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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Zusammenfassung

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

Die linksseitige Zerscherung geht wahrscheinlich auf Kru-
stenbewegungen in der ausgehenden Kreide oder im Alttertiär
zurück. Sie war in der Greiner Scherzone von einer Dekom-
pression des Systems um etwa zwei Kilobar begleitet. Die Be-
wegungen erfuhren auch die überlagermögliche Glocknerdecke.
Dies belegt, daß sie jünger als die eoalpine Deckenstapelung
erdickung der Kruste sind. Die Seitenverschiebungen
weisen auf erhebliche latere Formänderung des verdickten
Orogenkeils hin. Sie können mit fortgesetzter krustaler Kom-
pression nach der Kollision der Europäischen und der Adriati-
ischen Platte erklärt werden.

Abstract

Structural analysis of the Greiner schist belt located be-
 tween the Tux and Zillertal granite gneiss "cores" reveals two
phases of Alpine strike-slip shearing imprinted onto a pre-Al-
Pine 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 li-
mited 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 accompani-
ed by an estimated two kilobar decompression within the
Greiner Shear Zone. The movement also affected the overly-
 ing Glockner Nappe and therefore is younger than the eo-
Alpine overthrusting. The strike slip motion indicates major late-
ral 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 paleogeog-
graphic 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
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 STOCKHERT (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 (1986, 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 of 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

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**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** = Almen fault
- **S** = Saizachtal fault
- **DAV** = Deferegggen-Antholz-Vals fault
- **KV** = Kalkstein-Vallargafault
- **PL** = Periadriatic lineament
- **J** = Judicaria fault
- **E** = Engadine fault

Simplified after BÖGEL & SCHMIDT (1976).
VENEDIGER NAPPE

Wolfendorn nappe

Granitoid gneiss cores of basement complex plus autochthonous cover on their margins – in general moderately deformed

Schist belts within basement complex – strongly deformed:
metasediments, metavolcanics, migmatites, banded gneisses

AUSTROALPINE NAPPE SYSTEM

GLOCKNER NAPPE

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 aerial 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 (Ackermann 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 metasedimentary cover of the Tux and Zillertal gneisses (Christa, 1931; Lammerr 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 Schönbielcher 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 apatitic 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 apatitic 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. Lammere, 1986). A strong mineral stretching lineation plunges WSW at shallow angles (Figs. 3, 4), which is, in general, defined by stretched quartz aggregates, elongate feldspar, and shape preferred alignment of small hornblende crystals as well as oval-shaped cordierite pseudomorphs (Lammere, 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 Pfltscher 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 Pfltscher 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 Greinerschist 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 Greinerschist 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 (S) is plane in inner garnet core, rotational in outer core and part of rim. Lower arrow points out euhedral post-tectonic overgrowth without internal fabric. Top of micrograph shows NWW, rotation sense of garnet is anticlockwise (sinistral).
Crossed nicols, long side is ca. 10 mm.

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-
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 [1010] in a \( \langle 1120 \rangle \) 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 \( \langle c \rangle \)-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 main 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 overly-sense of rotation of synkinematically grown garnet WSW of Berliner Hütte along strike of the Greiner Shear Zone is best interpreted as heritage of the earlier sinistral episode.

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 VICCHI & 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.

### 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 equilibration 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 boudined (Fig. 5a,b). A close look at Fig. 5a reveals that the boudined 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 pro-
gressive deformation. These observations are some-
what at variance with SELVERSTONE’S (1985) interpreta-
tion, who emphasizes that hornblende growth was enti-
relly posttectonic. SELVERSTONE et al. (1984) suggest 
that some of the inclusions in hornblende are pseudo-
morphs after lawsonite. This indicates that deformation 
started while the rocks were still in the lawsonite stabili-
ity 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 recogni-
tion. The large euhedral garnet of the graphite-biotite 
schists and the hornblende garnet schists also sug-
gests a syn- to posttectonic growth with respect to 
the main Alpine shearing episode. The garnet overgrows 
a foliation defined mainly by graphite particles. This in-
ternal foliation has ent a stage of posttectonic over-
growth, but the presence of pressure shadows with 
some grains indicates that deformation partly continu-
ed until growth of the garnet rims terminated. In most 
cases kyanite and staurolite porphyroblasts show post-
tectonic overgrowth of the main Alpine foliation. 

From the above observations and Fig. 15 of SELVER-
STONE et al. (1984), the p-T-conditions for the begin-
ning 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 be-
 tween 6 and 8 kbar and temperatures between 500 and 
570°C. This constrains an average syntectonic decom-
pression 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 verti-
cal 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 fol-
 lows that the region of the Zillertal core and its cover 
must have held an approximately constant depth du-
ring the sinistral shearing episode. Thus, juxtaposition 
of the assemblages indicating different pressure histo-
ries was probably enabled by the movements along the 
Greiner schist belt.

7.2. Tectonic Implications

The strong fabric orientation caused by the sinistral 
shering episode in the Greiner schist belt has obliterated 
possible older Alpine fabrics caused by the collisi-
onal 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 out-
side the Greiner Shear Zone. Recent models from the 
Austroalpine realm speak in favour of oblique collision 
with west-directed nappe transport, followed by north-
ward compression (RATSCHBACHER, 1986). Similar dis-
placement 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 ex-
plains why the foliation and stretching lineation within 
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 
NWW-SSE shortening, has been reactivated by the 
shering event. In the Bündner Schiefer of the Glock-
ner 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 Ven-
ediger 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; TAPPON-
NIER et al., 1982; HOWELLE et al., 1985) as a conse-
quene 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 dextral 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 Defereggeng-Antholz-Vals lineament to the south of the western Tauern Window (Sassi et al., 1978; Stockhert, 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 gneissens 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-Gahtal 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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