Carpathian-Balkan Geological Association, XVI Congress	Field Guide "Transsect through central Eastern Alps"	pp. 103 - 137	Salzburg - Wien, 1998

Transect through the central Eastern Alps: Description of stops

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Introduction

The locations of stops refer to official Austrian maps OEK 50 (scale 1:50,000). A set of copied maps with detailed locations can get received from authors on request.

Stop no. 1. Pettenbach, Upper Austria..

Location: OEK 50 Grünau. Core storage of the Rag AG at Pettenbach.

For introduction, see H. POLESNY (this volume).

Stop no. 2. Rehkogelgraben section S of Hagenmühle. Middle to upper Cretaceous marls of the "Buntmergelserie" (Ultrahelvetic unit)

Location: ÖK 50, sheet 67 Grünau im Almtal, 13°55' E/ 47°56' N. Creek south of Hagenmühle, situated in the valley of the Dürre Laudach (S of Vorchdorf).

Description is from follows Egger et al. (1997).

Prey (1952; see Tollmann, 1976; and Plöchinger, 1983) introduced the term "Buntmergelserie" (variegated coloured marls) for the pelitic rocks of the Ultrahelvetic continental slope. These rocks were deposited from the Albian to the Eocene. Due to increasing water depths to the south the marls were replaced by claystones and might interfinger with thinbedded turbidites and variegated shales of the Rhenodanubian flysch (Egger, 1995). Within the Rhenodanubian flysch a number of tectonic windows with Ultrahelvetic rocks exist. Some of these structures are bound to internal overthrusts within the flysch nappes, others cut the flysch units diagonally. The Rehkogelgraben window belongs to the latter type of structures which were formed by huge, dextral strike-slip faults. The age of these faults is estimated as Oligocene. In the Miocene, ENE-striking sinistral strike-slip faults cut the older NW-striking dextral strike-slip faults. These younger faults terminate the Rehkogelgraben window to the west and to the east (Egger, 1996).

The narrow road and the creek expose steeply south-dipping reddish marls and grey marly limestones of Coniacian to Santonian age. Samples (180 and 181) from the outcrop at

the outer bend of the creek contained well preserved planktonic foraminifers of Santonian age (*Marginotruncana coronata* (BOLLI), *Marginotruncana sinuosa* PORTHAULT, *Marginotruncana marginata* (REUSS), *Marginotruncana paraconcavata* PORTHAULT and *Globotruncana lapparenti* BROTZEN). The Santonian rocks border tectonically to grey marls and highly bioturbated spotted marly limestones of Cenomanian age. Sample 182 contained only badly preserved and small foraminifers: *Hedbergella cf. planispira* (TAPPAN), *Hedbergella cf. delrioensis* (CARSEY), and *Globigerinelloides sp.* In sample 185, *Biticinella breggensis* (GANDOLFI), *Hedbergella planispira* (TAPPAN), *Clavihedbergella subcretacea* (TAPPAN) and *Globigerinelloides sp.* prove the late Albian.
Just beside the small road bridge red marls are exposed along the creek. They are of early Campanian age (*Marginotruncana coronata* (BOLLI), *Marginotruncana marginata* (REUSS), *Globotruncana lapparenti* BROTZEN, *Globotruncana bulloides* VOGLER, *Globotruncana elevata* (BROTZEN)).

Stop no. 3. Hatscheck quarry near Gmunden. Altlengbach Formation of the Rhenodanubian flysch zone

***Location:** OEK 66 Gmunden. Upper levels of the quarry S Pinsdorfberg.*

St. FREIMÜLLER, F. NEUBAUER

The quarry exposes the Ahornleiten member (Maastrichtian) of the Altlengbach Formation of the Rhenodanubian flysch zone (Egger et al., 1997). Grey calcareous marls representing Bouma T_d are typical for the Ahornleiten member. These marl layers can reach thicknesses up to 8 metres. Together with sandy to silty hardbeds at their base isolated complete turbidites are up to 10 meters thick. The sand/shale ratio is generally low. The southern, stratigraphically higher part of the quarry exposes some altered, greenish ash tuffs, the northern, deeper level altered whitish tuffs intercalated within marls and greywackes.

From a structural point of view, the outcrop exposes a superposed sequence of structures. These structures include: (1) blind thrusts and buckling structures due to bedding-parallel slip; (2) structures related to faults postdating folding and thrusting, e.g. E-W extension (Figs. 1, 2). A complicate sequence of superposed fault patterns can be found in the outcrop (see Fig. 3).

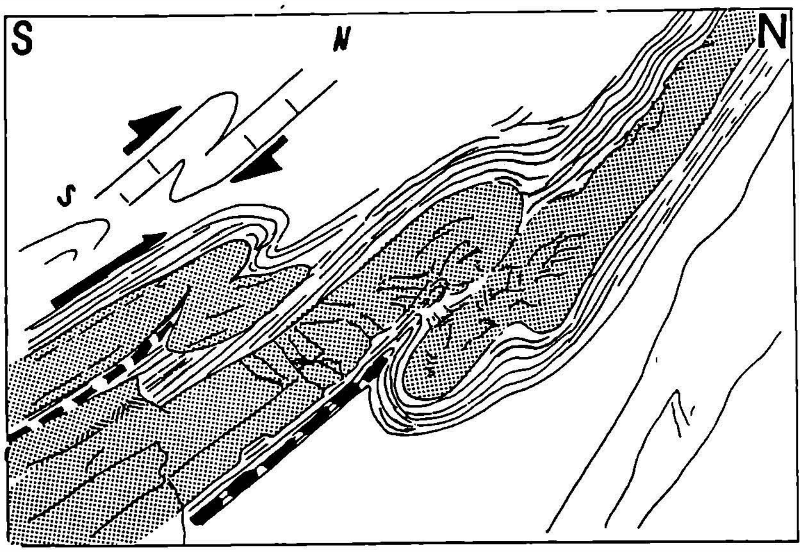

Fig. 1. Structures related to bedding-parallel slip within the Hatscheck quarry (from Freimüller, 1998).

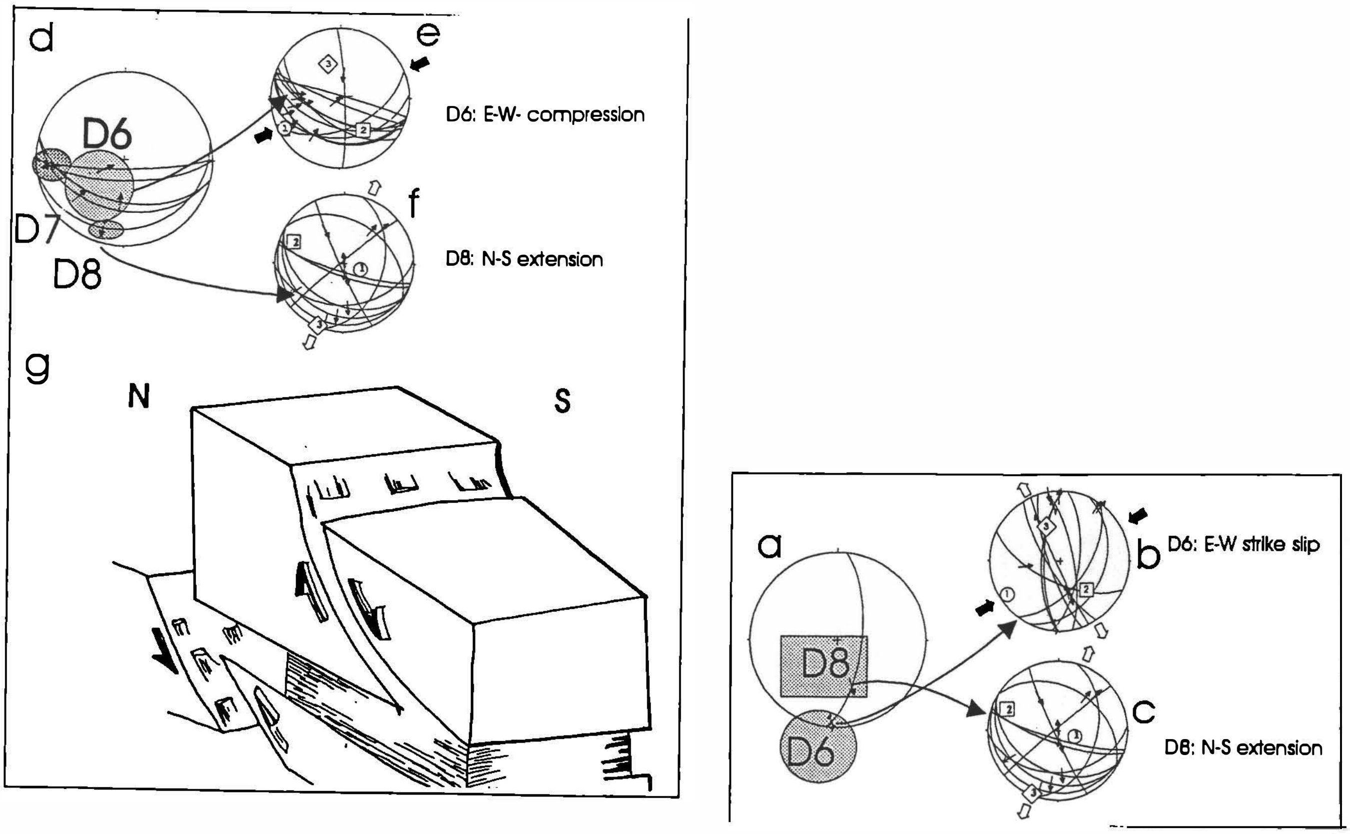

Fig. 2. Faults postdating thrusting in the Hatscheck quarry (from Freimüller, 1998).

Further reading: Egger et al. (1997); Freimüller (1998); Meschede and Decker (1994).

Stop no. 4. Lukasedt-Dreimühlen. Hall Group – Lukasedt Formation, Lower Miocene, Eggenburgian to Ottnangian; Fan-delta sediments of the Palaeo-Salzach.

***Location:** ÖK 50, sheet 63 Salzburg, Oichtental, ca. 1.3 km E of Oberndorf, ca. 300 m N of Lukasedt, ca. 100 m N Dreimühlen. Ca. 35 m long and 6-8 m high road cut to the N of Lukasedt, between two mills, at the right side of the Oichten creek.*

The outcrop is situated immediately N of the basal thrust of the Helvetic unit and shows a dipping of the beds with 45°-70° towards the NW.

The basal strata consist of *c.* 8 m thick silty sands to silts with clasts of quartz, quartzite, and dolomite. The silty matrix contains up to *c.* 80 cm large clasts of fine grained sandstone. Fossil fragments (gastropods, bivalves, scaphopods, corals, balanides, and foraminifers) are rather abundant. They are followed by 3.7 m of laminated and ripple bedded, brown and grey silts-fine sands, rich in plant material, and then fine sands. The brown and grey, micaceous sandstones are cemented with calcite.

These sediments belong to the Eggenburgian, deposited in distal parts of a fan-delta complex. The Lukasedt Formation is restricted to the SW in Salzburg and was deposited on top of the Perwang imbricates in a relative narrow erosional channel. This fan-delta is the main sediment source for the Ottnangian sediments (Innviertel group) of the Upper Austrian Molasse basin.

Further reading: Egger et al. (1997).

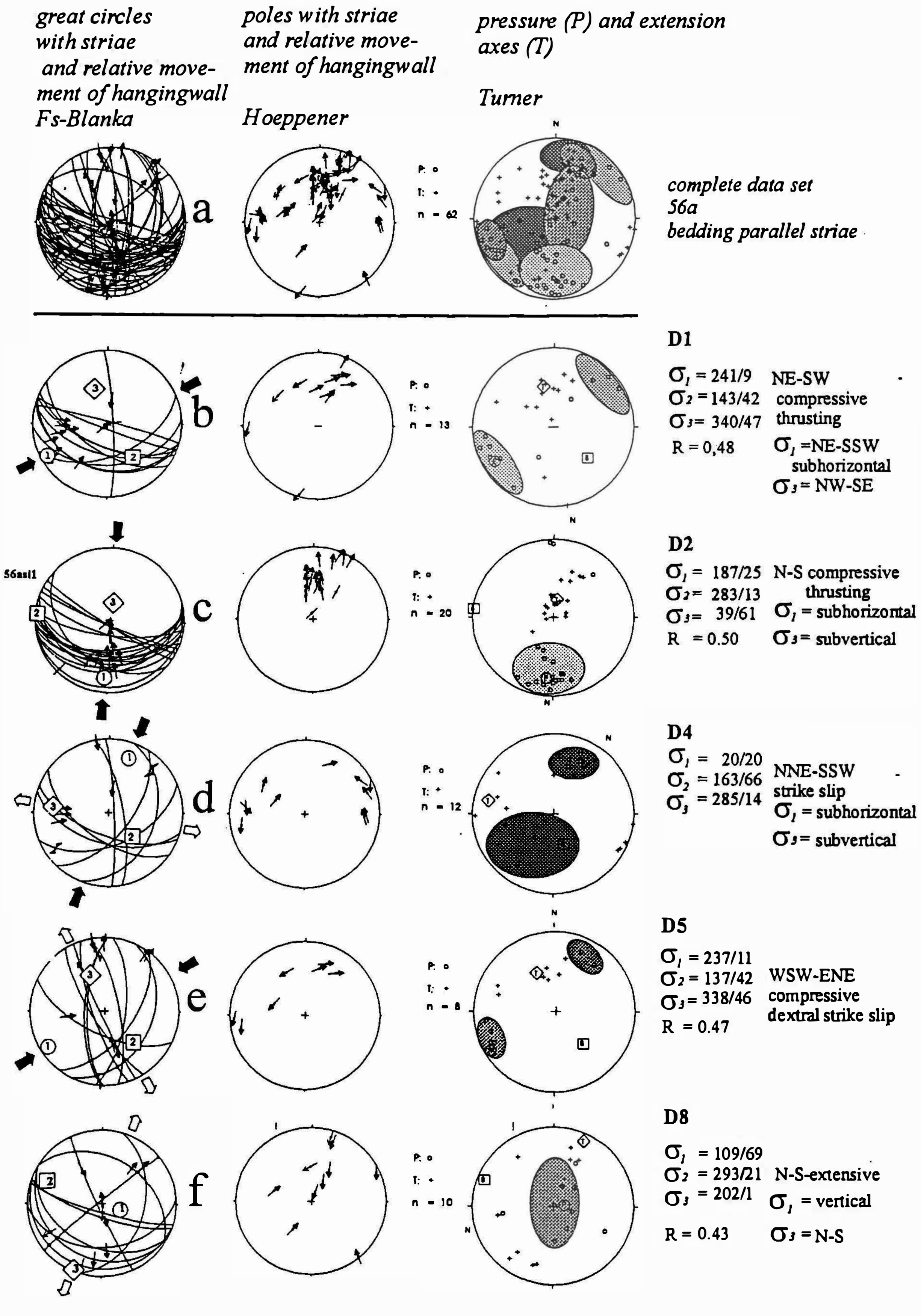

Fig. 3. Paleostress patterns from the Hatscheck quarry (from Freimüller, 1998).

