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5TH WORKSHOP OF ALPINE GEOLOGICAL STUDIES FIELD TRIP GUIDE E5 LOW T - HIGH P METAMORPHISM IN THE TARNTAL MOUNTAINS (LOWER AUSTROALPINE UNIT)

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With 7 figures

1 Introduction

Despite extensive investigation of the Alpine P-T-t evolution in the Eastern Alps and especially within the frame of the Tauern Window, only little work has been carried out so far within nappe units exposed around central parts (Penninic, Piemontais) of the Tauern Window. They are defined in the Eastern Alps as the Lower Austroalpine units (LAA) and are exposed in the northeastern and northwestern rim around the Tauern Window (Tollmann, 1977). They have generally been regarded as a low-grade metamorphic system related to lower to middle greenschist facies (Tollmann, 1977). Published geochronologic data are very limited (Häusler, 1988) compared to the extensive geochronological research within Penninic units and the Tauern Window in general (Cliff et al. 1971, 1985; Oxburgh & Turcotte 1974; Miller 1977; Satir 1975; Blanckenburg et al. 1989; Zimmermann et al. 1994).

Although it has been widely accepted that the LAA units comprise tectonically different segments of the Eastern Alps compared to the Penninic units, the tectonic relations NW and S of the Tauern Window are complicated by exposure of ultramafic-mafic structural units within the LAA sequence. The largest of these is represented by a fragment of the Mesozoic oceanic crust. This ultramafic-mafic body is named by Dingeldey et al. (1997) "Reckner Complex" (or "Reckner Ophiolite"). The exposed sections of this disrupted suboceanic lithosphere occur within an area of 20 km2, and have been investigated and described in detail by DINGELDEY (1990, 1995) and Koller et al. (1996). Beside remnants of an oceanic event, the Reckner Complex (RC) records a high-pressure, low-temperature (HP-LT) metamorphic evolution which is uncommon for the Austrian parts of the LAA nappe system (Hoinkes et al., 1999). Therefore, the correlation of the RC with other structural elements of the LAA system is uncertain and a relation to ophiolites exposed in central Tauern Window has been proposed (Dingeldey, 1995). A better correlation was defined to the Zone of Matrei at the southern rim of the Tauern Window (Koller et al., 1999, Melcher et al., 2001).

The paper by Dingeldey et al. (1997) presents results of a collaborative petrological and geochronological study along the northwestern borders of the Tauern Window and is the base for this excursion guide. It comprises data collected along several representative profiles from the highest LAA nappe units tectonostratigraphically downward to Southpenninic units exposed in the Tauern Window area. These results help to understand the tectono-thermal evolution of the northern rim of the Penninic Tauern Window.

2 Geological setting

The excursion area is situated in the "Tarntal Mountains", also named "Tarntaler Berge", which are a mountain range about 25 km SE of the city of Innsbruck, Tyrol (Fig. 1). The Penninic unit and the Austroalpine nappe system in the framework of the Tauern Window are the deepest exposed parts of the Eastern Alps. Tectonostratigraphically the major structural units in the excursion area include from the top to the base the following units (Fig. 2):

a) The "Quartzphyllite Nappe" (QPN) comprised of supposed Paleozoic units with monotonous phyllites and subordinate carbonates.

