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Sinistral Ductile Shearing Associated with Metamorphic Decompression in the Tauern Window, Eastern Alps

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With 7 Text-Figures and 1 Table

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Tirol
Ostalpen
Tauernfenster
Tektonik
Gefüge
Metamorphose

Inhalt

Zusammenfassung

Eine Strukturanalyse der Greiner Schiefer zwischen den Tuxer und Zillertaler Zentralgneis-„Kernen" ergibt zwei Phasen duktiler lateraler Zerscherung, deren Strukturen auf prä-alpine tektonische Gefüge aufgeprägt sind. Die erste alpine Zerscherung war linksseitig und erfaßte den gesamten Greiner-Schiefergürtel und Teile der benachbarten Gneise. Die Deformation hat leicht oblate Geometrie bei sehr hohen Strains. Eine zweite, untergeordnete Phase erzeugte wenige mesoskopische Scherzonen mit dextraler Kinematik und geringfügigen Versatzbeträgen.

Die linksseitige Zerscherung geht wahrscheinlich auf Krustenbewegungen in der ausgehenden Kreide oder im Alttertiär zurück. Sie war in der Greiner Scherzone von einer Dekompression des Systems um etwa zwei Kilobar begleitet. Die Bewegungen erfaßten auch die überlagernde Glocknerdecke. Dies belegt, daß sie jünger als die eoalpine Deckenstapelung und Verdickung der Kruste sind. Die Seitenverschiebungen weisen auf erhebliche laterale Formänderung des verdickten Orogenkeils hin. Sie können mit fortgesetzter krustaler Kompression nach der Kollision der Europäischen und der Adriatischen Platte erklärt werden.

Abstract

Structural analysis of the Greiner schist belt located between the Tux and Zillertal granite gneiss "cores" reveals two phases of Alpine strike-slip shearing imprinted onto a pre-Alpine tectonic fabric. The first Alpine shearing was sinistral and affected the whole schist belt and parts of the neighbouring gneisses. Deformation creates slightly oblate strain ellipsoids. A second and subordinate phase of ductile deformation is limited to a few mesoscopic dextral shear zones with minor displacements.

The sinistral strike-slip shearing, which is inferred to be of uppermost Cretaceous to lower Tertiary age, was accompanied by an estimated two kilobar decompression within the Greiner Shear Zone. The movement also affected the overlying Glockner Nappe and therefore is younger than the eo-Alpine overthrusting. The strike slip motion indicates major lateral shape changes in the thickened orogenic wedge and may be related to continued crustal compression after continental collision.

1. Introduction

It is a widely accepted idea that the major paleogeographic units in the Eastern Alps had their long axes east–west, parallel to the strike of the orogenic belt. This has led to simple N–S convergence models for the

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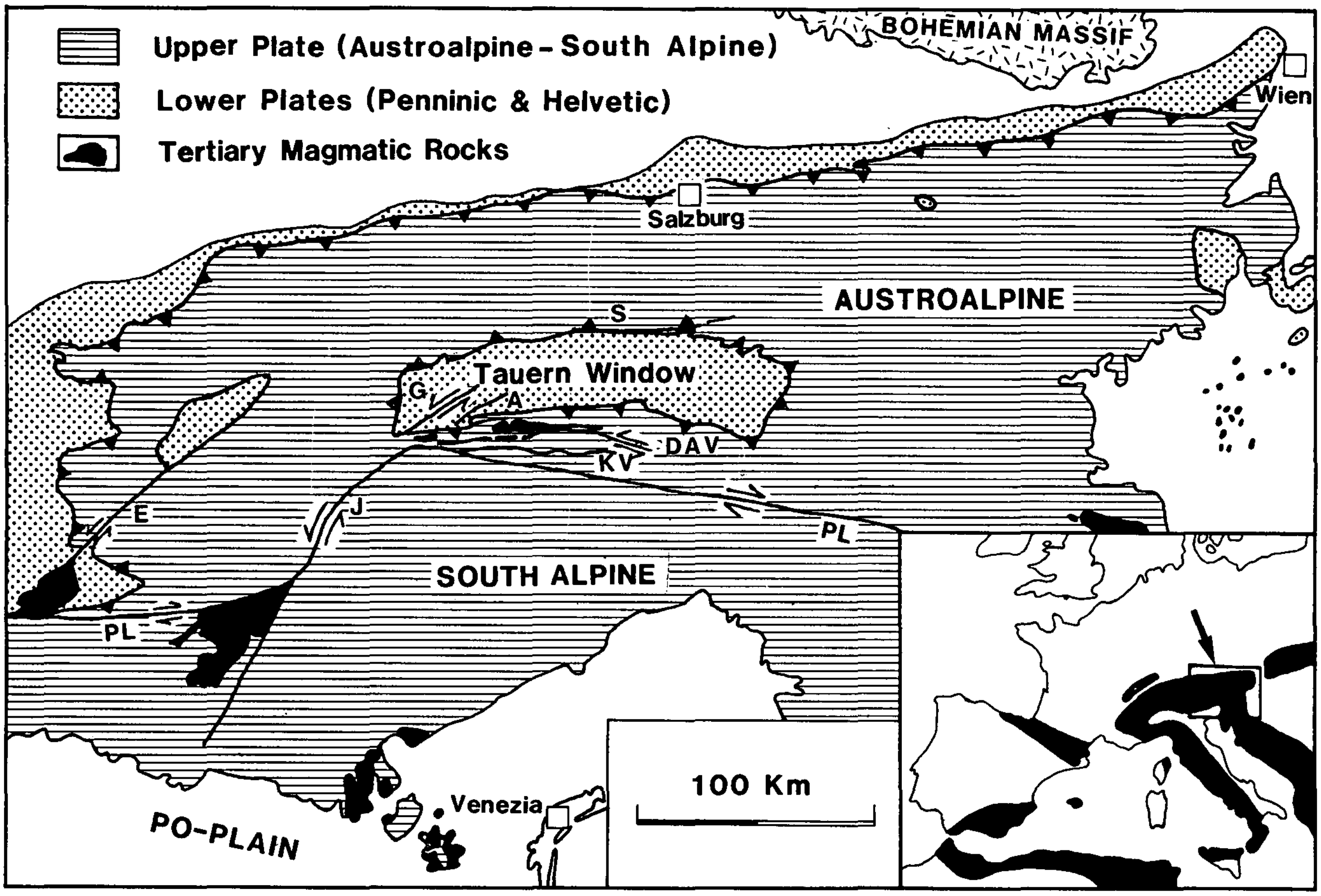
Eastern Alps (e.g. HAWKESWORTH et al., 1975; ROEDER, 1976; and contributions in CLOSS et al., 1978). A recent development of research of the kinematics during Alpine orogeny focusses on the pressure-temperature history of metamorphic rocks involved in the mountain building process. Regional examples for the Eastern Alps are given by SELVERSTONE et al. (1984), SELVERSTONE & SPEAR (1985), DROOP (1985), HOLLAND & RAY (1985), and STÖCKHERT (1986). These studies furnish valuable information about vertical displacement histories (burial, uplift) but there is only limited information concerning the kinematics of basement nappe movements of the Eastern Alps (BRUNEL & GEYSSANT, 1977; RATSCHBACHER, 1986; RATSCHBACHER & OERTEL, 1987; RATSCHBACHER et al., 1987; RING et al., 1988, 1989). To date there is also very little knowledge on the kinematics of high angle strike-slip faults that dissect the Alpine nappe edifice and may represent major structural modifications of the orogenic wedge in response to crustal convergence. Pertinent data supporting post-nappe wrenching in the Eastern Alps come from the publications of NIEVOLL (1985), KLEINSCHRODT (1986), KROHE (1986), KAZMER & BLAU (1987), and SCHMID & HAS (1987). An instructive short review of the topic is found in NEUBAUER (1988, pp. 96–98).