Stop no. 5: Haunsberg-St. Pankraz. Roterzschichten and Mittelschichten (Ypresian), Schwarzerzschichten (Lutetian), Fossilschicht (Lutetian) of the Helvetic zone.

***Location:** ÖK 63 Salzburg, Quarry (Schlößlbruch) ca. 3.7 km ESE of Oberndorf, ca. 1.8 km NNW point 835 (Haunsberg), ca. 700 m S of Kroisbach.*

General description: The Roterzschichten are red-brown, quartz-bearing calcarenites rich in nummulites. They are overlain by yellowish-white fine- to medium-grained quartzarenites (Mittelschichten), and then again quartz-bearing, brown-grey calcarenites. The Fossilschicht is a marly sand very rich in macrofossils. These sediments represent the deposits of a subtropical, oxygen-rich, shallow sea with different amounts of terrigenous influx.

The quarry also shows various sets of subvertical brittle faults. The dominating set trends NNE parallel to the Saalach fault further to the west. This set was activated first as a sinistral strike-slip fault by N-S contraction, later as a dextral fault due to ENE-WSW contraction. Furthermore, some sinistral strike-slip faults parallel to subvertical bedding planes can be observed. Relationships between the earlier two fault sets remain unclear.

Further reading: Egger et al. (1997).

Stop no. 6: Nockstein. Basal thrust of the Tirolic nappe complex.

***Location:** OEK 64 Strasswalchen. Quarry at the toe of Nockstein.*

F. NEUBAUER

The quarry exposes Cenomanian marls of the "Cemomanian Randschuppe" which are overridden by Triassic Hauptdolomite of the Tirolic nappe complex within the Northern Calcareous Alps. The thrust surfaces shows brittle, bedding-parallel slickensides and stylolites and NNE-directed striations due to NNE transport of the Tirolic nappe. The overlying Hauptdolomite is heavily faulted.

Stop no. 7: Gaisberg: Panorama

***Location:** OEK 64 Strasswalchen. Plateau of Gaisberg (1287 m).*

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The Gaisberg panorama (Fig. 4) is one of most impressive overview of the structural units exposed at the transition to the foreland along northern margins of the Alps. The northern part exposes the Molasse peripheral foreland basin as plain and the hilly area with the Rhenodanubian/Helvetic thrust wedge. The basal thrust surface of the Northern Calcareous Alps is at the northern toe of the Gaisberg and extends towards W through Salzburg city where it is located at the northern toe of the Kapuzinerberg and Hohensalzburg castle.

The Gaisberg and the southern adjacent Osterhorn mountains belong to the Tirolic nappe within the Northern Calcareous Alps. The view towards SW exposes the overlying Lower Juvavic nappe with Hallstatt limestones. These are overriden by the Upper Juvavic nappe exposed within the Untersberg mountains.

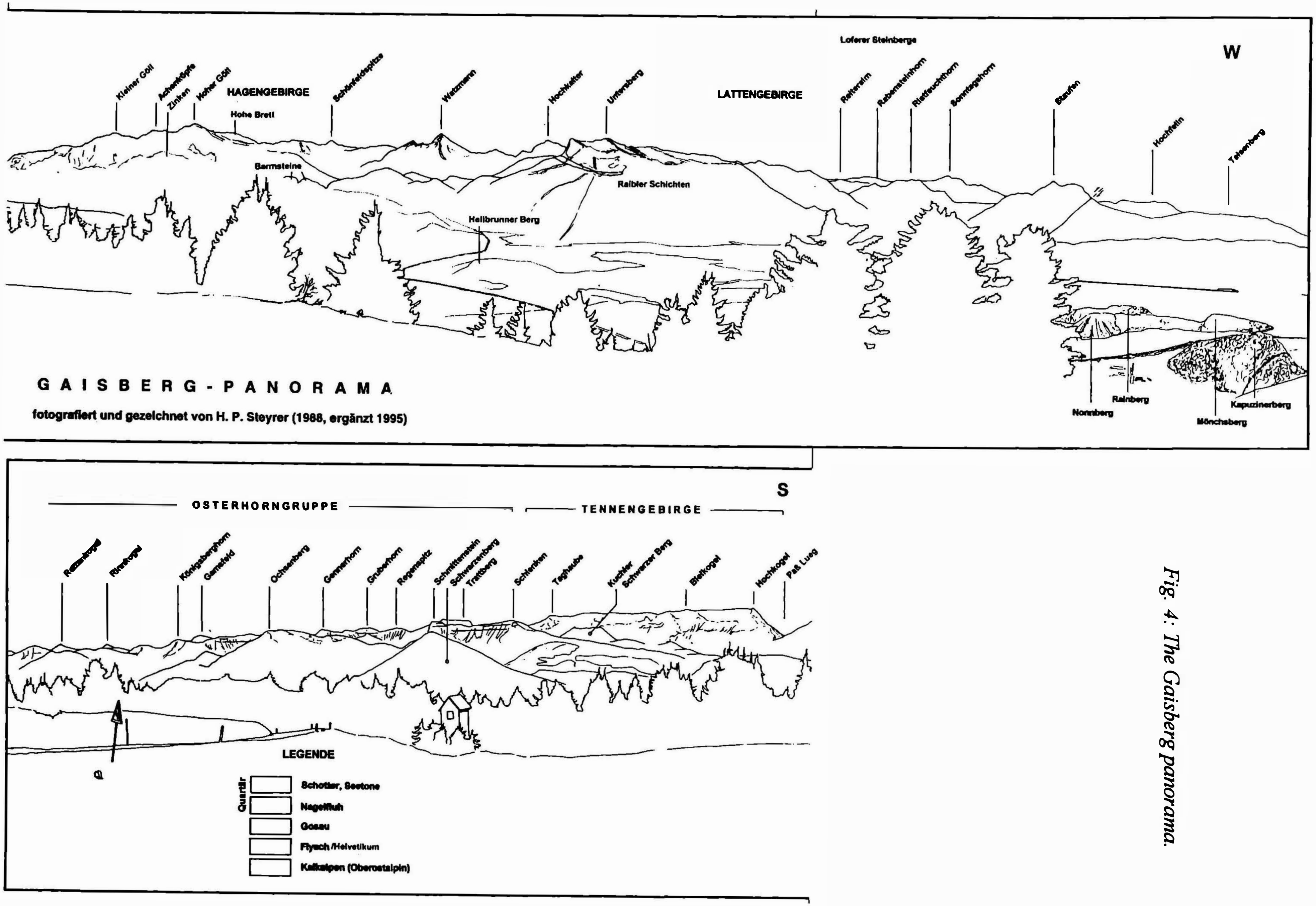

Fig. 4: The Gaisberg panorama.

Stop no. 8: Adnet quarries (Scheck and Lienbacher quarries). Liassic Adnet limestone.
Location: *OEK 94 Hallein. The quarries are located to the NE of the village Adnet.*

The Adnet Limestone is exposed in many quarries towards east of Adnet village. Illite-crystallinity data of this region and pre-depsoitional apatite fission track ages indicate that formation temperatures never exceeded diagenetic conditions (Kralik et al. 1987; Schweigl, 1997).

The Adnet Formation is 30 metres thick at the type-locality Adnet and ranges chronologically from the Hettangian to the Aalenian (e.g., Tollmann 1976). Where breccias are intercalated, the whole sequence attain thicknesses up to 100 metres (Tollmann 1976, Böhm et al. 1995). The Adnet Formation overlies Upper Triassic basin and reef limestones which were exposed during the lowermost Hettangian time. Doggerian limestones rich in cherts form the hanging wall.

The Adnet Knollenkalk facies (Fig. 5) is found in both the lower and upper parts of the Adnet Formation, where it averages approximately 15 m in thickness. The transition from the Adnet Knollenkalk to overlying Upper Liassic marls and to the paleogeographically adjacent Hierlatz limestone are continuous. Crinoidal Hierlatz Limestones also occur as fillings of Neptunian dikes cutting through the Adnet limestone. Thick (up to 60 m) nodular breccias, known locally as Adnet Scheck, occur within the Adnet Formation in the Pliensbachian. The Adnet Scheck and its equivalents in the Osterhorn mountains are interpreted as products of redeposition of a nodular limestone in a swell or seamount area (Hallam 1967, Hudson & Jenkyns 1969, Jurgan 1969, Bernoulli & Jenkyns 1970, Böhm et al. 1995).

The Adnet Knollenkalk facies is a red, cephalopod-rich, nodular, phacoidal limestone (Figs. 5, 6). It consists of limestone-marl interbeds and/or limestone nodules within a marly matrix. The red color is caused by hematite coatings. Occasionally the Adnet Knollenkalk has a pale green to grey color as a result of secondary alteration. The facies frequently contains ferromanganiferous crusts and nodules, which often contain sessile foraminifera and serpulae that are sometimes associated with boring algae. These facts have been used to interpret the Adnet Knollenkalk and all red limestones of the Tethyan Jurassic as having been deposited in relatively shallow water environments. However, other investigations indicate that these Jurassic nodular limestones appear to have formed in pelagic, deep water environments.

In exposures of the Adnet facies, red nodular limestone containing abundant cephalopods, manganiferous nodules, and crusts are the predominant rock types. The more calcareous parts of red nodular limestones contain calcite-replaced sponge spicules, crinoid fragments, and foraminifera in a marly or micritic matrix. Marl-rich layers have higher fossil contents and are especially rich in crinoid fragments. The micritic nodules are generally pink to light red and make up the bulk of the rock, while the marly, micritic matrix is dark red. Where manganese has been replaced by iron, the matrix becomes black. The matrix sometimes includes abundant white or red crinoidal or other skeletal fragments. A complete spectrum of microfacies, from extremely nodular beds to homogeneous beds of red limestone with different amounts of ferruginous or manganiferous crusts and nodules, is present.

Ammonites occur on nearly every bedding plane, but are most often preserved as molds. Nautiloids, belemnites, gastropods, bivalves, calpionella, coccolithophorida, radiolaria, and trace fossils are rare. Shells and skeletal fragments of benthonic crinoids, echinoids, ostracods, pelecypods, gastropods, sponge spicules and benthonic foraminfera make up 20 to 40 percent of the rock and are embedded in a fine grained, micritic matrix. There are deep sea stromatolites (Böhm & Brachert, 1993). Solution effects are evident in the preservation state of fossils, especially ammonite moulds and corroded crinoid stems.

Unlike typical concretions primary laminations do not pass across matrix and nodules of the nodular limestone; rather the whole rock is strongly deformed. The boundaries of the

Adnet nodules are generally sharp, stylolitic, often with truncated fossils and enriched with ferruginous or manganese minerals (Garrison & Fischer 1969). In contrast, Jenkyns (1974, his Fig. 3) reported a belemnite that crosses the matrix-nodule boundary.The nodules may laterally grade into more continuous centimetre-thick beds with irregular surfaces.

Depending on their clay content nodular limestones are comprised of nodule-rich layers. Most nodules are rounded while others are distinctly angular. Some have a ferruginous or manganiferous rim or their boundary to the matrix is stylolitizised.

The Adnet Scheck generally occurs as a breccia of red Adnet limestone nodules within a red marly Adnet matrix. In the Adnet quarries the Scheck is a breccia with a matrix of white, sparry calcite

The Adnet Knollenkalk includes many structures, including stylolites, that are characteristic of protomylonites (standard structural terminology in e.g., Wise et al. 1982, Heizmann 1985). These include stylolitic bed-parallel foliation, S-C-fabrics, shear bands, and σ-clasts resulting from deformation in a semiductile regime. The semiductile structures cut synsedimentary Neptunian dikes filled by Hierlatz or Adnet sediments and postdate both sediment deposition and early submarine lithification. The roughly E-trending Neptunian dikes are centimeters to decimeters wide and are mainly oriented perpendicular to bedding. Brittle deformation structures, thrust faults, dip-slip faults with en-echelon extension vein arrays cut the semiductile structures. At Adnet, the limestones of the Adnet Formation lie subhorizontally or dip gently towards the S (maximum angle of dip: 15°).