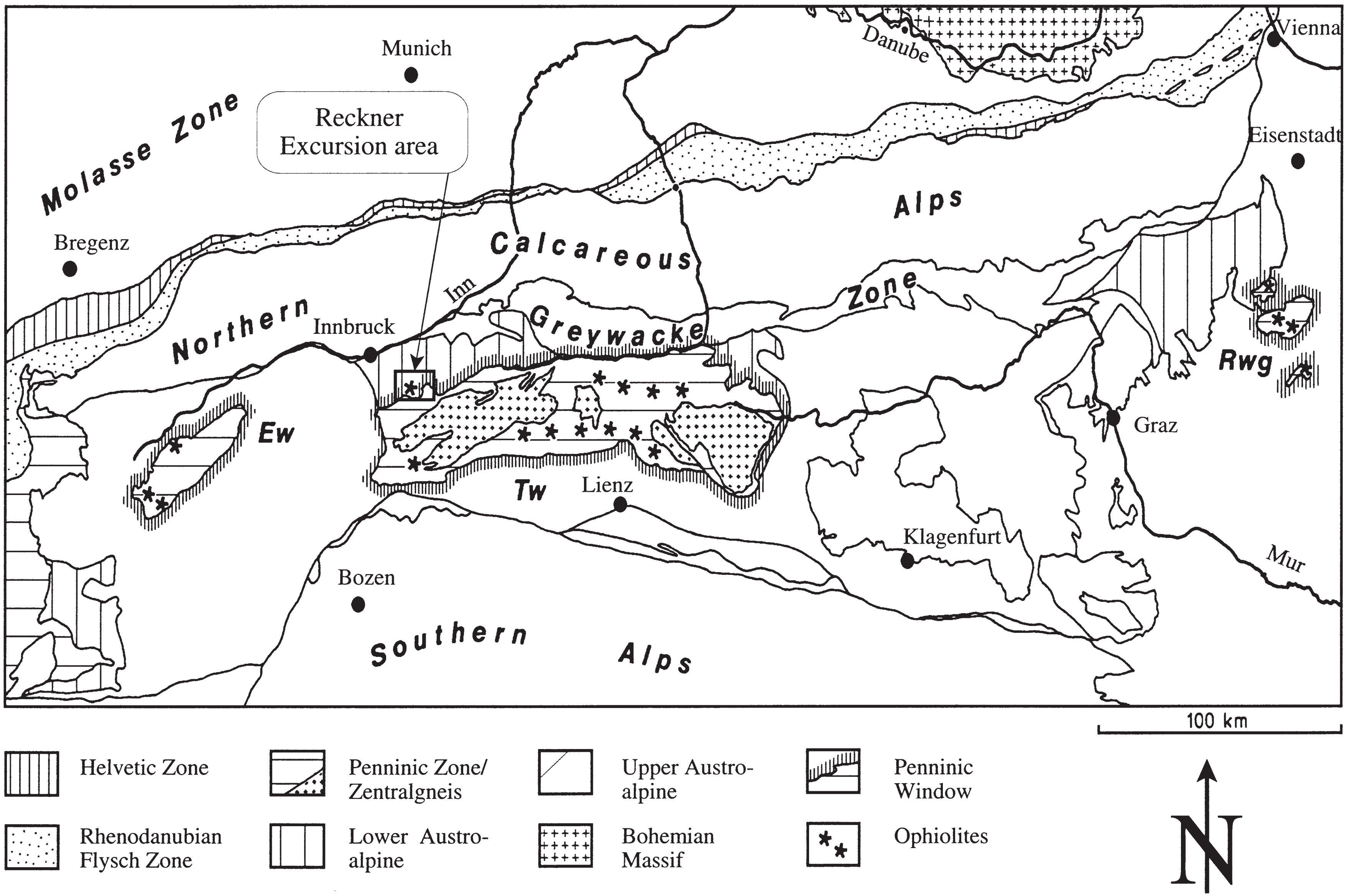

Fig. 1: Simplified tectonic map of the Eastern Alps after Höck & Koller (1987). An arrow to the excursion area at the northwestern rim of the Tauern Window is shown in addition. Ew = Engadine Window, Tw = Tauern Window, Rwg = Rechnitz window Group.

b) The "Reckner Complex" (RC) which represents an ultramafic-mafic association of a Mesozoic oceanic lithosphere fragment with remnant HP metamorphic relics.
c) The "Reckner Nappe" (RN) and "Hippold Nappe" (HN), both consisting almost entirely of Mesozoic metasedimentary rocks with Permian to Early Cretaceous sedimentation ages. The Hippold nappe rests at least partially on a crystalline basement (BHN) with pre-Alpine age.
d) The "Bündner Schiefer sequence" of the Southpenninic zone (PENN), which includes a thick sequence of monotonous calcareous micaschists (this sequence also hosts the wide spread Mesozoic ophiolites of the central Tauern Window (e.g. the Glockner Nappe: Höck & Koller, 1987, 1989; Höck & Miller, 1987).

The tectonic relationships between these units are illustrated in Fig. 2 and in the profile section (Fig. 3). The deformational style in Mesozoic nappes of the LAA (RN, HN) is characterized by repeated recumbent folds. Although the general succession is upright, it is inverted in the RC and QPN. Because of their general low-grade character, all units except the Reckner Complex do not contain any critical metamorphic index minerals except phengite (Tab. 1). While phengite is ubiquitous in silicic rocks, other minerals typical of a HP metamorphism occur only in the basic rocks of the Reckner Complex.

The RC primarily consists of serpentinized lherzolite with subordinate harzburgite, dunite (Fig. 4) and some small isolated gabbro bodies. The predominately lherzolithic compositions contrast markedly the harzburgite-type ophiolites of the Southpenninic system exposed widely in the Eastern Alps (Höck & Koller, 1987, 1989; Koller, 1985). HT minerals such as Mg-hornblende, pargasite and Ti-phlogopite only occur in structurally deeper levels of the RC and are related to remnants of a high-temperature (Tab. 2) hydrothermal regime corresponding to an oceanic metamorphism event shortly after emplacement of the ophiolite fragment onto the ocean floor (Dingeldey et al., 1995, Koller et al., 1996).

Further main rocks of the RC are rare ophiolitic gabbros with partially preserved Cpx and widespread blueschists, representing a sequence of former oceanic crust strongly reduced in thickness. This thin horizon normally occurs below the ultramafitite and the sedimentary rock successions of the Reckner nappe.

The RN succession is strongly folded and partly overturned (Fig. 3), in general exhibiting a stratigraphic sequence from the Anisian to the Late Malmian. The succession starts with Anisian "Rauhwacke" followed by calcareous micaschists, radiolarites and various phyllites, partially with stilpnomelane (Fig. 5). The Hippold nappe (HN) contains quite similar rock successions as the RN, but massive carbonate rocks are more common including carbonate breccias sometimes with traces of chromite (Pober & Faupl, 1988). The Penninic nappe is represented in the excursion area only by calcareous mica schists.

The magmatic evolution of the RC is defined by an Jurassic Sm/Nd age (Meisel et al., 1997) on base of different gabbroic and possible cummulate samples. Further remnants of an oceanic metamorphism event can be traced in the RC commonly by the formation of pargasite or Mg-hornblende in the ultramafic rocks and by large Ti-rich biotite flakes replacing former pyroxenes in cumulate rocks. Most of the biotite is transformed into the assemblage Cr-rich chlorite + rutile during the Alpidic overprint. Preserved biotite still gives an Jurassic $^{40}Ar/^{39}Ar$ laser age (Dingeldey, 1995) equivalent to the Sm/Nd age (Meisel et al, 1997) within the range of error.

