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ALPINE ECLOGITES IN THE TAUERN WINDOW

by

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1. Geologic setting

The Tauern Window (TW) represents the largest exposed section of the lowest major tectonic unit in the Eastern Alps (the "Penninic" unit, see Plate 1 of SCHUSTER & KURZ, this volume). It represents an exhumed section of the nappe stack that developed in a subduction zone during closure of the Penninic ocean in the Upper Cretaceous and Tertiary (Fig. 1). From base to top, the Penninic nappe stack includes (KURZ et al., 1998, 2001):

(1) *The Venediger Nappe (VN) and the Wolfendorn Nappe:* these nappes comprise a pre-Variscan basement intruded by Variscan granitoids (the "Zentralgneis") with a cover sequence of Jurassic metacarbonates ("Hochstegen Marble Formation") and Cretaceous metapelites and metapsammites ("Kaserer Group", sedimentation up to Eocene) (FRISCH, 1980, 1984; LAMMERER, 1988). The Wolfendorn Nappe mainly forms a duplex of the cover sequences of the Hochstegen Marble Formation and the Kaserer Group, underlain by thin slices of former continental basement.
(2) *The Storz and Riffl Nappes* comprise Variscan and Alpidic polymetamorphic basement rocks covered by metapelites and graphitic quartzites of the Murtörl Group, which was assumed to be of either late Paleozoic or, more likely, Cretaceous age (KURZ et al., 1998, and references therein). The nature of the tectonic contact between the Venediger Nappe and the Riffl Nappe (Fig. 1a) has been highly debated and is interpreted by FRISCH (1977, 1980) to be related to the Variscan orogeny.
(3) *The Eclogite Zone* (EZ) is restricted to the central southern TW and is characterized by a Mesozoic volcano-sedimentary sequence of a distal continental slope that has experienced HP metamorphism. The Eclogite Zone is tectonically positioned above the Venediger Nappe Complex and is overlain by the Rote Wand-Modereck Nappe (Fig. 1a-c). Where the Eclogite Zone is absent, however, the Rote Wand-Modereck Nappe is overthrust directly onto the Venediger Nappe (Fig. 1a).

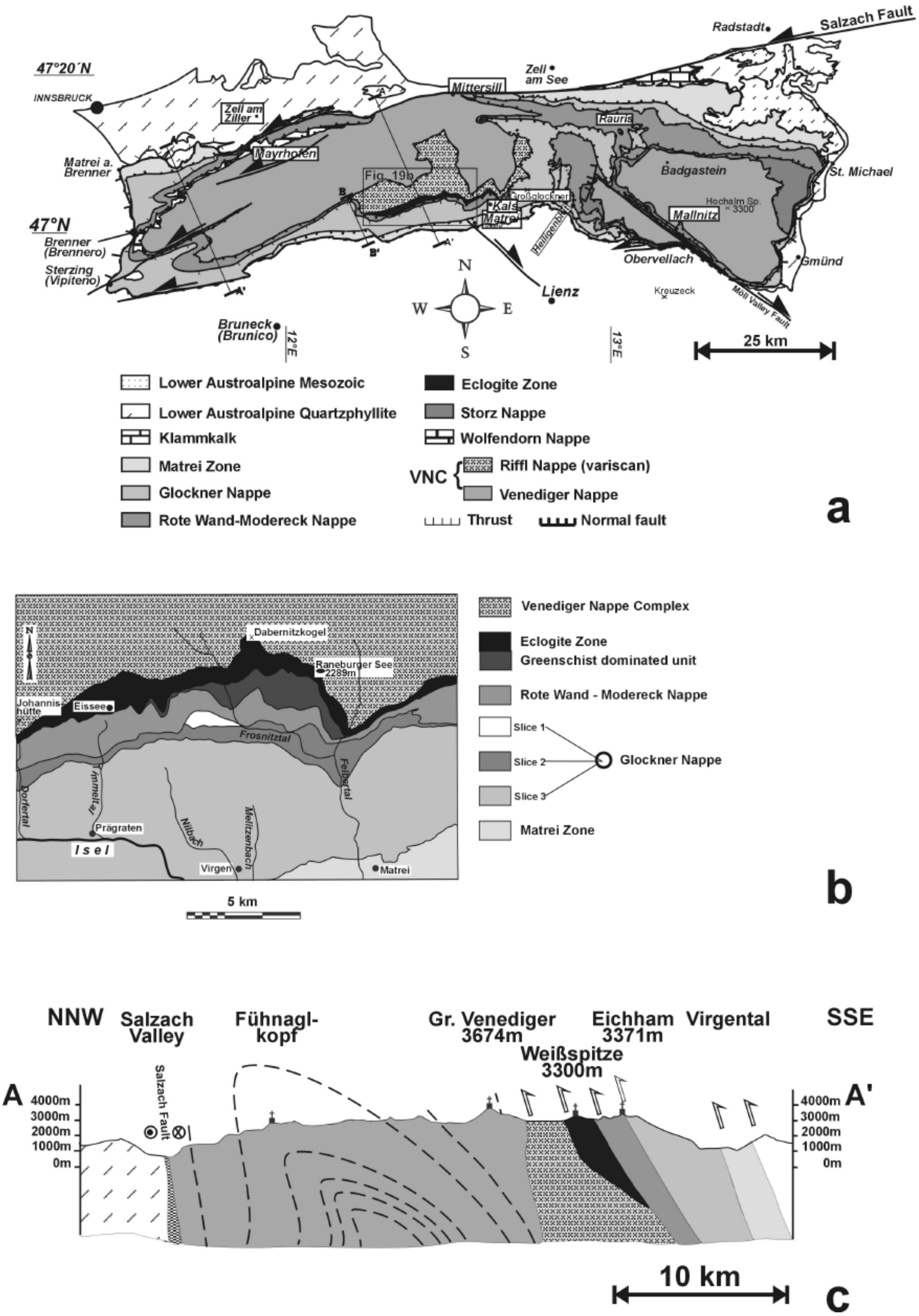

Fig. 1

a) Geologic overview of the Tauern Window (according to KURZ et al., 1998, 2001); b) Simplified geologic map showing major tectonic units in the southern Großvenediger area. The excursion area (2nd and 3rd day in the Eclogite Zone) is in the Dorfer and Timmeltal areas close to the western edge of the figure; c) Simplified geologic profile across the TauernWindow in the Großvenediger section (line A-A' in Fig.1a).

(4) *The Rote Wand-Modereck Nappe* (RMN) is formed by basement rocks of the Rote Wand-Modereck Lamella that are covered by Permian to Triassic quartzites, Triassic metacarbonates, Jurassic breccias, calcareous micaschists and metatuffs as well as Cretaceous metapelites and metapsammites.
(5) *The Glockner Nappe* (GN) comprises an oceanic basement made up of an incomplete ophiolitic sequence of serpentinites, ultramafic rocks, MORB-type metabasics (greenschists and amphibolites) of supposed Jurassic to Cretaceous age (BICKLE & PEARCE, 1975; HÖCK & MILLER, 1980), covered by or intercalated with a sequence of quartzites, micaceous calcitic marbles and calcarous schists (the "Bündner Schists").
Terrigenous sequences have been observed locally, for example in the central and western parts of the TW. It is very important to note that the base of the Glockner Nappe is made up of former oceanic lithosphere, while the cover sequences of several other nappes within the TW are underlain by continental basement. Hence the separation of the Glockner Nappe from the Rote Wand-Modereck Nappe in the footwall is only possible if serpentinites and other remnants of former oceanic lithosphere are intercalated between meta-sediments.
(6) *The Matrei Zone* is interpreted to represent an accretionary wedge that is characterized by metamorphic flysch sediments (mainly calcareous and carbonate-free micaschists), breccias and olistoliths, mainly of Austroalpine derivation (FRISCH et al., 1987).
(7) *The Klammkalk Zone* comprises calc-schists, massive marbles and thin-bedded green phyllites; it forms a low-grade metamorphic equivalent to the “Bündnerschiefer” of the Glockner Nappe.
(8) *The Lower Austroalpine nappe* stack, in the hanging wall of the Penninic nappe stack, comprises pre-Alpine continental basement units and Permian to Mesozoic cover sequences, predominantly derived from a rifted, passive continental margin.

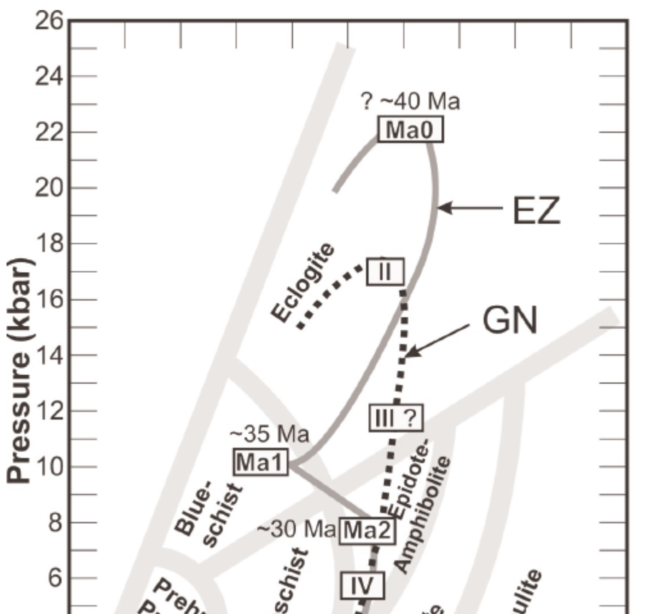

Fig. 2
P-T paths recorded from HP-rocks of the Eclogite Zone (EZ) and Glockner Nappe (GN). See Tables 1 and 2 for data sources and references.

2. Tectonometamorphic evolution

2.1. HP evolution

The rocks exposed within the EZ in the southern Großvenediger area have been affected by a multiphase tectonometamorphic evolution. Inclusions in garnet from eclogites (Ep, Chl, Pa, Bt, Phe, Qtz, Ab - see Tab. 1a for mineral abbreviations used in the text) and from metasediments (rhombic form-relics of Pa+Zo+Qtz interpreted as pseudomorphs after lawsonite by FRY (1973), Tab. 1b), document a pre-eclogite stage of prograde metamorphism in greenschist-to-blueschist facies. The eclogite facies rocks were then buried to a depth of at least 65 km, as has been concluded from the HP parageneses of eclogites (Tab. 1a), associated metapelites (Tab. 1b) and metacarbonates (Tab. 1c), which all yielded similar PT paths with peak conditions of ~20 kbar, ± 600°C (Ma0 in Fig. 2).

Omphacite microstructures, in particular shape fabrics and crystallographic preferred orientations (CPOs) (Fig. 3), indicate that the final phases of the prograde evolution are characterised by flattening strain (documented by S-type omphacite CPOs). L-type CPOs formed at the pressure peak and along the exhumation path and document a constrictional strain geometry.

In the tectonically higher RMN and GN eclogite facies metamorphism is only locally recorded and former eclogites are much more affected by retrogression (KURZ et al., 1996; STURM et al., 1997; PROYER et al., 1999; DACHS & PROYER, 2001, 2002). The pre-eclogite stage in such retrogressed rocks is nevertheless still recognizable by inclusions preserved in garnet cores (e.g. ?magmatic augite and chromite, Plag, Chl, Akt, Barr/Glau, etc., Tab. 2) pointing to an early greenschist (?ocean-floor) and blueschist stage. Generally, eclogite facies assemblages documenting P-T conditions of ~17 kbar / 570 °C (Tab. 2, II in Fig. 2) can only be observed in the southern sections of these nappes, which would be related to a more distal (southern) paleogeographic position.

