Excursion B1: Cross section from the Austroalpine nappes to the Penninic and Subpenninic nappes of the Tauern Window

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The topic of this field trip is to visit and understand the structure of the Austroalpine nappes east of the Tauern Window, and the structure of Penninic and Subpenninic nappes within the Tauern Window. The Tauern Window exposes exhumed parts of Europe-derived crust that were accreted to the base of an Adria-derived upper plate, represented today by the Austroalpine nappes.This excursion will provide a cross section from the Austroalpine nappes east of the Tauern Window across the Eastern margin of the Tauern Window (Katschberg fault) into the central parts of the eastern Tauern Window.

The excursion will start and end in Schladming. Accomdation will be in Gmünd (travel time from Schladming approximately 45 minutes).

Day 1

Guided by: Walter Kurz, Harald Fritz & Kurt Krenn

Day one will cover the Austroalpine nappe system east of the Tauern Window. At good weather conditions a walking tour with a complete cross section from the Bundschuh Complex to the Gurktal nappe system is planned. Alternative exposures can be visited by bus travel along the road across the Nockberge.

Figure 1: Pre-Alpine basement of the Bundschuh Complex (left), overlain by Triassic low-grade metamorphic dolomites (Stangalm Mesozoic unit) (right).

The Austroalpine nappes in the field trip area comprise from bottom to top (Fig. 2):

1) The Bundschuh nappe system: pre-Alpine metamorphic basement (paragneisses, orthogneisses, metapelites) (Bundschuh Complex), overlain by a Permian to Triassic cover (meta-conglomerates, quartzites, dolomites) (Stangalm Meszoic unit). The sedimentary contact is tectonically reactivated by a low-angle normal fault (Fig.2).
2) The Gurktal nappe system:

a. The Phyllonite Zone: strongly retrogressed phyllites, overlain by Paleozoic carbonates. This unit was interpreted Tollmann as the base of the Upper Austroalpine nappe system. The phyllonites, however, now mark a low-angle detachment, related to Late Cretaceous extension.
b. The Pfannock slice: this unit comprises a pre-Alpine basement of orthogneisses (Pfannock Gneiss), covered by a partly inverted sequence of Carboniferous and Permian conglomerates, Permian to Triassic sandstones (Werfen Formation), and Triassic (Anisian to Carnian) carbonates.
c. The Gurktal nappe s.str. (including a lower Murau Nappe and a higher Stolzalpe Nappe): in the field trip area, this unit consists of Palaeozoic phyllites, greenschists and dolomites.

This cross section provides an overview of the structure of the upper part of the Bundschuh nappe, and the structure of the Gurktal nappe system. This section is a key area for the understanding of the Eo-Alpine history of the Austroalpine unit. It is under discussion for a long time and was one major argument for the subdivision of the Austroalpine by TOLLMANN (1977).

The **Bundschuh Complex** is overlying the Radenthein Complex with an Eo-Alpine thrust contact (SCHUSTER & FRANK, 2000). Its lower part consists of fine-grained paragneisses with some intercalations of felsic biotite-free orthogneisses and amphibolites (Priedröf paragneisses, Bundschuh orthogneisses). Micaschists and interlayered amphibolites are restricted to the uppermost part of the unit in the center of a large scale gentle syncline structure. The Priedröf paragneisses contain a mineral assemblage of garnet + biotite + plagioclase (albite and oligoclase) + muscovite + quartz. In the micaschists additional staurolite and pseudomorphs after staurolite (rarely containing chloritoid) may be present. Garnets are very characteristic in the whole unit. In the paragneisses they have an average grain-size of less than 0.5 mm, whereas in the micaschists they are up to 2 cm in diameter. Optically an inclusion-rich, often idiomorphic core can clearly be distinguished from an inclusion-free rim. The cores are compositionally homogenous with low CaO contents of 3-5 wt%. Their age is presumed to be Variscan, because Variscan Rb-Sr ages (c. 350 Ma) were determined on muscovites of orthogneisses from the uppermost part of the unit (FRIMMEL, 1986). In the rim the CaO content is much higher (6-8 wt%), FeO, MgO and also XMg is lower. Based on the regional metamorphic history this garnet generation is eo-Alpine in age. Eo-Alpine metamorphic conditions reached up to 600 °C and 10 kbar in the lowermost parts in the south and greenschist facies conditions below the transgressive Mesozoic unit.

The Bundschuh Complex is overlain by a Permian to Triassic metasedimentary sequence, known as the Stangalm Mesozoic. The **Mesozoic Stangalm Unit** is unconformalbly transgressing onto the pre-Alpine syncline structure. The lowermost part consists of Permian to Early Triassic quarzites. Above Anisian carbonates and Carnian phyllitic schists are preserved (TOLLMANN, 1977). A phyllonite horizon (Phyllonite Zone), composed of highly sheared Paleozoic and Mesozoic rocks marks the border to the overlying Pfannock slice. The Pfannock orthogneiss, which is very similar to the Bundschuh orthogneisses (FRIMMEL, 1988) forms the stratigraphically deepest part. It is transgressed by Permian to Carboniferous clastic sediments. Continuing Mesozoic carbonates and schists reach up to the Rhaetian Kössen Formation. The sediments show a lower greenschist facies metamorphic imprint.

The uppermost tectonic unit is the **Gurktal nappe system**. The latter comprises clastic metasediments with some intercalations of carbonates and metatuffitic layers, which were deposited in Lower Palaezoic times. During the Variscan tectonothermal event they experienced a greenschist facies metamorphic imprint. After that Carboniferous sediments of an intramontane basin (KRAINER, 1993) and Permo-Mesozoic sediment were deposited on top. During the eo-Alpine event the whole sequence suffered anchizonal to lower greenschist facies metamorphic conditions.

A tectonostratigraphic section including the Bundschuh Complex, the Stangalm Mesozoic, the Phyllonite zone, the Pfannock slice and the base of the Gurktal nappe is exposed in the area around the Erlacher Hütte (1636 m) (46°52’10”N; 13°44’55”E) (Figs. 2, 3).

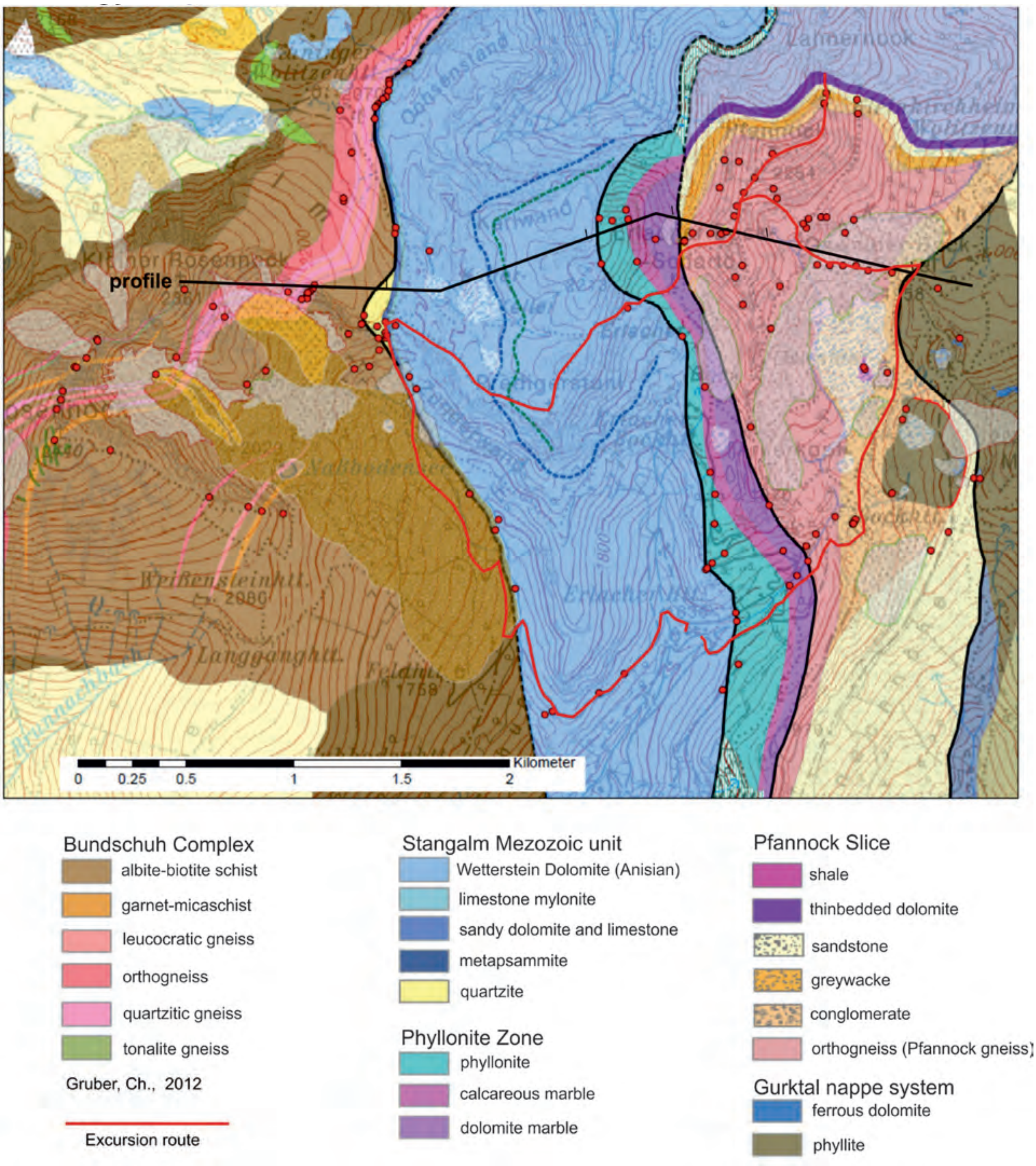


Figure 2: Geological map of the Nockberge area around the Erlacher Hütte. B1 field trip (day 1) is indicated.

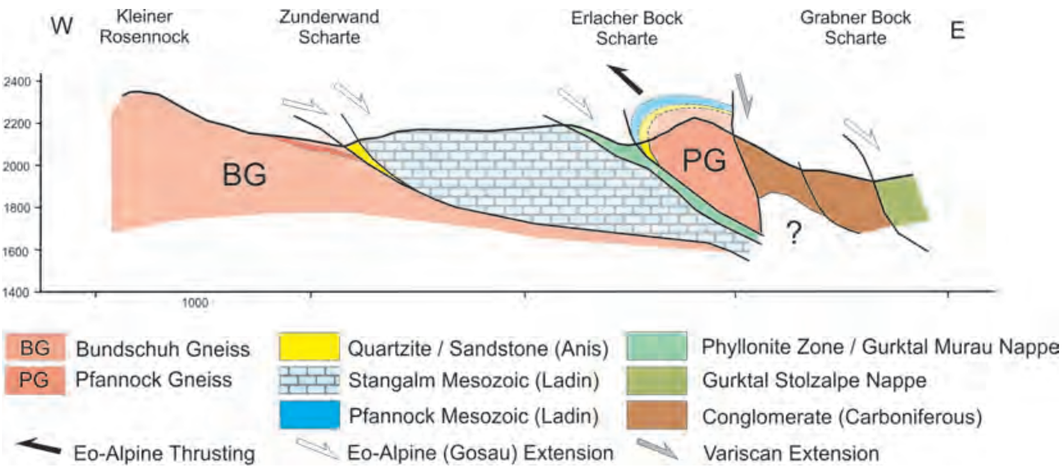


Figure 3: Geological and tectonic sketch profile of the Nockberge area around the Erlacher Hütte. For profile section see Fig. 2.

Stop 1 – Contact between the Bundschuh Complex basement and the Stangalm Mesozoic unit

The contact between the Bundschuh Complex basement and the Stangalm Mesozoic unit (Fig. 1) is exposed along the Zunderwand northwest of the Erlacher Hütte, and in the col between the Kleiner Rosennock (2361 m) and the Predigerstuhl (46°52'54"N; 13°43'53"E). The Bundschuh basement at this site mainly consists of dark micaschist and micaschists with albite blasts with a well developed penetrative foliation dipping towards the southeast (Fig. 4). This foliation is crosscut by multiple sets of shear bands, partly forming an extensional crenulation cleavage, indicating a top-to-the-east sense of shear.

The Stangalm Mesozoic unit comprises coarse-grained metaconglomerates and quartzites at the base, overlain by medium grey to dark, bedded dolomites with detritic flakes of white mica, and light grey to pink dolomite marbles, representing an equivalent of the Anisian Wetterstein Formation (Fig. 5). The metaconglomerate pebbles are highly elongated parallel to the stretching lineation, which is plunging towards the ESE. Generally, sense of shear is top-to-the-east and strain within the metaconglomerates shows a flattening geometry.