Both metasedimentary nappes (RN and HN) and the ophiolitic nappe (RC) have been metamorphosed by a low T - high P event (Fig. 6) with pressures between 8.5–10 kbar and temperature around 350°C. No high pressure event is recorded from the structural highest LAA nappe (Quartzphyllite nappe) with maximum P-T conditions of approximately 4 kbar and ~400°C. The "Bündner Schiefer" sequence below the LAA were metamorphosed at intermediate pressure (6–7 kbar). In all units a slight increase of temperature during decompression and a similar cooling history can be observed (Fig. 6, Tab. 2).

Whole-rock $^{40}Ar/^{39}Ar$ plateau ages of silicic phyllites and cherts with abundant high-Si phengites (Fig. 5) record ages around 50 Ma in the Reckner Nappe, and 44-37 Ma in the Hippold Nappe and Southpenninic "Bündner Schiefer" sequence (Fig. 7). These ages are interpreted by Dingeldey et al. (1997) to closely date the high-pressure metamorphism. No plateau ages were found in the Quartzphyllite nappe, where only a rejuvenation of an Variscan age was observed (Fig. 7).

Closer to the tectonic boundaries also strong rejuvenation and no plateau age (Fig. 7) was reported by Dingeldey et al. (1997).

The paleogeographic reconstruction is mainly controlled by the interpretation of the actual nappe pile. A general model is still missing, but Dingeldey

Fig. 2: Simplified tectonic map of the excursion area in the "Tarntal Mountains"after ENZENBERG (1967). The Southpenninic "Bünder Schiefer Nappe dips northwards below the Lower Austroalpine (LAA) nappe system. BHN for basement of the Hippold nappe. The trace of the geological profile in Fig. 3 is shown in addition.

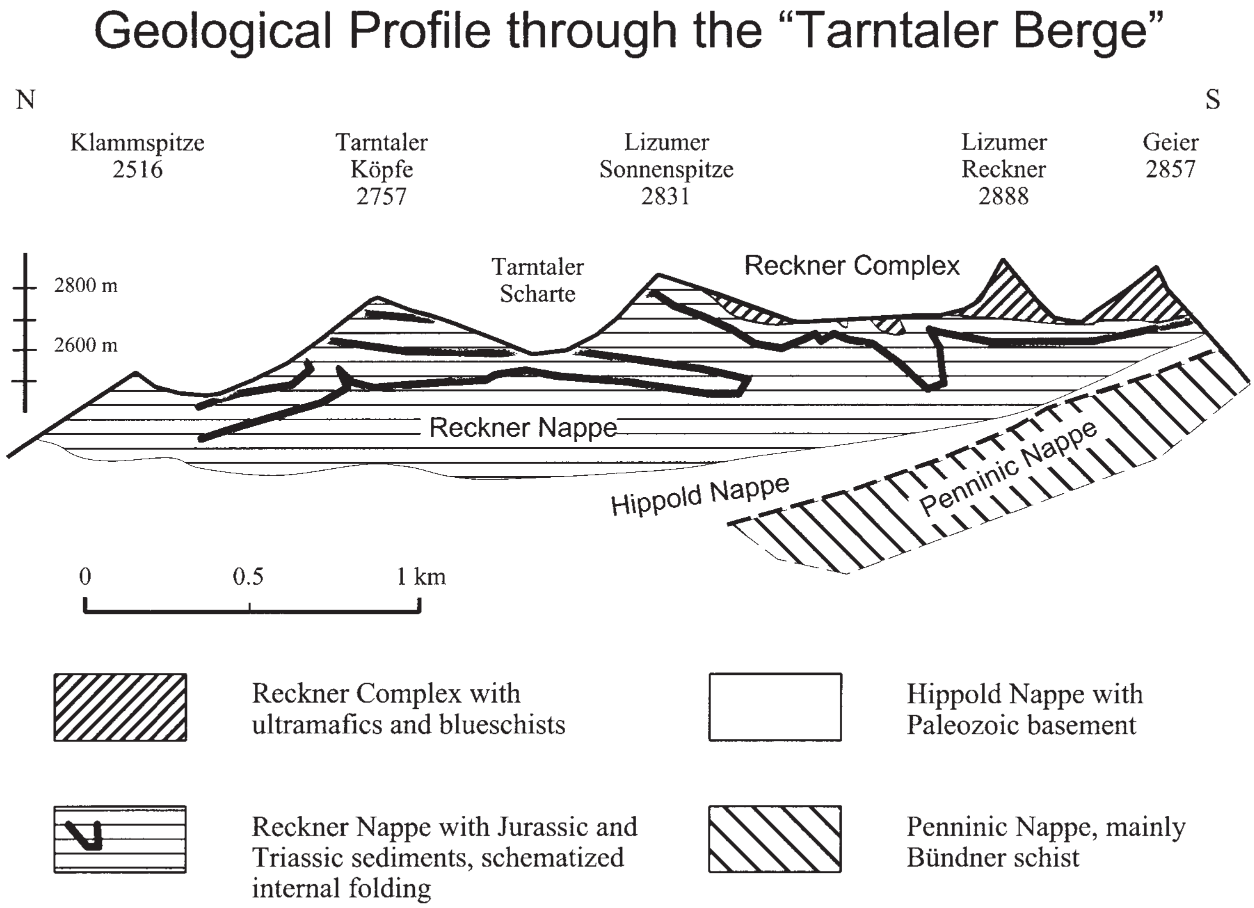

Fig. 3: Geological profile through the "Tarntaler Berge" simplified after Tollmann (1977) and Häusler (1988). The internal folding, the partially overturned stratigraphy and the thinning of the nappes near the LAA - Penninic boundary is typical for the geology of this area.

et al. (1997) try to establish a model in which the LAA including the Reckner Complex was derived from south of the South Penninic ocean. Both oceanic areas were divided by the Paleozoic base of the Hippold nappe.

