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Structural Studies in the Western Habach Group (Tauern Window, Salzburg, Austria)

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With 13 Text-Figures

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Hohe Tauern
Habach Group
Habach Syncline
Knappenwand Syncline
Zentralgneis
Knappenwand Gneiss
Tectonics

Contents

Strukturuntersuchungen in der westlichen Habach-Gruppe (Tauernfenster, Salzburg, Österreich)

Zusammenfassung

Die Habachmulde enthält Metabasite, basische Vulkanoklastika, graphitführende und graphitfreie Metasedimente, Quarzite, saure Metavulkanite und intermediäre Amphibol/Biotit-Epidot-Plagioklas-Gneise. Die Knappenwandmulde besteht überwiegend aus Metabasiten und sauren Orthogneisen sowie untergeordnet aus Metasedimenten. Die Gesteine der Knappenwandmulde wurden von den Granitoiden des Knappenwandgneises intrudiert. Der Gesteinszug des Knappenwandgneises wird als Teil der Südlichen Sulzbachzunge (Zentralgneis) gedeutet.

Präalpidische Deformationsstrukturen sind selten. In der ersten alpidischen Deformationsphase entstanden sehr enge bis isoklinale Großfalten mit Amplituden bis etwa 5 km. Während dieser Phase wurden die Gesteine der Habachgruppe zur Habachmulde und Knappenwandmulde gefaltet. Insbesondere der Internbau der Habachmulde belegt ihre Synklinalstruktur. Die Zentralgneiszungen repräsentieren zugehörige Antiklinalstrukturen. In einer zweiten Deformationsphase wurde die erste Faltengeneration nahezu koaxial zu einer großen Antiformstruktur (Sulzauer Antiform) gefaltet. In der dritten alpidischen Phase wurden alte Bewegungsbahnen reaktiviert. Sehr spät entstanden bruchhafte Störungen.

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Abstract

The rocks of the Habach syncline comprise metabasites, basic volcaniclastics, graphitic and non-graphitic metasediments, quartzites, acidic metavolcanics and intermediate amphibole/biotite-epidote-plagioclase-gneisses. In the Knappenwand syncline mainly metabasites and leukocratic orthogneisses as well as metasediments occur. The Knappenwand gneiss shows intrusive contacts to the Knappenwand syncline and is considered to be part of the metagranitoids of the Southern Sulzbach Zentralgneis.

Pre-Alpidic structures are rare. During the first Alpidic deformation phase very tight to isoclinal large scale folds with amplitudes of about 5 km formed. The rocks of the Habach Group were folded into two large synclines, while the so-called Zentralgneis-Zungen ("tongue"-like structures) represent their associated anticlines. The internal structure of the Habach syncline reflects its synformal nature. A second deformational phase refolded the first folds nearly coaxially and created an antiformal structure (Sulzauer antiform). In the third Alpidic phase old faults were reactivated.

1. Introduction

In the past many geologists who worked in the region of the Habach Group focussed on mineralogical and geochemical topics (e.g. GRUNDMANN, 1983; STEYRER, 1982) or problems on ore deposits (e.g. HÖLL & SCHENK, 1988). Few dealt with tectonic problems since the basic publications of FRASL (1953, 1958), e.g. FRISCH (1977, 1980), REITZ et al.

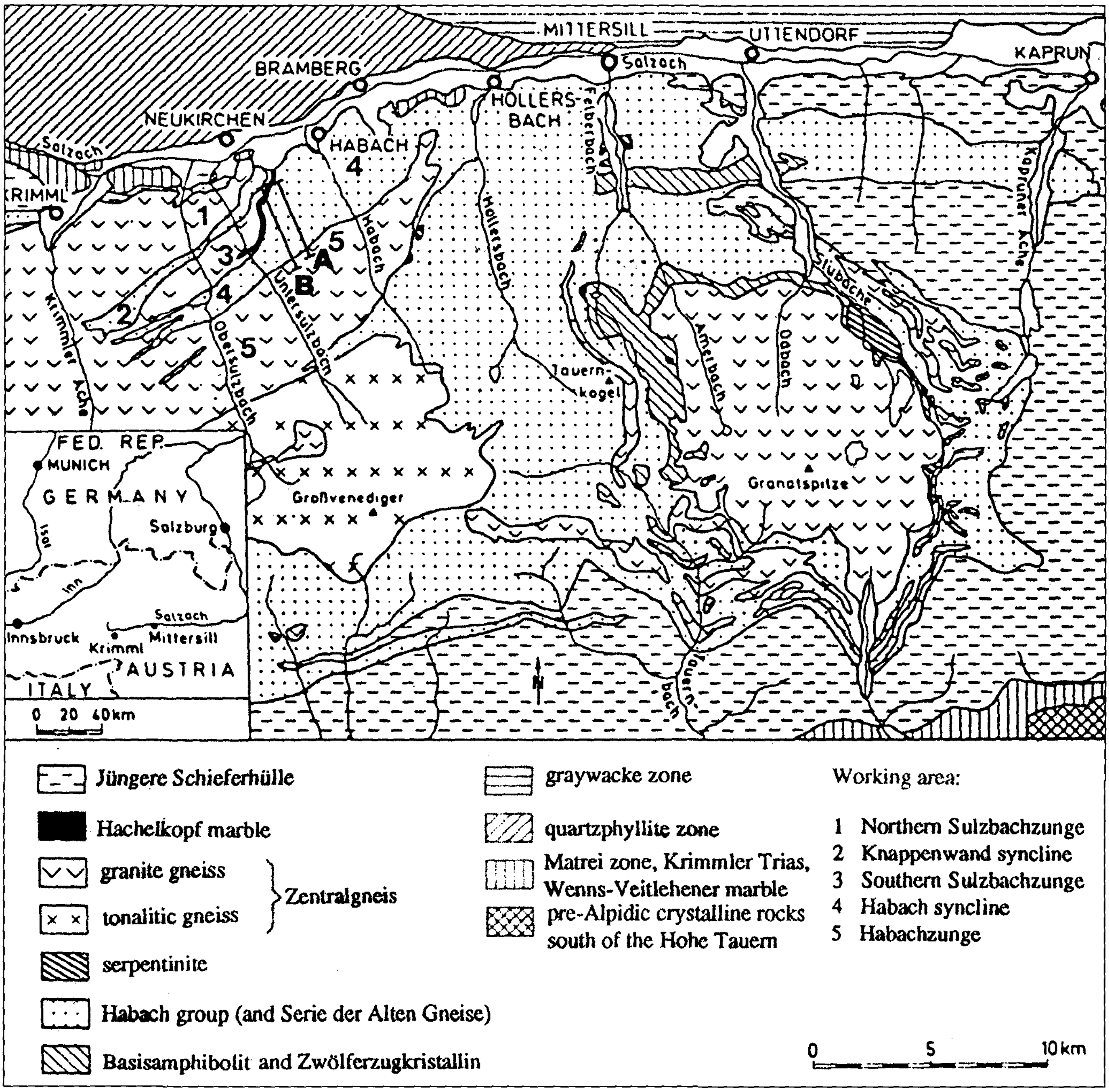


Fig. 1.
Generalized map with the working area in the Tauern Window (modified after SCHENK & HÖLL, 1989).
The lines mark the locations of the cross sections in Fig. 7.

(1989). But only structural investigations combined with detailed mapping can elucidate the lithostratigraphic relationships of the Western Habach Group.

Tectonic studies in polymetamorphic areas are subject to major problems because of the complex structures resulting already after two deformation events. It is often overlooked that already two non-coaxial deformations produce at least 4 different orientations of fold axes (RAMSAY & HUBER, 1987). Geological studies in the Habach Group have to consider not only the Alpidic metamorphism but also pre-Alpidic events and deformations. Pre-Alpidic metamorphic mineral relicts have been described e.g. by CORNELIUS (1944) and by KOLLER & RICHTER (1984).

Following the concept of FRISCH (1977, 1980) the working area belongs to the Venediger nappe. Its Alpidic tectonic style is characterized by competent Zentralgneis cupolas with large wavelengths and small amplitudes divided by schistose rocks forming steep and narrow synclines with short wavelengths and high amplitudes (FRISCH, 1980).

