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ALPINE KINEMATICS OF THE EASTERN CENTRAL ALPS

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Introduction

The Eastern Alps are considered to result from the collision of the Austro-Alpine microplate with the European continent after consumption of the South Penninic oceanic realm (e.g., Ratschbacher et al., 1989 and references cited therein). However, the application of new methods in structural analysis significantly changed notions about Alpine kinematics in the Central Alps during the last decade. The major progresses were the interpretation of Mid Cretaceous structures due to dextral transpressive convergence (Ratschbacher, 1986), the recognition of Late Cretaceous extension and their relation with ductile sinistral strike slip zones (Neubauer, 1988; Ratschbacher et al., 1989) and of the Neogene setup as escape tectonics (Neubauer, 1988; Ratschbacher et al., 1989, 1991) related to the uplift of Penninic metamorphic domes (Genser and Neubauer, 1989; Ratschbacher et al., 1990). Compilations of these structural data are given in Behrmann, 1990, Neubauer and Genser, 1990; Platt et al., 1989, Ratschbacher et al., 1989. In this contribution we add new data which change the previous models significantly.

The thrust surfaces propagated in space and time both from intra-Austro-Alpine thrusting to overriding of the Penninic units and afterwards to intra-Penninic thrusting (e.g., Ring et al., 1990). In this contribution we shortly review kinematic paths and timing of Alpine structures which are responsible for the Alpine architecture of the eastern Central Alps.

Succession of deformation events

All data clearly suggest a changing displacement path for each unit. The displacement paths of thrusts show changing directions of displacement deduced from overprinting relations in mylonite zones (Krohe, 1987; Ratschbacher, 1986), from incremental strain analyses (Fritz, 1988; Fritz et al., 1991), from the relation to the growth of metamorphic minerals and from the general evolution from early penetrative ductile structures to late cool brittle structures.

Early Alpine nappe stacking in Austro-Alpine units

The onset of compression after a period of Permian to Mesozoic crustal extension in both Austro-Alpine and Penninic domains is not very well constrained by geochronological data. Sedimentological analyses of the Northern Calcareous Alps and the Flysch zone proof an Early Cretaceous flysch deposition which corresponds to ductile thrusting within the Austro-Alpine units which is responsible for intra-Austro-Alpine nappe stacking (e.g., Decker et al., 1987). Thrusting commenced with stacking of the Upper Austro-Alpine unit onto the Middle Austro-Alpine units (Tollmann, 1959, 1987), and continued with emplacement of the Middle Austro-Alpine eclogite-bearing nappes onto weakly metamorphosed Lower Austro-Alpine units (Dallmeyer et al., this volume). Evidence of general amphibolite facies conditions (Frank, 1987), and especially of high pressures in the southern Middle Austro-Alpine units (Thöni and Jagoutz, 1991; Miller, 1990), suggest deep burial of these units during continent-continent collision (Fig. 1) rather in a lower plate than in an upper plate position. General characteristics of intra-Austro-Alpine thrusting are:

1) Thrust geometries with ramps which climb from the basement to the cover towards North, respectively Northwest (Ratschbacher and Neubauer, 1989). Large portions of cover sequences are therefore missing in the Austro-Alpine units. These are probably accumulated in the northern Calcareous Alps (Neubauer and Genser, 1990).

2) A nearly complete decollement of cover units in large portions of the Central Alps. Relatively complete sections are only preserved in some limited Lower Austro-Alpine areas.

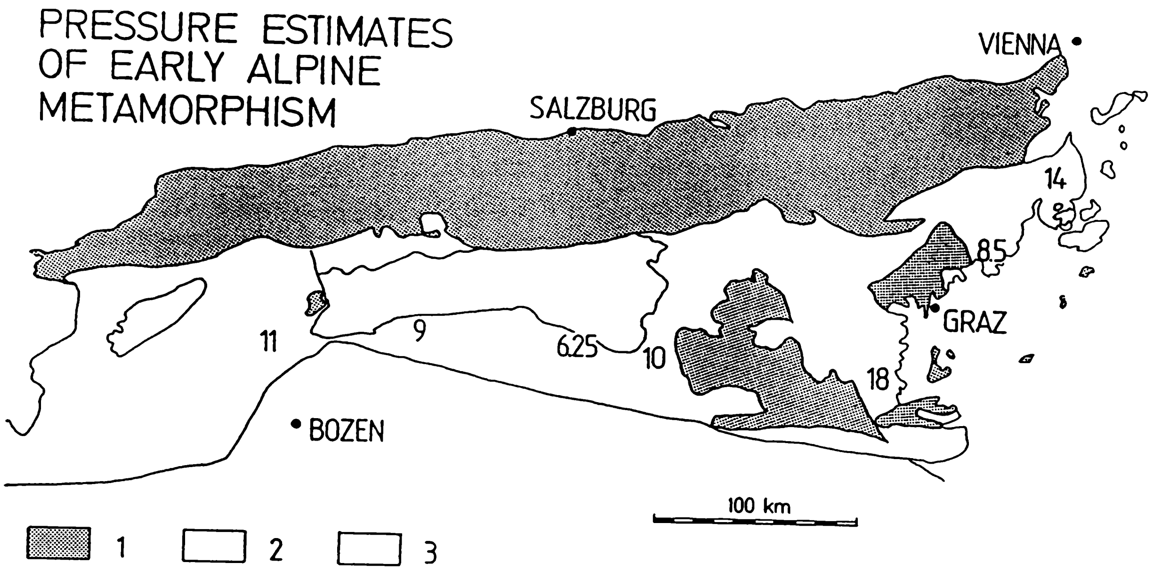

Fig. 1: Pressure estimates of the Early Alpine metamorphism within the Middle Austro-Alpine unit. Legend: 1 - Upper Austro-Alpine units, 2 - Middle and Lower Austro-Alpine units; 3 - Penninic units.