Most bedding planes in the Knollenkalk were formed by anastomosing stylolitic foliation. The stylolites have their stylolite teeth oriented parallel to the maximum compressive stress. In the Adnet Knollenkalk, only a small proportion of the stylolites are oriented subvertically, indicative that they were produced by sedimentary or tectonic load. Many stylolites are obliquely oriented to bedding, which suggests principal stress σ_1 oblique to the bedding plane, e.g., by contraction due to transport of a thrust sheet over the Adnet Formation. Subvertically oriented stylolites are older than the obliquely oriented ones. Bedding-parallel fibrous slickensides and lineations within the Knollenkalk are associated with the stylolites. Thus most of the stylolites of the Adnet Knollenkalk are tectonic in origin.

Two types of extension gashes occur in the Adnet quarries: the first type is filled with white calcite and are millimetres to several centimetres in width. They are cut by stylolitic seams and shear planes. They are subvertical to the bedding planes and trend predominantly E-W. The second type are veins filled with white calcite and have a width of several centimetres. They are often overprinted by dip-slip faults and cut the solution seams and shear zones. There are two sets of these veins, oriented N-S and roughly E-W, respectively. Riedl shears and S-C-fabrics give the shear sense of movement of the hanging wall to the NNE.

Shear bands that cut nodule margins are up to several centimetres thick. Many nodules appear to represent σ-clasts with pressure shadow tails. During advanced stages of deformation, mesoscale out-of-sequence shear planes caused decomposition of competent limestone layers into boudin-like clasts and nodules, often containing remnants of fossils (e.g., ammonoidea). These clasts acted as rigid particles within a more deformable, argillaceous matrix. Sometimes these nodules rotated, producing asymmetric pressure shadows until σ-clasts developed. Porphyroclasts of σ_a and σ_b- type (Passchier & Simpson, 1986) are present, but formation temperature was not high enough to produce recrystallisation within pressure shadows. Biogenic and other clasts were flattened and partially dissolved along clast edges (Figs. 5d, e). The transition between more or less nodular beds depends on the silt and clay contents. While limestones with very little clay contents were structurally resistant to strain, clay-rich limestones tended to be structurally responsive.

Offsets of crinoidal Neptunian dikes (along cm-wide, internally finely foliated, shear zones that subparallel bedding planes) clearly demonstrate the occurrence of ductile shear zones in otherwise nearly undeformed limestone. Lineation along stylolitic foliation surfaces are weakly developed, but trend NNE to NE. Strata-parallel slickensides indicate top to the NNE displacement (Fig. 7).

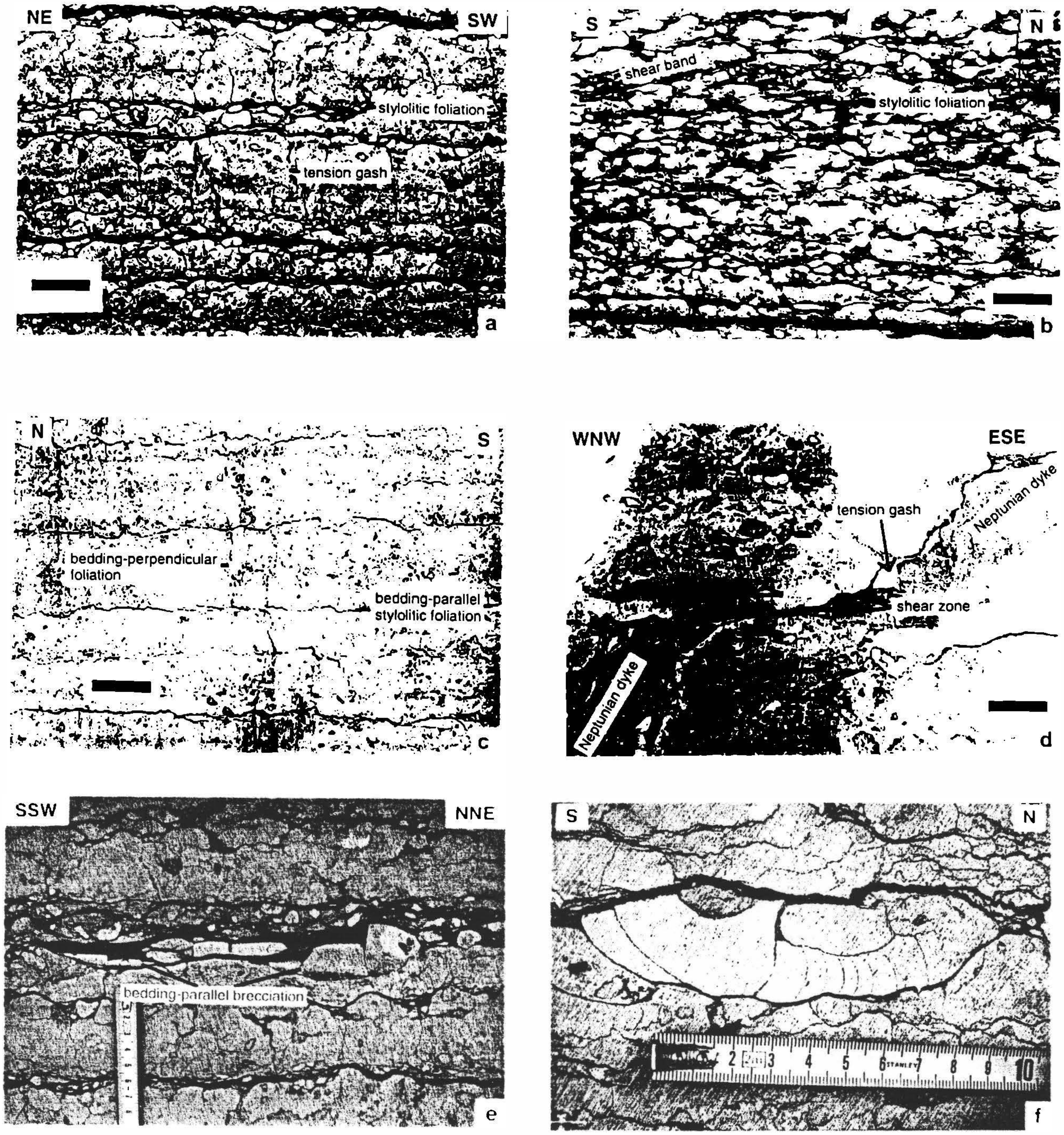

Fig. 5. Field photographs: a) Representative nodular limestone with mainly competent layers; stylolites parallel and perpendicular to bedding planes; scale bar = 10 cm. b) Nodular limestone with shear planes; rich in nodules; scale bar = 5 cm. c) Sets of oblique and subvertical stylolites; scale bar = 10 cm. d) Neptunian dike offset by a subhorizontal semiductile shear zone; note S-C fabric; scale bar = 5 cm. e) Protomylonitic character of the nodular limestone: ammonite dissected and elongated by a shear zone; scale in centimetres. f) Ammonite mold deformed by pressure solution along seams oriented oblique to bedding; scale in centimetres.

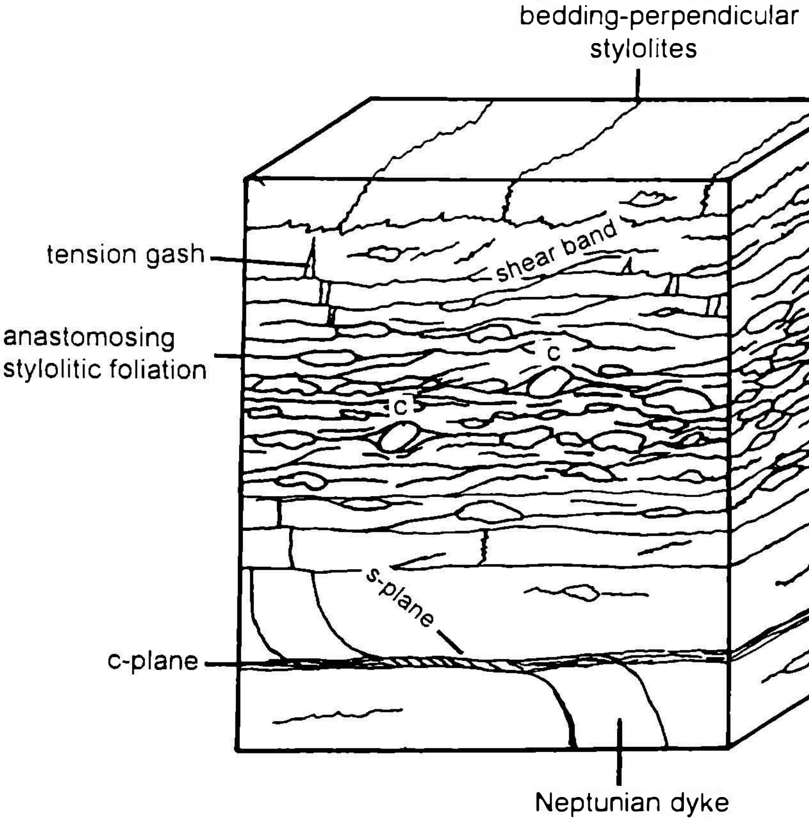

Fig. 6: Sketch of deformation features observed in the Adnet Knollenkalk, shear bands, stylolites, σ-clasts, and semiductile shear zone offsetting a Neptunian dike. c = tectonic clast with strain shadows.

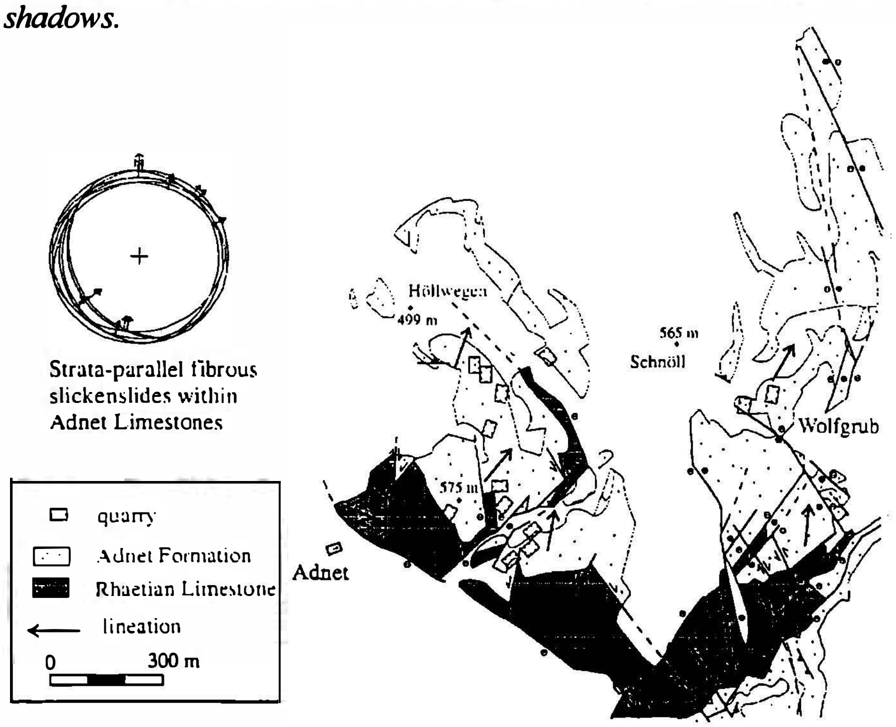

Fig. 7: Orientations of three deformation stages recorded in the Adnet quarries from oldest to youngest: a) Extension gashes filled with calcite, mainly oriented E-W. b) Strata-parallel fibrous slickensides and twins 1a and 2a indicating NNE-SSW contraction. c) Extension veins, oriented N-S and E-W and twins 1b and 2b showing extension with σ_1 subvertical. Schmidt plots, lower hemisphere.

Further Reading: Böhm et al. in Egger et al. (1997); Schweigl (1997); Schweigl and Neubauer (1997); Schweigl and Neubauer (submitted).

Stop no. 9: Quarry Leube, Oberalm and Roßfeld Fm.

Location: OEK 63 Salzburg. The quarry of the Leube Cement Co. is located on Guthratsberg near Gartenau.

The quarry of Leube Company exposes a section from Oberalm Limestone (Tithonian to Early Berriasian), Schrambach Marl Fm. (Berriasian-Early Valangian) to the Rossfeld Formation (Hauterivian-?Barremian). The Oberalm Limestone is a grey, cherty, decimetre-bedded deep-water limestone with allodapic limestone interlayers (Barmstein Limestone). The uppermost level of the quarry exposes impressive very coarse-grained Barmstein Breccia. The source of these allodapic limestones is located to the west and represented by a carbonate platform which is similar to Plassen Limestone. Furthermore, Permian Haselgebirge clasts are common.

The Oberalm Limestone grade into the Schrambach Marl Fm. within which allodapic limesatone layers are missing. Oberalm and Barmstein Limestones and Schrambach Marls are rich of nannofossils including calpionellids, radiolarians and foraminifera. The siliciclasticRoßfeld Formation starts with a spectacular "wildflysch" bed which is rich in carbonate clasts (e.g. Dachstein Limestone), which are typical for Upper Juvavic nappe, and some green basaltic components. The Roßfeld Formation is interpreted to represent the infilling of a deep sea trench in front of thrust sheets (Faupl and Tollmann, 1979).

In terms of structures, the succession is exposed on limb of an anticline (Schneiderwald anticline: Fig. 8). In the core of the anticline Haselgebirge is found.

Further reading: Wagreich et al., 1996; Böhm et al. in Egger et al. (1997); Plöchinger (1983).

