Jb. Geol. B.-A. | ISSN 0016-7800 | Band **136** | Heft 2 | S. 495–502 | Wien, Oktober 1993

Sinistral Strike-Slip Faults in the Central Tauern Window (Eastern Alps, Austria)
A Short Note

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With 10 Text-Figures

Österreichische Karte 1 : 50.000
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Salzburg
Ostalpen
Tauernfenster
Scherzonen
Transpression
Deformation
Strukturanalyse
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Zentralgneis

Inhalt

Linksseitige Blattverschiebungen im zentralen Tauernfenster (Ostalpen, Österreich)

Zusammenfassung

Die alpidische Deformation der Venedigerdecke (Hohe Tauern, Salzburg, Österreich) wird entscheidend von Kompetenzkontrasten zwischen relativ starren Zentralgneisen und ihren Hüllgesteinen (Habachformation, Untere Schieferhülle) bestimmt. Auf die oberkretazisch-alttertiäre Platznahme der Venedigerdecke erfolgt im Tertiär eine transpressive Einengungstektonik, die ältere Gefügemerkmale stark überprägt. Zwischen der Ahrntal-Störung und der Salzachtal-Störung, beides Linksseitenverschiebungen, sind weitere Scherzonen ausgebildet. Diese steilstehenden Scherzonen zeigen ebenfalls einen sinistralen Schersinn an und sind unter duktilen bis spröd-duktilen Deformationsbedingungen entstanden.

Die dominierenden tektonischen Elemente in den untersuchten Gesteinsserien sind die steilstehende, nach S einfallende penetrative Schieferung und konstant ENE–WSW-streichende Streckungslineationen. Scherkriterien in den Granitoiden zeigen einen sinistralen Schersinn an. Quarz-c-Achsen-Verteilungen innerhalb der relativ starren Zentralgneis-Körper weisen auf eine koaxiale Deformation hin, während nicht koaxiale Deformation an diskreten Scherzonen stattfindet. N–S-Kompression führt zu einer passiven Rotation der starren Blöcke im Uhrzeigersinn und damit zur Bildung der Scherzonen. Transpressive, laterale Bewegungen an „wrench-faults“ generieren eine (sub)horizontale Streckungslineation, dabei entsteht eine „flower“ ähnliche Struktur. Die Hüllgesteine werden flach nach SW ausgequetscht. Eine darauffolgende Deformationsphase erzeugt sowohl links- als auch rechtsversetzende Scherzonen.

Schließlich führt die Aufdomung der Region des Tauernfensters und damit das Erreichen anderer tektonischer Bedingungen zu einer spröden Deformation. Es bilden sich konjugierte Kluftsysteme und Harnischflächen aus, die eine E–W-gerichtete Extension anzeigen.

Abstract

The alpine deformation of Penninic series in the Tauern Window (Salzburg, Austria) is partly controlled by the contrast between rigid variscan Zentralgneis bodies and incompetent metapelites and metavolcanic rocks of the Habach-Formation (Lower Schieferhülle). The emplacement of the Venediger nappe due to N–S compression around the Cretaceous-Tertiary boundary is followed by an intensive shearing during the Tertiary. In the region between two sinistral strike-slip faults, the Ahrntal Fault in the south, and the Salzachtal Fault in the north, further sets of sinistral shear zones are developed. Deforming conditions are ductile to brittle-ductile.

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The dominant structural features are steeply S-dipping penetrative foliation and an associated ENE–WSW trending stretching lineation in all stratigraphic units. Shear criteria in the granitoids indicate a sinistral sense of shear. Inside these gneiss bodies quartz-c-axis fabrics prove coaxial deformation patterns, while the shear zones have been deformed under rotational strain. N–S compression leads to passive clockwise rotation of the rigid blocks and constrained sinistral shear zones. Lateral transpressional movement of material along wrench faults produces horizontal stretching lineations and generates a flower-like structure. The prevariscan series are sandwiched and squeezed out to SW at a low angle. A following, but subordinate phase creates only a few right-lateral and left-lateral displacements.

