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The Alpine Structural Evolution of the Eastern Southalpine Basement

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8 Text-Figures

Ostalpen
Südalpines Grundgebirge
Variszische Orogenese
Alpidische Orogenese
Deformation
Strukturanalyse
P-T-Bedingungen

Contents

Die alpidische Strukturentwicklung im östlichen Teil des südalpinen Grundgebirges

Zusammenfassung

Variskische und Alpine tektonometamorphe Ereignisse können im östlichen südalpinen Grundgebirge unterschieden werden. Alpine Deformationen beanspruchten im wesentlichen das Permo-Mesozoische Deckgebirge, allerdings wurde auch das Variskische Grundgebirge remobilisiert. Relikte einer ersten Deformationsphase im Grundgebirge korrelieren mit einer paläogenen SW bis WSW-gerichteten krustalen Einengung und wurden von neogenen lokalisierten Aufschiebungen überprägt. Diese Aufschiebungen folgen einem NNW/NW-orientierten regionalen Beanspruchungsplan und führten an der Valsugana Line zu nach Südosten, über das mesozoische Deckgebirge der Venetianischen Prä-Alpen, gerichteten Bewegungen. In den nördlichen Südalpen kam es an der Villnöß und der Würzjoch Linie zu nordwärts orientierten Rückaufschiebungen. Strukturen, die mit diesen Rückaufschiebungen in Zusammenhang gebracht werden können, treten auch an der Periadriatischen Linie auf und sind dort mit dextraler Blattverschiebungsdeformation assoziiert. Druck und Temperaturabschätzungen im Grundgebirge liegen bei ca. 200°C und 2 kbar im Raum um Brixen und 150°C und 1.5 kbar an der Basis der Karnischen Alpen.

Abstract

Alpine and Variscan tectonometamorphic events can be unravelled in the eastern Southalpine basement. Alpine contraction mainly affected the Permo-Mesozoic cover, but also remobilised the Variscan basement. Deformation within the quartzphyllitic basement is characterized by distributed Alpine faulting. Relics of a first deformation event in this basement correlate with Paleogene SW to WSW-directed crustal shortening. Associated structures are cut by Neogene reverse faults which follow NNW/NW-oriented regional shortening. The southern part of the basement was thrust southeastward at the Valsugana line onto the Mesozoic cover of the Venetian pre-Alps. In the northern part of the Southern Alps backthrusting towards the north at the Villnöß and Würzjoch lines took place. Structures which can be related to this backthrusting event were also observed at the Periadriatic line where they are associated with dextral strike-slip displacements. P-T conditions in the basement near Brixen were approximately 200°C and 2 kbar, whereas 150°C and 1.5 kbar were estimated for the base of the Carnian Alps.

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1. Introduction

The structure of the Alps results from various superimposed orogenic cycles of which the Alpine orogeny left the most severe imprint. However, the intensity of Alpine deformation and metamorphism differs considerably from place to place and the Periadriatic fault system (Text-Fig. 1) generally separates rocks which suffered intense Alpine polyphase metamorphism and deformation on the north and west from weakly metamorphosed and moderately deformed rocks in the south. In the eastern Southern Alps (Text-Fig. 2) comparison of deformation structures and metamorphism between the pre-Permian basement and the Permo-Mesozoic cover allows to separate Alpine from pre-Alpine induced metamorphic and tectonic events in the basement. We showed that the ductile deformation history of this area is entirely due to Variscan orogenic activity (RING & RICHTER, 1994). Alpine deformation is thought to be mainly restricted to the Permo-Mesozoic cover rocks and has recently been analysed by DOGLIONI (1985, 1987) and DOGLIONI & BOSSELINI (1987). In the basement Alpine overprint is locally absent or weak, because of the rigid behaviour of a large mass of thick (about 2000 m) Permian quartzporphyry (Text-Fig. 2) which largely sealed the basement. Nevertheless, we shall concentrate in this communication on the Alpine structural evolution of the quartzphyllitic basement.

2. Pre-Alpine Geology

The eastern Southalpine basement-cover complex crops out in a 300 x 200 x 150 km large triangle between the Giudicarie line to the west, the Pustertal line to the north (both belonging to the Periadriatic fault system) and the post-orogenic deposits of the Po Plain to the southeast (Text-Fig. 1, 2). The Valsugana line separates the basement and its Permo-Mesozoic cover from the Venetian pre-Alps in the southeast (DOGLIONI, 1987).

2.1. The Sedimentary and Magmatic Record

A huge mass of monotonous quartzphyllite makes up the base of the Southalpine unit in the study area. It is best exposed in the west around Brixen-Toblach, as well as in the Cima d'Asta, Agordo/Cereda and Recoaro windows (Text-Fig. 2). Palynologic data show that clastic sedimentation commenced at least in the Cambrian (KALVACHEVA et al., 1986). Locally metabasalt (Late Ordovician and younger; M. HINDERER, personal communication), metaporphyroid (Late Ordovician; SCHÖNLAUB, 1979) and graphitic, siliceous shale (probably of the same age) are intercalated (e.g. Villnöß-Tal, Text-Fig. 2). The metabasalt shows geochemical affinities to alcalic intraplate basalt (HINDERER, 1989) as well as to subalcalic and tholeiitic basalt (KRECIJ, 1987). The porphyroid is generally correlated to the Blasseneckporphyroid in the Eastern Alps (SCHÖNLAUB, 1979; HEINISCH, 1981). It originated from pyroclastic rocks and lavas in the north (Carnian and Eastern Alps) and subaeric ash-flows in the south (Brixen area, J. LOESCHKE, personal communication). This volcanism was of intermediate to acidic composition and had a calc-alcaline chemistry (e.g. KRECIJ, 1987). Porphyroid volcanism probably took place in a late- to post-collisional back-arc setting which is related to earlier (Cambrian to Early Ordovician?) subduction processes further north (e.g. LOESCHKE, 1989).

Late Ordovician (Ashgillian) carbonates are overlain conformably by Silurian deposits which developed into shallow water carbonate platform facies and shale-dominated basinal facies (SCHÖNLAUB, 1979). This trend continues on into the Devonian when reefs developed temporarily on the carbonate platform. From the Late Devonian (Frasnian) until the Viséan pelagic sedimentation smoothed out the facies differences. Heterogenous flysch sedimentation on continental crust (Hochwipfel Flysch) occurred in an E–W-trending basin from the Viséan until the Westphalian B (TESSENSOHN, 1971) and reflects Variscan orogenic activity. Westphalian D to Stephanian molasse-type sediments (Auernig Schichten) and uppermost Carboniferous to Lower Permian undeformed clastics (Waidbrucker Konglomerat, Nassfeld Schichten) rest unconformly on the deformed older strata. The Late Ordovician to Late Carboniferous strata is exposed in the east (Carnian Alps, Text-Fig. 2).

