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Low angle normal faults at the eastern margin of the Tauern window (Eastern Alps)

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With 6 figures

Abstract

Low angle normal faults of ductile to brittle behaviour, working under greenschist facies to cool, brittle conditions, are described from the SE – margin of the Tauern window. They are regarded to belong to the decompression path of the Tauern metamorphism, and therefore to the uplift of the Tauern window. This normal fault zone at the eastern margin of the Tauern dome is discussed to be a part of a sinistral pull-apart dome model.

Zusammenfassung

Vom Ostrand des Tauernfensters werden duktile und spröde Abschiebungen beschrieben, die unter plastischen, grünschieferfaziellen bis kühlen, spröden Bedingungen gebildet wurden. Sie werden dem Dekompressionspfad der Tauernmetamorphose und damit dem Aufstieg des Tauernfensters zugeordnet. Diese Abschiebungszone am Ostrand des Tauerndomes wird als Teil eines sinistralen pull-apart-Dom-Modelles diskutiert.

1. Introduction

The uplift history of metamorphic core complexes in mountain ranges has some interest from the petrological point of view (e.g. SELVERSTONE, 1985; SELVERSTONE & SPEAR, 1985). On the other hand, structural work concerning the uplift history is rather scarce (for a review, see CONEY, 1980). The Tauern window is a structure most suitable to reconstruct the structures related to the uplift history, because there is much information from petrological (DROOP, 1985; SELVERSTONE & SPEAR, 1985), geochronological (CLIFF et al., 1985; GRUNDMANN & MORTEANI, 1985; GRUNDMANN, 1987; STAUFENBERG, 1987), geodetical (SENFTL & EXNER, 1973) and first structural work (SELVERSTONE, 1988, BEHRMANN, 1988).

The Tauern window exposes an old continental basement composed of gneisses, amphibolites and Hercynian granites, belonging to the European foreland. It is thrusted by Mesozoic oceanic crust and by the upper-plate continental crust of the Austroalpine unit, a sequence of pre-Alpine basement rocks covered by Permomesozoic sediments. All these units are subdivided into several nappes.

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2. The structure along the eastern boundary of the Tauern window

In detail (Fig. 1), the area of the eastern Tauern window is built up, according to EXNER (1980 a), from the footwall to the hangingwall by the Gößkern (Fig. 2 a), made up of granitic to granodioritic rocks of Hercynian age (Central gneiss). They intruded a sequence of mainly migmatites, banded gneisses and minor amphibolites and micaschists (Central "Schieferhülle"). They are overlain by tonalitic rocks and beyond granitic rocks. The relationship to the underlying rocks is under debate. The next higher unit is the Silbereckserie, a sequence of Permomesozoic metasedimentary and minor metavolcanic rocks. It is overlain by the Storz complex, a unit of old basement, built up of paragneisses, migmatites, orthogneisses, and amphibolites mainly. On the top lies a sequence of Permomesozoic metasediments and metavolcanics, the Peripheral "Schieferhülle", a derivative of former oceanic crust.

These Penninic units are thrusted by the Austroalpine unit, which is divided into three units, two of them, the Lower and Middle Austroalpine appear in the viewed area. The Lower Austroalpine is overturned with some remnants of a Mesozoic sedimentary cover (quartzites, dolomites) at the footwall, overlain by progressively metamorphosed quartz phyllites with intercalations of Paleozoic dolomites and quartzites, and finally retrograde metamorphosed quartz phyllites. The overlying Middle Austroalpine is a unit of basement rocks. It mainly consists of amphibolite-facies micaschists in the area under investigation, paragneisses and minor orthogneisses, amphibolites and quartzites. At the base, there is a zone of epizonal recrystallization of the former micaschists, e.g. transforming staurolite to sercite.

2.1. Map-scale features of crustal thinning

The overall structure of the eastern Tauern window is a dome structure with dipping of the units to the periphery (inset at the lower left of Fig. 1). Particularly at the eastern margin, the units dip rather constantly towards the E to SE with intermediate angles (approximately 30° to 45°). The characteristic feature from the map-scale is the thinning of the units at the eastern margin (Fig. 1), which are much thicker in the south and especially in the north of the Tauern window, for instance the Lower Austroalpine with several nappes in the northeastern corner.

