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Extreme crustal extension in the Rába River extensional corridor (Austria/Hungary)

Gábor C. Tari

AMOCO, 501 WestLake Park Boulevard, Houston
TX 77079-2696, Texas, U.S.A.

ABSTRACT

Structural interpretation of reflection seismic profiles combined with well data reveals distinct modes of upper crustal extension in the NW Pannonian Basin. As the first manifestation of extensional collapse at the beginning of the Middle Miocene (~17.5 Ma, Ottnangian/Karpatian boundary) the Rechnitz metamorphic core complex has been formed in the Rába River extensional corridor. This metamorphic core complex style, ENE-WSW trending extreme upper crustal extension can be characterized by a minimum of 80 km horizontal extension.

Shortly after this period the style of syn-rift extension changed to a wide-rift style one (16.5-13.8 Ma, Early and Middle Badenian) producing a minimum of 40 km extension in a NW-SE direction across the Danube basin. The predominance of low-angle normal faults in the Neogene structure of the Danube basin excludes its pull-apart basin origin proposed by many. The still continuing but diminishing continental extension during the Late Miocene and Pliocene (12.5-5.5 Ma, Sarmatian-Lower Pannonian) could not advance to the localization of extension into a narrow rift zone in the NW Pannonian basin, except perhaps the center of the Danube basin.

Reassessment of published geologic maps, microtectonic measurements and radiometric age data in eastern Austria, supplemented by well and reflection seismic data in western Hungary, led to a structural model of the entire crust in this largely extended area. The new model is very specific about the geometry of a number of Alpine structural elements down to the depth of the Mohorovicic discontinuity (25-35 km) and it also represents a significant departure from the traditional interpretations of the very same region.

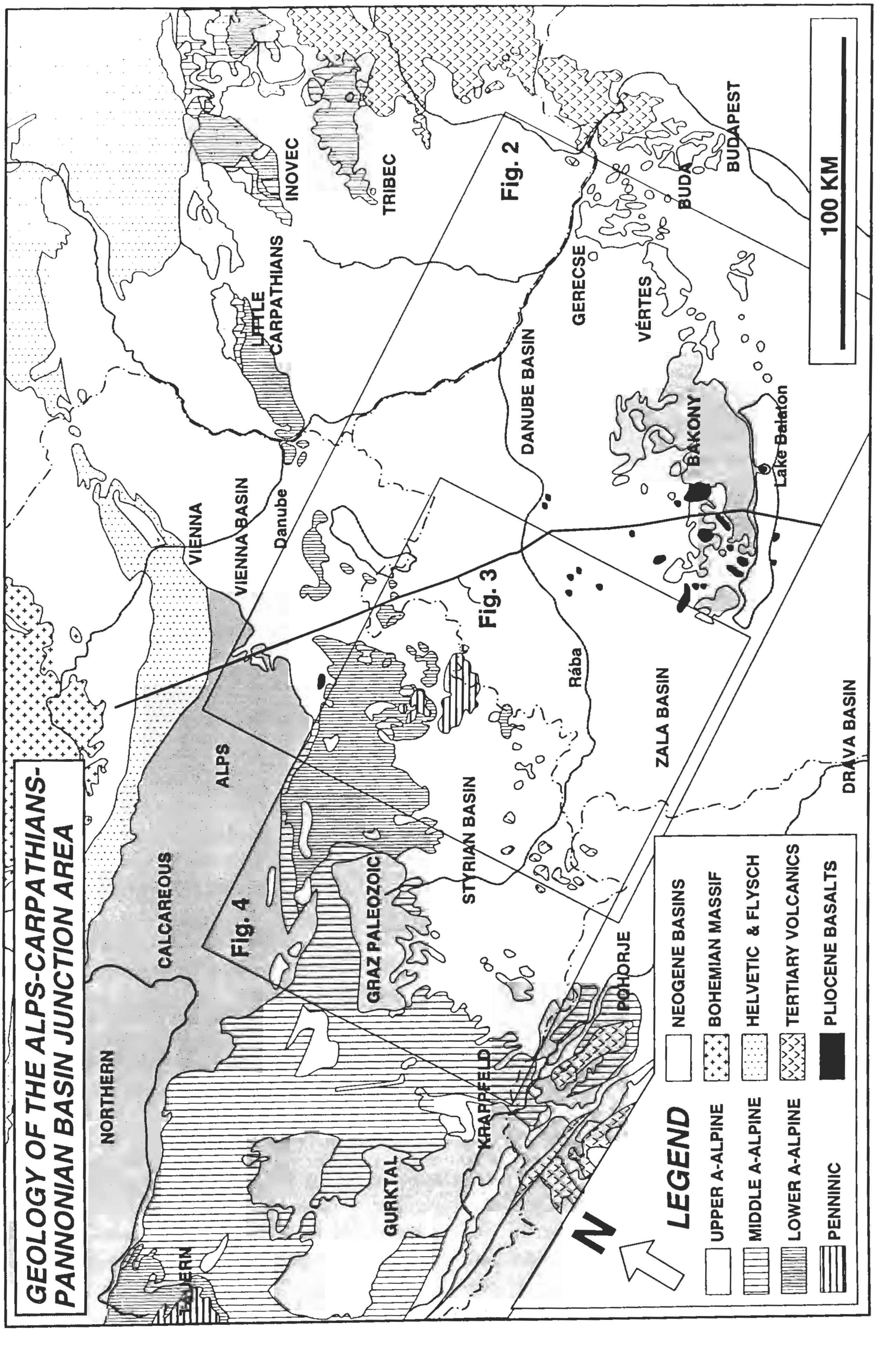
Key words: crustal extension, Rechnitz metamorphic core, Danube Basin, Pannonian Basin

Introduction

The Rába(Raab) River extensional corridor (RRec) of eastern Austria and western Hungary is a part of the Neogene Pannonian basin system stretching from the Styrian basin to the southern half of the Danube basin (Fig. 1). The reason for introducing this new term is the recent recognition of extreme crustal extension in this area, especially regarding the interpretation of the Rechnitz Window group in terms of a metamorphic core complex (Tari and Bally, 1990; Tari, 1994; Tari and Horváth, 1995). Thus the present paper focuses only on the Middle Miocene syn-rift tectonics in the RRec, which is largely responsible for the observed large-magnitude extension in the transition zone between the Eastern Alps and the Pannonian basin.

In this summary the syn-rift period is further subdivided into a Karpatian "metamorphic core complex" style extension followed by an Early-Middle Badenian "wide-rift" style extension, adopting the terminology proposed by Buck (1991). The temporal progression of the dominant extensional style in the RRec and in the broader NW Pannonian basin is discussed in details by Tari and Horváth (1995).

The Styrian and Danube basins were interpreted by many (e.g. Ratschbacher et al., 1990; Bergerat, 1989; Vass et al., 1990) as major pull-apart basins. In this paper an alternative tectonic scenario is proposed (e.g. Tari, 1994; Szafián and Tari, 1995) emphasizing the role of low-angle normal faults in the formation of the Rrec (Fig. 2). These detachment faults are also responsible for the presence of major omission contacts in the RRec which were otherwise unexplained (cf. Schmidt et al., 1984). Note that in


GEOLOGY OF THE ALPS-CARPATHIANS-PANNONIAN BASIN JUNCTION AREA
LEGEND
UPPER A-ALPINE
MIDDLE A-ALPINE
LOWER A-ALPINE
PENNINIC
NEOGENE BASINS
BOHEMIAN MASSIF
HELVETIC & FLYSCH
TERTIARY VOLCANICS
PLIOCENE BASALTS
N
100 KM
NORTHERN
CALCAREOUS
ALPS
GURKTAL
KRAPPFELD
POHORJE
GRAZ PALEOZOIC
STYRIAN BASIN
ZALA BASIN
DRAVA BASIN
Rába
Fig. 4
Fig. 3
Fig. 2
VIENNA
VIENNA BASIN
Danube
DANUBE BASIN
LITTLE CARPATHIANS
INOVEC
TRIBEC
GERECSE
VÉRTES
BAKONY
Lake Balaton
BUDA
BUDAPEST

this paper we use the terms low-angle and detachment fault interchangeably.

