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The "Hochfeiler Duplex" – Imbrication Tectonics in the SW Tauern Window

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With 17 Text-Figures and 1 Table

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Südtirol
Zillertaler Alpen
Tauern Window
Zentralgneis
Glockner Nappe
Thrust Fault
Duplex
Allanite

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Der „Hochfeiler-Duplex" – Imbrikationstektonik im südwestlichen Tauernfenster

Zusammenfassung

Die Gegend um den Hochfeiler, Zillertaler Alpen, im süd-westlichen Tauernfenster, wurde mit lithostratigraphisch – strukturgeologischen Methoden untersucht. Stark deformierte Sedimente und orthogene Gesteine sind zwischen dem hier geologisch tiefsten Stockwerk des Tauernfensters, dem Zillertaler Zentralgneiskern, und der penninischen Glocknerdecke eingearbeitet worden.

Kartierungen im Maßstab 1 : 10.000 zeigen, daß Gesteine, die früher als Metasedimente eingestuft wurden, den variszischen Zentralgneisen zuzuordnen sind, was zu einem neuen Strukturmodell für das Hochfeilergebiet führt. Eine früh-alpidisch angelegte Duplexstruktur, bestehend aus Zentralgneis-Lamellen und Metasedimenten über dem Zentralgneiskern wurde bei ansteigender Metamorphose stark oblat deformiert. Anschließend erfuhr das gesamte Gebiet einschließlich des Zentralgneiskerns eine langwellige Großfaltung bei prolater duktiler Deformation mit Ost-West orientierten Extensionsachsen. Vorher angelegte Mikrostrukturen wurden dabei weitestgehend ausgelöscht.

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Abstract

A structural and lithostratigraphic study was carried out in the area around the Hochfeiler, Zillertal Alps, southwestern Tauern Window. Strongly deformed sedimentary and orthogenic rocks are sandwiched between the lowermost basement of the Western Tauern Window, the Variscan granitoids of the Zillertal Zentralgneis Core, and the Penninic Glockner Nappe.

Mapping in 1 : 10.000 scale has shown, that some rocks, previously thought to be of sedimentary origin, in fact belong to the Variscan Zentralgneis. This leads to a new structural model of an early Alpine duplex structure with Zentralgneis- and metasedimentary horses. The duplex above the Zillertal Zentralgneis Core suffered ductile oblate deformation during increasing metamorphic conditions. The whole Hochfeiler area including the Zillertal Zentralgneis experienced later large scale upright folding combined with ductile east-west extension. Early microstructures have been overprinted extensively due to following events.

1. Introduction

The Hochfeiler (3510 m), highest peak of the Zillertal Alps, is located at the Austrian/Italian border 30 km east of the Brenner Pass. Here, in the south-western part of the Tauernwindow, Variscan granitoids affected by Alpine deformation, called "Zentralgneis", crop out in two large anticlines plunging to the west (Fig. 1).

The southern Anticline with the Zillertal Zentralgneis in its core is followed to the north by a complex synform, the Greiner Syncline, and the Tux Zentralgneis Anticline. Prevariscan as well as Postvariscan units form the cover of the Zentralgneis. The Prevariscan units mainly consist of amphibolites and graphitic ("Furtschagl"-)schists of Precambrian or Lower Paleozoic age. The Postvariscan sequence transgresses with Permian (?) conglomerates grading into finer clastic and finally mature quartzites, again overlain by cargneules and marbles (Triassic), quartzites and marbles (Hochstegen Marble, Jurassic) and Lower Cretaceous calcareous micaschists (calc mica schists) and clastics (Kaserer Serie; THIELE, 1970; LAMMERER, 1986).

This sequence with Helvetic affinities is overthrusted by a Penninic ophiolite nappe system ("Glockner Nappe") with a km thick pile of thrust sheets mainly consisting of metabasalts and calc mica schists. The entire Tauern Window is on its rim overlain by the East-Alpine Nappes. Stacking of nappes in the Cretaceous led to Eoalpine high

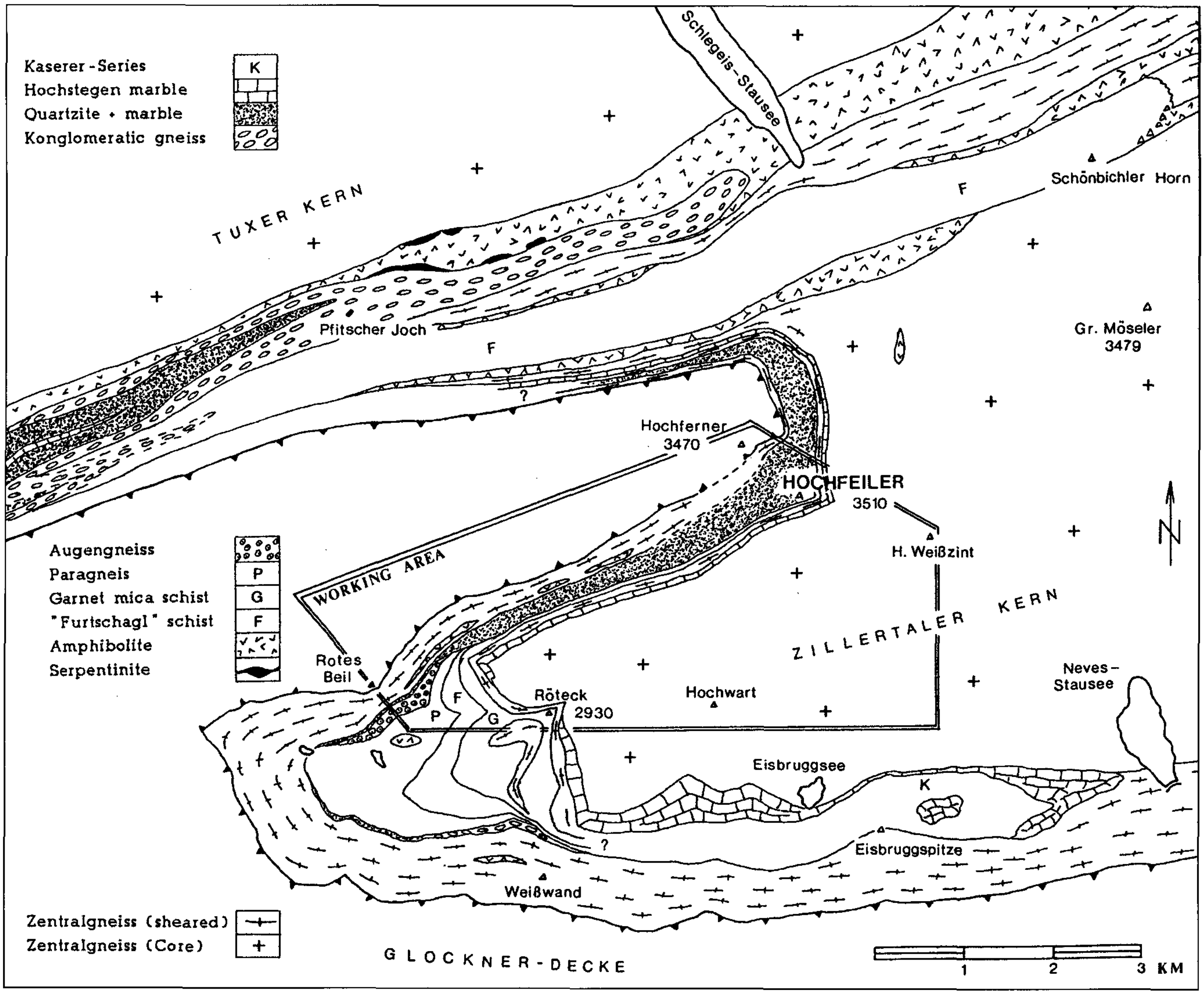


Fig. 1.
Tectonic map of the southwestern Tauern Window, showing the location of the working area.

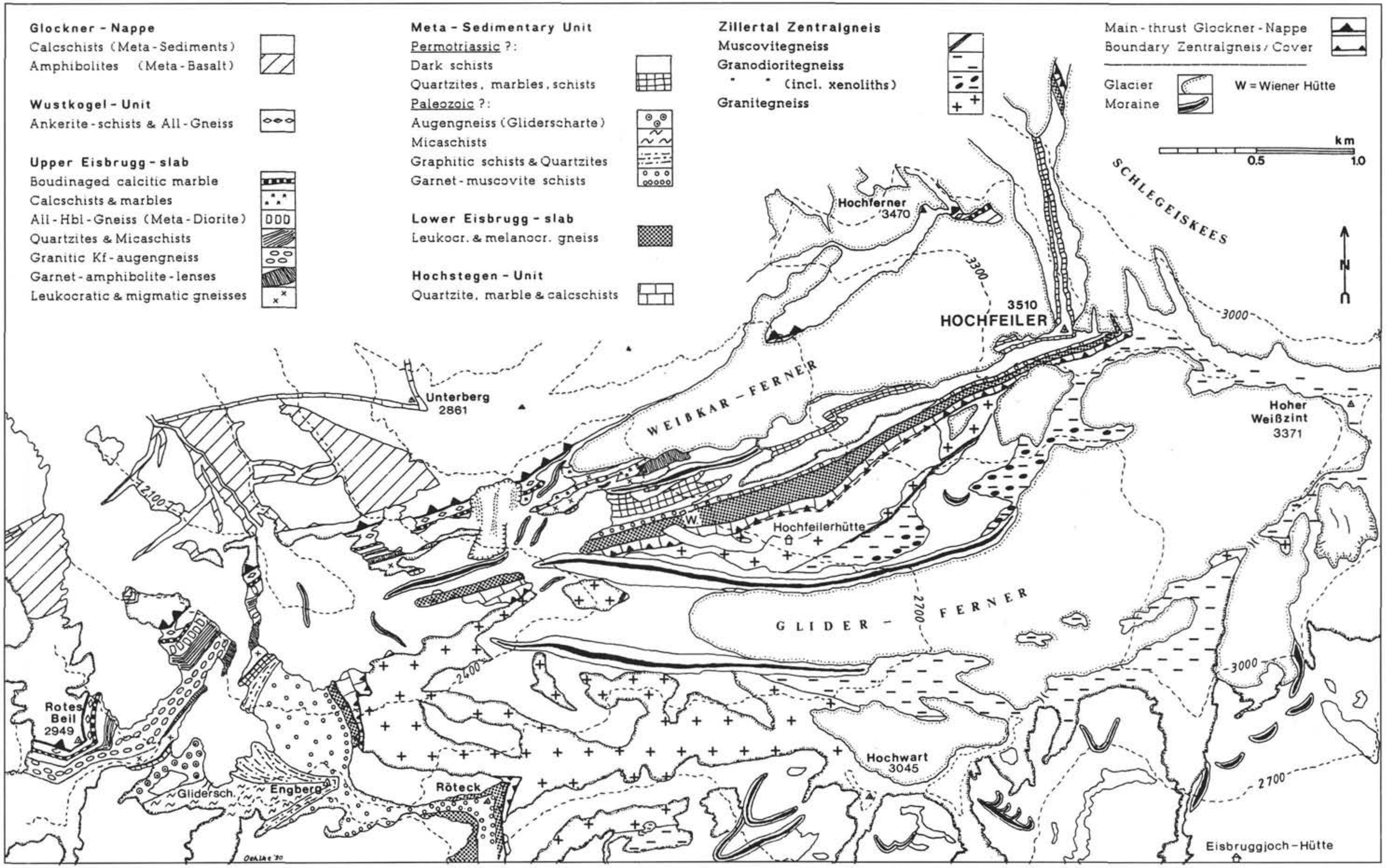


Fig. 2.
Geological map of the Hochfeiler massif.