The Tauern window and its Austroalpine frame were affected by two Alpine metamorphic events (HAWKESWORTH, 1976). The older one is also preserved in the Middle Austroalpine unit. The younger event ("Tauern crystallization") exclusively affects the Penninic units, the Lower Austroalpine and the base of the Middle Austroalpine (retrograde metamorphosed base). This younger metamorphic event is the consequence of the burial of the Penninic units by the thrusting of the Austroalpine. The peak of this metamorphic event reached the amphibolite facies and dates between 40 and 30 m.y. before present time (for a review, see CLIFF et al., 1985; GRUNDMANN & MORTEANI, 1985; GRUNDMANN, 1987). The distribution of the metamorphic isogrades in the present structure is characterised by the thinning of the metamorphic edifice of the Tauern window in relation to metamorphic peak conditions at the eastern margin of the Tauern window, e. g. the albite-oligoclase boundary and the first appearance of biotite are found close to the margin (HÖCK, 1980).

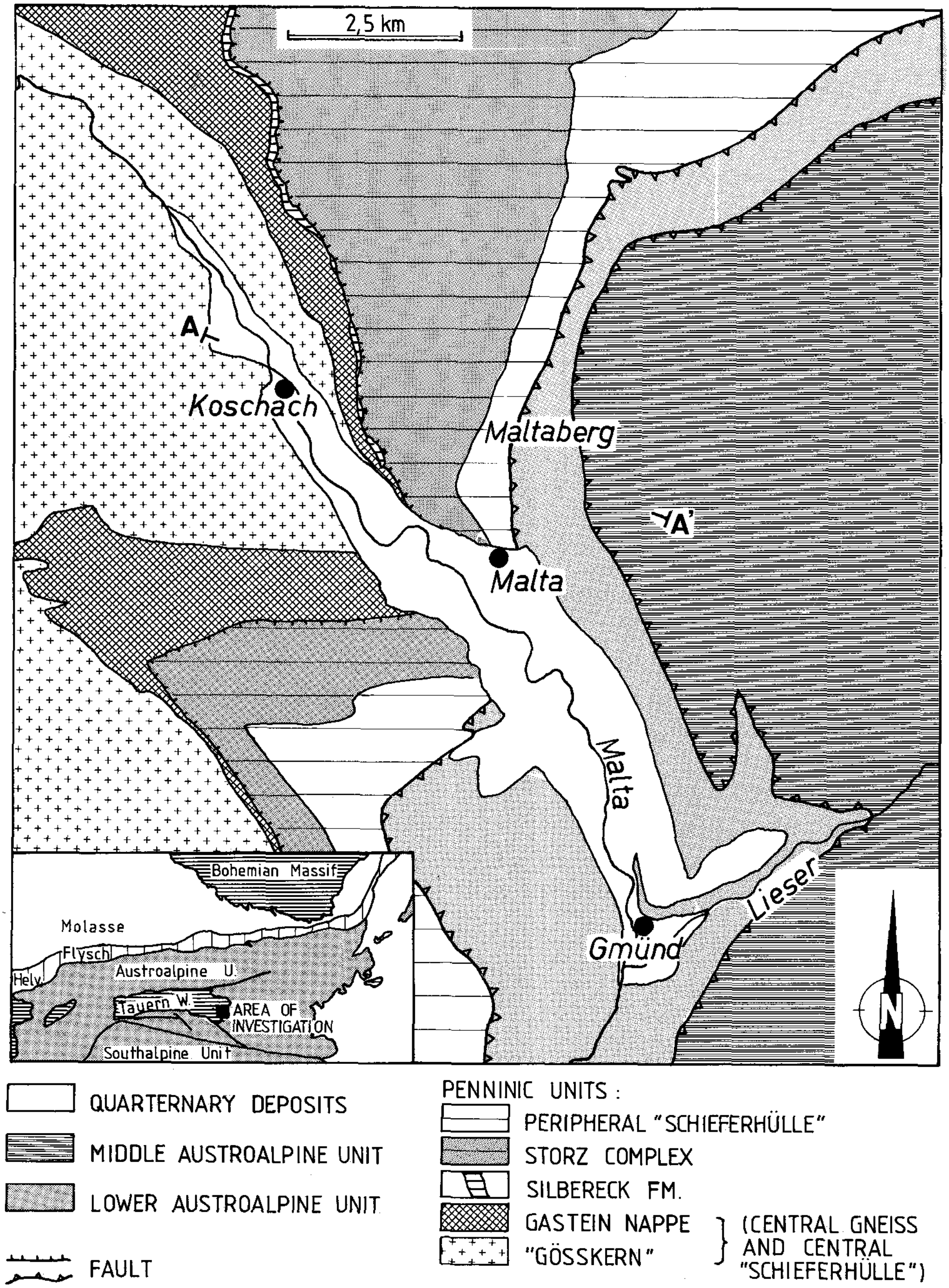

Fig. 1: Simplified geological map of the eastern Tauern window (after EXNER, 1980 a). Insert shows location of the investigated area. A–A': Section in Fig. 2.

2.2. *Low angle normal faults*

These features are related to the occurrence of low angle normal faults, which are the topic of this paper. Their mesoscopic appearance ranges from ductile, continuous to discontinuous, brittle low angle normal faults. The ductile low angle normal faults represent the youngest ductile deformation event in this area. From bottom to top, these fault zones vary in type: In the granodiorites of the Gößkern discrete types of movement zones were