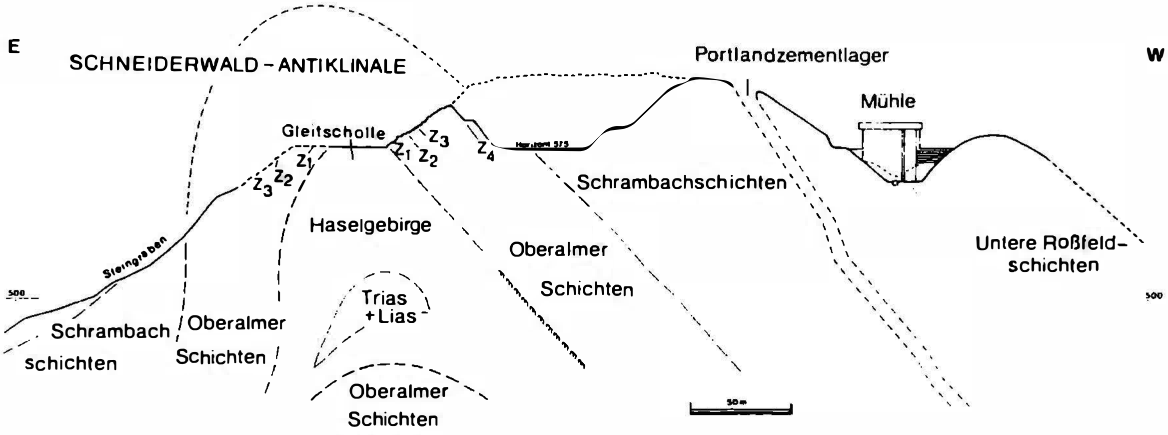

Fig. 8. N-S trending Schneiderwald anticline (from Plöchinger, 1983).

Stop no. 10: Kiefer quarry. Untersberg Limestone of the Gosau Group.
Location: OEK 63 Salzburg.

The Untersberg Limestone represents a detritic carbonate sediment deposited on a slope and derived from a carbonate platform. It also comprises clasts from the underlying Trassic Dachstein Limestone and from the Late Jurassic Plassen Limestone. Basal sectors of the section are stained by fine-dispersed bauxite-mud clasts. These grade into white, well-sorted detritic limestone and grey marls. Lower and middle portions of the section are interpreted to represent an inclined carbonate platform slope with erosional channels, scour and fill structures, slumping, olistolites, mass and debris flows with angular clasts. Beds with graded bedding and grain flows with reversed grading are interpreted to represent channel fillings.

The Untersberg "Marble" represents one of the most prominent building stones used for sculptures, fountains and decorations in Salzburg city.

Further reading: Leiss (1988); Wagreich et al., 1996; Böhm et al. in Egger et al. (1997).

Stop no. 11: Dürrnberg: Salt mine
***Location:** OEK 94 Hallein. Salt mine at Dürnberg near Hallein.*

The Salt mine is located within the Hallstatt unit (Lower Juvavic unit). It exposes the Permian Haselgebirge which comprises salt and grey shale. Various kinds of salts are exposed which are likely the result of deformation and recrystallization (modern structural investigations are missing). There is a controversy whether the emplacement of Haselgebirge results from tectonic transport or gravity sliding into the Upper Jurassic Oberalm basin. For detailed, see Fig. 9.

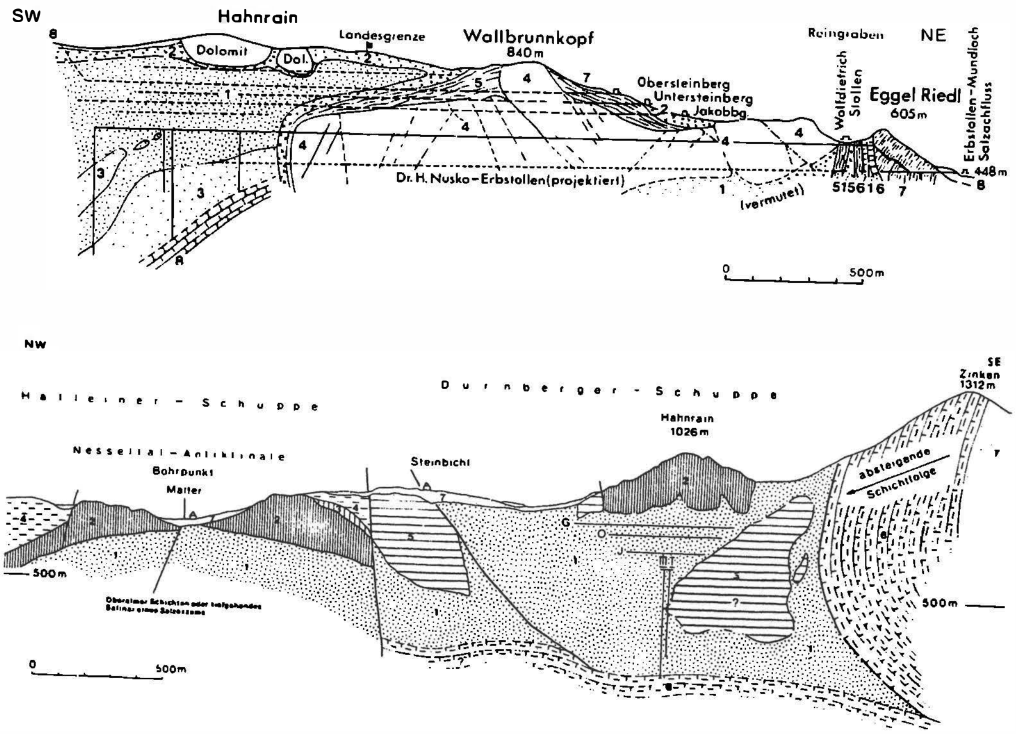

Fig. 9. Geology of the salt mine of Dürrnberg (from Plöchinger, 1983).

The salt mining started at ca. 2,500 B.C. and continued with intense mining during the Hallstatt period.

Further reading: Plöchinger (1983).

Stop no. 12: Paß Lueg: Dachstein Limestone

Location: OEK 94 Hallein. Road cut to the S of Lueg saddle along the Federal Road.

The road cut exposes bedded Dachstein Limestone with the famous loferite cycle. The exposure, an ice-polished surface, is rich megalodonts (*Conchodus infraliasicus* STOPPANI).

Further reading: Plöchinger (1983).

Stop no. 13: Road cut between Alpendorf and Sulzau: Salzach-Enns fault

Location: OEK 125 Bischofshofen. Road cut along road to Sulzau (2 km SW of Alpendorf).

X. WANG

From Sulzau to the north of Alpendorf, the Salzach-Enns fault extends ENE-WSW and represents the boundary between the Upper Austroalpine unit, namely Grauwacken zone, and the Lower Austroalpine cover of Radstädter Tauern to the south. The Grauwacken zone is here composed of black phyllite. The southern side of the Salzach-Enns fault exposes grey to dark calcitic phyllite of the Lower Austroalpine cover. The valley on the eastern side of the road follows the fault zone, indicating that formation of the valley is likely related with movement of the fault. Structures related with the fault occur mainly in calcite phyllite/calcitic schist of the southern side of the fault. Overall, the calcite phyllite steeply dips to NNE. Crenulation lineations occur universally in phyllite and calcite schist. Outcrop-scale, transected folds trend gently ESE. Crenulation lineations always cut transected folds in a counterclockwise sense. This indicates a sinistral strike-slip displacement. Predominant south-dipping slickensides and gently plunging striations indicate a sinistral strike-slip shear, toe. In many cases, striations are subparallel with lineations. In general, steeply plunging striations overprint gently plunging lineations, showing uplift of the southern side of the fault following sinistral strike-slip shear.

Further reading: Wang and Neubauer (1998).

Stop no. 14: Peterlehen/Steinbach E of Wagrain: Neogene Wagrain basin

Location: OEK 126 Radstadt. Brook S Steinbach S of the road between Reitdorf and Wagrain.

X. WANG

In Peterlehen, southeast of Mayerdörfl, Lower Miocene sedimentary rocks are exposed along a nearly S-N trending valley. This sedimentary sequence includes a conglomerate at the bottom, upwards follow alternations of conglomerate and micaceous sandstone, and fine-grained sandstone, mudstone and shale at the top (Trauth, 1925). The middle sector of the succession occurs in Peterlehen. The rock association comprises mainly grey, middle- to fine-grained micaceous sandstone and conglomerate with intercalations of thin coal layer. The conglomerate shows a well-developed roundness. Diameter of components of the conglomerate is between 5 to 8 cm. The beds dip to SE (158°) at an angle 52°. Occasionally, step normal faults cut through the sequence. A lot of slickensides and striations occur in sandstone and only a few in conglomerate. Most of the slickensides dip to SE with striations indicating downsliding of the hangingwall, but a minority of them with low angle striations indicate dextral strike-clip shear. Tensor analysis yielded two stages of palaeostress. One maintains the principal stress axes: σ_1: 84/358, σ_2: 06/194, σ_3: 02/104, the other shows the principal axes σ_1: 03/157, σ_2: 86/287, σ_3: 04/066, which represent by dextral strike-slip shear.

Further reading: Wang and Neubauer (1998).

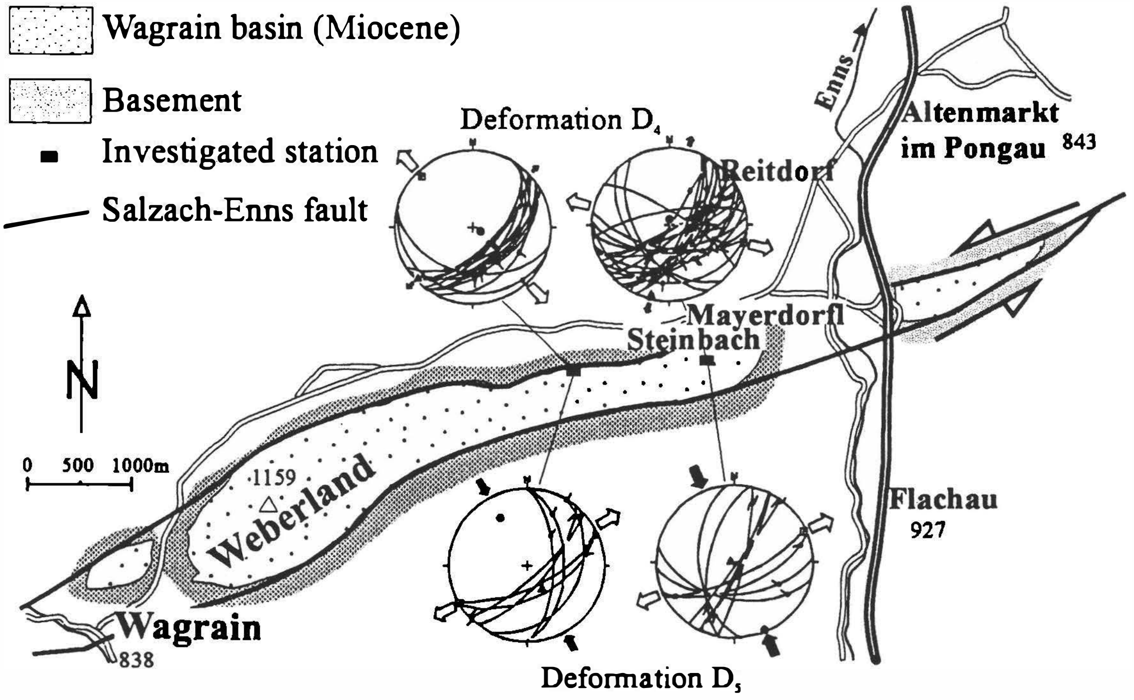

Fig. 10: Paleostress patterns of the Wagrain basin (from Wang and Neubauer, 1998).

North-eastern Tauern window, Zederhaus valley

The Zederhaus valley exposes a section through the Permomesozoic sequence of the Penninic Tauern window, that can be divided into several nappes, here. On top of the Storz nappe follow the Schrovin nappe, the Glockner nappe, and the so called Nordrahmenzone (north frame zone), finally overthrusted by the nappes of the Lower Austro-Alpine unit.

The Storz nappe comprises mainly basement rocks, migmatites and amphibolites intruded by Variscan granites and on top black phyllites. The Schrovin unit includes quartzites, dolomite and calcite marbles, interpreted as Triassic, and some slivers of orthogneisses. They likely represent the sheared-off cover of a continental basement. The Glockner nappe comprises some ultrabasic rocks (serpentinites), greenschists and calcschists, grading into phyllites and marbles, respectively. It represent rocks of an oceanic lithosphere. The overlying Nordrahmenzone is essentially a melange, consisting of a phyllitic matrix with clasts of mainly basement and Triassic cover rocks, that range in size from mm to mountain (e.g., the Weißeck) scale.

Structurally, the oldest foliation in the Storz nappe strikes E-W to NW-SE, the stretching lineation plunges gently to the WSW to SW. Shear sense indicators point to NE-vergent transport during this deformation phase (Kruhl, 1993, Kurz et al., 1996). In the Schrovin unit this stretching lineation plunges to the N to NNE. This penetrative foliation is overgrown by kyanite, chloritoid, hornblende and white mica. In the Glockner nappe and the Nordrahmenzone, these structure are overprinted by a N-dipping penetrative foliation and a related ESE-trending stretching lineation. The foliation is subparallel to lithologic contacts, also sheath folds develop during this deformation. N-plunging stretching of the older deformation phase are only preserved in some quartzites. Asymmetric quartzite boudins in thick calcschists indicate shear senses top-to-the-WNW, but mostly coaxial structures dominate.

Subsequently, the penetrative foliation was isoclinally folded around subhorizontal axes subparallel to the older ESE-trending stretching lineation. The axial plane foliation s3 is subparallel to the penetrative foliation. A further deformation led to the formation of tight to closed, N-vergent folds, whichs axes are subhorizontal or plunge gently to the W.
Younger structures, belonging to the doming of the Tauern window, indicate orogen-parallel, ESE-WNW-directed extension.

Stop no. 15. Quartzites and whiteschists at the base of the Schrovin unit.