In the Western Tauern Window the Alpidic tectonic history has been subdivided into 4 deformational phases D_1–D_4 by LAMMERER (1988): During the transport of nappes (= D_1) over the Tauern Window large scale tight to isoclinal recumbent folds (= D_2) formed with amplitudes of up to 5 km. Subsequent refolding by slightly inclined large scale folds (= D_3) shows wavelengths of about 10 km. Brittle deformation (= D_4) accompanied the uplift of the Tauern Window. The phases D_1 and D_2 are expressions of a thrust regime, while D_3 and D_4 are interpreted as the results of a transpressional regime. Large scale folds in the northwestern Tauern window are also described by MILLER et al. (1984) and SENGL (1991). BEHRMANN & FRISCH (1990) postulated sinistral shearing in the Greiner syncline.

The aim of this paper is to present a short overview about the structural development of the working area. The resulting consequences for the lithostratigraphic sequence of the Habach Group are not considered here. A new model for the lithostratigraphy will be presented elsewhere after finishing all studies. This paper summarizes two years of own mapping and field work. In part the maps of 6 unpublished diploma theses (LAURE, 1985; DIETRICH, 1985; CARL, 1988; AIGNESBERGER, 1988; TOEPEL, 1988; GNIELINSKI, 1989) could be used.

2. Geological Setting

The study area is located at the northern margin of the Tauern Window (Fig. 1). The Tauern Window is subdivided into the Zentralgneis Cores, the Ältere Schieferhülle and the Jüngere Schieferhülle. The Ältere Schieferhülle represents in part the late Proterozoic to Paleozoic roof of the Zentralgneis granitoids, which intruded during Variscan times (e.g. CLIFF, 1981). The deposition of Mesozoic sediments on both the roof and the Zentralgneis was confirmed by geological research in the Western Tauern Window (e.g. LAMMERER, 1986, 1988).

The Jüngere Schieferhülle is considered to be the remnants of the Penninic ocean thrusted over the Ältere Schieferhülle and the Zentralgneis. The Habach Group is part of the Ältere Schieferhülle respectively the roof rocks of the Zentralgneis granitoids.

In the study area rocks of the Habach Group, the Zentralgneis and probable Mesozoic marbles occur. The Zentralgneis bodies are generally refered to as so-called Zungen ("tongue"-like structures). The polymetamorphic rocks of the Habach Group form two large southwest – northeast trending structures in the Variscan granitoids (compare Fig. 2). In the geological literature these structures are called synclines. Hence the study area is subdivided from northwest to southeast into

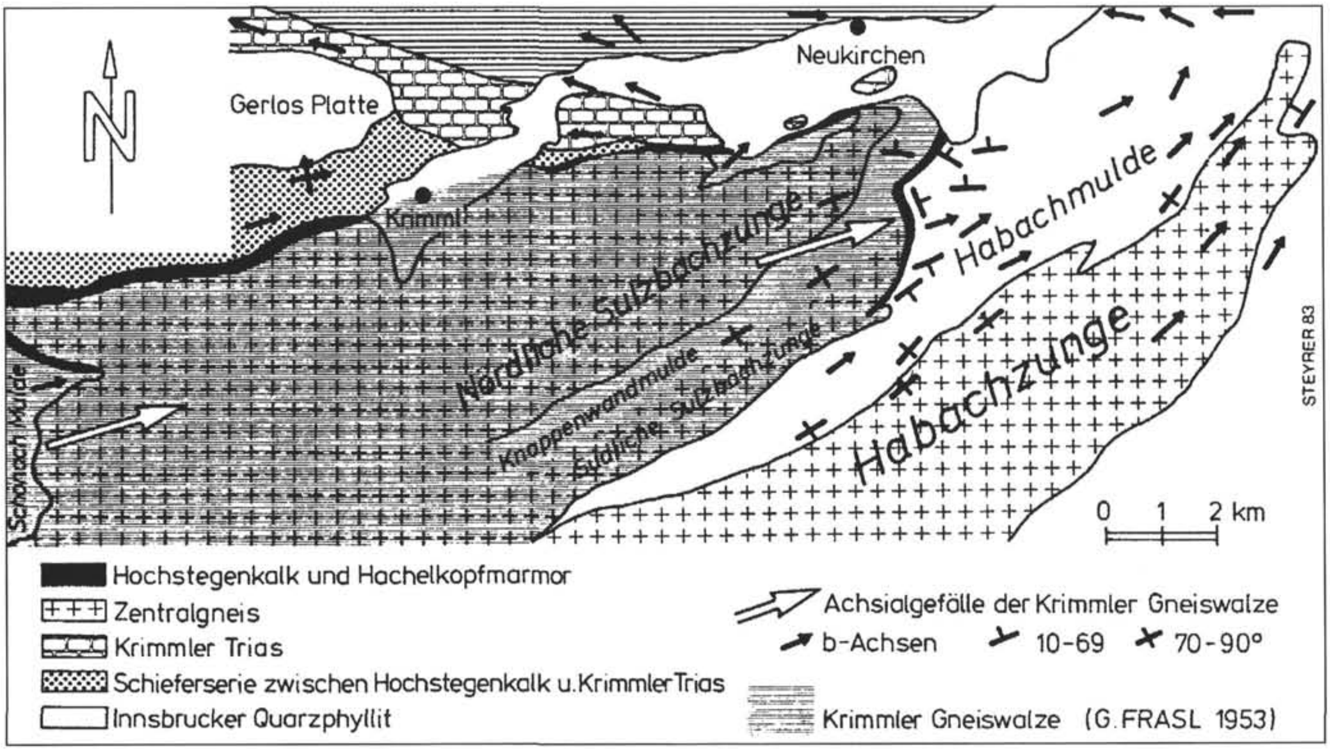


Fig. 2.
Generalized map of the working area from STEYRER (1983) using data from FRASL (1953).
The Knappenwand gneiss is plotted as part of the Knappenwand syncline.

- Northern Sulzbachzunge (Zentralgneis)
- Knappenwand syncline (Habach Group) } Krimmler Gneiswalze
- Southern Sulzbachzunge (Zentralgneis)
- Habach syncline (Habach Group)
- Habachzunge (Zentralgneis)

A true synclinal structure was sometimes assumed for both the Knappenwand and Habach synclines in literature but never confirmed up to now by detailed structural studies. The newly found intrusive contacts along the southwestern margin of the Knappenwand syncline (see chapter 3.2.) however provide good arguments to regard the Habach Group as the Variscan roof rocks indeed. Considering their fold structures (see chapter 4.) a true synclinal nature for both the Habach and the Knappenwand syncline is therefore strongly supported.

Frasl (1953) introduced the tectonical concept of the so-called Krimmler Gneiswalze for the region of the Western Habach Group. In this concept the two Sulzbachzungen and the Knappenwand syncline (including the Knappenwand gneiss) are considered as one cylindrical geological body (= the Krimmler Gneiswalze) formed during the main Alpidic deformation phase (Fig. 2).

In the north the rocks of the Tauern Window are cut by the Salzach fault which separates the Tauern window from the Austroalpine units. The southern contact of the Habachzunge to amphibolites of the Habach Group is represented by the Leckbach fault.

3. Lithological Units

In the following chapter the rocks of the working area are briefly characterized. A detailed petrographic description will be presented elsewhere. The lithostratigraphic term Habach Group is used here according to Hedberg (1976). For a thorough discussion about the correct lithostratigraphic nomenclature considering the Habach unit see Schenk (1990).

3.1. The Habach Group

The metabasic rocks comprise mainly different types of amphibolites of both intrusive and extrusive nature. These rocks have been thoroughly studied by Scharbert (1956), Steyrer (1982), Steyrer & Höck (1985) as well as by Seemann & Koller (1989). Metagabbros are described e.g. by Höck & Pestal (1990). Fine-grained acidic clasts (– 20 cm) in basic volcanoclastic deposits prove the existence of bimodal volcanism. The extruding volcanic material incorporated plutonic clasts (– 40 cm) of intermediate composition as well as rare quartzite clasts. Epidosites are mainly associated with the metabasites of the Knappenwand syncline. The epidosites are the host rocks for the famous epidotes found in Alpidic fissure veins. The epidosite layers partly show clast-like structures which probably are the result of boudinage.