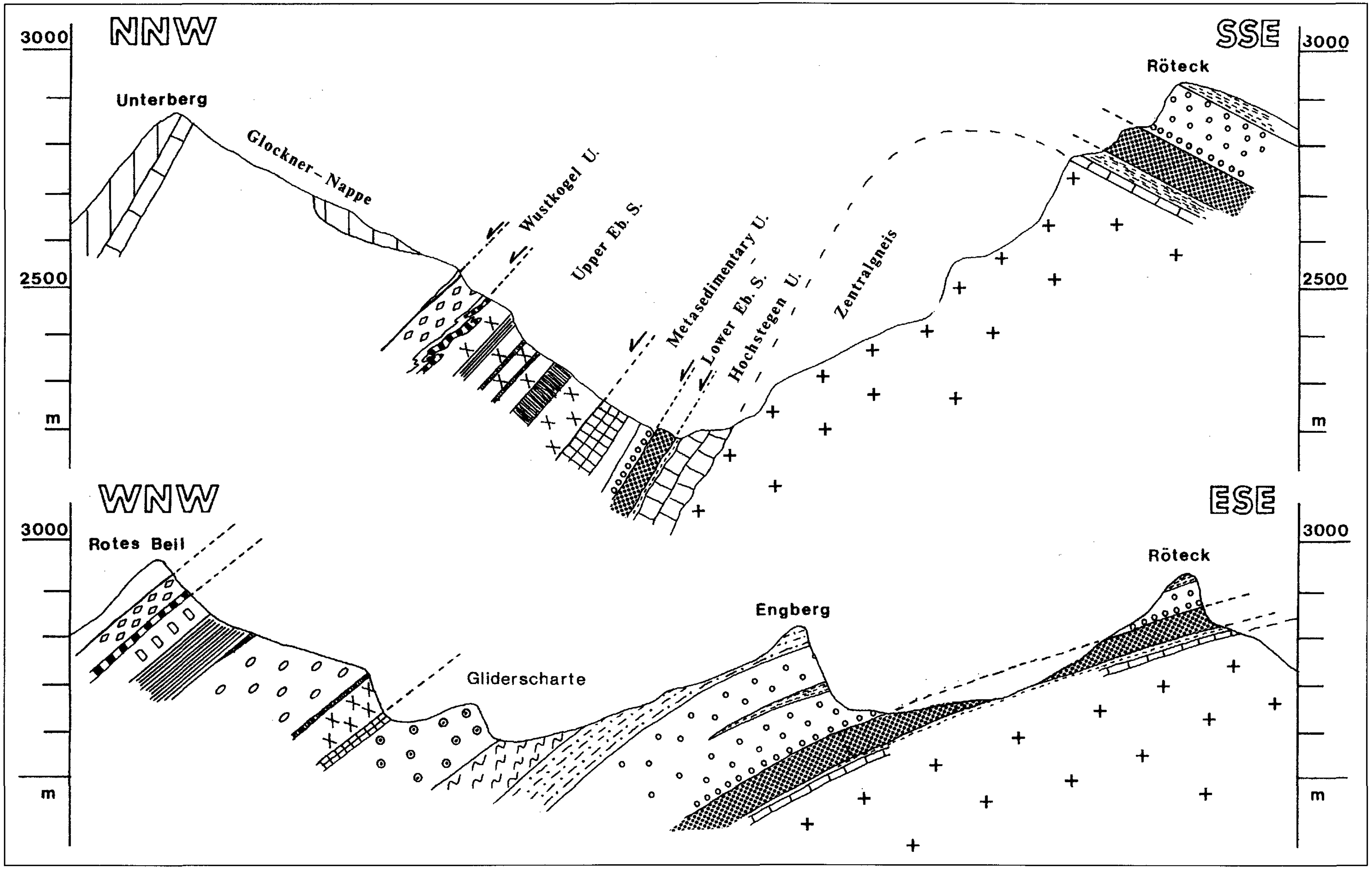


Fig. 3.
Cross-sections (A,B) through the Unterberg-valley (horizontal equals vertical scale; symbols same as in Fig. 2).
A: NNW–SSE section Unterberg–Röteck (central part of the valley); B : WNW–ESE section Rotes Beil–Röteck (southern crest).

high pressure/low temperature conditions (FRY, 1973) followed by amphibolite-facies metamorphism after maximal burial ("Tauernkristallisation" sensu SANDER, 1911, 1912, 1920; SELVERSTONE, 1985; DE VECCHI & MEZZACASA, 1986).

The early works of SANDER (1911, 1912, 1920) resulted in first large scale geologic maps of the area. SANDER (1911) already described an orthogenic gneiss slab overlying the southern margin of the Zillertal Zentralgneis Core (later called "Eisbrugg-Lamelle", LAMMERER et al. 1981). Following workers (LAMMERER et al., 1976; FRISCH, 1977) interpreted most of the sequence between basement and Glockner Nappe west of the Hochfeiler as being part of the "Kaserer Serie", whereas DE VECCHI & BAGGIO (1982) alternatively described orthogenic slices in Permian (?) arcosic gneisses.

Structural interpretations of the area (LAMMERER et al., 1976; FRISCH, 1977; TOLLMANN, 1977; DE VECCHI & BAGGIO, 1982; LAMMERER, 1988; LAMMERER & MORTEANI, 1990) differ substantially from author to author because of the lack of stratigraphic benchmarks. The newly built Hochfeiler Hütte (1986, at 2710 m above sea level) gave opportunity to examine the area in detail including mapping of the Unterbergtal south of the Hochfeiler in 1 : 10.000 scale (Fig. 2). Based on further detailed petrographic and structural analyses along cross-sections and in the whole area we try to deduce an explanation for the extremely differentiated sequence. The aim of this paper is to reconstruct the Eoalpine history of the area. Therefore detailed mesoscopic and microscopic descriptions of the important rock units are neccessary to work out the probable age and nature of the different units.

We are aware of the fact, that the Eoalpine features of the rocks are extensively overprinted by strong ductile deformation, but nevertheless many primary characteristics of the rock units can be recognized.

Another point to clearify is the fact, that a secondary recrystallization has affected most primary microscopic structures, e.g. small grainsize due to mylonitization processes, so that the term "mylonite" in the sense we use it here means a primarily strongly sheared horizon, at which relatively large movements must have occured. This is evident by stronger foliation than in the host rock, which often still shows coarser grainsize. That these horizons mostly occur at the border between metasedimentary and metaorthogenic rocks gives another clue.

Some minerals have been determined by powder-diffraction analysis and selected gneiss samples have been analyzed geochemically for main elements using AAS (Philips SP9–600 at Mineralogisches Institut der Universität Hannover).

2. Geological Setting

The Zillertal Zentralgneis Core crops out in the southeastern part of the Unterberg-valley, building most of the southern crest, wheras the northern flank is made up of the thrust sheets of the Glockner Nappe (Fig. 2). The especially interesting interlayered sequence is exposed on the southwestern ridge of Hochfeiler, which divides the valley in two glacier covered troughs (Fig. 4). The thickness of this sequence increases towards southwest to the Gliderscharte (Fig. 3).

The Zentralgneis is overlain by a massive marble passing upwards into carbonaceous clastics. A thrust fault separates these clastics from mylonitic granitoids, the Lower Eisbrugg Slab. On top of this slab, again with tectonic contact, a metasedimentary unit of possibly Paleozoic and Triassic age follows. Thrusted onto these slabs is the Upper Eisbrugg Slab, made up of Variscan metagranitoids, metamigmatites and large lenses of Prevariscan amphibolites, overlain by calc mica schists and marbles. The partly boudinaged marbles form a thrust fault contact to the next unit, the Permian Wustkogel Series, which finally builds the base of the Glockner Nappe.

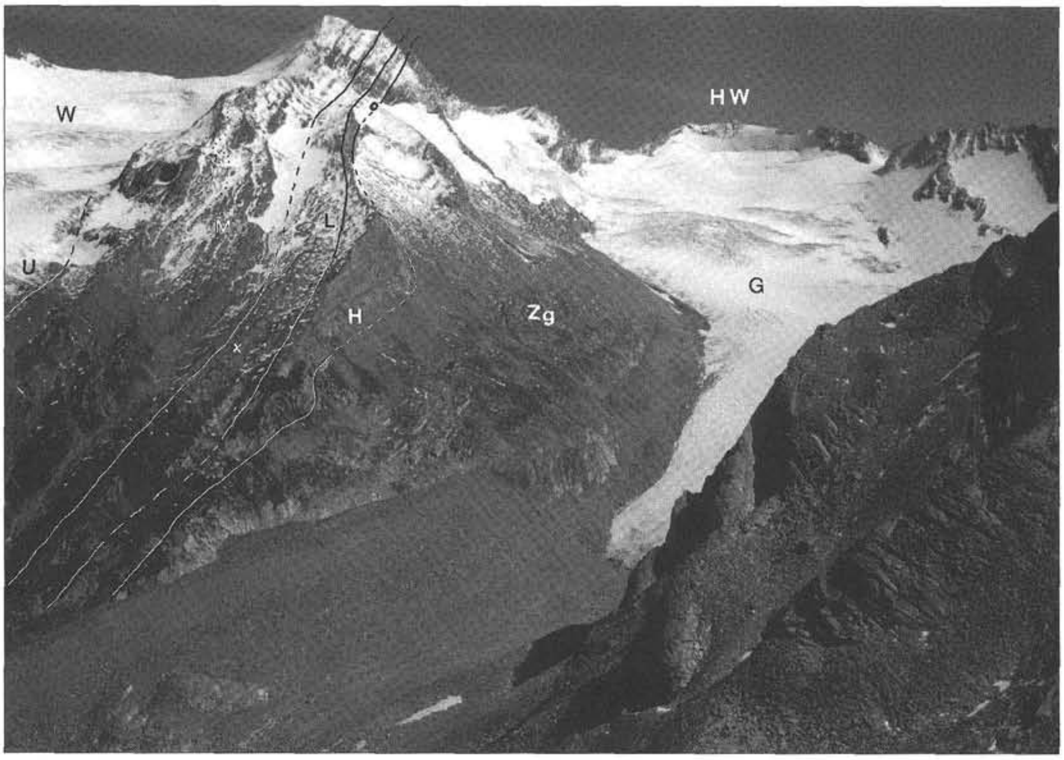


Fig. 4.
View from Röteck to the south-western ridge of Hochfeiler (left).
HW = Hoher Weißzint, W = Weißkarferner, G = Gliderferner, Zg = Zentralgneis, H = Hochstegen-Unit, L = Lower Eisbrugg Slab, M = Metasedimentary Unit, U = Upper Eisbrugg Slab,.
Black circle = Liassic? Quartzite, x = Biotite Schist.

3. Description of Rock Units (Tectono-stratigraphic Order)

3.1. Zillertal Zentralgneis Core

Variscan age metagranitoids (U/Pb intrusion ages of ca. 320 Ma, CLIFF 1981, 1990) form the lowermost structural unit of the working area.

In the west of the working area low deformed leucocratic metagranites dominate. They intrude Variscan metagranodiorites, that now show moderate to strong Alpidic deformation. The metagranodiorites make up the eastern part of the working area.

A third type, a muscovite gneiss, crops out only in small sheets. Aplitic and lamprophyric dykes penetrate the metagranites and metagranodiorites but never Postvariscan sediments.