Location: *ÖK 50, sheet 157 Tamsweg. National road from St. Michael to Zederhaus, ca. 500 m SE of Fell.*

J. GENSER

Strongly foliated, fine grained yellow quartzite to mica quartzite and whiteschists consisting of albite, white mica, and minor garnet and stilpnomelane.

Stop no. 16. Greenschists and calcschists of the Glockner nappe.

Location: *ÖK 50, sheet 156 Muhr. National road at highway bridge at Kraglau, c. 1.2 km SE of Zederhaus village.*

J. GENSER

Stop no. 17. Graphitic phyllites with dolomite clasts of the Nordrahmenzone.

Location: *ÖK 50, sheet 156 Muhr. National road at highway bridge c. 1 km SE of highway tunnel.*

J. GENSER

Biotite phyllites with cm thick layers of graphitic quartzites and massive clasts of unfoliated dolomite, several metres to deca-metres thick.

Stop no. 18. Chlorite-muscovite schist of the Nordrahmenzone.

Location: ÖK 50, sheet 156 Muhr. Rieding valley, road on top of the entrance of the highway tunnel (Tauerntunnel).

J. GENSER

Well-foliated, fine grained, phyllitic chlorite-muscovite schists with quartz lenses up to dm in size.

Stop no. 19. Granodiorite of the Gößcore

Location: ÖK50, sheet 182 Spittal an der Drau. Quarry Koschach. 13°27'45''E/46°58'15''N. Gmünd-Malta-Koschach (bridge across the Malta river)

J. GENSER

In the Göß valley the structurally lowest units of the eastern Tauern Window (and also the Eastern Alps) are exposed (Göß core). It consists mainly of different orthogneisses, ranging from granites to tonalites, that represent deformed Variscan granites (intrusion ages of ca. 320 Ma according to Cliff and Cohen, 1980). These orthogneisses are separated from the orthogneisses of the Hochalm core by a paragenetic series. In the Koschach quarry, a strongly lineated, light grey granodioritic augengneiss that is crosscut by several generations of pegmatites to aplites, is exposed.

The magmatic paragenesis of the granodiorite comprises plagioclase, K-feldspar (Karlsbad twinning), quartz, biotite, titanite, allanite, epidote, zircon, and apatite. Geochemically, the rocks resemble Na-rich, high K calcalkaline I-type granitoids, in part featuring almost trondhjemitic affinity (Marschallinger and Holub, 1991). Trace elements show volcanic arc granite characteristics with selective enrichment of LIL elements and low Rb/Zr.
The Alpine metamorphic paragenesis includes oligoclase, K-feldspar, quartz, biotite, clinozoisite(epidote), garnet, magnetite and sphene. Oligoclase displays inverse zoning (c. $An_{15} \rightarrow An_{25}$), K-feldspar is marginally replaced by myrmekite. Garnet formed due to the general reaction

$$Ep + Qtz \rightarrow Grs + An + Mag + H_2O.$$

In this outcrop one can distinguish 3 main deformational events:

1) The main deformation is responsible for the formation of the penetrative foliation and the pronounced lineation of the orthogneisses. Pegmatite veins are sometimes folded due to this deformation, older aplitic veins mostly not, pointing to low viscosity contrasts during deformation. The strain distribution is generally very homogenous. The dominant stretching lineation indicates a constrictional deformation geometry, corroborated by quartz-c-axes distributions (type I crossed girdles). In the Koschach quarry, the foliation dips steeply to the NNE (30/70), on the southern side of the Malta valley to the S (180/40), on the northern side to the ESE. The poles to the foliation hence display a great circle distribution around the stretching lineation (120/20), which is very consistent over the whole area. This distribution we interpret also to have formed in the constrictional deformation field, and not due to later

folding. Shear criteria that are mostly only weakly expressed and quartz-c-axes distributions indicate a non-coaxial deformation path with a dextral shear component. This deformation occurred at elevated temperatures up to the Alpine metamorphic peak, with dynamic recrystallization of plagioclase, K-feldspar and quartz. This deformation event must be placed in Oligocene times, based on radiometric dating of the metamorphic peak at about 20 Ma in deep tectonic levels of the eastern Tauern Window by Cliff et al., 1985.

2) Conjugate, ductile shear zones that are a few mm to cm wide, cut discordantly across the penetrative foliation. These shear zones dip to the ESE and WNW, and show a normal sense of shear to the ESE and WNW, respectively. This deformation led to a subvertical shortening and ESE-WNW-directed extension, therefore. In the shear zones, plagioclase, quartz, and biotite recrystallised, green amphiboles and calcite, respectively, formed. This indicates an activity of these structures at still elevated temperatures (upper greenschist to lower amphibolite facies conditions). This ESE-WNW extension is related to the uplift of the Penninic units.

3) Steeply dipping, ESE-WNW-trending faults (parallel to the main foliation) that show a normal sense of shear of the northern hangingwall indicate an extension in NNE-SSW direction, too. They were active from near peak metamorphic conditions (asymmetric folding of biotite schists and aplites, with static recrystallization of biotite after this deformation) to cool conditions (slickensides, cacirites, fault gouges).

Stop no. 20. Intrusive contact of the Malta tonalite with country rocks.

***Location:** ÖK50, sheet 156 Muhr. Bed of the Malta creek.*

J. GENSER

The Malta tonalite is the oldest member of the intrusion sequence of the Hochalm core (Holub & Marschallinger, 1989) with an age of ca. 320 Ma (Cliff & Cohen, 1980). In the inner parts of the Hochalm core it is mostly a massive, medium grained rock. In places, swarms of elliptic diorite inclusions occur. The magmatic paragenesis of the tonalite comprises plagioclase, quartz, K-feldspar, biotite, allanite, titanite, and epidote. Geochemical it represents a high-K, calcalkaline, I-type granitoid, that is strongly enriched in Na. The trace element spectrum is typical of VAG intrusions, enriched in Ce (Marschallinger & Holub, 1991).

In this outcrop, the intrusive contact to their country is perfectly preserved. These are migmatitic two mica gneisses, that are thought to be derived from shales. They contain oligoclase, quartz, biotite, white mica, K-feldspar, epidote and sphene. Locally, boudins of calcsilicate rocks occur. Other extensional structures, that interfere with the intrusion of the tonalite, can be found as well.

Stop no. 21. Leucocratic granitoid gneisses (Kölnbrein leucogranite).

***Location:** ÖK50, sheet 156 Muhr. Kölnbrein quarry NW Kölnbrein dam.*

J. GENSER

The huge quarry near the Kölnbrein dam exposes the latest large area Variscan intrusion, the so called Kölnbrein leucogranite (Holub, 1988). This granites intruded in several phases that may be distinguished mainly on the basis of mafic minerals amounts. The fine to medium grained leucocratic rocks incorporate a consistent population of country rocks, ranging from migmatitic paragneisses to older intrusives like the Malta tonalite or the Hochalm porphyric granite. Places of incomplete resorption of country rocks are characterised by schlieren textures.

The rock composition ranges from leucocratic granodiorites to granites, containing oligoclase, K-feldspar, quartz, muscovite, biotite, epidote and in places garnet. Geochemically, it is a high-K calc-alkaline I-type, Na-enriched plutonite; trace elements show a strong enrichment in LIL and Ce, with patterns typical of VAG types according to Pearce et al. (1984).

Stop no. 22. WNW-directed shear deformation in tonalitic gneisses of the Hochalm core.

Location: *ÖK50, sheet 182 Spittal an der Drau. 13°29'02''E/46°58'05''N. Rock wall on the NW side of the Malta valley (Rödern). From Malta village to the bridge over the Feistritz brook (first brook NW of village Malta), then 500 m along a path to a ledge.*

J. GENSER

In this outcrop, the same Malta tonalite as in stop no. 20 occurs., only strongly deformed.
The magmatic paragenesis comprises plagioclase, quartz, K-feldspar, biotite, allanite, titanite, and epidote. The Alpine metamorphic paragenesis consists of oligoclase, quartz, biotite, K-feldspar, clinozoisite, titanite, and muscovite (phengite). Oligoclase displays inverse zoning ($An_{15} \rightarrow An_{25}$), white mica is present in minor amounts only, mostly restricted to strongly deformed domains.

The tonalitic gneiss reaches the Malta valley as a strongly thinned lamella (ca. 200 m thick), which is due to high ductile deformation. The tonalite shows a pronounced, homogeneous, penetrative foliation and a well developed stretching lineation. Aplites are folded due to this deformation, the foliation is parallel to the axial planes of the folds. The foliation dips gently to the E (90/30), the stretching lineation to the ESE (120/25). An abundance of shear criteria, as shear bands, σ-porphyroclasts, and also quartz textures indicate shearing top-to-the WNW.

This deformation occurred up to the metamorphic peak, with dynamic recrystallization of plagioclase, quartz, and biotite. It must be placed in Miocene times, too.

Stop no. 23. Ductile to brittle low-angle normal faulting to the ESE in the Peripheral Schieferhülle.

Location: *ÖK50, sheet 182 Spittal an der Drau. 13°30'25-30''E/46°57'35''N. Road cut on the road Malta - Maltaberg. From Malta village by car (difficult to access by big buses) or on foot (ca. 25 minutes to walk) on the road to Maltaberg up to the second corner closing to the W (1010 m NN).*

J. GENSER

This roadcut exposes a succession from the uppermost Storz Group (Vavra & Frisch, 1989), a pre-Variscan basement unit, here mainly amphibolites and plagioclase gneisses, overlain by the post-Variscan sequence of the Peripheral Schieferhülle. The latter sequence starts, approximately 70 m after the crossing path, with black albite porphyroblast schists. Then follow whiteschists, strongly retrogressed orthogneisses, and quartzites of probably Permo-Triassic age, and finally calcschists with intercalated greenschists and metapelites, the so called Bündner Schiefer, Jurassic-Cretaceous deep-sea metasediments and -volcanics. A detailed description of this section can be found in Exner (1980).

Alpine metamorphic parageneses comprise:

Quartz-albite-phengite-phlogopite-calcite-ilmenite (quartzites)
Albite-quartz-phengite-biotite-chlorite-calcite-ilmenite (semipelites)
Calcite-quartz-albite-muscovite-rutile-chlorite (calcschists)
Amphiboles-chlorite-albite-epidote-quartz-titanite-biotite-calcite (greenschists)

Two structural events can be distinguished in these outcrops:

1) A penetrative foliation with an only weakly developed stretching lineation. The foliation dips moderately to the ESE, the lineation trends NNE-SSW. These structures can best be seen in the rocks of the Storz Group, in higher units they are strongly overprinted by the second deformation. In deeper parts of the Storz unit and in more northerly parts of the Peripheral Schieferhülle, where these structures are often well preserved, a tectonic transport of top-to-the N can be derived. This deformation occurred close to metamorphic peak conditions.

2) The second deformation led to a further flattening of the older foliation and an extension in an ESE-WNW-direction. The deformation is noncoaxial, expressed in ESE-dipping shear bands, which often occur in multiple sets with different dip angles. A conjugated, WNW-dipping set of shear bands is only weakly developed and restricted to strongly deformed domains. Lineations on the shear bands plunge to the ESE and WNW, respectively. In calcschists zones with a new mylonitic foliation, angular to the older foliation, develop. This structures, as well as asymmetric calcite-c-axes textures, prove a dominant normal shear of the hanging-wall to the ESE. Other structures related to this extension are extension veins and boudins, mainly in competent quartzites. Small-scale, asymmetric folds that are overturned to the ESE are related to this shearing, too.

This deformation commenced after metamorphic peak conditions, as evidenced by greenschist facies minerals (chlorite, epidote) in shear zones in amphibolites and continued to cool conditions up to the formation of brittle normal faults. The main part of this deformation is ductile, however.

This deformational event, a low-angle normal faulting, led to the unroofing of the metamorphic dome of the Tauern Window by displacement of the Austro-Alpine upper crust to the ESE. $^{40}Ar/^{39}Ar$ dating of a single phengite grain from the quartzites yielded a plateau age of 21.9 ± 1.1 Ma. This age should give the age of cooling below ca. 375 °C and hence an upper limit for the low-angle normal faulting. This event must be place in the lower Miocene, hence. This is also corroborated by data from Cliff et al. (1985), which indicate nearly isothermal decompression and a following rapid cooling of the Penninic units in the time span between 20 and 16 Ma.

Stop no. 24. Metamorphism and deformation in the Lower Austro-Alpine unit.

Location: *ÖK50, sheet 182 Spittal an der Drau. 13°30'25-30''E/46°57'35''N. Road cut on the national road between Gmünd and Eisentratten, at the mouth of the Drehtal creek (point 789 in ÖK, parking place).*

J. GENSER

The outcropping diaphthoritic quartz-phyllites comprise a pre-Alpine mineral paragenesis of garnet, biotite, and large white mica. The retrograde Alpine paragenesis comprises chlorite, sericite, quartz and pyrite. Pre-Alpine garnets are often completely retrogressed to chlorite and white mica, biotites are bleached.

The rocks show a penetrative foliation, often with relics of a pre-Alpine foliation. Pre-Alpine quartz veins are folded isoclinally, during the Alpine foliation a second, discordant

generation of quartz veins developed. The stretching lineation strikes c. E – W. Pre-Alpine mica are rotated into the new foliation. Pseudomorphs after garnet are often stretched parallel to the lineation. Quartz-c-axes textures (oblique, simple girdles with marginal maxima) indicate shearing top-to-the-W. These textures and low-temperature plasticity of quartz point to cool, ductile deformation conditions. The foliation is subsequently folded around NE-SW striking axes into upright folds. Late-stage structures are slickensides and kink bands.
^{40}Ar/^{39}Ar dating of single muscovite grains from this outcrop gave late Variscan cooling ages (integrated ages of 242.9 ± 3.2 Ma and 239.6 ± 1.1 Ma.

