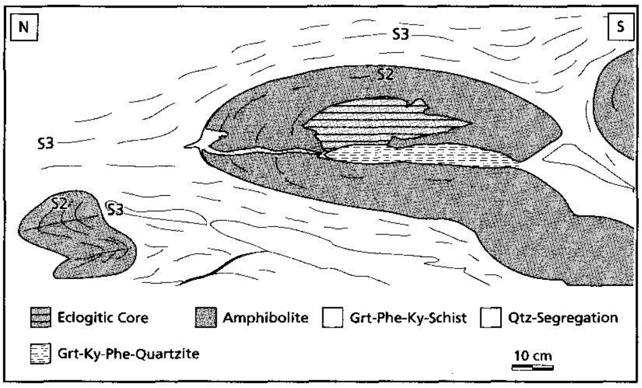


Fig. 9 Folded eclogite lens with concentric overprint under amphibolite facies conditions. The enclosed metapelite in the hinge of the fold has preserved the high-pressure assemblage Qtz + Ky + Grt + Phe (Stop 5).

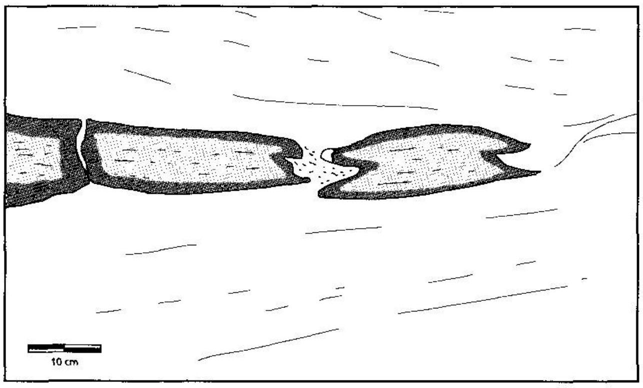


Fig. 10 Fish-mouth structures in metabasic lenses. The regular rim of retrogression implies that the stretching deformation was prior to the overprint (Stop 5).

STOP 6
CLINOZOISITE-BEARING ECLOGITE
(733.310/139.130; 2429 m)

This is a ca. 100 m by 40 m wide macroboudin of eclogite preserving an unique fabric: cm-large clinozoisite porphyroblasts are surrounded by a matrix of dark green omphacite. Garnet appears irregularly in aggregates. Clinozoisite seems to be grown during the high-pressure metamorphism, but it overgrows omphacite, quartz and, sometimes, garnet. The preserved assemblage displays eclogite facies conditions (Omp + Qtz + Czo ± Grt). Garnet is zoned with increasing Prp-content towards the rim (core: Prp_{16}; rim: Prp_{28}) and decreasing contents of Alm (Alm_{61}–Alm_{55}), Grs (Grs_{20}–Grs_{16}), and Sps (Sps_3–Sps_1). Analyses of omphacite indicate a high jadeite content (Jd_{47}).

STOP 7
METAPELITE (733.910/139.460; 2250 m)

Suggested reading: MEYRE et al. (1998).

Metapelitic lens (garnet-white mica-kyanite schist) of several meters within orthogneisses. Large garnet crystals, up to 2 cm in size, with inclusions of kyanite (several millimeters in size), white mica and quartz are abundant. Besides quartz and kyanite the other main components of this rock are phengitic muscovite and paragonite defining the distinct main foliation (Zapport deformation phase). Biotite only occurs as a retrograde product of muscovite. Small anhedral staurolite grows in pressure shadows of garnet within the main foliation. No feldspar was detected in this rock. Abundant shearbands of the Zapport deformation phase indicate top to north movement.

Garnet is essentially unzoned ($Alm_{72}Prp_{25}$ Grs_2Sps_1). Slightly decreasing Prp-values towards the rim are interpreted to be due to diffusional reequilibration. Phengite is zoned with respect to Si-content, with values up to Si = 3.4 p.f.u. in the core decreasing to Si = 3.1 p.f.u. in the rim. Phengitic white mica grown in shearbands (related to late stages of "Zapport") systematically reveals low Si values (Si = 3.1 p.f.u.) and is unzoned.

We assume that the main foliation began to evolve under high-pressure conditions (core of phengitic white mica) and continued under amphibolite facies conditions (growth of staurolite, phengite in shearbands).

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