Only the metagranodiorites often bear mafic enclaves. Characteristic is the biotite content (Table 1) and accessory allanite. Feldspars in the Zentralgneis metagranitoids recrystallize increasingly with deformation to fine grained aggregates, indicating amphibolite facies metamorphism for the deformation (VOLL, 1976; GANDAIS & WILLAIME, 1983). Strong lineation and weak schistosity develop with increasing deformation.

Leucocratic, mainly muscovite bearing quartz-feldspar gneisses occur as thin (m size) sheets only at or near the Variscan intrusion contact between metagranite and metagranodiorite. Strong deformation and medium grain size are characteristic.

Under the microscope (U.m.): Between the muscovite rich layers elongated porphyric quartz lenses can be found. In a matrix of quartz and albite grains isolated porphyroclasts of allanite and twinned plagioclase appear. This is typical for orthogenic gneisses of the area.

An orthogenic protolith is also indicated by major element geochemistry, which shows a tight positive linear correlation of both muscovite gneiss and metagranite for most elements (Fig. 9).

3.2. Hochstegen Unit (Jurassic)

The Hochstegen Unit covers the Zillertal Zentralgneis Core in the whole working area. It consists of only locally occuring basal quartzites overlain by an up to 80 m thick layer of massive marble grading upwards into calc mica schists (Fig. 6).

Basal Quartzite (Liassic ?)

In two small outcrops at the south-western ridge of the Hochfeiler between 3100 m and 3300 m above sea level thin (dm–m range) lenses of quartzites crop out in cores of folds in the contact between the Zillertal Zentralgneis Core and the Hochstegen Unit. Light colored muscovite quartzite layers are overlain by black graphitic quartzites. Locally arcosic layers are enriched in dark rounded K-feldspars. The whole basal quartzite reaches, if present, a thickness of up to 3 meters.

Similar quartzites at the base of the Jurassic Hochstegen marble are considered to be of Liassic age (FRISCH, 1980).

Hochstegen Marble (Upper Jurassic)

The granitoids of the Zillertal Zentralgneis are directly overlain by massive calcitic marbles with a sharp contact. The coarse grained marbles reach a maximum thickness of 80 meters and form a steep cliff above the Hochfeiler Hütte. On the southern flank of the valley the Hochstegen marbles decrease rapidly to a few meters thickness near the summit of the Röteck.

In the valley floor on spectacular glacially polished outcrops a thin (dm range) Fe, Cu, Zn sulfides bearing basal layer occurs. The lower part of the Hochstegen marbles consists of yellow or gray calcitic massive marbles with upwards decreasing quantities of thin dolomitic and quartz rich layers (cherts?).

The upper part consists of monotonous bluish-gray calcite marbles. Near the top of the marbles the mica content increases and the marbles grade into calc mica schists.

Fossils in a corresponding marble at Hochsteg near Mayrhofen in the northwestern Tauern Window yielded Upper Jurassic age (v. KLEBELSBERG, 1940; SCHÖNLAUB et al., 1975).

Calc Mica Schists (Kaserer Series, Lower Cretaceous ?)

The calc mica schists show a constant thickness of about 15 meters, cut off by an extremely sheared horizon.

U.m.: They consist of a micaceous-calcareous matrix with changing amounts of quartz, calcite, dolomite, and minor amounts of plagioclase, muscovite, fuchsite, and epidote. Cm–dm thick lenses of pure yellow calcite or dolomite marble reaching a length of several meters are a characteristic feature.

These calc mica schists overlying the Hochstegen Marbles fit well to descriptions of the lower Kaserer Series with a probably Lower Cretaceous age (THIELE, 1970; FRISCH, 1980; LAMMERER, 1986).

The Liassic (?) Basal Quartzites below Upper Jurassic Marbles with Lower Cretaceous (?) calc mica schists sedimented on top of them imply an upright sequence for the parautochthonous Hochstegen unit.

3.3. Lower Eisbrugg Slab

A slab of orthogneiss of about 50 meters thickness is thrusted on top of the Hochstegen Unit.

The name "Eisbrugg Slab" ("Eisbrugg-Lamelle"), is derived from the "Eisbrugg-Spitze" 2 km south of the working area, where a km-thick slab of moderately deformed metagranitoids is separated tectonically from the Zillertal Zentralgneis Core (WINKLER, 1987). This slab can be traced around the west-plunging end of the Zillertal Anticline into the working area (LAMMERER, 1983). The slab in this sense is identical with the here newly defined Upper Eisbrugg Slab. The observation of a second orthogneiss slab in structurally lower position led to the subdivision into two slabs as described below (Figs. 2,3,4).

Apart from basal mylonites the lower slab contains three main rock types, namely leucocratic orthogneisses, melanocratic gneisses and a boudinaged biotite-schist.

Basal Mylonite

On top of a darker 0.5 m thick horizon with a well developed sigmoidal-shaped fabric, that contains leucocratic lenses, succeed light colored, laminated quartzites sometimes enriched in simple-twinned albitic porphyroblasts. They embody a rotated S-shaped texture indicating synkinematic growth. In total the basal sequence measures less than 2 meters (Fig. 7). This horizon probably developed by intense shearing at a thrust-zone from the leucocratic orthogneisses. Evidence for an orthogenic protolith is given a.o. by the appearance of allanite (OEHLKE & LAMMERER, 1990), which is restricted to leucocratic gneisses in the area.

Table 1.
Selected modal analyses of characteristic (mostly orthogenic) smamples from Zillertal Zentralgneis core and the different Slabs of the Hochfeiler area.
Signs are always the same in the following diagrams.
All data as volume % (rounded); 300 points per count (x = <1 %).
Qz = Quartz; Kf = K'feldspar; Pl = Plagioclase (large, polysynthetic twinned crystals); Ab = Albite (recrystallyzed matrix minerals); Mu = Muscovite; Bi = Biotite; Ch = Chlorite; Gr = Garnet; Ep = Epidote; All = Allanite; Cc = Calcite; Ti = sphene; Z = Zirkon; O = Opake; A = Apatite; T = Tourmaline; R = rutile; Hbl = Hornblende.

1. Zillertal Zentralgneis Core

Granitegneiss ●

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	Gr	Ep	Akz.
OZG 8	36	19	14	15	14	x	1	x	x	Z O
OZG 9	33	25	20	14	4	2	x	x	x	Z O
OZG 10	24	30	27	9	9	x	x	x	x	Z O
OZG 38	29	23	24	12	7	x	3	x	1	Z O
OZG 51	29	26	9	17	11	1	2	x	2	Z O A

Aplite

OZG 39	31	26	15	23	x	1	2	x	2	

Granodioritegneiss ▲

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	All	Cc	Ep	Akz.
WZG 9	29	x	4	31	19	9	-	-	6	1	Z O A R
WZG 14	39	6	7	24	x	18	x	x	-	5	Z O A R
WZG 19	25	5	2	34	3	22	x	x	x	9	Z O A R
WZG 26	21	16	6	41	6	8	x	-	1	1	Z O A R

Muscovitegneiss ◩

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	All	Cc	Akz.
OZG 40	35	-	2	24	35	-	x	x	2	Z - A
WZG 16	32	2	7	18	37	1	x	x	2	Z - A

2. Lower Eisbrugg Slab (Untere Eisbrugglamelle)

Leucocratic Gneiss ○

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	All	Ep	Cc	Akz.
O-04	29	21	9	18	20	3	x	x	x	x	Z O A T
O-27	35	8	x	23	27	2	2	x	x	3	Z O A
O-48	33	13	10	18	27	1	x	-	x	-	Z O A
O-79	30	16	7	22	23	1	1	-	x	x	Z O A
O-99	31	24	4	22	16	-	1	x	x	x	Z O A

Melanocratic Gneiss △

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	Gr	Ep	Akz.
O-45	24	-	10	23	-	37	x	x	3	- O A

Biotite - schist (Lamprophyric dike)

Sample No.	Qz	Ab	Bi	Mu	Ch	Cc	Ti	Ap	Akz.
O-53	4	25	46	20	1	2	2	x	Ep

3. Upper Eisbrugg Slab (Obere Eisbrugglamelle)

Granitegneiss ◎

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	Gr	Ep	Akz.
O-77	33	26	-	22	7	12	1	x	2	Z - A R

Allanite - Hornblende - Gneiss (Meta-Diorite) ✳

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	Gr	Ep	All	Hbl	Akz.
O-31	32	-	-	27	3	26	1	x	6	1	4	Z O A Ti

4. Wustkogel-Unit (Base Glockner-Nappe)

Allanite - K´feldspar - Gneiss ◆

Sample No.	Qz	Kf	Pl	Ab	Mu	Bi	Ch	All	Cc	Akz.
O-44	27	11	-	11	50	-	x	x	x	Z O A
O-67	28	14	-	17	37	3	x	x	x	Z O A
O-85	29	16	-	17	36	1	x	x	x	Z O A

Fig. 6.
Schematic profile through Zentralgneis- and Hochstegen Unit (not to scale, located at SW-ridge of Hochfeiler about 3.100 m.
Projection nets: + = poles to foliation, o = mineral lineation, black circles = fold axes; Schmidt-net, lower hemisphere.

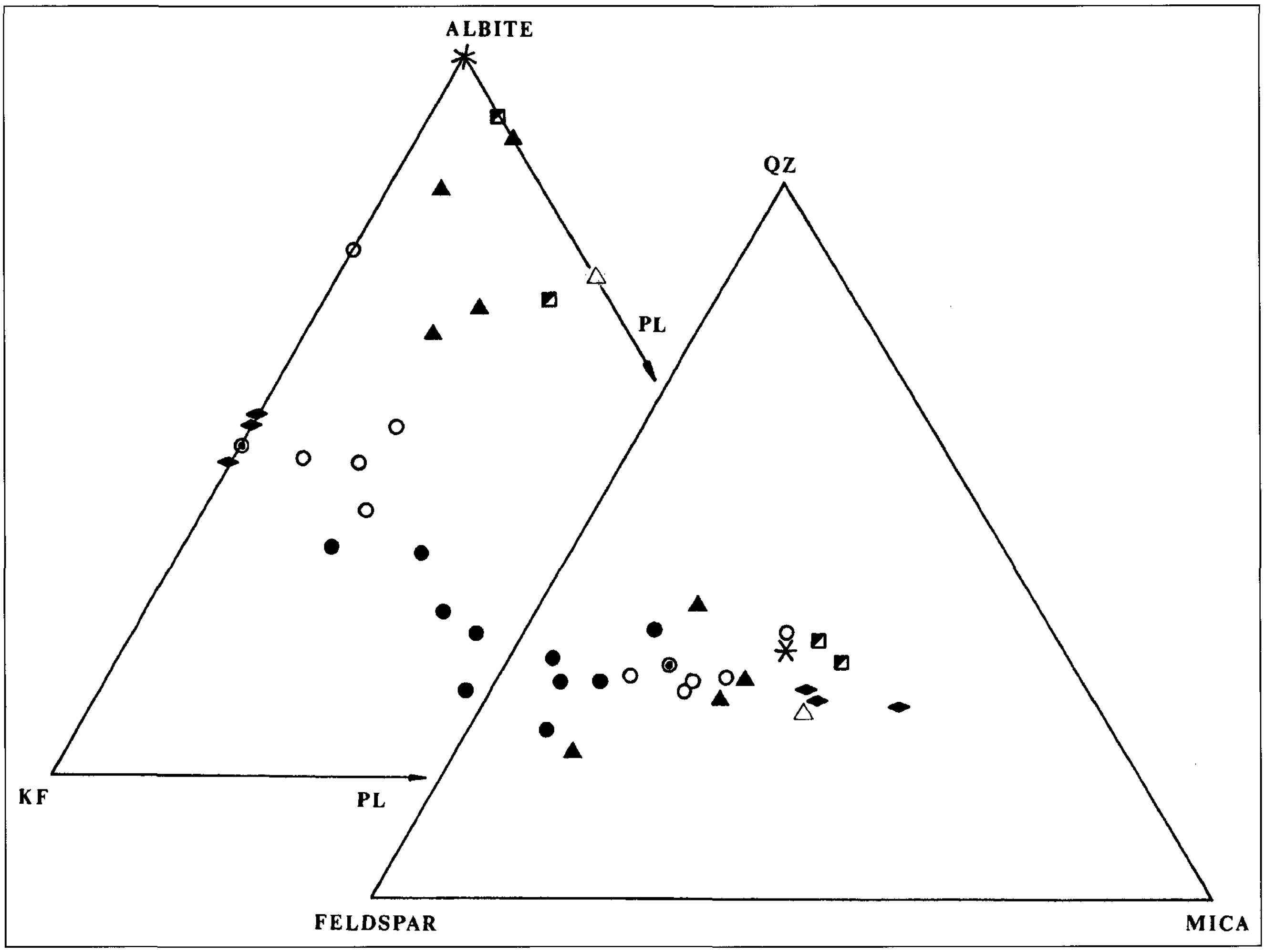


Fig. 5.
Ternary diagrams of modal composition of orthogenic rocks from the Unterberg-valley (Albite – K-Feldspar – Plagioclase; Quartz – Feldspar (total) – Mica (total)).
Symbols see Table 1).