Stop no. 25. Boundary between the Lower and Middle Austro-Alpine units

Location: *ÖK50, sheet 182 Spittal an der Drau. 13°34'13''E/46°55'22''. Road cut on a minor road that leads to a farm from the road from Eisentratten to Heitzelsberg.*

J. GENSER

Here, the same diaphthoritic quartz-phyllites with pre-Alpine garnet, biotite and white mica and the same ductile deformation structures as in the last stop crop out. Towards the base of the Middle Austro-Alpine unit, however, you can see an increase of late, brittle deformation structures. Cataclastic shear zones with cacirites that comprise fault breccias with clasts of several dm to fault gouges, develop. Motion on this late brittle shears is normal faulting towards the E. Therefore, it should be contemporaneous to the ductile low-angle normal faulting in the Penninic unit, representing the same orogen-parallel extension, but at a higher, and therefore cooler tectonic level.

Going towards the MAA, note the morphologic depression and the lack of outcrops, which must be due to an increase in brittle faulting towards the tectonic boundary. The boundary between the two units is a thrust that was reactivated as normal fault, therefore.

Stop no. 26. Base of the Middle Austro-Alpine unit (Bundschuh nappe)

Location: *ÖK50, sheet 182 Spittal an der Drau. 13°34'13''E/46°55'22''. Outcrop at the branch-off of the road Eisentratten – Heitzelsberg from the main road, immediately E of the new church.*

J. GENSER

The Bundschuh nappe of the MAA is here represented by typical garnet-micaschists. These mica-schists display two stages of metamorphism, a Variscan and an Alpine event. The Variscan paragenesis comprises staurolite and garnet, the Alpine one garnet (mostly as rims around Variscan cores), biotite, muscovite, plagioclase, chlorite, and quartz. Mostly, staurolite occurs as pseudomorphs only that are often deformed.

The micaschists display a well developed Alpine foliation with isoclinally folded quartz veins and boudinage garnets (Variscan cores). The main deformation occurred before the metamorphic peak, as mica and quartz recrystallised statically. Quartz-c-axes textures show random distributions. Late-stage structures are slickensides that indicate E–W extension.
Geothermobarometry of the Alpine paragenesis indicate conditions of c. 600°C and 10 kbar for the Alpine peak. ^{40}Ar/^{39}Ar dating of single muscovite grains from this outcrop gave a weakly disturbed plateau with an integrated age 107.5 ± 1.3 Ma. This age must be interpreted as cooling age after the Alpine metamorphism. The main deformation of the Bundschuh nappe must hence be older than this date.

Stop no. 27. Middle Austro-Alpine basement with Priedröf micaschist/paragneiss and Bundschuh orthogneiss; Alpine metamorphic overprint.

Location: *OEK 50, sheet 183, Radenthein. Road exposure along the Nockalm road in the Heiligenbach valley, ca. 400 metres South to the custom-house at Innerkrems.*

F. NEUBAUER

Both the Priedröf micaschist/quartzitic paragneisses (footwall) and the Bundschuh orthogneisses (hangingwall) are exposed along the Nockalm road and along the opposite wall of the valley. The Priedröf micaschist/paragneiss essentially contains quartz, feldspar, biotite, muscovite, garnet and rare pseudomorphs after staurolite. The Bundschuh orthogneiss is composed of K-feldspar porphyroclasts, quartz, plagiocalse and light-greenish white mica.

Theiner (1987) found a polymetamorphic evolution with a Variscan metamorphic overprint in nearby localities with ca. 600 – 640°C and Alpine temperatures ranging from 500 to 520°C based on garnetbiotite geothermometry. The age of the Bundschuh orthogneiss is uncertain. Rb-Sr whole rock investigations resulted in sets of subparallel isochrons with model ages between 371 and 397 Ma and high Sro ratios between 0.721 and 0.739 (Frimmel, 1988). White mica of the Bundschuh orthogneiss from the Innerkrems area range between 305 ± 12 and 119 ± 1 Ma (Theiner, 1987). Geochemical and petrography indicate a syn-collisional granites (Frimmel, 1988). The first age is interpreted to be close to the time of Variscan metamorphism, the second age as result of Cretaceous resetting of the Rb-Sr isotopic system.

Both lithologies contain a ESE plunging stretching lineation. Shear criteria suggest both a first top WNW shear and a later, semiductile ESE displacement.

Further reading: Frimmel, 1988; Pistotnik, 1974; Theiner, 1987.

Stop no. 28. Bridge Postmeister Alm. Primary base of the Stangalm Mesozoic sequence.

Location: *OEK 50, sheet 183, Radenthein. Road exposure along the Nockalm road in the Heiligenbach valley, E of bridge E Postmeister Alm.*

F. NEUBAUER

The outcrop exposes the primary contact between the basement (micaschist) and the transgressively overlying Quartzite (Skythian). The basement micaschist displays open folds which are discordantly overlain by quartzites of suggested Skythian age. The quartzite represents the basal formation of the Stangalm Mesozoic sequence. Hangingwall sectors of the quartzite are well foliated and displays an E-dipping foliation. New sericite is grown on the foliation plane. A new ^{40}Ar-^{39}Ar age of a concentrate of a few grains yielded a plateau age of ca. 89.0 ± 0.6 Ma.

Further reading: Pistotnik (1976).

Stop no. 29: Ductile low angle normal fault at the tectonic boundary between the Stangalm and Pfannock Permo-Mesozoic sequences and the Gurktal thrust system.

Location: *OEK 50, sheet 183, Radenthein. Nockalm road. Park your car at the Eisentalhöhe parking place. Follow the path to the Eisentalhöhe (exposure of Hauptdolomite and Kössen*

Formation of the Pfannock slice of the Gurktal Nappe Complex). Follow ridge from the Eisentalhöhe to the West which exposes the phyllonite zone and the underlying dolomite marble of the Stangalm unit.

F. NEUBAUER

The dolomite marbles of the Stangalm Mesozoic sequence are in part strongly foliated and lineated. The lineation plunges E and ESE. The marbles are overlain by a several tens of metres thick phyllonite which exhibit a clearly visible eextensional crenalution cleavage fabric. Sense of displacement is top to the E/ESE. The phyllonite was interpreted as Carnian Raibl Formation. But the inclusion of chlorite schists exclude this stratigraphic interpretation. This level is now interpreted as part of the Murau Nappe of the Gurktal Nappe Complex because lithological composition and continuous exposure to true Murau Nappe along the structural base of the Gurktal Nappe Complex. In the hangingwall, dark Late Triassic limestones which belong to the cover of the Pfannock Nappe of the Gurktal Nappe Complex are exposed. These limestones include in part rich faunas (*Thamnasteria rectilamellosa, Isoclinus bavaricus, Cardita austriaca*). Views from the parking place to the N (Fig. 11) and to the S show the structural contacts between various structural units (Fig. 12).

Further reading: Gosen, 1989; Pistotnik, 197 , Ratschbacher et al., 1990; Tollmann, 1975.

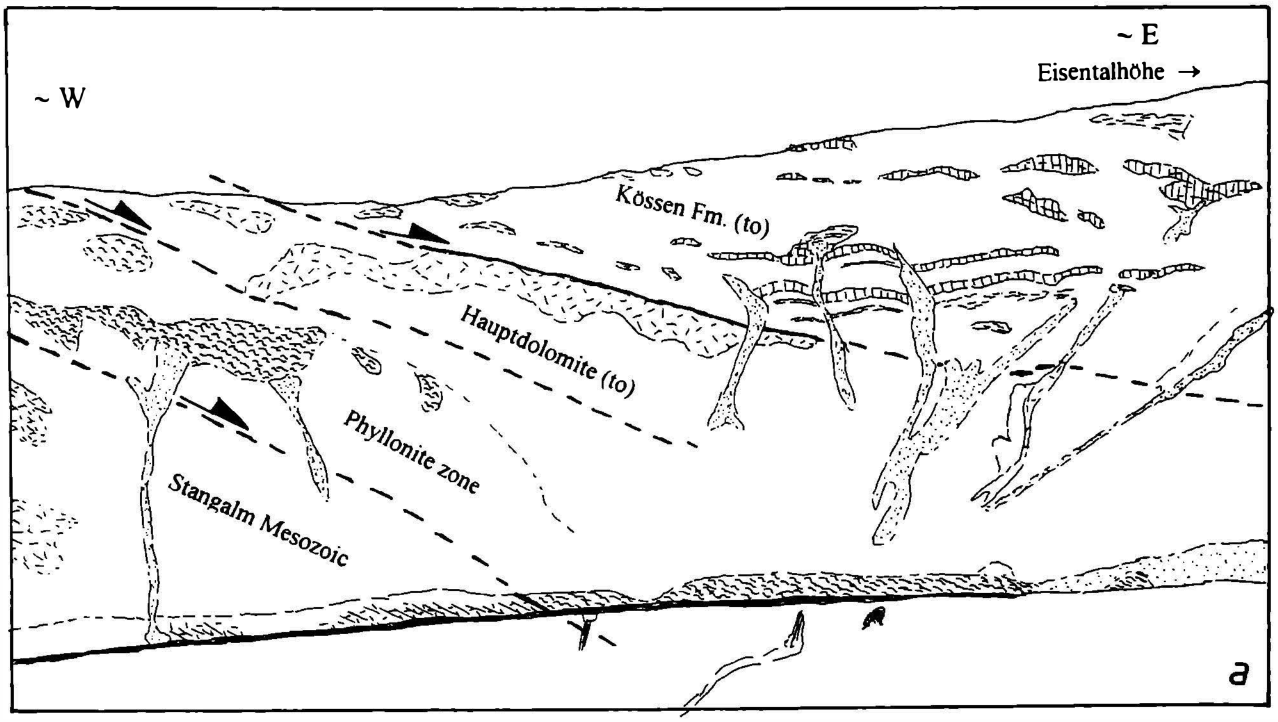

Fig. 11: View from the parking place "Eisentalhöhe" towards N displaying the low-angle normal fault contact between Middle and Upper Austroalpine structural units.

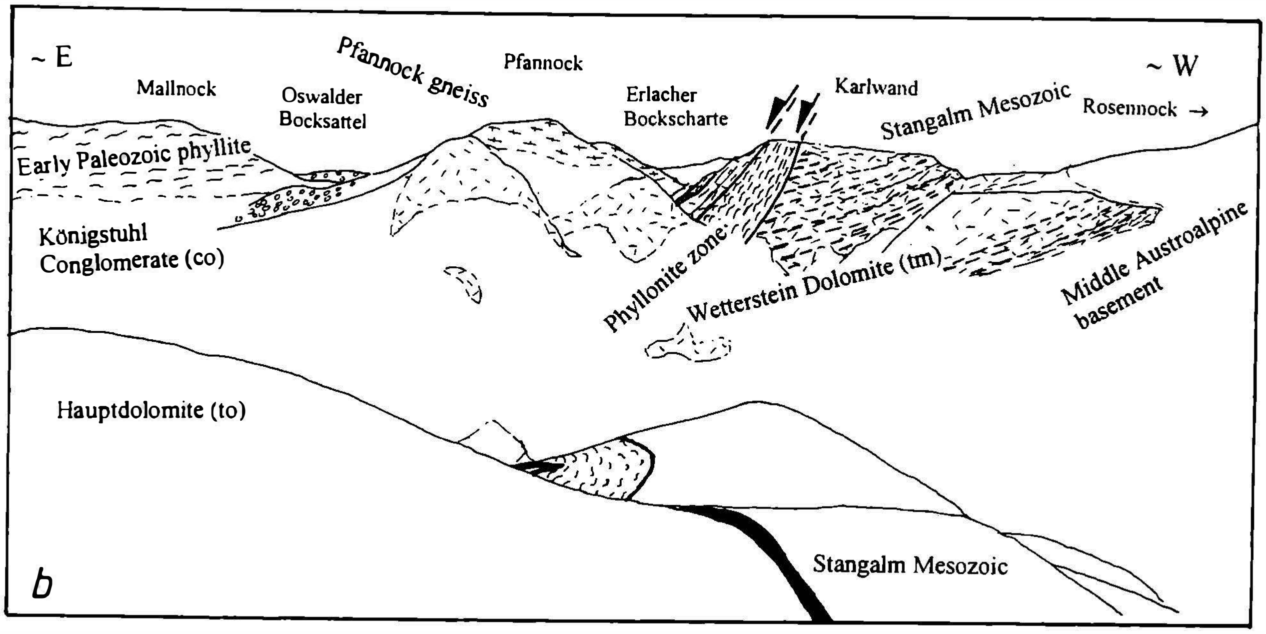

Fig. 12: View from the parking place "Eisentalhöhe" towards S displaying a high-angle normal fault contact between Middle and Upper Austroalpine structural units.

Stop no. 30: Saddle E Eisentalhöhe. Late Carboniferous molasse sediments (Stangnock Formation) of the Gurktal Nappe Complex.
Location: OEK 50, sheet 183, Radenthein. Walking tour to the western flank of Königstuhl. From the parking place "Eisentalhöhe " (2, 100m) of the Nockalmstraße (National Park " Nockberge ") footpath to the Königstuhl (2,336m) (about 1 hour) and Stangnock (2,316m).

The description is taken from K. KRAINER in Neubauer (ed., 1992).

The best outcrops of the Stangnock Formation are situated at the northern flanks of the Königstuhl and Stangnock mountains (Fig. 13).

The Stangnock Fm., exposed at the NW-margin of the Gurktal thrust system (Upper Austroalpine), represents a more than 400m thick sequence of intermontane molasse fillings, which accumulated under humid climatic conditions.The sequence starts with polymict conglomerates and intercalated immature, coarse-grained sandstones (poorly sorted, angular-subangular, feldspathic lithic arenites) at the base, deposited on the proximal part of a fluvial system (?alluvial fan). The main series is built up by a few, indistinctly developed megasequences, beginning at the base above a sharp, erosive boundary with sediments of a gravelly, braided river system, grading upward into a gravelsandstone facies, sometimes showing characteristic features of a meandering river system.