This study reports the results of a search for major high-angle transcurrent movement zones in the area of the western Tauern Window. We do not attempt to present a complete structural synthesis of the type suggested by LAMMERER (1988). We limit our attention to critical information, like senses of rotation in bulk flow, and the study of structural overprinting relationships important for the relative age of wrenching. Further, we review petrological data and age constraints on the pressure-temperature history of the Penninic zone, and discuss their significance to relative crustal movements.

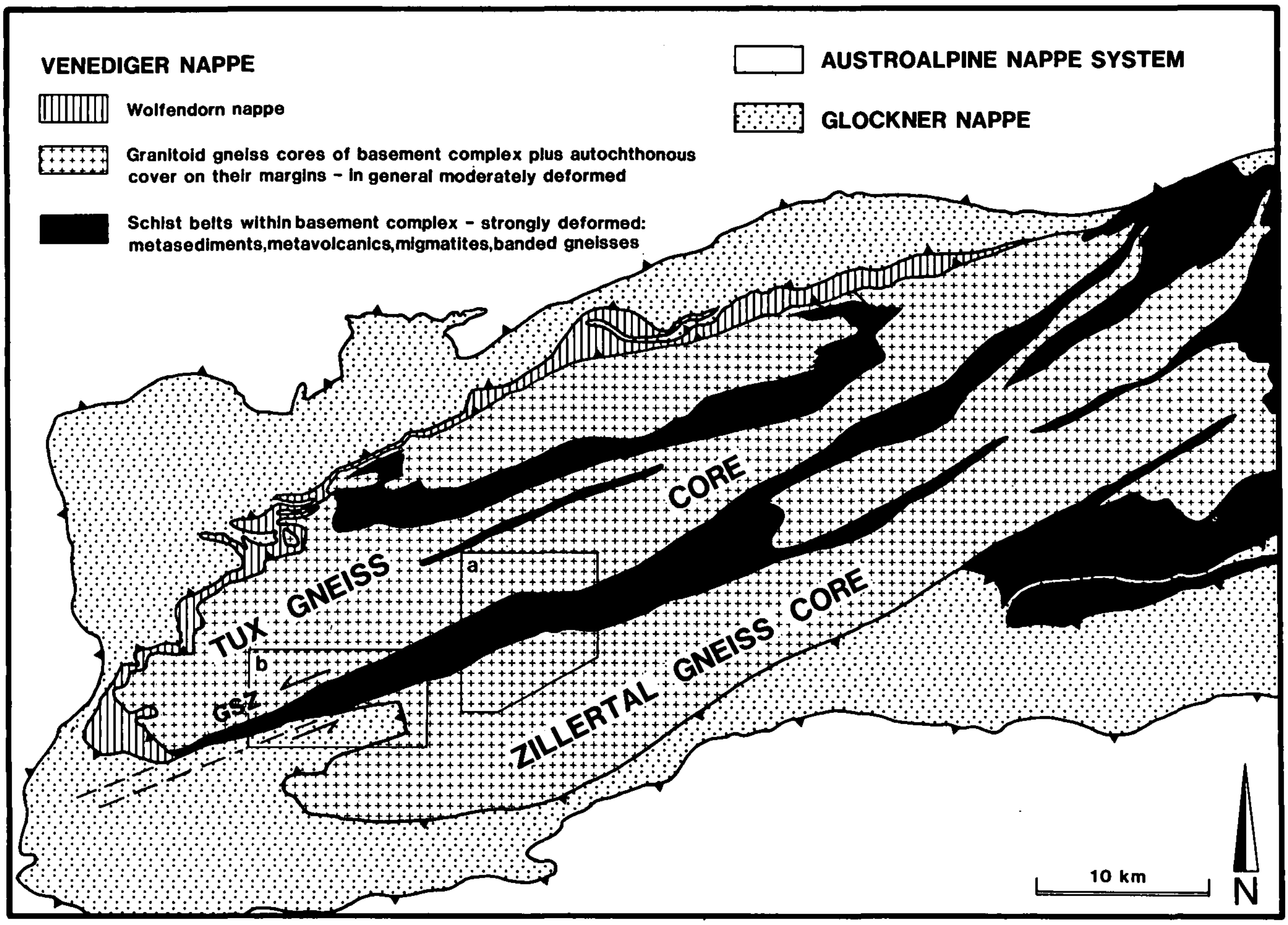
2. Geological Setting

The Tauern Window exposes a section of Penninic basement and cover rocks beneath the Austroalpine nappes (Fig. 1, Fig. 2). Extensive reviews of the regional geology are provided by OXBURGH (1968), BÖGEL & SCHMIDT (1976), FRISCH (1976), and TOLLMANN (1977). The lower tectonic mega-unit, the Venediger Nappe, comprises basement rocks and their post-Variscan cover (FRISCH, 1980). The basement complex consists mostly of Carboniferous granite gneisses intruded into Paleozoic clastic and volcanic sequences, in part forming migmatites (SATIR & MORTEANI, 1980; LAMMERER, 1986). This basement is thought to have been affected by pre-Alpine deformation and nappe tectonics (FRASL & FRANK, 1966; FRISCH, 1977, 1980). It is covered by a thin and uncomplete sedimentary sequence of Mesozoic age.