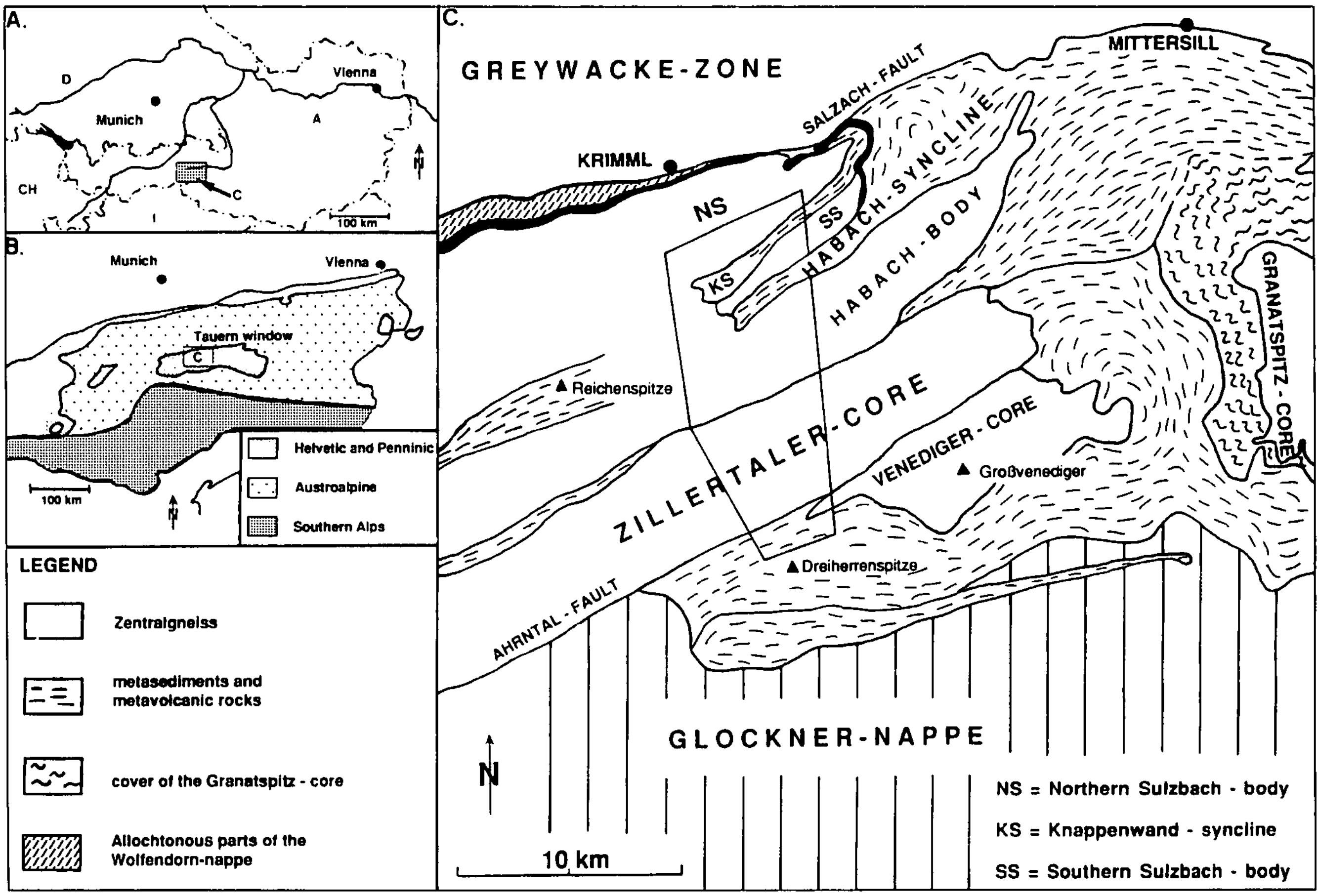
Finally the updoming of the Tauern Window produces E–W extension which leads to a brittle deformation with conjugate joint systems, shear fractures and slickensides.

1. Introduction

In several orogenic wedges tectonic movements parallel to strike are described (MALAVIELLE et al., 1984; RATSCHBACHER, 1986), indicated by stretching directions parallel to the displacement directions. The kinematic evolution in the Eastern Alps is interpreted with S- over N-directed nappe movements (TOLLMANN, 1977; FRISCH, 1977) constraining complex folding. Recent investigations in western parts of the Tauern Window show orogen parallel movement. LAMMERER (1988) explains these movements with a dextral transpressional model. We present the results of a structural and petrofabric analysis carried out in the northern part of the central Tauern Window (Text-Fig. 1). We focus our investigations on steep-sided sinistral shear zones which dissect the Penninic nappes: the shear zones of this region may host large displacements. The determination of direction and sense of displacement along ductile movement zones are examined in petrofabrics of quartz-rich tectonites. Rotation of clasts, asymmetric boudinage, as well as quartz-c-axis fabrics are helpful shear indicators.

A detailed assessment of the regional geology of the Tauern Window and the Austrian Eastern Alps is given in TOLLMANN (1977). The metamorphic and structural evolution has been reviewed by FRANK et al. (1987). The alpidic metamorphic evolution is terminated with a thermal peak at about 35–40 m.a. with an upper greenschist to amphibolite grade overprint (Tauern Crystallization [SANDER, 1921]), well after the pressure maximum (SELVERSTONE, 1985). The cooling and uplift history of the western Tauern Window is documented by GRUNDMANN & MORTEANI (1985).

Comparison of apatite fission track dating and K/Ar and Rb/Sr ages from white mica and biotites (RAITH et al., 1978) suggest that the last ductile tectonic movements occurred about 20 m.a., consistent with the cooling temperature of the micas. The data point to an uplift rate of approximately 0,5 mm/a. The cooling of the western part of the Tauern Window is accompanied by large scale vertical movements hosting several km displacement (GRUNDMANN & MORTEANI, 1985) in the past 20 m.a.



Text-Fig. 1.
Location of the investigated area in the Tauern Window/Salzburg, Austria.

2. Geological Setting

The studied area in the central Tauern Window near its northern margin (Text-Fig. 1) belongs to the Venediger nappe (FRISCH, 1974), which is regarded as the lower part of the Middle Penninic basement. The Venediger nappe yields two different petrologic and stratigraphic series:

The Habach-Formation (FRASL, 1958; STEYRER, 1983), outcropping in the Habach-Syncline and the Knappenwand-Syncline, contains prevariscan metavolcanic rocks and metapelites. Geochemically the metavolcanics can be classified as typical primitive island arc sequence, probably connected with a paleozoic backarc evolution (STEYRER, 1983; FRISCH & RAAB, 1987).