3 Excursion route and outcrops

The excursion route starts at the Lizumer Hütte (Fig. 2) and follows the official hiking path towards Junsjoch and Junssee. From the lake Junssee towards the summit of the Geier (altitude 2857 m) all typical rock types starting with the Penninic "Bündner Schiefer" followed by various rocks of the Hippold nappe (HN), the Reckner nappe (RN) and partially those of the Reckner complex (RC) will be visited and discussed in detail. From the Geier summit the route continues towards the north until the serpentinites at the southern flank of the Lizumer Reckner are reached. From there we continue to the saddle between Lizumer and Naviser Reckner by crossing the serpentinite block fields on the west side of the Lizumer Reckner. At this saddle outcrops of a gabbro complex and a huge hydrothermal alteration system related to the oceanic metamorphism event will be visited. From there we follow downwards to the upper Tarntal valley on the northeastern flank of the Lizumer Reckner and the Geier to reach the hiking path again and to return to the Lizumer Hütte close to the military camp Wattener Lizum.

In case of bad weather conditions an alternative route follows the military road to the Klammsee and to outcrops of the Reckner complex west of the Klammseejoch.

It must be stressed that all field work or leaving of the official hiking paths in the military training

	Rock Type	Typical Mineral Parageneses
Quartzphyllite Nappe	Quartzphyllite	Q + Mu ± Ab ± Chl ± Ru ± Mgt
Reckner Complex (Ophiolite)	Serpentinite	Liz ± Chrys + Mgt ± Tr ± Chl
	Ophicarbonate	Liz ± Chrys + Mgt ± Tr ± Chl + Cc ± Do
	Metasomatic rock types	relictic Ti-rich biotite ± Ru actual Cr rich Chl + Tit ± Cc
	Metagabbro	Mg-Pump + Chl + Ab + Act
	Blueschist	Ab + Q + Mu + Tit + Alk-Amph ± Stilp Ab + Alkpx + Tit ± Q ± Mu ± Amph Ab + Q + Chl + Stilp + Bio ± Mu + Pyrit
	Greenschist	Ab + Chl + Ep + Mu + Tit ± Q ± Stilp ± Mg-Pump
Reckner Nappe	Stilpnomelan-Phyllite	Q + Mu + Chl + Stilp ± Tit ± Ab ± Alk-Amph
	Radiolarite/ Phyllite	Q + Mu + Chl Q + Mu + Chl ± Stilp ± Ab ± Kfsp ± Tit
	Carbonate bearing phyllites	Q + Cc + Ank + Mu + Ru ± Ab ± Mgt
	Triassic carbonate rocks	no mica
Hippold Nappe	"Grauwacken"/ Carbonate-breccies	Cc + Q + Mu + Stilp ± Talk ± Chl
South Penninic nappe	"Bündner Schiefer"	Cc + Q + Ank ± Dol ± Ab + Mu + Graphit + Ru

Table 1: Typical mineral assemblages in the individual rock types and units of the "Tarntaler Berge" after Koller et al., (1996). Mineral abbreviations: Quartz Q, muskovite Mu, albite Ab, chlorite Chl, rutile Ru, magnetite Mgt, lizardite Liz, chrysotile Chrys, tremolite Tr, calcite Cc, dolomite Do, ankerite Ank, biotite Bio, titanite Tit, stilpnomelane Stilp, pumpellyite Pump, actinolite Act, Alkali-amphibole Alk-Amph, amphibole Amph, Alkali-pyroxene Alkpx, epidote Ep, all others are element symboles.

ground area "Wattener Lizum" needs the permission of the Austrian army.

In the following part a detailed description of some of the main rock types visited during the excursion is given:

3.1 Serpentinites

The serpentinites of the RC are mainly lherzolithes with subordinate harzburgites and dunites. The lherzolites of the Reckner are characterized quite well