2.2. Post-HP evolution

The major tectonic units of the TW (from the VN at the base, up to and including the GN) were subsequently affected by blueschist facies metamorphism (Tab. 1-2, Fig. 2). Generally, the P and T of this stage are not well constrained due to the subsequent strong overprinting by Barrovian-type metamorphism ("Tauern crystallization").
In the southern Großvenediger area, ZIMMERMANN et al. (1994) derived 450°C and 10-15 kbar for this stage from Alpine HP-veins in garnet amphibolites of the VN. Reliable quantitative P-T estimates for this blueschist stage are not available from rocks of the EZ. However, ZIMMERMANN et al. (1994) argue for conditions of P > 10 kbar and T < 450°C, based on ^{40}Ar-^{39}Ar dating on phengites from the VN, EZ and GN in the Großvenediger section, suggesting that all three tectonic units cooled below the K-Ar closure temperature of white mica (~ 400°C) at 34.4 ± 2.6 Ma (Ma1 in Fig. 2). From the occurrence of crossite and low-jadeitic pyroxene in metabasites from higher structural levels of the GN, HOLLAND & RAY (1985) determined P > 8 kbar and T = 400-450 °C for this stage.

Stage	***Eclogites of the EZ***	***Parageneses / Textures /Reactions***	***P, T estimates***	***Ref.*** [1)]
Pre-eclogite	Relics in Grt-cores	Ep, Chl, Pa, Bt, Phe, Qtz, Ab, Fe-Barr, Ilm, Mt, Ap	prograde greenschist- to Ep/Amph-facies	1, 2, 3, 4, 23
Eclogite Ma0	E1: coarse-grained, gabbroic eclogite	$Omph_1(Jd_{34})$+$Grt(Py_{33})$+Ky+Tc+Qtz±Rt±Ap±Pyr ($Omph_1$, Ky, Tc inclusions close to grt-rims)	P ~19 - 22 kbar T ~ 590 - 650 °C $a_{H2O} \sim 1$	1, 2, 5, 8, 9, 10
	E2: fine-grained, "cataclastic" eclogites	$Omph_2(Jd_{47})$+$Grt(Py_{38})$+Ky+Tc+Qtz±Rt±Ap±Pyr relictic coarse $Omph_1$ →$Omph_2$		
	E3: banded kyanite-talc eclogites	$Omph_2$+Grt+Ky+Tc+Rt+Qtz±Pa±Ap±Pyr		
	E4: fine-grained epidote eclogite-mylonites	$Omph_2$+Grt+Ep±Dol/Mag±Pa/Phe		
	E5: banded eclogite-mylonites	layers of $Omph_2$+Grt+Ep+Pa/Phe+Qtz alternating with bands of Ep+Omph+Grt+Qtz, Ep+Dol, Omph+Qtz, Ep, Carb +Qtz		
	Synmetamorphic veins	Qtz+Ky+$Omph_{(1,2)}$ ±MgCtd±Tc±Qtz±Zo/Ep±Rt±Ap±Mag		1, 2, 6
Blueschist Ma1	eclogite retrogression	Glau+Ep±Law stable (2), Omph/Grt → Glau/Barr±Pa, Rt → Sph±Ilm, Ky → Pa±Ep ^{40}Ar-^{39}Ar dating on Phe: 34.4 ± 2.6 Ma	P = 10 - 15 kbar[2)] 300 < T < 450 °C[2)] P > 10 kbar, T < 450 °C	1, 2, 10, 11, 11
	in greenschists of Glockner Nappe:	Law-pseudomorphs crossitic amph, jadeitic Px	P > 4 kbar, T = 300-350 °C P > 8 kbar, T = 400-450 °C	23, 12 19, 13
Greenschist / Amphibolite Ma2	eclogite retrogression	Act+Ab+Chl±Ep±Phe±Sph±Carb±Qz±Mt Grt → Chl±Ep±Carb±Bt, Omph → Sym(Ab+Di),	P = 6 - 10 kbar T ~ 550°C	14, 17

Table 1a

Summary of mineral assemblages, parageneses and P-T estimates for eclogites of the Eclogite Zone (south-central TW). Eclogite types E1 - E5 are according to MILLER (1977).

Stage	***Metapelites of the EZ***	***Parageneses / Textures /Reactions***	***PT estimates***	***Ref.***
Pre-eclogite		rhombic form-relics (Pa+Zo+Qtz) as inclusions in Grt: pseudomorphs after ?Law (Law+Ab → Pa+Zo+Qtz)	? prograde blueschist facies	1, 3, 5
Eclogite Ma0	Metapelites with Omph-relics	$Grt(Py_{24-35})$+Phe_1(Si up to 3.47 apfu)+Qtz±Tc± $Omph(Jd_{42-54})$ ±Ky±Zo±Pa±Ru	P ~ 20 kbar at T = 600°C	3
	Grt-Ctd quartz-mica schists	Grt+Ctd+Ky+Phe_1+Qtz+Zo/Ep±Dol±Zn-Stau	P = 19 ± 2 kbar, T = 590 ± 20°C	16
		Grt+Ctd+Phe_1(Si up to 3.33 apfu, zoned)+Ky+Ru+Qtz	P ~ 25 kbar, T ~ 600 °C	7
late-eclogite		early decompression	P ~ 16 kbar, T < 550 °C	7
Blueschist		not clearly discernible in metapelites		
Greenschist / Amphibolite Ma2	Metapelites with Omph-relics	Omph → Sym; Omph+Ky → Pa+Zo/Ma±Sym; Tc+Phe_1 → Bt+Chl+Qtz; Grt+Phe_1 → Bt+Plag±Phe_2(Si=3.06-3.15 apfu) ±Chl±Cal Ky+Zo → Ma+Qtz	P = 7.5 ± 1 kbar, T ~ 525°C P = 6-7 kbar, T = 500-550°C P = 9-10 kbar, T ~ 550 °C	3, 4 18 8
	Grt-Ctd quartz-mica schists	Grt+Phe_1 → Bt+Chl		16
late alteration		Sudoite+Kaolinite	P ≤ 3 kbar, T = 200-350 °C	16

Table 1b

Summary of mineral assemblages, parageneses and P-T estimates for metapelites of the Eclogite Zone (south-central TW). For references and mineral abbreviations see next page and below.

Mineral abbreviations (Tables 1-4 and text):

Ab albite, Act actinolite, Amph amphibole, Ap apatite, Barr barroisite, Bt biotite, Cal calcite, Chl chlorite, Cpx clinopyroxene, Ctd chloritoid, Di diopside, Dol dolomite, Ep epidote, Glau glaugophane, Gr graphite, Grt garnet, Hbl hornblende, Ilm ilmenite, Carb carbonate, Kfs K-feldspar, Ky kyanite, Law lawsonite, Mag magnesite, Ma margarite, Mt magnetite, Ol oligoclase, Omph omphacite, Pa paragonite, Phe phengite, Phl phlogopite, Plag plagio-clase, Pyr pyrite, Px pyroxene, Qtz quartz, Sph sphene, Stau staurolite, Sym symplectite, Rt rutile, Tc talc, Tr tremolite, Win winchite, (C)Zo (clino)zoisite

Other abbreviations and symbols:

apfu atoms per formula unit, —> transforms/reacts to (texturally mostly also rimmed by)

Stage	(Impure) Marbles of the EZ	Parageneses / Textures /Reactions	P, T estimates	Ref.
Pre-eclogite		not preserved		
Eclogite Ma0	Marbles with HP relics	Cal+Qtz±Omph(Jd_{30-32}) ±Zo±Dol±Qtz ±Phe_1(Si = 3.32-3.47 apfu); Omph inclusions in Tr/Akt-cores	P > 10 kbar at 550°C	1, 3
	Siliceous dolomites	Di+Tr_1(coarse-grained)+Dol+Cal+Qtz±Zo	P = 18-25 kbar, T ~ 600°C, a_{H2O} ~ 1	15
	Kyanite-Zoisite marbles	Ky+Zo+Dol+Qtz; Zo+Phe_1(Si~3.36 apfu)+Dol+Cal+Qtz		16
Blueschist Ma1	Marbles with HP relics	? Inclusions in Tr/Akt-cores: Omph → Barr+Ab+Cal (±Di); Phe_1 → Phe_2(Si ~ 3.1 apfu)	P, T uncertain	3
Greenschist / Amphibolite Ma2	Marbles with HP relics	Tr(with relics of Omph/Barr in core preserved)+Cal+ Plag($Ab_{>98}$)±Dol±Qtz±Zo±Phe_2	T ~ 530 (Cal/Dol)	4
	Siliceous dolomites	Ta+Tr_2(fine-grained)+Dol+Cal+Qtz±Zo±Chl	P = 8 - 15 kbar, a_{H2O} = 0.2-0.8	15
	Kyanite-Zoisite marbles	Ky+Dol+Phe_1+Zo → Chl+Ma+Pa+Cal+Phe_2	P = 3-10 kbar, T = 450-550°C	16

Table 1c

Summary of mineral assemblages, parageneses and P-T estimates for (impure) marbles of the Eclogite Zone (south-central TW). For references and mineral abbreviations see below and previous page.

Stage	Retrogressed eclogites of the Grossglockner area	Parageneses / Textures /Reactions	P, T estimates	Ref.
Pre-eclogite I	Relics in Grt-cores	magmatic: Augit, Chromit, ?Ilm greenschist: Act, Plag, Chl, Cal, Sph blueschist: Act → Barr, primary Augit → Omph, Aegirine-Augit, Win/Glau	prograde greenschist facies (ocean floor ?) → blueschist facies: P ~ 6 kbar, T ~ 400 °C	20, 21
Eclogite II	retrogressed eclogites	Grt-Omph($Jd_{40-50}Ae_{5-20}$)-Pa-Glau-Zo-Qtz-Rt±Phe(Si = 3.3-3.43 apfu) ±Dol	P ~17 kbar, T ~ 570°C	21
		Grt: strong compositional hiatus between core ($Alm_{36}Py_4Gr_{31}Sp_{29}$), and rim ($Alm_{60}Py_{18}Gr_{21}Sp_1$) → natural diffusion couple allows to constrain time of meta-morphism ~ 1 Myr and age of HP-event ~ 40 Ma	diffusion modelling → fast exhumation rates in the order of several cm yr^{-1}	22
late-eclogite III		growth of coarse-grained Barr	still in eclogite facies ?	20, 21
Blueschist		not clearly discernible in retrogressed eclogites		
Greenschist / Amphibolite IV	further eclogite retrogression and hydration	Omph → Sym(Cpx, Amph, Ab), Glau → Sym, rims: Pa+Ep+Mt around Grt, CZo around Pa, Cpx around Qtz, Rt → Ti-hematite → Sph fully hydrated: Amph+Plag+Chl+Ep+Sph±Cal±Qtz	P = 5 - 6 kbar T = 500 - 530°C	21

Table 2

Summary of mineral assemblages, parageneses and P-T estimates for retrogessed eclogites of the Grossglockner area of the TW. For references and mineral abbreviations see below and previous page.