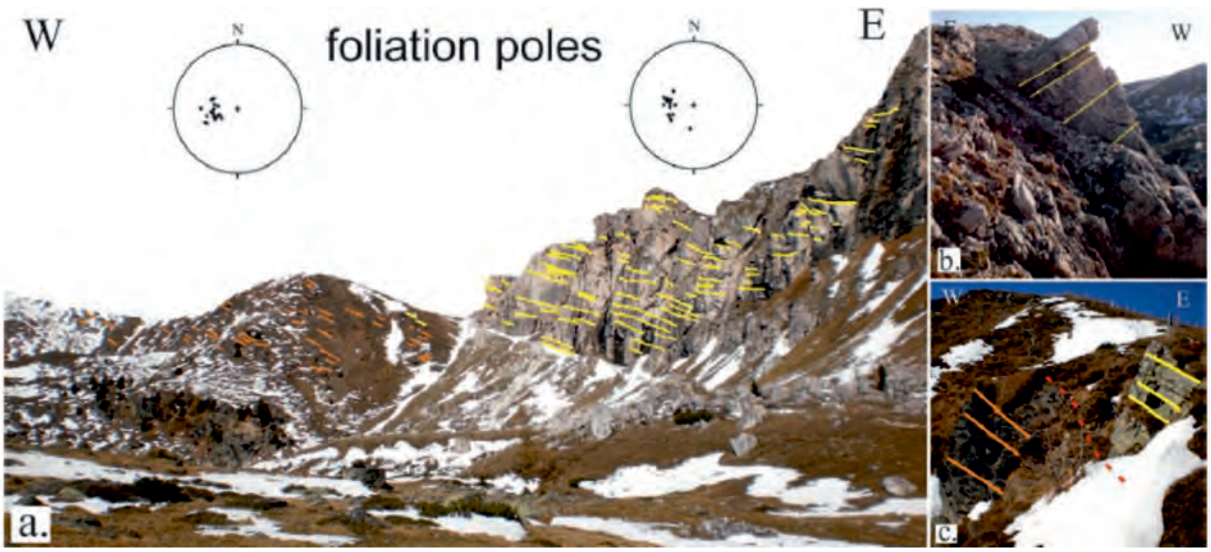


Figure 4: a - Panoramic view of the site exposing the contact between the lower Bundschuh complex basement (left) and the Stangalm Meszoic unit (right). b – Detailed view of the bedding within the Stangalm Mesozoic unit. c – Eastward dipping foliation within the Bundschuh complex basement.

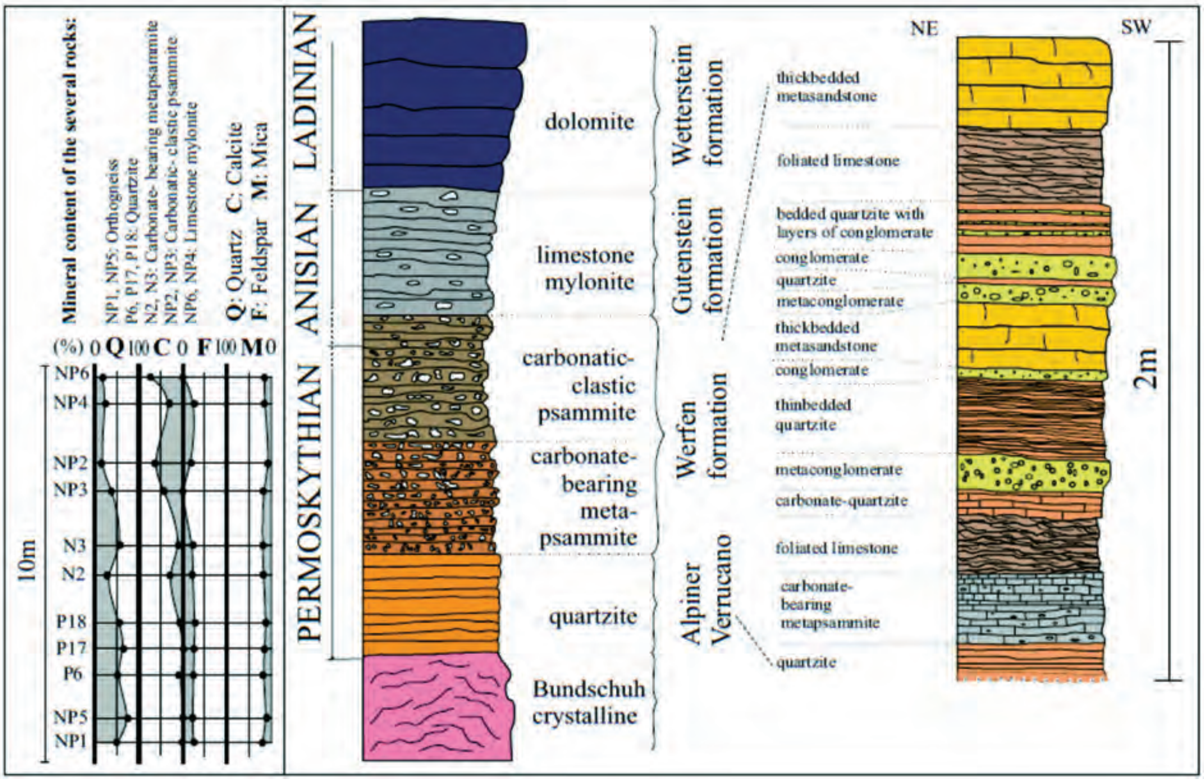


Figure 5: Columnar lithostratigraphic section of the upper part of the Bundschuh complex basement and its sedimentary cover.

Stop 2 – Phyllonite Zone and base of Pfannock Gneiss

Erlacher Bockscharte (46°52'58"N; 13°44'54"E)

The Stangalm Mesozoic unit is bound from the Pfannock slice above by the Phyllonite Zone. According to VON GOSEN et al. (1987), the Phyllonite Zone represents the basement of the Murau Nappe as part of the Gurktal nappe system, which is mostly built up by lower- and upper Palaeozoic meta-sediments.

The matrix of the phyllites is mainly built up by quartz. In some domains plagioclase (albite) is also very dominant and defines an important component of the middle- to fine-grained matrix. In most cases the amount of quartz reaches more than 70 percent. Muscovite and subordinate chlorite are the secondary components. The Phyllonite Zone shows indication for very strong tectonic as well as metamorphic overprint at greenschist facies metamorphic conditions. Macroscopic quartz layers of several decimeter thickness are not rare and a penetrative foliation as well as isoclinal folds are very characteristic features for this unit, too. The penetrative foliation dips with a mean angle of 78° to the east (Fig. 6). The penetrative foliation is crosscut by single sets shear bands dipping towards ESE, which indicate a top-to-the ESE sense of shear. Locally, multiple sets of these shear bands form an extensional crenulation cleavage.The phyllonites are overlain by a sequence of carbonates, mainly lower Paleozoic (Devonian) cherty calcite marbles and radiolarian bearing calcite marbles.

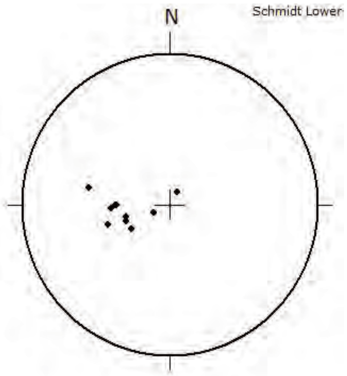


Figure 6: Equal area projections of penetrative foliation orientation data within the Phyllonite Zone.

Stop 3 – Pfannock Gneiss and Carboniferous to Triassic cover

Pfannock (2254 m) (46°53’16”N; 13°45’14”E)
ridge from Pfannock towards northeast; Lahnernock (46°53’31”N; 13°45’28”E).

This site exposes the lithostratigraphic sequence of the Pfannock slice, with the Pfannock gneiss basement, and a Carboniferous to Triassic cover sequence. According to FRIMMEL (1988), the Pfannock gneiss and the orthogneisses within the Bundschuh complex are quite similar. The protolith is classified as granite. The geochemical signatures give evidence for a S-type-granite without a trend of differentiation. Actually these granites are interpreted syn- to postcollision granites, but could also part of a volcanic arc part setting.

At its base the Pfannock gneiss is strongly overprinted by cataclastic deformation. This makes it, in some exposures, hard to distinguish from the Carboniferous metaconglomerates forming the base of the cover sequences.

The metaconglomerates of the Pfannock slice have a red Fe-rich matrix, which includes quartz and feldspar, as well as mica flakes. Quartz is poly- as well as monocrystalline. The clasts are poorly rounded, implying a short distance of transportation. In some domains the red matrix gets relieved by a sericite-quartz-matrix. According to KRAINER (1984) these conglomerates are deposited in a fluviatile environment. Clasts derived mainly from the nearby Pfannock gneiss (Fig. 7) but include also components from the Gurktal Nappe System.

Figure 7: Fabric variation of Carboniferous clastic sediments. Sediments formed by progressive disintegration of Pfannock gneiss and nearby deposition.

Along the ridge from the Pfannock to the Lahnernock an almost complete lithostratigraphic section from the Upper Carboniferous to the Lower Triassic is exposed (Fig. 8). The complete section is inverted due to recumbent folding related to the emplacement of the Pfannock slice during Alpine nappe stacking (Fig. 3). Beside the Carboniferous conglomerates, this succession comprises red clastics, mainly build up of coarse grained breccias to conglomerates. Along this section the thickness of these beds makes up approximately 50 meters. These clastics are generally assumed to be of Permian age. These clastics grade into the Werfen Formation (Skythian), mainly consisting of red sandstones. Beds thickness vary from a few meters to about 20 meters. Thin bedded dolomites and dolomite schists build up the Pfannock beds. At its base, the dark, thin bedded dolomites may contain sandy layers of quartz and detrital white mica. The dolomite schists may also contain calcitic layers. The Pfannock beds are generally assumed to be of Lower Anisian age. These are stratigraphically overlain by massive, light grey dolomites (Wetterstein formation; Anisian to Ladinian), building of the slope towards the Lahnernock.

Farther towards north, this iverted sequence additionally comprises sandy schists as equivalent to the Raibl formation (Carnian), cherty dolomites (Upper Carnian), Norian dolomites (Hauptdolomit formation) and Plattenkalk, as well as Rhaetian limestones and marls (Kössen Formation).

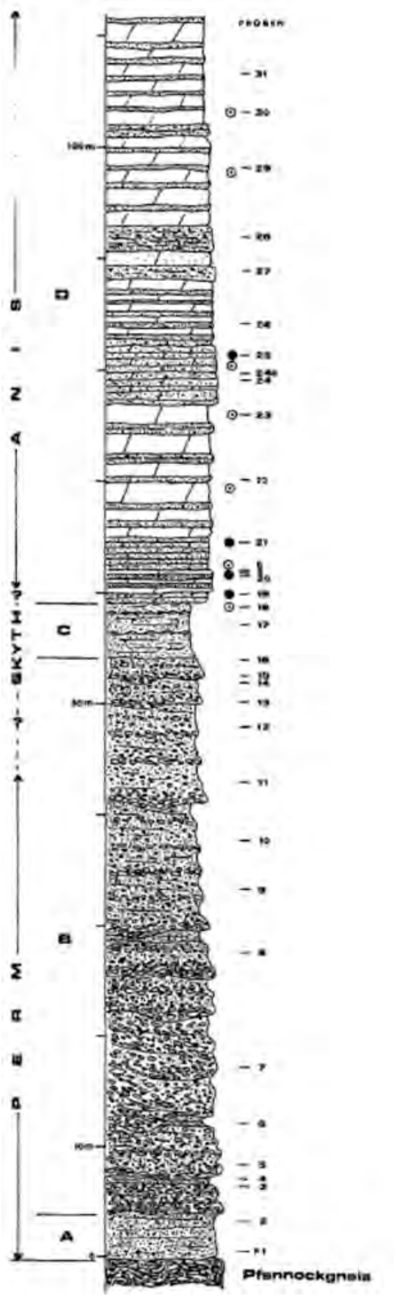


Figure 8: Columnar lithostratigraphic section of the Permian to Lower Triassic sequence at the ridge from the Pfannock to Lahnernock (after KRAINER, 1984).

The history of the **Gurktal nappe system** indicates that it was part of the eo-Alpine tectonic upper plate (SCHMID et al., 2004). It shows an upward decrease of the eo-Alpine metamorphic grade until reaching diagenetic conditions in the Permo-Mesozoic sediments at the top, indicating that it has not been buried since Permian times. It was affected by W-directed thrusting in the Lower Cretaceous (FRITZ, 1988; DALLMEYER et al., 1998), whereas in the Upper Cretaceous it was affected by ductile extensional deformation and normal faulting (NEUBAUER et al., 1995), as for the upper part of the Koralpe-Wölz nappe system. The extensional deformation led to the formation of basins (Kainach, Krappfeld, St. Paul) and the deposition of the Gosau Group sediments, which are Santonian to Paleogene in age (e.g. EBNER & RANTITSCH, 2000). The formation of these sedimentary basins is also linked to the rapid exhumation of the eclogite bearing unit (KURZ & FRITZ, 2003).