The most important evidence for low-angle normal faulting comes primarily from reflection seismic data combined with well data in the Hungarian part of the RRec. Note, that the most important seismic profiles were already published in several contributions (Tari et al., 1992; Horváth, 1993; Tari and Horváth, 1995) and they will not be repeated here. Similarly, for a detailed description of the regional transect shown in Fig. 3, the reader is referred to Szafián and Tari (1995). In the present paper only a few additional points are made regarding the structural evolution of the RRec.

Regional structure transect across the NW Pannonian basin

The regional structural transect (Fig. 3) crosses the entire NW Pannonian basin (Figs. 1 and 2). The northwestern, Austrian part of this transect is based on a section published by Wessely (1987). The Hungarian part of the transect is based on the systematic structural interpretation of about two hundred industry seismic reflection profiles by Tari (1994). Interval velocities of the major units were compiled based on well-shots and reported interval velocities in several seismic surveys, which were adopted for the depth-conversion of selected seismic sections. The deep structure of the middle stretch of the Danube basin was further constrained by the reinterpretation of the coincident MK-1 deep reflection seismic profile of Posgay et al. (1986). Abundant well data were provided by the monographic work of Körössy (1987) in the Hungarian Danube basin (Little Hungarian Plain).

The interpretation of several, SE-dipping low-angle normal faults along the transect represents a significant departure from earlier models which tend to operate with subvertical strike-slip faults (e.g. Balla, 1994). The presence of detachment faults clearly suggest a significant amount of NW-SE directed extension during the Middle Miocene. It is to be noted, however, that the transect cannot be balanced strictly in its present form. One difficulty is related to significant out-of-plane movements. For example, one has to keep in mind that large amount of extension (i.e. ~80 km) took place roughly perpendicularly to the transect as the Rechnitz metamorphic core complex was formed (see below). Similarly, the Eoalpine nappe structure of the Bakony Mts. records a significant period of WSW-directed thrusting during the Cretaceous making any kind of balancing hardly feasible without taking into account the third dimension.

Another difficulty comes from the poor data quality at depth (i.e. mid-crustal depth). Although many of the major low-angle faults are shown to be detached at the basal décollement of the Austroalpine system, some of the more internal faults may be detached at a much shallower level. For example, the enigmatic Rába fault (see Szafián and Tari, 1995, for a summary) may be simply the short-cut fault (sensu Gibbs, 1984) onto the Répce fault making the Mihályi high a hangingwall anticline. This, fairly "dramatic" alternative interpretation would generally increase the magnitude of extension across the Danube basin. Anyhow, preliminary balancing attempts even on the "conservative" version of the transect shown in Fig. 3 indicate that about 40 km horizontal extension occurred along the section during the Middle Miocene.

Interestingly enough, a recently published transect across the Slovakian part of the Danube basin also shows low-angle normal faulting during the Miocene (Lankreijer et al., 1995).

Subdivision of the Middle Miocene syn-rift tectonics in the RRec

During the Middle Miocene syn-rift phase two extensional systems are distinguished. The earlier system accommodated extension in a ENE-WSW direction, whereas the subsequent, almost per-pendicular

Fig. 1 (p. 2). Major tectonic units of the Alps-Carpathians-Pannonian Basin junction area (Tari, 1994). Insets show locations of Figs. 2 and 4, trace of regional transect shown in Fig. 3 is also indicated.

extensional system had an NW-SE orientation. This relationship first observed by Ratschbacher et al. (1990) based on microtectonic measurements in the Rechnitz Window group. These authors observed an Oligocene to Early Miocene(?) ductile extensional event (D2) trending ENE. This extension apparently occurred at midcrustal depth (~10 km, Koller, 1985). Ratschbacher et al. (1990) also reported a subsequent, Middle to Late Miocene brittle E-W extensional event (D4).

These observations can be reconciled with the results of seismic intrepretation. The earlier ductile extensional event corresponds to the formation of the major Rechnitz detachment fault (see below) and it is manifested by the formation of the Rechnitz-Wechsel metamorphic core complex system (ENE-WSW extension). During the subsequent extensional period (NW-SE extension) a series of smaller, brittle detachment faults formed (e.g. Fertö, Ikva, Répce and Rába faults, see Fig. 3) in a more distributed deformational style. These extensional modes somewhat overlapped in space and time in the NW Pannonian basin.

Thus following the terminology of Buck (1991), in the area of the RRec an earlier metamorphic core complex and a subsequent wide rift style of Middle Miocene upper crustal extension can be distinguished (Tari, 1994). The dominant mode of continental extension is a function of the original heat flow and crustal thickness (Buck, 1991). It is hard to evaluate the heat flow at the onset of extension but it was at least as high as the recently observed maximum values in the Danube basin (90-95 mW/m^2; Dövényi and Horváth, 1988). In fact, thermal modelling in the Styrian basin (Sachsenhofer 1991; Ebner and Sachsenhofer, 1995) suggests an initial heat flow of about 120 mW/m^2 during the Karpatian.

As to crustal thickness, the only slightly extended Bakony Mts. to the E and the unextended central zones of the Eastern Alps to the W (Fig. 1) may show the paleothickness (32-45 km) of the crust just prior to the Miocene extension (e.g. Posgay et al., 1991). At present the Mohorovicic discontinuity is at 26-30 km depth beneath the Styrian and Danube basins. Therefore based on the results of Buck (1991) a temporal progression of extensional style can be outlined: a Karpatian core complex style extension was followed by a Badenian wide-rift style extension. Moreover, in the center of the Danube basin a narrow-rift style extension might have began during the Sarmatian and the Lowermost Pannonian, but this extension could not develop into a well-defined rift-graben.

Metamorphic core complex interpretation of the Rechnitz Window

Core complex type extension in the transition zone between the Eastern Alps and the Pannonian basin was first recognized by Tari and Bally (1990). They compared the formation of the Rechnitz Window group to the well-known metamorphic core complexes of the western US (Davis and Lister, 1988; Lister and Davis, 1989; cum. lit.). In the following the supporting evidence is briefly summarized based on the detailed work of Tari (1994).

It is important to realize that there are tectonic contacts in the RRec (Figs. 4a,b) where a significant part of the Austroalpine system (up to 10 km) is missing in contrast to neighboring areas where the same succession appears to be complete (Fig. 5). The major omission contacts are as follow (see Fig. 4b for location).

(1) Anger area, where the Anger Crystalline (Upper Austroalpine) lies right on top of the Strallegg Gneiss (Lower Austroalpine), according to Flügel and Neubauer (1984), and Neubauer et al. (1992).

Fig. 2 (p. 5). Alpine structural elements revealed by reflection seismic data in the Hungarian part of the NW Pannonian Basin (Tari, 1994). For location see Fig. 1. Compare with Fig. 3.