Leucocratic Mylonitic Orthogneisses

Leucocratic orthogneisses predominate in the main part of the Lower Eisbrugg Slab. They are of uniform composition and distinctly finer grained than the less deformed Zentralgneis of the Zillertal Core (Table I, Fig. 5).

U.m.: Larger, presumably magmatic plagioclase porphyroclasts occur as well as recrystallized millimeter-thin/decimeter-long lenses composed of fine grained neoblasts of albite, K-feldspar and quartz. Thin intercalations of mica are mostly formed of phengitic muscovite. Allanite, which is finer-grained and without alteration rim as e.g. in the metagranodiorites, appears as characteristic accessory mineral. The small grainsize and the lack of any sign of metamictization or an secondary alteration rim seems to support a metamorphic recrystallization.

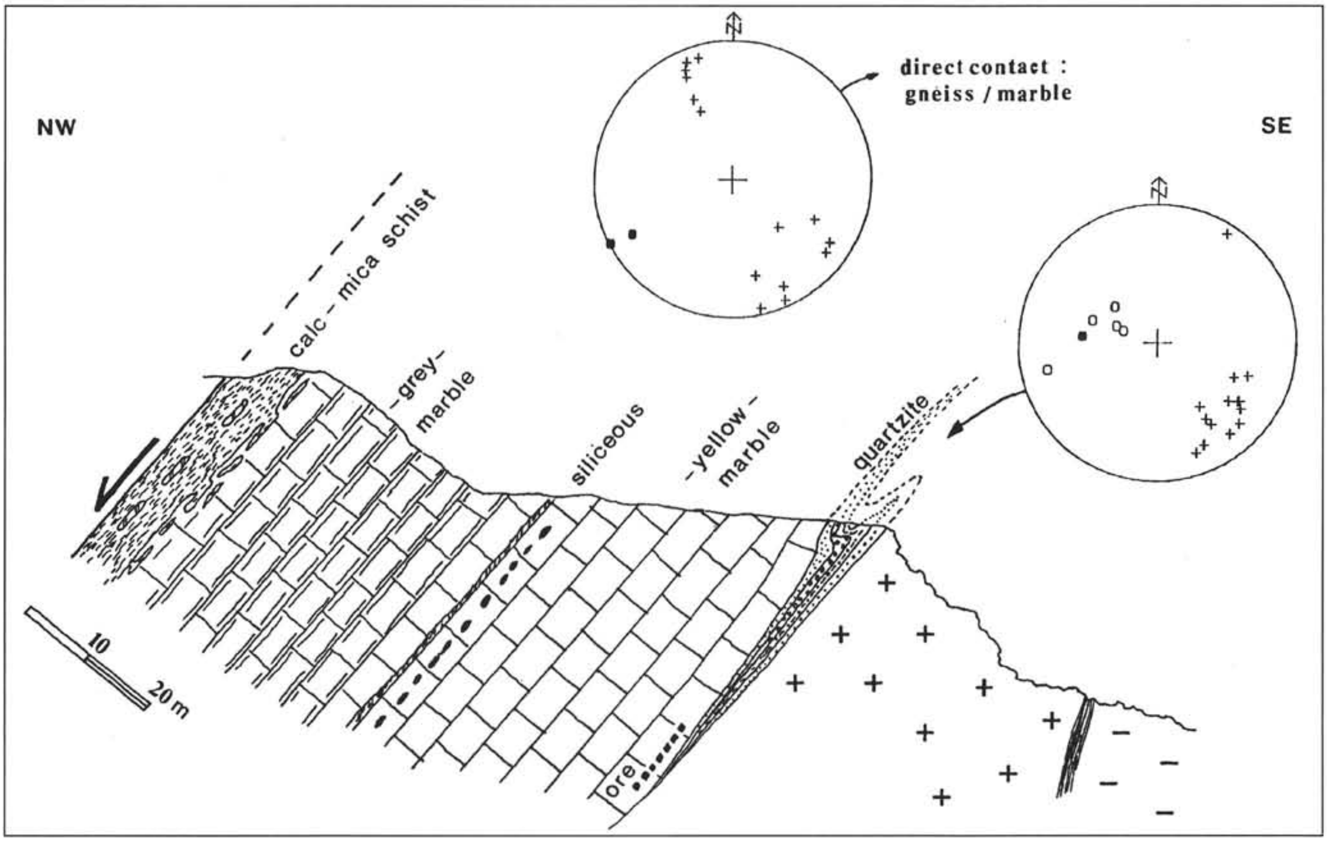
Strong oblate deformation otherwise erased primary magmatic features. In the upper meters of the unit an increasing number of small garnets (mm range) have grown in the leucocratic orthogneisses. Near the top-boundary they reach diameters of up to 2 cm. Major element analysis supports the derivation of the leucocratic gneisses from granitic gneisses of the Zentralgneis Core despite of the penetrative mylonitization. This is expressed especially in the Na_2O/K_2O-diagram and other element/element correlation plots (Fig. 9).

So far, the occurence of typical magmatic allanite is thought to be an indicator for the origin of some gneisses (EXNER, 1966; OEHLKE & LAMMERER, 1990), which gives supplementary arguments on the protolith.

Biotite Schist

300 meters ENE beside the ruins of the "Alte Wiener Hütte" near the footpath to the Hochfeiler peak a dark boudinaged biotite schist cuts the leucocratic orthogneisses (thickness 0.2 m, Fig. 8).

Fig. 7.
Schematic profile through Lower Eisbrugg Slab.
Not to scale, located above ruins of Wiener Hütte about 2.700 m, projection nets see Fig. 6.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direct contact : gneiss / marble
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-yellow-marble
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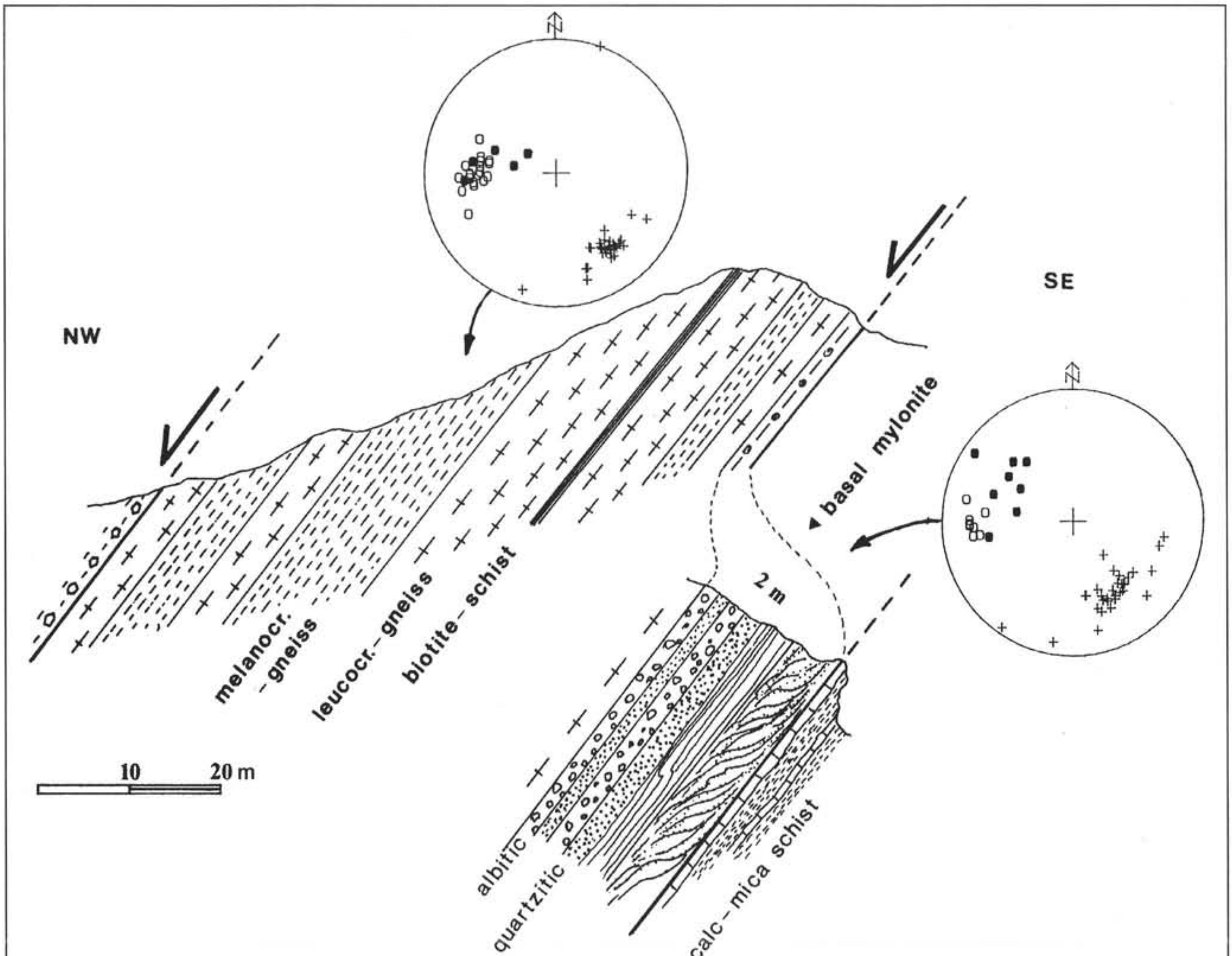
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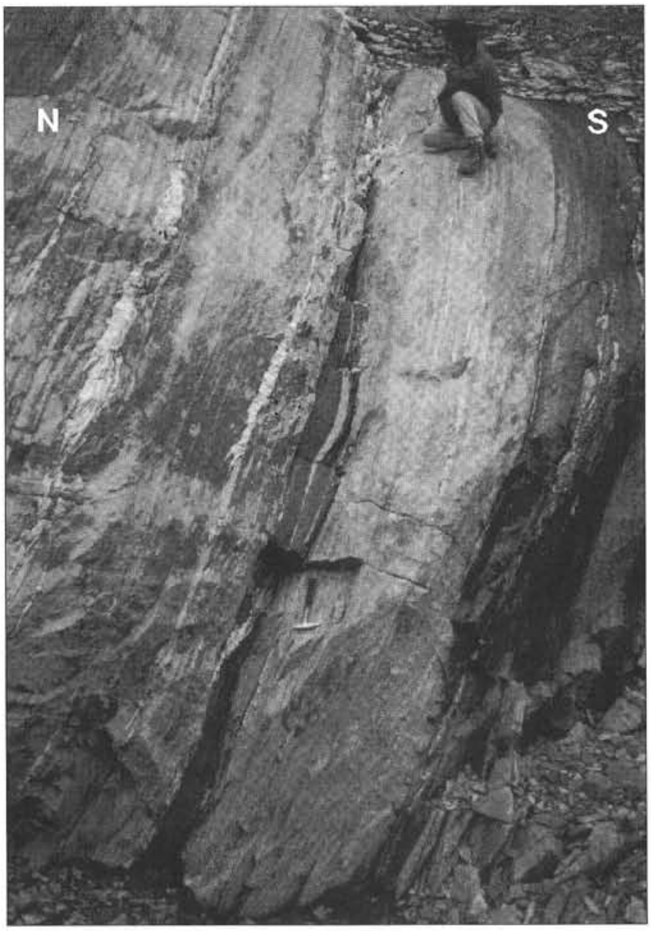


Fig. 8.
Boudinaged Biotite Schist within leucocratic orthogneisses of the Lower Eisbrugg Slab.
Location near ruins of Wiener Hütte, M. WEGER for scale.