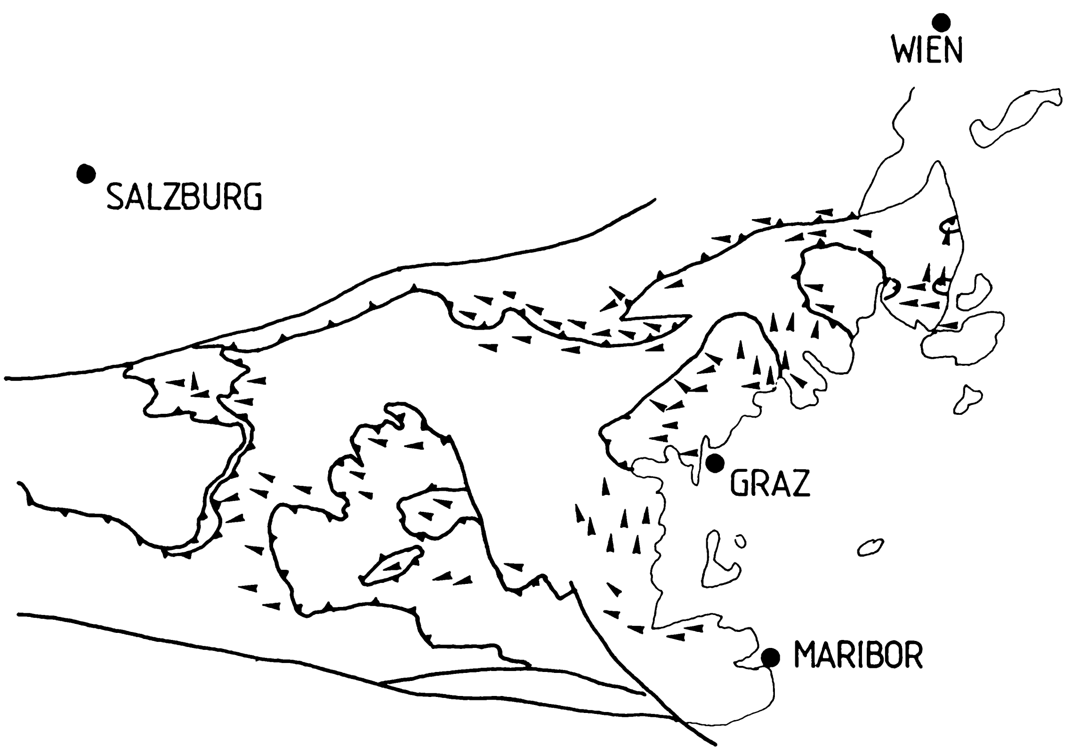

Fig. 2: Early to Mid-Cretaceous motion in the eastern Central Alps. Data base, see text.