SUBCROP OF PRE-SENONIAN BASEMENT
JURASSIC-M. CRETACEOUS
TRIASSIC-PERMIAN
CARBONIFEROUS GRANITES
LOW-GRADE PALEOZOIC
CRYSTALLINE PALEOZOIC
PENNINIC
DINARIC-TYPE PALEO-MESOZOIC
TISIA-TYPE PALEO-MESOZOIC
MIOCENE NORMAL FAULT
MIOCENE LOW-ANGLE DETACHMENT FAULT
CRETACEOUS THRUST
CRETACEOUS-MIOCENE STRIKE-SLIP FAULT
ADAPTED FROM:
FÜLÖP ET AL. (1987)
FUSÁN ET AL. (1987)
KRÖLL ET AL. (1988)
WESSELY (1988)
TARI (1994)
50 KM
Vértessomlyó
Herend
Litér
Veszprém
Balaton
Buzsák
Takácsi
Telegdi-Roth
Rába
Padrag
Nagytilaj
Répce
Ikva
Fertő
Rechnitz
Zala
FIGURE 3

(2) Wechsel area, at the northeastern margin of the Wechsel Window, where the deepest Wechsel unit within the Lower Austroalpine has a fault contact with the "Grobgneiss" complex (Eselsberg Gneiss, Neubauer et al., 1992).

(3) Kirschlag area, at the northeastern margin of the Berstein Window (see also Fig. 6a) where the Middle Austroalpine is right on top of Penninic greenschists (Pahr, 1980; 1984).

(4) Eisenberg area, where the largest omission of tectonostratigraphy is suggested by the outcrop of the Upper Austroalpine Hannersdorf Paleozoic having a poorly defined fault contact with Penninic greenschists (Tollmann, 1977; Schmidt et al., 1984).

Note that along strike, in the Pohorje Mts. (Fig. 1) the Middle Austroalpine is at least 5 km thick (Hinterlechner-Ravnik and Moine, 1977) and in the Hungarian part of the Danube basin the Middle Austroalpine(?) and the Lower Austroalpine together is at least 10 km thick based on reflection seismic data (e.g. Tari and Horváth, 1995). These supposedly intact tectonostratigraphic columns provide the basis to estimate the thickness of the missing section due to detachment faulting (Fig. 5).

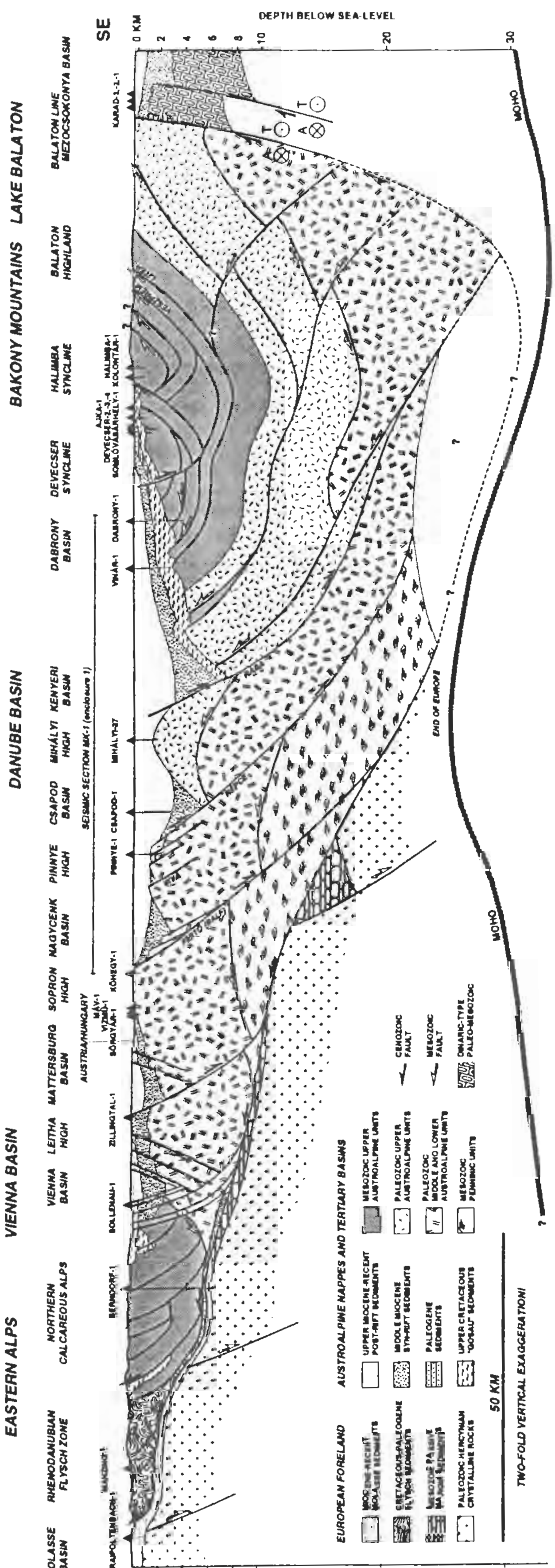
Similar omission contacts of lesser magnitude can be observed on the detailed tectonic map of the Rechnitz Window group (Fig. 6). Supporting subsurface evidence comes from the Maltern-1 well drilled at the southern margin of the Bernstein Window (Fig. 6b). In this well beneath 55 m of Lower Austroalpine Grobgneiss the entire Wechsel succession was represented by 45 m thick (!) albitegneiss on top of Penninic serpentinite (Pahr, 1977).

These prominent omission contacts cannot be explained by steeply dipping normal faults with several kilometers of vertical offset (see e.g. cross-section by Tollmann, 1989), but instead, in terms of large-scale detachment faulting involving the whole RRec area. In fact, the major omission contacts summarized in Fig. 5 are related to the very same detachment fault (top to the NE-ENE) that formed the Rechnitz metamorphic core complex.

Reflection seismic data show that the clearly defined Hungarian east plunge of the Rechnitz window displays a dome-like feature and that its tectonic contact with the overlying Austroalpine units is a major detachment fault (e.g. Tari et al., 1992). This observation leads to asking what is the specific nature of the upper and lower plate of this system, where is the breakaway of the core complex-forming detachment fault and what is the direction and magnitude of extension?

There are a number of original elements on the cross-section shown in Fig. 7, which is drawn parallel with the dominant displacement direction (WSW-ENE) during the core complex-type extensional period. The upper crustal part of the cross-section displays the main geometric characteristics of a core-complex forming detachment fault, i.e. its low-angle character and the updoming of its middle portion (e.g. Wernicke, 1985). Around and on top of the Rechnitz core complex the upper plate is extremly thinned by a number of internal low-angle normal faults which developed within the hangingwall of the large Rechnitz detachment fault. In this way the Lower Austroalpine units thinned sufficiently to expose the lower plate. Note that to the W of the Rechnitz window the detachment fault climbs up-section with respect to the footwall (or lower plate), even though it dips westward. The westward dip of the Penninic/Austroalpine boundary immediately to the W of the Rechnitz window group was estimated as about 10° by Walach (1977) and Walach and Wéber (1987) based on magnetic anomalies. The only possible candidate for the upper/lower plate boundary to the W of the lower plate culmination is at the eastern edge of the Graz Paleozoic (Fig. 4b), where the whole Middle Austroalpine is missing. The Graz Paleozoic itself is shown as a major extensional allochthon, where extension has not been sufficient to expose the lower plate (Fig. 7).