In the uppermost Carboniferous post-orogenic granitoids intruded, accompanied by large masses of andesitic to rhyolitic, generally ignimbritic volcanism (PICHLER, 1959). Plutonism commenced with calc-alkali granites (e.g. Brixen and Cima d'Asta granites, 290 Ma; BORSI et al., 1972) and evolved to (per) alkaline composition during the Permian (250 Ma; BONIN, 1988). Magmatism seems to be related to strike-slip controlled extensional deformation preceding the formation of oceanic crust. Extension created two major N–S-trending elements, the Atesina platform in the west and the Carnico-Bellunese basin

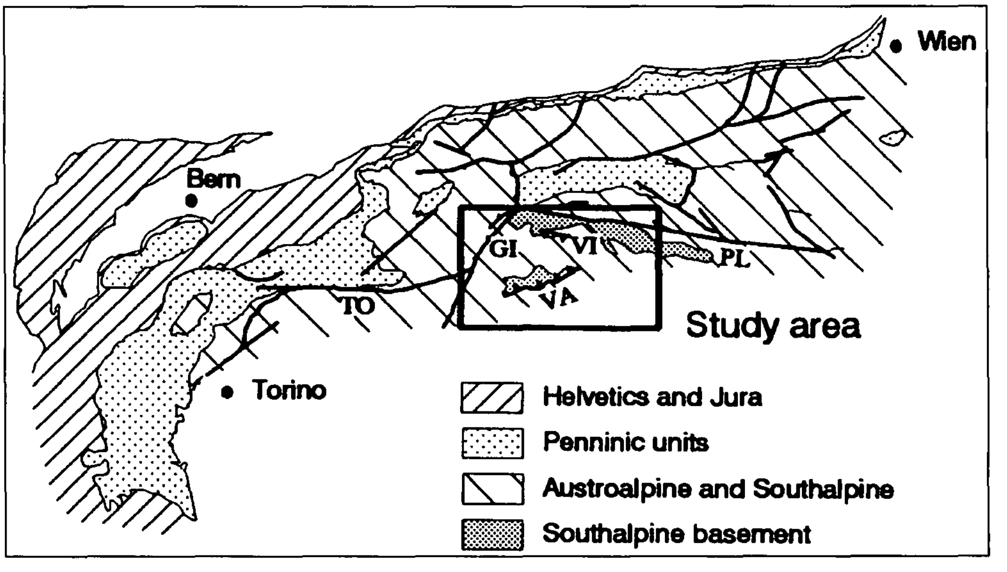
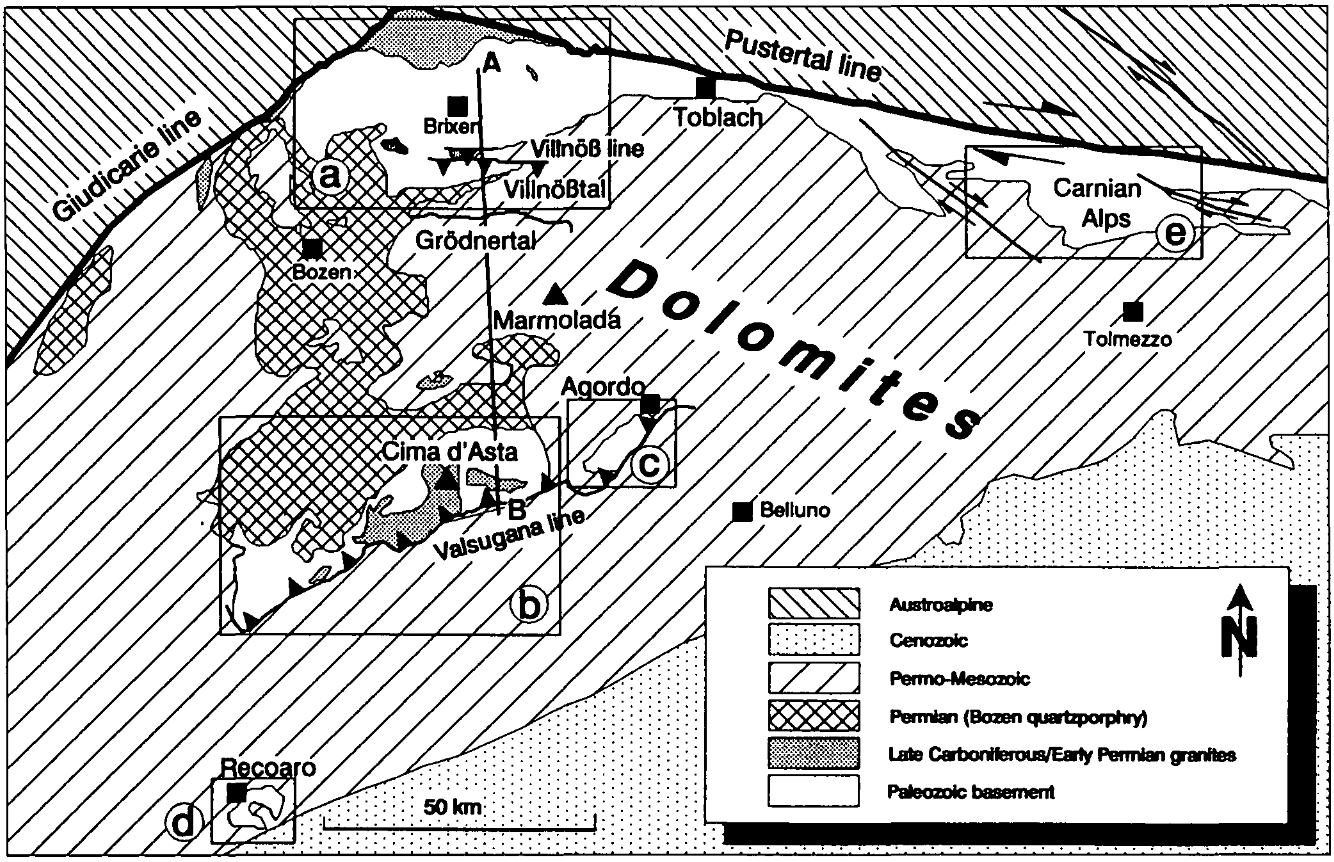


Fig. 1.
Location of study area in the Alps.
GI = Giudicarie line, TO = Tonale line, PL = Pustertal line (all belonging to the Periadriatic fault system), VI = Villnöß line, VA = Valsugana line.