U.m.: It is mainly composed of biotite, albite, and muscovite with minor amounts of quartz, calcite, titanite, epidote, and apatite (Tab. I). The albite shows a slightly curved internal structure and a newly grown rim.

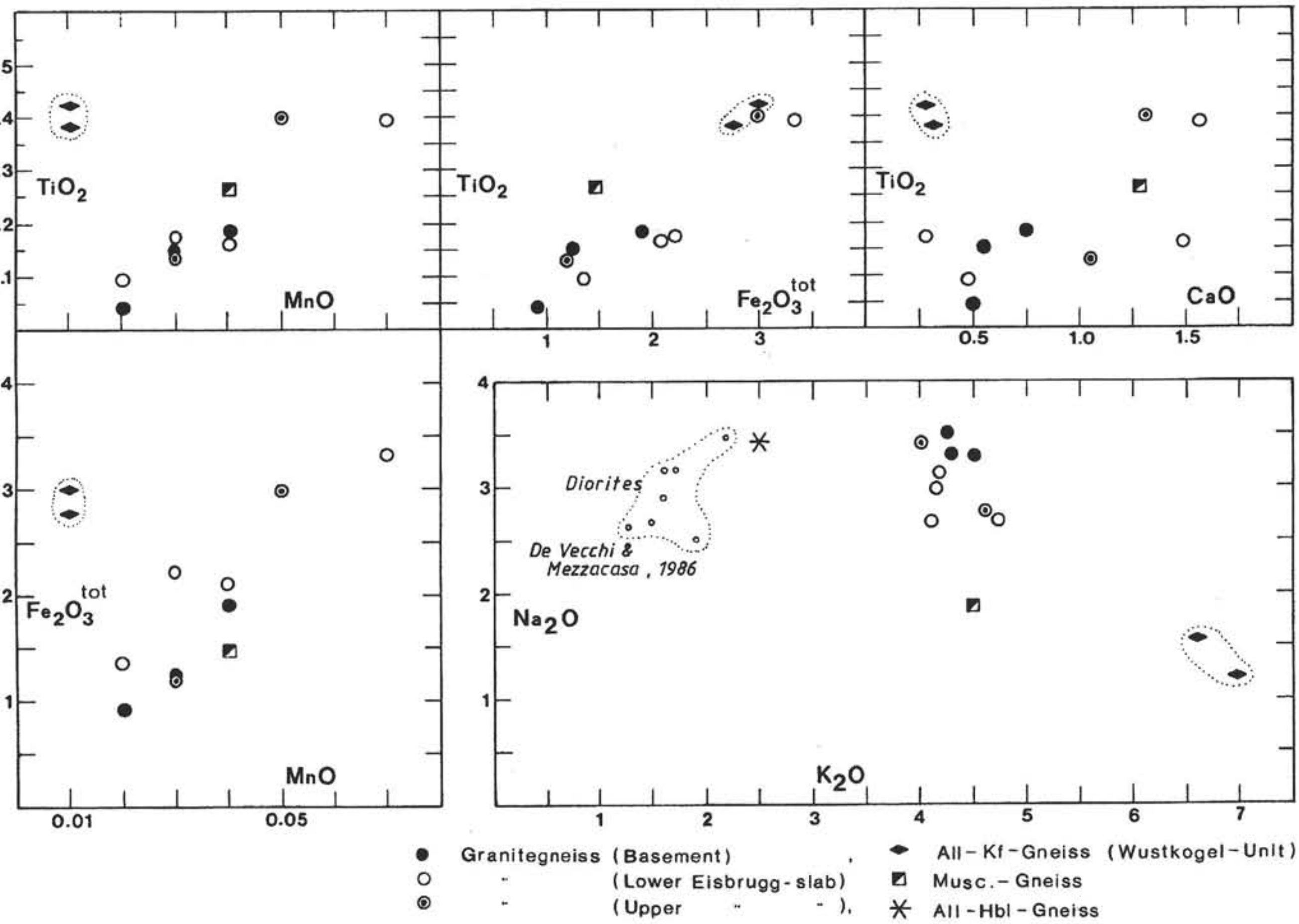
The modal and chemical composition (especially a high K_2O (8.02 wt %) and TiO_2 (1.55 wt %) content) of the schist resembles that of lamprophyric dykes occuring within less deformed Variscan metagranitoids of the Tauern Window (MORTEANI, 1971) or of lamprophyres of the External Massifs in the Central Swiss Alps (OBERHÄNSLI, 1986, 1987).

Melanocratic Gneiss

Several bands of biotite-rich melanocratic gneisses are interlayered with the leucocratic orthogneisses (Fig. 7). They occur especially in the upper half of the Lower Eisbrugg Slab.

U.m.: Besides green alpidic biotite an older red-brownish Ti-rich biotite appears. Other constituents are quartz, plagioclase, secondary albite and minor epidote, calcite and large apatite grains (0.5 mm).

Fig. 9. ▼
Selected major-element variation diagrams of orthogenic samples from the Unterberg-valley.
Scale in weight %, symbols see Tab. I.



Retrograde Variscan amphibolites, which formed the roof of the granitic plutons could be the protoliths (reaction Mu + Hbl = Bio + Plag + Ep + Q, HOERNES, 1973, p. 97). An alternate possible protolith could be Variscan diorites similar to the outcrops in the upper Neves Valley (DE VECCHI & MEZZACASA, 1986).

Both interpretations support an orthogenic character of the whole slab.

3.4. Metasedimentary Unit (Paleozoic and Triassic?)

Between the two Eisbrugg Slabs a unit consisting of various metasediments with possible Paleozoic and Triassic ages is sandwiched.

3.4.1. Paleozoic Metasediments

Garnet-Mica Schists

Garnet-mica schists build up the main part of the southern flank of the valley between Röteck and Gliderscharte. The thickness of this sequence rapidly decreases towards the valley floor. On the southwestern ridge of the Hochfeiler it reaches only a thickness of 10 to 20 meters (e.g. Alte Wiener Hütte).

The basal garnet-mica schists represent a mylonite zone, which developed from the orthogneisses of the Lower Eisbrugg Slab. The main mineral with up to 2/3 of the rock volume is an almandine-rich garnet (diameter up to 2 cm).

U.m.: S-shaped inclusion trails indicate synkinematic growth. The preserved foliation mainly consists of elongated quartz grains besides some opaque minerals, muscovite, epidote and tourmaline. The upper part of the sequence bears a decreasing amount of smaller garnets. Micas are mostly muscovite. Only in the thicker segment on the southern flank of the valley large single flakes of Ti-rich red biotite occur.

At the top of Röteck a thin layer of orange weathering graphite-phyllite with high amounts of rutile crops out, which divides the garnet-mica schists into two limbs (Fig. 3 b).

Graphitic Garnet-Mica Schists and K-Feldspar Augengneiss

The coarse grained garnet-mica schists are overlain by an alternating series of fine grained black graphitic mica schists and orange weathering quartzites (N-face of Engberg). A very similar sequence occurs in the Greiner Series, the "Furtschagl Schists", Paleozoic or older deep-sea sediments (LAMMERER et al., 1976). The relative age is evident by the intrusion of Variscan granitoids at Schönbichler Horn. Between these Paleozoic and the overlying Triassic metasediments an augengneiss occurs in the Gliderscharte. This K-feldspar augengneiss builds up the turret in the middle of the Gliderscharte (Fig. 13) and contains cm-sized white K-feldspars in a fine-grained dark matrix. Magmatic origin of this augengneiss seems evident by penetration with aplitic dykes.

3.4.2. Marbles, Quartzites, and Micaschists (Triassic ?)

A series of quartzites, marbles and micaschists occurs a few meters wide at the western margin of the Gliderscharte and considerably thickens to the summit of Hochfeiler. The milky-white, up to 0.5 meters thick quartzites consist almost entirely of quartz occasionally enriched in muscovite. Heavy minerals like zirkon, apatite, epidote and ores, typical for mature sediments, occur.

Boudinaged layers of fine grained and pure dolomitic marbles (white-grey) overlie muscovite bearing calcitic marbles (yellow). Ocre-coloured marbles which are characterized by nodular or cellular textures, probably indicate a lagoonal environment of sediment formation. Near the base of the sequence thin layers of rusty weathering greenish chloritoid schists appear possibly derived from coloured clays, which are characteristic Keuper sediments of the Helvetic chain in the Western Alps (FREY, 1969).

As described by FRASL (1958), FRISCH (1980) and LAMMERER (1986), such an association of marbles, quartzites and chloritoid schists is typical for Triassic metasediments in the Tauern-Window. Keuper metasediments at the base of the sequence imply, that it is at least partially overturned. Marble outcrops, similar in association and tectonic position near the Wolfendorn, yielded Anisian age (FRISCH, 1975). Isoclinal recumbent as well as gentle folds in the marbles and quartzites are excellently emphasized by lithological contrasts.

3.5. Upper Eisbrugg Slab

The Upper Eisbrugg Slab is divided from the underlying metasediments by a basal mylonite similar to that of the Lower Eisbrugg Slab. The total thickness is distinctly higher than in the lower slab (350 – 150 meters, thinning to the north-east). It consists of acidic to intermediate orthogneisses and migmatites including lenses of garnet amphibolites which sometimes are bordered by a thin, light-coloured, yellow dolomitic layer.

Basal Mylonite

The base of the Upper Eisbrugg Unit is characterized by strongly laminated and folded aplitic and leucocratic gneisses (Fig. 11).

U.m.: The leucocratic gneisses contain recrystallised allanite without any alteration rim (see 3.3.) and rarely preserved ribbon-like quartz grains surrounded by finer grained quartz neoblasts. This demonstrates strong grain flattening by plastic deformation followed by (primary and) secondary recrystallisation (Fig. 12).

As in the Lower Eisbrugg Slab a massive layer (1–2 meters) mostly consisting of porphyroblastic albite with internally rotated textures appear above the basal mylonite in this thrust zone (Fig. 10). In addition to allanite opaque minerals occur in this "albitite". Blastesis of this amount of albite requires metasomatic matter-exchange by fluid mass transport, which could be due to the development of the thrust-zone.