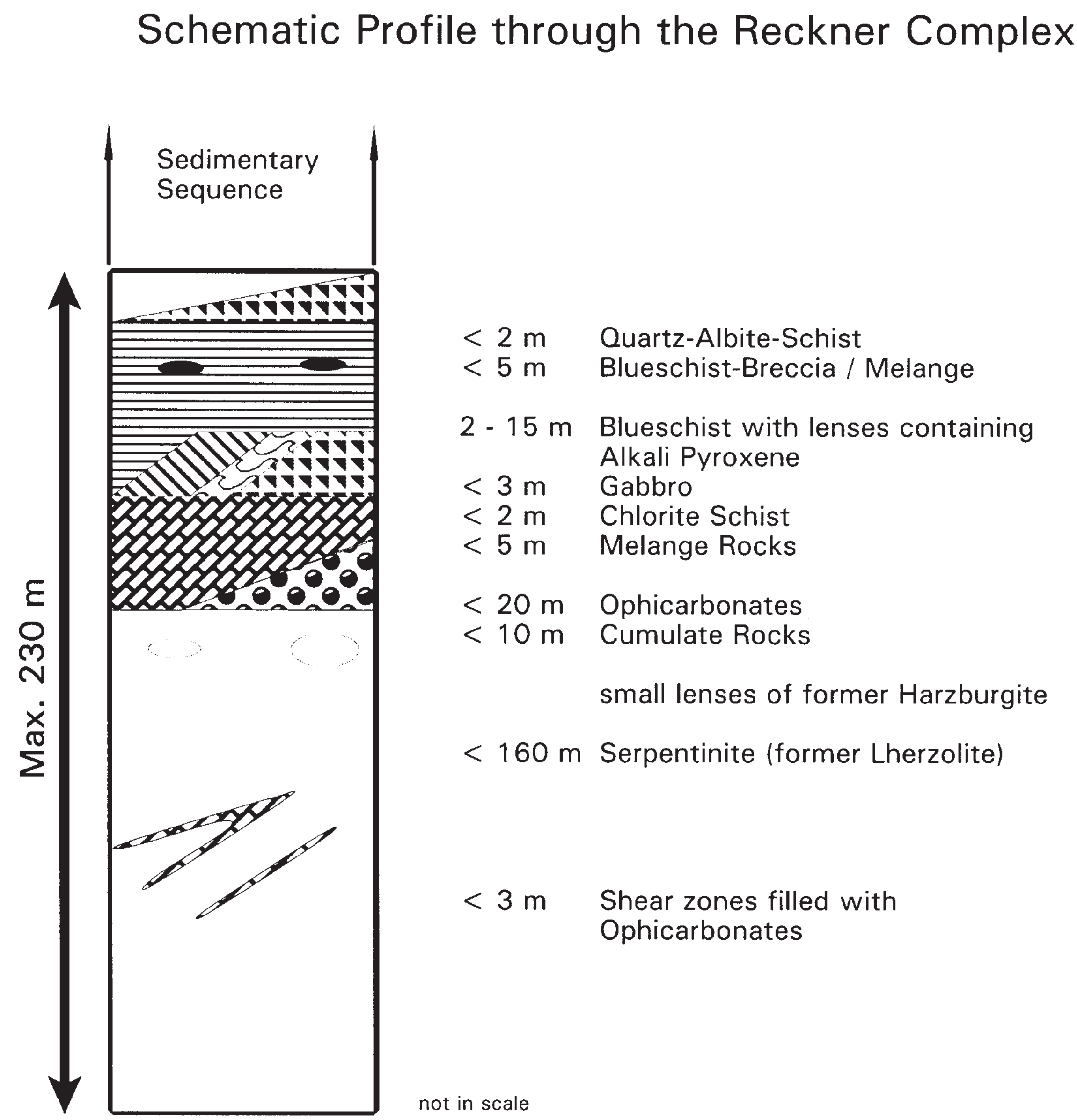

Fig. 4: Schematic profile through the Reckner Complex with a maximum thickness of about 230 m mainly formed by serpentinites. Please note that the profile occurs in the field only in overturned position.

with high Al contents (up to 5 wt.% Al_2O_3) in contrast to the low Al (1-1.5 wt.% Al_2O_3) in all serpentinites of the Penninic Mesozoic ophiolites (Melcher et al., 2001). Primary clinopyroxene is rather well preserved in the former lherzolites of the RC and they are Mg rich (XMg 0.90–0.91) with ~ 2 wt.% Na_2O and 5–6 wt.% Al_2O_3. Minor amounts of pargasite and Mg-hornblende as remnants of the oceanic metamorphism can be found locally. Only some serpentinite complexes within the Zone of Matrei at the southern rim of the Tauern Window can be compared to the serpentinites of the RC.

3.2 Metagabbros

Few lenses of isotrope gabbros are found in the ultramafics close to the contact to the blueschists. Most of the primary cpx is replaced by actinolite. The former plagioclase consists of albite, chlorite and fine-grained Mg-rich pumpellyite. The chemical composition of these gabbros is typical for N-type MORB ophiolites.

At one locality a Ti-rich cumulate gabbro variety can be observed, which was interpretated by Dingeldey (1995) as an ultramafic cumulate. This lense un-

Metamorphic Event	Reckner Complex (Ophiolite)	Reckner/Hippold Nappe	South Penninic Nappe
1. Ozeanic Metamorphism	P ?? (rather low, no data) T 670 - 780 °C (O_2-Isotope-Thermometry)	———————	———————
2. High Pressure Event	PTAX: P_{max} ~ 9-10 kbar T_{max} ~ 370 °C Phengite barometry: P_{max} ~ 10 kbar (calculated at 350 °C)	PTAX: P_{max} ~ 9-10 kbar T_{max} ~ 360 °C Phengite barometry: P_{max} ~ 10 kbar (calculated at 350 °C)	Phengite barometry: P_{max} ~ 6 kbar (calculated at 350 °C)
3. Thermal Peak	PTAX: P_{max} ~ 4 kbar T > 400 °C O_2-Isotope-Thermometry T~395-415 °C Calcite-Dolomite-Thermometry T_{max}~380 °C	T_{max} ~ 400 °C (Paragonite-component in micas)	T_{max} ~ 500 °C (Paragonite-component in micas)

Table 2: Summarized P and T conditions of the metamorphic evolutions of the individual nappes in the excursion area after Dingeldey (1995), Dingeldey at al. (1997), and Koller et al. (1996) divided into three different events.

derwent an intensive metasomatic alteration forming several cm large aggregates of Ti-rich (up to 7 wt.% TiO_2) biotite pseudomorph after primary pyroxene. During the Alpine overprint these biotites are mainly replaced by Cr-rich chlorite and rutile.

Caused by the fact that most of the mafic rocks contain still stilpnomelane only rarely newly formed, low-Ti and green coloured biotite, formed as a late phase related to the thermal peak of the metamorphic evolution, these high Ti-biotites can not be formed during the Alpine metamorphism and must be formed during relative high temperatures possible related to the oceanic metamorphism.