1) References (Tables 1-2)

1 MILLER (1977), 2 HOLLAND (1979), 3 DACHS (1986), 4 DACHS (1990), 5 FRANK et al. (1987), 6 THOMAS & FRANZ (1989), 7 STÖCKERT et al. (1997), 8 HOSCHEK (2001), 9 HOSCHEK (2004), 10 KURZ et al. (1998), 11 ZIMMERMANN et al. (1994), 12 FRY (1973), 13 HÖCK (1974, 1980), 14 RAITH et al. (1977), 15 FRANZ & SPEAR (1983), 16 SPEAR & FRANZ (1986), 17 HOERNES & FRIEDRICHSEN (1974), 18 HOSCHEK (1982), 19 HOLLAND & RAY (1985), 20 PROYER et al. (1999), 21 DACHS & PROYER (2001), 22 DACHS & PROYER (2002), 23 RAITH et al. (1980)

2) estimated from omphacitic pyroxene in Alpine HP-veins of garnet amphibolites from the Venediger Nappe (foot-wall of Eclogite Zone, Ref. 11)

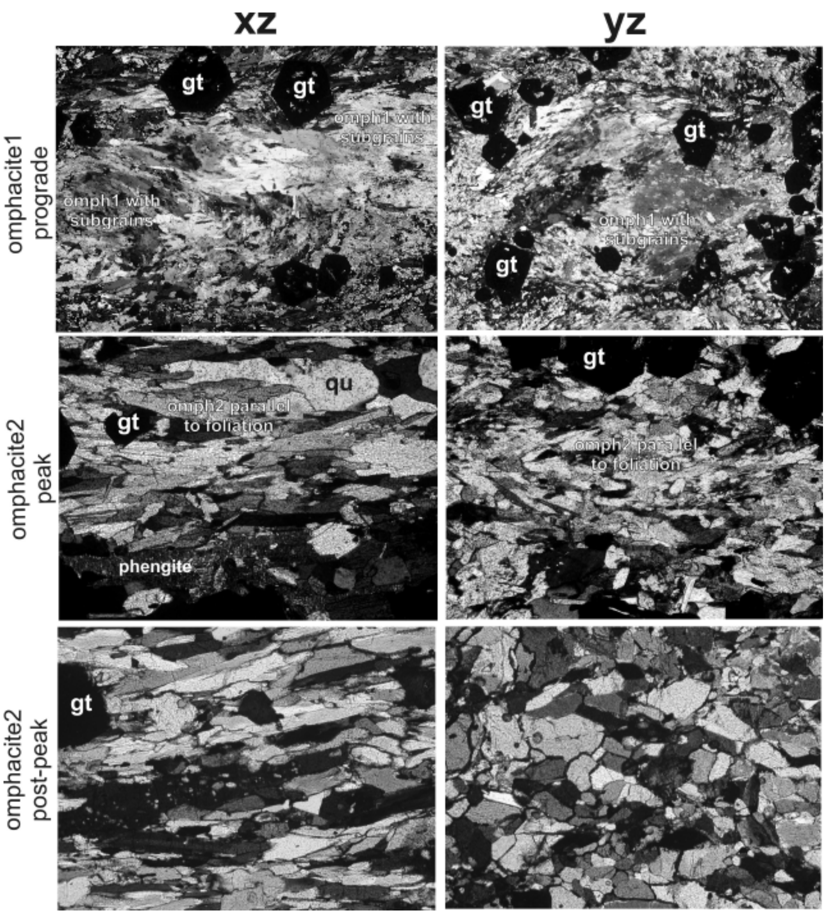

Fig. 3a
Representative microstructures of Eclogite Zone eclogites at distinct stages of pressure vs. temperature evolution (crossed polarizing filters; long axis of photographs represents ~4 mm; gt-garnet; qu-quartz).
Top: coarse-grained, weakly foliated eclogite, showing Omph1 with subgrains. Centre: Eclogite mylonite with remnants of Omph1, surrounded by fine-grained dynamically recrystallized Omph2. Bottom: Eclogite mylonite showing dynamically recrystallized Omph2 with shape preferred orientation in X-Z (left) and equigranular fabric in Y-Z (right).

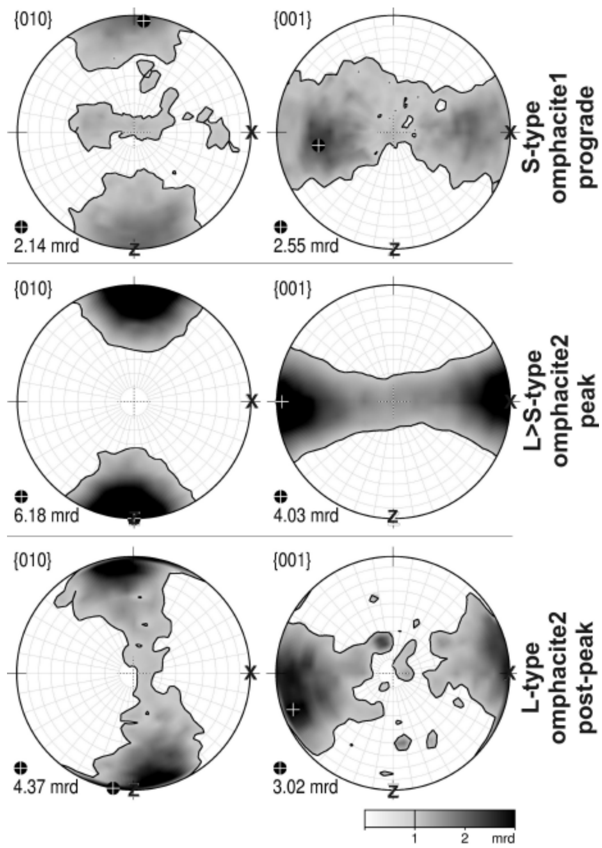

Fig. 3b
Representative crystallographic preferred orientations (CPO) of Omph at distinct stages of pressure vs. temperature evolution. CPOs have been analysed by neutron texture goniometry at Forschungszentrum Jülich (Germany). Recalculated pole figures {001},{010} describe orientation of the poles to the (001) and (010) omphacite planes, including the equivalent (00-1) and (0-10) poles. X marks trace of foliation and lineation; Y is at centre of pole figure, Z is vertical; lower-hemisphere equal-area projection; mrd-multiples of random distribution; white cross marks position of maximum.

Within the VN and GN of the western and eastern TW, peak pressures of up to 10-12 kbar have been evaluated for the blueschist event (SELVERSTONE et al., 1984, 1992; SELVERSTONE, 1993; CLIFF et al., 1985; DROOP, 1985; FRANK et al., 1987).
Within the basal GN of the Grossglockner area this phase of metamorphic overprinting is not clearly discernible in retrogressed eclogites (PROYER et al., 1999), but is evidenced by pseudomorphs after lawsonite and high-Si phengites in metabasites and calc-schists (HÖCK, 1974, 1980; FRANK et al., 1987).
Finally, the entire nappe pile was affected by Barrovian-type upper greenschist to lower amphibolite facies metamorphism ("Tauern crystallisation"), with peak conditions of ~ 7 kbar, 500-550°C in the EZ and RMN of the southern Großvenediger area (e.g. DACHS, 1990; Ma2 in Fig. 2) and 5-6 kbar, 500-530°C in the Grossglockner region (DACHS & PROYER, 2001; IV in Fig. 2). Corresponding mineral isograds run approximately parallel to the outline of the TW and are concentrically arranged, such that metamorphic grade increases from the periphery towards the interior of the window (see HOINKES et al., 1999 for further details and references).

In contrast to supposed Cretaceous ages, phengite $^{40}Ar^{39}Ar$ mineral ages between 32 and 36 Ma from the EZ (ZIMMERMANN et al., 1994) and of 38 Ma from the RMN (HANDLER et al., 2001; KURZ, unpublished data) are interpreted to represent cooling ages related to Eocene blueschist facies metamorphism (Ma1 in Fig. 2). Assuming a similar age for the blueschist event in the GN of the Grossglockner area, the diffusion modelling of DACHS & PROYER (2002) on a garnet overgrowth textures preserved in retrogressed eclogites indicates that the eclogite facies event in the TW (at least in the Grossglockner area) is not older than ~ 40 Ma. KÜHN et al., (this volume) report multi-mineral Rb/Sr ages for eclogites of 31.5 ± 0.7 Ma.
Alpine low-Si micas of all tectonic units, on the other hand, record younger ages < 27 Ma for the late cooling of the entire nappe pile (Ma2, IV in Fig. 2) with the youngest ages, down to 14 Ma, in the western and eastern TW (e.g. ZIMMERMANN et al., 1994; INGER & CLIFF, 1994).

3. Summary of the geodynamic evolution

The Eclogite Zone (Tauern Window, Eastern Alps, Austria) represents one of only a few examples of high-pressure units where both the prograde and the retrograde metamorphic evolution are documented. The eclogites are associated with rocks of continental origin and occur as layers and boudins on a scale of a few centimetres to several metres in thickness. The southward subduction of a single lithospheric slab, comprising the Penninic oceanic units in the south and the European margin in the north (represented by the Venediger Nappe Complex), resulted in nappe stacking within the Penninic units of the Tauern Window. After the consumption of the Penninic oceanic basin the European margin was incorporated into the subduction zone, which resulted in eclogite facies metamorphism in the Eclogite Zone and in the southern structural sections of the Rote Wand - Modereck Nappe. The Eclogite Zone ascended towards the surface and was emplaced on the subducted European margin, which is mainly exposed in the Venediger Nappe Complex. According to recently published geochronological data, this phase of continental collision and related Alpine high-pressure metamorphism and nappe stacking within the Penninic units is inferred to having occurred in the Paleogene (approximately 45-40 Ma) (KURZ et al., 2001). The main deformational phase related to nappe stacking occurred during the Eocene.

The change from flattening along the prograde path to constrictional strain at the pressure peak is interpreted to be controlled by the force balance between slab pull (related to a subducted oceanic slab) and the buoyancy of adjacent subducted continental crustal material in which the eclogites are included. At a certain lithospheric level the buoyancy forces related to the subducted continental part exceeded the externally applied slab pull forces related to the oceanic part. This is assumed to happen in an array where the subducted continental rocks are entirely surrounded by high-density lower crustal and upper mantle material, resulting in the buoyancy-driven extrusion of low-density continental material between two lithospheric plates (Fig. 4). That part of the subducted slab that is in buoyant equilibrium will therefore be affected by constrictional strain (KURZ, 2005).