The tectonometamorphic evolution of the Austroalpine nappes along this section comprises pre-Alpine high grade metamorphism at upper greenschist to amphibolite facies condition within the Bundschuh Complex. The penetrative foliation is assumed to have formed during a pre-Alpine deformation event, as the foliation and folds within the Bundschuh Complex are discordantly overlain by the low-grade metamorphic sedimentary sequences of the Stangalm Mesozoic unit. The primary contact, however, was strongly overprinted during Alpine nappe stacking (early Cretaceous) and subsequent late Cretaceous extension. Nappe stacking related structures are strongly overprinted by extensional fabrics, especially along former thrusts. Extensional structures are mainly related to top-to-the SE to ESE shearing at low-grade metamorphic conditions and mainly affect the Phyllonite horizon and the base of the Gurktal nappe system.

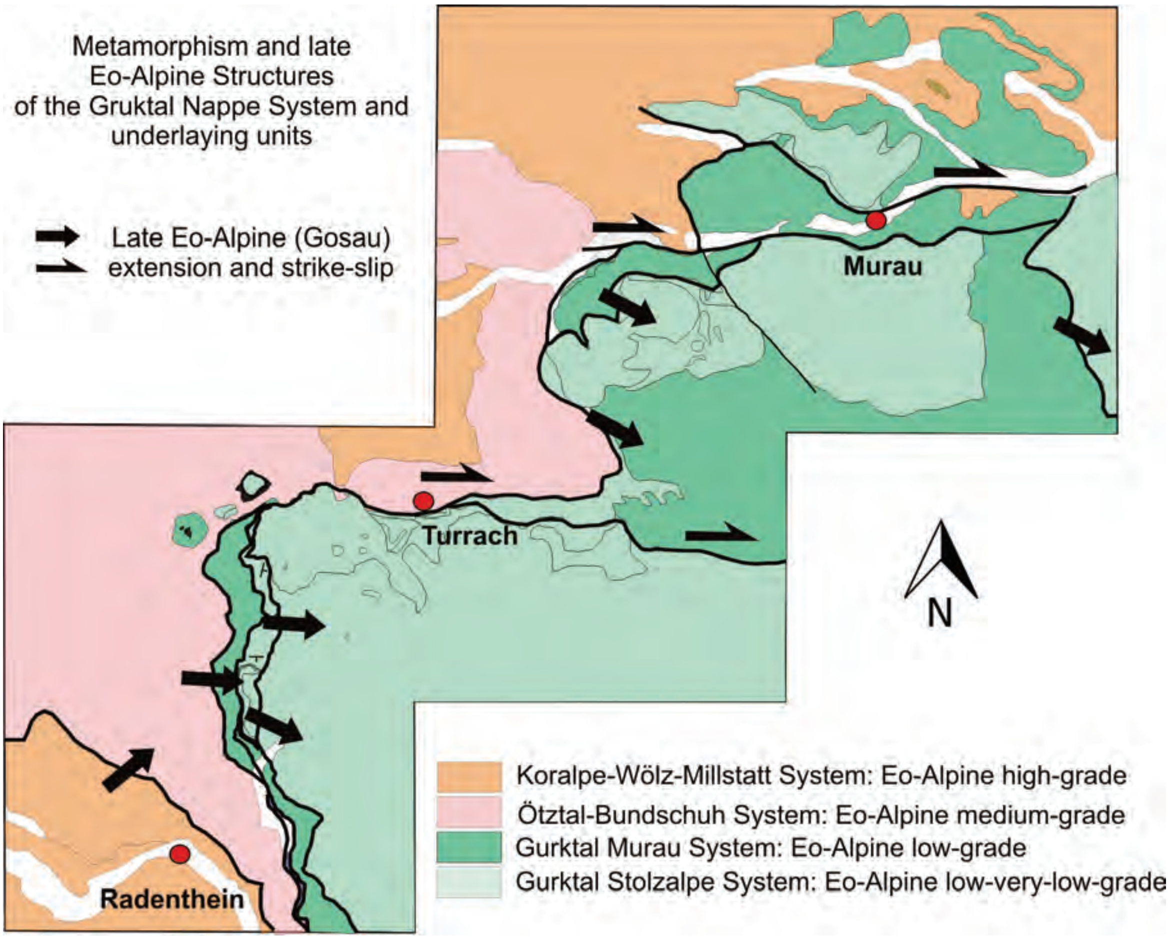


Figure 9: Overall geometry of late Eo-Alpine (Gosauic) strike-slip and extensional structures at the base of the Gurktal nappe system. Mention staircase geometry as result of extensional bridges linking strike-slip domains.

Recumbent, isoclinal folding within the Pfannock slice is interpreted to be related to the detachment of the main part of the Permian to Triassic sequence along the contact to the coarse grained Carboniferous metaconglomerates. This resulted in thickening of the stratigraphic succession in the fold hinge and the inverted limb of the recumbent fold.

In general, structural studies along the tectonic boundaries boundary display a complex Alpine tectonic evolution (Figs. 3, 9). (1) The contact between the Pfannock Gneiss and the Carboniferous conglomerates is interpreted as late-Carboniferous cataclastic fault zone that formed in the course of exhumation of the basement and coeval deposition of Carboniferous sediments. Cataclastic pebbles are present within the Carboniferous sediments and suggest exhumation prior to deposition of rocks. The pre-Carboniferous fault can be traced all along the eastern and southern margin oft he Pfannock Gneiss. (2) The Pfannock slice includes an inverted suite of Permian to Mesozoic sediments. It is interpreted as a tectonic sliver with the Pfannock Gneiss in the core of a northwest vergent fold. Shearing and folding is correlated with Cretaceous northwestward nappe stacking. (3) The actual geometry of the boundary is result of bulk extension during the late Cretaceous. Extensional structures with E- to SE displacement dominate N-S trending segments, dextral strike-slip zone the W-E trending segments. The overall geometry can be described by eastward spreading units with normal faults forming extensional bridges between strike-slip domains (Fig. 1.9).

Day 2

Guided by: Mark R. Handy, Silvia Favaro & Andreas Scharf

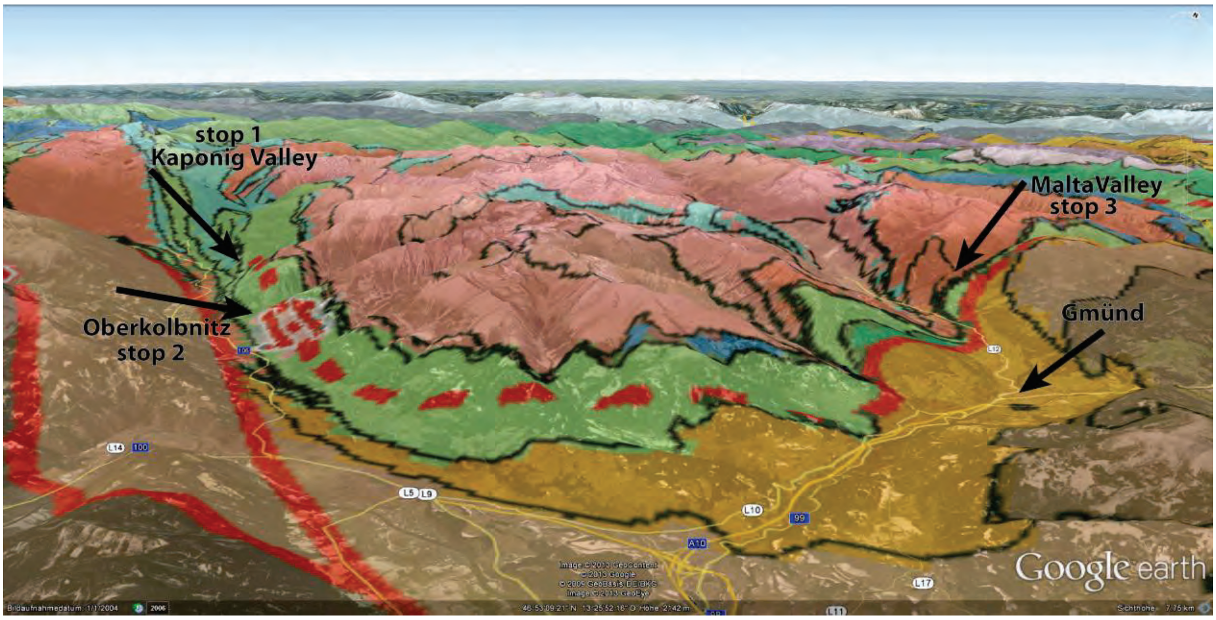
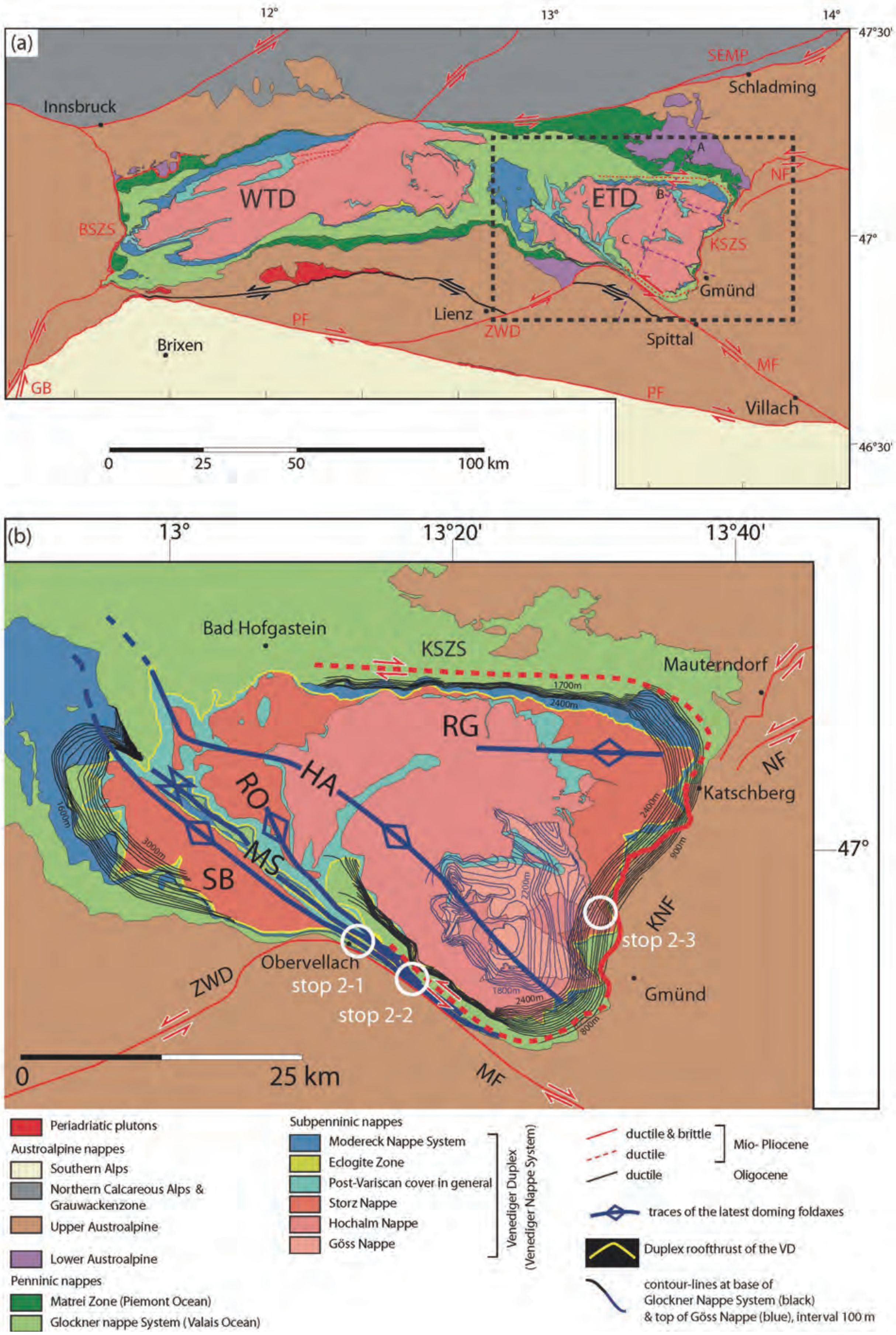


Figure 10: Google Earth image with superposed tectonic map of the southeastern end of the Tauern Window as viewed to the NNW. Black arrows indicate the stops described below and show the town of Gmünd, where we will spend a night. Symbols as in the tectonic map of the Tauern Window (Fig. 11, 27).