observed, mostly some millimeters to few centimeters in thickness (Fig. 2 b), but also a singular mylonitic shear zone with a thickness of some meters was observed. They occur as conjugate low angle shears with dip to the ESE or WNW respectively (Fig. 3 a). The lineations on the mylonitic foliation of these shear zones are orientated ESE–WNW. The kinematic framework indicates an extension in ESE–WNW direction and a thinning in the vertical direction. There are two different observed deformation mechanisms, one mylonitization due to crystal plasticity, the other cataclastic flow. Both styles include grain-size reduction, in our case of cataclastic flow until a macroscopically indistinguishable, black mass (for features of deformation mechanisms, see SCHMID, 1982). The contact to the host rock is rather sharp. The mylonitic shear zones keep the mineral assemblage of their

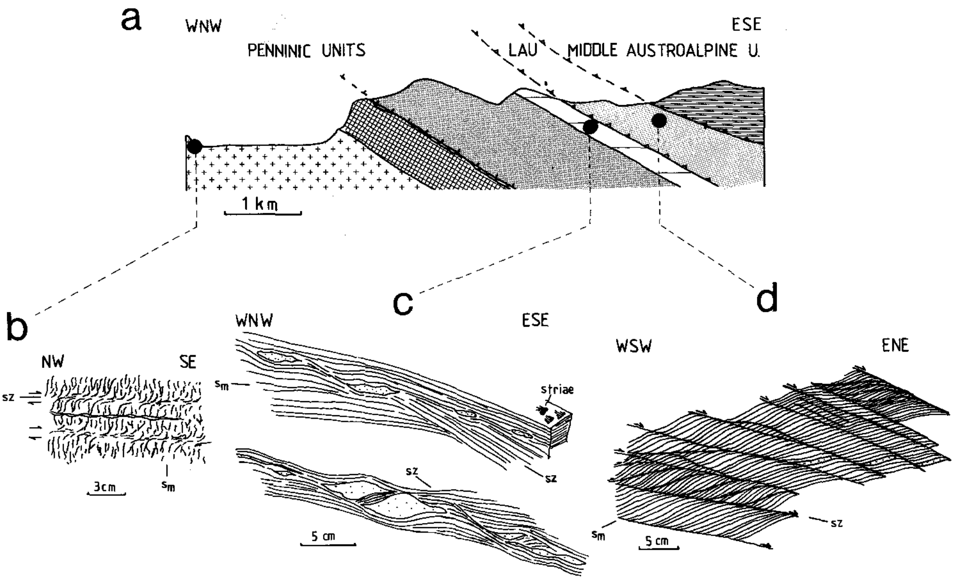

Fig. 2: Mesoscopic features of low angle normal faults across the boundary of the Tauern window to the Austroalpine unit.
a) Section LAU – Lower Austroalpine Unit.
b) Ductile shear zones at the Koschach quarry, Malta valley (Gößkern granodiorite).
c) Ductile to semiductile normal faults in the Peripheral "Schieferhülle", Maltaberg.
d) Brittle and semiductile normal faults in the Lower Austroalpine unit, east of Malta.
sm: Foliation formed during synmetamorphic thrusting.
sz: Shear zones and shear bands of normal faulting.

metamorphosed protolith. In the cataclastic shear zones, very fine grains of quartz, biotite and amphibole form the matrix which includes large, broken grains of feldspar, epidote and sphene. This indicates the operation of the shear zones under upper greenschist facies conditions.