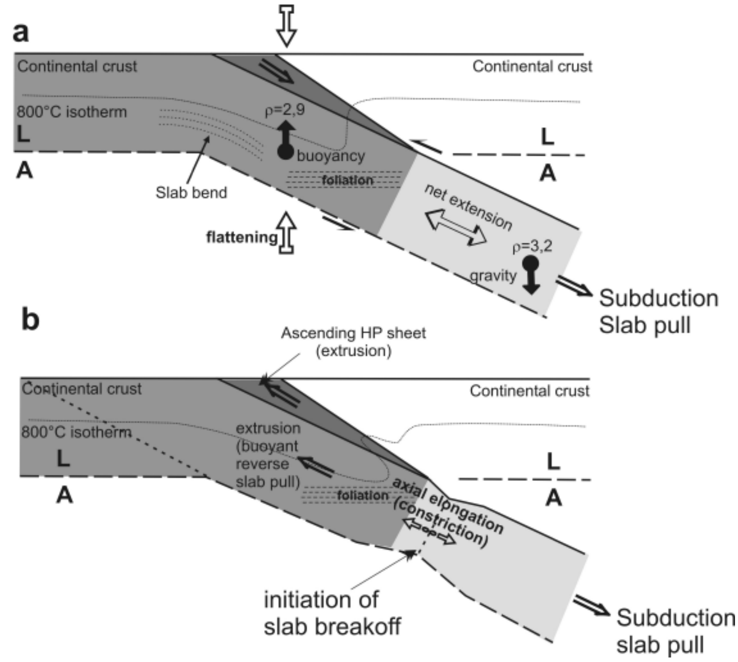

Fig. 4
Schematic cross section through a convergent plate margin showing qualitatively the force balance within the downgoing slab (a) and the mechanism of slab break-off initiation with the related crustal deformation processes (b).

4. Excursion Locations

First Day

Itinerary: Seggau - Graz - Klagenfurt - Spital a.d.Dr. - Mölltal - Heiligenblut - toll road "Großglockner Hochalpenstrasse" - Fuscher Törl - Edelweißspitze - Franz-Josefs-Haus - Heiligenblut - Winklern - Iselsberg Pass - Lienz - Matrei - Virgental - Prägraten - Hinterbichl.
Object of excursion: Introduction to the geology of the TW, retrogressed eclogites in the Großglockner area.
Topographic maps: Österreichische Karte 1:50000, sheet 153, Grossglockner, Alpenvereinskarte Großglocknergruppe 1:25000 (published by Österreichischer Alpenverein).
Geologic maps: HÖCK, V. & PESTAL, G. (1994): Geologische Karte der Republik Österreich 1:50000, sheet 153, Grossglockner, Geologische Bundesanstalt Wien.
CORNELIUS, H. P. & CLAR, E. (1934): Geologische Karte des Großglocknergebietes 1:25000, Geologische Bundesanstalt Wien.
CORNELIUS, H. P. & CLAR, E. (1935): Erläuterungen zur geologischen Karte des Großglockner-gebietes 1:25000. Geologische Bundesanstalt Wien, 34 p.
GPS: GPS coordinates are given according to the grid UTM (WGS84).

Fig. 5

Locations Edelweißspitze (1) and Gamsgrube (2) in the Großglockner area of the Hohe Tauern.

Location 1: Fuscher Törl (2404 m), RMN: geologic overview

The bus will be parked at Fuschertörl on the "Großglockner Hochalpenstrasse" and we intend to walk up to the Edelweißspitze (2580 m, GPS coord. 0335512/5221195) which will take us ~ 30 minutes (it is usually very windy there, so please take appropriate clothes and shoes with you). The main purpose of this stop is to get a first impression of the geology of the TW.

The huge dome-like structure of the TW can be seen to the north and, if the weather is clear, Zell am See, with its lake marking the northern border of the TW, is visible down in the Salzachtal valley. The white rocks further to the N already belong to the Northern Calcarous Alps of the Austroalpine Nappe Complex.

On the way up to Edelweißspitze we find yellowish dolomites, on the northern flank are outcrops of grey to light coloured quartzites and quartzitic schists intercalated with dark graphitic schists containing kyanite and chloritoid + chlorite. This flat lying sequence represents upper-Triassic sediments of the RMN (local name "Seidlwinkl-Trias") that underwent upper greenschist facies metamorphism (T around 500°C).

Location 2: Franz Josefs-Haus (2400 m), GN: retrogressed eclogites of locality "Gamsgrube" (GPS coord. 0328388 / 5217240)

The area around Franz-Josefs-Haus is probably the most touristic place along the "Großglockner Hochalpenstrasse" because it is close to Austria's highest peak, the Großglockner (3798 m), and allows a visit of one of the largest glaciers in Austria (the "Pasterze"). We will leave the bus for ~1.5 hours and walk along the footpath to the Hofmannshütte (2444 m). This path was closed several years because of rock avalanches, but has recently been reconstructed and now runs through several tunnels for public safety.

The rocks encountered around Franz-Josefs-Haus are typical greenschists ("prasinites") of the GN (Ab/Ol, Chl, ± Act/Hbl, Ep, ± Bt ± Carb ± Sph ± Phe), that might contain rhombohedral aggregates of Czo+Chl (pseudomorphs after lawsonite). The prasinites dip moderately to steeply towards the southeast because we are already in the southern part of the metamorphic dome, and represent MORB-type oceanic crust (BICKLE & PEARCE, 1975; HÖCK & MILLER, 1980). The other main rock types of the GN along the path are brownish to grey calc mica schists ("Bündner Schists", Cal, Phe, Qtz, ± Dol ± Bt ± Zo ± Chl ± ore ± graphitic-pigment) with occasional bands of relatively pure marbles and garnet mica schists.

At the Gamsgrube location is a band of rather inaccessible eclogitic amphibolite with an average thickness of ~ 20 m, running from near Hofmannshütte along the steep slope due north towards Fuscherkarkopf (from 2400 m to over 3000 m). This band is underlain by graphitic garnet-micaschists and overlain by carbonaceous garnet-micaschists and greenschists of the Bündner Schist country rocks (PROYER et al., 1999). The early workers in the Großglockner area already recognized the eclogitic nature of these rocks and used the term "eclogitic prasinites" for them (CORNELIUS & CLAR, 1939).

Boulders of this rock type can be found directly above Hofmannshütte on the footpath from Hofmannshütte to Oberwalderhütte. The most striking feature in hand specimen is the fine-grained reddish garnet set in a dense dark green foliated matrix. STURM et al. (1997), PROYER et al. (1999) and DACHS & PROYER (2001) performed a detailed petrographical study on these retrogressed eclogites, revealing a four-stage metamorphic evolution with peak pressures of ~17 kbar and temperatures of ~570 °C, followed by the main greenschist/amphibolite facies event ("Tauerncrystallization") constrained at P = 5 - 6 kbar, T = 500 - 530°C (Tab. 2).
Some petrographic characteristics of the retrogressed eclogites from the Gamsgrube location are shown in Figs. 6a,b. Representative microprobe analyses of minerals from this and the following locations are given in Tab. 3.

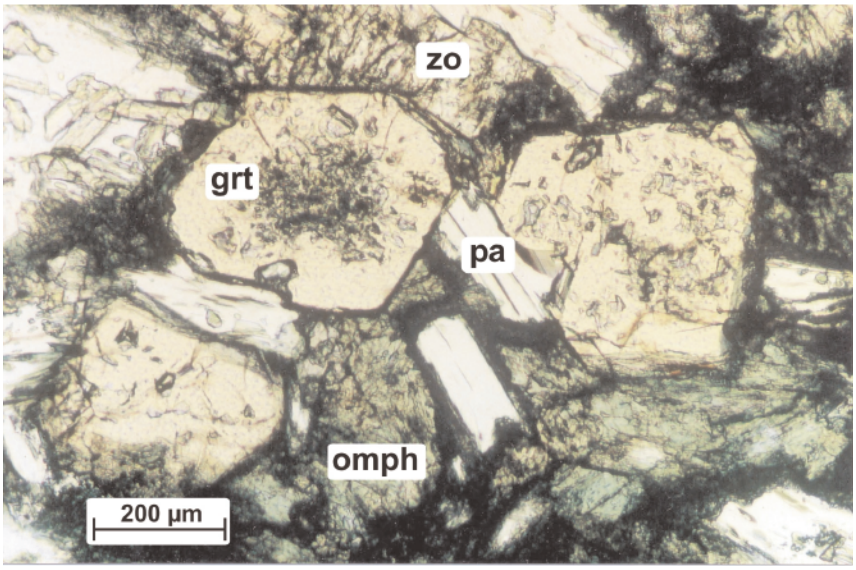

Fig. 6a
Eclogite paragenesis from Gamsgrube: garnet (grt), omphacite (omp), paragonite (pa) and zoisite. Additional dolomite, glaucophane, quartz and phengite are not within view. Dark areas show incipient breakdown to extremely fine grained symplectite.

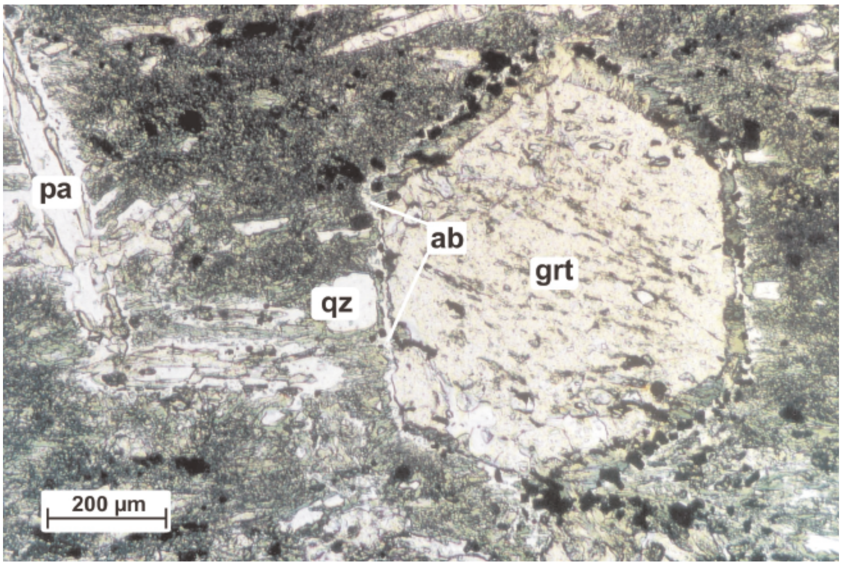

Fig. 6b
Gamsgrube: Replacement of idiomorphic garnet by polycrystalline rims of pargasitic amphibole + epidote (inner rim) and albite (ab) + magnetite (outer rim). Note the lack of corrosion of garnet along grain boundaries with matrix quartz (qz) and the light green rims of diopside around quartz grains. Paragonite (pa) is rimmed by clinozoisite and albite.

Another interesting feature found in this band of retrogressed eclogites was described by DACHS & PROYER (2001, 2002, their sample G5): the matrix assemblage in this rock is Grt + Omph + Pa + Glau + Zo/CZo + Phe + Dol + Qtz + Rt. The inclusion assemblage of Grt changes from core (Ep/CZo, Pa, Cal, Amph, Chl), where they are numerous and minute, to rim (CZo, Omph, Dol, Qtz), where they are few and coarse-grained (Fig. 7a).

The discontinuity in the inclusion texture, as visible under microscope, coincides with an abrupt change in chemical zoning, mainly in X_{Fe} and X_{Mn} from which times of diffusion can be calculated (Fig. 7b). Diffusion modelling on this overgrowth texture gave the fastest exhumation rates ever reported in the TW, of the order of several cm yr^{-1} (DACHS & PROYER, 2002).