Fig. 3 (p. 7). Regional structure transect across the NW Pannonian Basin adopted from Tari (1994). The Austrian part of the transect is based on a geologic section published by Wessely (1987). A detailed description of this transect can be found in Szafián and Tari (1995)


NW
SE
EASTERN ALPS
VIENNA BASIN
DANUBE BASIN
BAKONY MOUNTAINS
LAKE BALATON
MOLASSE BASIN
RHENODANUBIAN FLYSCH ZONE
NORTHERN CALCAREOUS ALPS
VIENNA BASIN
LEITHA HIGH
MATTERSBURG BASIN
SOPRON HIGH
NAGYCENK BASIN
PINNYE HIGH
CSAPOD BASIN
MIHÁLYI HIGH
KENYERI BASIN
DABRONY BASIN
DEVECSER SYNCLINE
HALIMBA SYNCLINE
BALATON HIGHLAND
BALATON LINE
MEZOCSOKONYA BASIN
AUSTRIA/HUNGARY
SEISMIC SECTION MK-1 (enclosure 1)
DEPTH BELOW SEA-LEVEL
KM
MOHO
END OF EUROPE
EUROPEAN FORELAND
AUSTROALPINE NAPPES AND TERTIARY BASINS
50 KM
TWO-FOLD VERTICAL EXAGGERATION!

Therefore the breakaway of the Rechnitz detachment fault should be placed to the W of the Graz Paleozoic. The contact between the Graz Paleozoic (upper plate) at its western edge and the underlying Middle Austroalpine (lower plate) is indeed a documented down-to-the-E low-angle normal fault (e.g. Krohe, 1987; Fritz et al., 1991), for which most authors postulated a Late Cretaceous age. Although a period of normal faulting during the Senonian cannot be excluded, from a regional perspective this low-angle normal fault contact seems to be dominantly Miocene in age.

At any rate, the original position of the headwall breakaway was certainly to the W of its present-day erosional exposure at the western end of the Graz Paleozoic or in the Pohorje Mts. (Fig. 4b). An educated guess would place the inferred pre-erosional position of the breakaway along the crest of the Koralpe, where the present-day morphology still seems to reflect its breakaway range character (i.e. upward flexure toward the eastern side of the range, cf. Wernicke, 1985).

As to the map view, the upper/lower plate contact can be traced with reasonable confidence based on stratigraphic omissions (Fig. 4b). To the S of the Rechnitz window, in the Eisenberg Mts. the Upper Austroalpine Hannersdorf succession is obviously in an upper plate position separated from the underlying lower plate Penninics by the Rechnitz detachment fault. To the NE of the Rechnitz Window group the upper/lower plate contact can be placed on the surface at the northeastern margin of the Berstein window, where the Middle Austroalpine Kirschlag klippen are in direct contact with the Penninics (Fig. 6b). In the subsurface, to the E and NE of the Rechnitz metamorphic core complex the detachment fault can be traced downdip with confidence based on seismic data in western Hungary. To the N and NW the upper/lower plate contact is placed on the northeastern flank of the Wechsel window (Fig. 4b). The isolated Tertiary basin fragment at Kirchberg (Ebner et al., 1991) seems to lie right on top of the Rechnitz detachment fault.

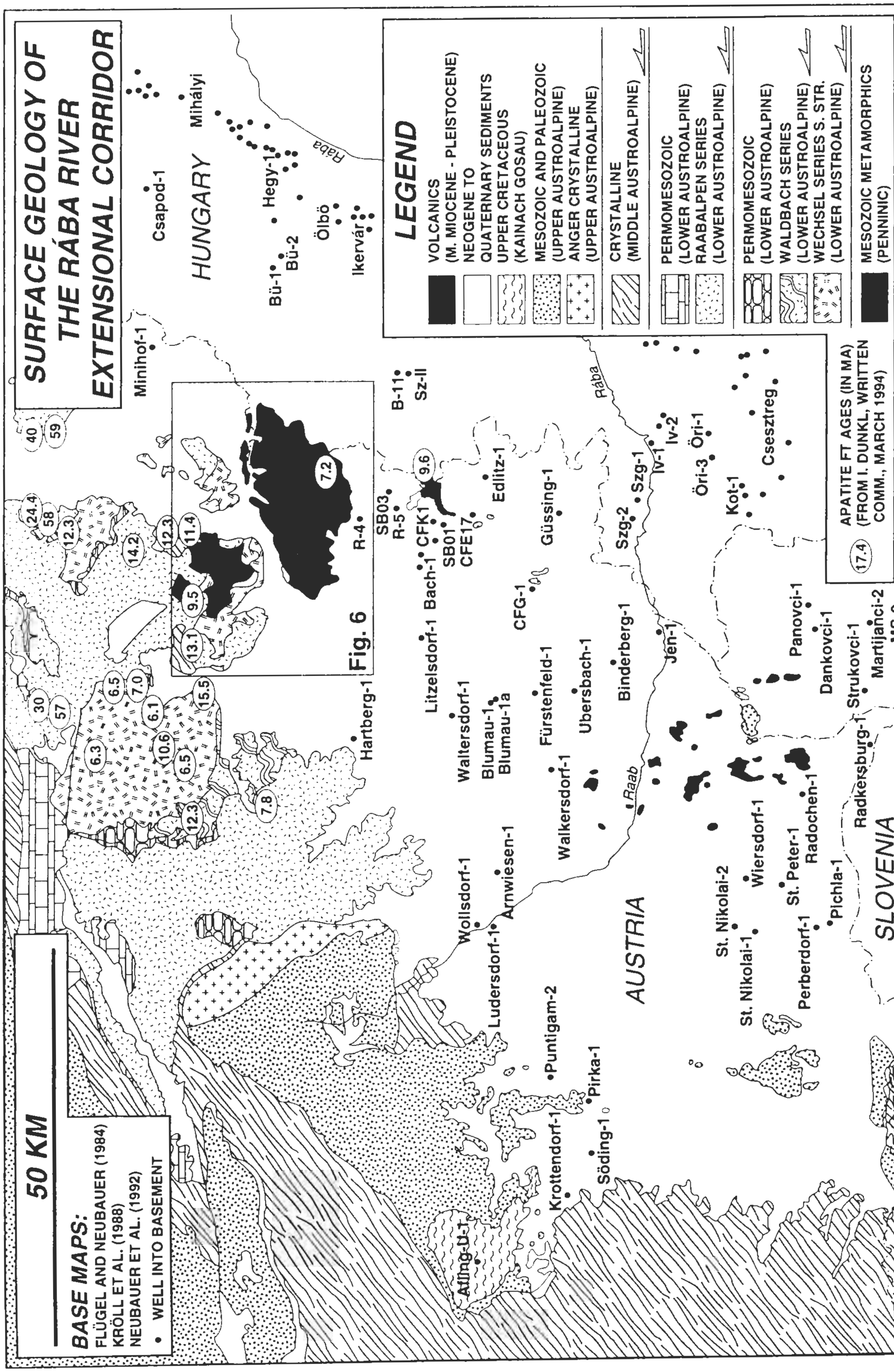
Farther to the NW and W the surface trace of the detachment fault is ill-defined; it dips probably gently to the N and runs between Lower Austroalpine units. The map of Flügel and Neubauer (1984) indeed shows repetition of these units in the area of Mürzuschlag, which might be attributed to the detachment fault. To the W, the left-lateral Badenian Trofaiach Line (Nievoll, 1985) seems to crosscut the extensional system. While the upper/lower plate contact is clearcut along the Graz Paleozoic on the surface to the S, it is only tentatively placed at the northern margin of the Pohorje Mts., in the Remschnigg area (Fig. 4b).