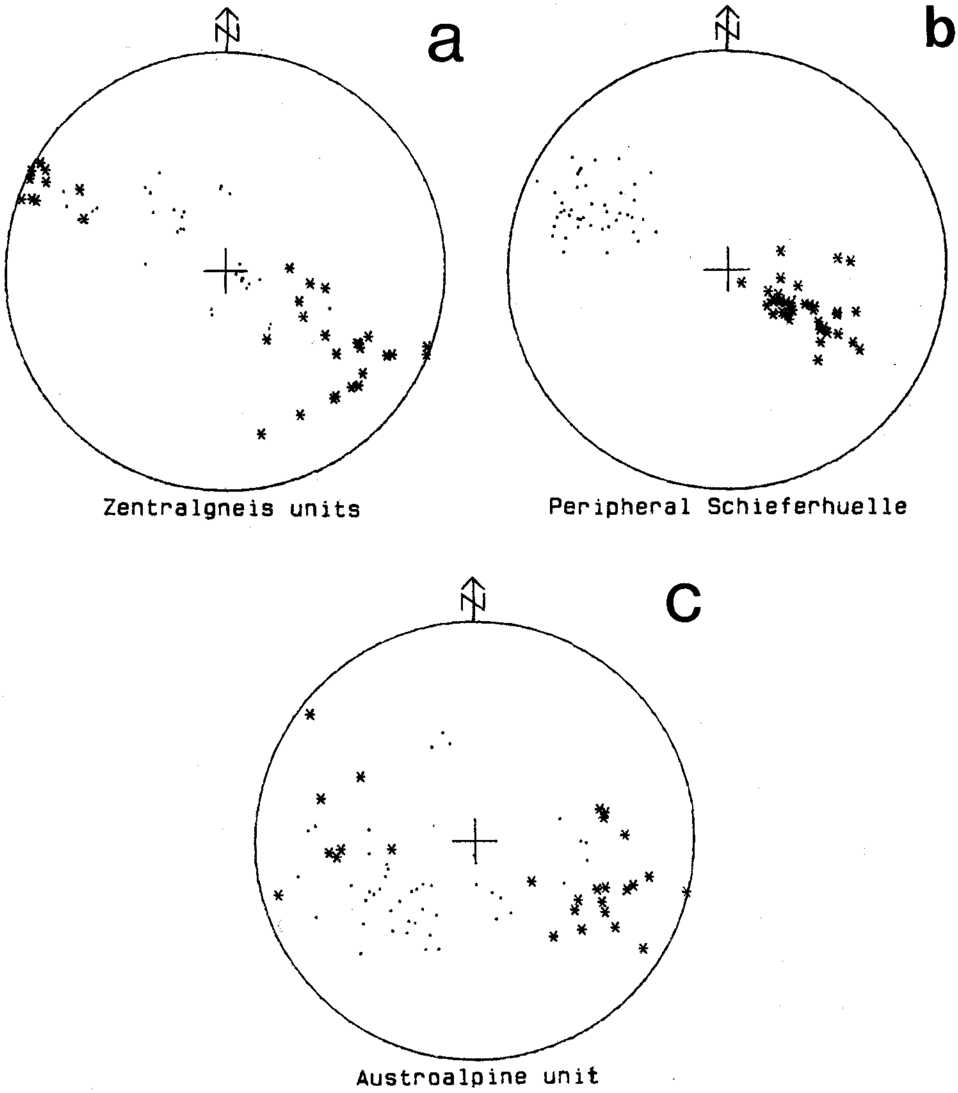

Fig. 3: Poles of the mylonitic foliation (.) and the stretching lineation (*) due to the normal faulting in the LAMBERT projection:
a) Central gneiss units;
b) Peripheral "Schieferhülle";
c) Austroalpine unit.

In the overlying migmatites and the tonalite gneisses and granite gneisses, there are only a few expressions of these low angle normal faults. There are ductile shear zones in the range of millimeters to decimeters in thickness with mylonitization of the host rock and semiductile shear bands, which can curve into open fissures, filled with quartz and chlorite. There are also conjugate sets, but the set dipping to the ESE is dominating.