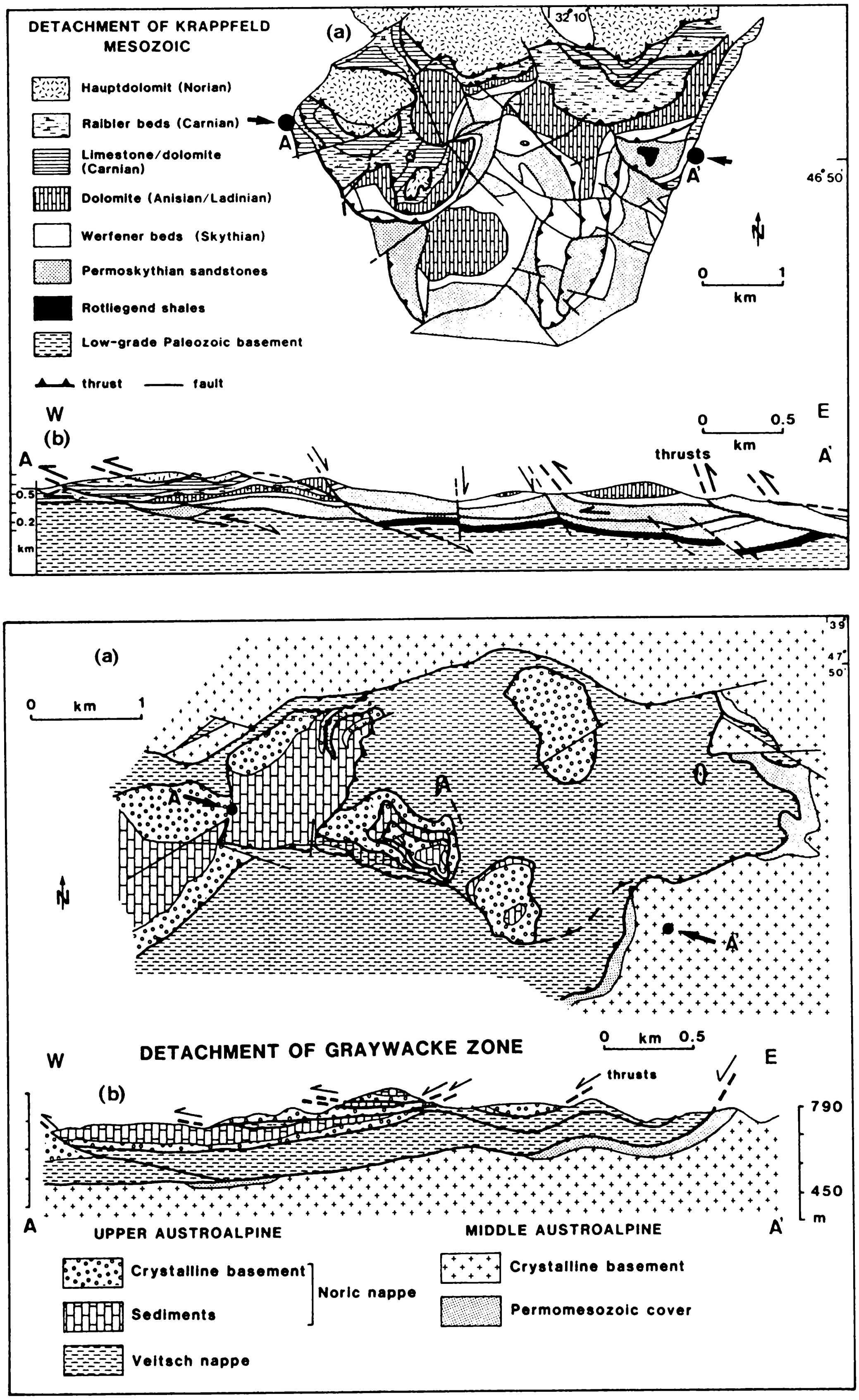

Fig. 3: Geometry of thrust and extensional faults a) in the Krappfeld Permomesozoic unit (cover of the Gurktal Thrust Complex) b) eastern Graywacke Zone (from Ratschbacher and Neubauer, 1989).

3) There is a break in metamorphic conditions due to the emplacement of eclogite-bearing Middle Austro-Alpine nappes onto weakly metamorphic Lower Austro-Alpine units (Dallmeyer et al., this volume).

3) Fabrics of ductile thrusting are often connected with decreasing P-T conditions of Cretaceous metamorphism.

4) Late Cretaceous marine basins overstep Alpine thrust surfaces of the Upper Austro-Alpine units; therefore, such thrust surfaces must predate deposition of these basins.

In the present-day geographic frame, displacement started with top to the NW displacement (Fig. 2), especially in northern portions of the Austro-Alpine units; whereas in more southern ones a top to the W to WSW displacement is common (Fritz, 1988; Genser, 1992; Neubauer, 1987, 1990). Examples of map-scale geometries which proof displacement to the NW are given in Fig. 3. The eastern portion of the Middle Austro-Alpine units is dominated by N to NNE trending stretching lineations which show a general top to the N displacement which is interpreted to be younger than the WNW-directed displacement of other areas (Reindl, 1990; own unpubl. data). These fabrics may be related to the emplacement of the eclogite-bearing units.

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Late Cretaceous extension and strike-slip in the Austro-Alpine units

The period of pre-Gosauian nappe stacking was followed by crustal extension combined with strike-slip displacement in a sinistral wrench corridor (Fig. 4). Some of the resulting shear zones