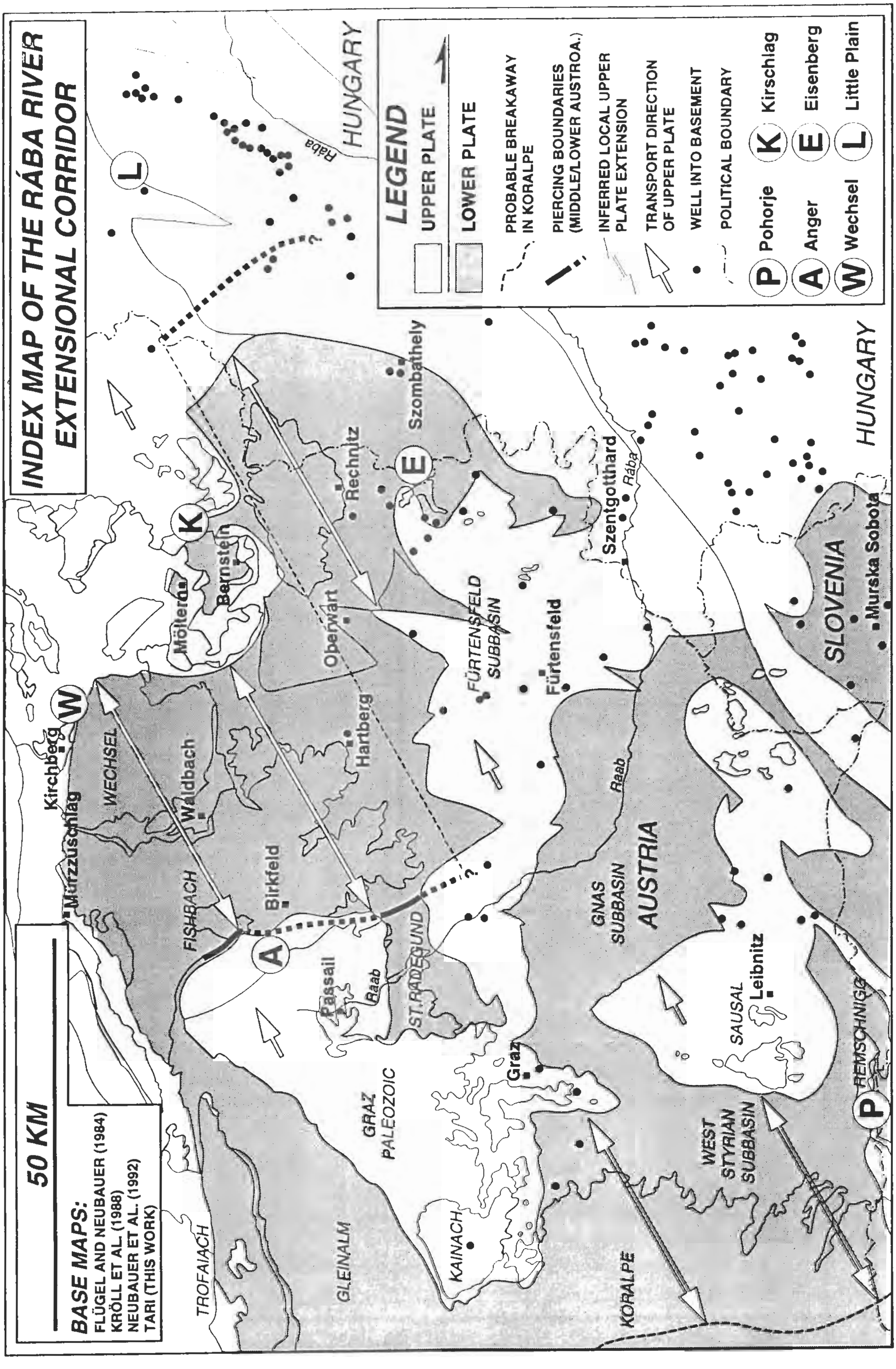
In the subsurface the upper plate is identified as the Paleozoic succession of the Upper Austroalpine as described by Kröll et al. (1988). Unfortunately, the contour of the upper plate beneath the Styrian basin is uncertain. The upper plate probably may even cover the basement in central part of the basin as well in the Gnas subbasin, where there is no well control and Kröll et al. (1988) only inferred the subcrop of crystalline rocks (Fig. 4b).

The detachment fault itself was penetrated by a number of wells (Fig. 4a). In the Kainach Gosau area the Afling U 1 well reached the Middle Austroalpine below the Graz Paleozoic (Kröll and Heller, 1978), whereas in the Styrian basin wells Pichla 1, Wiersdorf 1 and Waltersdorf 1 reached the crystalline basement (Middle or Lower Austroalpine?) beneath Upper Austroalpine low-grade metamorphics (Kröll et al., 1988).

Note that the cross-section specifically implies that the Rechnitz detachment fault soles out in the middle crust (Fig. 7). Such a midcrustal level could coincide with the top of the European plate (cf. Fig. 3). The European basement promontory of the Bohemian Massif (Fig. 1) indeed reportedly projects below the eastern end of the Eastern Alps and can be followed to the SE below the Alpine edifice as far as the Graywacke Zone (Wessely, 1987). The onlap relationships on the flanks of the Bohemian Massif show that it was a positive topographic feature throughout the Mesozoic and Paleogene at the southern margin

Fig. 4a (p. 9). Surface geology of the Neogene Rába River extensional corridor (RRec) of Austria/Hungary. Sources listed on the map.


SURFACE GEOLOGY OF THE RÁBA RIVER EXTENSIONAL CORRIDOR
50 KM
BASE MAPS:
FLÜGEL AND NEUBAUER (1984)
KRÖLL ET AL. (1988)
NEUBAUER ET AL. (1992)
• WELL INTO BASEMENT
LEGEND
VOLCANICS (M. MIOCENE - PLEISTOCENE)
NEOGENE TO QUATERNARY SEDIMENTS
UPPER CRETACEOUS (KAINACH GOSAU)
MESOZOIC AND PALEOZOIC (UPPER AUSTROALPINE)
ANGER CRYSTALLINE (UPPER AUSTROALPINE)
CRYSTALLINE (MIDDLE AUSTROALPINE)
PERMOMESOZOIC (LOWER AUSTROALPINE)
RAABALPEN SERIES (LOWER AUSTROALPINE)
PERMOMESOZOIC (LOWER AUSTROALPINE)
WALDBACH SERIES (LOWER AUSTROALPINE)
WECHSEL SERIES S. STR. (LOWER AUSTROALPINE)
MESOZOIC METAMORPHICS (PENNINIC)
17.4 APATITE FT AGES (IN MA) (FROM I. DUNKL, WRITTEN COMM., MARCH 1994)
HUNGARY
AUSTRIA
SLOVENIA
Fig. 6
Rába
Raab
Csapod-1
Mihályi
Hegy-1
Bü-1
Bü-2
Ölbö
Ikervár
Minihof-1
B-11
Sz-II
SB03
R-5
R-4
CFK1
SB01
CFE17
Bach-1
Edlitz-1
Güssing-1
Szg-1
Szg-2
Iv-1
Iv-2
Öri-1
Öri-3
Kot-1
Csesztreg
CFG-1
Litzelsdorf-1
Hartberg-1
Waltersdorf-1
Blumau-1
Blumau-1a
Fürstenfeld-1
Übersbach-1
Binderberg-1
Jen-1
Panovci-1
Dankovci-1
Strukovci-1
Martijanci-2
MS-2
Walkersdorf-1
Wollsdorf-1
Arnwiesen-1
Ludersdorf-1
St. Nikolai-2
St. Nikolai-1
Wiersdorf-1
St. Peter-1
Radochen-1
Radkersburg-1
Perberdorf-1
Pichla-1
Puntigam-2
Pirka-1
Krottendorf-1
Söding-1
Afling-U-T
40
59
24.4
58
12.3
14.2
12.3
11.4
7.2
9.6
9.5
13.1
30
57
6.5
7.0
6.1
15.5
6.3
10.6
6.5
12.3
7.8