The most expressive development of low angle normal faults is located in the upper parts of the Storz complex (Figs. 1, 2), and especially in the metasedimentary and metavolcanic rocks of the Peripheral "Schieferhülle". In the Storz complex, there are several zones with a concentration of ESE dipping ductile shear bands. The shear bands have a spacing of few centimeters and lengths in the range of centimeters to decimeters. They show recrystallization of quartz and biotite and some chloritization of biotite. Feldspars show cataclastic behaviour. In the Peripheral "Schieferhülle", almost all lithological units show marked ductile to semiductile shear bands with a spacing in the range of millimeters to decimeters. They crosscut the foliation of the rock in angles of about 30° and curve into this foliation. They occur as single sets, as conjugate sets or as multiple sets, depending on the relative strength of the rocks. Both conjugate sets and multiple sets occur only in very micaceous rocks and in greenschists, which have the closest spacing of the shear bands too. The conjugate set, which dips to the WNW, always shows weaker development. In calcphyllites and marbles, the discrete shear zones can pass into broader zones of penetrative deformation (Fig. 2 c). The orientation of these normal faults is to the ESE, also the lineation on the shear bands is plunging in this direction (Fig. 3 b). The shear bands show crystallization of chlorite, subgrain formation of equigranular subgrains to recrystallization of quartz and recrystallization of micas. These rheological features indicate shearing at lower greenschist facies conditions. The micas and ribbons of quartz curve into the shears. There is no enrichment of micas in the shears.

The Lower Austroalpine unit shows this normal faulting acted only in several discrete zones (Fig. 2 d), but in different styles. They exhibit semiductile to brittle behaviour and a more scattered orientation of the faults, simply because of the influence of the older folded foliation on the formation of them, but the overall direction of hangingwall transport is still to the E to SE. The semiductile shears are similar to those in the Peripheral Schieferhülle (Fig. 4), but here also brittle normal faults occur. Often there are both conjugate sets, but the SE-dipping set is dominating and crosscuts the other one. This normal faulting can be traced into the base of the Middle Austroalpine, here only brittle shears are occuring. The striae are plunging to the SE (Fig. 3 c).

In conclusion, we can say that there is evidence of small scale low angle normal faulting in all units of the eastern margin of the Tauern window with a concentration of the displacement in the Peripheral "Schieferhülle". The formation of this shearing is connected with the young metamorphic event of the Tauern crystallization, which is obvious from the ductile behaviour and the crystallization of certain minerals in the shear bands. The strain distribution is that of an extension in the direction of WNW–ESE and a thinning of the affected units in a subvertical direction.

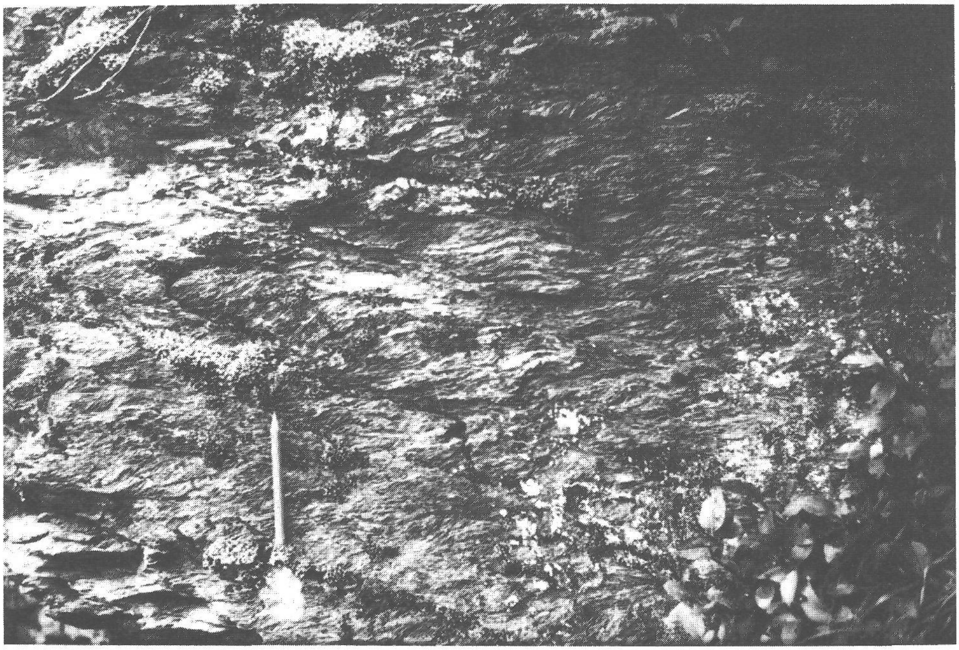

Fig 4: Shear band foliation in the Lower Austroalpine unit.