Introduction

The Tauern Window and adjacent areas in the Eastern Alps (Fig. 11a) expose a nappe stack that formed during the convergence of the Adriatic and European plates in Late Cretaceous to Cenozoic time (e.g., TRÜMPY, 1980; SCHMID et al., 2004). From top to bottom, this nappe stack comprises Adria- derived (Austroalpine), oceanic (Penninic units = Matrei Zone, Glockner Nappe System) and Europe- derived (Modereck Nappe System, Venediger Nappe System with its Subpenninic units) crustal slices that were sheared, multiply folded and exhumed in Oligocene to Miocene time (Fig. 11; e.g., KURZ et al., 2008; SCHMID et al., 2013). In contrast, the Austroalpine units were affected by Late Cretaceous deformation and metamorphism (e.g., HOINKES et al., 1999; FROITZHEIM et al., 1994; VILLA et al., 2000; SCHUSTER, 2003) before being thrust onto the Penninic units. Crustal accretion (D1) leading to nappe stacking (D2) below the Austroalpine units occurred primarily in Palaeogene to Eocene time and culminated in high-pressure metamorphism and later folding (D3) of



(a)
12°
13°
14°
47°30'
47°
46°30'
Innsbruck
Schladming
SEMP
WTD
ETD
A
B
C
NF
KSZS
BSZS
Gmünd
Lienz
ZWD
Spittal
Brixen
PF
MF
GB
Villach
0
25
50
100 km
(b)
13°
13°20'
13°40'
47°
Bad Hofgastein
KSZS
Mauterndorf
RG
HA
RO
MS
SB
NF
Katschberg
KNF
stop 2-3
Obervellach
stop 2-1
stop 2-2
ZWD
Gmünd
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25 km
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2400m
1600m
3000m
2400m
900m
2200m
1800m
2400m
800m
Periadriatic plutons
Austroalpine nappes
Southern Alps
Northern Calcareous Alps & Grauwackenzone
Upper Austroalpine
Lower Austroalpine
Penninic nappes
Matrei Zone (Piemont Ocean)
Glockner nappe System (Valais Ocean)
Subpenninic nappes
Modereck Nappe System
Eclogite Zone
Post-Variscan cover in general
Storz Nappe
Hochalm Nappe
Göss Nappe
Venediger Duplex
(Venediger Nappe System)
ductile & brittle
ductile
ductile
Mio- Pliocene
Oligocene
traces of the latest doming foldaxes
Duplex roofthrust of the VD
contour-lines at base of Glockner Nappe System (black) & top of Göss Nappe (blue), interval 100 m

Figure 11 (previous page)**:**
(a) Tectonic map of the Tauern Window; dotted box shows location of Fig. 11b. BSZS – Brenner Shear Zone System; GB – Guidicarie Belt; KSZS – Katschberg Shear Zone System including the Katschberg Normal Fault (KNF) along its central part; MF – Mölltal Fault; NF – Niedere Tauern Southern Fault; PF – Periadriatic Fault; SEMP – Salzach-Ennstal-Mariazell-Puchberg Fault; ZWD – Zwischenbergen-Wöllatratten-Drau Fault. ETD Eastern Tauern Subdome; WTD – Western Tauern Subdome. Purple dotted lines (A-C) mark the trace of cross-sections in Fig. 2.3.
(b) Tectonic map of the eastern Tauern Window showing location of the three stops. White lines delimit the upper and lower limit of Katschberg-related shearing (maps from SCHARF et al., 2013). Structure of the Eastern Tauern Subdome: (a) Contours: black - basal thrust of the Glockner Nappe System, blue - top of the Göss Nappe within the Venediger Nappe System; Post-nappe folds and dome axes: HA - Hochalm Dome; RG - Rotgülden Dome; RO - Romate Fold; SB - Sonnblick Dome; MS - Mallnitz Synform.

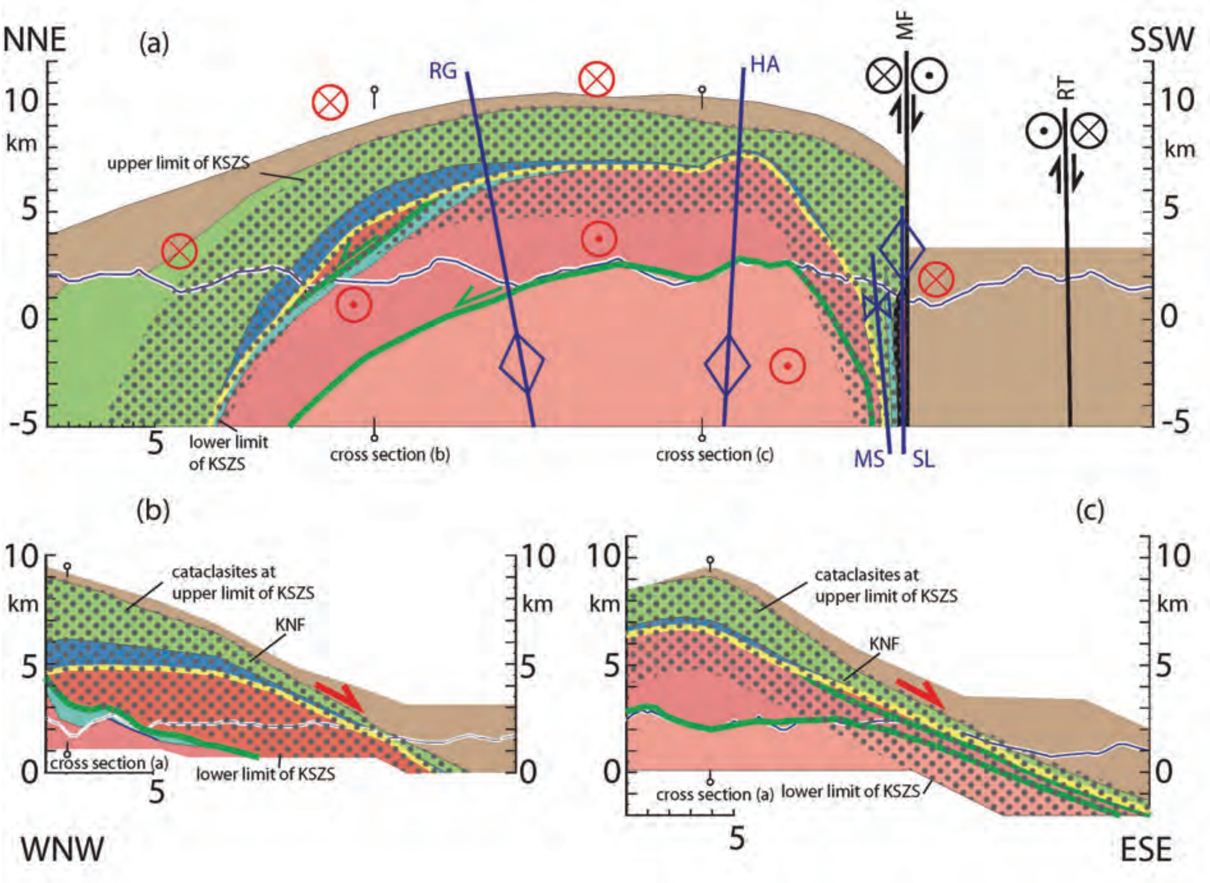


Figure 12: Cross sections across the easternmost Tauern Window corresponding to profile traces in Fig. 11a. Legend as in Fig. 11:
(a) Section perpendicular to the Katschberg transport direction and crossing the northern and southern branches of the KSZS that bound the Hochalm- (HA) and Rotgülden (RG) domes. These domes deformed the underlying Venediger Nappe System. Other structures include the Mallnitz Synform (MS), Sonnblick Gneiss Lamellae (SL), Mölltal Fault (MF) and the Ragga-Teuchl Fault (RT);
(b) and (c): Cross sections parallel to the ESE transport direction of the KSZS and perpendicular to the KNF, respectively. Grey stippled pattern indicates Katschberg mylonitic shearing; the mylonite belt along the KNF is capped by cataclasites. Green lines are nappe contacts within the Venediger Nappe System; yellow line marks the roof thrust. Major nappe contacts and fault boundaries were constructed with the aid of structural contour maps.

Penninic nappes exposed in the central part of the Tauern Window (e.g., KURZ et al., 2008). The age of this high-pressure metamorphism is controversial, with Eocene (RATSCHBACHER et al., 2004) and Oligocene ages (GLODNEY et al., 2005; NAGEL et al., 2013) proposed so far. The main accretion of Europe-derived nappes occurred in Late Eocene to

Oligocene time (D4) followed by Miocene folding, exhumation and orogen-parallel extension (D5, Figs. 12 & 13; e.g., SCHMID et al., 2013).

Exhumation is greatest at the western and eastern ends of the Tauern Window, where basement rocks with Barrow-type, greenschist- to amphibolite-facies rocks are exposed in the cores of upright D5 folds and domes (Eastern- and Western Tauern subdomes in Fig. 11a). This thermal peak metamorphism, termed the "Tauernkristallisation" (SANDER, 1911), is marked by widespread static recrystallization and overprints all nappe systems, including the D4 Venediger Duplex (LAMMERER & WEGER, 1998; SCHMID et al., 2013) but is itself overprinted by mylonitic fabrics of the D5.

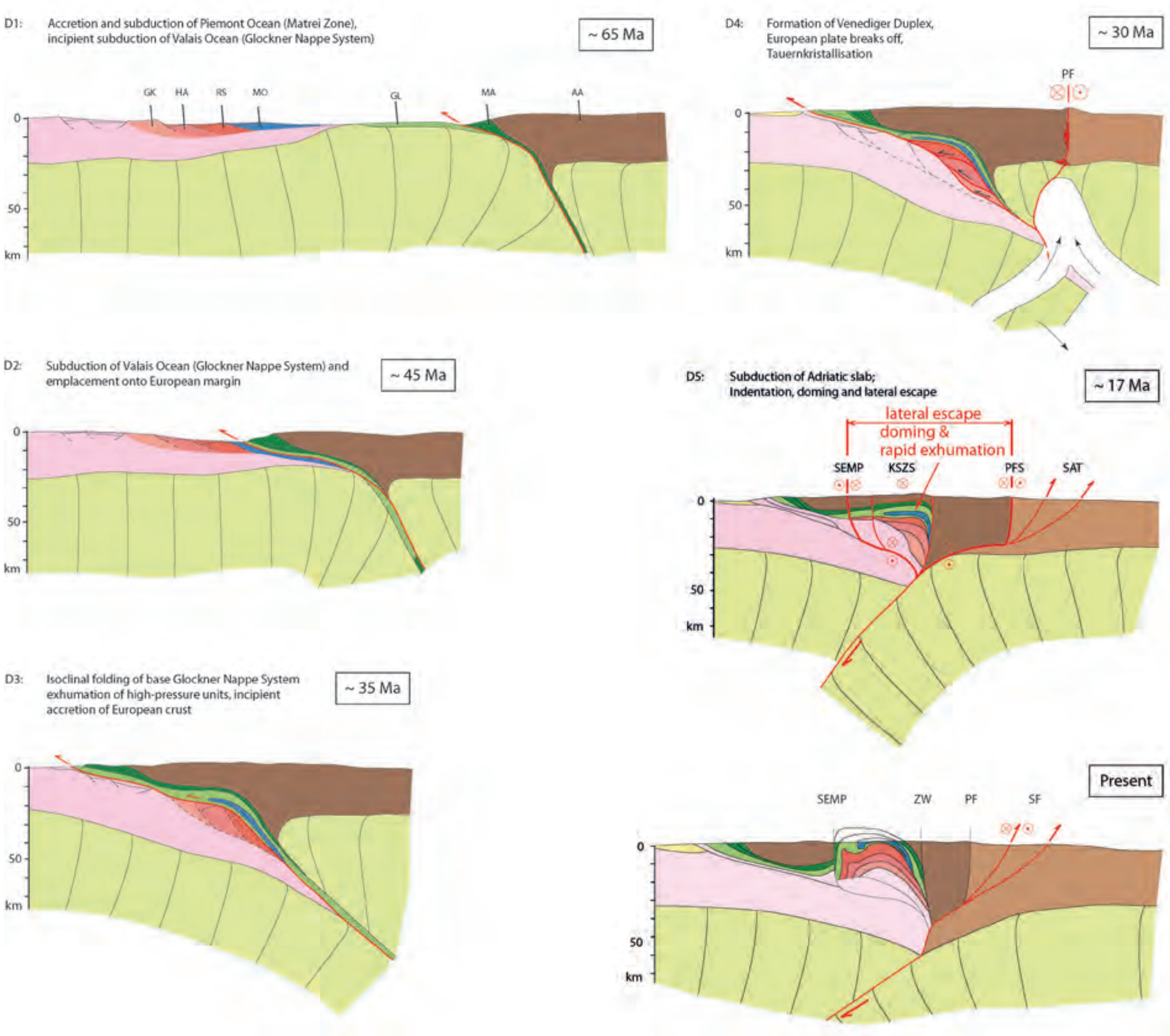


Figure 13: Sketches of illustrating the evolution in a north-south trending section through the eastern part of the Tauern Window (SCHMID et al., 2013). (a) D1 subduction of the Piemont-Liguria Ocean and accretion of oceanic relics in front of the Austroalpine nappe stack, ~ 65 Ma; (b) D2 subduction of the Valais Ocean and parts of the distal European margin, ~ 45 Ma; (c) D3 exhumation of the high-pressure units and incipient accretion of the European crust, ~ 35 Ma; (d) D4 formation of the Venediger Duplex and "Tauernkristallisation" at ~ 30 Ma. (e) D5 Indentation, doming and lateral extrusion, ~ 17 Ma; (f) Present-day section. Tectonic nappes: AA – Austroalpine units; GK – Göss Nappe; GL – Glockner Nappe System; HA – Hochalm Nappe; MA – Matrei Zone. MO – Modereck Nappe System; RS – Romate-Storz Nappe; SA – Southern Alps. Major Faults: KSZS – Katschberg Shear Zone System; PF – Periadriatic Fault; SEMP – Salzach-Ennstal-Mariazell-Puchberg Fault; SF – Sava Fault; ZW – Zwischenbergen-Wöllatratten Fault. Active faults are marking red and inactive faults are in black.