The Venediger Nappe, itself structurally complex, is buried by the thrust mass of the Glockner Nappe. The



Text-Fig. 1.
Geological sketch map of the Eastern Alps showing the position of the Greiner Shear Zone in the Tauern Window and related faults.
G = Greiner Shear Zone, A = Ahrntal fault, S = Salzachtal fault, DAV = Defereggen-Antholz-Vals fault, KV = Kalkstein-Vallarga fault, PL = Periadriatic lineament, J = Judicaria fault, E = Engadine fault.
Simplified after BÖGEL & SCHMIDT (1976).



Text.-Fig. 2.
Geological map of the western Tauern Window after FRISCH (1980).
The part of the map covered by the Penninic basement complex shows the aereal distribution of strongly deformed rocks (black) and moderately deformed to undeformed rocks (cross ornament).
GSZ = Greiner Shear Zone. Polygons a (Fig. 3) and b (Fig. 4) outline the studied areas.

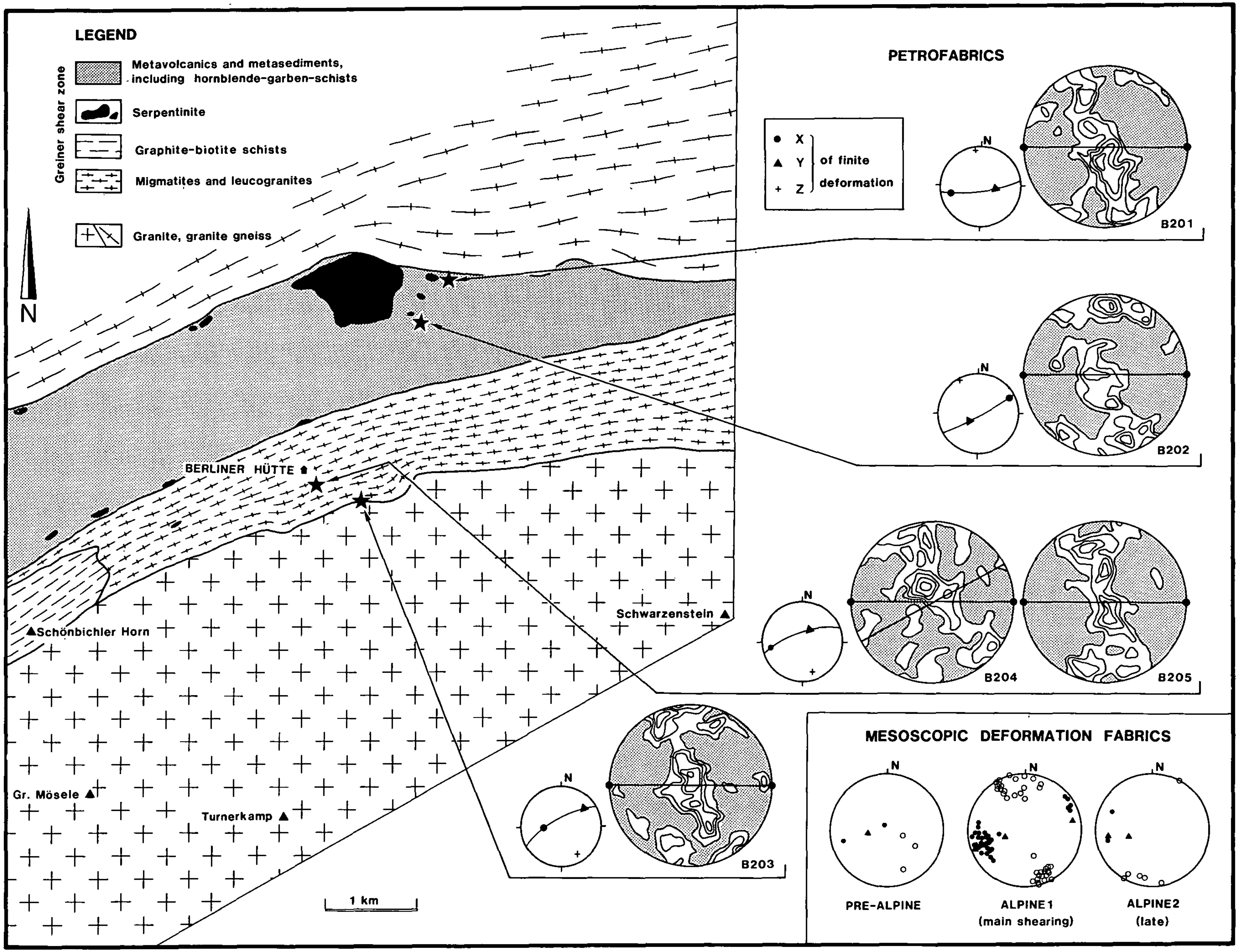
latter represents tectonized relicts of a Mesozoic ocean floor, and its sedimentary cover (BICKLE & PEARCE, 1976; ERNST, 1973; FRISCH, 1974, 1980). A zone at the base of the Glockner nappe contains Eo-Alpine high pressure metamorphic assemblages (ACKERMAND et al., 1978; MILLER, 1977; HOLLAND, 1979; FRANZ & SPEAR, 1983) demonstrating that it formed part of a subduction complex in the Cretaceous. The thermal peak of metamorphism was reached about 40 Ma ago, well after the pressure maximum (see discussion in SELVERSTONE, 1985).

The Greiner schist belt is sandwiched between the Tux gneiss core to the N, and the Zillertal gneiss core to the S. Classically it has been interpreted as a large, tight synform of pre-Alpine metasedimetary cover of the Tux and Zillertal gneisses (CHRISTA, 1931; LAMMERER et al., 1976; FRISCH, 1977). Structural support for this concept is mainly given by a kilometer-amplitude syncline of Triassic marbles and quartzites between St. Jakob and Pfitscher Joch (Fig. 4). However, there is no obvious large-scale bilateral symmetry of lithologies that would suggest that the structure is that of a single large fold. In contrast to large parts of the more rigid gneisses, the Greiner schist formation suffered intense Alpine deformation. The schist belt consists of metavolcanic hornblende schists, serpentinites, and graphite-biotite schists grading into migmatites near the contact with the Zillertal gneiss core (Fig. 3).