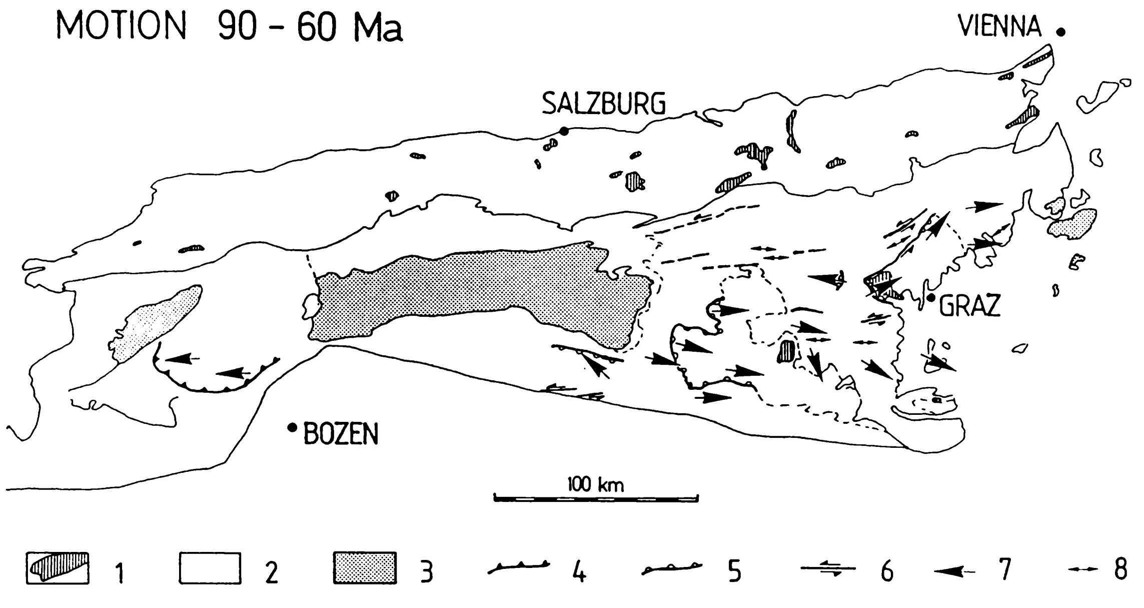


Fig. 4: Late Cretaceous motion in the eastern Austro-Alpine units. Legend: 1 - Gosau basins; 2 - Austro-Alpine Nappe Complex; 3 - Penninic units. Late Cretaceous ductile/brittle fault zones: 4 - thrust; 5 - low-angle normal fault; 6 - strike slip fault; 7 - sense of shear; 8 - coaxial deformation .

reactivated previous ductile thrust faults along nappe boundaries. The general displacement is directed to E, NE and SE. General features of these faults are: 1) The break of metamorphic isogrades along such fault zones with the superposition of amphibolite areas by low to very low grade areas; 2) distinction in cooling age provinces between ca. 120 Ma in hangingwall units and ca. 90 - 75 Ma cooling ages in footwall units; 3) fabrics which show a sequence from ductile to brittle behaviour reflecting motion during cooling from peak metamorphic conditions.

Therefore, these shear zones operated as low-angle normal faults leading to extension of higher intra-Austro-Alpine nappes and subsidence of late Cretaceous Gosau basins.

A detailed study done in the Gleinalm area displays a clear relationship between NE-trending sinistral strike-slip faults and low-angle normal faults, linking segments of the strike-slip faults (Fig. 5). Therefore, we think that extension is related to a major sinistral wrench corridor.

The decompression and unroofing of possible Cretaceous eclogites in the Koralm/Saualm area started during this time. All resulting structures indicate motion of hangingwall units towards the southeastern sector (Neubauer, 1991).

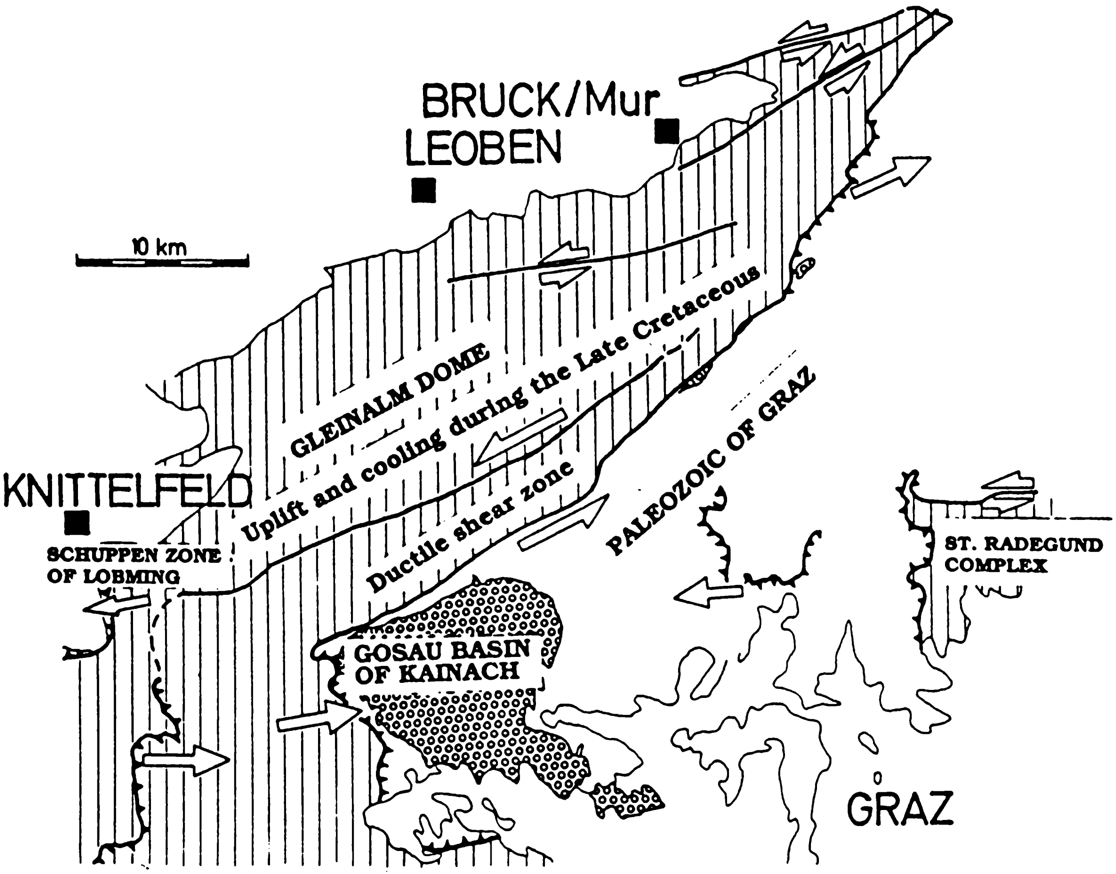


Fig. 5: Structures related to the uplift of the Gleinalm metamorphic dome.