Text-Fig. 2.
Tectonic sketch map of the Southern Alps.
Locations discussed in text; line A-A': cross-section of Fig. 3; boxes (a–e) refer to areas where Variscan deformation was studied (RING& RICHTER, 1994).

in the east (e.g. BOSSELINI, 1965), and minor horst and graben structures (e.g. VIEL, 1979) in the upper Southalpine crust.

During the Late Anisian and Early Ladinian E–W-oriented sinistral transpression set in and caused local transtensile and transpressive deformation (BLENDINGER, 1983) which is related to sinistral movements between Europe and Africa (DOGLIONI, 1987). In the Late Ladinian strike-slip movement, coupled with south-directed thrusting, was restricted to a small "push-up" area around Monte Marmolada. Lateral displacement was more than 10 km and thrusting amounted to more than 3 km (BLENDINGER, 1985). This local phenomenon is explained by a right-stepping left-lateral NNE–SSW-trending fault perhaps connected with emplacement of a magma chamber. Its evacuation in the Latest Ladinian and Early Carnian was associated with the collapse of its roof and extrusion of shoshonitic lavas (BLENDINGER, 1985).

Transitional tholeiites (BONIN, 1988) in the Early Jurassic reflect the opening of the Liguria-Piemont ocean. The Southern Alps became part of the eastern passive continental margin of this ocean, i.e. the northwestern edge of the Adriatic plate. Rifting produced differential subsidence between the Atesina platform and the Carnico-Bellunese basin and N–S-trending normal faults (DOGLIONI, 1987).

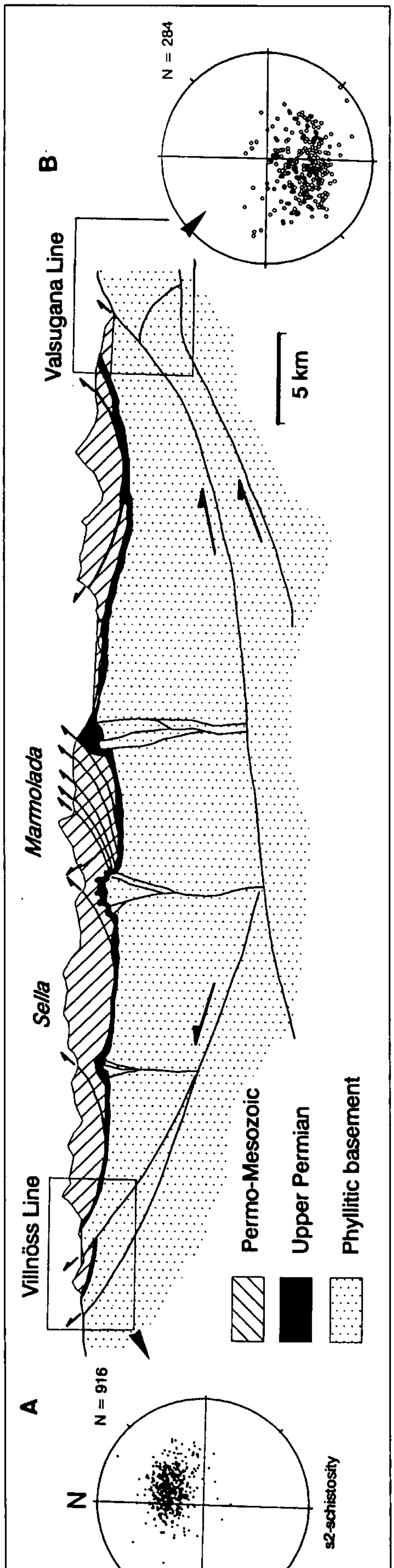
2.2. The Variscan Orogeny in the Eastern Southern Alps

Major Variscan deformation (D_{V2}, where V stands for Variscan) was studied in five areas (a–e in Text-Fig. 2, see RING & RICHTER, 1994, for detailed analysis). It commenced in the Late Carboniferous (310–320 Ma) and lasted until the Carboniferous/Permian boundary (290 Ma). Tectonic movement was north-directed and was accompanied and followed by greenschist-facies metamorphism. Metamorphic conditions reached 450–550°C and 5–6 kbar in the Brixen area and decreased in a southeasterly direction. Thrusting followed subduction of the Plankogel terrane and collision of the Noric terrane (northernmost part of Gondwana) with Laurasia and is interpreted to result from late-orogenic extensional collapse of the Variscan mountain chain. Extensional deformation caused exhumation of the basement rocks as evidenced by greenschist-facies basement pebbles, which show no substantial retrograde overprint, in Late Carboniferous/Lower Permian conglomerates.

3. Structures Resulting from the Alpine Orogeny

3.1. Review of the Structural Evolution of the Permo-Mesozoic Cover

A Late Cretaceous deformation event is restricted to the western Southern Alps and is followed by west to southwest-directed pre-Miocene (Paleogene) thrusting (D_{A1}, where A stands for Alpine; DOGLIONI & BOSSELINI, 1987). Corresponding structures reach as far west as the Bozen anticline and as far north as the Grödnertal (Text-Fig. 2). The Paleozoic basement is thought to lack thrusts or folds



Text-Fig. 3.
Schematic cross-section showing SE-directed thrusting at Valsugana line and N-directed backthrusting at Villnöß and Würzjoch lines.
Boxes refer to sketches in Figs. 6 and 8. Insert: lower hemisphere projection of main (Variscan) foliation, s_{V2}, which traces orientation of the main Alpine faults.

related to this event. During the Neogene the cover was thrust south to southeastwards over the Venetian pre-Alps at the NE–SW-trending Valsugana line (D_{A2}, Text-Figs. 3, 5, 8) and were backthrust to the north at the Villnöß and Würzjoch lines (Text-Figs. 3, 4, 6, 7). Prominent ramp-flat structures (Text-Fig. 5) and NNE–SSW-oriented sinistral as well as NW–SE-trending dextral strike-slip faults in the cover are related to this event (Doglioni, 1987).