2.3. *Estimation of the minimal amount of displacement*

There are different ways to derive the amount of displacement across shear zones. One can examine the angle between the shear bands and the foliation, according to Platt (1984). The difficulty with this method is that it is limitated to two critical cases, which have different changes of the angle with increasing shear angle. Furthermore, the occurrence of multiple sets of shear bands indicates large displacement, but precludes their exact calculation.

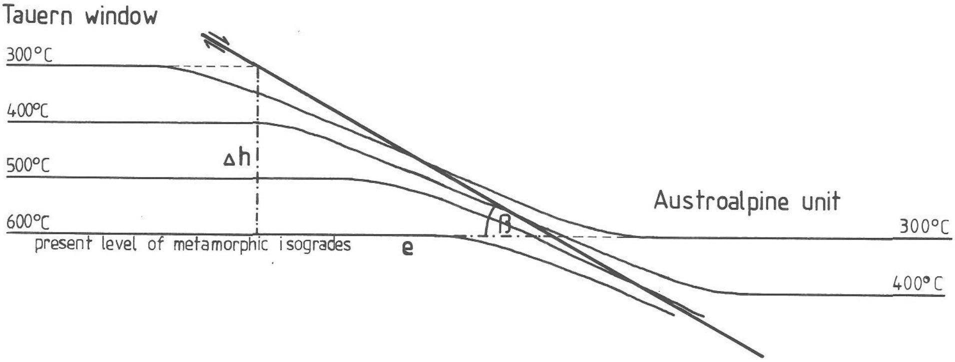

Fig 5: Model for the estimation of the minimal amount of lateral displacement.

Another approach would be to measure the displacement along the individual shear bands, e.g. at quartz veins and to summarize the individual amounts of displacement. The difficulties are, this is also valid for the former method, the different density in the distribution of shear bands and that there is no continuous section.

Therefore, the minimal displacement is estimated by means of a simplified model (Fig. 5). As a reasonable model, all the shears are joined in one normal fault zone with a dip angle of 30°, which is quite realistic according to the measured data (average angle between the older foliation and the late-stage low angle normal faults). The second quantity is the differential uplift of the central part of the Tauern window, which now has the same elevation as the base of the Middle Austroalpine. The differential uplift can be deduced from the metamorphic isogrades at their peak conditions: The Gößkern reached a temperature of close to 600° C, the base of the Middle Austroalpine unit of 300° C during the late Alpine metamorphic event, therefore a difference of 300° C, which results with a geothermal gradient of 30° C/km according to GRUNDMANN & MORTEANI (1985) in a differential uplift of 10 km. There is a simple relationship between this differential uplift and the horizontal extension, namely

$$e = dh/\tan\beta$$

In our case, the horizontal extension amounts to 17.3 km, which is regarded as a minimum estimation because of the large angle supposed between normal faults and foliation.

3. Discussion of a pull-apart dome model

The structure along the eastern margin of the Tauern window points to an overall low angle normal fault separating Penninic rocks from those of the originally overlying Austroalpine plate. It is worth to mention that the metamorphic dome of the late Alpine Tauern crystallization is bounded by faults in most places (Fig. 6 b):

- BEHRMANN (1988) and SELVERSTONE (1988) describe a low angle normal fault at the western margin of the Tauern window, which transported the Austroalpine unit to the W. We interprete this fault to be the conjugate low angle normal fault to that of the eastern margin described in this paper.
- KLEINSCHRODT (1987) points out the dominant sinistral displacement along the DAV-line, which is the southern border of the metamorphic dome of the Tauern crystallization (BORSI et al., 1973; KLEINSCHRODT, 1987 and references cited therein). This fault has no eastern continuation.
- The northern margin of the Tauern window is defined by the Tauern-Nordrand (= Tauern northern margin) fault (MOSTLER, 1964). This fault is part of a larger Ennstal–Tauern-Nordrand (ETN) fault system, for which a predominant sinistral displacement is postulated by map-scale features: On the north-western side of this fault, the Greywacke zone shows an offset of at least 60 km to the W. Thus we prefer a lateral displacement contradictionary to the usually postulated vertical displacement (see references in TOLLMANN, 1986). This fault has no western continuation beyond the central Tauern area.

