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BASEMENT TECTONICS OF THE DANUBE LOWLANDS

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Abstract: In the basement of the Danube Lowlands, meso- and epi- to anchizonal metamorphites can be distinguished. The subdivision of mesozonal metamorphites into "Tatric" and "Veporic" Units (Slovakia) is lacking in composition criteria, and ranging all of them into "Lower Austroalpine" (Hungary) seems to be groundless. Distinction and correlation of "Austroalpine" and "Tatroveporic" mesometamorphites is advisable instead. Epi- to anchizonal metamorphites in Hungary are classified into five units, viz. Szentgotthárd Phyllite (analog of the Sausal Series in the basement of the Styrian Basin, Upper Austroalpine?), Bük Dolomite (analog of the Graz Paleozoic, Upper Austroalpine), Vaszar Slate (Paleozoic basement of the Transdanubian Range), Nemeskolta Slate (heterogeneous fill of the dislocation zone of the Rába Line) and Mihályi Slate. In seismic sections, the Mihályi Slate emerges from-below Bük Dolomite in the south and mesometamorphites in the north. It is a monotonous carbonate-rich shaly-silty sequence with sporadic tuff and tuffite intercalations. Metamorphic parameters are similar to those of the Rechnitz–Köszeg Penninics but K/Ar white mica ages fall in Early Cretaceous. Correlation of Mihályi Slates with the Penninics would be possible if we accept that, in the Alpine–Carpathian junction zone, Penninic sediments extend beyond the area of the Tertiary metamorphism. In the basement of the Slovakian Danube Lowlands low-metamorphic rocks on the buried southwestern continuation of the Považský Inovec Mts. and in western Ipeľ Basin may be regarded as possible analogs of the Mihályi Slate. That would be in harmony with outlining an Ivrea type body in the area since above that body, tectonic units of deepest position - Penninics and even its foot (Kolárovo granites and gneisses?) - are to be expected.

Key words: Alps, Carpathians, age, anomaly, correlation, crust, geophysics, metamorphism, phyllite, tectonics.

Introduction

The tectonic qualification of the southeastern Danube Lowlands areas - "Transdanubian Range Unit" - is uniform in Slovakia and Hungary (Fusán et al. 1987b; Fülöp & Dank 1987; Dank & Fülöp 1990) whereas there is a serious discrepancy in the tectonic subdivision of the areas with metamorphic basement. Subdivision in Hungary (Császár & Haas 1984; Brezsnyánszky & Haas 1985; Fülöp & Dank 1987; Dank & Fülöp 1990; Fülöp 1990) seems to be based on clear chronological and petrographical criteria: the "Penninic Unit" consists of metamorphosed Mesozoic, the "Lower Austroalpine Unit", of pre-Mesozoic crystalline rocks metamorphosed in amphibolite facies, and the "Upper Austroalpine Unit", of anchi- and epimetamorphic Paleozoic rocks. At the same time, distinction between the "Tatric" and "Veporic" crystalline rocks in Slovakia (Fusán et al. 1972b, 1987b) seems to be based first of all on the position of the boreholes in the regional tectonic structure, not on real petrographic features.

That difference forms a barrier for tectonic correlation of the metamorphic units in the basement of the Danube Lowlands. The barrier in question, however, is not necessarily impassable, and the correlation opens new perspectives in understanding the basement structure.

Tectonic position and formulating problems

The major tectonic boundary within the pre-Tertiary basement of the Danube Lowlands is the Rába Line (Scheffer & Kántás 1949) in Hungary and Hurbanovo Line (Gaža & Beinhauerová 1977) in Slovakia. The Transdanubian Range Unit is situated southeast of them, while the Alpine–Carpathian transition section (at least 120 km) is situated the northwest and north of them (Fig. 1). The transition is expressed in the "Little Carpathian" influence in the Rosalia Mountains, Leitha and Hainburg Hills (Pahr 1980b) and in the "East Alpine" influence in the Little Carpathians (Maheľ 1986). As a consequence, applicability of pure Alpine or pure Carpathian terminology seems to be doubtful.