The basement accommodated this deformation by complex fault patterns which will be described for the Villnöß, Würzjoch, Periadriatic (N-directed backthrusts) and Valsugana lines (SE-directed forethrust).

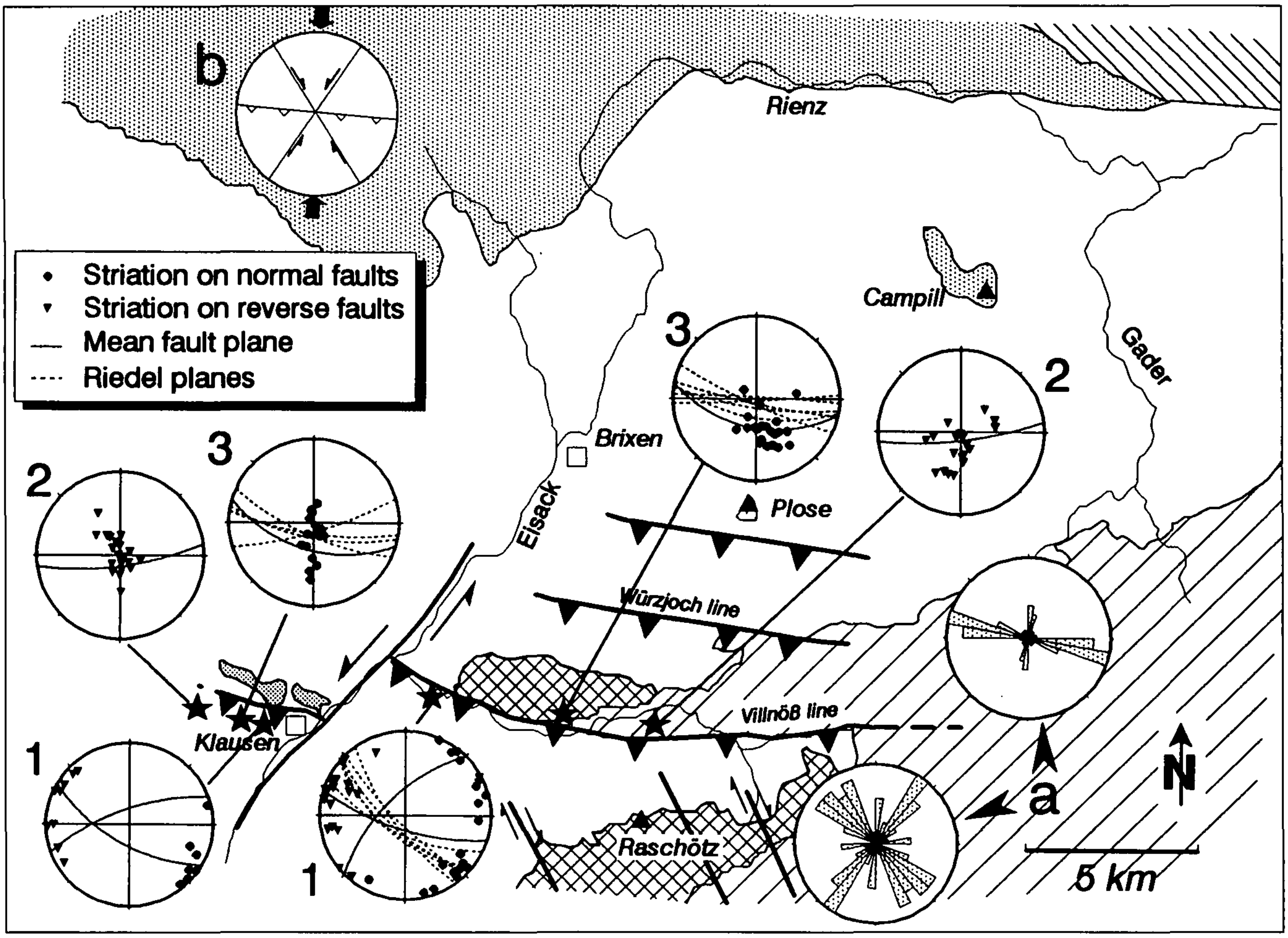
3.2. Description of Major Fault Zones in the Basement

Deformation mechanism in these zones was cataclastic flow. The morphologies of the major fault zones are characterized by the presence of anastomosing clay-rich gouge zones within broad (1–30 m) zones of cataclasite, breccia and hematite-clay-coated fractured rock. The clay and the hematite are derived from the alteration of both feldspar and mafic minerals (mainly biotite and amphibole). Alteration and bleaching of intact rock in the vicinity of faults also occur, but is confined to narrow centimetre-scale zones adjacent to fractures. Tectonic slivers and inclusions in fault zones may approach a metre in diametre; large inclusions are generally rhomb or phacoid-shaped. Phacoids resulted from progressive linking of through-going fault-parallel shear fractures by short cross-fractures. Brittle grain-size reduction during subsequent fault movements streamlined larger inclusions and produced interstitial gouge. Fractures with quartz-clay alteration similar to that which occurs within faults are also spatially associated with faults. Linear grooves and occasionally tectonic "chatter marks" and small step-like slickensides are present on the fault surfaces. These kinematic indicators were used to deduce the slip-direction. At the Villnöß line grooves are non-parallel on adjacent gouge surfaces and indicate that increments of slip were non-coaxial.

3.3. Deformation at the Villnöß and Würzjoch Lines

Results from fault-slip analysis (Text-Fig. 4) at the Villnöß line reveal an early increment of conjugate strike-slip deformation (D_{A1}). Dextrally displacing minor faults strike NE–SW to ENE–WSW and sinistral fault planes strike ESE–WNW to E–W. Related structures are scarce and include sinistrally displacing Riedel shears striking NW–SE. We tentatively correlate this increment with the top-to-the-SW/W-directed thrusting event in the cover (Doglioni & Bosselini, 1987) which was due to overall NE–SW-oriented shortening.