Brenner- and Katschberg shear zone systems at both ends of the Tauern Window. The age of the "Tauernkristallisation" is constrained to be somewhere in the range of 30-25 Ma (Rb/Sr on garnet- bearing assemblages, CHRISTENSEN et al., 1994; Rb/Sr white mica of VON BLANCKENBURG et al., 1989; KURZ et al., 2008; U-Pb allanite, CLIFF et al., 1998; INGER & CLIFF, 1994; Sm-Nd garnet isochron age of FAVARO et al., in prep.).
The Katschberg Shear Zone System (KSZS) at the eastern end of the Tauern Window is a belt of mylonites up to 5 km wide that separates the Penninic and Subpenninic units from the overlying Austroalpine nappes. The KSZS accommodated c. 26 km of east-directed orogen-parallel stretch in the Miocene (SCHARF et al., 2013; Fig. 11b). The central segment of the KSZS comprises the Katschberg Normal Fault (KNF, GENSER & NEUBAUER, 1989), whereas northern and southern branches are steeply dipping and accommodated dextral and sinistral strike-slip motion, respectively (Fig. 11b). These branches are interpreted as stretching faults in the sense of MEANS (1989) due to the decreasing amounts of displacement towards their western ends as inferred from the progressive weakening of their fabric toward the center of the Tauern Window (SCHARF et al., 2013).

Stop 1 – Kaponig Valley (N 46°56'33'' E 13°12'04'' Alt. 1100 m)

Directions: From Schladming follow the A10 to Spittal a. d. Drau. Few km before arriving at Spittal, turn west onto the A9. After 3 km the autobahns ends as the main road 106. Drive to Obervellach and turn right (north) to Mallnitz. After c. 1 km, turn right (first road after Obervellach), then follow this road until you reach the old train station, where we will park our cars (Fig. 14).

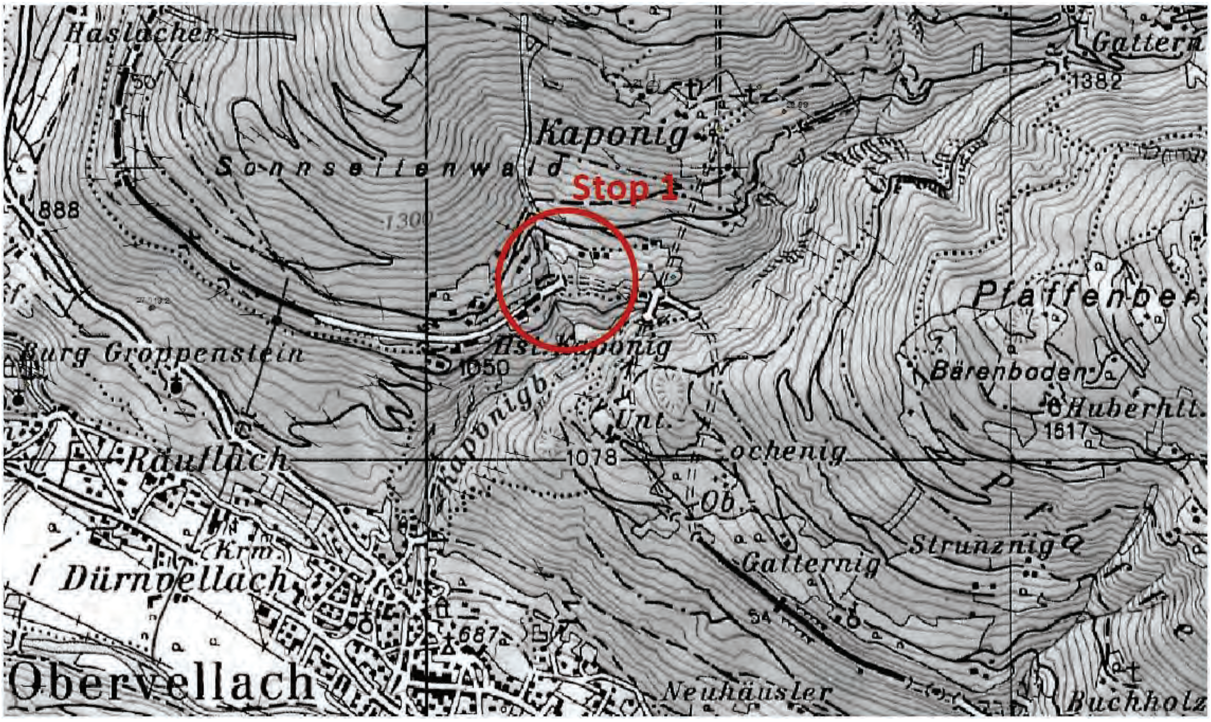


Figure 14: Location of Stop 1

In the Kaponig Valley, we observe the following sequence of folded nappes from left (south) to right (north) in Fig. 15: Sonnblick Nappe, Modereck Nappe System (MNS), Geißel Nappe belonging to the Glockner Nappe System, Modereck Nappe System, Kolm Nappe (also belonging to the Glockner Nappe System) and the Hochalm Nappe.

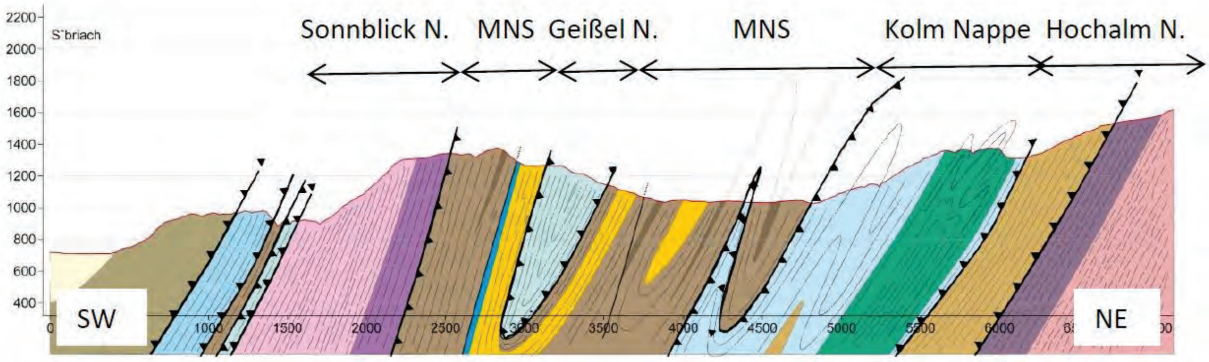


Figure 15: Profile 1 (trace and legend in Figure 26) near the Kaponig Valley: nappe sub-division

The Kolm Nappe is interpreted to be the lower subunits of the Glockner Nappe System. Its lithologies are gray‐blue, thickly bedded, mica‐bearing marble intercalated with dark, grayish to brownish calcareous mica schist of the "Bündnerschiefer Group" (PESTAL et al., 2009). Other large ophiolitic bodies contain prasinite, amphibolite and serpentinite. The Geißel Nappe is interpreted to be the upper unit of the Glockner Nappe System. It differs from the Kolm Nappe in nappe having no amphibolites and more stratified and finer-grained marbles.

The section in Fig. 16 crosses several D5 synforms and antiforms as well as the D3 antiform overlying the roof thrust of the Venediger Duplex. These structures were all highly sheared, mostly during D4 (in the east) and D5 (in the west) events. The internal part of the Mallnitz Synform is made up of Geißel Nappe in its core surrounded by the Modereck Nappe System on its limbs (Fig. 16).

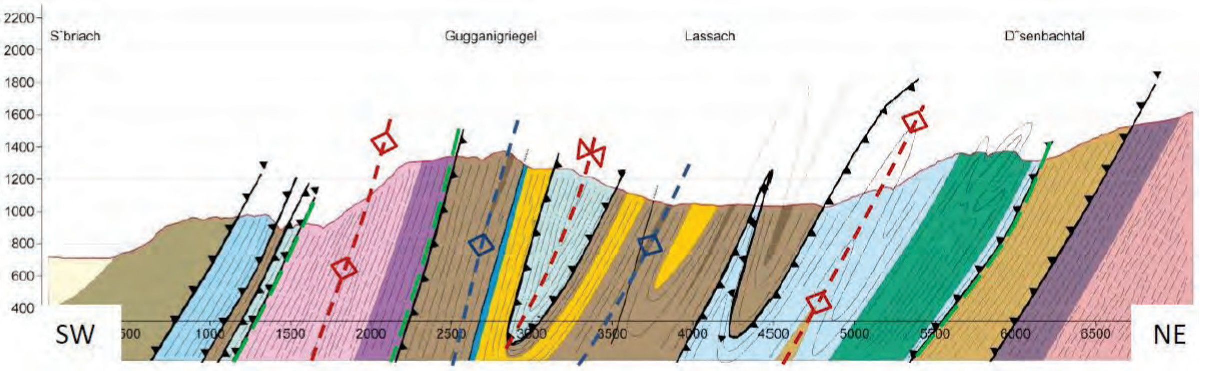


Figure 16: Profile 1 (trace and legend in Figure 26) near the Kaponig Valley: D5 folds marked in red, axial traces of D3 in blue, D4 roof thrust of the Venediger Duplex in green dashed lines.

A second D5 synform is developed at Auernig, near Mallnitz. This fold is open, with its hinge in the Kolm Nappe and its axial plane dipping parallel to that of the Mallintz Synform. The roof thrust of the Venediger Nappe System (Fig. 17) is a thin D5 shear zone at the base of the Kolm Nappe that also affects garnet and chloritoid-bearing schists of the Romate Nappe and schist of the Brennkogel Formation derived from the underlying Hochalm-Ankogel Nappe. A small D5 antiform located between the two synforms is located just west of Mallnitz (Fig. 17).

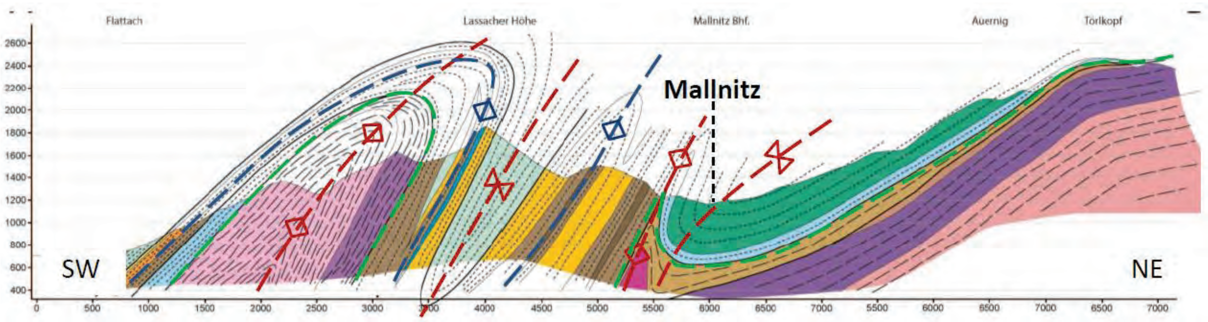


Figure 17: Profile 2 (trace and legend in Figure 26) near Mallnitz. D5 folds marked in red, axial traces of D3 (blue), D4 roof thrust of the Venediger Duplex (green).

Stop 2 (A) – Danielsberg (N 46°53'18'' E 13°16'51'' Alt. 966 m)

Directions: From Obervellach, head southeast on the main road 106. Then turn left onto a road just before Penk that leads to Preisdorf and follow it for a kilometer until you reach a little road on the right that leads to Danielsberg (Fig. 18).