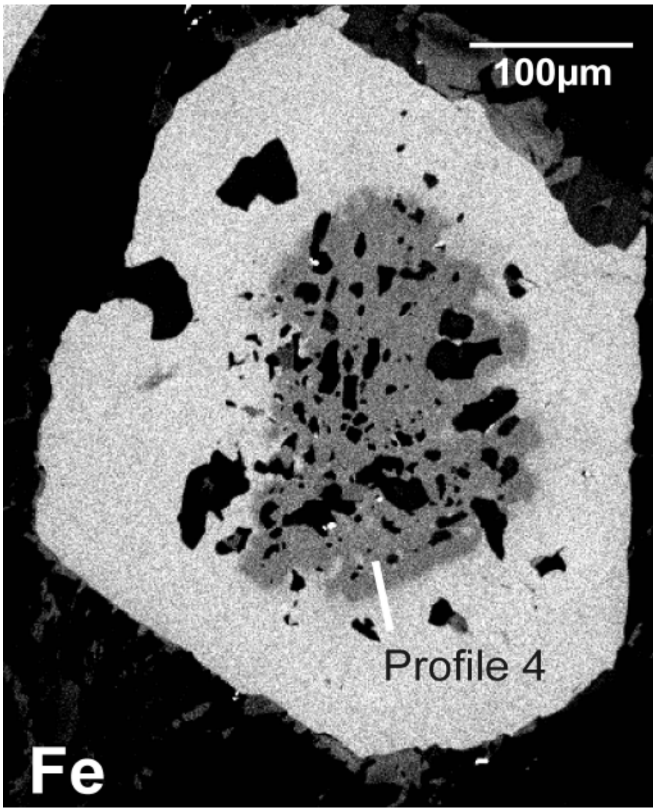

Fig. 7a
Eclogite garnet with discontinuous growth zoning from the Dorfertal.

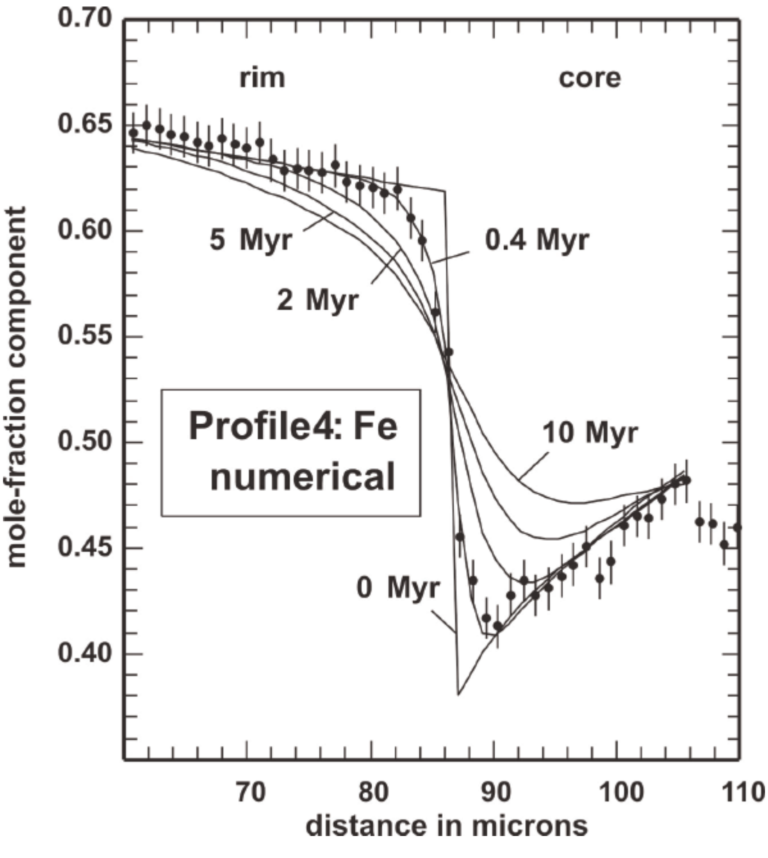

Fig. 7b
Result of numerical diffusion modelling for a detailed zoning profile for Fe, giving a best fit time span of 1.2 Ma from prograde growth of the eclogitic rim until diffusion closure at around 500°C during exhumation.

We return to the bus and continue the itinerary to Hinterbichl (~ 2 hours drive time), where accommodation will be provided.

	Location 2: retrogressed eclogites (GN)							Location 3: retrogressed eclogites (EZ)							Loc.4: marble with HP-relics (EZ)			
Mineral	Grt-c [1]	Grt-r	Omph	Phe	Pa	Glau	Dol	Grt-r	Omph-i-grt	Omph	Glau	Ep	Ky	Pa	Omph	Barr	Tr/Act	Ab
Stage	II	II	II	II	II	II	II	Ma0	Ma0	Ma0	Ma1	Ma0	Ma0	Ma0	Ma0	Ma1	Ma2	Ma2
SiO_2	37.42	37.7	56.08	51.58	47.51	57.72	0	38.77	55.91	55.83	57.56	38.19	36.75	48.87	55.35	53.94	56.34	67.84
TiO_2	0.22	0.09	0.05	0.17	0.04	0.03	0	0.01	0	0.049	0.06	0.14	0.013	0.12	0	0.02	0	0
Al_2O_3	20.75	20.72	9.8	27.96	38.63	11.43	0	22.03	7.81	9.89	10.31	25.34	62.38	37.87	7.82	6.64	0.61	19
Cr_2O_3	0	0	0	0.67	0	0	0	0.08	0.053	0.048	0.1	0.03	0.05	0.02	0	0	0	0
FeO	22.96	28.54	8.49	2.43	0.55	8.13	10.91	22.96	12.17	8.92	8.57	10.14	0.91	1.09	4.93	4.29	5.2	0.11
MgO	1.22	1.8	6.37	3.52	0.36	11.06	15.6	9.71	5.91	6.84	13.51	0.35	0	0.15	11.85	20.53	22.69	0.07
CaO	11.74	9.42	11.23	0.16	0.14	0.89	29.91	5.09	9.13	10.31	1.9	22.52	0	0.24	14.92	8.18	12.44	0.22
MnO	5.30	1.05	0.11	0	0	0	0.39	1.2	0.2	0.097	0.06	0.13	0.01	0.01	0.06	0.02	0.26	0
Na_2O	0.04	0.02	7.56	0.65	7.21	6.8	0	0	9.32	8.66	6.02	0.02	0	7.37	5.24	4.16	0.05	11.79
K_2O	0	0	0	9.51	1.06	0.03	0	0	0	0	0.06	0	0	0.7	0.02	0.02	0.02	0.05
Total	99.65	99.34	99.69	96.65	95.5	96.09	56.81	99.85	100.5	100.64	98.15	97.99	100.21	96.44	100.19	97.8	97.61	99.1
Oxygens	12	12	6	11	11	23	2	12	6	6	23	12.5	5	11	6	23	23	8
Si	2.987	3.022	2.020	3.382	3.035	7.970	0	2.955	1.994	1.974	7.814	3.004	0.993	3.092	1.967	7.404	7.826	2.995
Ti	0.013	0.005	0.001	0.008	0.002	0.003	0	0.001	0	0.001	0.006	0.008	0	0.006	0	0.002	0	0
Al	1.952	1.957	0.416	2.160	2.909	1.860	0	1.979	0.328	0.412	1.649	2.349	1.987	2.823	0.327	1.074	0.100	0.989
Cr	0	0	0	0.035	0	0	0	0.005	0.001	0.001	0.011	0.002	0.001	0.001	0	0	0	0
Fe3	0.053	0	0.069	0	0	0.005	0	0.104	0.327	0.230	0.166	0.667	0.021	0	0.101	0.245	0.009	0.004
Fe2	1.480	1.913	0.187	0.133	0.029	0.934	0.282	1.359	0.036	0.034	0.807	0	0	0.058	0.045	0.248	0.595	0
Mg	0.145	0.215	0.342	0.344	0.034	2.277	0.718	1.103	0.314	0.361	2.734	0.041	0	0.014	0.628	4.201	4.699	0.005
Ca	1.004	0.809	0.433	0.011	0.010	0.132	0.990	0.416	0.349	0.391	0.276	1.898	0	0.016	0.568	1.203	1.851	0.010
Mn	0.358	0.071	0.003	0	0	0	0.010	0.077	0.006	0.003	0.007	0.009	0	0.001	0.002	0.002	0.031	0
Na	0.006	0.003	0.528	0.083	0.893	1.821	0	0	0.644	0.594	1.584	0.003	0	0.904	0.361	1.107	0.013	1.009
K	0	0	0	0.795	0.086	0.005	0	0	0	0	0.010	0	0	0.056	0.001	0.004	0.004	0.003
Cations	8	8	4	6.95	7	15.01	2	8	4	4	15.06	7.98	3	6.97	4	15.49	15.13	5.02
X_{Fe} [2]	0.5	0.64	0.45	0.618	0.965	0.03		0.46	0.33	0.39	0.186			0.908	0.28	0.596	0.1	0.99
X_{Mg}	0.05	0.07	0.07	1.542	1.944	1.83		0.37	0.32	0.22	1.463			1.915	0.09	0.478	0	0.01
X_{Ca}	0.33	0.27	0.48			1.951		0.14	0.35	0.39	1.81				0.63	1.82	1.67	0
X_{Mn}	0.12	0.02				0.29		0.03			0.23					0.06	0.11	