INDEX MAP OF THE RÁBA RIVER EXTENSIONAL CORRIDOR
LEGEND
UPPER PLATE
LOWER PLATE
PROBABLE BREAKAWAY IN KORALPE
PIERCING BOUNDARIES (MIDDLE/LOWER AUSTROA.)
INFERRED LOCAL UPPER PLATE EXTENSION
TRANSPORT DIRECTION OF UPPER PLATE
WELL INTO BASEMENT
POLITICAL BOUNDARY
P Pohorje
A Anger
W Wechsel
K Kirschlag
E Eisenberg
L Little Plain
50 KM
BASE MAPS:
FLÜGEL AND NEUBAUER (1984)
KRÖLL ET AL. (1988)
NEUBAUER ET AL. (1992)
TARI (THIS WORK)
HUNGARY
Rába
Szombathely
Rechnitz
Szentgotthard
Kirschlag
Kirchberg
Möltern
Bernstein
Oberwart
FÜRTENSFELD SUBBASIN
Fürtensfeld
SLOVENIA
Murska Sobota
WECHSEL
Waldbach
Hartberg
Raab
Mürzzuschlag
FISHBACH
Birkfeld
GNAS SUBBASIN
AUSTRIA
ST. RADEGUND
Passail
Leibnitz
SAUSAL
Graz
GRAZ PALEOZOIC
REMSCHNIGG
WEST STYRIAN SUBBASIN
KAINACH
GLEINALM
KORALPE
TROFAIACH

of the European plate. We suggest that the present-day triangular shape of the outcropping Bohemian Massif should be extrapolated to the SE and this basement promontory actually continues beneath the Alpine edifice all the way to the Rechnitz area (cf. Figs. 1 and 7).

Presently the Mohorovicic discontinuity is roughly flat at about 30-32 km depth along the dip cross section (Fig. 7; Posgay et al., 1991), except at the western end where the Moho starts to deepen due to the Alpine root. The flat Moho means that space conservation requires the hot lower crustal material to flow laterally under the Rechnitz core complex. Such a mechanism is quite plausible as it was shown by Block and Royden (1990).

As to the timing the above described core complex scenario is also supported by radiometric dating (Dunkl, 1990, 1992, this volume; Demény and Dunkl, 1991). The classical Middle Miocene Styrian unconformity outcropping at several places to the E of the Sausal area (Fig. 4b) is characterized by a prominent angular discordance (Friebe, 1991a; 1993). This unconformity was dated by Friebe (1991b) as uppermost Karpatian (about 16.5 Ma) and seems to postdate most of the core complex type extensional deformation in the Styrian basin.

Another structural element which has been mapped seems to be also important in the broader Rechnitz area, i.e. the well-developed corrugations of the detachment surface parallel to the slip-direction with wavelengths of 5-10 km and amplitudes of 300-500 m (Fig. 6b). These mullion or megagroove structures are quite characteristic for the lower plates of metamorphic core complexes (e.g. John, 1987; Howard and John, 1987).

The amount of WSW-ENE extension across the Rechnitz detachment is difficult to constrain. The striking correspondence between the contours of the upper plate segments separated by the Wechsel and Rechnitz areas (Fig. 4b) suggests 40 ± 5 km extension. Since this separation probably occurred during the advanced stage of detachment faulting when the lower plate updomed, this figure is clearly a minimum estimate. Additional extension within the upper plate can be estimated from the distance between the breakaway in the Koralpe and the western edge of the upper plate (30 ± 10 km). The total of about 70 km extension is certainly too low, since it does not involve the pronounced early Middle Miocene thinning of the upper plate, especially in the Rechnitz area.

The best way to estimate the extension is to find piercing points within the lower and upper plate. The contact between the Lower and Middle Austroalpine can be traced fairly well within the lower plate in the St. Radegund area (Fig. 4b). The matching boundary can be found in the subsurface of the Danube basin, described by Tari (1994). Their apparent offset is 80±10 km measured parallel with the transport direction of the upper plate.

Conclusions

Some of the most important observations and interpretations of this paper can be summarized as follows:

(1) The syn-rift extension can be subdivided in the Rába(Raab) River extensional corridor (NW Pannonian basin) into an earlier metamorphic core complex type (17.5-16.5 Ma, Karpatian) and a subsequent wide-rift style (16.5-13.8 Ma, Early and Middle Badenian) rifting having different direction and amount of extension.

(2) Recognizing piercing points within the lower and upper plate, the normal offset associated with the Rechnitz detachment fault is 80 ± 10 km measured parallel with the transport direction (i.e. to the ENE).

Fig. 4b (p. 10). Index map and upper/lower plate subdivision of the Rába River extensional corridor of Austria/Hungary (Tari, 1994). See text for detailed explanation.