This can be illustrated by the problem of the identification of Penninic sequences in the transition area. In the Alps, the Tertiary metamorphism is one of the most principal features of the Penninics (Frank et al. 1987), and, in Hungary, it is used as the main diagnostic criterion (Árkai & Balogh 1989; Fülöp 1990). Relics of the Cretaceous metamorphic minerals (Lelkes-Felvári 1982; Koller 1985) clearly demonstrate that Tertiary metamorphism of the Eastern Alps affected already metamorphosed Penninic sequences. Thus, no direct causal relationships between the closure of the Penninic basin and Tertiary metamorphism can be supposed. If so, the eastern closure of the Penninic basin and the eastern termination of the Tertiary metamorphism do not necessarily coincide, and Penninic sequences with no Tertiary metamorphism are not excluded in the transition area. Consequently, the age of the metamorphism in that area does not necessarily serve a firm basis for identification of the Penninics. To be more precise, Tertiary ages confirm it, but Cretaceous ages do not exclude it, and the last conclusion outlines the main difference from the Alpine s.s. areas.

The Slovak experience points to difficulties in distinction between the "Tatric" and "Veporic" crystalline basement, and the

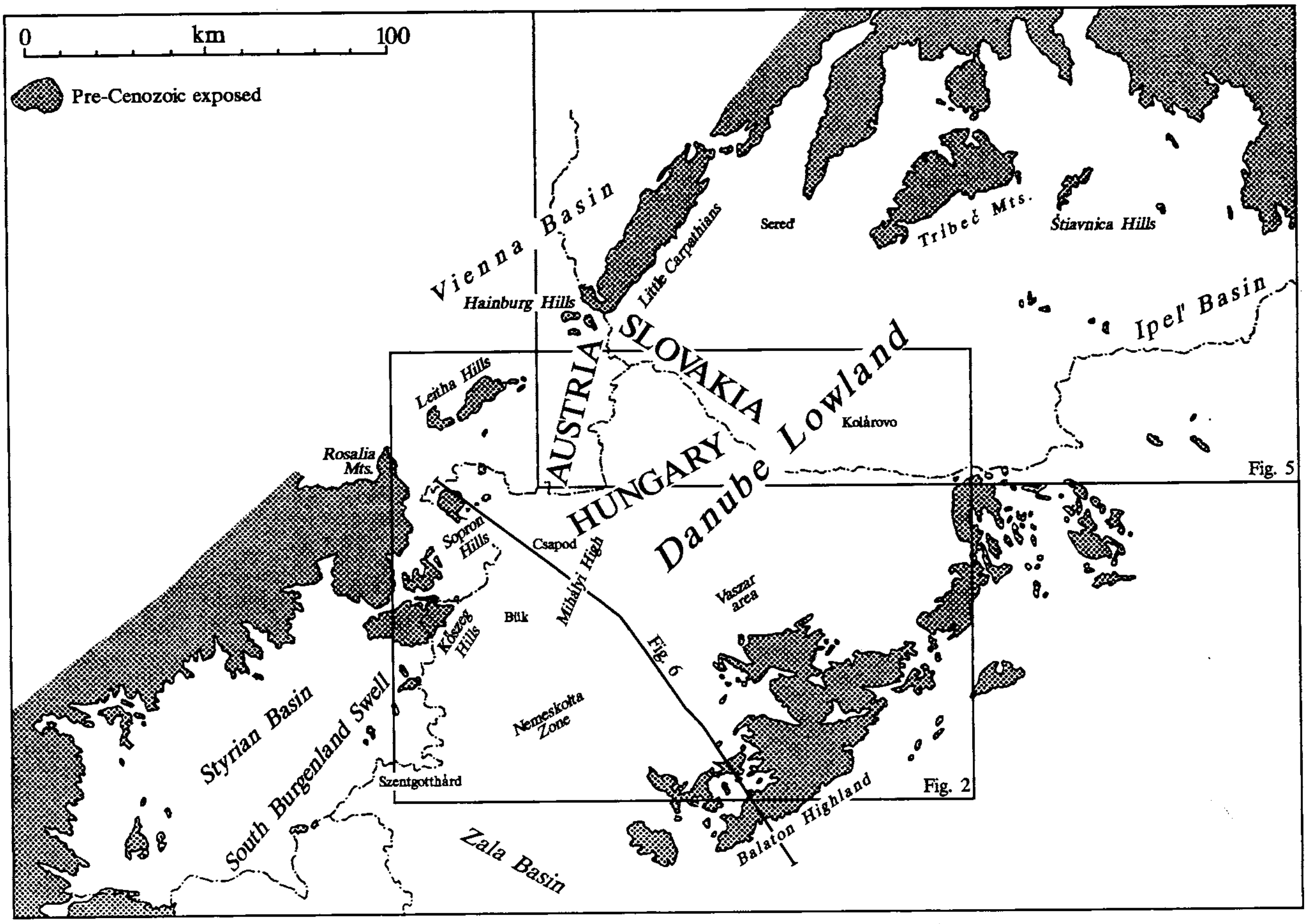

Fig. 1. Index map.

confidence of numerous authors in assigning all crystalline rocks from boreholes in the Hungarian Danube Lowlands to the Lower Austroalpine Unit seems to be groundless. On the analogy with the concept for the Styrian basement (Flügel 1988a, b), from a petrographic point of view it would be most correct not to subdivide "Tatroveporic" crystalline in Slovakia at least south of the Tribeč-Štiavnica area. In that case, correlation of the "Austroalpine" and "Tatroveporic" crystalline would not generate problems.