Metasediments are frequent in the Habach syncline. The Habach phyllites (Frasl, 1953) sensu stricto represent metamorphosed bituminous shales. Deposition in an anoxic environment lead to the conservation of microfossils in these rocks: Reitz & Höll (1988) discovered acritarchs as the first fossils of the Habach Group and confirmed an upper Riphean to Vendian age for them. Also graphitic phyllites near the Gerlos pass north of the Farmbichl yielded Upper Proterozoic acritarchs (Reitz et al., 1989). Besides the phyllitic rock types graphitic schists and quartzites can be found in the Habach syncline. Widely distributed are also non-graphitic mica schists and paragneisses (see also Steyrer, 1982; Dietrich, 1985). Many different types of quartzites (kyanite quartzites, muscovite quartzites, pyrite quartzites) as well as pyritic muscovite schists are summarized as the quarzite unit in this paper. This unit occurs in the Untersulzbach and Obersulzbach Valley. Accessory topaz (Karl, 1954) in these rocks is unique in the Eastern Alps. In the Knappenwand syncline metasedimentary rocks are not as frequent as in the Habach syncline. They comprise banded gneisses, mica schists and metaconglomerates. Recently found marbles (Fig. 3) are also of sedimentary nature according to isotope analyses (Carl, 1988). The marbles can locally be altered to calcsilicate rocks.

Acidic metavolcanics (Heuschartenkopf gneiss, sensu Frasl, 1949) form a lithostratigraphic marker horizon in the Habach syncline. They may show porphyric textures with feldspar or quartz phenocrysts. In the past these rocks of the Habach Group have partly been mapped together with fine-grained Zentralgneis equivalents (kalifeldspar-plagioclase-gneisses, see chapter 3.2.) as albite gneisses (Steyrer, 1982). Distinguishing both units in the field is difficult but essential. Pyroclastic components often indicate a metavolcanic protolith forming

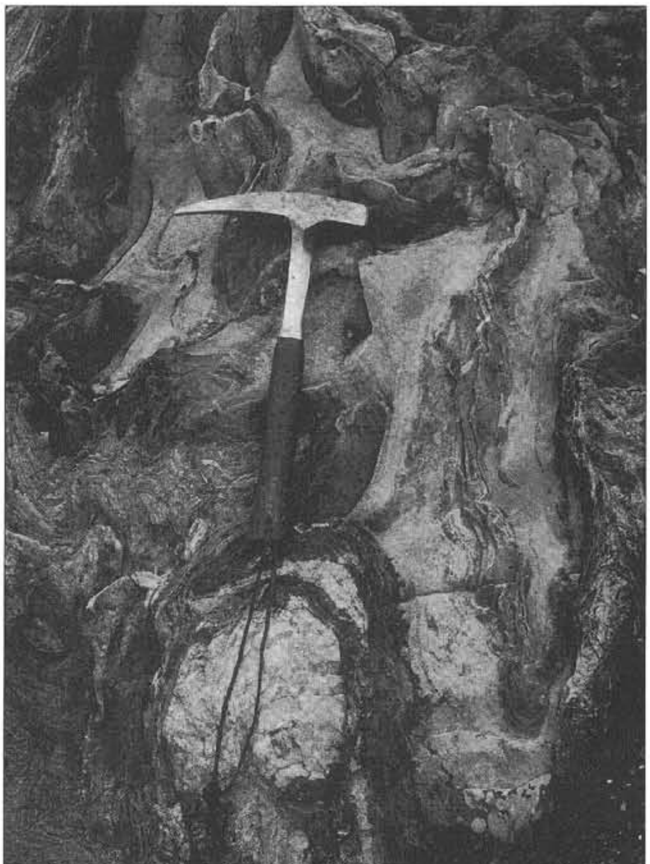
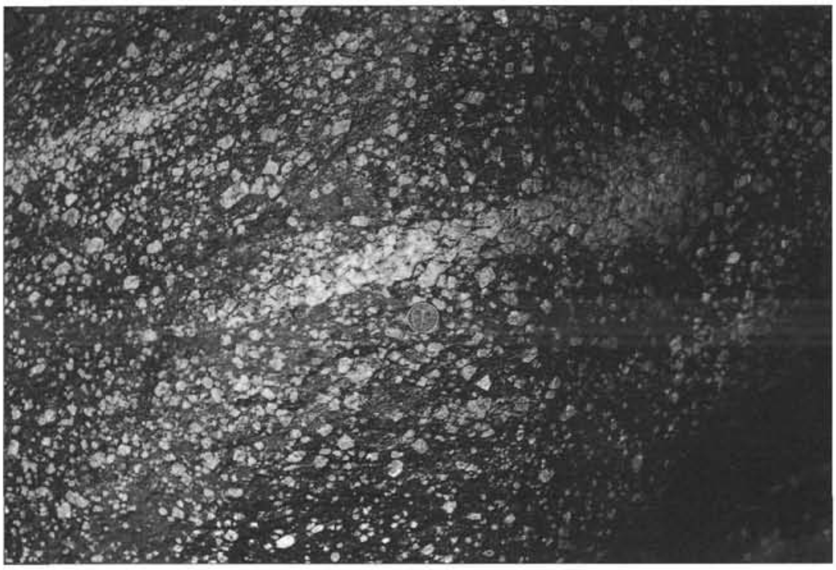


Fig. 3.
Light-coloured marble horizon showing superposed folding (Knappenwand syncline).
Location: About 400 m north of the Söllenkar Kogel, 2700 m above sea level.

Fig. 4.
Typical porphyric Knappenwand gneiss with schlieren of cumulated feldspar phenocrysts.
Scale = 1 Austrian Schilling. Location: Roll-block on the eastern banks of the Untersulzbach, 1050 m above sea level.



part of the Habach Group. Basic volcaniclastic intercalations in the acidic unit reach a thickness up to 50 m.

In the Knappenwand Syncline a variety of acidic orthogneisses is intercalated with the basic rocks. Acidic volcaniclastic rocks and fine-grained intrusive orthogneisses with rare xenoliths are present. At least some of the coarse-grained types of orthogneisses have to be attributed to the Zentralgneis varieties present at the contacts of the Knappenwand syncline.

The high-K intermediate amphibole/biotite-epidote-plagioclase gneisses with transitions to amphibolites were investigated by STEYRER (1982). These rocks occur in the Peitingalm area (Habach valley) and are probably of volcanogenic origin. CARL (1988) proposed a close relationship to the Achselalm metadiorite based on geochemical analyses.

3.2. The Zentralgneis

The rocks of the three Zentralgneiszungen are predominantly coarse-grained. They may locally show feldspar phenocrysts and biotite/chlorite-rich schlieren. Aplites are common in the Northern Sulzbachzunge. Xenoliths of the roof rocks are frequent in the Southern Sulzbachzunge. Unambiguous intrusion contacts are seldom as a result of the strong deformation. Small bodies of Zentralgneis can be present locally in the rocks of the Habach Group.

The so-called Knappenwand gneiss (Fig. 4) is an orthogneiss of rhyolithic to dacitic composition (STEYRER, 1983; SEEMANN & KOLLER, 1989) with kalifeldspar phenocrysts. In the past its genesis has been the reason for controversial discussions: FRASL (1953) and STEYRER (1982, 1983) consider this gneiss as a metavolcanic rock and as part of the Knappenwand syncline (Fig. 2). KARL and SCHMIDEGG (geological map 151 Krimml) regard these rocks as part of the Southern Sulzbach Zentralgneis. The normal non-porphyric granitic gneiss of the Southern Sulzbachzunge passes into the Knappenwand gneiss by continuous enrichment of large kalifeldspars (1–3 cm). This transition zone was already described by FRASL (1953). But also in the normally non-porphyric Zentralgneis type cumulated kalifeldspar phenocrysts sometimes occur (Fig. 5). Aplites and xenoliths in the non-porphyric type and the Knappenwand gneiss are equally frequent. Furthermore recently discovered intrusive contacts (Fig. 6) as much as frequently occurring concordant sills in the southwestern Knappenwand syncline confirm the plutonic nature of the Knappenwand gneiss. Its close relationship to the Southern Sulzbach Zentralgneis leads to an interpretation as a porphyric Zentralgneis type. The continuous enrichment of the kalifeldspars at the approach of the Knappenwand syncline rocks supports this interpretation: In the roof regions of high plutonic bodies (here: Southern Sulzbach Zentralgneis) often magmatites with accumulated feldspars occur (here: Knappenwand gneiss).