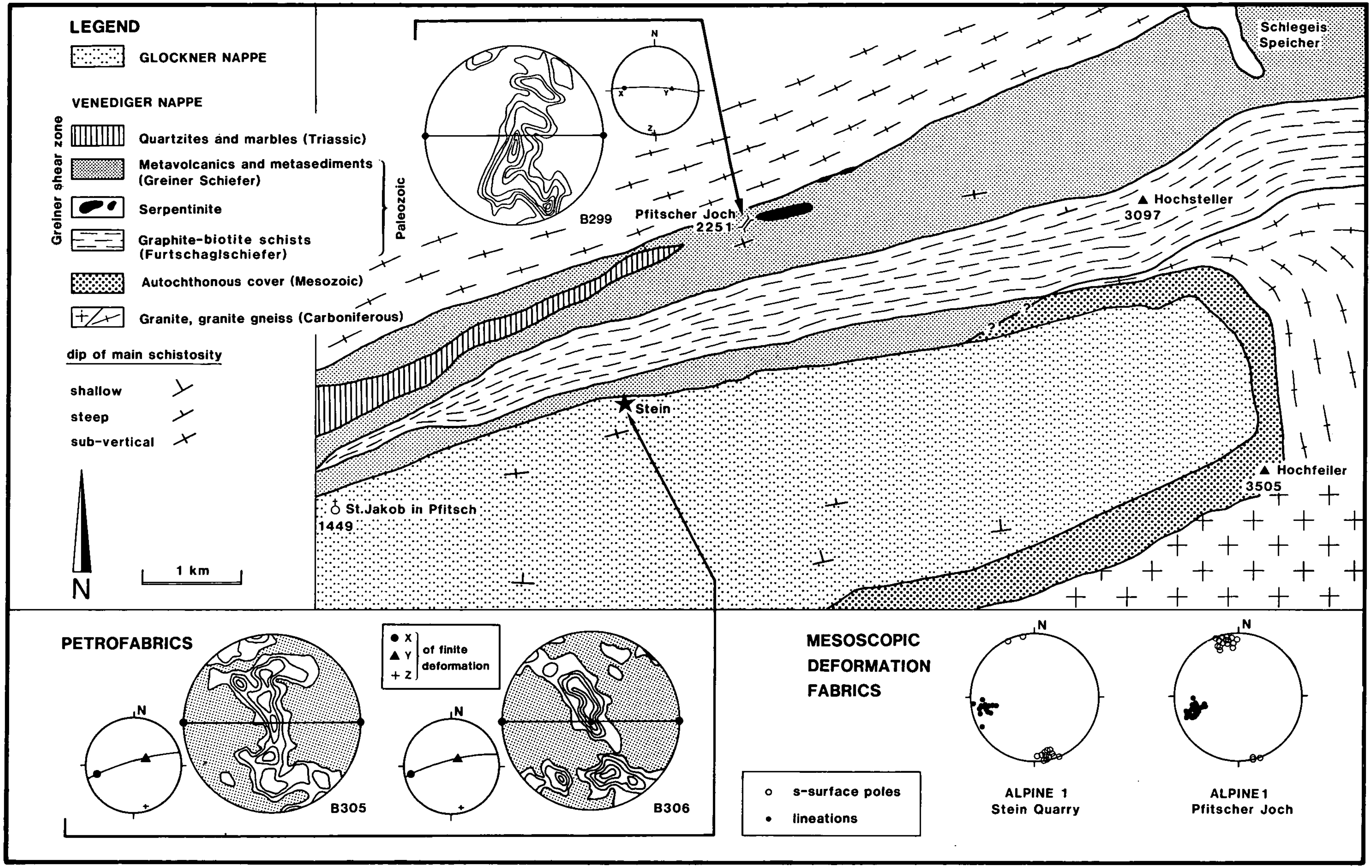
3. Mesoscopic Structures and Deformation History

The best insight into the deformational history of the Greiner schists is offered by the glacier polished surfaces around Berliner Hütte and along the footpath from there to the Schönbichler Horn (see Fig. 3 for locations). Both graphite-biotite schists and migmatites display a pre-Alpine foliation defined by deformed mineral aggregates in the schists, and stretched and boudinaged melanocratic layers or pods in the migmatites. The pre-Alpine fabric is crosscut by aplitic dykes related to the Permo-Carboniferous intrusives.

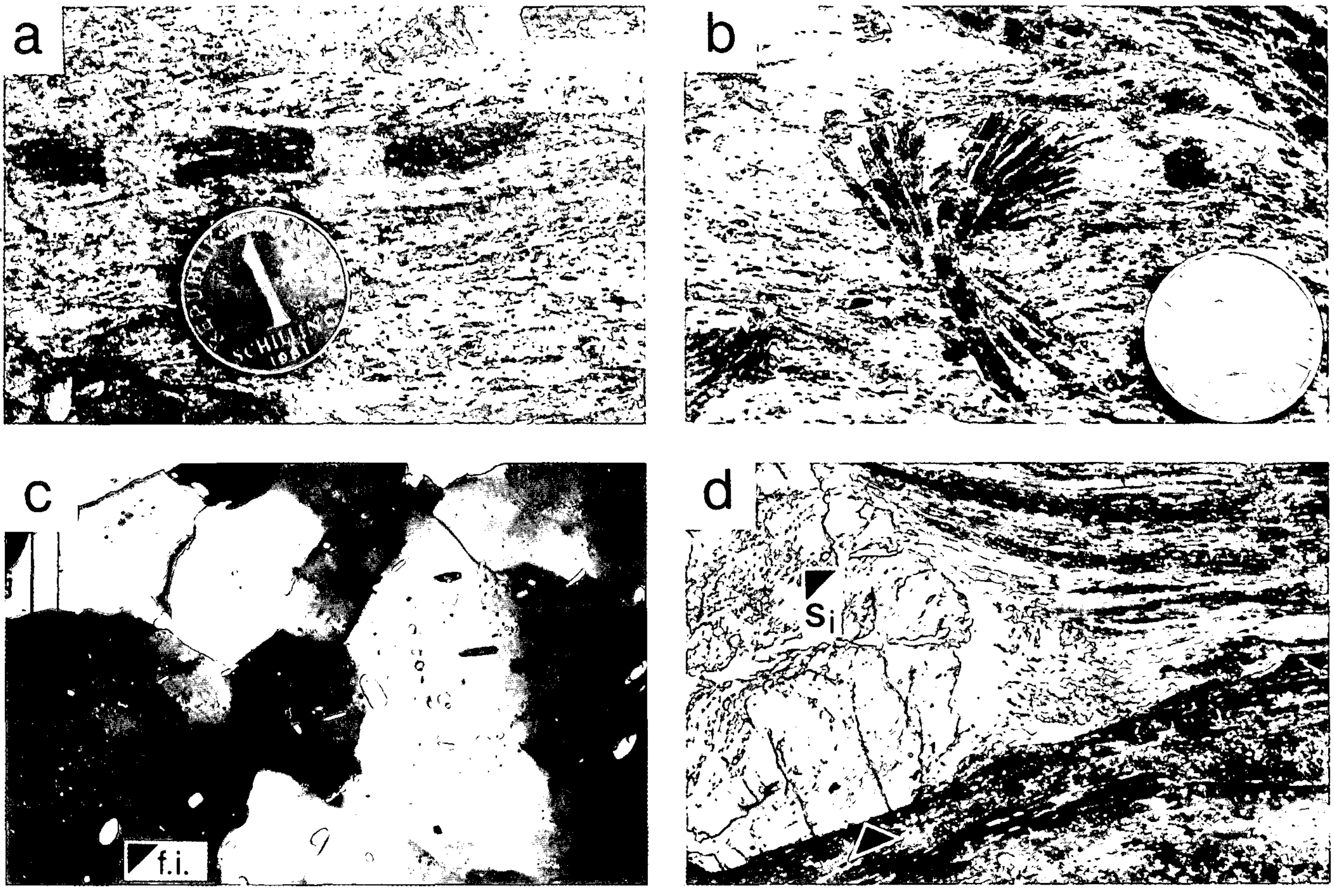
The dominant ENE–WSW-trending structures are the result of the second deformation visible in the field, and are of Alpine age. This deformation affects all rocks of the Greiner schist belt. It overprints the pre-Alpine fabric and aplitic dykes as well as, to a variable degree, the metagranites and metatonalites of the adjacent gneiss cores. It is characterized by a steeply dipping foliation (Figs 3, 4) with a consistent trend parallel to the near-vertical boundaries of the schist belt (e.g. LAMMERER, 1986). A strong mineral stretching lineation plunges WSW at shallow angles (Figs. 3, 4), which is, in general, defined by stretched quartz aggregates, elongate feldpar, and shape preferred alignment of small hornblende crystals as well as oval-shaped cordierite pseudomorphs (LAMMERER, 1986). The fa-