At the top of this sequences usually shales are developed, containing abundant plant fossils. At some places the shales, which are interpreted as overbank fines deposited on flood plains and in oxbow lakes, are overlain by thin anthracite seams. Conglomerates of the main series are very rich in quartz (>90%), sandstones are classified as moderately sorted, subangular lithic arenites - sublitharenites, in part lithic wackes, with high amounts of polycrystalline quartz (Fig. 14).

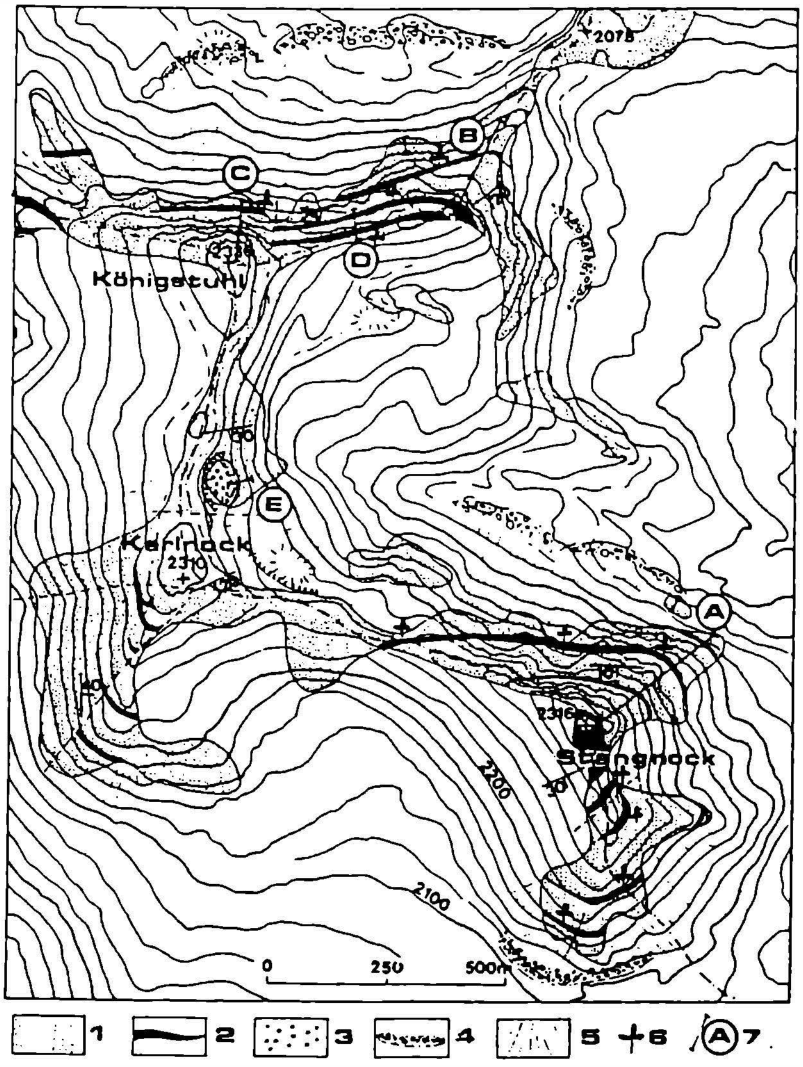

Fig. 13: Geologic map of the Stangnock-Königstuhl area with position of investigated sections and some important plant fossil localities. 1 Conglomerates and sandstones of the Stangnock Fm., 2 shales of the Stangnock Fm., 3 sediments of the Lower Permian Werchzirm Fm., 4 boulder walls, 5 talus cones, 6 plantfossil localities, 7 investigated sections (from Krainer, 1989b).

The top series does not show significant differencies in facies compared to the main series, slight differences exist concerning the composition of the sediments. Volcanic rock fragments, especially volcanic quartz, are a characteristic feature of the sandstones, referring to first volcanic activity during the uppermost Carboniferous in the studied area.

The sharp, erosional appearance of the megasequences and the top series, starting with coarsegrained accretions, is referred to synsedimentary fracture tectonics. From current directions which show a significant eastward trend, it is concluded that the intermontane basin developed in an approximately east-west-direction.

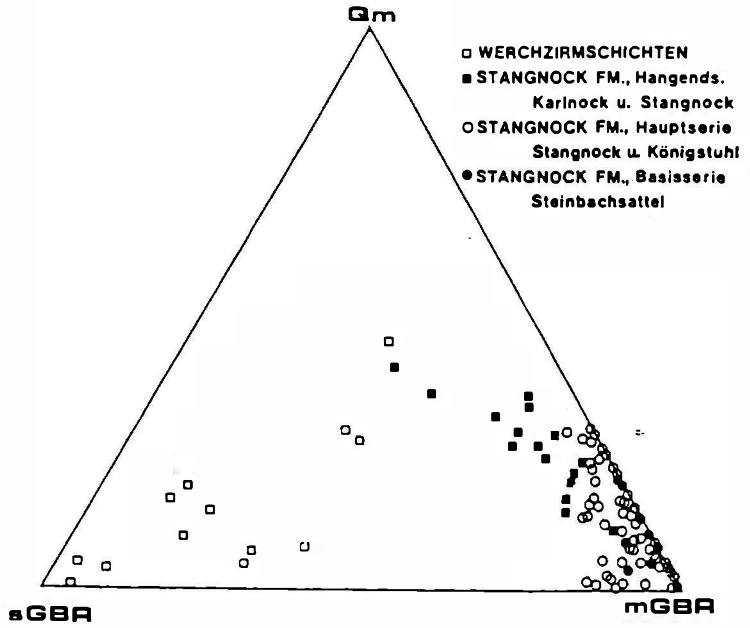

Fig. 14: Sandstones of the Stangnock Formation and overlying Lower Permian Werchzirm Formation plotted in the Qm (total quartz) - sGBR (sedimentary rock fragments) - mGBR (metamorphic rock fragments) compositional diagram. Sandstones of the top series (Hangendserie) are characterized by higher amounts of monocrystalline quartz and sedimentary rock fragments, sandstones of the Werchzirm Formation are mainly composed of sedimentary rock fragments (from Krainer, 1989 b).

Well preserved plant fossils from dark shales of the Stangnock Fm. are known from several localities for more than 200 years. The complete fossil list contains 72 taxa (see Fritz, Boersma and Krainer, 1990). A flora rich in Linopteris neuropteroides and *Lycophyta*, containing *Neuropteris scheuchzeri* and *Sphenophyllum oblongifolium* but without Pecopteris feminaeformis in the lower part of the Stangnock Formation (localities Brunnachhöhe and Turrach 1) indicates Cantabrian age *(Odontopteris cantabrica* Zone). The flora from the horizon Königstuhl 31a (lower part of the Stangnock Formation) with *Sphenophyllum oblongifolium, Callipteridium pteridium, Odontopteris* and *Pecopteris feminaeformis* points to Barruelian age (*Lobatopteris lamuriana* Zone). The *Alethopteris zeilleri* Zone (Stephanian B) with the significant species *Sphenophyllum thonii* var. minor is represented by the flora Turrach 5 (lower part of the Stangnock Formation). The Sphenophyllum angustifolium Zone (Stephanian C) is indicated by the flora from the localities Königstuhl 25a and Reißeck (middle part of the Stangnock Formation) containing the species *Sphenophyllum angustifolium*.

The uppermost part of the Stangnock Formation is characterized by the first appearance of *Callipteris* cf. *conferta* (locality Stangnock Südostgrat 1), indicating uppermost Stephanian C/Autunian age (*Callipteris conferta* Zone).

Further Reading: Frimmel, 1986, 1988. Fritz et al., 1990; Krainer, 1989a, b.

Stop no. 31. Schiestlscharte, Nock Formation

Location: OEK 50, sheet 183, Radenthein. Schiestelscharte at the Nockalm Road.

F. NEUBAUER; descriptions follows partly Giese in Neubauer (1992).

The exposed rocks belong to the undated, basal part of the Nock sequence which is composed of mafic schists, quartz-feldspar-schists and phyllites. Quartzites, white marbles and Fe-dolomites are sometimes intercalated. Due to the lack of marker horizons and intense imbrication with overlying phyllites, a detailed lithostratigraphic section has not been established. The structural details of the section are shown in Fig. 15.

Mafic schists are often laminated. The layers are mm to cm thick and are composed of chlorite-epidote, chlorite-actinolite-epidote and quartz-albite-epidote. In these layers phenocrysts of plagioclase and brown basaltic hornblende occur which are regarded as primary volcanic constituents. The lamination refers to different tuff, ash-tuff, crystal tuff and tuffite layers. Therefore, most of the mafic schists are pyroclastic in origin. Massive, partly feldspar porphyritic rocks which represent effusives are rare.

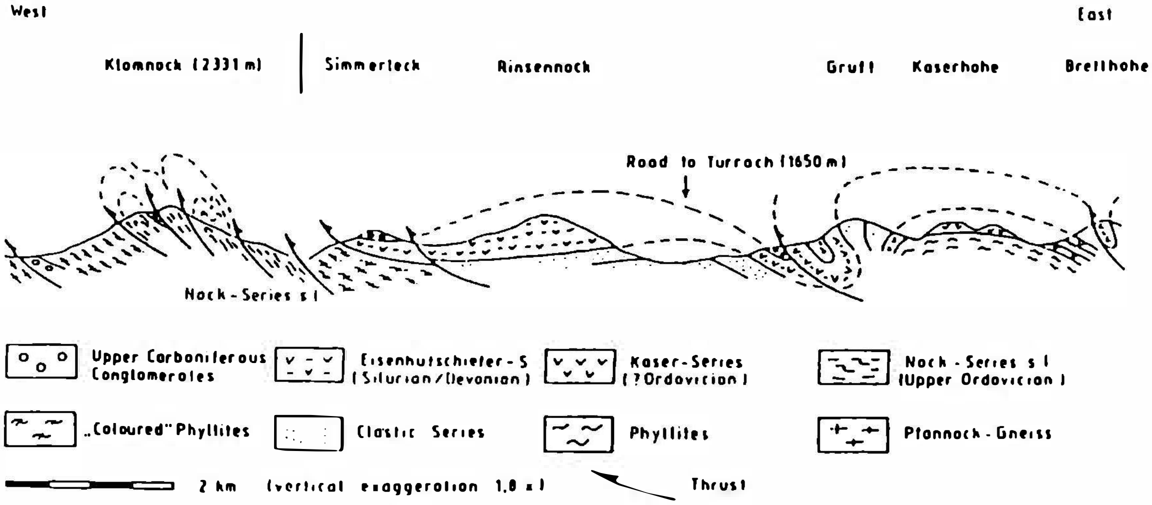

Fig. 15: Schematic sketch of the Eisenhutschiefer series at the eastern and northeastern side of the Rinsennock (Loeschke, 1989; from Giese in Neubauer, ed., 1992).

Pyroclastics are dominated by fine-grained ash tuffs and tuffites, in part reworked with turbiditic features. Coarse lapilli tuffs, volcanic breccias and agglomerates indicate proximal, shallow marine deposition close to a former eruption center. Basaltic conglomerates and 'tailed bombs' in volcanic breccias argue for temporarily subareal conditions of a volcanic island.

Pillow basalts have aphyric, vesicular and poiphyritic textures with phenocrysts of Ti-rich clinopyroxene and plagioclase. Intrusives show intersertal and intergranular textures and consist of Ti augite, plagioclase, kaersutite and red- to brown-colored biotite.

Chemical compositions clearly reveal an alkaline character. Pillow basalts classify mainly as alkali basalts and hawaiites. Intrusives are more evolved and have compositions of hawaiites and mugearites. Intermediate rocks show strong enrichment of incompatible elements and are phonolytic trachytes. MORB normalised distribution patterns are in exzellent accordance with alkali basalts of oceanic islands.

In conclusion, the Eisenhutschiefer series at the Rinsennock represents an alkali basalt hawaiite - mugearite - trachyte suite of an oceanic island volcano.

Stop no. 32. Twengbach/Hohensaß. Paragneiss of the Bundschuh nappe.

Location: *OEK 183 Radenthein. East of bridge over Twengbach (700 metres E bridge 880) on road between Bad Kleinkirchheim and Radenthein.*

F. NEUBAUER

The road cut exposes well recrystallized basement gneisses a few hundred metres neneath the ductile low angle normal fault beneath the Gurktal extensional allochthon. The gneisses contain The mineral assemblage plagioclase + quartz + muscovite + garnet + ilmenite ± pargonite. Geothermobarometry yielded ca. 600 and 10-11 kbar. These conditions were interpreted to represent Cretaceous peak P-T conditions. Metamorphic fabrics are entirely annealed.

Further reading: Koroknai et al. (1996).

Stop no. 33. Acherlabach section. Periadriatic fault.

Location: *OEK 196 Obertilliach. Lower Archerlabach brook ca. 2 km SE of Liesing. Follow road ca. 1.5 km east of Liesing towards bridge 919 over Gail river.*

F. NEMES, F. NEUBAUER

The Archerlabach brook exposes a ca. 400 m long N-S trending section across the E-W-trending Periadriatic Lineament (Fig. Xy). It represents the best and a comlete exposure of the Periadriatic fault. From N to the S the Archerlabach section includes (Figs. 14, 15):

1) Gailtal Metamorphic Complex: Diaphtoritic garnet-bearing micaschists of the Gailtal Metamorphic Complex form the northern edge of the Periadriatic Lineament. The micaschists are well recrystallized under peak metamorphic conditions and include only a few features of retrogression, like chloritization along scarce fault planes. The subvertical foliation trends E. This mylonite is characterised by plastical deformation of minerals, shows evidence of internal grain rotation and grain size reduction. The occurrence of chloritized garnet and biotite, but also new grown fine-grained mica on shear planes indicates diaphthoritic overprint. Main features are well defined quartz bands and mica layers, and a granoblastic quartz fabric.