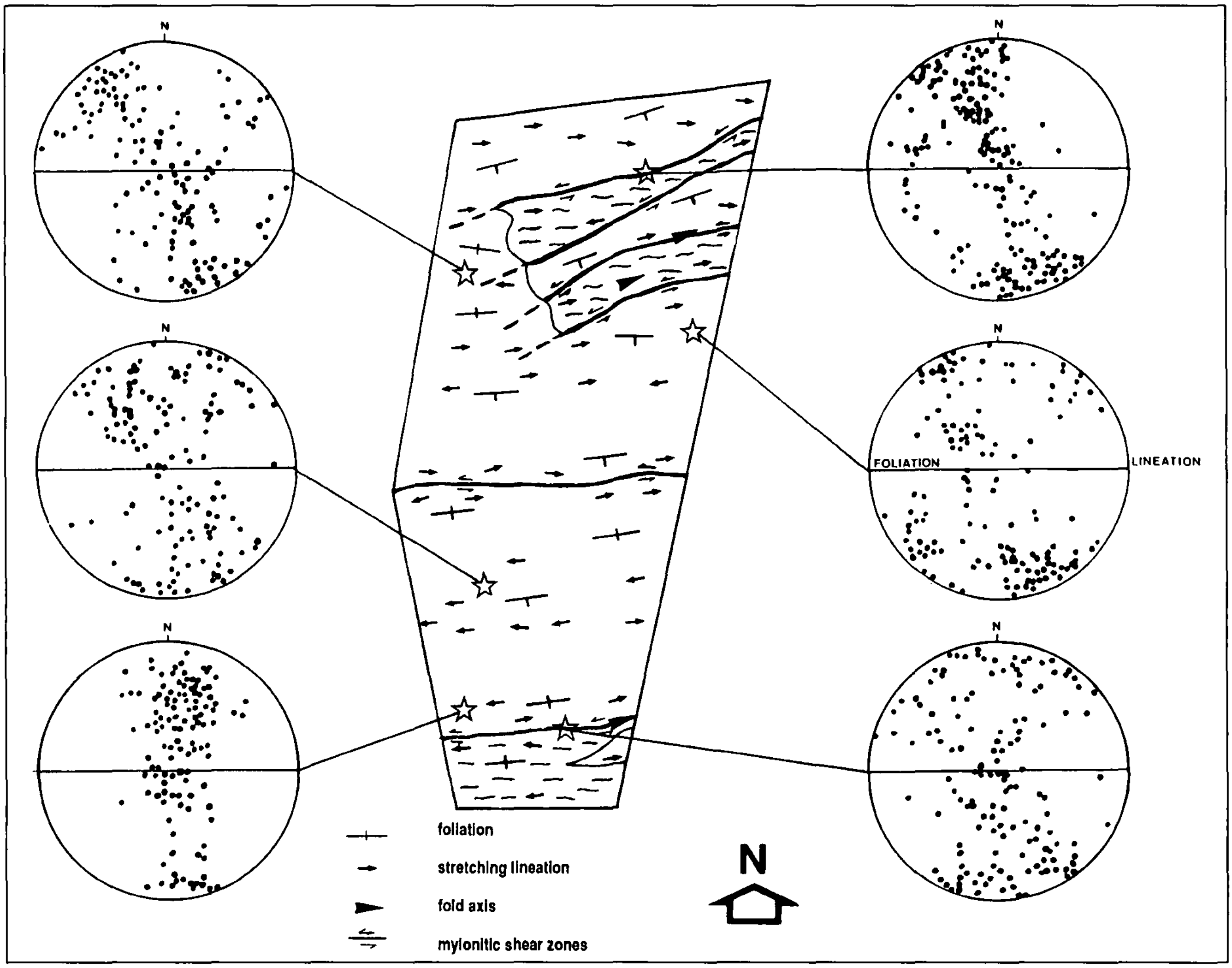
The Zentralgneis unit represents variscan granitoids which intruded the pre-existing series. The contacts are tectonically overprinted by progressive Alpine deformations. However, several Zentralgneis complexes are separated by shear zones. The geochemical composition of the granitoids ranges from tonalites and granodiorites to aplitic granites. The intrusion of the Zentralgneis into paleozoic clastic sediments and metavolcanics of the Lower Schieferhülle formed migmatites near the Ahrntal-fault. With the exception of the Southern Sulzbach body, a common magmatic evolution of the granitoids has been shown with geochemical and zircon morphology studies by WINKLER et al. (1990) and REICHERTER & FIMMEL (1990). The granitoids are considered to be collisional melting products of a mature island arc (VAVRA, 1989).

3. Structural Analysis

The main structural features are shown in Text-Fig. 2. In all lithological units a pervasive transposition foliation is developed homogeneously, predominantly dipping steeply to SSE (Text-Fig. 3A). This foliation is mainly due to the preferred orientation of white mica and biotite in the gneissic rocks, in the metapelites and the metavolcanics of chlorite and amphibole. Sometimes crenulation is observable in prevariscan gneisses and in the Habachphyllites which obliquely disturbs the main foliation.