Nappe stacking in the Penninic units

The timing of eclogite formation due to burial in the Penninic zone is controversial. Generally, a cretacous age of eclogite formation is assumed (Fig. 6) (Behrmann and Ratschbacher 1989).

At the eastern margin of the Tauern Window two main deformation events can be distinguished. The older one is expressed in the formation of a mylonitic foliation with a N-S-trending stretching lineation (Fig 7). Shear criteria indicate a noncoaxial displacement path with a motion of top to the N. This deformation affects the higher parts of the Penninic domain and is related to an internal stacking of Penninic units (Storz complex onto Central gneiss units). The deformation is

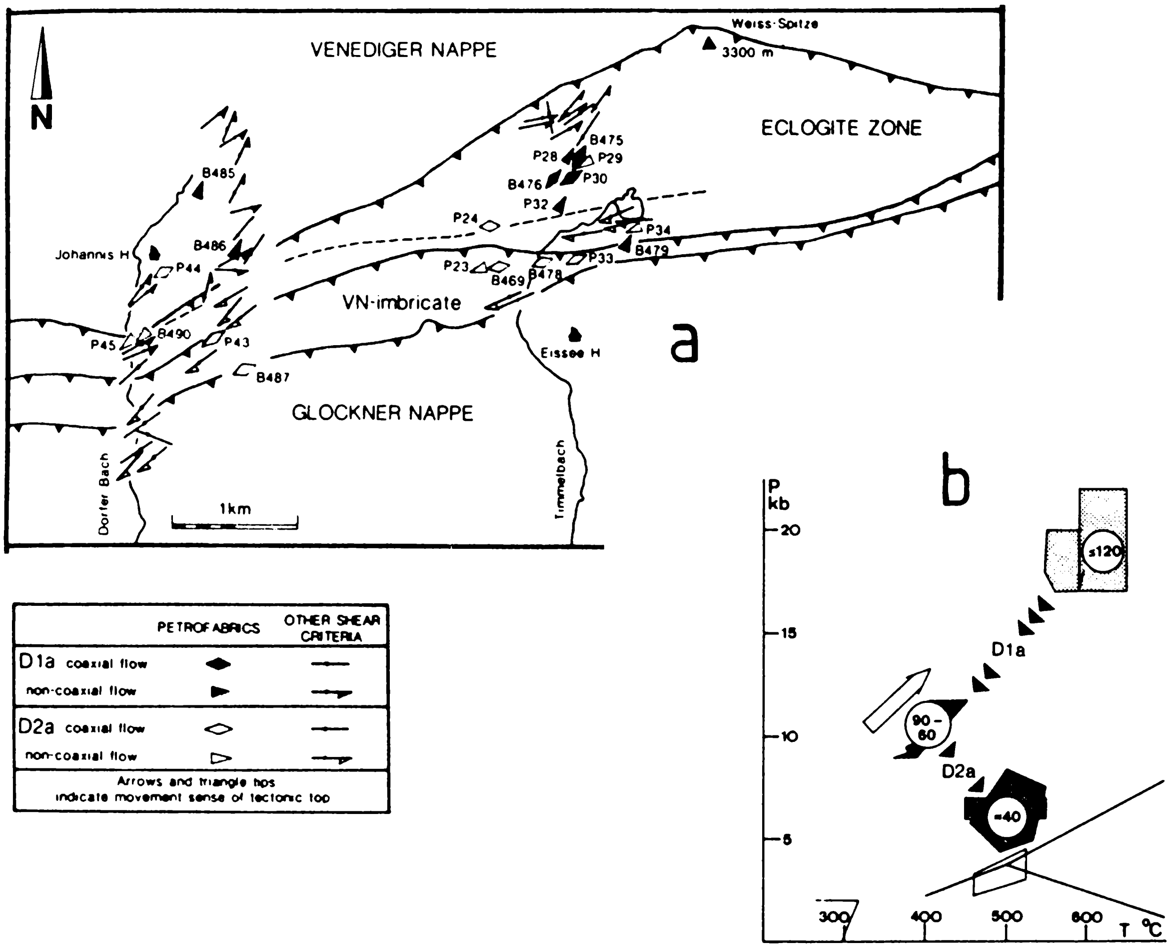


Fig. 6: Displacement path (a) and suggested P-T path and time of deformation events in the Penninic eclogite zone of the southern Tauern Window (from Behrmann and Ratschbacher, 1989).

contemporaneous with peak metamorphic conditions in higher parts of the Penninic realm and can thus be dated at about 40 Ma (timing of metamorphic peak according to Hawkesworth, 1976).