The position of low-grade metamorphic rocks in the Hungarian Danube Lowlands is, however, really problematic. In current geological and tectonic maps (Fülöp & Dank 1987; Dank & Fülöp 1990), they are named "Upper Austroalpine Unit" with reference to the analogy with the Graz Paleozoic (Fülöp 1990). That analogy, however, has never been analysed and confirmed since the appearance of that statement (Balázs 1975) although it wandered from publication to publication and, in last decade, transformed into an axiom.

Low-grade metamorphic rocks in the Hungarian Danube Lowlands basement

Rocks in the basement of the Hungarian Danube Lowlands were primarily identified as "crystalline", "metamorphic" etc. A distinction between crystalline rocks and metamorphic slates was introduced by Balázs (1967) and used for subdivision ("Upper Proterozoic crystalline" and "Variscan metamorphic sequence") in tectonic maps by Balogh & Körössy (1968). Somewhat later, the Kőszeg slates were parallelized with the Penninic sequence (Nagy 1972), regarded as Mesozoic, and excluded from the Variscan metamorphites.

Low-grade metamorphites were drilled in several areas (Fig. 1). Vaszar Slate was regarded analogous to those in the Balaton Highland both being covered by Permian sediments (Juhász 1967). Nemeskolta Slate was also correlated with the Balaton Highland slates (Juhász & Köháti 1966; Balázs 1967, 1971, 1975) although no overlying Permian or Mesozoic sediments were penetrated. Characteristic of the Vaszar and Nemeskolta Slates is the low carbonate content (Balázs 1971) therefore those sequences have been separated from the carbonate-rich Mihályi Slate correlated with the Graz Paleozoic (Balázs 1975).

The two types of slate have been recognized in one succession in the borehole Ikervár Ike–4 (Fig. 2) of the Nemeskolta area (Balázs 1967) which was declared to be the stratotype of the Paleozoic of the Hungarian Danube Lowlands (Balázs 1971, 1975). The low-carbonate sequence was penetrated in a lowermost position whereas the carbonate-rich sequence, in a topmost, with a mafic volcanic sequence lying between them. The uppermost part of the volcanic sequence was qualified as a tectonic breccia, nevertheless, the stratigraphic nature of the succession has not been doubted (Fülöp 1990).