Text-Fig. 3.
Simplified geological map of the Berliner Hütte area (after LAMMERER et al., 1976).
Shown are mesoscopic deformation fabrics and quartz ‹c›-axes fabrics. All diagrams are lower hemisphere, equal area projections.
Mesoscopic fabrics: open circles = poles to foliation; solid circles = stretching lineations; solid triangles = fold axes.
The stippled areas in the quartz fabric diagrams represent population densities less than uniform distribution. Contour values are 1, 2, 3, 4, 6 times uniform distribution. 150 ‹c›-axes were measured at random in every sample.
Horizontal lines = trace of the main Alpine foliation; black dots = stretching lineation. The second solid line in B204 is the trace of a single set of extensional crenulation cleavage.
The small diagrams depict the orientation of the principal strain axes for each sample: solid circle = X; solid triangle = Y; cross = Z; solid line = foliation trace.



Text.-Fig. 4.
Simplified geological map of the Pfitscher Joch area (after BAGGIO et al., 1975; LAMMERER et al., 1976).
Quartz ‹c›-axes fabrics of the Stein quarry (lower diagrams) and a cm-scale late Alpine dextral shear zone near Pfitscher Joch (upper diagram).
Sign conventions are as in Fig. 3. 110 quartz ‹c›-axes were measured at random in each specimen. Contours are 1, 2, 3, 4, 6, 10 times uniform distribution.



Text.-Fig. 5.
a) Boudinaged hornblende crystal in "garben" schists of the Greiner schist belt. Note internal fabric within the hornblende, and its continuity with the external main Alpine foliation.
Locality: Schwarzsee, sampling site of B202 (Fig. 3).
Section perpendicular to foliation and parallel to stretching direction.
b) Hornblende "garben" (sheafs) overgrowing main Alpine foliation.
Same locality and orientation as in a).
c) Microstructure of deformed and statically annealed quartzite of the Greiner schist belt.
Note abundance of equilibrium grain boundaries and triple points. Fluid inclusion (f.i.) has negative crystal shape.
Crossed nicols, long side of micrograph is 1 mm.
d) Rotated garnet in mica schist of the Greiner schist belt.
Internal fabric (Si) is plane in inner garnet core, rotational in outer core and part of rim. Lower arrow points out euhedral posttectonic overgrowth without internal fabric. Top of micrograph shows NNW, rotation sense of garnet is anticlock- wise (sinistral).
Crossed nicols, long side is ca. 10 mm.

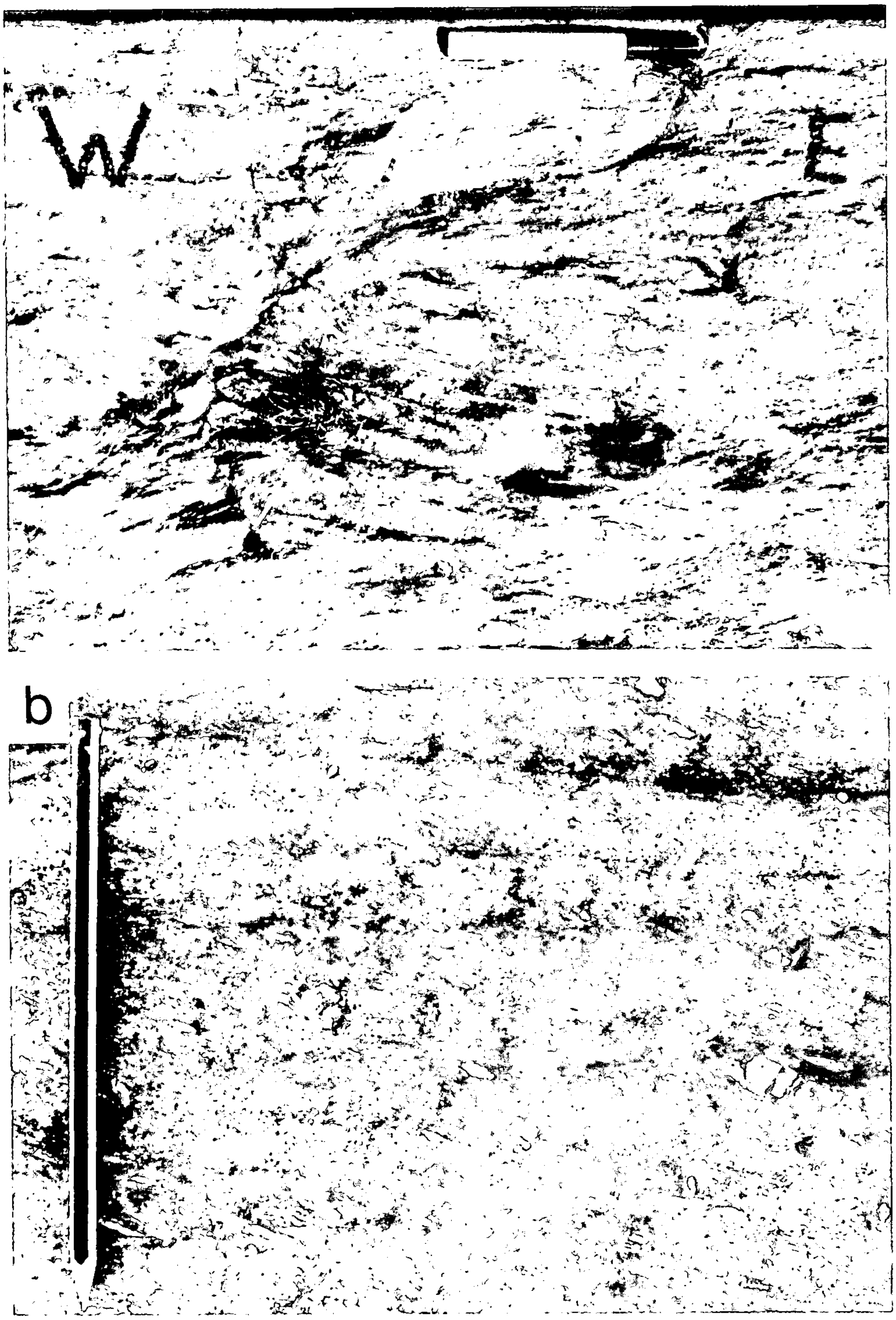
mous hornblende "garben" (sheafs) are syn- to posttectonic with respect to this second deformation. Many hornblende crystals are boudinaged or bent (Fig. 5a,b) indicating post-crystalline strains. However, most crystals overgrow the second foliation and lineation. Figure 5b shows that the garben do not only radiate within the plane of foliation but also across it. Associated folds of the first foliation or the migmatitic banding are exceedingly rare but where encountered, their axes are always sub-parallel to the stretching lineation (Fig. 3). Asymmetric mesoscopic structures in the XZ plane of finite strain indicate a sinistral sense of shear. Figure 6a shows asymmetric foliation boudinage (PLATT & VISSERS, 1980), and Figure 6b asymmetric tailed K-feldspar porphyroclasts of the σ-type (JORDAN, 1986).