Orthogneisses

Migmatic gneisses in the northeastern part of the valley grade into dioritic and granitic orthogneisses, the latter enclosing thumb-nail sized K-feldspar porphyroclasts and cut by abundant aplitic dykes, which are sheared and boudinaged. The modal (Tab. I, Fig. 5) and chemical composition (Fig. 9) of the metagranite is very similar those from the Zillertal Zentralgneis Core, but they are enriched in biotite.

A darker, strongly flattened variety of the orthogneisses contains large amounts of biotite and epidote as well as small tschermakitic hornblende needles and accessory porphyric allanite enclosed by an alteration-rim (Allanite – Hornblende gneisses). Chemical analysis shows dioritic

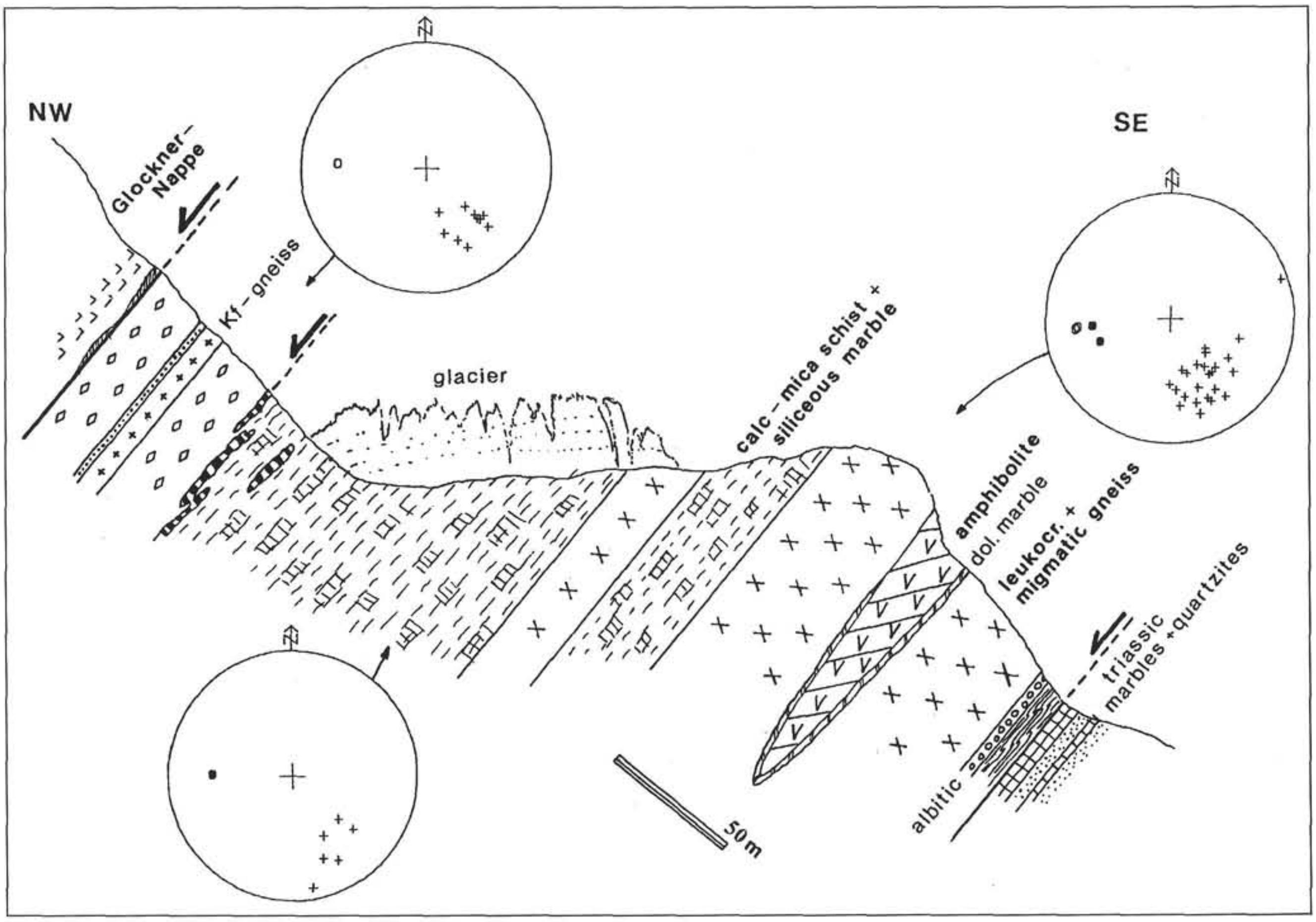


Fig. 10.
Schematic profile through Upper Eisbrugg Slab and Wustkogel Unit, located near the front of the Weißkarferner, projection nets see Fig. 7.

composition very similar to the results of DE VECCHI & MEZZACASA (1986). This is distinctly expressed in the Na_2O/K_2O-diagram (Fig. 9). Between granite-gneiss and meta-diorite a small layer of apatite-bearing quartzites with intercalated garnet-mica schists occurs (Fig. 2).

Garnet-Amphibolites

Lens-shaped bodies of dark green garnet-amphibolites intruded by aplitic dykes occur amidst the Upper Eisbrugg Slab. The largest lens, 20 meters thick, is located at the southern margin of the Weißkarferner near the front of the glacier (Fig. 10). Here allanite bearing aplitic dykes cut discordantly through an earlier foliation. The lens is surrounded by a thin dolomitic marble (FRANZ et al. (1981) discovered the boron mineral karlite. A characteristic feature of this marble are small tourmaline-needles, demonstrating as well a relatively high boron content.

Smaller amphibolite lenses occur along the border of the porphyroclastic K-feldspar granitegneiss.

This variety in Prevariscan rocks next to the Variscan magmatoids points to the Variscan near-roof position of this slab before thrusting affected the basement.

Calc Mica Schists and Micaceous Marbles

At the front of the Weißkarferner a complex made up of calc mica schists and silicious marbles is folded into the orthogneisses (Fig. 10). Microscopic and mesoscopic appearance is very similar to those of the former described

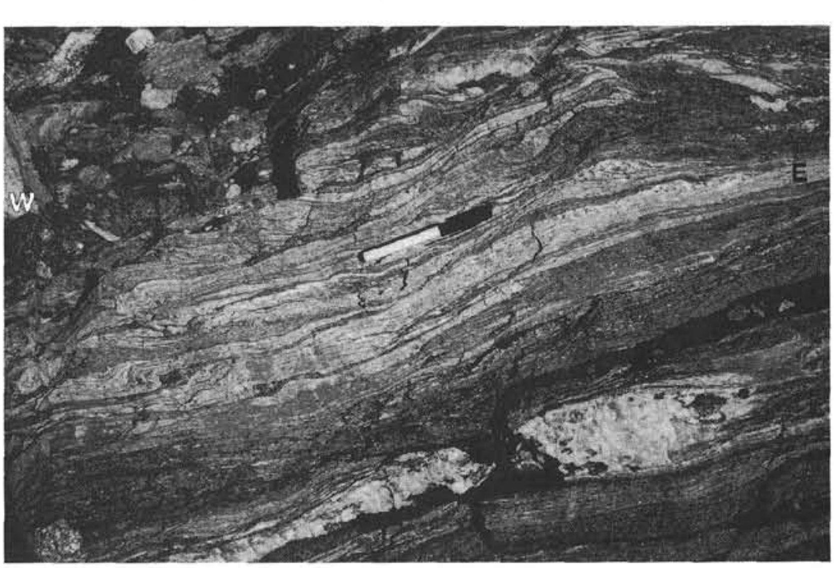


Fig. 11.
Basal Mylonite of the Upper Eisbrugg Slab showing strongly sheared leucocratic gneisses.
Pen = 14 cm, Location 200 m south of the front of Weißkarferner.

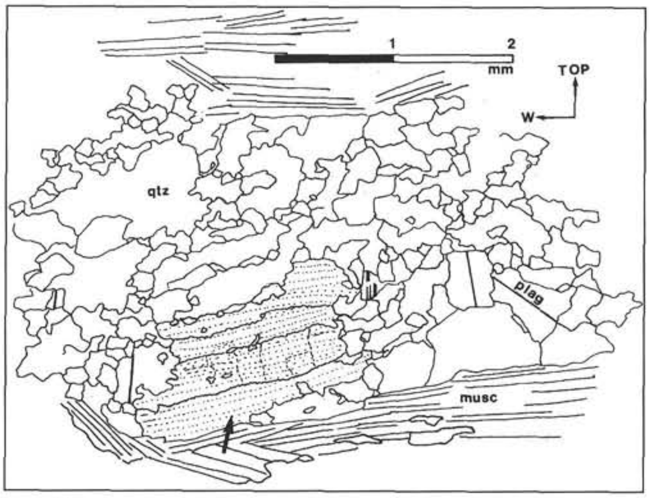


Fig. 12.
Sketch drawn from basal mylonite of the Upper Eisbrugg Slab after thin section cut parallel to lineation and perpendicular to foliation.
Lineation is parallel to scale mark. Thin layers of quartz containing only few plagioclase grains are bordered by muscovite flakes. Some quartz grains (arrow!) are remarkably elongated and show a strong undulatory extinction parallel to the elongation. Grain boundaries are finely serrated. Only few small recrystallized grains occur along the margins.

Kaserer Series (3.2.), or likewise the calc mica schists of the overlying Glockner Nappe.

However, the top of the Upper Eisbrugg Slab is cut by boudinaged and extremely sheared pure calcitic marbles with yellow and bluish-grey banding.

They reach a thickness of up to 3 meters and define a thrust zone separating phengitic gneisses at the base of the Glockner Nappe from the Upper Eisbrugg Slab (Fig. 14). The purity and colour of the marbles and their association with calc-mica schists suggests that they could belong to the Jurassic Hochstegen-marble despite their minor thickness.

In this case they might represent the primary Jurassic sediment on top of the Upper Eisbrugg Slab (see Fig. 17).

3.6. Wustkogel Unit (Permian ?)

Phengitic Gneisses and Schists

Ankerite-albite gneisses and -schists up to 50 meter thick are thrusted on top of the boudinaged marbles (Fig. 10). The schists and gneisses are monotonous, grey-greenish coloured.

U.m.: They are made up mostly of quartz, albite, muscovite, epidote and minor amounts of tourmaline and apatite. The albite has overgrown an earlier foliation marked by oriented inclusion trails of quartz, muscovite, and epidote. Significant for all rock types is a content of brownish carbonate, determined as ankerite.

The phengitic gneisses and schists seem to represent a fine to medium grained clastic sequence of probable Permoscythian age, the Wustkogel Series. This series is often described to have an inverse attitude at the base of the Glockner Nappe (FRASL, 1958; THIELE, 1970; POPP, 1985; LMMERER, 1986).

K-Feldspar Gneiss

Amidst the clastic sequence, near the top of the unit, a strongly foliated and banded greyish gneiss up to 8 meters thick was found (Fig. 10). It is characterized by single K-feldspar porphyroclasts, high amounts of phengitic muscovite and a near to total lack of biotite. Towards the top it grades into thin quartzitic layers overlain by a thin fine-grained carbonatic mylonite horizon. A probable orthogenic protolith of the K-Feldspar Gneiss is again indicated by the occurence of allanite (see before). Either it was extruded as Permian volcanic rock in a terrestrial environment, or has been thrusted as a third slab of Variscan Zentralgneis near the base of the Glockner-Nappe. Because of the similar modal composition of both, these two possibilities have been investigated with geochemical analyses: All variation-diagrams of 9 major-elements except one (TiO_2/Fe_2O_3: Fig. 9) show no correlation to the Zentralgneis samples. Particularly conspicious is the relatively high K_2O-value in relation to a low Na_2O-content. Summarizing all observations we tend to the interpretation as volcanic component within the Wustkogel Unit.