3.3 Blueschists

A subordinate lithologic element of the RC are the blueschists which commonly occur as fine-grained, laminated rock consisting of albite, quartz, sodic amphibole (normally crossite to Mg-riebeckite), titanite, rare phengite and occasional sodic pyroxene (acmite-jadeite to acmite-diopside). Geochemical and Pb-isotopic characteristics suggest that the blueschists represents no pure basaltic source. The source may be reworked basaltic rock mixed with sediments or former sediments which were metasomatized and possibly mixed with detrital volcaniclastic or sedimentary material of basic composition (Dingeldey, 1990, 1995; Dingeldey et al., 1995).

The sodic pyroxene is commonly zoned with maximum values of 41 mol% jadeite end-member in cores. In the presence of albite this provides evidence of minimum metamorphic pressures in the range of 8–10 kbar according to the geothermobarometric method of Popp & Gilbert (1972) at assumed temperatures of 300–350°C which are deduced indirectly by compositions of relic Mg-rich pumpelleyite in a

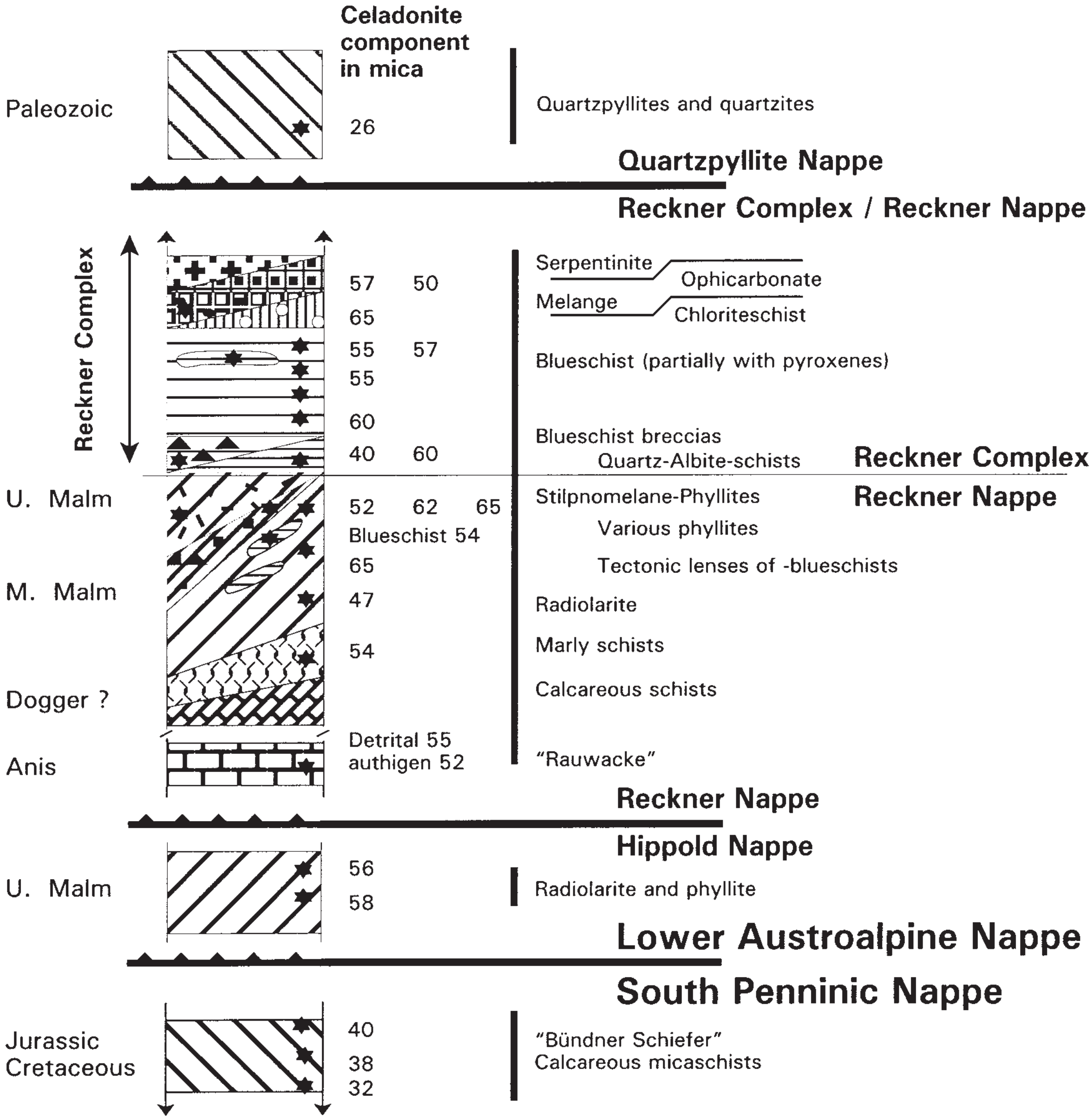

Fig. 5: Schematic tectono-stratigraphic column through the LAA unit into the underlying Penninic unit with definition of the typical rocks and stratigraphic relationships. The maximum celadonite component of white micas after DINGELDEY et al. (1997) is shown.

gabbroic assemblage including albite, chlorite and actinolite according to the experimental results of Schiffman & Liou (1980). Generally, phengite is rare in blueschist, but when observed, is very rich in SiO_2 (up to 64 mol% celadonite component), confirming a HP-metamorphic evolution.