	Loc. 5: coarse-grained gabbroic eclogites (EZ)						Loc. 8: fine-grained banded eclogites (EZ)						Loc. 9. fine-grained boudinaged eclogites (EZ)						
Mineral	Grt-r	Omph1	Omph2	Pa	Parg-r-grt	Mg-Hbl-sy	Grt-r	Omph2	Pa	Glau	Hast-i-grt	Ed-sy	Grt-r	Grt-c	Omph1	Omph2	Pa	Barr	Mg-Hbl
Stage	Ma0	Ma0	Ma0	Ma0	Ma1?	Ma2	Ma0	Ma0	Ma0	Ma0	Ma0	Ma2	Ma0	Ma0	Ma0	Ma0	Ma0	Ma1?	Ma2
SiO_2	37.67	55.76	57.31	49.05	41.23	48.58	37.96	57.41	48.73	59.93	43.64	47.23	39.36	37.9	55.9	56.65	46.14	50.28	51.82
TiO_2	0.02	0.1	0.03	0.1	0.022	0.08	0.17	0.02	0.07	0.04	0.329	0.463	0.041	0.2	0.069	0.07	0.08	0.302	0.224
Al_2O_3	21.6	10.58	15.19	38.39	19.26	11.23	21.61	12.32	39.24	12.11	12.18	10.61	22.31	20.79	7.94	11.3	40.68	11.31	4.42
Cr_2O_3	0	0.43	0.12	0	0	0.015	0	0	0.08	0.015	0	0.036	0.068	0	0.024	0.08	0	0.047	0.012
FeO	29.02	4.49	2.03	0.13	13.09	6.23	25.61	2.45	0.15	3.89	13.95	10.39	24.76	21.02	7.91	3.03	0.45	12.24	12.44
MgO	2.64	8.17	6.93	0.26	9.43	17.31	4.97	7.93	0.11	13.94	13.04	15.49	6.8	4.03	8.81	8.96	0.32	12.46	15.46
CaO	8.19	12.74	9.78	0.17	10.28	11.5	8.09	11.53	0.3	1.14	11.36	11.3	7.69	9.22	13.19	12.88	0.15	7.35	12.8
MnO	0.89	0.02	0.04	0	0.26	0	1.4	0	0.02	0.005	0.078	0.107	0.357	6.96	0	0.04	0	0.078	0.26
Na2O	0.01	7.47	8.76	7.45	3.81	2.62	0.01	8.55	7.16	7.02	3.28	2.95	0.021	0.01	7.14	7.23	7.29	4.2	0.857
K2O	0.01	0	0.01	0.82	0.71	0.28	0	0.01	0.53	0.02	0.175	0.139	0	0	0	0	0.64	0.262	0.124
Total	100.05	99.76	100.2	96.37	98.092	97.845	99.82	100.22	96.39	98.11	98.032	98.715	101.41	100.13	100.98	100.24	95.75	98.529	98.417
Oxygens	12	6	6	11	23	23	12	6	11	23	23	23	12	12	6	6	11	23	23
Si	2.986	1.979	1.991	3.091	6.004	6.796	2.97	2.001	3.064	7.948	6.366	6.688	2.994	2.974	1.978	1.991	2.937	7.065	7.386
Ti	0.001	0.003	0.001	0.005	0.002	0.008	0.01	0.001	0.003	0.004	0.036	0.049	0.002	0.012	0.002	0.002	0.004	0.032	0.024
Al	2.018	0.442	0.622	2.851	3.305	1.851	1.993	0.506	2.908	1.893	2.094	1.771	2	1.923	0.331	0.468	3.052	1.873	0.742
Cr	0	0.012	0.003	0	0	0.002	0	0	0.004	0.002	0	0.004	0.004	0	0.001	0.002	0	0.005	0.001
Fe3	0.009	0.097	0	0	0.298	0.338	0.049	0.069	0	0.003	0.502	0.437	0.006	0.106	0.199	0.037	0	0.461	0.362
Fe2	1.915	0.036	0.059	0.007	1.296	0.391	1.626	0.002	0.008	0.429	1.2	0.793	1.569	1.274	0.035	0.052	0.024	0.977	1.121
Mg	0.312	0.432	0.359	0.024	2.047	3.61	0.58	0.412	0.01	2.756	2.836	3.27	0.771	0.472	0.465	0.469	0.03	2.61	3.285
Ca	0.696	0.484	0.364	0.011	1.604	1.724	0.678	0.431	0.02	0.162	1.776	1.714	0.627	0.775	0.5	0.485	0.01	1.106	1.955
Mn	0.06	0.001	0.001	0	0.032	0	0.093	0	0.001	0.001	0.01	0.013	0.023	0.463	0	0.001	0	0.009	0.031
Na	0.002	0.514	0.59	0.91	1.076	0.711	0.002	0.578	0.873	1.805	0.928	0.81	0.003	0.002	0.49	0.493	0.9	1.144	0.237
K	0.001	0	0	0.066	0.132	0.05	0	0	0.043	0.003	0.033	0.025	0	0	0	0	0.052	0.047	0.023
Cations	8	4	3.99	6.97	15.8	15.48	8	4	6.93	15	15.78	15.57	8	8	4	4	7.01	15.33	15.17
X_{Fe} [2]	0.64	0.43	0.6	0.909	1.996	1.204	0.55	0.51	0.936	0.052	1.634	1.312	0.52	0.43	0.31	0.46	1.063	0.935	0.614
X_{Mg}	0.11	0.09	0	1.942	1.309	0.647	0.19	0.07	1.972	1.84	0.46	0.459	0.26	0.16	0.19	0.04	1.989	0.937	0.128
X_{Ca}	0.23	0.48	0.4		2	2	0.23	0.42		1.966	1.96	1.98	0.21	0.26	0.5	0.5		1.97	2
X_{Mn}	0.02				0.39	0.1	0.03			0.13	0.3	0.2	0.01	0.15				0.27	0.25

[1] -c: core, -r: rim, i-grt: inclusion in Grt, r-grt: rim around Grt, -sy: in symplectite

[2] X_{Fe}, X_{Mg}, X_{Ca}, X_{Mn} for Grt; X_{Jd}, X_{Ae}, X_Q for Omph; Al^{IV}, Al^{VI} for Phe and Pa; Al^{IV}, Al^{VI}, $(Ca+Na)_B$, X_{Fe} for Amph; X_{Fe} for Dol; X_{Ab}, X_{An}, X_{Or} for Plag

Table 3

Representative chemical analyses and formulas for minerals from locations 2, 3, 4, 5, 8 and 9.

Second Day

Itinerary: Using "Venediger Taxi" minibuses we will climb up from Hinterbichl to Dorfertal - Johannishütte (2121 m). After having viewed the locations here we will return to Hinterbichl around noon. After some refreshment and having picked up our equipment for staying overnight we will again use the "Venediger Taxi" and go to Prägraten - Bodenalm (1955 m). From here we will take the footpath to the Eisseehütte (2500 m) in Timmeltal (~ 2.5 hours walk), where we will stay overnight. Please be properly equipped for alpine conditions (mountain-boots, warm clothes, and gloves etc.).

Object of excursion: eclogite lenses and HP-metasediments of the EZ in the Dorfertal-section of the southern Großvenediger area; cross-section through lithologies of GN, RMN and EZ.

Fig. 8

Locations in the Dorfertal (3, 4) and the Timmeltal (5 - 9) of the Eclogite Zone.

Topographic maps: Österreichische Karte 1:50000, sheet 152, Matrei in Osttirol, Österreichische Karte 1:50000, sheet 151, Krimml, Alpenvereinskarte Venedigergruppe 1:25000 (published by Österreichischer Alpenverein).

Geologic maps: FRANK, W., MILLER, CH. & PESTAL, G. (1987): Geologische Karte der Republik Österreich 1:50000, sheet 152, Matrei in Osttirol, Geologische Bundesanstalt Wien.

KARL, F. & SCHMIDEGG, O. (1979): Geologische Karte der Republik Österreich 1:50000, sheet 151, Krimml, Geologische Bundesanstalt Wien.

RAITH, M., MEHRENS, C. & THÖLE, W. (1980): Gliederung, tektonischer Bau und metamorphe Entwicklung der penninischen Serien im südlichen Venediger-Gebiet, Osttirol. Jb. Geol. B.-A. Wien, 123, 1-37, 1 geologic map.

SCHMIDEGG, O. (1961): Geologische Übersicht der Venedigergruppe nach dem derzeitigen Stand der Aufnahmen von F. Karl und O.Schmidegg. Verh. Geol. B.-A. Wien, Jg. 1961, 35-36, 1 geologic map 1:100000.

Geology along Dorfertal (from south to north)

Because the rocks dip steeply towards south, the route from Hinterbichl (1330 m) up to Johannishütte (2121 m) offers a cross-section from tectonically higher to tectonically lower units (from the GN, through RMN and EZ down to the upper VN - Fig. 2c). The metamorphic grade increases northwards accordingly from ~ 450°C in the area south of Hinterbichl to ~ 530°C in EZ and VN rocks at Johannishütte, as determined by calcite-dolomite geothermometry (DACHS, 1990) and phase relations in metasediments and metabasics (e.g. HOSCHEK, 1980; RAITH et al., 1977).

The steep flanks at the beginning of the valley are made up of a thick prasinite layer from the GN (Ab, Ep, Chl, Amph (act.Hbl-Barr), ± Bt ± Cal ± Qtz ± Phe ± Sph ± Pyr ± Mt; DACHS et al., 1991), which is quarried for building stone and as ornamental stone. The prasinites intercalate with brown-weathered calcareous schists (Cal/Dol, Phe, Qtz, ± Pl ± Chl ± Zo ± Grt ± Bt ± Tur ± Ap), with mainly tectonic contacts. Former pelitic horizons in these Bündner Schists are present as thin layers of (garnet-)mica schists (Phe, Qtz, ± Grt, Pa, Chl, Bt, Zo, Cal, Dol, Plag, Pyr). A large serpentinite body outcrops at 1760m, surrounded by brown calcarous mica schists, and is also quarried. At the contact with the Ca-rich metasediments a rodingite series is developed (grossular/andradite Grt, Di, Ep, Tr, Calc, Chl, etc., DIETRICH et al., 1986); along strike a number of such serpentinite bodies can be mapped and this tectonic horizon is considered to form the base of the GN in this area. The rocks underlying the RMN again comprise greenschists and calcareous mica schists similar to the GN, with a thin Permo-Triassic sequence at the base consisting mainly of quartzites or quartzitic schists (Qtz, Phe, Plag, ± Chl, Cal, Dol, Pyr) and marbles, with a maximal thickness of around 50m at Zopetscharte (Cal, Dol, Phe, Zo, Tr, Chl, Qtz). This unit rests upon mica schists and paragneisses (i.e. meta-arkoses: Plag, Kfs, Qtz, Phe, Bt, Chl, Zo/Ep) with some garnet amphibolites interfolded, which are considered to be the continental basement of the RMN (KURZ et al., 1996, 1998). Rocks of the tectonically deeper EZ, which has its maximal thickness further east in the Timmeltal, are tectonically reduced in the Dorfertal section to a small horizon crossing the valley north of "Ochsnerhütte" at around 2070 m (for further details see Locations 3 and 4). Mica Schists with aplitic veins and gneisses at Johannishütte (2121 m) and further north already belong to the upper parts of the VN.

Location 3: Dorfertal, close to Johannishütte (2121 m), EZ: Eclogite lenses and host rocks
(GPS coord. 0297995 / 5214990, 2380 m)

From Johannishütte we follow the footpath to Zopetscharte. After ~ 30 min walk, at a point just below 2480 m, the path crosses a band of outcrop approximately 30m high that consists of brown calcarous and grey quartzitic schists with, in places, dark lensoid bodies of garnet-bearing banded eclogites that usually have dimensions ranging from several metres to tens of meters. Boulders from these banded, boudinaged eclogites can be found further down along the path where blocks of more coarse-grained varieties also occur.
Microscopic investigation reveals a paragenesis of Grt + Omph + Phe + Ep + Amph + Pa + Qtz. Garnets are up to 2 mm in size, with a smooth bell-shaped prograde compositional zoning (Mn, Fe and Ca decreasing to wards the rim), and inclusion-rich: Epidote and paragonite predominate in the cores, sometimes forming rhomb-shaped pseudomorphs after lawsonite, and omphacite enters in towards the rims. The amphibole is a greenish-blue barroisite. Omphacite and epidote are mostly alligned to the strong foliation, amphibole and paragonite only to a lesser degree (Fig. 9).