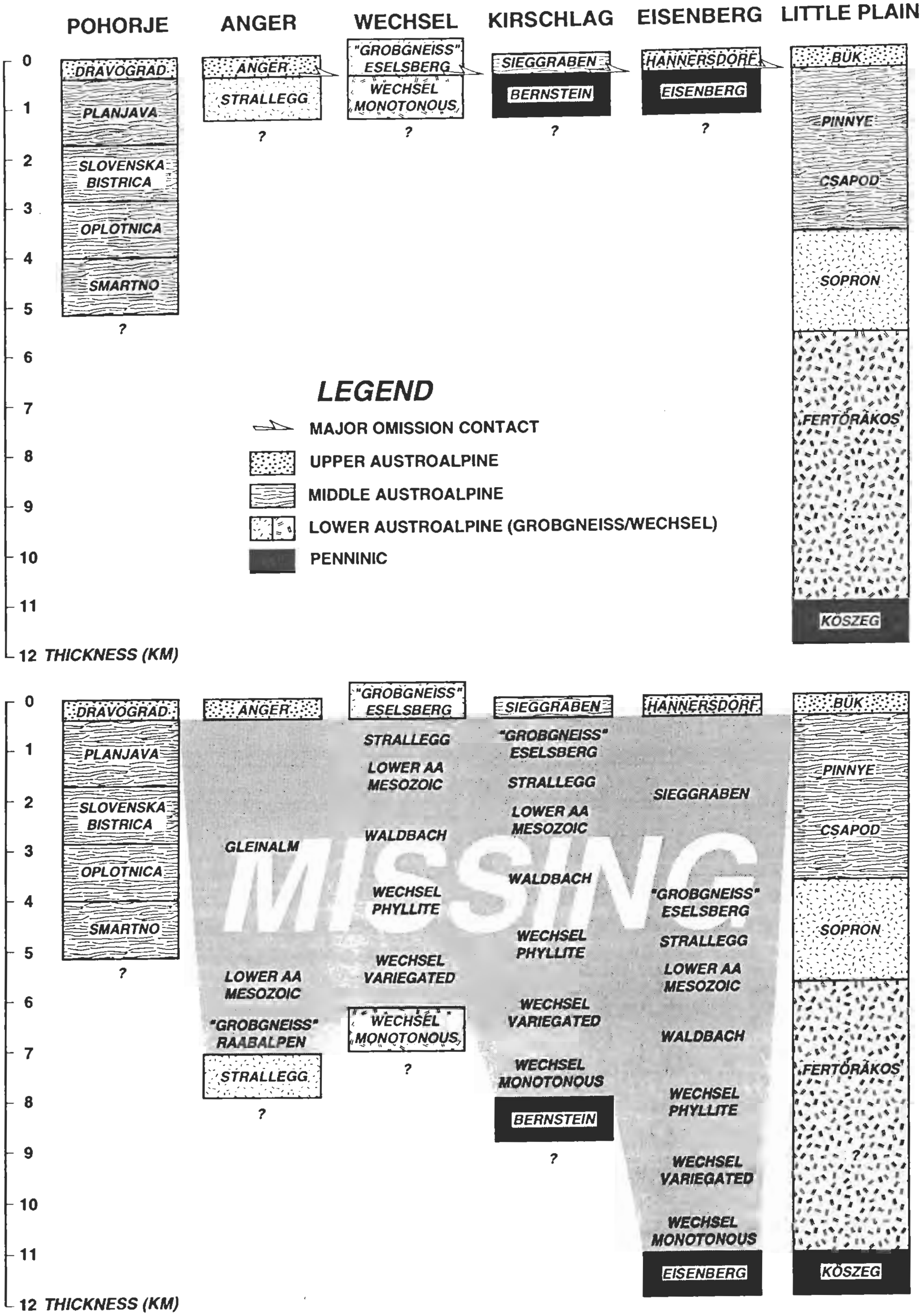


Fig. 5. Major omissions in tectonostratigraphy in the the Rába River extensional corridor (Tari, 1994). Lower part shows the estimated thickness of missing section. Location of these columns is shown in Fig. 4b. Based on various sources listed in the text.

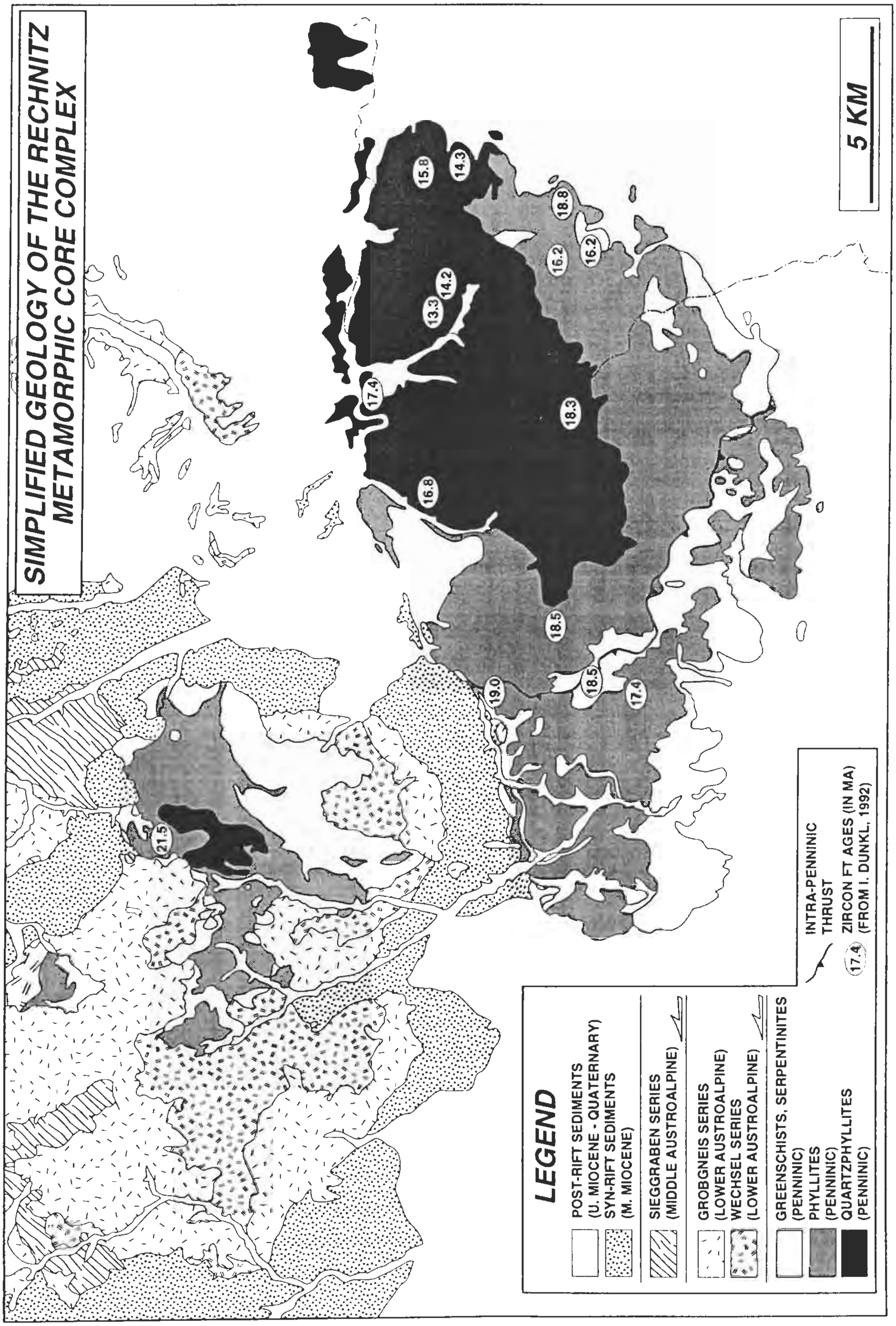


Fig. 6a. Tectonic map of the Rechnitz metamorphic core complex (Tari, 1994) simplified after Pahr (1984); Hermann and Pahr (1988). Fission track data are from István Dunkl (pers. comm., 1994, see also this volume).