As a consequence the Knappenwand gneiss is not a constituent of the Knappenwand syncline (compare Fig. 2) like suggested e.g. by FRASL (1953), but is part of the Southern Sulzbachzunge.

Fine-grained kalifeldspar-plagioclase-gneisses crop out along the southern border of the acidic metavolcanics (see chapter 3.1.). U-Pb age determinations on zircons of rock samples collected near bridge 1107 in the Habach valley yielded a magmatic age of about 334 Ma (VAVRA & HANSEN, 1991). The investigated rock type was des-

Fig. 5.
Feldspar phenocrysts concentrated around a xenolith in normal non-porphyric Zentralgneis of the Southern Sulzbach Zunge.
Scale = 10 Austrian Groschen. Location: Untersulzbach valley, 15 m southwest of bridge, 1153 m above sea level.

Fig. 6.
Knappenwand gneiss granitoids intruding metasediments with a pre-Variscan layering.
Location: Northwestern Seebachkar, 2300 m above sea level.

cribed as a high-K metarhyolite. The sampling locality (written comm. VAVRA) lies within the kalifeldspar-plagioclase-gneisses according to own mapping. The resulting age agrees very well with Variscan Zentralgneis ages (e.g. CLIFF, 1981). Furthermore a volcanogenic protolith could not be confirmed petrographically. This evidence favours an interpretation as a fine-grained Zentralgneis equivalent as already assumed by FRASL (1949).

Medium-grained metagranitoids that are locally amphibole-bearing occur at the so-called Kuh near the contact of the Habach syncline to the Habachzunge. They show strong epidotization and saussuritization and often contain dark, biotite-rich xenoliths. At the Schottmeiler these orthogneisses are intruded by coarse-grained granitoids.

3.3. The Hachelkopf Marble

The Hachelkopf marble is a very pure calcite marble that typically shows a grey and white respectively yellowish layering. It is suggested to be the stratigraphic equivalent to the Jurassic Hochstegen marble and was described in detail by FRASL (1953). Together with basal quartzites and graphitic schists the Hachelkopf marble forms the hanging wall of the Southern Sulzbachzunge (including the Knappenwand gneiss). It is tectonically overlain by the Habach syncline. The marble has been subject to strong shearing and boudinage according to own field studies. This indicates the presence of a major thrust, which is termed Hachelkopf thrust in this paper. Often up to three thin subparallel marble horizons can be mapped along the thrust. The marble reaches a thickness of about 10 m only below the Hachelkopf peak. Due to the strong deformation this rock cannot be considered as the autochthonous cover of its foot wall.

4. The Structure of the Western Habach Group

All cross sections presented here are based on detailed mapping in a scale of 1 : 10000. A map of the working area is in preparation. A series of cross sections is convenient for the documentation of local structures. The profiles Fig. 7a and b show the core of the Habach syncline in detail. They provide a new interpretation of the Heuschartenkopf area with respect to STEYRER (1983). To reveal the interrelations of the huge fold structures in the working area however there is need for a presentation as a whole. For this reason a generalized cross section perpendicular to the Alpidic fold axes was constructed (Fig. 8), like they have been presented by LAMMERER (1988) for the western Tauern Window. For the construction a mean value of 54°/26° was taken for the Alpidic B_{A1}- and B_{A2}-axes (see chapter 4.5). Errors will be greatest for the eastern limb of the Habach antiformal syncline due to its shallow dipping fold axis. In this area only maximum thicknesses are shown.

In these presentations (Fig. 7, 8) it is noteworthy that the complex internal structure of the Habach syncline reflects its isoclinal fold structure. The acidic metavolcanics act as a marker horizon. These rocks as well as amphibolites and basic volcaniclastics can be traced around a core of intermediate amphibole/biotite-plagioclase-epidote-gneisses. The acidic metavolcanics overlie both metasediments in the northwest and basic metavolcanics in the southeast (Fig. 8). In the uppermost part of the section the acidic metavolcanics can be traced around the (subvolcanic?) kalifeldspar-plagioclase-gneisses which intruded between metabasites and the acidic metavolcanics. The subseqently intruded granitoids of the Habachzunge are dipping north at their northernmost occurence. On the southern margin of the Habach syncline the structure is complicated by a large parasitic fold developed during phase D_{A1}.

4.1. Pre-Alpidic Events

Fold axes visible in the field can rarely be unambiguously attributed to a pre-Alpidic deformation. These axes show a big scatter due to the overprinting by the Alpidic folds. Relics of an old, probably Variscan cleavage cut by the two Alpidic ones can often be seen microscopically in the mica-rich Habach phyllites (sensu stricto).

During the intrusion of the Habachzunge granitoids a huge block was separated from the roof rocks (now: Habach syncline). This block comprises amphibolites and pyritic quartzites being typical for the quartzite unit of the Habach syncline. These rocks are nowadays exposed amidst the Habachzunge granitoids to the west of the Foissenalm (Obersulzbach valley).

4.2. First Alpidic Phase D_{A1}

During and after the Alpidic thrusting of nappes over the Tauern Window an extreme ductile deformation prevailed in the Zentralgneis and the Habach Group rocks. In this tectonic phase D_{A1} (= D_2 according to LAMMERER, 1988) very tight to isoclinal, probably recumbent folds with am-

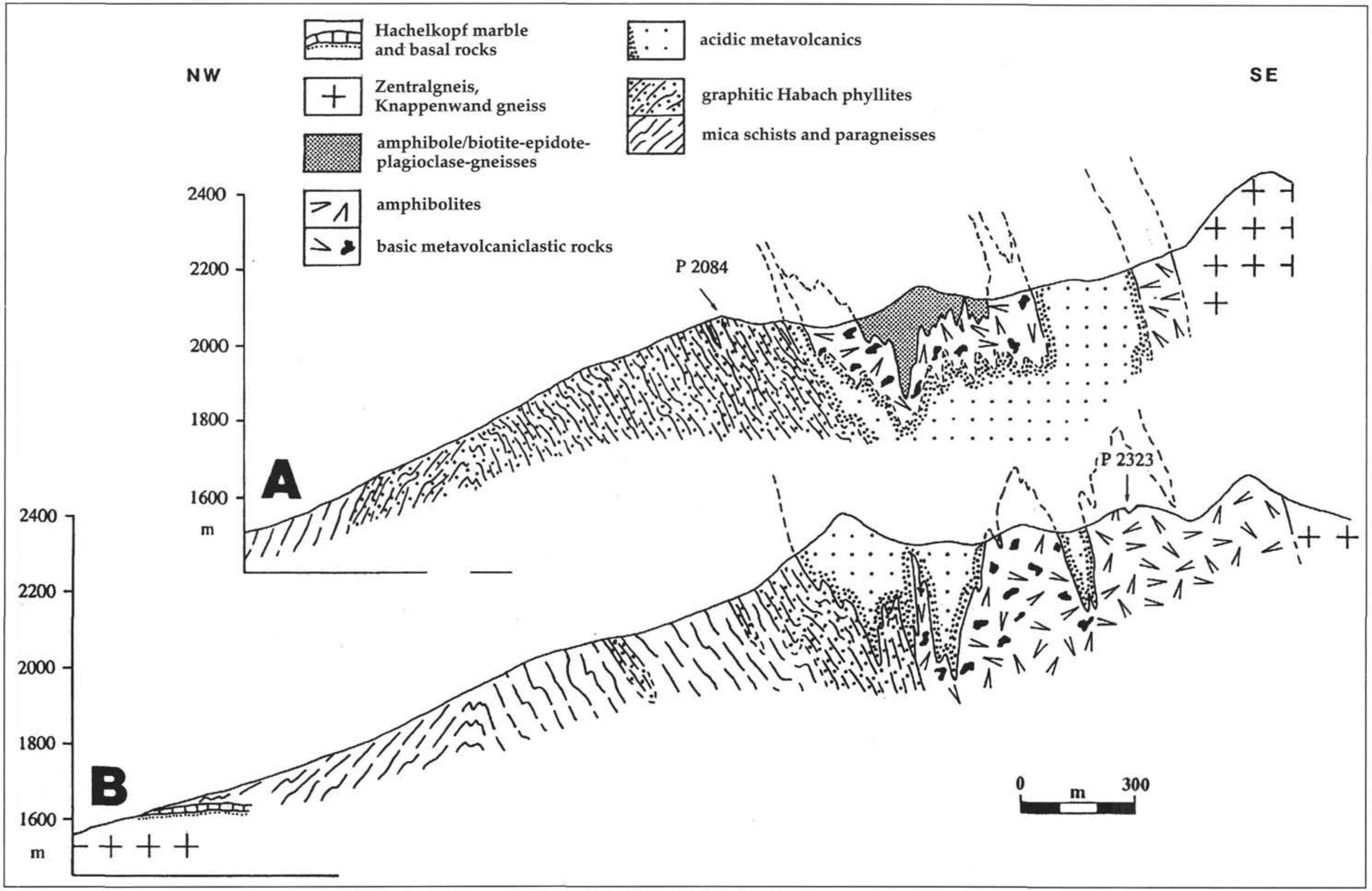


Fig. 7.
Cross sections showing the core of the Habach syncline in the Heuschartenkopf area.
For locations compare Fig. 1.