These structures are overprinted by a WNW-directed shearing in deeper parts. Most of the Zentral gneiss units, down to the deepest exposed levels, are first deformed by this shearing. The mylonitic foliation belonging to this deformation generally dips to the E(SE); areas with steeply dipping foliations (e.g. around Koschach) show a constrictional strain with a component of dextral shearing. This deformation is synmetamorphic in these levels, the timing must hence be Oligocene (metamorphic climax in deep levels at about 25 Ma according to Cliff et al., 1985). This WNW-directed motion can be related to an ongoing stacking of continental crust by subduction of the European foreland. For other Penninic windows see Fig. 8.

Oligocene and Neogene extension and strike-slip in the Central Alps

The eastern portion of the Central Alps shows a pattern of brittle ductile faults which are related to a sinistral wrench corridor along the northern margin of the Central Alps, and a dextral wrench corridor along the Periadriatic Lineament (Neubauer, 1988; Ratschbacher et al., 1989, 1991). In detail, motion along the sinistral zone often predates dextral displacement along the Periadriatic Lineament. Therefore, detailed structural studies record differing displacement paths from place to place within the orogen. In any case, the result is an extrusion of the eastern Central Alps towards east, crustal extension of the intermediate portion between the two wrench corridors, and exhumation of

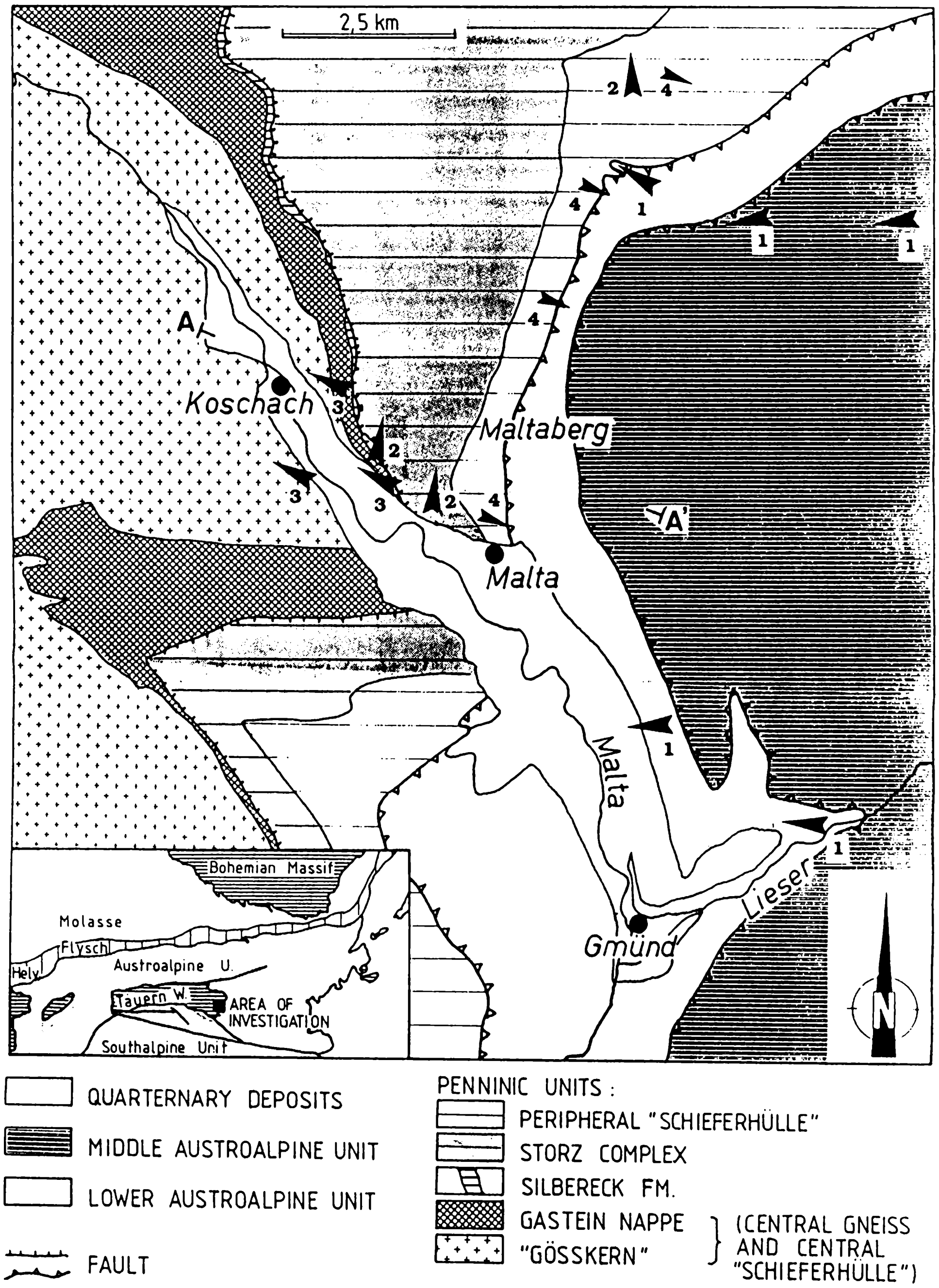


Fig. 7: Displacement path at the eastern margin of the Tauern Window (Genser, 1992). Suggested timing of displacement: 1 - Cretaceous thrusting; 2 - Paleogene thrusting; 3 - Oligocene thrusting; 4 - Neogene extension.