Triassic quartzites at the strongly sheared and sliced base of the Glockner Nappe in the quarry of Stein (Fig. 4) display foliation and lineation orientations identical to those within the Greiner schist belt. Due to this evidence, we conclude that the Glockner Nappe was already in place during the strong shearing event in the Greiner schist belt.

The main Alpine deformation fabrics in the Greiner rocks are locally overprinted by steep-sided centimeter- to meter-scale shear zones. The trend of the shear zone boundaries is 270° to 300°, and associated stretching lineations as well as fold axes have a gentle westerly plunge (Fig. 3). The sense of shear along these zones is consistently dextral, and there is some retrograde alteration of the earlier Alpine mineral assemblages, which attained the greenschist/amphibolite facies boundary.

4. Quartz ‹c›-Axes Facrics

Quartz rich tectonites were sampled on a N–S profile across the Greiner schist belt in the vicinity of Berliner Hütte (Fig. 3). Unfortunately the central part of the zone lacks quartzites pure enough for petrofabric analysis. Some preferred orientation patterns of quartz ‹c›-axes are similar to asymmetric type I crossed girdles in the sense of LISTER & WILLIAMS (1979). This counts espe-



Text.-Fig. 6.
a) Asymmetric foliation boudinage in meta-conglomerate. W face of Rotbachlspitze.
b) asymmetric tailed K-feldspar porphyroclasts in mylonitic granitic gneiss, both indicating sinistral sense of shear. Foliation is near-vertical, WSW is to the left. Langsee W of Pfitscher Joch (b).

cially for specimens B201, B203 and B205, although none of the fabrics has a complete and evenly populated topology. B204 displays a rather diffuse single girdle inclined with respect to the foliation. The strongest maximum is usually located near the Y axis of finite strain, indicating that a significant portion of the intracrystalline glide in the quartz was on [10$\bar{1}$0] in a ‹11$\bar{2}$0› direction. The stretching lineation therefore corresponds to the glide direction of a majority of the grains, and the deviation from bulk plane flow was probably not very large (see paragraph on strain below). Since the specimens were sampled in localities not affected by the locally developed late dextral shearing, they are interpreted to reflect the main shearing event in the Greiner schist belt. The central girdle portions of the fabrics are consistently oblique with respect to the nearly vertical XY plane of finite deformation, as marked by the main Alpine foliation. Empirical interpretation (e.g. BOUCHEZ & PECHER, 1981; BEHRMANN & PLATT, 1982) suggests a sinistral sense of vorticity at least in late stage flow during the shearing event. "Late stage" may signify the last approximately 30 % axial shortening parallel to Z. This seems to be the minimum shortening strain needed to create or substantially modify a preferred ‹c›-axes orientation pattern of distinct topology (see fabric modelling of LISTER & HOBBS, 1980). Thus, the petrofabric data indicate that the Greiner schist belt acted as a sinistral shear zone, accommodating a WSW–ENE relative movement between the comparatively rigid Tux and Zillertal gneiss cores.

Supporting evidence for this interpretation comes from the sense of rotation of synkinematically grown garnet (Fig. 5d), orientations of a single set of extensional crenulation cleavage (specimen B204, Fig. 3), and the mesoscopic shear indicators mentioned in the last Section (Fig. 6).

Two supplementary samples were collected from the quartzite quarry at Stein (Fig. 4) about 12 kilometers WSW of Berliner Hütte along strike of the Greiner Shear Zone. The quartzites, which represent terrestrial or shallow- water meta-sandstones, are considered by FRISCH (1980) to be part of the imbricated basal zone of the otherwise mainly oceanic Glockner Nappe.

Both quartz ‹c›-axes fabrics have crossed-girdle outlines, revealing kinematic characteristics similar to those within the Greiner schist belt. B305 shows a tendency towards development of a small circle girdle around Z indicating that deformation is likely to have been in the flattening field. These data confirm that the overlying Glockner Nappe was affected by the same episode of sinistral shearing as the Penninic basement complex. At least in the place where the Glockner Nappe overlies the Greiner schist belt in the Pfitsch Valley, no later nappe movements between the two units occurred. Also any deformation associated with earlier nappe emplacement (e.g. deformational episodes D_1 and D_2 of LAMMERER, 1988) are overprinted by the sinistral movements. Critical overprinting relationships to support this can be found in the southwestern continuation of the Greiner schist belt in the lower Pfitsch valley. Along the old road between Kematen and Sterzing (around UTM 5202500/693000) isoclinal folds with vertical axial planes and associated foliation overprint older folds and foliations (presumably D_2 of LAMMERER, 1988) within the calcschists of the Glockner Nappe.