A more pronounced set of structures cuts the strike-slip faults and consists of arrays of mesoscopic faults with off-sets <10 m which are developed in a layer at least 1.5 km thick in the hanging wall of the backthrusts (D_{A2}). Often secondary planes (syn- (R) and antithetic (R_1) Riedel shears; Hancock, 1985) developed and indicate the sense of movement (Text-Fig. 6). Faults take three general attitudes to the main (Variscan) foliation (s_{V2}). They are: (1) initially parallel to s_{V2} and propagate stepwise upward; (2) at a low angle (<30°) to s_{V2}; (3) at a high angle (>40°) to s_{V2}. Sets (1) and (2) show reverse off-sets of s_{V2} and are contraction faults (Norris, 1958). They are associated with fault gouges and kink bands and strike parallel to or up to 45° to the underlying thrust. Set (3) depicts normal off-sets of s_{V2}, they are locally conjugate and are extension faults (Norris, 1958). These faults either strike subparallel or subnormal to the underlying backthrust (Text-Fig. 6f). We observed that the contraction faults were subsequently cut by two or three generations of extension faults which became steeper with time



Text-Fig. 4.
Map of Neogene (D_{A2}) deformation structures and fault-plane data at Villnöß line west and east of the river Eisack.
Stars mark locations where measurements were carried out. In each lower hemisphere projection the mean fault trace, Riedel planes and all measured striations are shown; numbers on upper left refer to different, unravelled increments: 1. increment corresponds to strike-slip deformation resulting from NE/ENE-directed shortening (D_{A1}), 2. increment shows reverse faulting followed by normal faulting (3. increment; D_{A2}).
a) Rose diagrams of joints at Villnöß line and at Raschötz.
b) Orientation of thrusts and conjugate strike-slip faults indicates N–S-oriented D_{A2}-shortening in the Villnöß area.

(Text-Fig. 6b–d), i.e. high angle faults generally off-set low angle faults. In the east, Permo-Triassic cover sequences make up the hanging wall of the Villnöß and Würzjoch lines (Text-Figs. 3, 4, 6). We found a geometrical relationship between the orientation of bedding in the Gröden sandstone, the cleavage poles in the ductile Bellerophon shales (both units are Permian in age) and the Würzjoch line (Text-Fig. 6e). Text-Fig. 4 shows the pattern of thrust-related strike-slip faults in the basement. A N/NNE–S/SSW-oriented principal shortening direction is derived from this fault array which is in accordance with findings of DOGLIONI (1987) in the Permo-Mesozoic cover.

Fault-slip data in the very vicinity of the Villnöß line (Text-Fig. 4) supplies a similar deformation sequence. Reverse faulting with a maximum shortening direction approximately N–S (second increment in Text-Fig. 4) is replaced by normal faulting (third increment in Text-Fig. 4).

This complex history of reverse and normal-slip and the early increment of strike-slip may readily explain why grooves are non-parallel on adjacent gouge surfaces at the Villnöß line.

3.4. Deformation at the Periadriatic Line

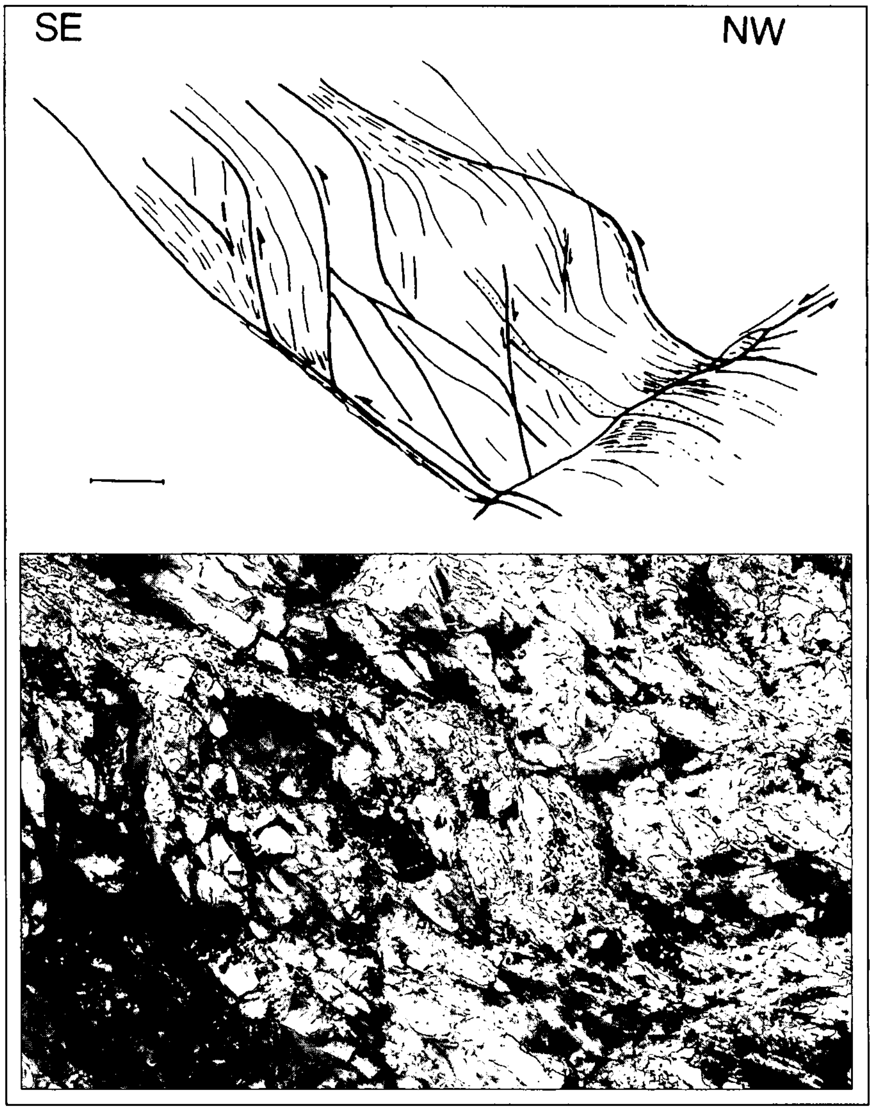
Fault-slip analysis (Text-Fig. 7) reveals a first increment of shallowly dipping NNE–SSW-oriented shortening (D_{A1}). Minor NE-striking faults in the vicinity of the main fault are related to this event and depict oblique-sinistral off-sets, whereas E–W to ESE-striking faults have reverse and dextral off-sets. These faults seem to be associated with NW-striking, upright to slightly NE-verging meso-scale folds.

A more pronounced second increment shows strike-slip movements along steeply inclined surfaces (D_{A2}). Synthetic riedel shears strike N 120–140° S and occur at the km- to mm-scale on both sides of the fault. They run at 15 to 30° to the main fault trace of the Periadriatic line (c. N 100–110° S) and indicate dextral displacement along the Periadriatic line. These cross-faults either merge with or off-set the Periadriatic line. Antithetic riedel shears strike N 15–60°E. All of these structures result from NW–SE-oriented subhorizontal shortening.