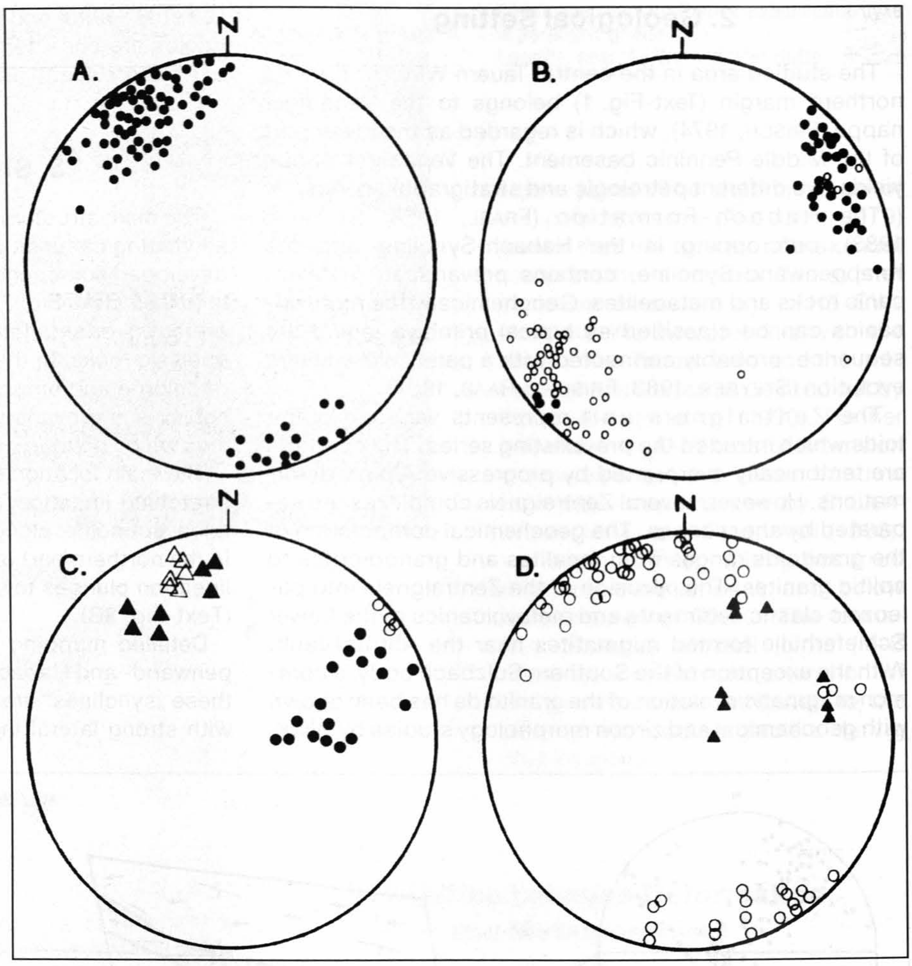
The main foliation shows a WSW–ENE oriented mineral stretching lineation. It is expressed by the alignment of mica, actinolite, elongate feldspar and elongate xenoliths. In the northern part of the studied area the gently inclined lineation plunges toward ENE, in southern parts to WSW (Text-Fig. 3B).

Detailed mapping of the western parts of the Knappenwand- and Habachsynclines (Text-Fig. 1) showed that these „synclines“ are unfolded parts of prevariscan series with strong lateral facies differences. The rocks contain



Text-Fig. 2.
Structural map with quartz-c-axis plots.
See Text-Fig. 1 for locality.

Text-Fig. 3.
Different equal area plots.
A) Polar projection of foliation planes.
B) Stretching lineations.
○ = northern area, ● = southern area.
C) ● = fold axes, ○ = lineation, △ = fold planes, ▲ = fold limbs.
D) Poles of ductile-brittle shear zones.
○ = sinistral faults, ▲ = dextral faults.

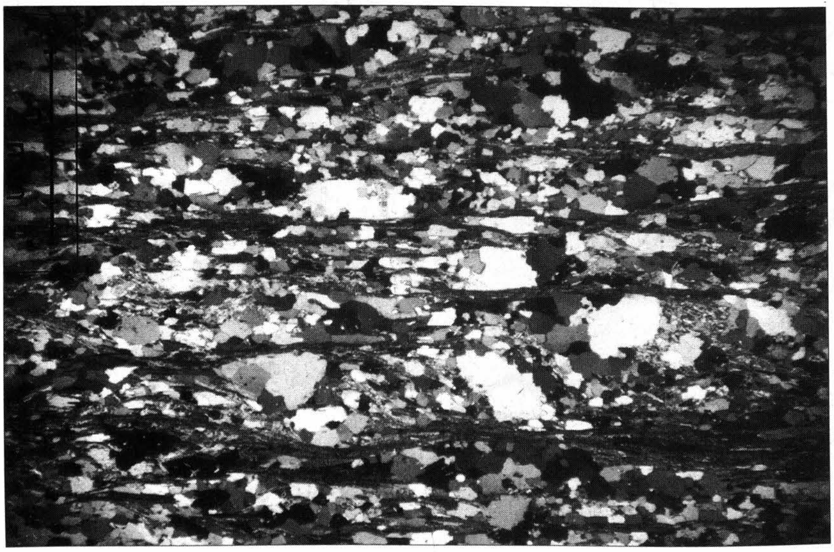


the same tectonic features as the Zentralgneis bodies. We find no indication for large scale folding.