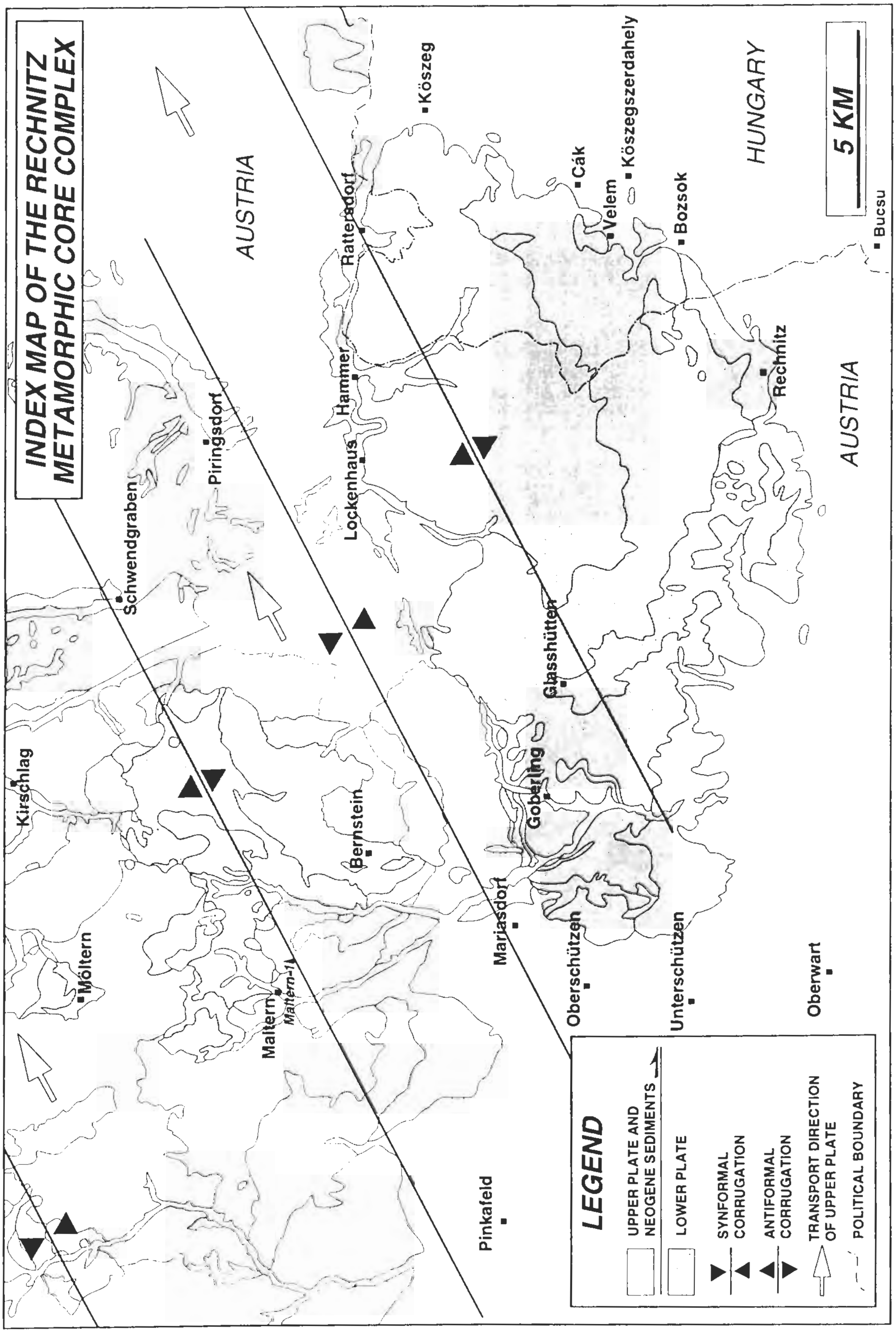


Fig. 6b. Index map and upper/lower plate subdivision of the Rechnitz metamorphic core complex (Tari, 1994; Tari and Horváth, 1995).

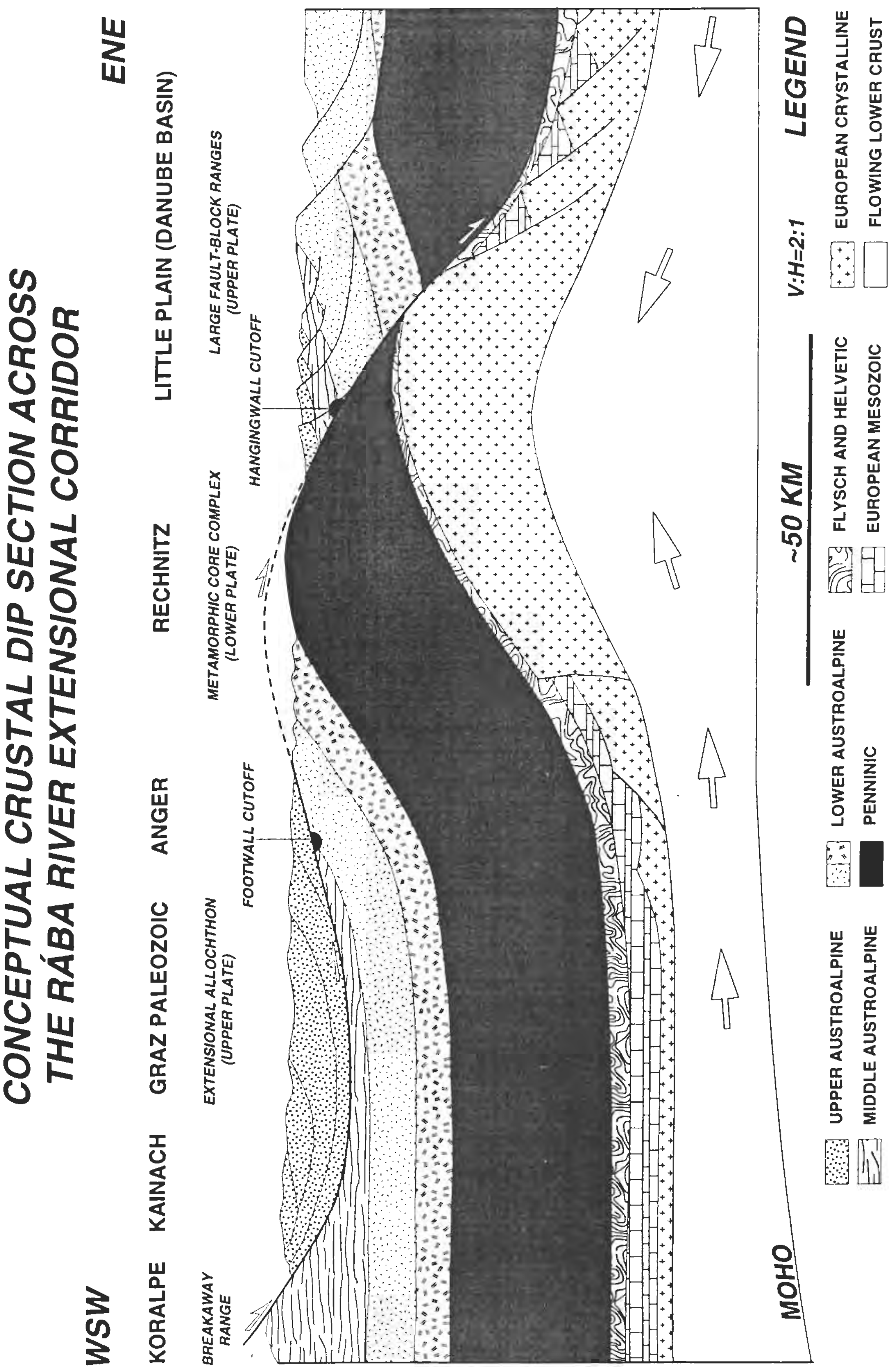


Fig. 7. Conceptual crustal dip section across the the Rába River extensional corridor (Tari, 1994). Vertical exaggeration is about twofold. Note that the Neogene Styrian and Danube basins are omitted for clarity, the section is drawn at the level of the pre-Tertiary basement.

(3) The apparent lack of any syn-rift strike-slip structures and the presence of several major low-angle normal faults in the NW Pannonian basin suggest a primarily extensional origin for both the Styrian and Danube basins as opposed to the traditionally held pull-apart basin interpretation.

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