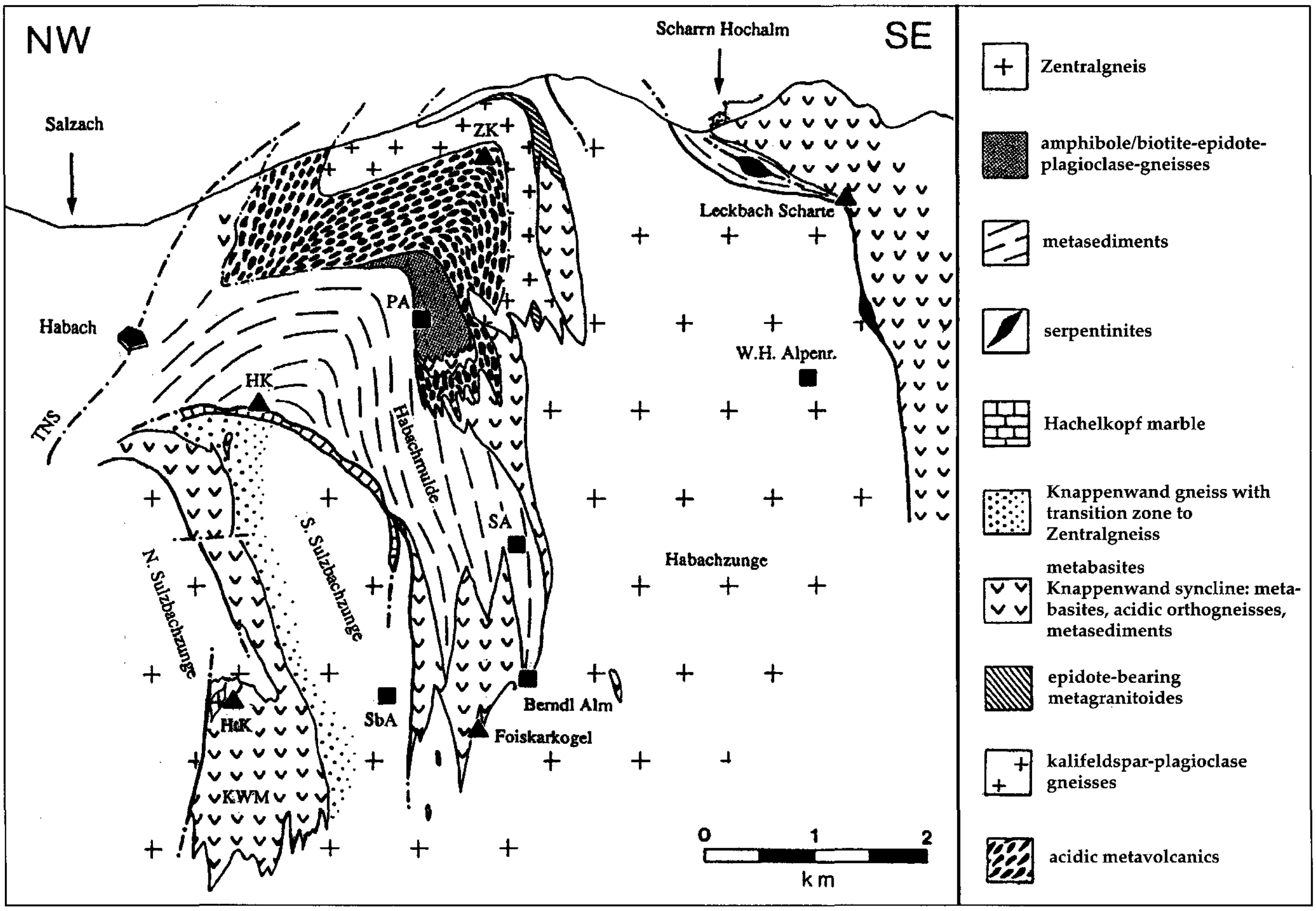


Fig. 8.
Cross section through the western Habach Group perpendicular to the Alpidic fold axes (no vertical exaggeration).
KWM = Knappenwand syncline, TNS = Salzach fault (not exposed), HtK = Hütteltalkopf, HK = Hachelkopf, SbA = Seebach Alm, PA = Peitingalm, SA = Stocker Alm, ZK = Zwölferkogel. Heavy lines = faults and thrusts.

plitudes of about 5 km formed: The rocks of the Habach Group were folded into the Knappenwand and Habach synclines, while the Zentralgneiszungen represent their associated anticlines (Fig. 8). Furthermore the folding caused the formation of the dominating axial plane parallel cleavage S_{A1}. It is mainly oriented subparallel to the lithological boundaries, except in D_{A1}-fold cores where it cuts through the lithology.

Along the Hachelkopf thrust the Hachelkopf marbles acted as a detachment horizon. Here the Habach syncline was thrust onto the Southern Sulzbach Zentralgneis and the Hachelkopf marble. Macroscopic shear sense indicators suggest movements directed about south to north. Clues to such movements were already described by FRASL (1953) in the Untersulzbach valley. Here the Zentralgneis of the Southern Sulzbachzunge has been moved over the Hachelkopf marble for at least 350 m. Also the doubling of the sequence Knappenwand gneiss – Hachelkopf marble in the eastern Aschbach supports north directed movements.

In 1951 a marble outcrop was found by SCHMIDEGG at the Aschbach creek at 1020 m above sea-level (mentioned by FRASL, 1953). This marble occurrence was thought to indicate that Hachelkopf marble rests on top of the Knappenwand syncline and even on the whole Krimmler Gneiswalze (FRASL, 1953). This could not be confirmed. The aforementioned outcrop could not be found again during field work. Nevertheless the presence of marble at this locality might be considered as a clue to north directed dragging of imbricated marble along the Hachelkopf thrust.

If a top-to-the-north sense of thrusting can be confirmed further, this would indicate a sedimentary deposition of the (now parautochthonous) Hachelkopf marble on or south of the Southern Sulzbach Zentralgneis.

4.3. Second Alpidic Phase D_{A2}

The originally recumbent D_{A1}-folds were refolded during the deformation phase D_{A2} in a large scale and nearly coaxial. An antiformal structure with an amplitude in the range of the D_{A1}-folds formed (Fig. 8). A very good exposure of the S_{A1}-planes changing from northwestern to southeastern dip is found along the scenic footpath to the Untersulzbach cascades near Sulzau. Therefore this antiform is named Sulzauer antiform here. On its northern limb it creates the diving structures already recognized by FRASL (1953) and FRISCH (1977). Associated synformes have not been confirmed up to now. The axial surface of the Sulzauer antiform is south-vergent and subparallel to the Salzach fault. It approaches this fault from east to west.

During D_{A2} the cleavage S_{A1} was locally intensively folded and crenulated. In mica-rich rocks a crenulation cleavage S_{A2} formed.