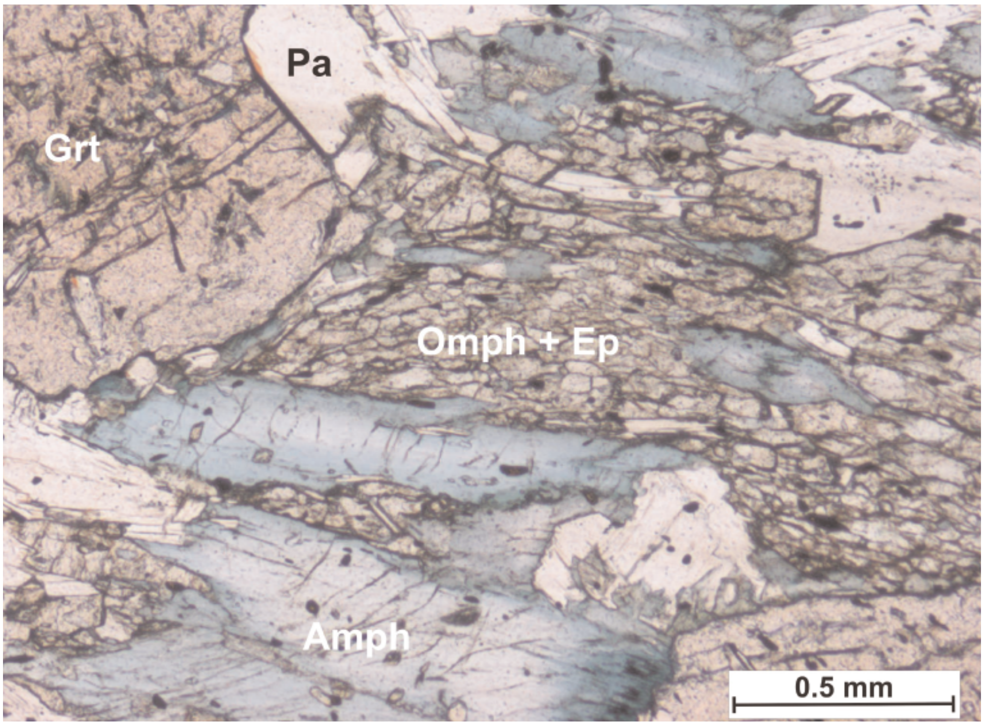

Fig. 9
Foliated eclogite from the Gastacher Wände, E of Johannishütte, with pale omphacite and epidote and bluish-green barroisitic amphibole.

Location 4: Dorfertal, EZ: Marble with Omph-relics
(GPS coord. 0297491 / 5214911, 2120 m)

About 250 m before Johannishütte along the eastern side of the road a thin marble outcrops within a sequence of mostly quartzitic schists. Following this marble layer along strike, a sequence of white carbonate-rich material is interfolded with dark-green amphibolitic material, crossing the river at 2090 m, where there is a little bridge with a footpath across it.

Under the microscope and as revealed by EMP-work, Cal, Qz, Tr are the main constituents and ± Tc-Zo-Dol-Chl-Phl-Sph can also be observed. That this marble experienced eclogite facies conditions can be inferred from the irregularly distributed brown symplectite patches (mainly fine-grained barroisitic Amph+Ab) that are always surrounded by pure albite rims. Omph is only rarely still present, either in the core of larger Tr-grains (in this case rimmed by Barr), or isolated in the Cal-rich matrix (then rimmed by Di). The omphacites preserved in Tr-cores were obviously decomposed in a two-stage process (DACHS, 1986):

Omph + H_2O + CO_2 → Barr + Ab + Cal and

Barr ± Cal → Tr + Ab

Third Day

Itinerary: From Eissehütte (2528 m) we will follow path 923 to Wallhorntörl (3045 m). In the area just below (Wallhornkar) will be the highest planned stop (Location 7). There will also be the possibility for interested colleagues to climb Weißspitze (3300m) which, however, requires some alpinistic skills. We will then return along path 923 and turn east to Eissee for the last stop at Location 9, before returning past Eisseehütte to Bodenalm where the minibuses will again pick us up and bring us down to Prägraten. From here back to Graz via Matrei in Osttirol, Lienz and Klagenfurt.

Object of excursion: eclogites and HP-metasediments of the central EZ in Timmeltal (Fig. 10)

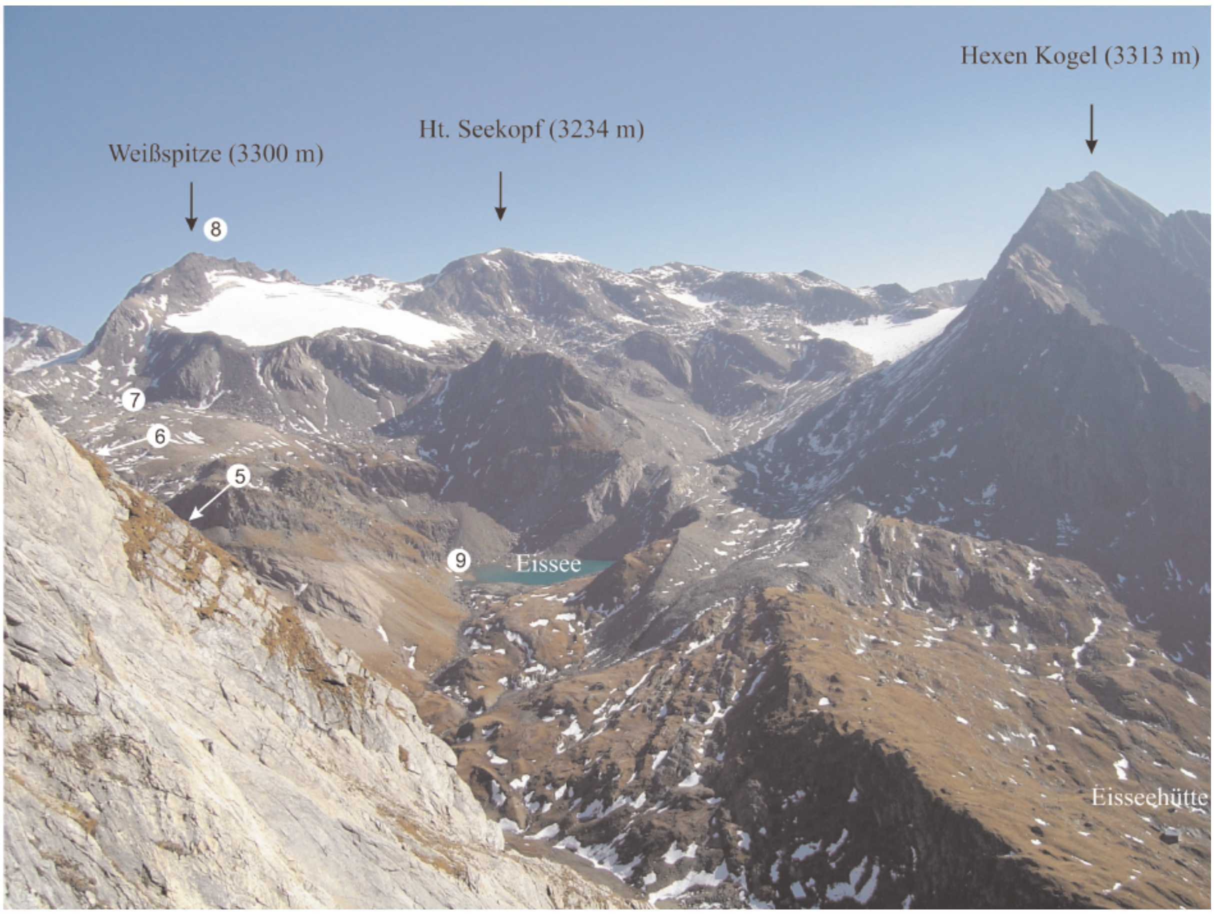

Fig.10
Central EZ of the upper Timmeltal with Eissee in the middle, seen from Zopetscharte (2958 m) looking towards the northeast. Eisseehütte (2500 m) is visible close to the lower right corner. The line marks the footpath. Numbers indicate the designated Locations (Locations 5 and 6 not in view). Light coloured rocks in the left foreground are a ~50 m thick marble (Permo-Trias of RMN), underlain by arkose-gneisses of Zopetspitze (3198 m).

Fig. 11a
Large single grains of red garnet and green omphacite in a whitish matrix are typical features of the gabbroic eclogites of the Eclogite Zone.

Location 5: Upper Timmeltal: Coarse-grained gabbroic eclogites of the EZ (type E1, Tab. 1)
(GPS coord. 0300678 / 5215621, 2726 m)

The first stop along the footpath from Eissee to Weißspitze is a field of huge eclogite boulders (type E1 of MILLER, 1977) with spectacular coarse-grained omphacite crystals clearly discernible in hand specimen (Fig. 11a). The coarse grained omph I ($Jd_{44-52}Ae_{5-10}$, supposedly pseudomorphic after augite) shows dynamic recrystallization to a more jadeitic omph II ($Jd_{60}Ae_{0-2}$) along the margins, coexisting with garnet, paragonite, quartz and rutile, now embedded mainly in late stage symplectite (Fig. 11b). MILLER (1977) describes inclusions of talc and kyanite in the margins of garnets of this type, indicative of a prior metamorphic stage at pressures above the stability fields of paragonite (HOLLAND, 1979).

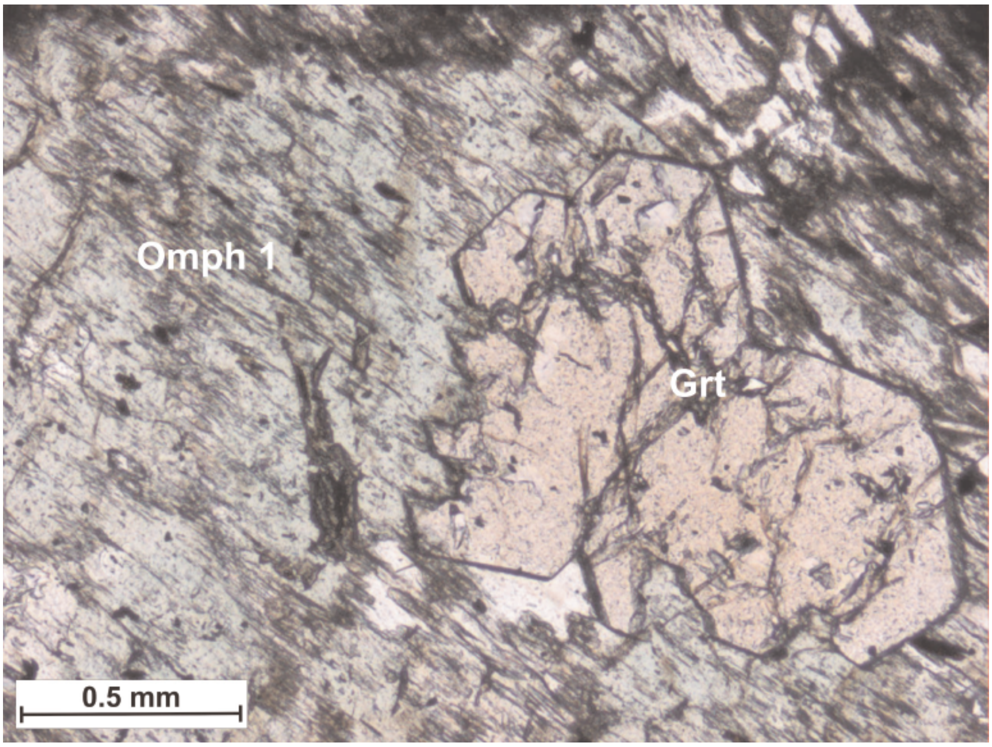

Fig. 11b
Idiomorphic garnet intergrown with mm-sized grain of omphacite 1 in coarse grained gabbroic eclogite.