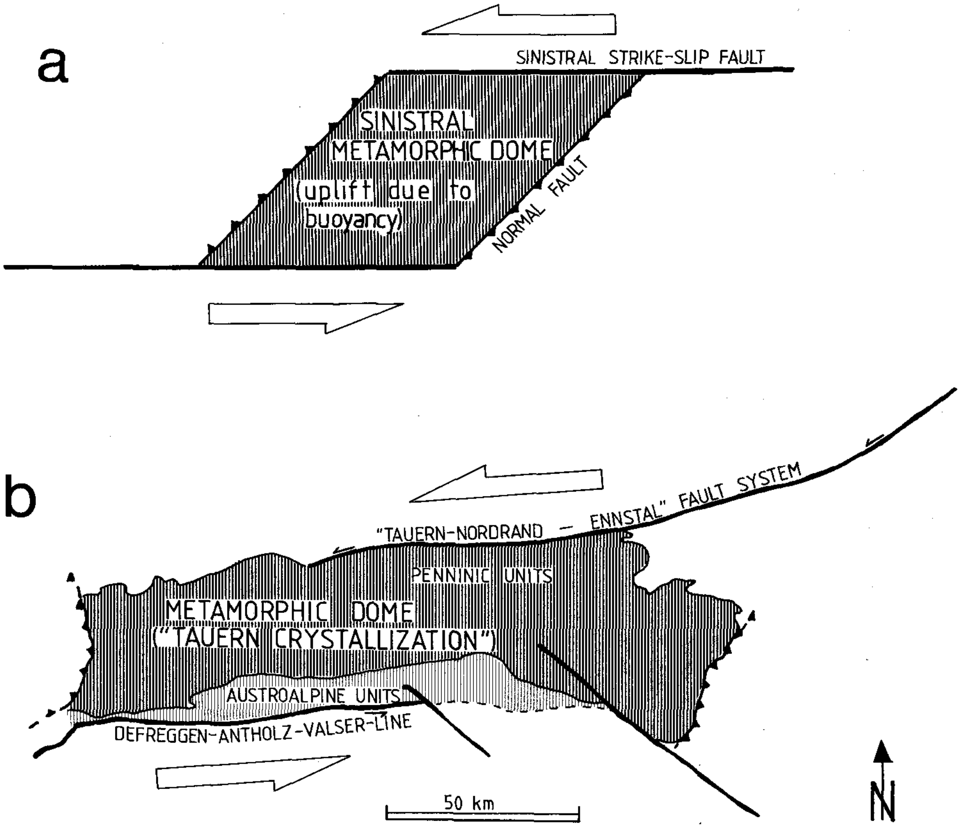

Fig. 6: Pull-apart dome model for the Tauern window:
a) The model;
b) The metamorphic dome of the Tauern crystallization interpreted as a pull-apart dome structure.

This configuration of structural elements is interpreted in terms of a pull-apart dome model (Fig. 6 a): The E–W striking strike-slip ETN-fault ends at the NW corner of the Tauern window and is replaced by the DAV-fault at the southern margin, opening a space between these two faults. The space is filled by the upwelling dome of the Tauern crystallization. The opening of the Tauern dome is caused by crustal stretching in an ESE–WNW direction. This extension is also supported by the orientation of mineralized "Alpine fissures" as well as by gold-quartz veins in the central part of the Tauern window. This point of view is also supported by geophysical arguments: The force driving the uplift is thought to be the buoyancy due to a negative Bouguer gravity anomaly (Giese, 1980). The uplift and cooling of the Tauern area since the Oligocene time is evidenced by geochronological models (for a review see Grundmann & Morteani, 1985; Frank et al., 1987). A more comprehensive discussion of structures related to pull-apart metamorphic domes of the Alps is given in Neubauer & Genser (in prep.).

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