Mesoscopic folds are encountered mainly near lithological contacts. The axes of the isoclinal folds are plunging E-ENE (Text-Fig. 3C) and plot close to the maximum of the stretching lineations. Further south in higher metamorphic areas (near the Warnsdorfer Hütte, see Text-Fig. 1) in migmatitic rocks ptygmatic, polyharmonic folds and asymmetric en echelon-folds with thickened hinges and thinned limbs are observed. They may be attributed to the competence difference between the quartz-feldspar layers and the biotite-rich matrix (BRUN & MERLE, 1987).

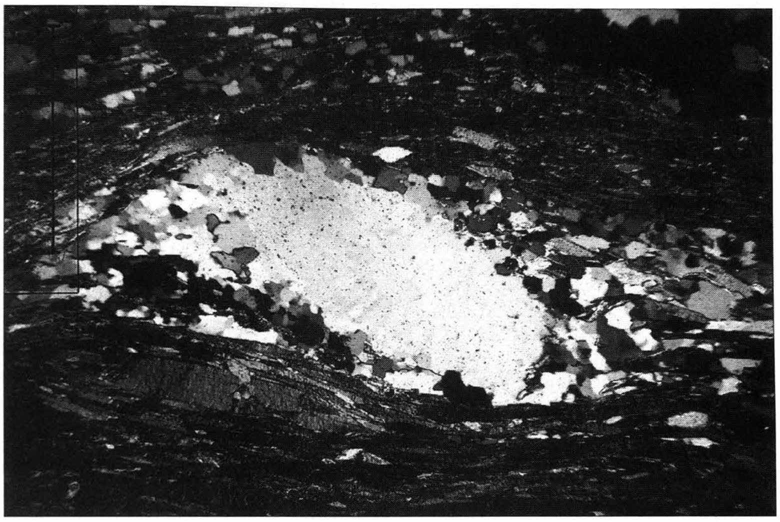
The region hosts an impressive number of steeply dipping and foliation (sub)parallel shear zones within the gneiss-bodies and at lithological boundaries, respectively (Text-Fig. 3D). Within these shear zones the rock shows only rotational deformation. Ductile shear zones offer an opportunity to study the progressive development of mylonitic microstructures and fabrics with increasing strain. Significant sigmoidal bending of the foliation indicates sinistral sense of shear in movement zones in the glacier polished outcrops near the Warnsdorfer Hütte. They range from mm to several m in width. In shear zones granitoid rocks are emaciated to „phyllonites“ (CORNELIUS & CLAR, 1939) containing almost quartz and white mica (see Text-Fig. 5). Amphibolites are changed to chlorite-schists. Extension crenulation cleavage (PLATT, 1984) cuts the mylonitic foliation at a low angle NE–SW, which indicates that a subordinate phase of brittle-ductile deformation followed ductile shearing. It is limited to a few mesoscopic conjugate shearbands. The sense of shear along these later developed shear bands is both sinistral and dextral. Aplitic dykes are deformed during the brittle-ductile phase and cut by left-lateral shear-bands connected with a sigmoidal bending of the dykes.

Shear zones and displacement/stretching directions are variously indicated by several characteristic structural features. Granitic rocks within transform faults show S-C fabrics as result of the ductile deformation (in the sense of BERTH et al., 1979). The S and C surfaces are expressed by white mica and parallel to S aligned elongate quartz grains. The sense of shear and the displacement in all samples is determined to be sinistral (Text-Fig. 4). The angular relationship



Text-Fig. 4.
S-C-mylonite indicating sinistral sense of shear.
Zentralgneis sample of the Northern Sulzbach body near Hopffeldboden/Obersulzbachtal.
Length of scale bar 2 mm, x-Nicols.

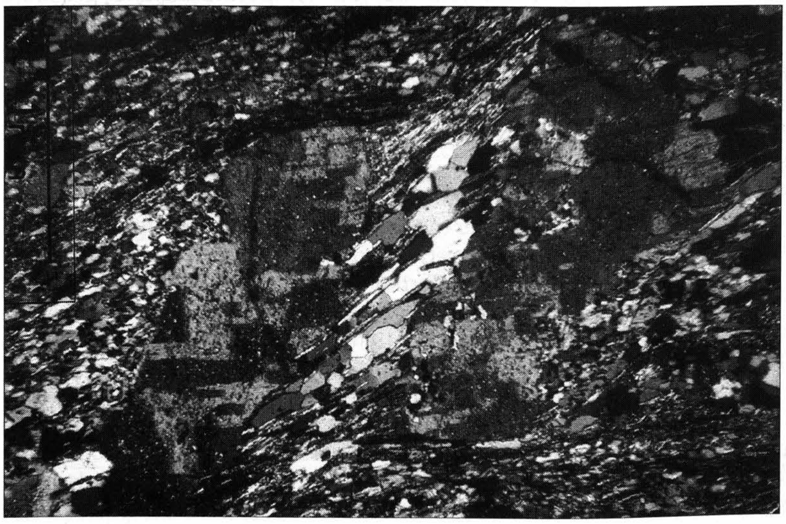
Text-Fig. 5.
σ-type quartz-clast with asymmetric tails of dynamically recrystallized quartz grains in a mylonitic gneiss, indicating sinistral sense of shear.
Sample from the Krimmler Achental, tectonized aplitic Zentralgneis, so-called phyllonite.
Length of scale bar 1 mm, x-Nicols.