4.4. Third Alpidic Phase D_{A3}

The situation below the Hachelkopf peak has been described in detail by FRASL (1953): The shallow-dipping

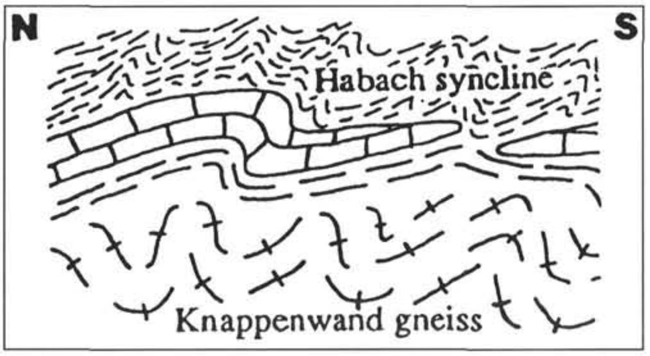


Fig. 9.
Schematic sketch of the structures beneath the Hachelkopf peak.
The Hachelkopf marble and its basal rocks show a shallow dipping foliation, boudinage and rare folds, while foot and hanging wall are strongly folded (without scale).

marble horizon and its basal rocks cover the Knappenwand gneiss showing a steep schistosity. The Habach syncline schists overlying the marble show a steep cleavage. Frasl (1953) noticed that this cleavage was younger than the marble cover. Narrow folds appear more frequently with increasing distance to the marble (Fig. 9).

Due to own investigations the tectonic style over and beneath the marble is dominated by south-vergent, parasitic D_{A2}-folds and a S_{A2} crenulation cleavage dipping *mostly steep to the north. In contrast folds are rare in the* marble and its foliation is commonly shallow-dipping. The marble must have been overprinted by late movements along the Hachelkopf thrust. These D_{A3} movements therefore clearly postdate the folding event D_{A2}. More detailed studies on the complex deformation history of the Hachelkopf marble are in preparation.

There is evidence for similar late movements at the Leckbach fault. The superposed fold system of the Habach antiformal syncline was cut by this fault in the area of the Achselalm. The movements had an northeast-southwest oriented component due to stretching lineation measurements. At the Achselalm the shear plane is dipping shallowly to the west, but changes its strike and dip towards the Leckbach Scharte. There it dips steeply north.

As the Tauern Window finally reached the transition zone to brittle deformation the shear planes partly became true brittle faults. At the Leckbach fault tectonically brecciated amphibolites and biotite schists were cemented by quartz.

4.5. Structural Analysis

The result of all deformation phases is a complex superposed fold system. While mapping this system the geologist has to be *aware that on west slopes of the north-south* oriented mountain ranges he is moving approximatly in the YZ-plane of the strain ellipsoid respectively in the XZ-plane on east slopes. This effect results from the prolate deformation (Weger & Lammerer, 1992) and the B_{A1}/B_{A2} axes dipping eastnortheast. This implies that approximate true profiles through the folds can only be seen on the west directed slopes. Fold interference patterns are rare (Fig. 10). According to Ramsay & Huber (1987) they mostly can be classified between the types E and F, just like expected for nearly coaxially oriented fold axes.

The D_{A1}/D_{A2} fold system was geometrically analyzed using a method of Ramsay & Huber (1987). In a superposed fold system these authors suggest to differentiate domains with (sub)cylindrical folds and fairly constant orientation of fold axes. Borders of domains fulfilling theses *conditions are represented by the axial surfaces of the* D_{A1}-folds and major faults. Habach syncline and Habachzunge have been analyzed analogue to this method. Structural data of this region are presented in Fig. 11:

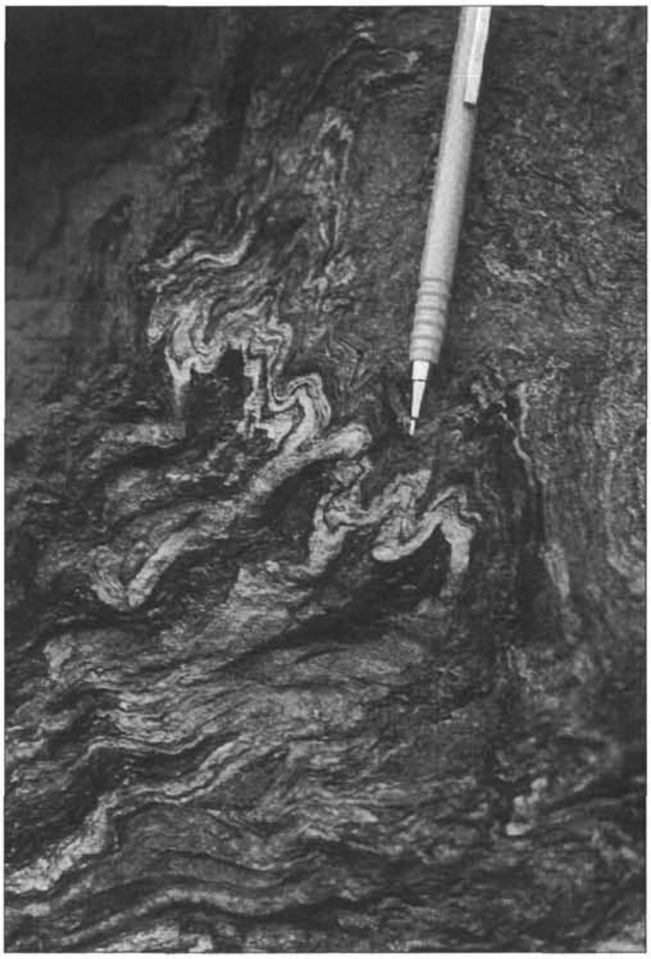
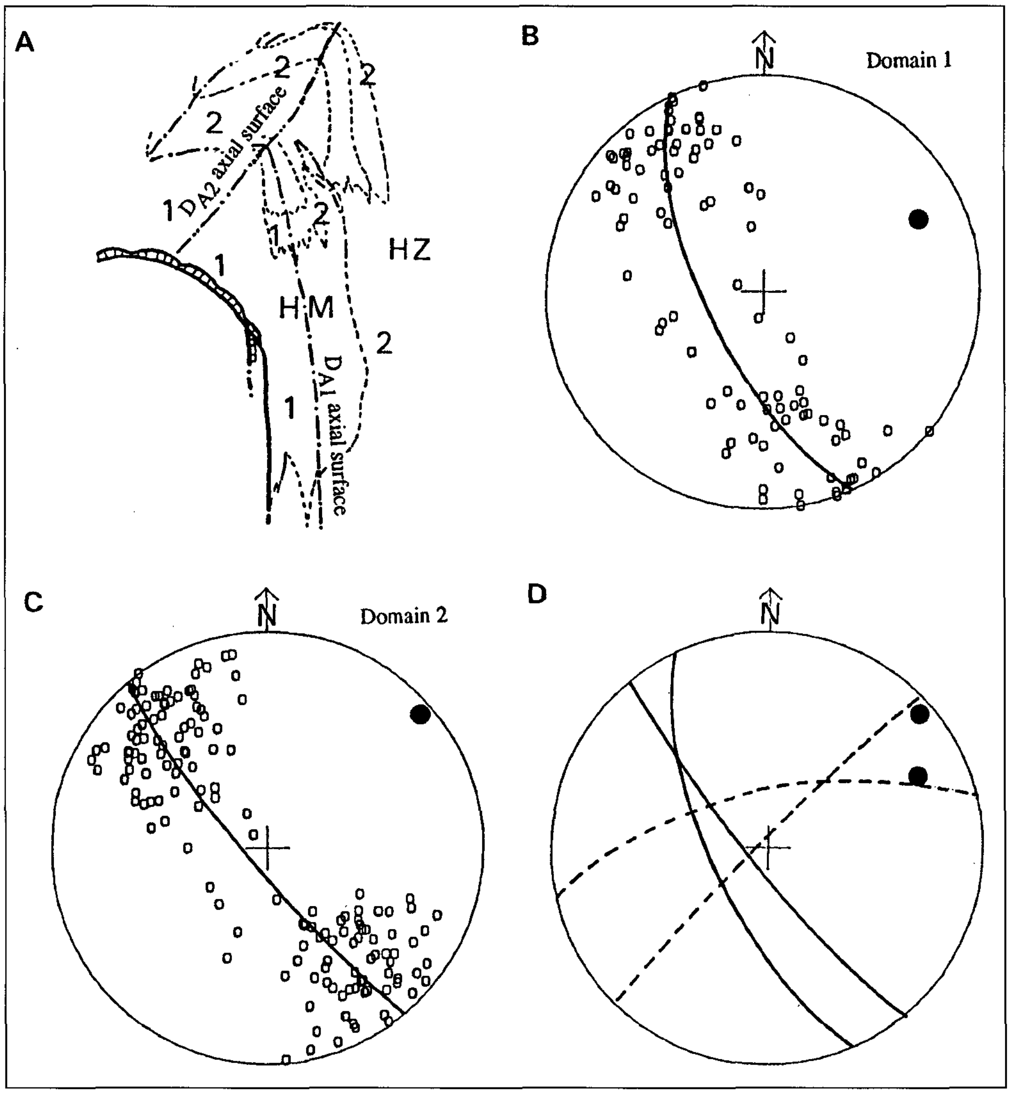


Fig. 10.
Fold interference pattern of carbonate layers within Habach phyllites.
Location = Street to the Reintal Alm, 1425 m above sea level.