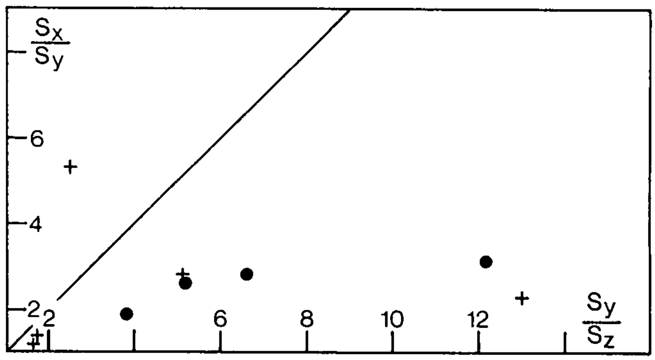
A small-scale E–W-trending shear zone near Pfitscher Joch was found overprinting the main Alpine structures. The ‹c›-axes fabric of a quartz-rich lithology in this shear zone was measured. The central portion of the girdle indicates a clockwise sense of vorticity (Fig. 4). This suggests a dextral sense of displacement, in line with the mesoscopic observations on late Alpine shear zones around Berliner Hütte. Note, however, that one of the two strong population maxima is located on one of the peripheral legs of the crossed girdle. This pattern is best interpreted as heritage of the earlier sinistral episode.

5. Finite Strain

The Greiner schist belt contains a laterally persistent layer of a deformed metaconglomerate (LAMMERER, 1986; LAMMERER et al., 1976; DE VECCHI & BAGGIO, 1982), which is considered to be the basal formation of the post- Variscan cover sequence. Finite strain of the pebbles was analyzed using LISLE's (1977) harmonic mean method. The XZ plane of finite deformation is subhorizontal. The values for ENE–WSW elongation and NNW–SSE shortening in our samples can be seen from Table 1. Due to a competence contrast between pebbles and matrix, the pebbles probably reveal only part of the bulk strain, and constitute a minimum estimate. In a Flinn plot all samples lie within the flattening field with k-values smaller than one (Fig. 7). This means subvertical stretch in the Y direction which needs to be matched by a corresponding change in shape of the Tux and Zillertal gneiss wall rocks. Indeed, ratios of principal strains in sheared Zillertal gneisses (Fig. 7; LAMMERER, 1988: Fig. 9.) are similar to those in the deformed conglomerates with one exception.

Table 1.
Listing of finite deformation data.
$\bar{H}$ = harmonic mean; n = number of measurements per principal section; S = stretch; X, Y, Z = principal axes of finite strain (X>Y>Z).

Sample No.	B300	B301	B304	B355
$\bar{H}_{X/Z}$	39.51	19.33	13.64	7.32
n	16	54	19	7
$\bar{H}_{Y/Z}$	12.54	6.78	5.15	3.90
n	30	52	23	6
S_X	4.99	3.80	3.30	2.39
S_Y	1.58	1.33	1.25	1.27
S_Z	0.13	0.20	0.24	0.33



Text.-Fig. 7.
Flinn plot of strain data.
Dots = metaconglomerates of the Greiner schist belt.
B300, B301, B304 come from the surroundings of Pfitscher Joch, B355 comes from Schwarzsee.
Crosses = sheared Zillertal Zentralgneis (from LAMMERER, 1988).

6. Relation between Deformation and Metamorphism

The quartzites suffered thorough static annealing after deformation. Quartz grains are large and equant, undulatory extinction is absent, and grain boundaries are dominantly straight with near equilibrium configuration of triple points (Fig. 5c). There are fluid inclusions with equilibrated negative crystal shapes (Fig. 5c).

A closer approximation of the relations between deformation and metamorphism can be attempted by studying the relationships between the formation of the main Alpine foliation and growth of p-T-critical metamorphic minerals. Pargasitic hornblende is syn- to postkinematic. Although many crystals do not show deformation, others are bent or boudinaged (Fig. 5a,b). A close look at Fig. 5a reveals that the boudinaged hornblendes have a planar internal fabric continuous with the external foliation. This allows for the interpretation of syntectonic overgrowth of the foliation, no rotation, and later breaking up of the hornblende by progressive deformation. These observations are somewhat at variance with SELVERSTONE's (1985) interpretation, who emphasizes that hornblende growth was entirely posttectonic. SELVERSTONE et al. (1984) suggest that some of the inclusions in hornblende are pseudomorphs after lawsonite. This indicates that deformation started while the rocks were still in the lawsonite stability field on their p-T-time path. The fact that there are no pseudomorphs preserved in the rock matrix means that deformation continued after lawsonite breakdown, deforming its break-down products beyond recognition. The large euhedral garnet of the graphite-biotite schists and the hornblende garben schists also suggests a syn- to posttectonic growth with respect to the main Alpine shearing episode. The garnet overgrows a foliation defined mainly by graphite particles. This internal foliation has ent a stage of posttectonic overgrowth, but the presence of pressure shadows with some grains indicates that deformation partly continued until growth of the garnet rims terminated. In most cases kyanite and staurolite porphyroblasts show posttectonic overgrowth of the main Alpine foliation.

From the above observations and Fig. 15 of SELVERSTONE et al. (1984), the p-T conditions for the beginning and the end of progressive shearing can be roughly estimated. Deformation began at minimum pressures between 8 and 10 kbar and temperatures between 450 and 550°C. It ceased at pressures between 6 and 8 kbar and temperatures between 500 and 570°C. This constrains an average syntectonic decompression of roughly two kilobars within the Greiner schist belt, if the high-pressure shearing preserved in hornblende inclusions is formed by the same tectonic event. Considering a rock density of 2.7 g/cm³, a vertical movement component of more than 7 kilometers along the Greiner schist belt can be calculated. In view of the limits on geobarometric constraints, however, this number should be viewed with some caution. On the other hand the idea of syntectonic decompression is independently supported by geobarometric data from the Glockner Nappe south of the Stein quarry area (SELVERSTONE & SPEAR, 1985). This part of the nappe rests upon Zillertal gneisses and probably did not suffer pressures much in excess of 7.5 kb. No fault of great throw can be identified between the axial crest of the Zillertal core and the Greiner schist belt. It follows that the region of the Zillertal core and its cover must have held an approximately constant depth during the sinistral shearing episode. Thus, juxtaposition of the assemblages indicating different pressure histories was probably enabled by the movements along the Greiner schist belt.