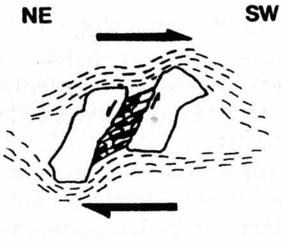


Text-Fig. 6.
δ-type feldspar-porphyroclasts in a porphyric gneiss of the prevariscan series.
Recrystallized material extends from the grain into asymmetrical rotated tails (counterclockwise rotation).
Locality: the glacier-polished outcrop near the Warnsdorfer Hütte/Krimmler Achental.

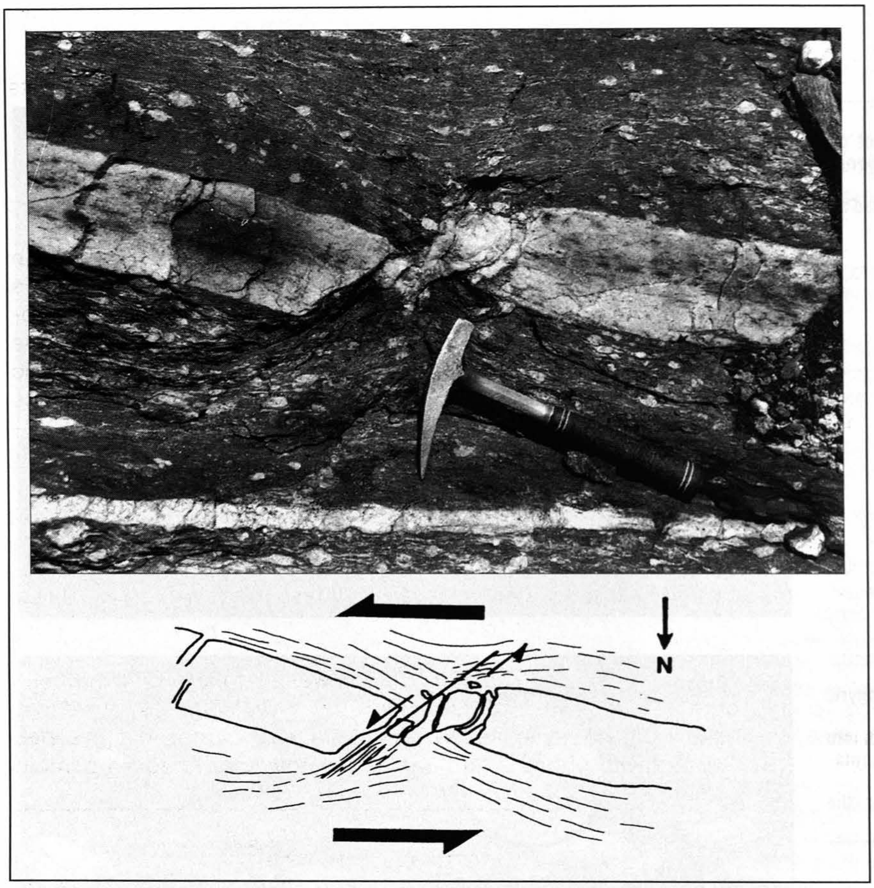
between the S- and C-surfaces decreases into parallelism towards the center of the movement zones. Outside these shear zones granitoids seem to remain unaffected and show only coaxial deformation.

Sinistral σ-type quartz clasts in mylonitic gneisses have dynamic recrystallized quartz grains in the pressure shadows (Text-Fig. 5). Porphyric granitoids contain feldspar clasts in a ductile matrix which build an asymmetric augen structure (SIMPSON & SCHMID, 1983). The tails of the feldspar grains are composed of fine-grained material of the same composition as the porphyroclast. They extend along the foliation plane and indicate a sinistral sense of shear (Text-Fig. 6). Very common are δ-type and σ-type clasts. This points to an inhomogeneous deformation and a different vorticity. Garnet-porphyroblasts and biotites of paragneisses and migmatitic rocks are often associated with pressure shadows, again indicating sinistral shearing. Some of the garnets bear a sigmoidal internal foliation, which recorded a counter-clockwise rotation of the crystals.





Text-Fig. 7.
Rigid broken plagioclase crystall. Albite and quartz annealed the antithetic fracture.
Zentralgneis sample of the Northern Sulzbach body near Hopffeldboden/Obersulzbachtal.
Length of scale bar 1 mm, x-Nicols.



Text-Fig. 8.
Boudinaged and antithetic rotated aplitic dyke in porphyric gneiss.
Locality: near the Warnsdorfer Hütte.

The plagioclases deformed below their recrystallization temperature show a rigid deformation. In a ductile matrix they are displaced by microfractures, indicating an antithetic dextral sense of displacement along these fractures and an overall sinistral shearing (Text-Fig. 7). The model of a sheared stack of cards (ETCHECOPAR, 1977) was applied to explain the structure. The fractures are annealed by albite (An_6) and quartz.