3.5. Deformation at the Valsugana Line

Although the first faulting increment (D_{A1}) was not observed at the Valsugana line, the mesoscopic fault pattern depicts similar characteristics as major faulting (2. and 3. increment) at the Villnöß and Würzjoch lines (D_{A2}, Text-Fig. 8). Reverse faults are SE-directed (Text-Fig. 5, 8a–c), they are either parallel or at a low angle to the s_{V2}-foliation. DOGLIONI (1987; Text-Fig. 8) described a north-vergent

Text-Fig. 5.
Ramp-flat structures in Jurassic carbonates near Pergine indicating top-to-the-SE-directed thrusting in Permo-Mesozoic cover (D_{A2}). NW-dipping normal faults seem to be concurrent with top-to-the-SE thrusting. Subsequently the rock was extented along SE-dipping normal fault.
Scale bar is 10 cm.



"fish structure" caused by both overthrusting and wedging of the basement over and into the cover at the Valsugana line. Basement wedging caused local backthrusts. The thrusts are cut by extension faults which became steeper with time and are parallel and perpendicular to the contraction faults. Low angle extension faults parallel to the contraction faults are conjugate (Text-Figs. 5, 8). Such conjugate low angle extension faults were not observed at the Villnöß and Würzjoch lines.

4. Alpine P-T Conditions

The post-Variscan overburden is in the order of 4000–5000 m. An average geothermal gradient of 25–30°C/km and a pressure gradient of 1 kbar/3 km yields P-T conditions in the order of 1.5 kbar and 100–150°C at the Permian base. The colour of Middle Triassic polls and diverse organic matter suggest temperatures around 100°C (B. LIGOUIS & P. LITTMANN, personal communication), the colour alteration index of Ladinian conodonts yields temperatures between 50–70°C (EPSTEIN et al., 1977).

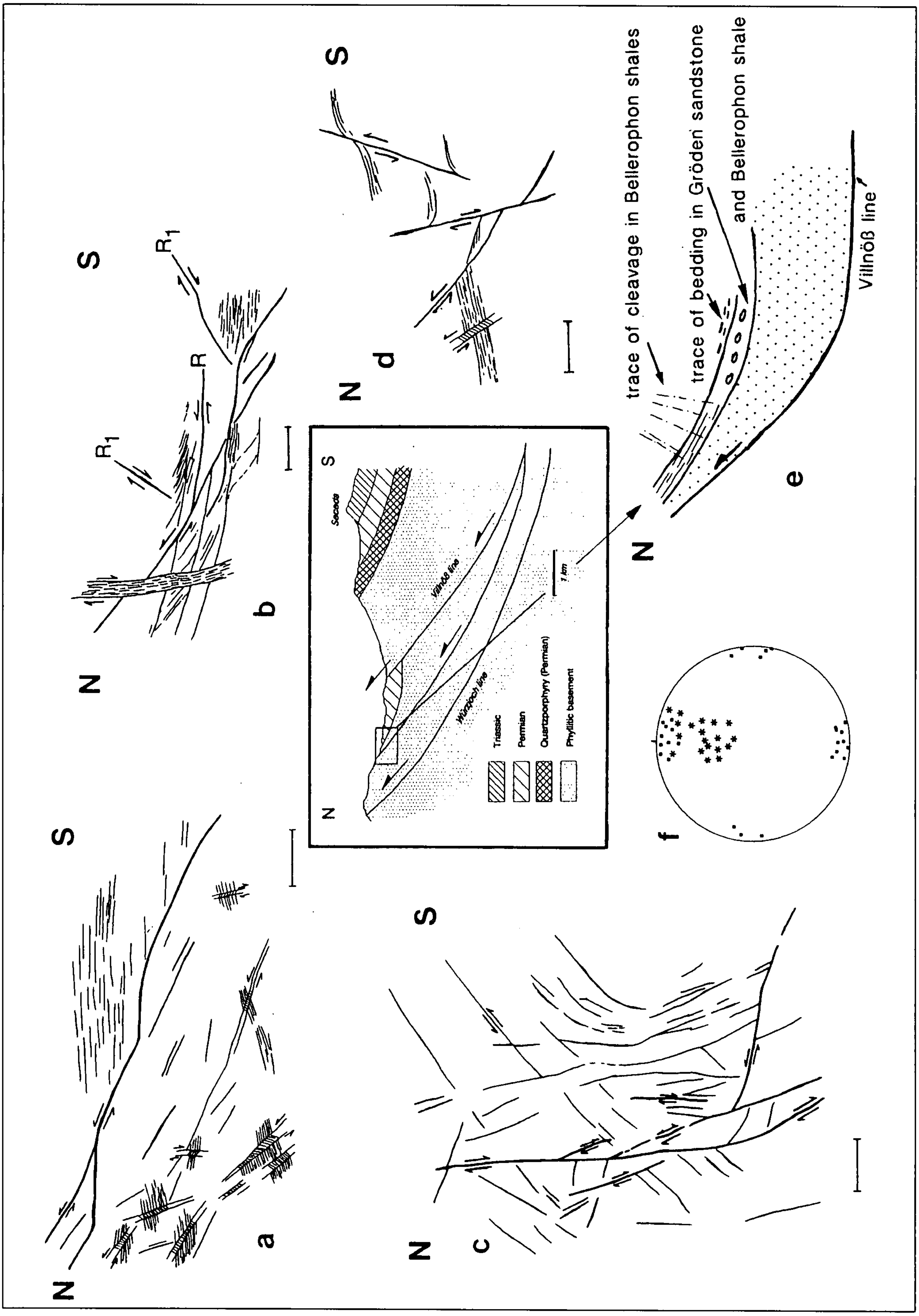
Hence we propose Alpine P-T conditions in the Brixen area, where the deepest part of the basement is exposed, to be c. 2 kbar and 200°C (1000 m pre-Variscan overburden is added). Since the Carnian Alps lay just beneath the Permian base we consider 1.5 kbar and 150°C as realistic. It should be noticed that these values are rather rough estimates, however, the error range may not exceed 0.5 kbar and 50°C.