7. Discussion

7.1. Age Constraints for Deformation

An excellent discussion of the pressure-temperature-time evolution of metamorphism in the Greiner schist belt is to be found in SELVERSTONE (1985). The arguments are based on published isotopic age data from other parts of the Tauern Window, namely those of RAITH et al. (1978) and BORSI et al. (1978), and call for a thermal peak of metamorphism around 40 Ma ago. An exact age for the pressure peak in the Greiner schist belt cannot be provided, but the ages of high pressure amphiboles in the central Tauern Window (RAITH et al., 1977) suggest that the subcretion of the Penninic below the Austroalpine upper plate, and therefore the deepest burial, was essentially accomplished before the Cretaceous/Tertiary boundary. As the main Alpine shearing in the Greiner schist belt has to be placed between the pressure and temperature peaks of metamorphism, we conclude that the movements along the Greiner schist belt are of latest Cretaceous to early Tertiary age and ceased around 40 Ma ago. Note that SELVERSTONE's (1985) evolutionary model calls for the pressure divergence between the juxtaposed parts of the Glockner Nappe and the Penninic basement complex to have been eliminated in the time span between 60 and 40 Ma ago.

7.2. Tectonic Implications

The strong fabric orientation caused by the sinistral shearing episode in the Greiner schist belt has obliterated possible older Alpine fabrics caused by the collision and crustal thickening in the Cretaceous. The megascopic expression of the collisional stage are nappes and thrust slices accompanied by folding on all scales as well as an early Alpine foliation in rocks outside the Greiner Shear Zone. Recent models from the Austroalpine realm speak in favour of oblique collision with west-directed nappe transport, followed by northward compression (RATSCHBACHER, 1986). Similar displacement paths were documented at the base of the Austroalpine (BEHRMANN 1987a), and near the top of the Penninic realm (RING et al., 1988, 1989). This explains why the foliation and stretching lineation within and outside the Greiner schist belt show a parallel trend. Probably a pre-existing foliation, which was formed during the west-directed nappe transport and steepened by folding around WSW-ENE fold axes by NNW-SSE shortening, has been reactivated by the shearing event. In the Bündner Schiefer of the Glockner Nappe, the SW prolongation of the Greiner schist belt exhibits three penetrative deformation events (see above) instead of two outside the shear zone. Why the early Alpine deformation events found in the Glockner Nappe (e.g. LAMMERER, 1988) cannot be identified in the Greiner schist belt on a mesoscopic scale remains unclear. Ductile deformation during stacking of an orogenic wedge, however, does not leave its trace everywhere, and orogenic accretion and its fabric of the Glockner Nappe may be older than that of the Venediger Nappe.

Approximately N-directed compression across the Alpine orogenic wedge may be responsible for the sinistral wrenching in the Greiner zone after completion of the nappe movements. The concept of large-scale transcurrent faulting (e.g. TAPPONNIER, 1977; TAPPONNIER et al.,1982; HOWELL et al., 1985) as a consequence of collision may be an explanatory model for the Greiner Shear Zone, which was active in the time span between crustal subcretion and the thermal peak in the ascending nappe pile.

There are other large ductile or semibrittle fault zones in the Austroalpine basement to the south of the Tauern Window (see Fig. 1), which have the same orientations and kinematics as the Greiner Shear Zone and are of broadly similar age. Across these faults progressively deeper crustal levels are exposed approaching the Tauern Window from the south. The most prominent example is the Defereggen-Antholz-Vals lineament to the south of the western Tauern Window (Sassi et al., 1978; STÖCKHERT, 1982; KLEINSCHRODT, 1987).

LAMMERER (1988: Fig. 11) presented a model to explain the formation of the present structure of the western Tauern Window by bulk dextral transpression. Note that the amount of shearing applied in the model relies solely on strain analyses (LAMMERER 1988: Fig. 9) which only furnish information on the extent, but not on the kinematics of deformation and its external reference frame. Also the model makes the untenable assumption of homogeneous simple shear in rocks with a wide range of different rheologies, and refers to an initial undeformed state that is inherently unknown. Simple shear also contradicts the strain data (LAMMERER 1988: Fig. 9, and this paper).

The quoted kinematic data from small scale ductile shear zones of the Zillertal gneisses (LAMMERER 1988: Fig. 10) are also at variance with the model, as there is a fairly even distribution of sinistral (250° strike) and dextral (mostly 290° strike) shear zones. This may either be achieved by a single phase of coaxial N-S lateral compression, or by superposed sinistral and dextral lateral shearing. The data set from the adjacent Greiner schists presented in this paper suggests the second possibility with a time sequence of sinistral and dextral shearing (see above).

Large scale tectonic unroofing of the Tauern Window as documented by SELVERSTONE & Hodges (1987), SELVERSTONE (1988), BEHRMANN (1987b, 1988) and GENSER & NEUBAUER (1989) most likely postdates the wrenching and leads to a further substantial reduction of the tectonic overburden in the middle and upper Tertiary.

8. Conclusions

Structural and petrofabric analysis in the Greiner schist belt reveals a large scale sinistral shear zone between the Tux and Zillertal gneisses in the Penninic basement complex of the Venediger Nappe in the western Tauern Window. The interaction of shearing and growth of pressure/temperature critical minerals indicates an approximate two kilobar syntectonic decompression of the Greiner schist belt rocks.

Isotopic ages in connection with petrological data constrain the age of shearing between latest Cretaceous and mid-Tertiary. This is after subduction/collision-related nappe movements and folding were completed, and essentially before the late Eocene thermal peak of metamorphism. These conclusions are supported by independent structural evidence. Sinistral shearing is compatible with continuing crustal convergence, which is considered to have followed dextral transpressive collision of Austroalpine and Penninic (Venediger Nappe) crustal blocks. The shearing may be interpreted as a response of the crust to continued convergence on the one hand, and as a reflection of the differential uprise of blocks of thickened crust after collision on the other.

In line with NEUBAUER (1988) we propose that the Greiner schist belt belongs to a set of east-north-east-trending sinistral shear zones in the Penninic realm of the Tauern Window and the Austroalpine basement to the south of it. Together with the dextral Pustertal-Gailtal line, which forms part of the Periadriatic lineament, this set of faults may be interpreted as a conjugate set of crustal-scale shear bands (Fig. 1). From north to south, deformation mechanics in the shear zones shows characteristics of increasingly higher crustal levels. This is in accordance with the observation that the northern block of the Greiner Shear Zone was elevated relative to the southern block during shearing and supports the suggestion that the sinistral shears to the south belong to the same set of faults.

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