Asymmetric boudins are useful kinematic indicators for the vorticity of deformation (HANMER, 1986). Due to lithological differences and therefore different deformation parameters boudinage generates under extensional regime (Text-Fig. 8). A rigid aplitic dyke in a ductile porphyry gneiss matrix is cut by extensional shears, the single boudins are rotated antithetic and lie oblique to the external planar foliation. The sense of shear is interpreted to be sinistral.

Varying kinematics in granitoid rocks can be demontrated by the comparison of quartz-c-axis fabrics showing orthorhombic symmetry (coaxial) or monoclinic symmetry (non-coaxial) (SCHMID & CASEY, 1986). Asymmetric fabrics indicate a sinistral rotation of the long and short principal axes of the finite strain as a consequence of large scale left-lateral displacement between the gneiss bodies (Text-Fig. 2). The non-coaxial deformation is strongly influenced by lithological contacts and is restricted to the left-lateral shear zones. Coaxial deformation is observed in deformed rock between the shear zones and is related to pure shear. Quartz-rich tectonites show signs of postkinematic recrystallization and annealing, this is expressed in a heterogeneous distribution of the quartz axes.

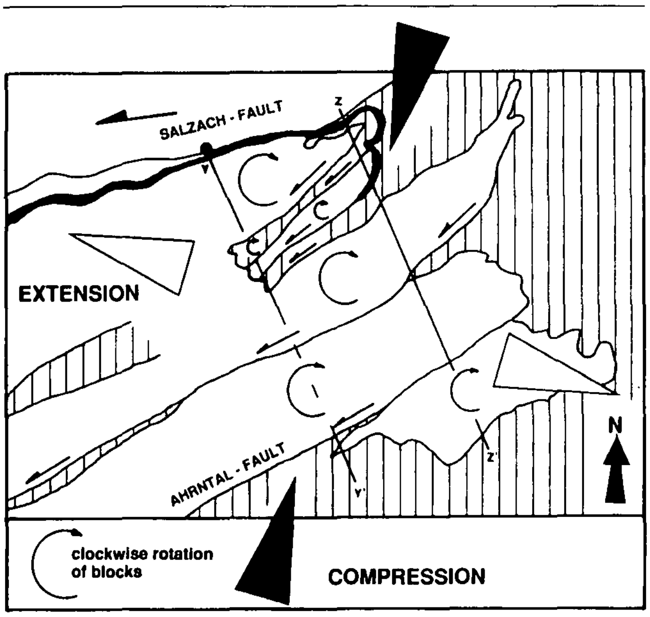
The deformational history is continued with a brittle post-metamorphic act. The brittle inventory consists of slickensides, quartz-filled pull aparts and systems of conjugate joints. The determination of the paleostresses (ANGELIER, 1979) shows that the axis σ_1 of maximum compression is vertical. The axis of minimum extension σ_3 is NE–SW-directed. We interpret this with the uplift of the Tauern area and the collapse of the orogen as pointed out by RATSCHBACHER et al. (1990). Further evidences for E–W crustal extension in the region of the Tauern Window have been documented by SELVERSTONE (1988) and BEHRMANN (1988), low angle normal faulting occurred after the thermal peak and below temperatures of 300°C. The formation of valley parallel joints (N–S directed) and schistic alteration of the granitoids are attributed to the relief of the loading glaciers during the Holocene.

4. Relation between Deformation and Metamorphism

Mesoscopic and microscopic features suggest that nappe emplacement took place under upper greenschist to lower amphibolite conditions. The whole ductile deformation history is outlasted by the thermal effects of Tertiary Tauern Crystallization.

Thermo-barometric estimates from oxygen-isotope studies (HOERNES & FRIEDRICHSEN, 1974) yield temperatures up to 550°C and pressures of 4–5,5 kbar, which complies with a loading of about 15 km. The annealed fractures of plagioclases are filled by albite (An_6) and quartz, the anorthite content indicates temperatures below 500°C for the Northern Sulzbach body during the Tauern-crystallization. Temperatures and pressures increase southward. The formation of the penetrative main foliation is connected with the nappe emplacement. Foliation planes are reactivated as slip planes.

Post-deformational growth of biotite crysts in greenschists of the Knappenwand syncline (Text-Fig. 1 and 10) across the main (ductile) foliation is observed. Rotated internal tracks indicate sinistral movements during growth. This points to the fact that the ductile deformation history of the Venediger nappe was not entirely completed by the onset of the Tertiary cooling in the tectonic edifice. Rb-Sr and K-Ar ages of biotites of the Krimmer Achental yield cooling ages of 19 m.a. (GRUNDMANN & MORTEANI, 1985). Sinistral strike-slip movements until approximately 20 m.a. can therefore be deduced, at least to the Miocene. Quartz shows sometimes dynamically rerystallized grains, especially in pressure shadows, or equilibrium configurations: large and equant grains, triple points, no undulatory extinction.



Text-Fig. 9.
Transpression model.
N-S compression leads to clockwise rotation of gneiss-bodies and wrenching at left-lateral shear zones. An overall sinistral transpression is assumed.

5. Discussion and Tectonic Model

The structural analysis of the area shows ductile kinematic indicators with a left-lateral displacement, but no large scale folding. These structures are overprinted by brittle-ductile deformation, with conjugate sets of shear bands. The last deformation event is brittle and produced conjugate joint systems, as well as slickensides.