The correlation of the Ike–4 upper sequence with Mihályi Slate (Balázs 1971, 1975) seems to be unconvincing since the rocks of the Ike–4 upper sequence are rich in graphitic and cal-

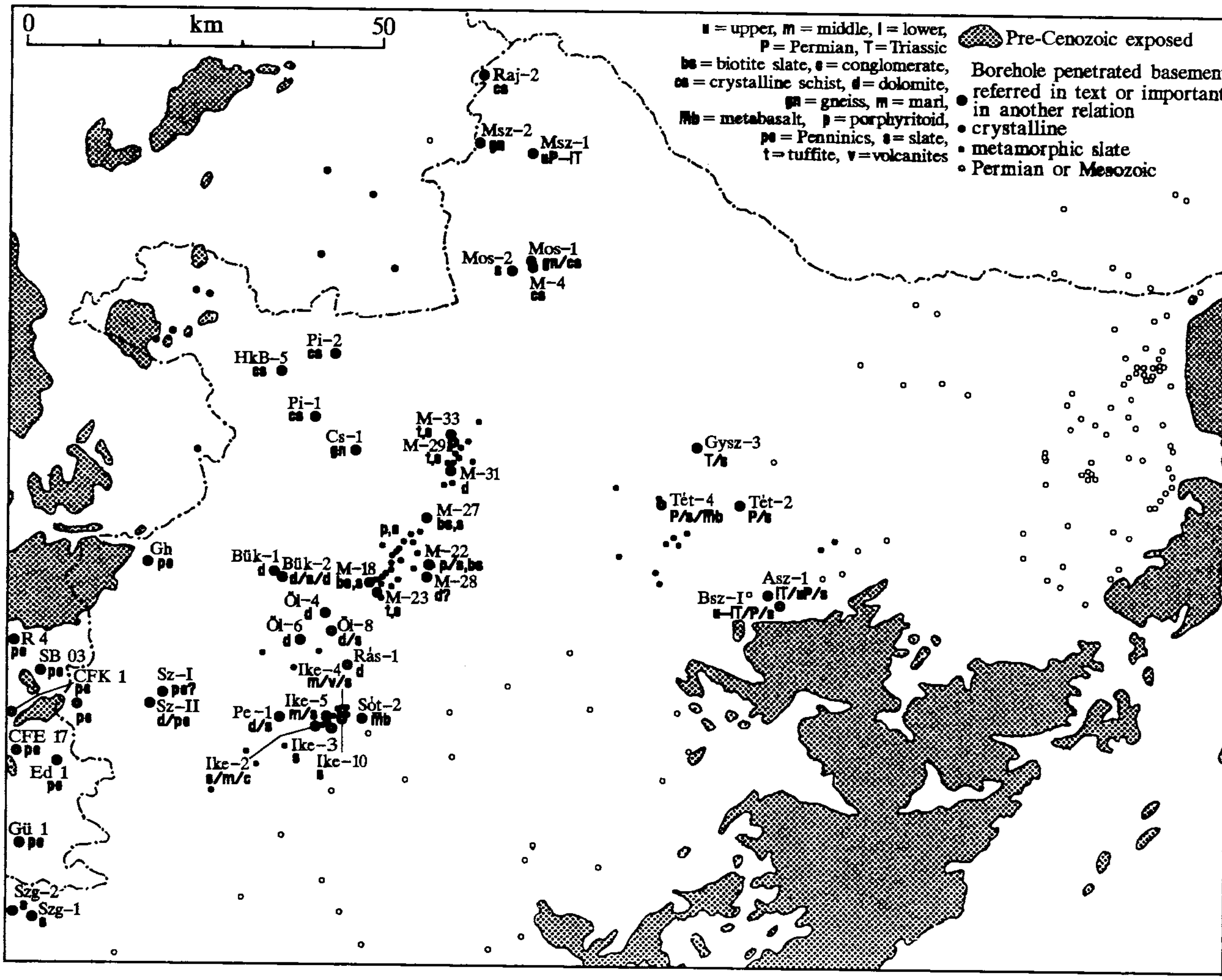

Fig. 2. Boreholes with metamorphites in Hungarian Danube Lowlands, after Körössy (1987), Császár et al. (1978) and Fülöp (1990).