Penninic metamorphic domes by the same process. For the Penninic Tauern Window two models have been postulated: 1) A pull-apart dome mechanism which is related to a step of sinistral strike slip faults (Genser and Neubauer, 1989); 2) brachyanticline (Laubscher, 1988; Ratschbacher et al., 1991). It should be noted that this pattern of large-scale faults is also supported by paleogeographic data (Kazmer and Kovacs, 1985). These authors first proposed a sort of escape model to explain paleogeographic data of the Alpine/Carpathian system. But the northern sinistral margin of the escaped block is, however, after our structural and paleogeographic data much more farther to the North, ca. 100 km, than suggested by these authors.

The recent seismic pattern of the region suggests a similar escape mechanism like that one which operated during the Neogene (Fig. 10; from Gutdeutsch and Aric, 1987).

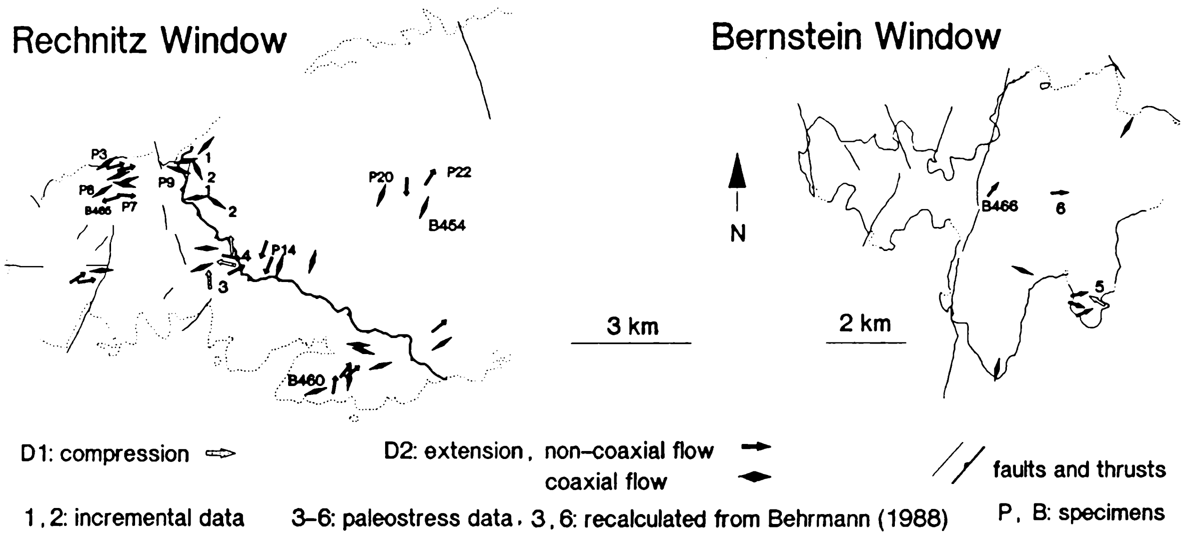
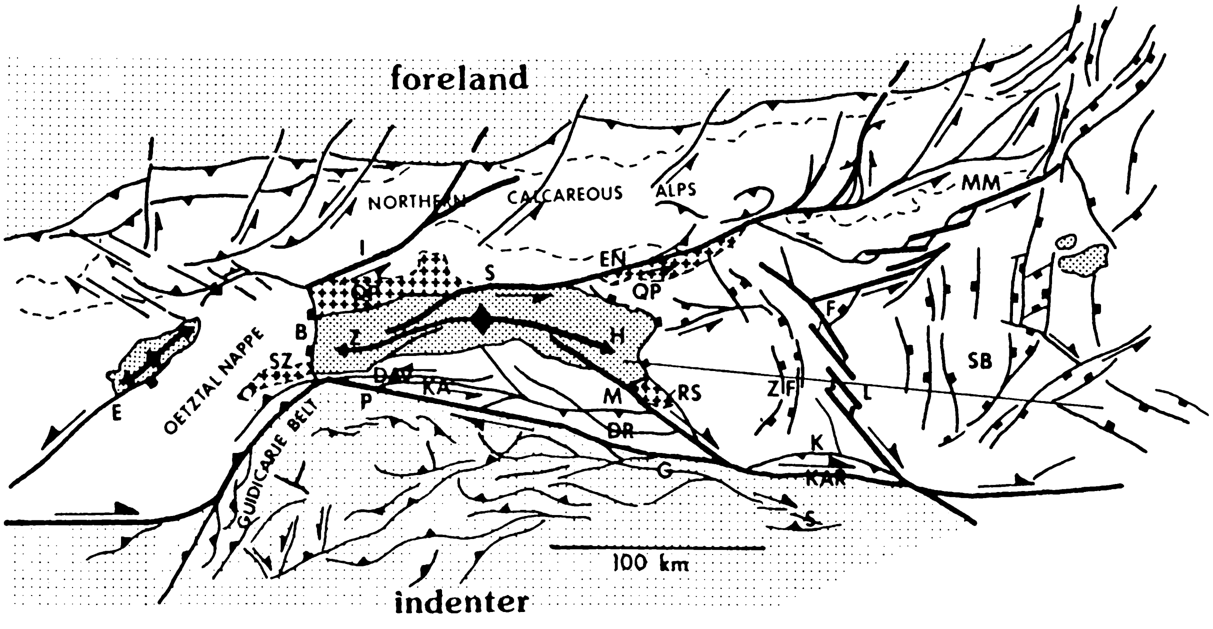


Fig. 8: Ductile and brittle structures in the Penninic Rechnitz and Bernstein Windows at the eastern margin of the Alps (from Ratschbacher et al., 1990).