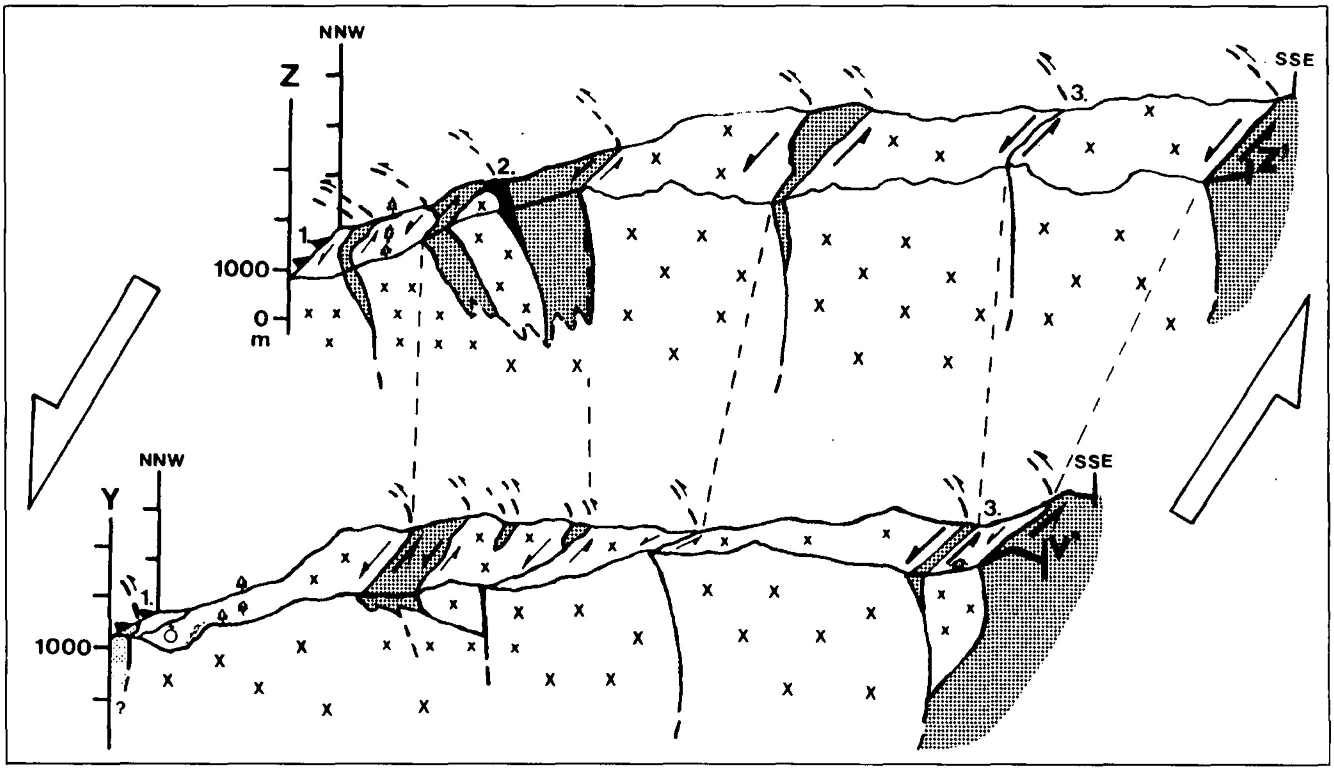
Ductile, sinistral shear zones are created well after the emplacement of the Penninic nappes around the Cretaceous/Tertiary boundary. West directed movements are connected to ongoing N–S compression and the initiation of shear zones, which are at least active until the Miocene. The initially ductile behavior increasingly changed to brittle deformation in time with the buoyant uplift and the updoming of the Tauern window area.

In contrast to existing models which interpret the investigated area as a folded pile of nappe due to S over N emplacement, a compression-extension model helps to explain large scale left-lateral movements. Due to a N–S compression (Text-Fig. 9) the Zentralgneis bodies are rotated clockwise along distinct faults. Transpression causes that the prevariscan series are sandwiched and squeezed out to SW at a low angle (Text-Fig. 10).

Orogen-parallel movements are indicated by (sub)horizontal stretching lineations. Strike slip motion leads to major lateral shape changes in the thickened wedge. The fanning of the shear zones creates a "flower"-similar structure. A sinistral transpressional model is applied to interpret the local configuration of the pre-Alpine gneiss bodies and the prevariscan series in the Central Tauern-Window.

Acknowledgements

Former reviews have been made by Drs. L. Ratschbacher (Tübingen) and G.W. Michel (Potsdam). Dr. U. Ring (Mainz), A.K. Seattely and T. Pletsch improved later English versions. All this is greatly acknowledged.



Text-Fig. 10.
Flower similar structure. Sections Y-Y' and Z-Z' see Text-Fig. 9.
1 = Salzach-fault, 2 = Mesozoic cover, 3 = Ahrntal-fault.
Transpression is seen to be the driving mechanism for the "squeezing out" of the prevariscan series at a low angle towards W and E. Sinistral strike-slip motions create a fanning of steeply dipping shear zones.

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Manuskript bei der Schriftleitung eingelangt am 22. Oktober 1992.