As a consequence of the phase relationships in most cases sodic pyroxene is the high pressure mineral and most of the blue amphiboles replace a former jadeite component bearing pyroxene formed during uplift and post high pressure evolution.

Within the blueschists of the Reckner Complex (RC), two types of white mica can be distinguished: Type I occurs in paragenesis with sodic pyroxene as well as inclusion within sodic pyroxene; type II is never observed with sodic pyroxene but sometimes with blue amphibole. Because sodic pyroxene usually grew during the older regional metamorphic event, textural relationships suggest that sodic amphibole typically resorbed sodic pyroxene in a younger metamorphic episode. Garben textures of amphibole fibers locally developed during synkinematic growth, often totally consuming the former pyroxene (see more details and cartoons in Fischer & Nothaft, 1954). Type I phengites are always Cr- and Si-rich and greenish in color. Molar contents of celadonite

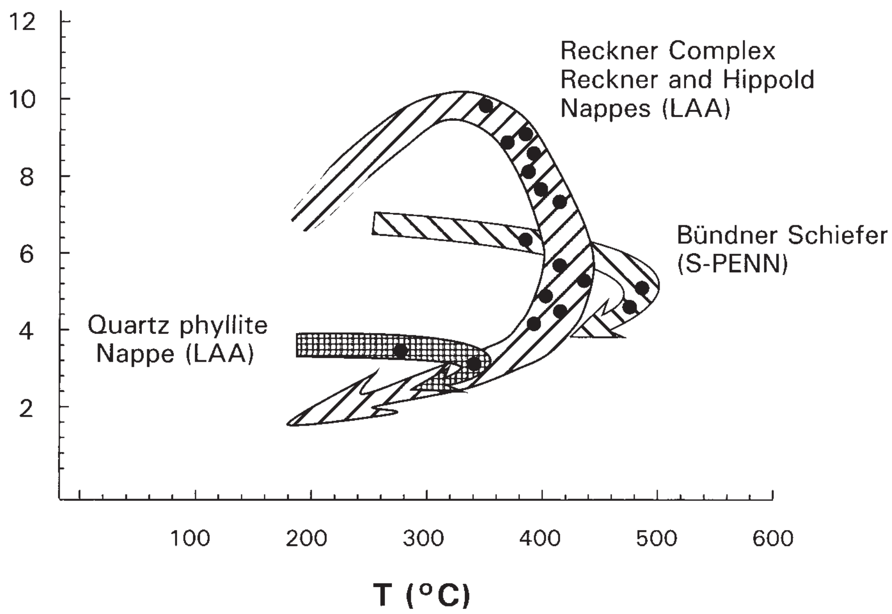

Fig. 6: Schematic P-T paths of the Alpine metamorphic evolution in the "Tarntaler Berge" for the individual units after DINGELDEY et al. (1997). Calculated P-T data are indicated by black dots. The metasedimentary (RN, HN) and the ophiolitic (RC) nappes feature a high P - low T event, the adjected South Penninic "Bündner Schiefer" sequence is characterized by medium pressures, and the Paleozoic quartz phyllite nappe by low pressures.

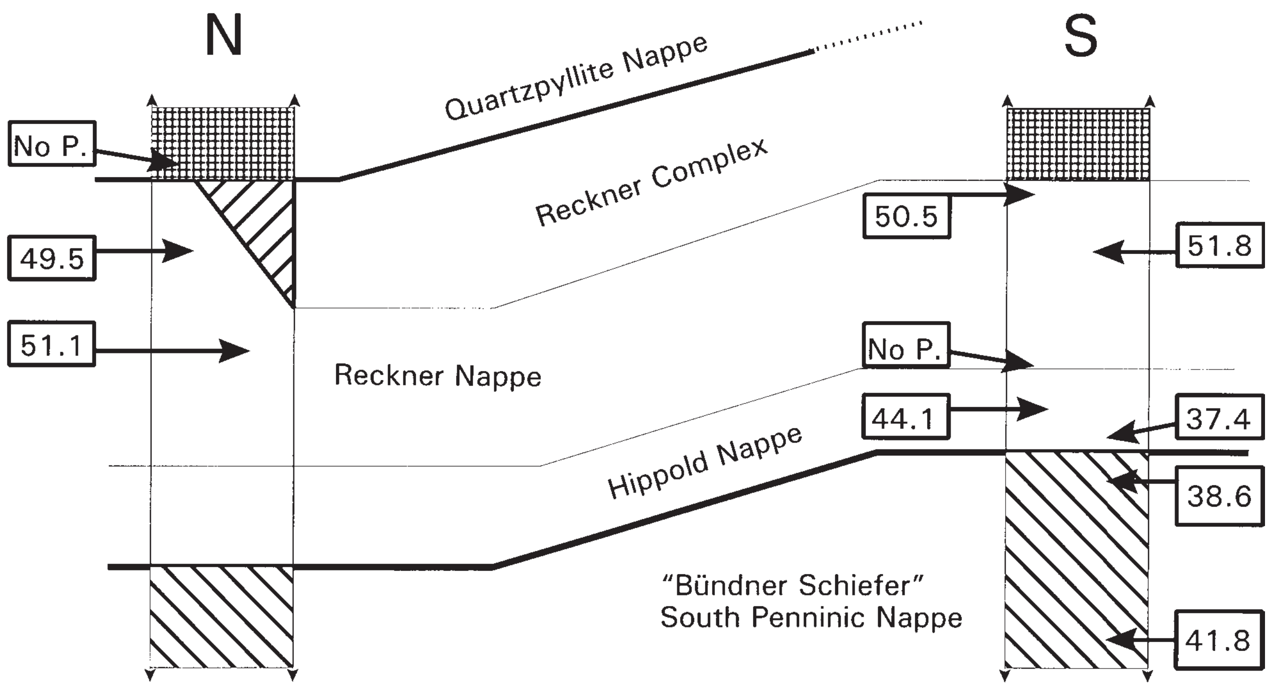

Fig. 7: Summarised $^{40}Ar/^{39}Ar$ plateau ages of various rocks samples and their relative stratigraphic positions in two profiles after Dingeldey at al. (1997) shown in two sampling profiles. The samples of profile N derive from the northwest of the Klammsee area and those of the profile S from the Reckner area (Fig. 1). No P. means no plateau age found in this sample.