careous matter which is unusual for Mihályi Slate. Consequently, the three slate sequences - Vaszar, Nemeskolta and Mihályi - should be discussed separately. Beside those three sequences, two others are frequently mentioned as distinct objects viz. Bük Dolomite and Szentgotthárd Phyllite.

Vaszar Slate is the only sequence of the three with a certain stratigraphic position: 5 boreholes of 16 penetrated it below Permian sediments, in 2 cases covered by Triassic. Moreover, in maps it is partly separated from other metamorphites by boreholes with Triassic beyond (i.e. NW) of it. It is represented by anchimetamorphic low-carbonate argillaceous-silty sediments (Árkai et al. 1987) with K/Ar white mica ages 311 ± 13, 325 ± 15 and 329 ± 13 Ma (Árkai & Balogh 1989). Their belonging to the Variscan basement of the Transdanubian Range Unit is hardly disputable.

Nemeskolta Slate was regarded as similar to Vaszar Slate in a petrographical sense (Balázs 1967, 1971, 1975, 1983; Árkai et al. 1987). A striking difference of the Nemeskolta metamorphic basement from that in surroundings of Vaszar consists in the presence of various other rocks. Of 13 boreholes with metamorphites, marls and marly slates were in 3, conglomerates, in 1, and volcaniclastics, in 2. Of 9 boreholes which penetrated the basement for at least 50 m, 3 displayed heterogeneous succession of metamorphites. As seen, the Nemeskolta basement known from boreholes in a maximum 3 km wide strip is heterogeneous both horizontally and vertically.

There are only two direct age determinations available. Upper Jurassic or Lower Cretaceous microfauna (Tintinnidae, Lombardia) was reported from Core 29 (0.05 m marls from 1959.0 - 1960.5 m) of the borehole Ike–2 (Juhász & Kőháti 1966) and a 314 ± 13 Ma K/Ar white mica age, from Core 15 (1.5 m slates from 1750.0 - 1753.0 m) of the borehole Ike–10 (Árkai & Balogh 1989).

It has been all the fashion for the last decade to express doubts concerning the microfauna (Kázmér 1986; Korössy 1987 and numerous oral comm.) and to declare the Paleozoic age to be proved. The single radiometric age, however, is not necessarily extentable on all the metamorphites in that strip, and the variable petrographic composition, in reality, leaves open the question on the uniformity and homogeneity of the Nemeskolta basement in a stratigraphic sense.

Characteristic of **Mihályi Slate** is its homogeneity. Of more than 40 boreholes, 2 penetrated dolomites (in breccias immediately below the overlying Miocene conglomerates, relationships with the slates being doubtful) and 6, mafic and/or intermediate volcaniclastic intercalations. The more than 100 cores mostly consisted of sericite to sericite-chlorite or even chlorite slates with various amounts of carbonate (calcite, dolomite, siderite)