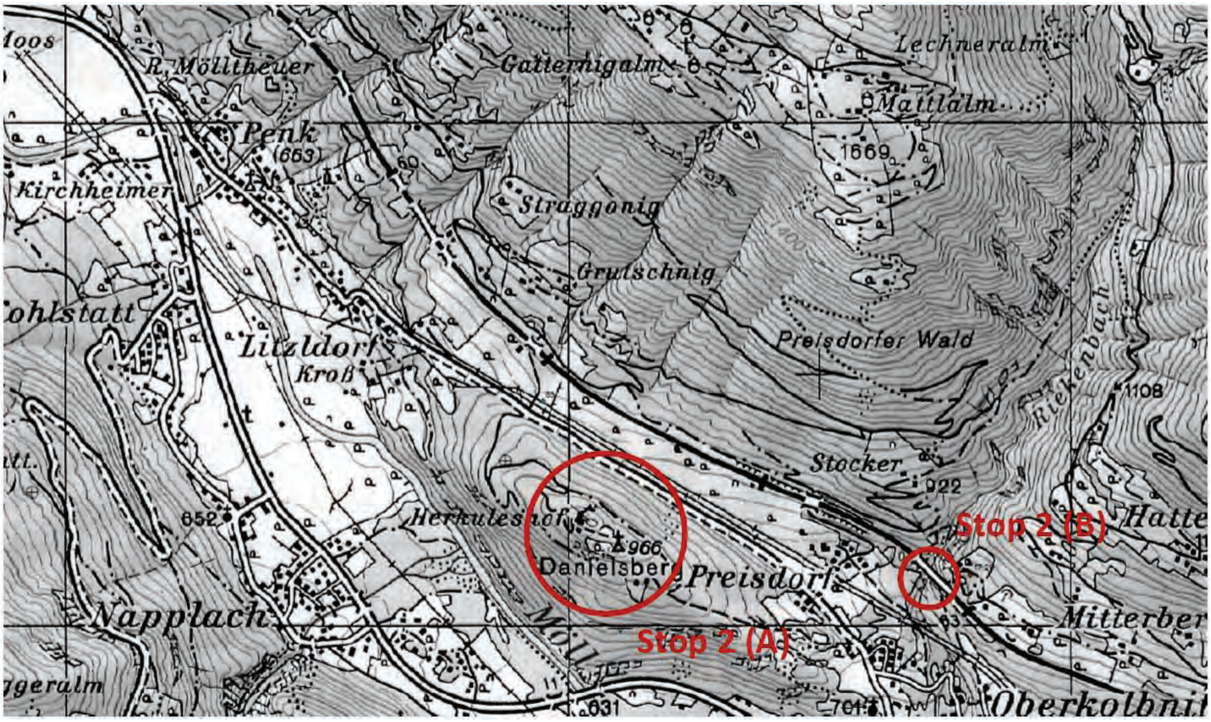


Figure 18: Location of Stops 2 (A) and 2 (B)

Danielsberg is located in the middle of the Mölltal Valley within the Austroalpine nappes. It is bounded to the northeast by the Mölltal Fault and to the southwest by a minor fault within the Austroalpine units. This hill is attributed to tectonics, as it coincides with a positive flower structure.

On top of Danielsberg, a little gothic-style church built in 1127 offers a nice panorama of the Möll Valley and the geology, including the next stop (Fig. 19).

Figure 19: View from Danielsberg to the southeast along the Möll Valley (Tauern Window with Penninic and Subpenninic nappes on the left, Austroalpine nappes on the right).

Stop 2 (B) – Oberkolbnitz (N 46°52’49’’ E 13°19’10’’ Alt. 775 m)

Directions: This outcrop is located in the Rieckengraben between the villages of Oberkolbnitz and Preisdorf. After leaving the cars along the road that leads up to the Rieckengraben (exactly under the railway bridge), take a small forest path that leads down to the streambed outcrop (Fig. 18).

In Fig. 20: The most competent lithologies in the outcrop shown in Fig. 20 are strongly sheared Augengneiss of the Sonnblick Lamellae (Abb. 27). All lithologies in this outcrop are affected by sinistral Katschberg mylonitic shearing and were later truncated by brittle faults planes associated with the Mölltal Fault.

In the Oberkolbnitz area, the Mölltal Fault is a NW-trending, subvertical zone of fractured rock and cataclasites some 10 m wide that delimits the southeastern Tauern Window from the Austroalpine nappes of the Eastern Alps. This fault overprints mylonites of the KSZS and is interpreted to have accommodated dextral strike-slip motion along the northeaster side of a triangular-shaped block of Austroalpine crust that indented the warm Penninic nappes in the eastern part of the Tauern Window (Figs 11a & b, 21; SCHARF et al., 2013).

Between Obervellach and Oberkolbnitz, the Mallnitz Synform changes its dip direction from steeply SW to steeply-to-moderately NE dipping (c. 040/30). The thickness of the Sonnblick Nappe decreases drastically going from NW to SE as the dome thins to become a narrow lamellae with a main S5 foliation that dips to the NE in the Möll Valley (Fig. 22). Along the NE slopes of this valley, the Sonnblick Lamellae as well as the adjacent Glockner- and Modereck nappe systems have narrowly spaced sinistral shear bands. These bands mark a c. 1 km wide zone of sinistral mylonitic shear that bends into continuity with the SE-dipping Katschberg Normal Fault (KNF) along the eastern margin of the Tauern Window (Fig. 11).

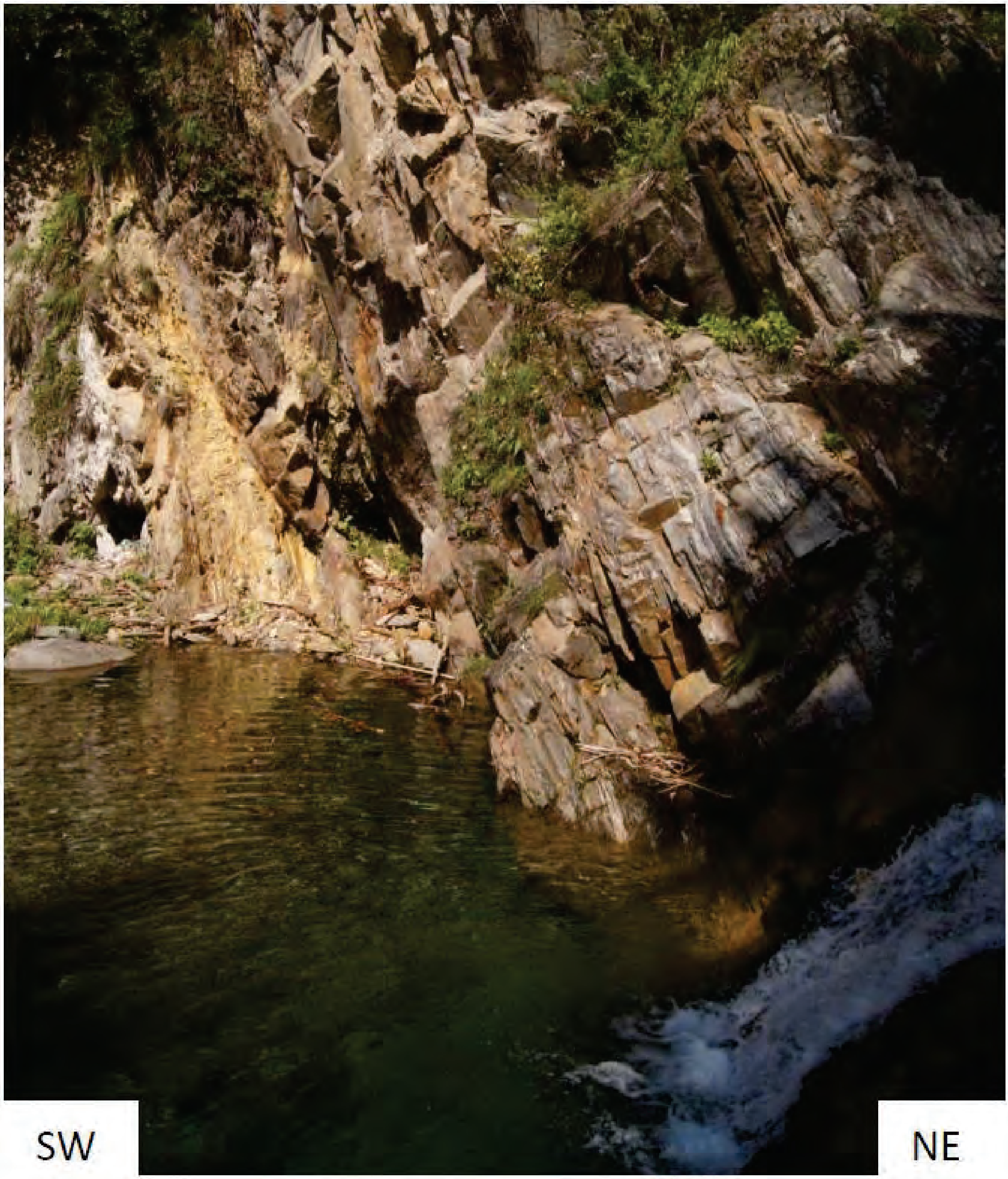


Figure 20: Outcrop at Oberkolbnitz. The mylonitic foliation dips to the NE. South of the Sonnblick Lamellae (right), yellowish layers of dolomitic marble intercalated with dark schist, grayish marble and calcareous mica schist of oceanic unit are exposed (left). All these lithologies are affected by sinistral Katschberg mylonitic shearing and are cut by later brittle fault related to the Mölltal Fault.

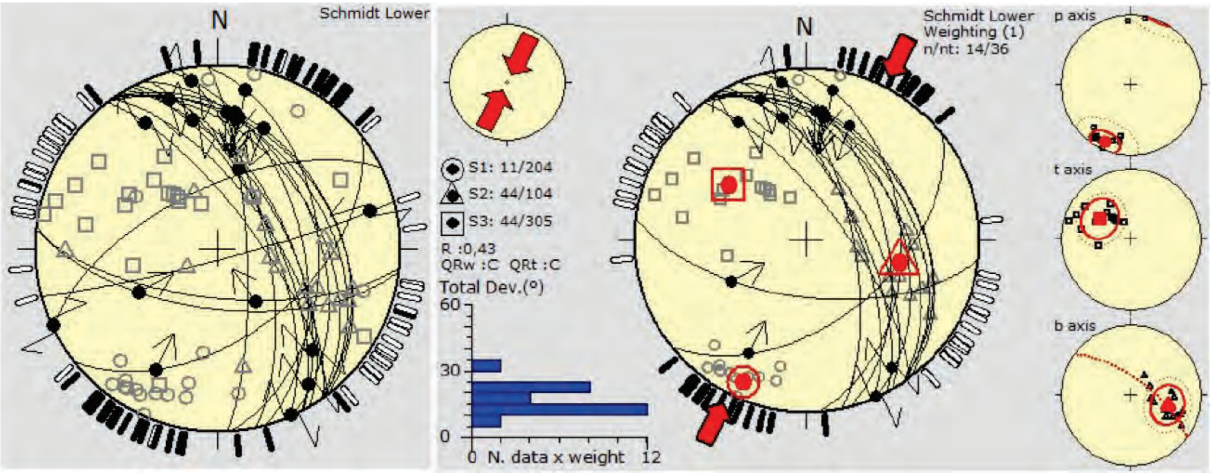


Figure 21: Fault analysis at Oberkolbnitz: (a) Equal area plot of brittle structures; (b) palaeostrain analysis.