Domain 1 represents the northwestern limb of the Habach antiformal syncline, domain 2 its southern to eastern limb together with the bordering limb of the Habachzunge (see Fig. 11A). The interlimb angle of the Sulzauer antiform measures about 55–65°. Both domains show approximately subcylindrical folds. The resulting fold axis of domain 1 is oriented about 65°/22° (Fig. 11B), the axis of domain 2 about 50°/5° (Fig. 11C). These two directions represent the major axes B_{A2} of the second Alpidic folding. *These differently oriented, diverging axes give evidence* that the D_{A2} axial surface is not a plane but somehow distorted. The D_{A2} axial surface is clearly changing in the easternmost part of the antiform, creating a range of axial surfaces (Fig. 11D). This region is increasingly influenced by the thrust of the Jüngere Schieferhülle, the Salzach fault and the Leckbach fault. The domain 2 fold axes therefore could have been originally subparallel to those of domain 1.

The refolded B_{A1}-axis is much more difficult to characterize. Due to field measurements its orientation changes around 60–70°/25° in the western part of the Habach syncline. In the area of the Peitingalm a dip of at least 33° can

Fig. 11.
Structural analysis of the refolded fold system.
A = Synoptic profile with domains 1 and 2 showing the axial surfaces of D_{A1}- and D_{A2}-folds; HM = Habach syncline; HZ = Habachzunge; B = Poles to S_{A1}, 100 data; C = Poles to S_{A1}, 174 data; D = Synoptic projection of both domains; lines = great circles of S_{A1} poles; filled circles = B_{A2} axes; dashed lines = maximum values of observed D_{A2} axial surfaces.



be deduced: The core of the Habach syncline represented by the outcropping amphibole/biotite-epidote-plagioclase-gneisses is dipping steeper than the ground surface.

5. Discussion and Conclusions

Regarding the Knappenwand gneiss as part of the Southern Sulzbach Zentralgneis has important consequences: The parautochthonous Hachelkopf marble is covering not the whole Krimmler Gneiswalze but only the Southern Sulzbach Zentralgneis. A mesozoic cover of the Northern Sulzbach Zentralgneis and the Knappenwand syncline is not exposed. If Hachelkopf marble exists in contact to the Knappenwand syncline rocks, its position most probably results from north directed dragging along the Hachelkopf fault. This is at variance with FRISCH (1977) considering the Knappenwand syncline as a pre-Alpidic structure with an autochthonous mesozoic cover (Fig. 12).

FRASL (1953) proposed the Krimmler Gneiswalze to have suffered a different tectonic history than its hanging wall during the main Alpidic deformation events. This can only be confirmed for the late D_{A3} deformation. S_{A1} cleavage

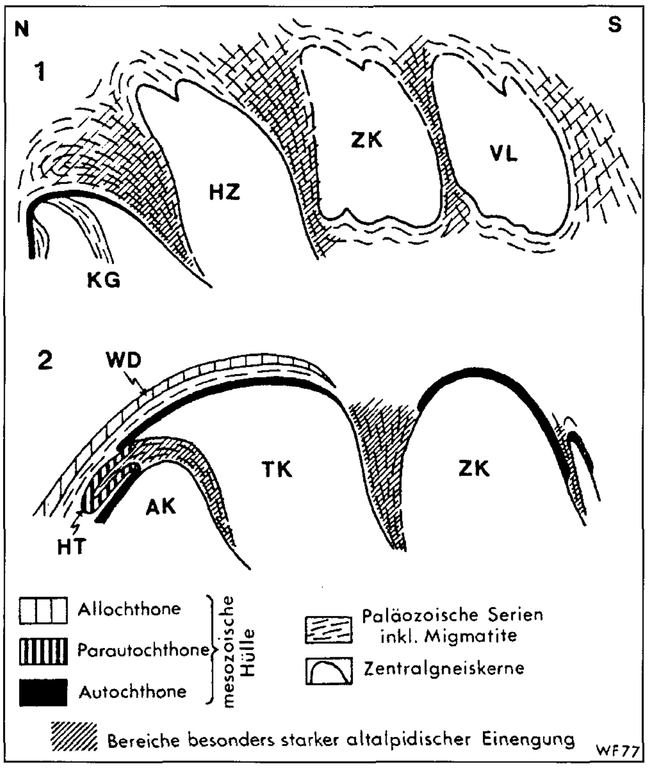


Fig. 12.
Schematic sketch of the structures of the Venediger nappe (from FRISCH, 1977). The Hachelkopf marble is considered as the autochthonous cover of the Krimmler Gneiswalze.
KG = Krimmler Gneiswalze, HZ = Habachzunge, ZK = Zillertal Zentralgneis core, AK = Ahorn Zentralgneis core, TK = Tux Zentralgneis core, WD = Wolfendorn nappe, HT = Höllenstein synform, VL = Venediger Zentralgneis lobe.

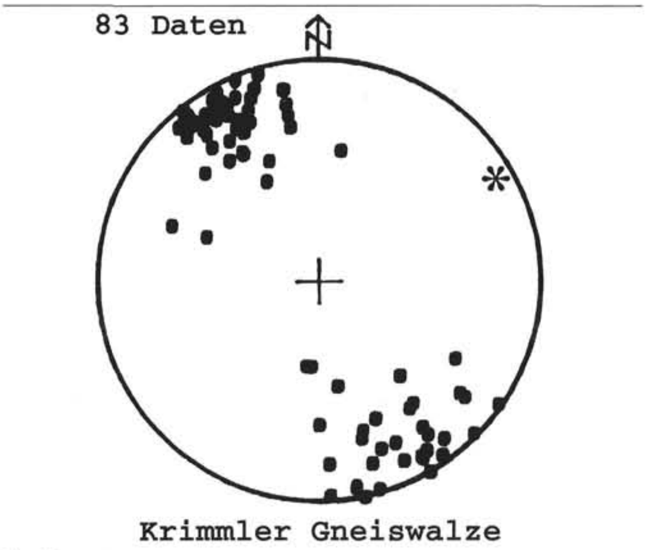


Fig. 13.
S_{A1} poles measured in the Krimmler Gneiswalze.
The distribution of poles agrees well with that of the Habach syncline (Fig. 11B). The lower frequency of shallow dipping planes causes a relatively large dip error of the computed B_{A2} axis 61°/7° (star).

planes (Fig. 13), lineations as much as fold vergence and fold styles show almost no differences in both areas. The Krimmler Gneiswalze is therefore considered as part of the Sulzauer antiform.

The Habach syncline shows the structure of a true isoclinal syncline like often assumed in literature. The Habachzunge is considered as its associated antiform. The Knappenwand syncline and the Southern Sulzbach Zentralgneis show similar structures. These D_{A1} folds were refolded nearly coaxially creating the Sulzauer antiform. It is supposed that this antiform is identical with the one creating the Ahorn Zentralgneis core and the diving structures of the northern Schönach syncline. Antiformal structures seem to be a common feature of the northern Ältere Schieferhülle and the Zentralgneis cores.

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References

Aignesberger, G.: Die Geologie der Knappenwandmulde im Bereich des Obersulzbachtales und Krimmler Achentales (Bundesland Salzburg/Österreich). Petrographie, Geochemie und Tektonik. – Unveröff. Diplomarbet, Univ. München, 171 S., München 1988.