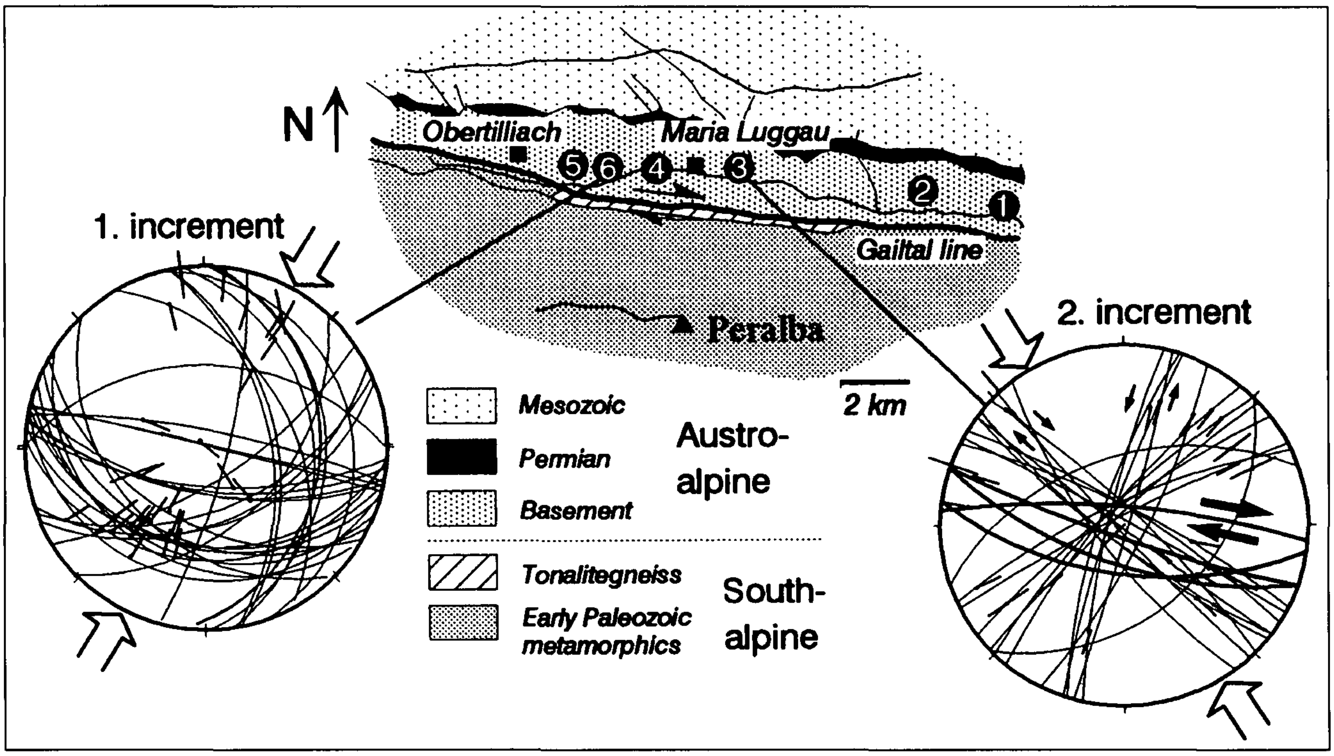
5. Discussion and Conclusions

Brittle Alpine deformation affected the eastern Southalpine basement. Deformation is distributed at shallow crustal levels into localised fault zones and the mechanism of deformation within these fault zones is heterogenous cataclastic flow.

The oldest recognisable structures in the quartzphyllitic basement are sinistral and conjugated dextral strike-slip movements along the Villnöß line which are due to NE–SW to ESE–WNW shortening (D_{A1}). In the eastern Southalpine cover rocks NW-trending large-scale folds occur in the Dinaride chain of Slovenia and in the Dolomite mountains of southern Tyrol (CARULLI et al., 1990; DOGLIONI, 1987). Similar structures have recently also been reported from the

Text-Fig. 6. →
Schematic cross-section across Villnöß and Würzjoch lines (see Text-Fig. 3 for location).
Sketches (a–e) illustrate characteristic deformational features of D_{A2}; mesoscopic fault patterns indicate N-directed reverse faulting and subsequent normal faulting.
a) Reverse fault and associated kink bands; road cut W of Würzjoch.
b) Reverse fault associated with syn (R) and antithetic (R_1) Riedel planes, reverse fault is cut by steep normal fault; S of St. Peter, Villnößtal.
c) Steep normal fault cutting thrust; road cut W of Klausen.
d) Reverse fault associated with kink bands cut by conjugate normal faults; road cut N of Klausen.
e) Enlarged sketch showing relation between backthrust plane in the phyllitic basement, bedding in the Gröden sandstones and cleavage in shales of the Bellerophon Formation.
f) Lower hemisphere projection of reverse faults (stars) and normal faults (squares).
Scale bar in a–d is 10 cm.


N
S
a
b
R
R1
c
d
Seceda
Villnöß line
Würzjoch line
1 km
Triassic
Permian
Quartzporphyry (Permian)
Phyllitic basement
trace of cleavage in Bellerophon shales
trace of bedding in Gröden sandstone
and Bellerophon shale
Villnöß line
e
f



Text-Fig. 7.
Fault-plane analysis at Gailtal fault (part of Periadriatic line) at Maria Luggau.
First increment corresponds to NNE–SSW-directed reverse faulting (D_{A1}) followed by second increment with WNW-oriented dextral strike-slip movements
(D_{A2}, see text for more explanation).
Numbers refer to locations where measurements were carried out.

Mesozoic rocks of the Karawanken mountains which straddle the Periadriatic line. The first deformation increment from the Periadriatic line at Maria Luggau (Text-Fig. 7) also fit into this regional trend. We therefore interprete all these structures to be part of a relatively broad belt that extended from the Dinaride chain across the Southern Alps into the Austroalpine domain of the Eastern Alps according to a model outlined by POLINSKI & EISBACHER (1992).

The onset of D_{A1} in the eastern portion of the Southern Alps is not well dated. Deformed Lower Cretaceous marls and undeformed Lower Miocene conglomerates supply rough age constraints (DOGLIONI, 1987). Comparison of similarly oriented crustal shortening in the Dinarides where this event is related to the Eocene Friuli-flysch (WINKLER, 1936), suggests an Eocene age for NE–SW-oriented shortening. A pre-Neogene age is confirmed by a Late Oligocene/Early Miocene conglomerate at Monte Parei in the Dolomite mountains which unconformably overlies deformed strata (CROS, 1966).