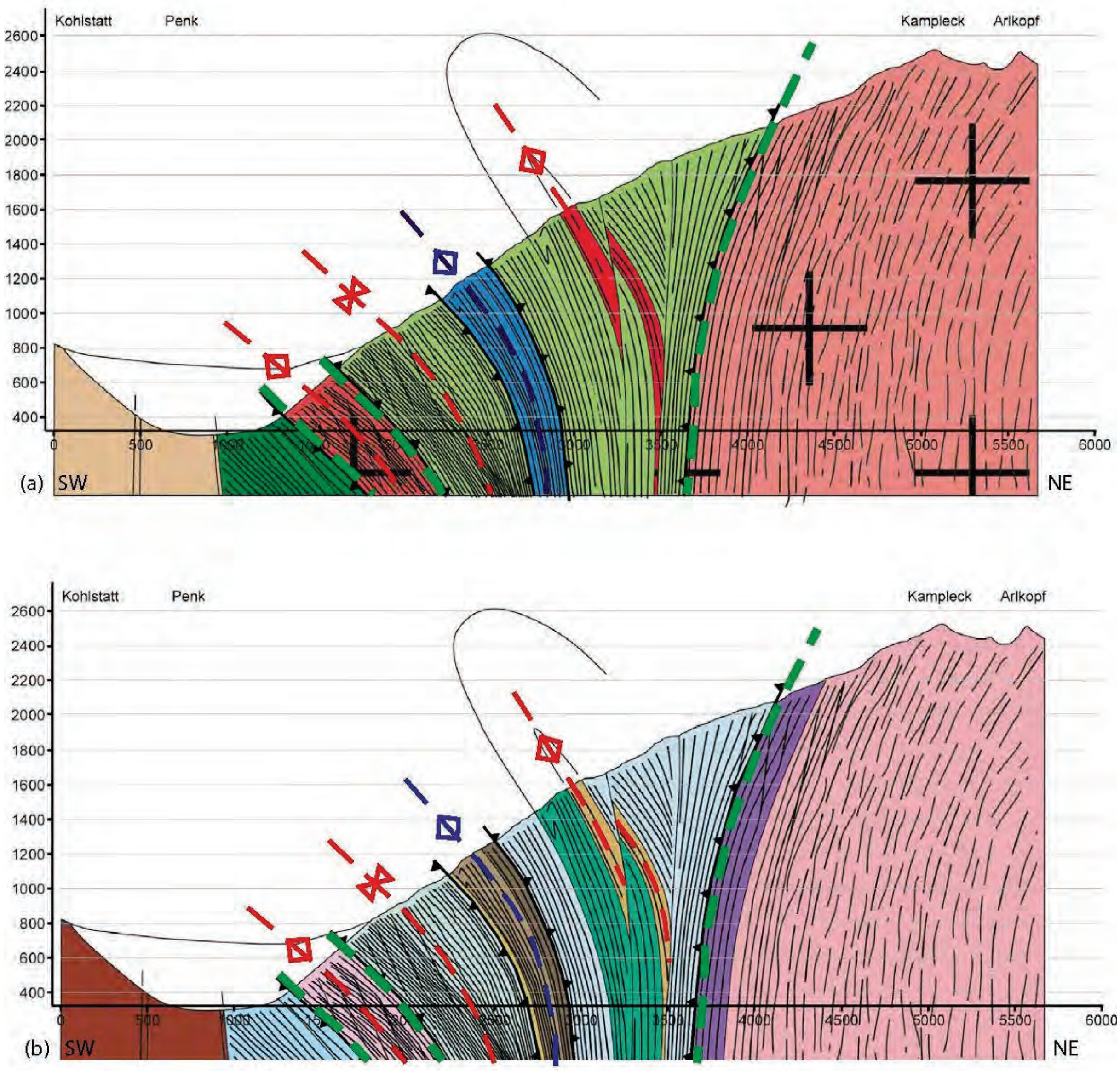


Figure 22: Profiles 3 (trace and legend in Figure 26) near Oberkolbnitz: (a) tectonic units, (b) lithology. D5 folds marked in red, axial traces of D3 (blue), D4 roof thrust of the Venediger Duplex (green).

Stop 3 – The Katschberg Normal Fault in the Malta Valley

Directions: From Gmünd, follow the road L12 into the Malta Valley and turn right (north) at the village of Malta. Drive up to the Maltaberg (the end of the road) and park at the Almhütte there at c. 1600 m (they serve cakes, coffee and Almdudler). From there, walk back to a forestry road branching off at an elevation of c. 1500 m (i.e., before the first U-bend). Follow this forestry road to the southwest into the "Ballonwald".

This stop consists of two sections of several small outcrops along a forestry road. It involves about 3 hours of easy walking and ends with a beautiful view of the Katschberg Normal Fault and the Hochalm Dome. The outcrops are of structures related to Miocene E to SE-directed shearing of Subpenninic and Penninic units in the footwall of the Katschberg Normal Fault (KNF). The entire stop is described in the explanations sheet of Map 182 "Spittal a. d. Drau", scale 1:50.000 (SCHUSTER et al., 2006).

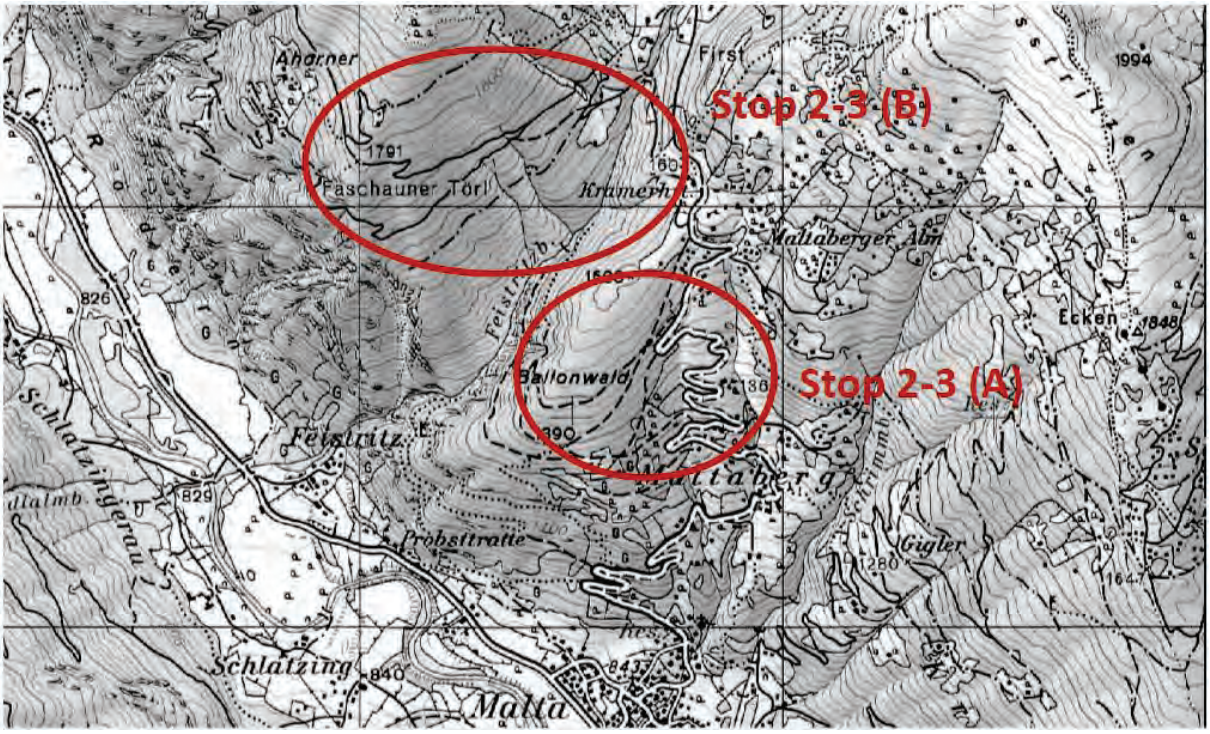


Figure 23: Location of Stops 3 (A) and 3 (B)

Section one, stop 3 (A) ("Ballonwald") (N 46°58'05'' E 13°29'56'' Alt. 1500 m) (Fig. 23)

Several small outcrops along the forestry road (1.5 km) oriented perpendicular to the strike of the Katschberg Normal Fault (KNF) reveal the lithologies in the footwall of the KNF: Penninic rocks (calc- schist and so-called "prasinite" of the Glockner Nappe System) and Subpenninic rocks (siliciclastic albite-bearing gneiss of the Modereck Nappe System, pre-Variscan paragneisses of the Storz Nappe).

The contact of the Modereck Nappe System with the underlying Storz Nappe marks the roof thrust of the Venediger Duplex (Figs. 11 & 12). All units dip moderately to the ESE and preserve top-ESE kinematic indicators. Peak temperature estimates obtained from Raman microspectroscopy on carbonaceous material (RSCM) in the metasediments above the aforementioned roof thrust yield temperatures of 515 ± 10° C in the structural lowest units and 460 ± 8° C in the structurally highest units (Fig. 24; Scharf et al., in press). This enormous decrease in peak temperature (field-gradient of 70° km-1; Fig. 25) corresponds with the zone of greatest tectonic omission in the footwall of the KNF.

Section two, stop 3 (B) ("Faschauer Törl") (N 46°58'38'' E 13°29'24'' Alt. 1791 m)

Directions: Return to the cars parked at the Almhütte and follow the path crossing the Feistritz Valley to the west.

This path (2 km long with an altitude difference of 200 m) has exposures of the Variscan granitic intrusions that intruded the pre-Variscan paragneisses seen along the path in the "Ballonwald". All these rocks belong to the Storz Nappe below the roof thrust of the Venediger Duplex (Figs. 11 & 12). The asymmetry of the feldspar augen in the intrusive rocks indicates top-ESE sense of shear. The end of this path provides a beautiful view of the "Faschauer Törl" (1791 m), where one can see the large-scale culmination of the Hochalm Dome, as well as the moderate eastward dip of all thinned Penninic- and Subpenninic units in the footwall of the KNF (Figs. 11 & 12).

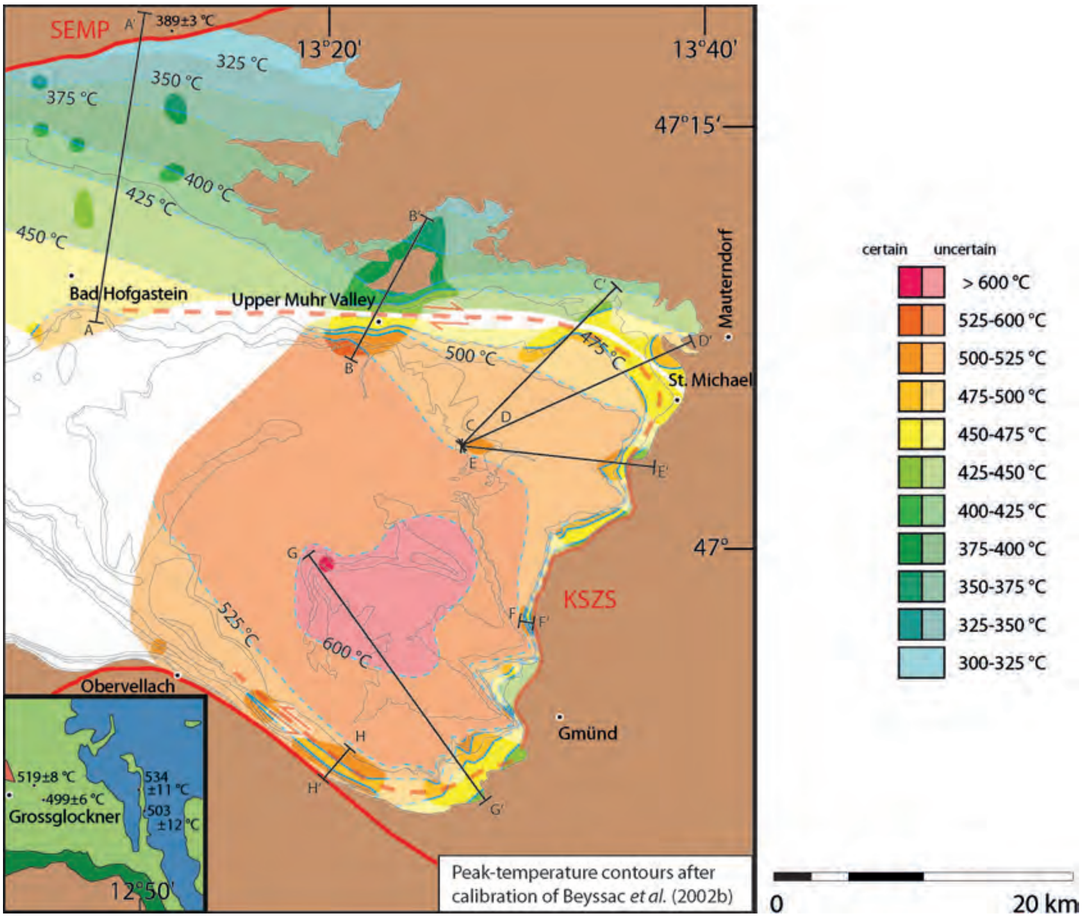
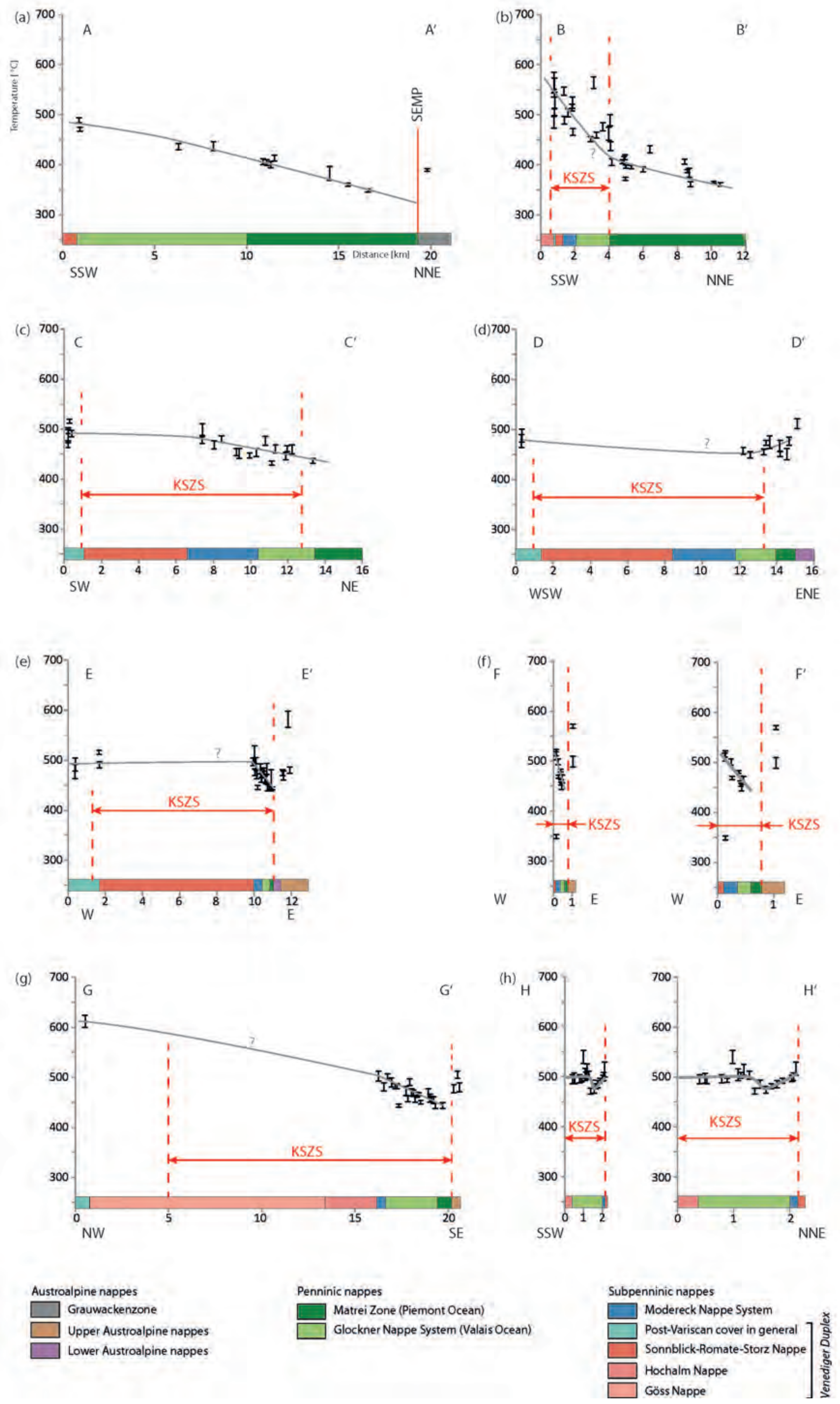