Strike-slip faults:
B Brenner, DAV Defereggen-Antholz-Vals, E Engadine, EN Ennstal
G Gailtal, I Inntal, KA Kalkstein, L Lavanttal, M Mölltal
MM Mur-Mürz, P Pustertal, S Salzachtal
Basins: F Fohnsdorf, K Klagenfurt, S Save
Grabens: SB Styrian, Z Zollfeld
Domes: H Hochalm, Z Zillertal
Lithological units:
DR Drauzug, KAR Karawanken, QP Quartzphyllite
RS Radenthein series, SZ Schneeberg Zug

Fig. 9: (Oligocene and) Neogene fault pattern of the Eastern Alps (from Ratschbacher et al., 1991).

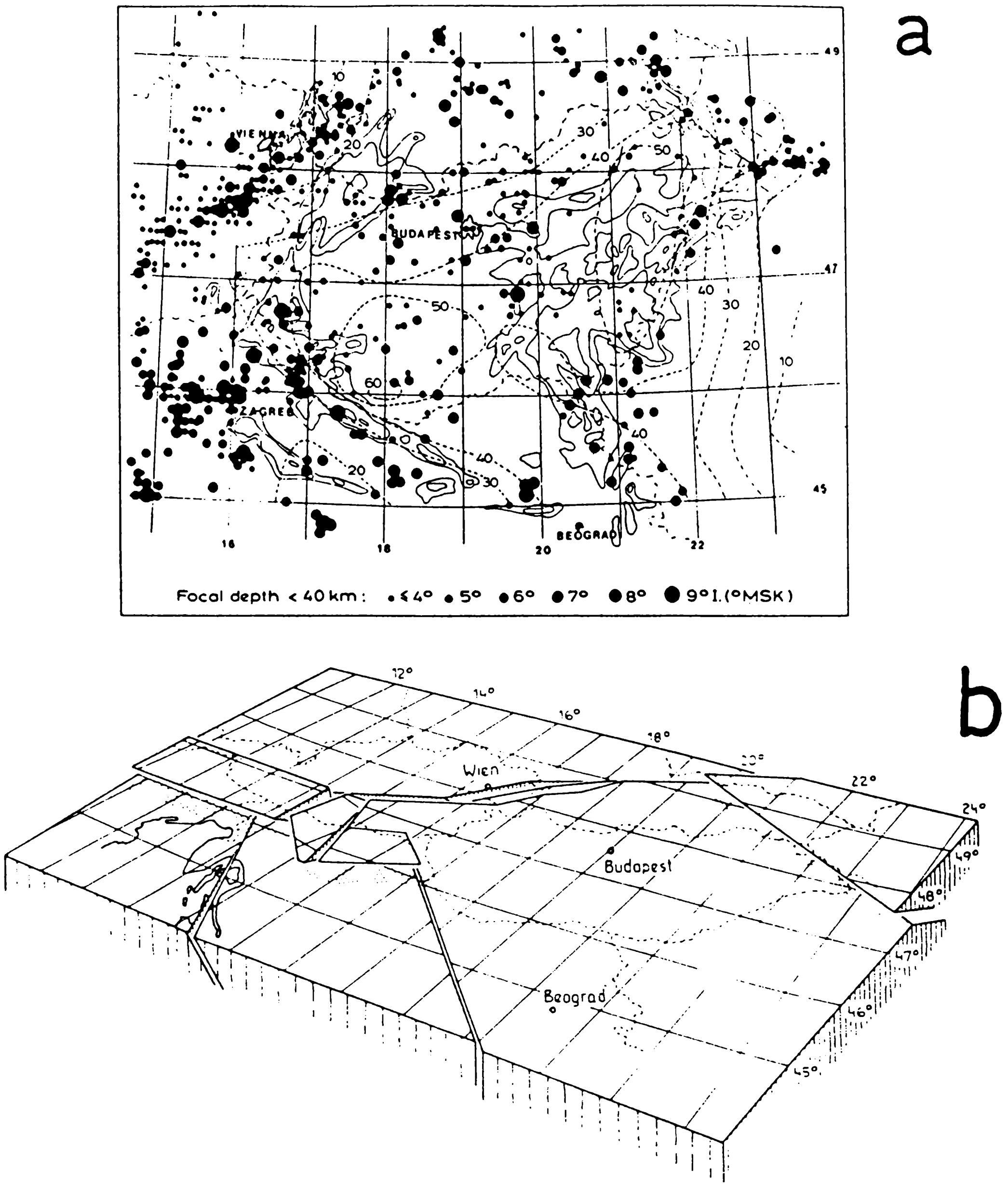


Fig. 10: Neogene motion of crustal blocks in the ALCAPA region.

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