Neogene southeast-directed thrusting and north-directed backthrusting led to a 60 km wide basement pop-up (Text-Fig. 3; DOGLIONI, 1987). On a regional scale this event resulted from NNW–SSE to NW–SE-oriented crustal shortening. The dextral strike-slip displacements at the Periadriatic line (Text-Fig. 7) fit into the kinematic framework of the D_{A2}-phase. Therefore, it is tempting for us to relate this event to a pattern of NW and SE-directed thrust faults and dextral cross faults which coincide with dextral strike-slip movement at the Periadriatic line in the Karawanken area as described by POLINSKI & EISBACHER (1992). These authors attribute a middle (?) to Late Miocene age to this deformation, whereas DOGLIONI & BOSSELINI (1987) reported a Late Oligocene to Late Miocene age to NW–SE shortening. POLINSKI & EISBACHER (1992) showed that distributed dextral shear is post-intrusive to the tonalitic Karawanken pluton indicating a post-Late Oligocene age (< 28.4 Ma, SCHARBERT, 1975) for this event.

The eastern Southern Alps therefore appear to have become part of the WNW-trending Miocene to Recent zone of dextral transpression between the Adriatic and European plates. The Periadriatic line arises to have transferred NW–SE shortening in the Southalpine-Dinaride fold-and-thrust belt on the southeast to the easterly extending crust of the eastern part of the Eastern Alps in the north (POLINSKI & EISBACHER, 1992).

Distribution and cross-cutting relationships of mesoscopic faults indicate that the basement was initially shortened and thickened in the overall transport direction, then flattened subparallel to the thrust surface and extended both subparallel and subnormal to the thrust's strike. The progressive increase in the angle of the mesoscopic faults is attributed to progressively lower temperatures. The switch from contractional to extensional structures goes along with decreasing temperatures and is thus interpreted to result from regional uplift which caused gravitational instabilities and created a tensile regime.

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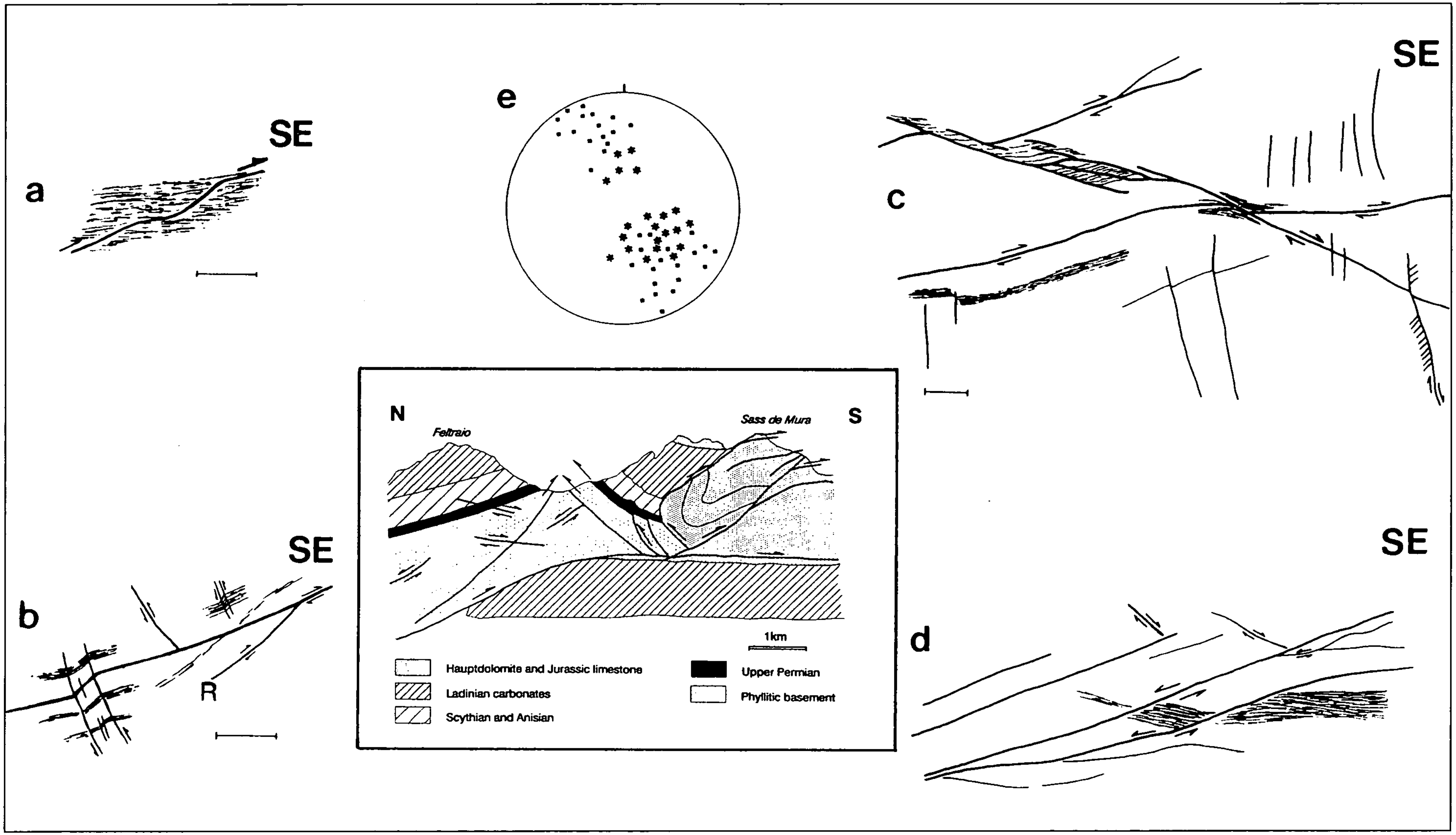

Text-Fig. 8.
Schematic cross-section across Valsugana line (modified after Doglioni, 1987).
(a–d) show representative structural features of D_{A2}; general direction of thrusting and reverse faulting was towards the SE.
a) SE-vergent thrust parallel and at low angle to s_{V2}; near Vetriolo.
b) SE-vergent thrusts associated with conjugate Riedel surfaces overprinted by NW- translating kink; road cut near Panarotto.
c) SE-directed thrusts cut by SE-dipping normal faults; road cut near Panarotto.
d) Major NW- and minor SE-dipping normal faults; road cut near Pergine.
e) Lower hemisphere projection of thrusts (stars) and normal faults (squares).
Scale bar in all examples 10 cm.

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