Figure 24: Peak-temperature contours based on the calibration of BEYSSAC et al. (2002) for CM. Transparent colours and dashed lines indicate areas and contours where the sample density is low. Brown = Austroalpine units. Grey lines = tectonic contacts separating units of the Tauern Window (after SCHMID et al., 2013). The peak-temperature contours are marked in blue. Inset shows estimated peak temperatures of 4 samples in the only area of high-pressure metamorphism. Trace of cross sections which are shown in Fig. 25. Profile "Ballonwald" is located along the cross section F-F'.

Figure 25 (next page)**:** Cross sections a-h of peak temperature along traces shown in Fig. 24. Calibration of BEYSSAC et al. (2002) with individual confidence interval bars (CI 95%). Colours along the horizontal axes indicate the tectonic units from the tectonic map of the Tauern Window (Fig. 11). The boundaries of the KSZS (Katschberg Shear Zone System, SCHARF et al., 2013) are marked in cross sections b-h by red dotted lines. Note that the horizontal axes in sections f and h are expanded by a factor of 3 for easier viewing. Peak-temperature points are projected into the sections from as much as 2.5 km on either side of the section planes, except in Fig. 25a where the projection is up to 5 km from the plane. Profile "Ballonwald" is located along the cross section F-F'.


(a)
A
A'
Temperature [°C]
SEMP
Distance [km]
SSW
NNE
(b)
B
B'
KSZS
SSW
NNE
(c)
C
C'
KSZS
SW
NE
(d)
D
D'
KSZS
WSW
ENE
(e)
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E'
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(g)
G
G'
KSZS
NW
SE
(h)
H
H'
KSZS
SSW
NNE
Austroalpine nappes
Grauwackenzone
Upper Austroalpine nappes
Lower Austroalpine nappes
Penninic nappes
Matrei Zone (Piemont Ocean)
Glockner Nappe System (Valais Ocean)
Subpenninic nappes
Modereck Nappe System
Post-Variscan cover in general
Sonnblick-Romate-Storz Nappe
Hochalm Nappe
Göss Nappe
Venediger Duplex

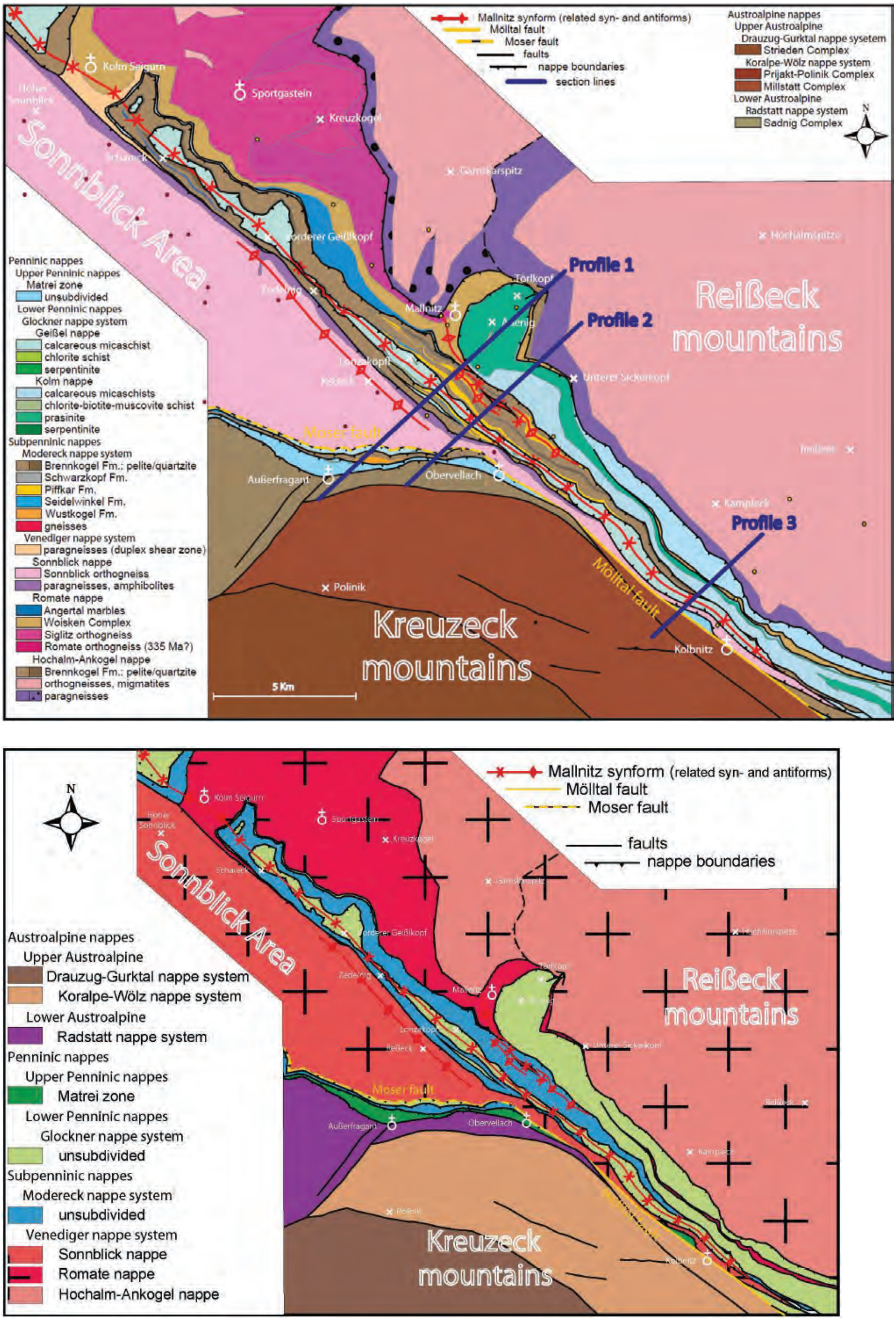

Figure 26: Maps derived from the filed work of Favaro S. and Schuster R. according with SCHMID et al. (2013) and PESTAL et al. (2009).

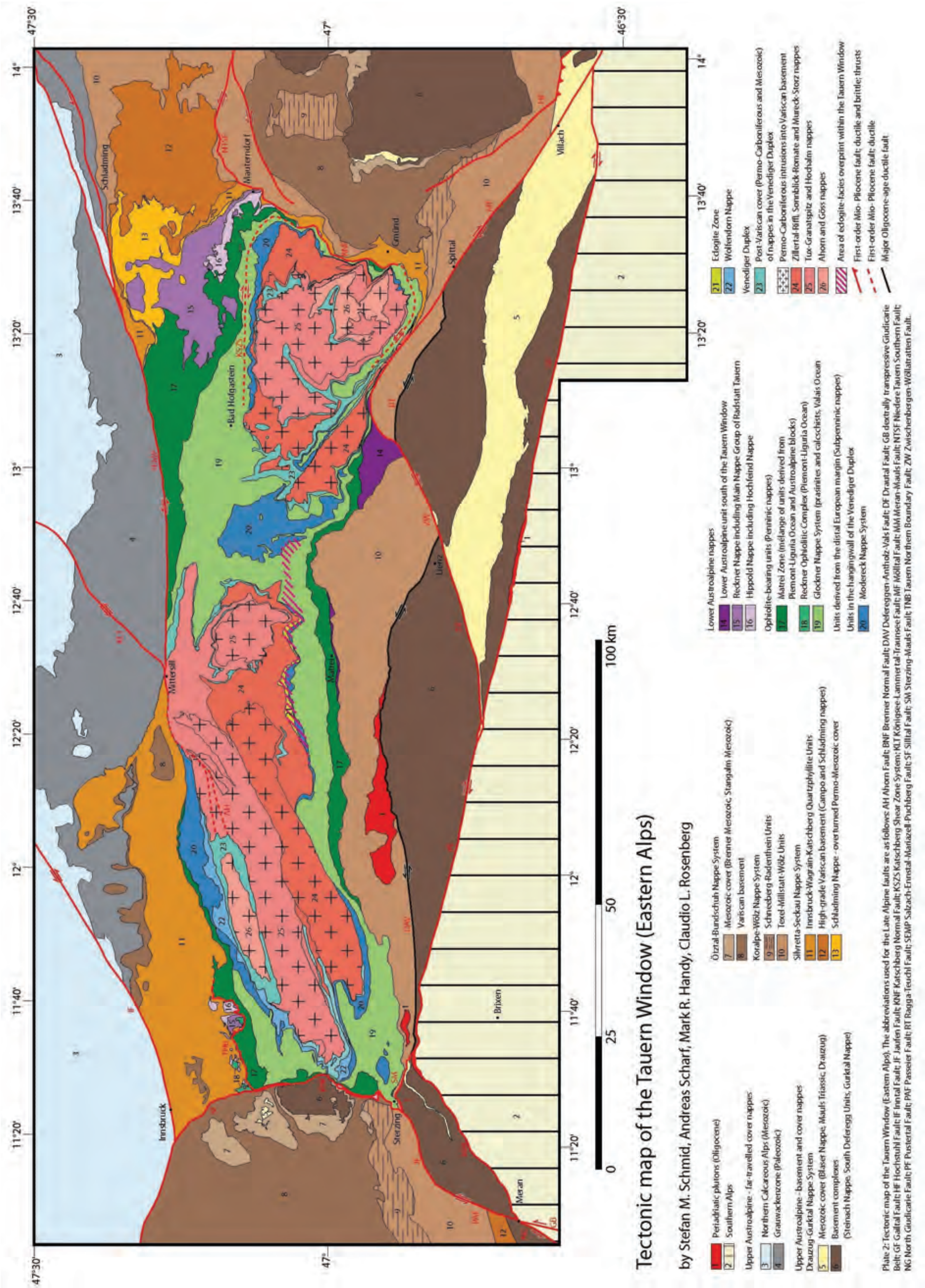

Figure 27: Tectonic map of the Tauern Window (SCHMID et al., 2013).

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