vary between 45 and 63 mol%, Cr reaches 0.4 p.f.u. and Na is generally low. Sodic pyroxene with high Al content in cores (up to 41 mol% jadeite endmember) and much lower Al in rims (<< 20 mol% jadeite) sometimes contains inclusions of Si-rich phengite (about 60 mol% celadonite). Blueschists containing large amounts of blue amphiboles usually also bear greater proportions of white mica. In pyroxene-bearing blueschists, dark blue-coloured rocks, an older, highly phengitic species locally contains up to 9 wt.% Cr_2O_3 at varying celadonite content between 30 and 65 mol%. Paragonite content is always <10 mol%. These phengites are comparable to those from the pyroxene-bearing blueschist. Generation II phengites, which were never observed in blueschist containing pyroxene, are mostly colorless with low Cr, celadonite between 12 and 36 mol% and paragonite up to 20 mol%.

3.4 Ophicarbonate rocks

The mineral assemblages of the ophicarbonate rocks show a wide variation. Several types can be observed. The normal ones are simple CO_2 metasomatized ultramafic rocks with serpentine minerals and carbonate phases. Most of the ophicarbonate rocks show a high oxidation rate visible on red iron oxide pigment. Unusual types of ophicarbonates contain alkali pyroxene and blue amphiboles. The latter type grades into typical blueschists and the mineral compositions are rather equivalent. Oxygen isotope composition investigations define high temperature conditions (Tab. 2) and they are the best argument for an important influence of the oceanic metamorphism beside the high grade of oxidation in this type of ophicarbonates. Similar rocks occur in the Rechnitz Window group (Koller, 1985).

3.5 Greenschists, phyllites, calcareous micaschist and radiolarites

Because all other diagnostic metamorphic minerals and assemblages (Tab. 1) are absent in these metasedimentary rocks, only white mica composition allows an evaluation of the metamorphic P-T evolution of the LAA units (QPN, RC, RN, HN) and upper parts of the PENN. The technique of phengite barometry (Massonne, 1981, 1991; Massonne & Schreyer, 1987) is the only possible attempt and was used by Dingeldey et al. (1997). Significant amounts of white mica commonly occur in Jurassic cherts and phyllites of the LAA nappes, calcareous micaschists of the PENN, and blueschists of the RC, but they are not large enough for separation. Due to restricted occurrence of low-variance assemblages, rather approximate P-T intervals can be determined instead of definite P-T equilibrium conditions.

White mica generally occurs in two distinct generations (I and II) in all samples examined except those from the Penninic "Bündner Schiefer" sequence where more penetrative deformation and recrystallization prevents recognition of older generations. The first mica generation is mainly fine-grained, of pale greenish color, and aligned within a regional S1 foliation. Some larger crystals are zoned with Si contents increasing from core to rim. Epitaxial overgrowth of high-Si mica often has occurred on low-Si muscovite. In these cases the muscovites are interpreted to be detrital relics. The younger white micas occur generally less widespread. These colorless crystals are relatively large, often euhedral, and locally aligned within an S2 foliation. Their Si content is generally low (< 6.6 p.f.u.) and often displays a slight reverse zonation (Si decreasing from core to rim). Epitaxial overgrowth on older phengite grains is rare.

The composition of white mica within the metasedimentary nappes of the LAA (Reckner and Hippold Nappe) is very similar to that within the Reckner Complex. Although of very small grain-size, two generations of micas can be distinguished: Generation I phengites vary between 27 and 67 mol% celadonite endmember in RN and between 31 and 60 mol% in HN. Generation II micas are colorless, vary between 20 and 36 mol% celadonite (RN) and 14 and 38 mol% (HN). Na is consistently low with maximum values of 13 mol% paragonite endmember in low-Si phengite.

3.6 Penninic calcareous micaschists

Within the Southpenninic "Bündner Schiefer" sequence, white micas are more deformed than in LAA samples. As a result no textural distinctions can be made. All micas are colorless or very pale greenish and less phengitic than in the RC, RN and HN. The highest celadonite content is around 40 mol% with an average between 25 and 30 mol%. Na is distinctly higher than in the LAA sequences, with a maximum value of 32 mol% paragonite endmember in low-Si micas. Na increases and Si decreases southwards from the main thrust plane between LAA and PENN.

3.7 Quartzphyllite of the Paleozoic Quartzphyllite nappe

In the Quartzphyllite Nappe at least two generations of white mica may be distinguished on the basis of textural characteristics. All are characterized by a nearly uniform chemistry with highest Si contents around 6.48 p.f.u. with most samples between 6.2 and 6.3 p.f.u. The majority of these micas are interpreted as of pre-Alpine age. The uniformly low Si-content is matched by a uniformly low Na-content; the highest measured Na contents correspond to approximately 15 mol% paragonite end-member.

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