Behrmann, J.H. & Frisch, W.: Sinistral ductile shearing associated with metamorphic decompression in the Tauern Window, Eastern Alps. – Jb. Geol. B.-A., **133**, 135–146, Wien 1990.

Carl, R.R.B.: Die Geologie der vorderen Hollersbachtal-Westseite (Scharrntal), Bundesland Salzburg/Österreich. Untersuchungen zur Petrologie, Lagerstättenkunde, Isotopengeochemie. – Unveröff. Diplomarbeit, Univ. München, 138 S., München 1988.

Cliff, R.A.: Prealpine history of the Pennine Zone in the Tauern Window, Austria: U-Pb and Rb-Sr geochronology. – Contrib. Mineral. Petrol., **77**, 262–266, Berlin 1981.

Cornelius, H.P.: Beobachtungen am Nordostende der Habachzunge. – Ber. R.-A. Bodenf., 25–33, Wien 1944.

Dietrich, M.: Geologische, petrographische und geochemische Untersuchungen an der Westflanke des vorderen Habachtales (Mittlere Hohe Tauern, Bundesland Salzburg/Österreich). – Unveröff. Diplomarbeit, Univ. München, 99 S., München 1985.

Frasl, G. & Frank, W.: Einführung in die Geologie und Petrographie des Penninikums im Tauernfenster. – Der Aufschluß, Sonderheft **15**, 30–58, 1966.

Frasl, G.: Die beiden Sulzbachzungen (Oberpinzgau/Salzburg). – Jb. Geol. B.-A., **96**, 143–193, Wien 1953.

Frasl, G.: Zur Seriengliederung der Schieferhülle in den Mittleren Hohen Tauern. – Jb. Geol. B.-A., **101**, 323–472, Wien 1958.

Frisch, W.: Der alpidische Internbau der Venedigerdecke im westlichen Tauernfenster (Ostalpen). – N. Jb. Geol. Paläont. Mitt. Mh., **11**, 675–696, Stuttgart 1977..

Frisch, W.: Tectonics of the western Tauern Window. – Mitt. österr. geol. Ges., **71/72**, 65–71, Wien 1980.

Gnielinski, F.v.: Petrographische, geochemische und tektonische Untersuchungen im Dreieck "Hollersbach – Wenns/Bramberg – Mahdleitengipfel" im Pinzgau, Land Salzburg, Österreich. – Unveröff. Diplomarbeit, Univ. München, 224 S., München 1989.

Grundmann, G.: Die Genese der regionalmetamorphen, metasomatisch-horizontgebundenen Beryll-Mineralisation des Habachtales. Land Salzburg, Österreich. – Diss. TU Berlin, 207 S., Berlin 1983.

Hedberg, H.D.: International stratigraphic guide. – John Wiley & Sons, 200 S., New York 1976.

Höck, V. & Pestal. G.: Exkursion E4: Habachformation, Altkristallin im Habachtal und Felbertal. – Mitt. österr. Min Ges., **135**, 129–137, Wien 1990.

Höll, R. & Schenk, P.: Metamorphosed hydrothermal eruption breccia (conglomerate) in the Felbertal scheelite deposit, Eastern Alps, Austria. – Marine Geol., **84**, 273–282, Amsterdam 1988.

Karl, F.: Aufnahmen 1953 auf Blatt Krimml (151). – Verh. Geol. B.-A., 48–51, Wien 1954.

Koller, F. & Richter, W.: Die Metarodingite der Habachformation, Hohe Tauern (Österreich). – Tschermaks Min. Pet. Mitt., **33**, 49–66, Wien 1984.

Lammerer, B.: Das Autochthon im westlichen Tauernfenster. – Jb. Geol. B.-A., **112**, 153–195, Wien 1986.

Lammerer, B.: Thrust-regime and transpression tectonics in the Tauern Window (Eastern Alps). – Geol. Rundschau, **77**/1, 143–156, Stuttgart 1988.

Laure, G.: Die Geologie des äußeren Habachtales. Petrographische, geochemische und tektonische Untersuchungen an Gesteinen nördlich der Habachgneiszunge. – Unveröff. Diplomarbeit, Univ. München, 204 S., München 1985.

Miller, H., Ledoux, H., Brinkmeier, I. & Beil, F.: Der Nordwestrand des Tauernfensters – Stratigraphische Zusammenhänge und tektonische Grenzen. – Z. dt. geol. Ges., **135**, 627–644, 1984.

Ramsay, J.G. & Huber, M.I.: The techniques of modern structural geology. Volume 2: Folds and fractures. – 309–700, Academic Press, London 1987.

REITZ, E. & HÖLL, R.: Jungproterozoische Mikrofossilien aus der Habachformation in den mittleren Hohen Tauern und dem nordostbayerischen Grundgebirge. – Jb. Geol. B.-A. Wien, **131**/2, 329–340, Wien 1988.

REITZ, E., DANECK, T. & MILLER, H.: Ein Nachweis jungproterozoischen Alters von Schwarzphylliten am Tauern-Nordrand (Salzburg, Österreich) und seine Bedeutung für den Bau der Hohen Tauern. – Jb. Geol. B.-A. Wien, **132**, 751–760, Wien 1989.

SCHARBERT, H.G.: Die Grüngesteine der Großvenediger-Nordseite (Oberpinzgau, Salzburg), I. – Sitzungsber. d. math.-naturw. Kl., Abt.I, **166**/7, 307 – 330, Wien 1956.

SCHENK, P.: Mikrothermometrische, gefügekundliche und geochemische Untersuchungen zur Genese der Scheelitlagerstätte Felbertal/Ostalpen. – Münchner Geol. Hefte, **1**, 198 S., München 1990.

SCHENK, P. & HÖLL, R.: Metamorphe hydrothermale Eruptionsbrekzien in der Scheelitlagerstätte Felbertal/Ostalpen (Österreich). – Mitt. österr. geol. Ges., **81**, 93–107, Wien 1989.

SEEMANN, R. & KOLLER, F.: Petrographic and geochemical investigations in the Knappenwand area, Habach formation (Tauern Window, Austria). – Mitt. österr. geol. Ges., **81**, 109–122, Wien 1989.

SENGL, F.: Geologie und Tektonik der Schönachmulde (Zillertaler Alpen, Tirol). – Unveröff. Diss. Univ. München, 183 S., München 1991.

STEYRER, H.P.: Geochemie, Petrographie und Geologie der Habachformation im Originalgebiet zwischen äußerem Habachtal und Untersulzbachtal (Pinzgau, Salzburg). – Unveröff. Diss. Univ. Salzburg, 178 S., Salzburg 1982.

STEYRER, H.P.: Die Habachformation der Typlokalität zwischen äußerem Habachtal und Untersulzbachtal (Pinzgau, Salzburg). – Mitt. Österr. Geol. Ges., **76**, 69 – 100, Wien 1983.

STEYRER, H.P. & HÖCK, V.: Geochemistry of the metabasites in the Habach Formation (Salzburg, Hohe Tauern, Austria): A preliminary report. – Ofioliti, **10**, 441–455, Bologna 1985.

TOEPEL, R.: Die Geologie am Westende der Habachmulde. Petrographische, geochemische und tektonische Untersuchungen im Seebachkar und Foiskar. – Unveröff. Diplomarbeit, Univ. München, 166 S., München 1988.

VAVRA, G.: Die Entwicklung des penninischen Grundgebirges im östlichen und zentralen Tauernfenster der Ostalpen. Geochemie, Zirkonmorphologie, U/Pb-Radiometrie. – Diss. Univ. Tübingen, 149 S., Tübingen 1989.

VAVRA, G. & HANSEN, B.T.: Cathodoluminescence studies and U/Pb-dating of zircons in pre-Mesozoic gneisses of the Tauern Window: implications for the Penninic basement evolution. – Geol. Rdsch., **80**, 703–715, Stuttgart 1991.

WEGER, M. & LAMMERER, B.: Oligocene–Miocene ductile east-west extension of the Variscan Basement of the Western Tauern Window, Eastern Alps. – Terra Nova Abstr. Suppl. 2 to Terra Nova **4**, 70–71, 1992.

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