Location 6: Upper Timmeltal: Eclogite (micro)fabrics
(GPS coord. 0301012 / 5215945, 2862 m)

Syn-eclogitic deformation structures are difficult to reconstruct because the eclogites are often retrogressed to garnet-amphibolites and garnet-bearing greenschists during exhumation. The degree of retrogression of the eclogites is irregularly distributed, both within the Eclogite Zone and within individual eclogite bodies. Where the stretching and/or mineral lineation is defined by HP minerals (e.g. Grt, Omph, Ky, Glau), its orientation is variable in some places. A majority of mineral lineations, especially of Omph and Glau, dip to the S to SW. Associated sense-of-shear criteria indicate top-to-the north general shear. The variation of lineation orientations may be related to variable rotation of eclogite slices and boudins during later greenschist to amphibolite facies deformation. The penetrative eclogitic foliation, generally oriented subparallel to principal tectonic contacts, is transposed subparallel to the penetrative mylonitic foliation formed

under amphibolite facies metamorphic conditions. In general the foliation strikes east-west and dips to the south. This foliation is defined by the subparallel arrangement of actinolitic Hbl, Ep, Chl and locally Bt, and is also associated with a well-developed, E-trending, subhorizontal stretching lineation, defined primarily by actinolitic Hbl and Plag. In metapelites and meta-carbonates, the foliation orientation is close to that of the shear planes (C). It is transected by C´ and to a lesser extent by C´´ shear bands at scales of centimetres, decimetres and metres. These sense-of-shear indicators (shear bands and extensional crenulation cleavage) document top-to-the W displacement related to the exhumation of the Penninic nappe stack under amphibolite to greenschist metamorphic conditions.
The whole lithological sequence is affected by E-trending isoclinal folds (Fig. 12) and subsequently by open to tight E-W striking folds with subhorizontal axes. A final deformation is documented by km-scale (map-scale) N-trending open folds.

Fig. 12
Folded eclogitic metasediments near the Wallhornkar.

Location 7: Upper Timmeltal (Wallhornkar): Various eclogite types of the EZ , HP veins and sediments

(GPS coord. 0301451 / 5216381, 2950 m)

The area below the Wallhorn Törl (3060m) exhibits a profile through a metasedimentary sequence of garnet amphibolites (retrogressed eclogites), marbles, calc-schists, garnet-micaschists and quartzites with relict HP-minerals (see DACHS 1986, Tab. 4, Fig. 13). This evidence shows that the entire Eclogite Zone (eclogites and the intercalated metasediments) have been subject to high-pressure metamorphism.

Adjacent to the outcrops, moraine material also contains blocks of eclogite with kyanite-omphacite-quartz-rutile veins, similar to those that we will find higher up at the summit of the Weißspitze.

Profile [m]	Description
0	strong retrogressed eclogite, Omph+Grt largely decomposed, dark green parts (Barr, Amph, Plag, Chl, Zo, Rt, Il, Mt,±Phe-Bt-Pa) irregularly mixed with bright-green zones (Ep, Plag, Amph, Bt, Phe, Carb)
34	brown weathered, strongly foliated graphitic Grt-mica schist (Grt, Phe1/2, Qtz, Chl, Pa, Zo, Cal, Dol, Ap, Rt, Gr)
43	amphibolite, in places with Grt
48	alternating bands of dark Grt-mica schists (Grt, Phe, Zo, Qz, Bt, Rt, Sph, Ap, Gr) and bright brownish calcarous-mica schists with quarzitic layers; s 185/45
53	coarse-grained Grt-amphibolite (Barr with Glau-cores, Grt with Omph inclusions, Plag, Chl, Bt, Pa, Phe, Qtz, Zo, Rt. s 176/60
62	yellow-brownish quartzite with limonite
63	concordant Grt-amphibolite
66	brown calcarous mica schist with cm-thick layers of Grt-mica schist. Late veins with Qtz, Fsp, Zo
67	s-parallel intercalated Grt-amphibolite (Grt, Amph, Plag, Chl, Phe, Sph)
85	bright-grey to yellowish strongly foliated Grt-mica schist (Grt, Qtz, Phe, Pa, Plag, Chl, Bt, Act, Tc, Rt, Sph) with s-parallel Qtz-veins
85.7	5 cm thick Grt-amphibolite band intercalated
86	dark-grey Grt-mica schists with Omph-relics (Grt, Phe1/2, Tc, Pa, Zo, Ky, Qtz, Plag, Chl, Bt, Omph, Sym, Ma, Cal, Rt, Ap)
86.7	brown, limonite-pigmented quartzite
88	strongly retrogressed eclogite (Grt, Omph, Sym, Amph, Phe, Chl, Bt, Zo/Ep, Rt)
91.5	yellowish, quartzitic Grt-mica schist with Qtz-veins (Grt, Phe, Qtz, Plag, Pa, Chl, Bt, Rt, Sph). Grades into a Zo-quartzite (Qtz, Phe, Zo, FeS).
91.8	retrogressed eclogite (Grt, Omph, Sym, Plag) partly transformed to amphibolite (Amph, Plag, Phe, Pa, Chl, Tc, Zo/Ep, Qtz, Cal, Dol)
92.1	yellowish calcite marble
92.4	bright quartzitic Grt-mica schist with Qtz-veins. Grades into
92.9	white quartzite (Qtz, Phe, Zo, FeS). Without tectonic contact follows a (Fig. 10)
93.1	strongly retrogressed eclogite (Omph, Grt, Sym, Zo/Ep, Amph, Phe, Chl, Plag, Qtz)
93.4	bright quartzite
93.7	Qtz-bearing Cal/Dol-marble (Cal, Dol, Qtz, Tr, Zo, Chl, Plag)
95	brownish calc-mica schist with more pure carbonate layers
96.3	Ky-bearing, Grt-mica schist with Carb and Zo (Phe1/2, Zo/Ep, Chl, Grt, Ky, Qtz, Ab, Cal, Dol, Rt, Il, FeS) grading into a
97	Cal-marble with Omph-relics (Cal, Phe, Zo, Tr, Tc, Chl, Qtz, Omph, Di)
97.7	Grt-amphibolite
98	Cal-marble, grading into a
99.3	Ky-Zo bearing Grt-mica schist (Grt, Phe, Zo, Qtz, Ky, Pa, Ma, Bt, Rt, Ap) with Qtz-veins
101	calc-mica schist with layers of pure Cal-marble
103	quartzitic, brown-weathered Grt-mica schist with Grt up to 2 cm in size and s-parallel layers of green Grt-amphibolite
105.5	bright quartzitic mica schist without Grt
109	dark graphitic Grt-mica schist
109-133	quartzites, quartzitic and graphitic mica schists, calcarous schists with layers of Grt-amphibolite

Table 4

Detailed lithological profile across a sequence of more or less strongly retrogressed high-pressure metasediments in the Wallhornkar; from DACHS (1986).

Fig. 13
Meters 92.1 (right) to 95 (left) from the metasedimentary sequence in the Wallhornkar (Table 4).

Fig. 14
Kyanite-omphacite-quartz-seggregation in eclogite from the Weißspitze.

Location 9: Upper Timmeltal (Eissee): Eclogite-boudins/Edelweiß
(GPS coord. 0301357 / 5215748, 2681 m)

The towering rock masses north of the Eissee consist of strongly boudinaged banded eclogite (Fig. 15) with a paragenesis of Omph + Grt + Glau + Pa + Ru + Qtz. Greenish actinolite and some albite form along cataclastic veins.

Along the eastern shore of lake Eissee, eclogite boudins are exposed in a matrix of marble mylonite, calcareous micaschists and metapelites. Symmetrically boudinaged eclogite layers locally document pure shear deformation as well as strain partitioning during deformation under amphibolite facies metamorphic conditions.

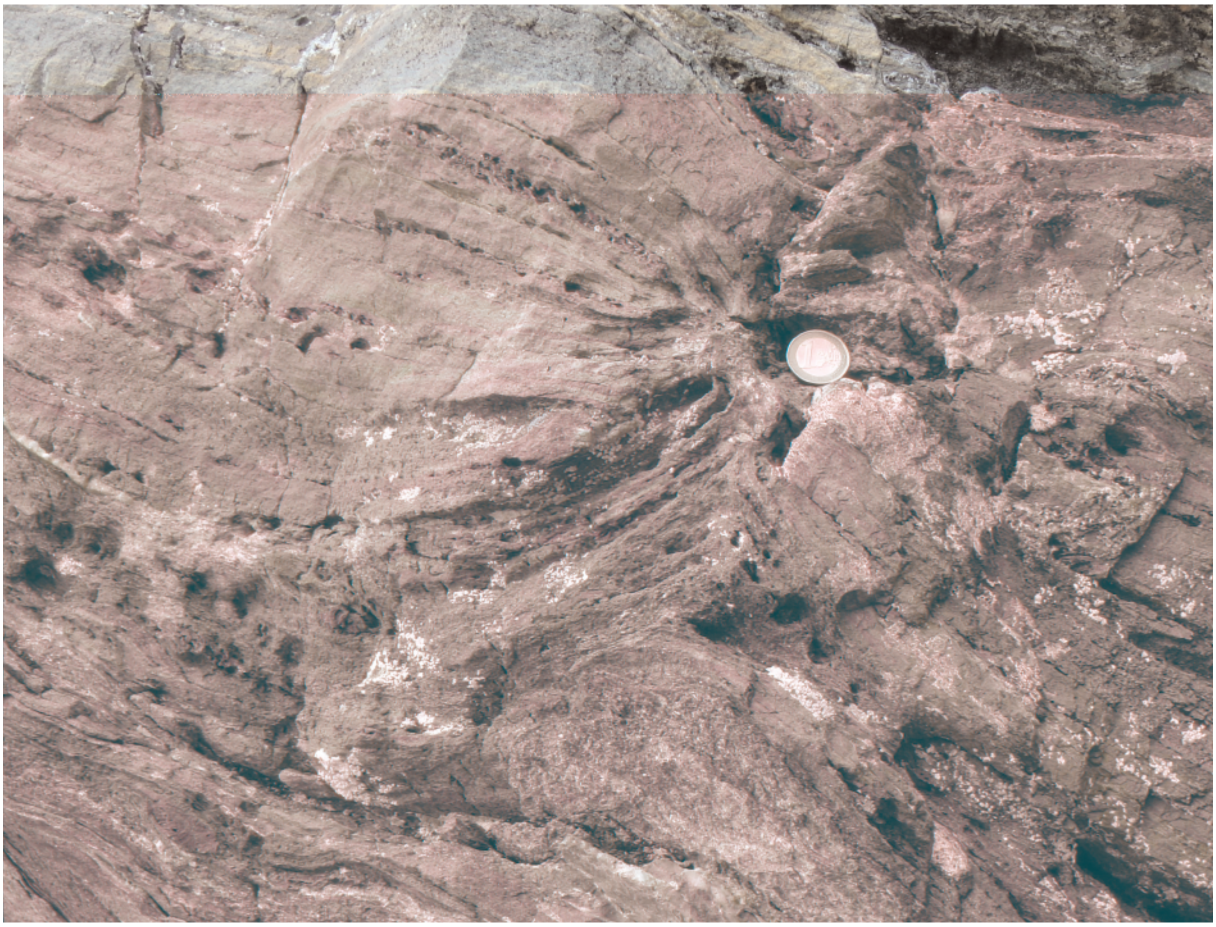

Fig. 15
Foliated and boudinaged eclogite from north of Eissee.

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