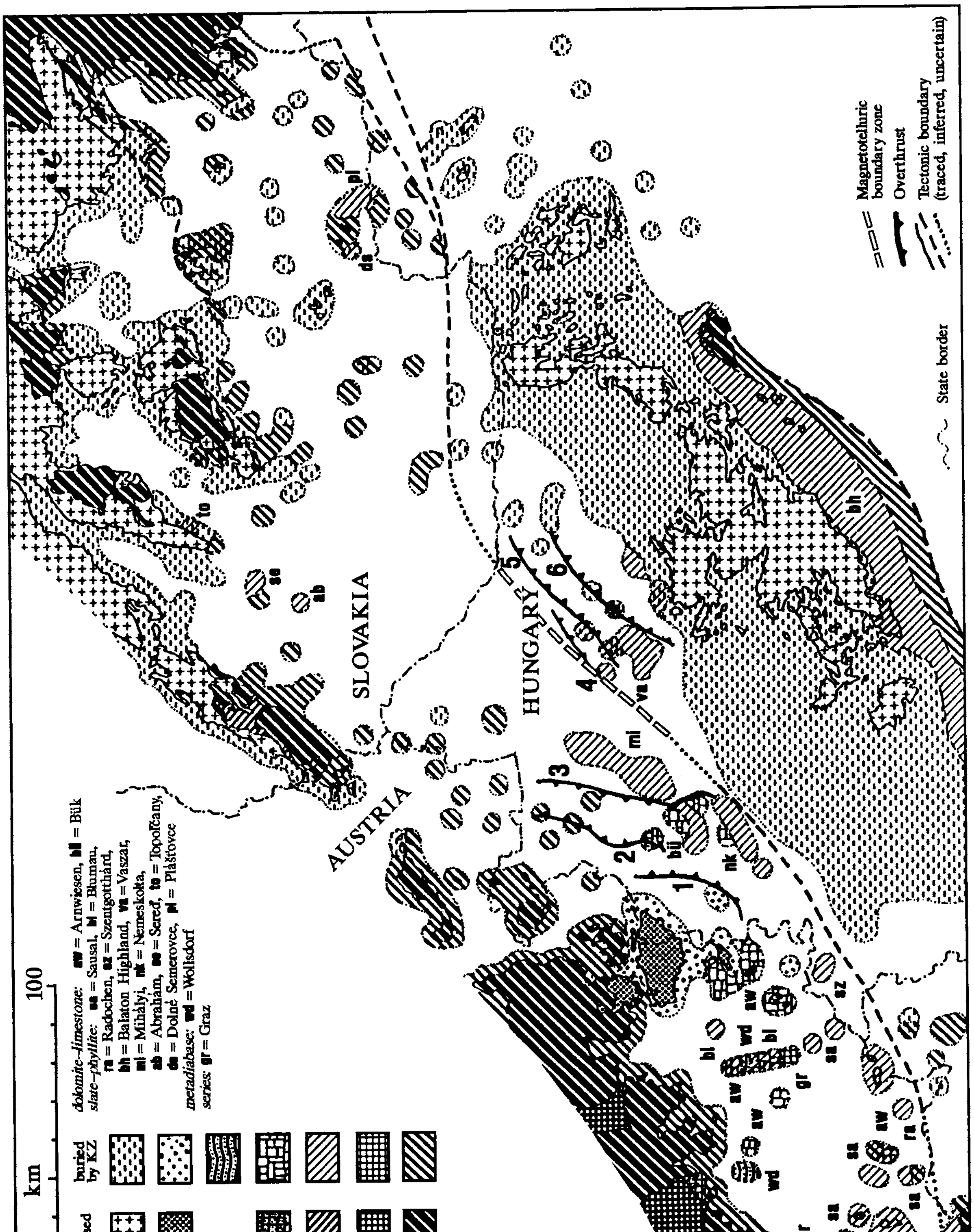

Fig. 3. Pre-Cenozoic rock associations in the basement of the Danube Lowlands and its surroundings constructed by 2.5 km extrapolation from exposures and boreholes. Intra-basement overtrusts, after Pogácsás et al. (1991), and magnetotelluric boundary zone, after Hobot et al. (1991), indicated.

veins and infillings. In subordinated amounts, siltstones and sandstones as well as calcareous and dolomitic slates occur. Limestones are only observable as some cm lenses in calcareous slates. Acid volcanic influence reported by Balázs (1971) seems to be doubtful: idiomorphic albite and albite-oligoclase crystals are most probably porphyroblasts, not crystalloclasts, since the expected accompanying quartz is completely absent.