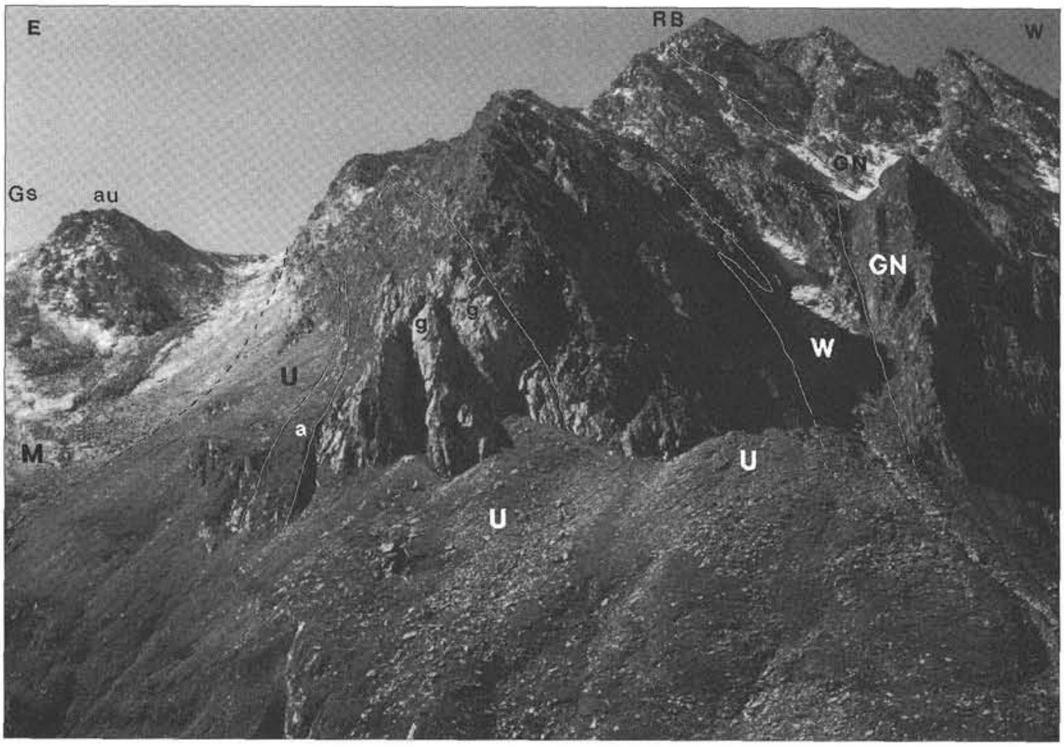


Fig. 13.
South-western flank of Unterberg-valley from Gliderscharte (GS) to Rotes Beil (RB), showing main parts of the Upper Eisbrugg Slab (U) inluding granitic gneiss (g) and amphibolite (a).
Left Metasedimentary Unit (M) with augengneiss at Gliderscharten-turret (au). Right Wustkogel-Unit (W) and Glockner-Nappe (GN).

Fig. 14.
Outcrop-wall W in front of Weißkarferner (height ca. 40 m).
U = Upper Eisbrugg Slab, W = Wustkogel-Unit, m = boudinaged marbles embedded in siliceous marbles and calc-mica schists.

3.7. Glockner Nappe

The Glockner Nappe mainly consists of amphibolites in the western part of the working area (DE VECCHI, 1989) and a thick sequence of monotonous calc mica schists with intercalated rare quartzites and marbles in the eastern part between Vordere Weißkarspitze and Hochferner (LAMMERER et al., 1981). A lense of spessartine-quartzites has been discovered at Vordere Weißkarspitze (OEHLKE, 1988) as well as a thin layer of coarse-grained boudinaged amphibolite without garnet near the thrust horizon of the nappe.

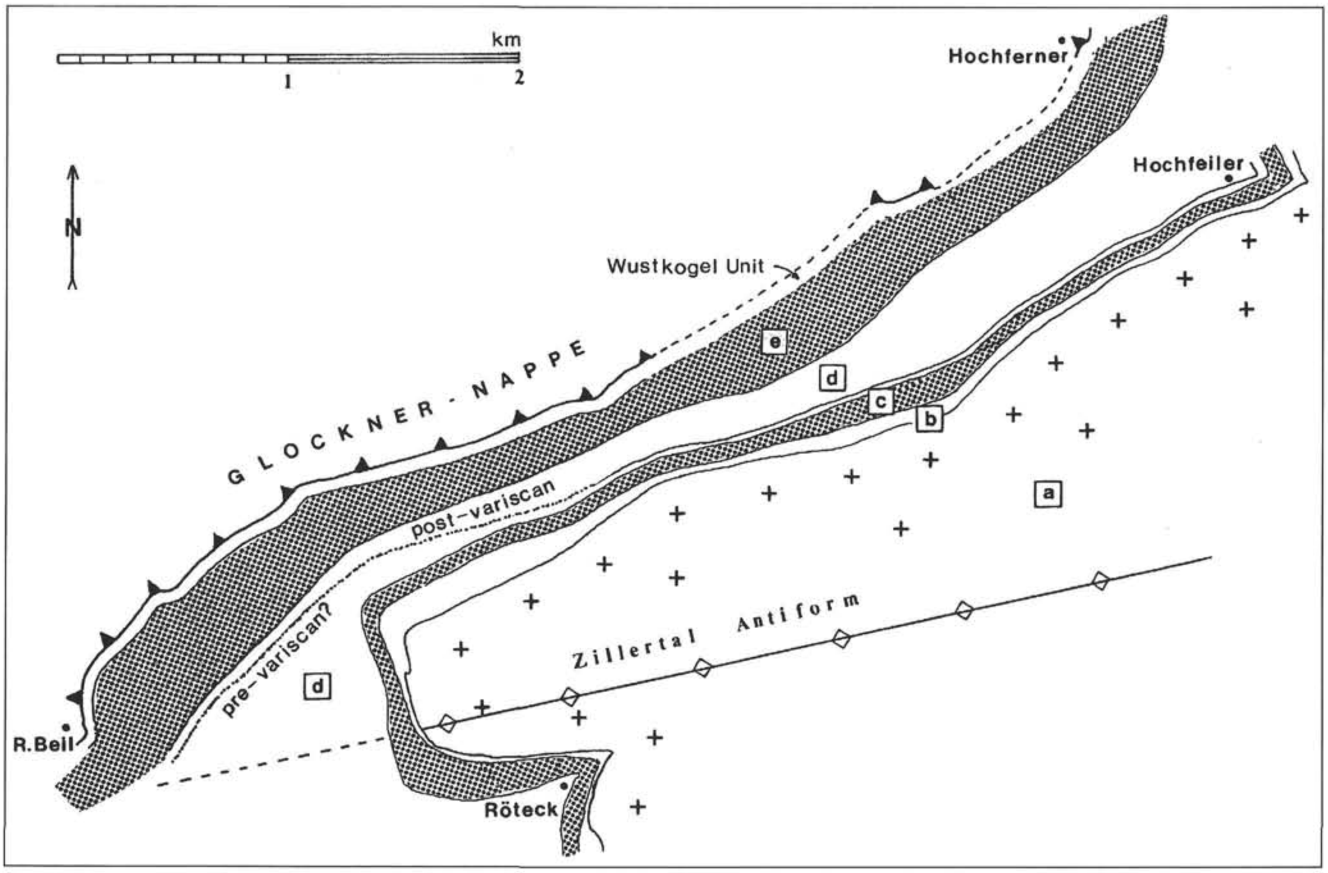


Fig. 15.
Tectonic map of the working area showing main units of the Hochfeiler Duplex.
a = Zillertal Zentralgneis Core, b = Hochstegen Unit, c = Lower Eisbrugg Slab, d = Paleozoic and Triassic Metasediments, e = Upper Eisbrugg Slab.

4. Structural Features

4.1. Pre-Alpine Structures

Pre-Alpine structures in the area are mainly overprinted by the penetrative Alpine deformation. Nevertheless, pre-Variscan relicts (foliation in garnet amphibolites (3.5) cut by aplitic dikes of Variscan age) and Variscan relicts (metamigmatites of the Upper Eisbrugg Slab, magmatic features of metagranitoids) are preserved. The magmatic contact between the metagranite and metagranodiorite, is marked by the strike of a muscovite gneiss.

4.2. Early Alpine Structures

The clockwise PT-path (SELVERSTONE, 1985) implies rapid burial through stacking of nappes on the prograde part of the path. At this early stage the stacking of the different ortho- and paragneiss slabs on top of each other was initiated (D 1 sensu LAMMERER 1988). This stacking leads to the formation of tectonic contacts between the different units: The mylonitic layer at the base of the Lower Eisbrugg Slab was created by this early thrusting, as well as the very similar contact between Metasedimentary Unit and Upper Eisbrugg Slab. Boudinage of marbles on top of the Upper Eisbrugg Slab and of amphibolites at the base of the Glockner Nappe probably was started at this stage. Lenses of Liassic (?) Quartzites squeezed between Zillertal Zentralgneis and Hochstegen marble could result either from a primary structure like sedimentation in channels or tectonic boudinage due to thrusting. The lack of strong shearing of the underlying Zentralgneis expected for such a boudinage argues for a sedimentary phenomenon.

Early Alpine structural features, especially clues for the transport direction of the thrusting-event, are erased by the following penetrative deformation. Works of the last decades on to the last years (e.g. FRISCH, 1984; TOLLMANN, 1987) assume south-north vergent thrusting because of generally east-west trending fold axes. However, in the overlying East Alpine Nappes southeast – northwest directions were also deduced (RATSCHBACHER, 1986). The only vague arguments for transport directions preserved in the working area are the thickening/thinning configura-