Also phyllonites are associated with micaschists in the Gailtal metamorphic Complex, and are characterised by plastic and cataclastic deformation. The strongly foliated fabric consists mainly of layers marked by sericite chlorite and quartz bands.

2) Fault gouge: A 40 m thick package of fault gouge indicating plastic deformation under semi-ductile conditions is one of the main deformation features in the cross section. This gouge is a paste-like rock material formed in a fault zone with less than 30% fragments (e.g., Groshong, 1988).

Development of cacirites is characterised by the occurrence of fault gouges and up to 30 m wide cataclastic bodies. The development of ultraclataclasites is restricted to cataclastic bodies. All lithologies in the Archerlabach cross section are affected by cataclastic deformation, including micaschists from the Gailtal Metamorphic Complex, sandstones of the Gröden Formation and tonalites.

The fault gouges are of variable origin, the subhorizontal stretching lineation plunges gently to the east and indicates ductile to semi-ductile deformation in a strike-slip regime. Macrofabrics are characterised by tectonic deformation caused a planar fabric in unconsolidated material. Axial-plane mineral foliations are often found and also broken, rough slabs parallel to the foliation. These fault gouges have usually fine-grained matrix and a major component of clast orientation.

These rocks may have suffered large strain rates. These rocks are characterised by the presence of stylolites and solution cleavages, but relatively undeformed material in a clast-bearing matrix. Boudins are located between ductile layers and result from strain in the stiffer layers.

3. Gröden Formation: Sandstones of the Gröden Fm. and chlorite schists are folded in large isoclinal folds with subvertical axial plane and fold axes oriented parallel to the strike of the Periadriatic Lineament. These structures indicate massive N-S directed shortening perpendicular to the fault and lengthening of the rocks in strike-slip direction. The deformation in these sandstones is characterised by planar fabrics and broken elongated clasts parallel to the foliation. These deformed sandstones have a fine-grained matrix and a major component of preferred clast orientation.

Boudins are usually located between strongly foliated schists and are barrel-shaped in cross sections with veins forming the top and end of the barrel. The macroscopic features of these dark red sandstones and fine conglomerates are ductilely deformed conglomerate components, elongated components bedded in red-grey matrix. The foliation strikes E-W and is clearly developed in areas adjacent to the tonalitic body. The contact to the tonalites and adjacent rocks is clearly reflected by S-C fabrics and other strike-slip related structures.

4. Chlorite schists: Chlorite schists and black phyllites are interbedded between cataclastic tonalites and ductile deformed fault gouges. They are strongly affected by brittle deformation which is indicated by steep thrusts, backthrusts and oblique dextral strike-slip faults. The chlorite schists are derived from the adjacent tonalite and show cataclastic fabrics indicated by brittle fracturing, showing also often evidence of grain-size reduction and internal clast rotation. Deformation caused a well-developed planar fabrics, mineral shape foliations and asymmetrical kink bands.

5. Tonalite: The tonalite suite dips to the S, and is partly overthrusted by black slates (Carnic Alps). The tonalites have a preferred orientation and planar subvertical. This is mainly characterised by parallel lengthened and recrystallized quartz grains with undulose extinction. Plagioclase shows post-crystallisation deformation with banded twin lamellae. The dynamically developed banding in the tonalites is presented by S-C fabrics and augen-like texture. Regarding the planar anisotropies in the rocks, these are a secondary formation due a strong deformation event. This is also indicated by the generally tectonic contact of the tonalitic bodies to the country rocks and post-magmatic semi-ductile deformation in tonalites and country rocks. Adjacent rocks were also deformed during the ductile deformation on tonalites and country rocks were mainly overprinted by low grade metamorphism.

The tonalites show clearly cataclastic macrofabrics showing also often evidence of grain-size reduction. The most distinctive textural features in cataclasites are grain fracture and grain size reduction. Grain sizes within the matrix are reduced to sizes of 5-25 µm, larger fragments may be rounded.

6. Black slate: The black slates from the Carnic Alps show steep foliation and large isoclinal folds with axes parallel to the strike of the fault zone. Asymmetrical kink bands and symmetrical crenulations occur as macroscale deformation in unlithified slates. In these black slates often microlaminations and grain fabrics occur. This fissility of shale is significantly enhanced by fine-scale interbedding of clay bands, as the fissility of slate may have been caused by closely spaced lamellae of different compositions. Dark banded phyllites are involved in massive cataclastic deformation which is expressed especially by S-C fabrics.

Further reading: Nemes (1997).

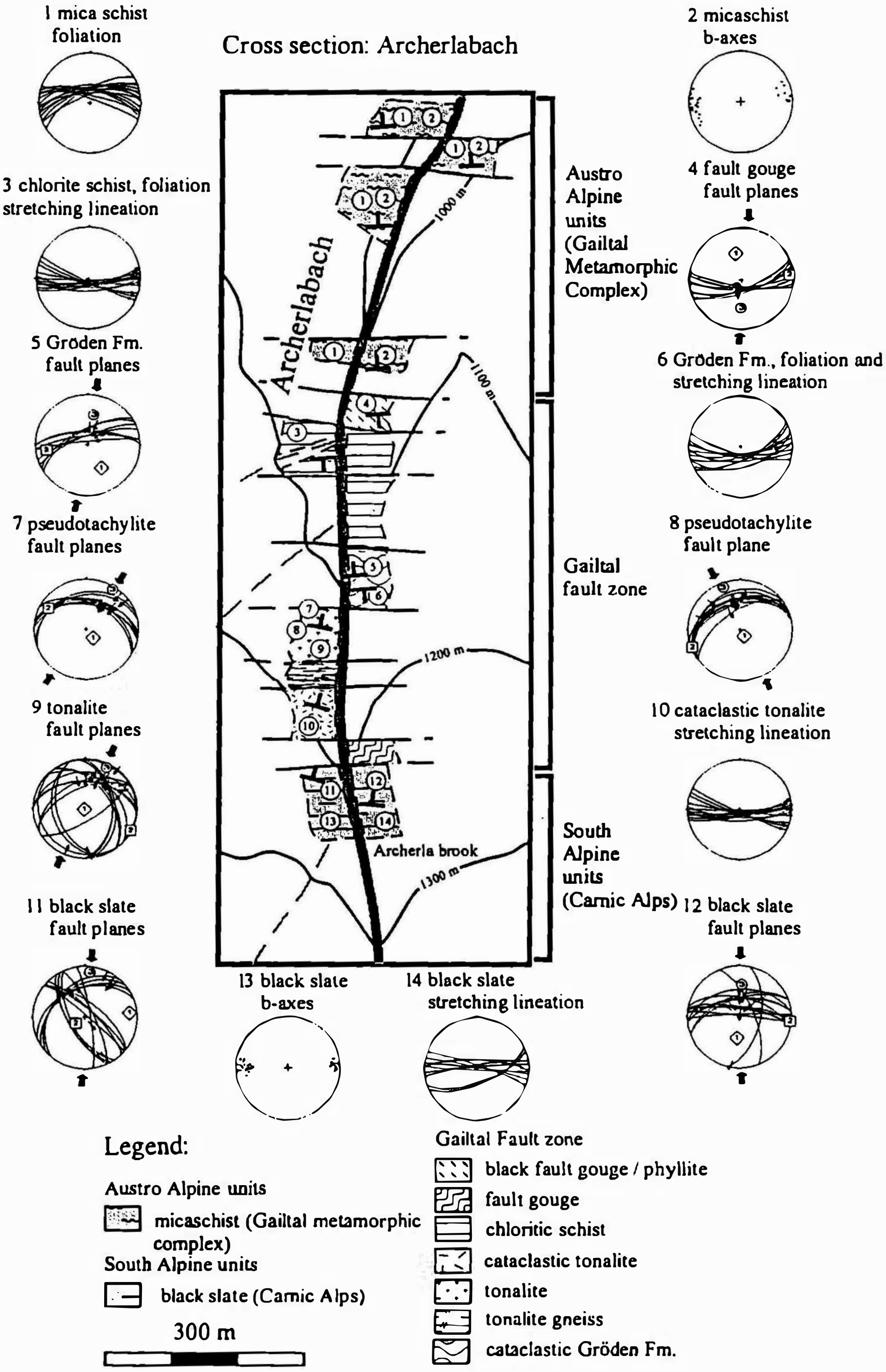

Fig. 16. Map of the Archerla brook displaying a section through the entire Periadriatic fault (from Nemes, 1997).

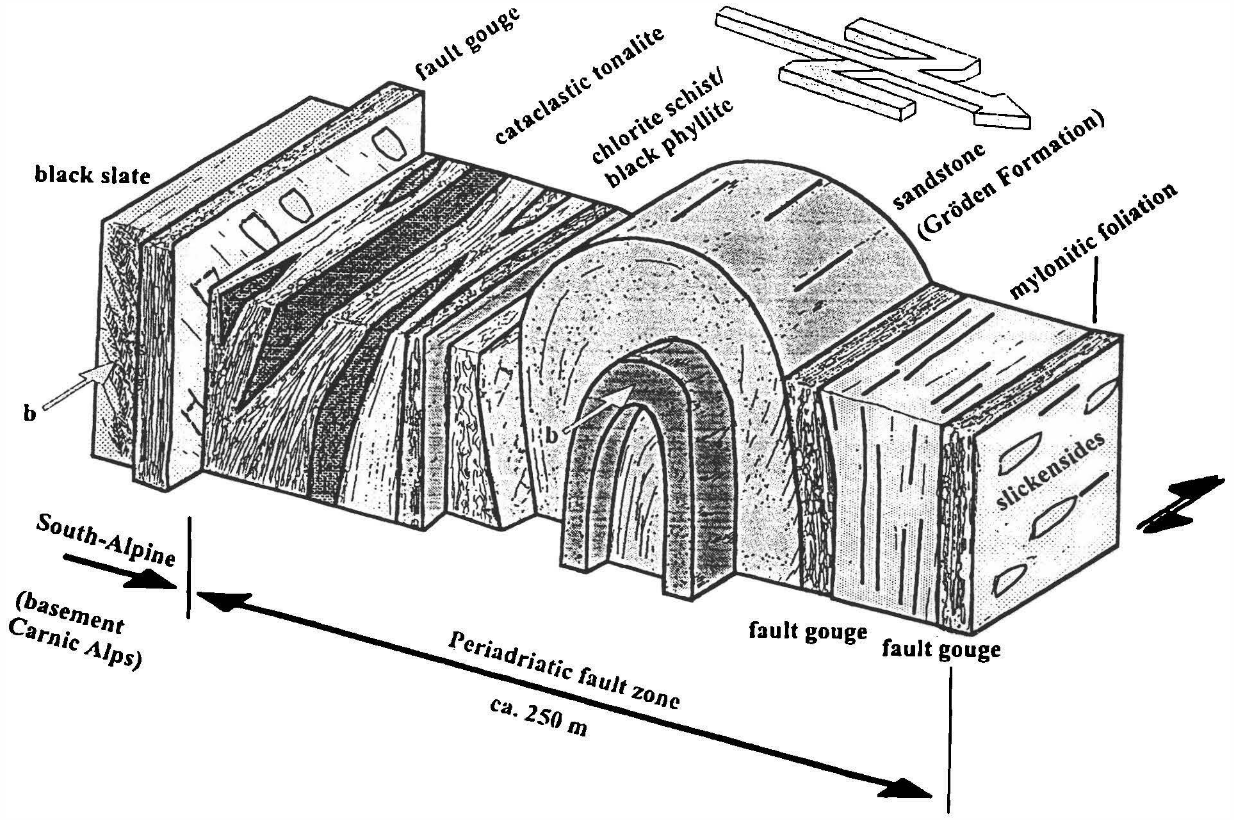

Fig. 17. Schematic diagram displaying structures exposed within the Archerlabach section.

Stop 32. Tröpolach: Eder Limestone mit Alpine ductile fabrics along the Periadriatic fault

Location: *OEK 198 Weißbriach. Road cut on Naßfeld road, ca. 200 metres S to Oselitzen near Tröpolach.*

F. NEMES, F. NEUBAUER

The outcrop exposes Steeply dipping. E-trending Eder limestone (metamorphic), actually a mylonite with a promeinent foliation and a subhorizontal stretching lineation. The mylonite is interpreted to represent an expression of Oligocene deformation along the Periadriatic fault.

Further reading: Läufer et al. (1997); Nemes (1997).

Stop no. 33. Hochwipfl Group

Location: *OEK 198 Weißbriach. East Oselitzen river bed, below curve/bridge of Naßfeld road, ca. 700 metres S to Oselitzen near Tröpolach.*

D. MADER, F. NEUBAUER

The outcrop exposes greyish to dark siltstones and graywackes of the Hochwipfl Group (Early Carboniferous). The Hochwipfl Group is interpreted to represent the infilling of a synorogenic flysch basin on top of the Devonian carbonate platform.

Further reading: Mader (1998).

Stop 34. Walking tour from saddle between Gartnerkofel and Garnitzenberg. Middle Triassic, Permian and Late Carboniferous of the Southalpine unit

Location: *OEK 198 Weißbriach. Walking tour down from the saddle between Gartnerkofel and Garnitzenberg.*

A walking tour down from the top station of the cable-car down to Naßfeld saddle allows to study Middle and Lower Triassic, Permian and Late Carboniferous formations. The section starts with massive Ladinian Schlern Dolomite, shallow water deposits,

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