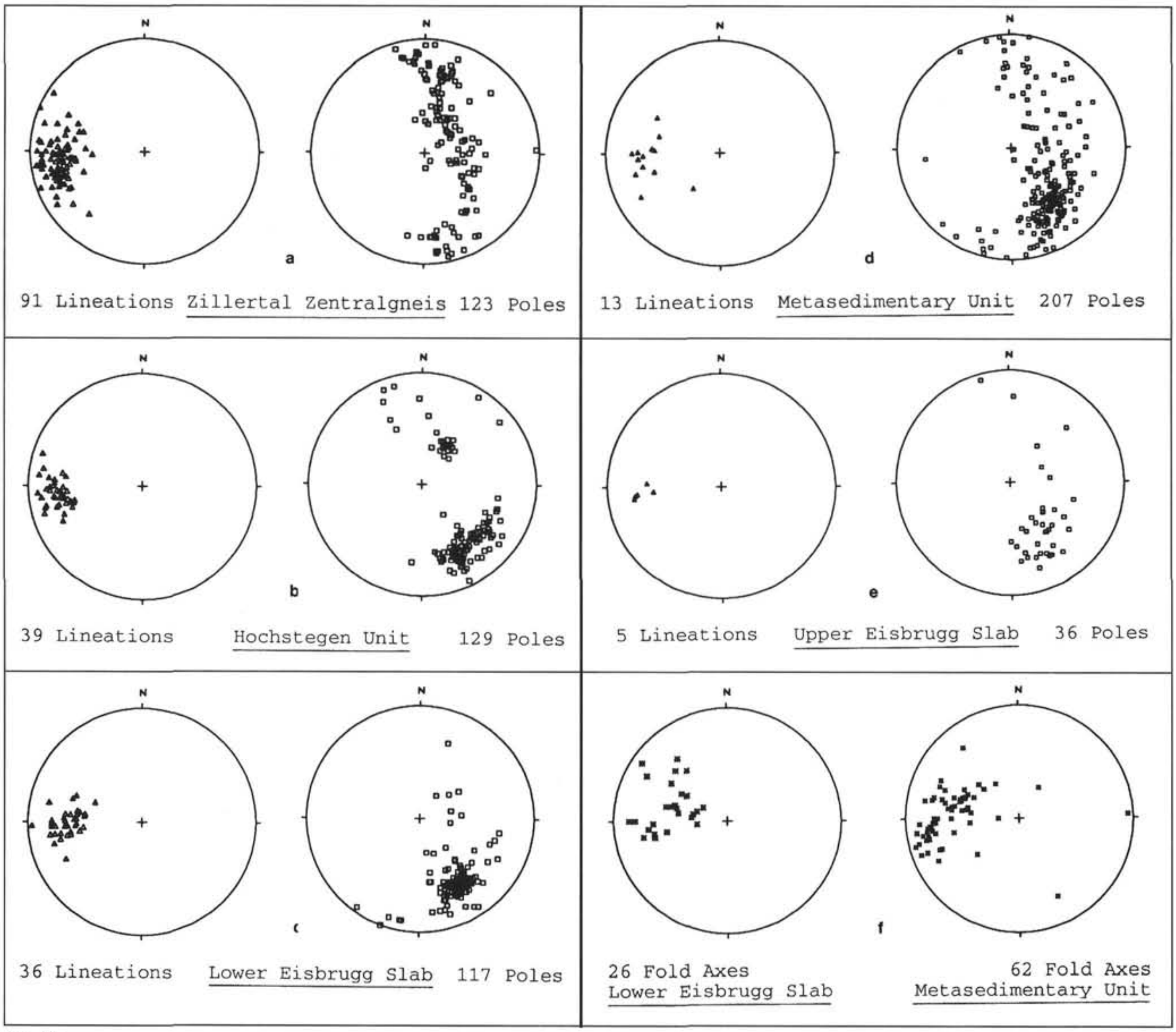


Fig. 16.
Tectonic projection nets (Schmidt net, lower hemisphere) showing mineral lineations (left), poles to foliation (right) and fold axes (f) of the main units (Fig. 15).

tion of the thrust-slices below the Glockner Nappe indicating northwestern oriented transport. Northwest plunging fold axes at the base of the Lower Eisbrugg Slab (Fig. 7) give no clue to the transport direction because they probably were rotated due to later ductile deformation.

4.3. Meso Alpine Structures

Ongoing stacking of the alpine nappe pile caused up to 30 km (LAMMERER, 1988) deep burial of the rock units. Thrust movements of the Glockner Nappe continued. The prograde metamorphism was accompanied by strong oblate ductile shearing of the units above the Zillertal Zentralgneis Core. This led to isoclinal folding associated with strongly developed schistosity (D_2 sensu LAMMERER, 1988) creating S-tectonites in the orthogneiss slabs and isoclinal folds mainly in quartzites and marbles of the Metasedimentary Unit. In the Zillertal Zentralgneis a D_2 schistosity was formed only locally in the last meter below the contact to the Hochstegen Unit. The penetrative D_2 schistosity in all units above the Zillertal Zentralgneis suggests, that it was formed when the units already were stakked on top of each other.

During Oligocene/Eocene amphibolite metamorphism all rock units of the area suffered ductile prolate straining (D 3 sensu LAMMERER 1988).

In the Zillertal Zentralgneis Core a dominant stretching lineation with a weak schistosity was developed, resulting in a moderately deformed L-tectonite (WEGER, 1988; WEGER & LAMMERER, 1991). The prolate deformation of the Zillertal Zentralgneis accounts for the great circle spread of schistosity poles on the projection net (Fig. 16 a). East-west extension due to prolate ductile deformation is documented by shallow west dipping mineral lineations in all units (Fig. 16 a–e).

The Zillertal Anticline was formed contemporaneously with prolate straining. The units above the Zillertal Zentralgneis show a great circle spread of schistosity poles on the projection nets (Fig. 16 b–e) due to D_3 folding of the Zillertal anticline. Maxima in the southeastern quadrant of the projection net result from the position of the working area on the northern limb of the Zillertal Anticline. West dipping fold axes (Fig. 16 f) are due to subparallel D_2 and D_3 folding. Shallow west dipping fold axes together with parallel mineral lineations indicate transpressional movements during D_3 (LAMMERER, 1988).

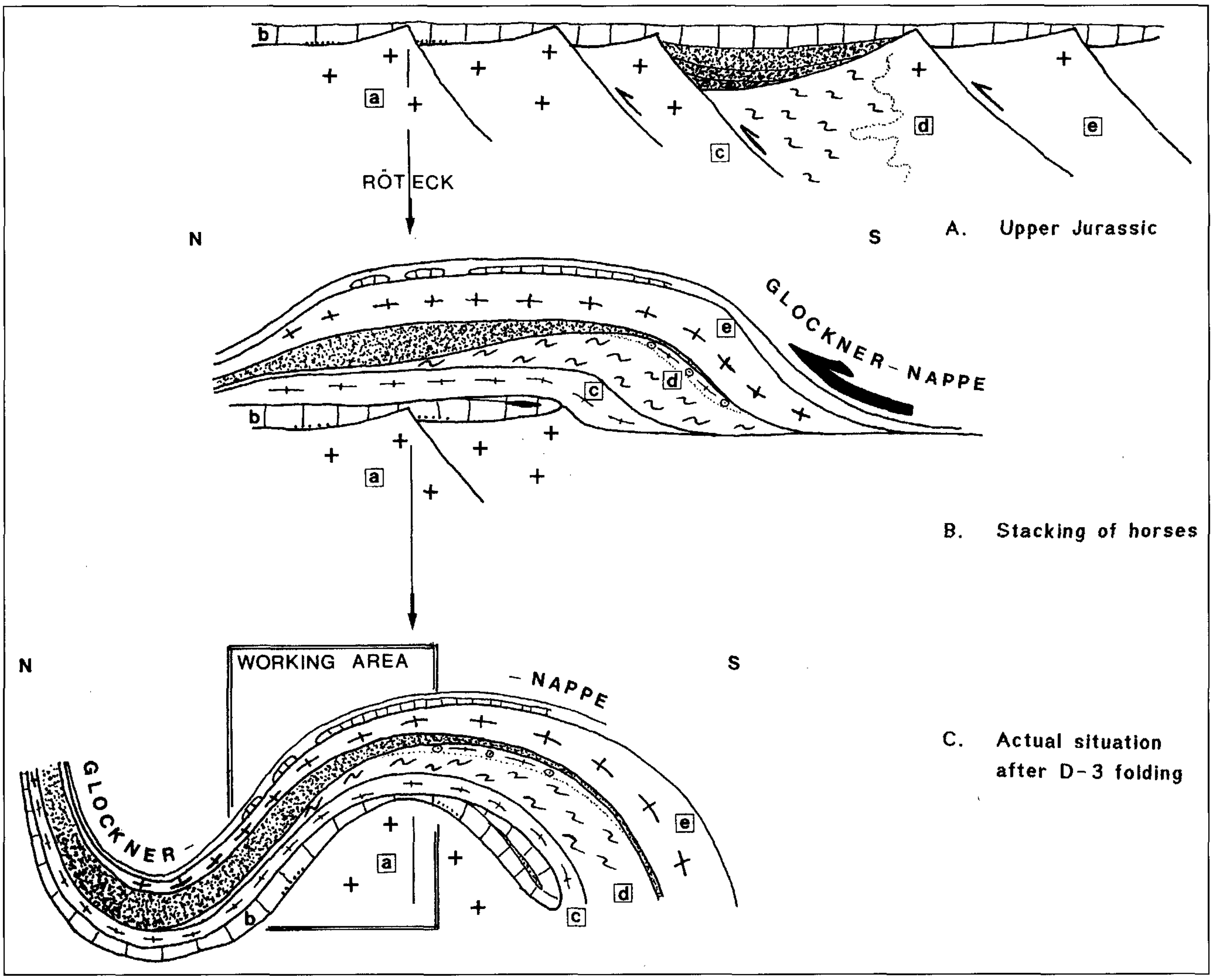


Fig. 17.
Schematic sketch of the development of the Hochfeiler Duplex.
A: Situation in the Upper Jurassic, proposed reactivation of normal faults, B = Eoalpine stacking of horses, C = Actual situation.
a = Zillertal Zentralgneis Core, b = Hochstegen Unit, c = Lower Eisbrugg Slab, d = Paleozoic and Triassic Sediments, e = Upper Eisbrugg Slab.

5. Conclusions: The Hochfeiler – Duplex

In the tectono-stratigraphic description of the whole sequence we showed, that various orthogenic slabs and metasedimentary units are stacked on top of the parautochthonous Hochstegen unit above the Zillertal Zentralgneis. The units are separated by discrete shear zones, that we interpret as Eoalpine thrust zones overprinted later under amphibolite facies metamorphism. They thus form an imbricate stack of horses below the Glockner Nappe, a duplex structure as defined by Boyer & Elliott (1982): "A duplex is an imbricate family of horses" (p. 1197) and "A horse is a pod of rock completely bound by fault surfaces" (p. 1202). The four horses of the duplex are formed by the two Eisbrugg slabs, the Metasedimentary Unit, and the Wustkogel Unit. The thrust related contacts and the mere fact, that orthogenic and paragenic rock units of different nature and age rest on top of each other are the main arguments for a stacking of horses. Duplexes have been recognized in similar tectonic environments of the western (Butler, 1983) and Central Alps (Boyer & Elliott, 1982). A qualitative restoration of the proposed duplex leads to differences in the sedimentary environment. This could be due to extensional normal faulting. Permo–Mesozoic clastic sediments are deposited only locally in halfgrabens, while the Hochstegen limestone finally equalized the relief. Compressional reactivation of the former normal faults to thrust faults overprinted earlier extensional features (Fig. 17a). Along these thrust faults the horses were stacked upon each other. The inverted sedimentary basins became part of the duplex together with basement horses, that carry only a thin sedimentary cover. Missing parts of the sedimentary sequence could be sheared off (Fig. 17b). Initial imbrication angles between the horses and the roof thrust, in this case the basal thrust of the Glockner Nappe, are obscured by following ductile deformation. The floor thrust of the duplex is represented by the basal mylonite between Hochstegen Unit and Lower Eisbrugg Slab. Changes in thickness of the horses can be attributed to both imbrication and inhomogeneous deformation. The duplex model additionaly explains overturned sequences, namely the Wustkogel horse and parts of the Metasedimentary and Upper Eisbrugg horses. We propose the name "Hochfeiler Duplex" for this regional structure presuming, that similar early Alpine duplex structures upon gneiss cores occur among widespread parts of the Tauern Window, too.

During Mesoalpine deformation the whole duplex suffered strong oblate deformation followed by moderate prolate deformation with east–west extension axes. Folding of the Zillertal Anticline steepened the former shallow thrusts (Fig. 17c).

Recognition of Eoalpine structures seems difficult due to massive mesoalpine overprinting, but they nevertheless can be worked out by small scale analysis of tectonic transsects.

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