Mihályi Slate was traced for about 30 km in a SSW–NNE direction that points to its great thickness. Its metamorphism, according to Árkai et al. (1987), took place in the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. In some of Mihályi phyllites, biotite was observable (e.g. in Lelkes-Felvári's photo, see Fig. 29D in Fülöp 1990) that points to presence of the biotite subfacies as well. Consequently, the metamorphic grade of Mihályi Slate is analogous to that of Kőszeg Slate (Lelkes-Felvári 1982).

Árkai et al. (1987) concluded from illite-crystallinity measurements on the high geothermal gradient during the metamorphism of Mihályi Slate characteristic of the Variscan metamorphism and different from that of the Penninics. That conclusion, however, is unconvincing since measurement results from Mihályi were compared with the expectable value for Kőszeg (Lelkes-Felvári 1982), not with measurement results which display no significant difference.

Árkai & Balogh (1989) reported a 116 ± 5 and a 123 ± 5 Ma K/Ar white mica age (Early Cretaceous) which significantly differs from those for the Penninics (Tertiary). That fact was interpreted in a pure "Alpine" framework in terms of excluding Mesozoic and confirming Paleozoic age of Mihályi Slate. That argumentation, however, would only be valid if the Mihályi area were constituent of the Alps s.s. As shown above (Chapter 2), it cannot be excluded that the extreme eastern Penninics extends beyond the area affected by the Tertiary metamorphism. Mihályi Slate, thus, may represent Penninic sediments with no Tertiary, i.e. with only Cretaceous metamorphism, and this would be in harmony with all data available.

Bük Dolomite was defined as a stratigraphic unit (Fülöp 1990) on the basis of the Bük–1 (Fig. 2) borehole section with dolomites and dolomite breccias for about 200 m (9 cores). Up to 20 km south and southeast of Bük–1, 7 other boreholes also penetrated dolomites, dolomite breccias and dolomite sandstones. The maximum thickness of dolomites (280 m) was observable in the borehole Ölbő Öl–6. Within the 140 m basement sequence of Bük–2, marly slates (calcareous phyllites) of about 100 m in the thickness were both covered and underlain by dolomites whereas, in boreholes Öl–8 and Pecöl Pe–1, the dolomites were underlain by calcareous sericite slates. In the area with dolomites in the basement, four boreholes only penetrated various slates in a 20 - 60 m thickness. As seen, the dolomites both vertically and horizontally alternate with calcareous slates and are probably close to them in a stratigraphic sense. Consequently, when discussing the basement tectonics, considering a dolomite-slate sequence seems to be necessary.

Sporadic b_o values (Árkai et al. 1987) are analogous to those of Mihályi, not Nemeskolta Slate. K/Ar white mica ages (140 ± 6, 149 ± 6, 178 ± 7, 180 ± 7 and 203 ± 8, Árkai & Balogh 1989) are significantly older than those for Mihályi Slate.

Szentgotthárd Phyllite is known from two boreholes (Fig. 2) in about 25 km of the Nemeskolta and 60 km of the Mihályi area. Phyllites, sometimes with 1 - 2 mm calcite strips along the foliation, are analogs rather of the Mihályi than of the Nemeskolta Slate. The illite crystallinity of a single sample (b_o = 9.017 Å, Árkai et al. 1987) is equal to that for Kőszeg Slate (b_o = 9.015 Å, Lelkes-Felvári 1982), and the K/Ar white mica age of the same single sample is 143 ± 6 Ma (Árkai & Balogh 1989), a little older than the ages for Mihályi Slate and equal to the youngest Bük Dolomite ages.

Structural relationships between the rock groups outlined above are visible in seismic sections. In the Hungarian Danube Lowlands, six intra-basement overthrusts (Fig. 3) have been recognized (Pogácsás et al. 1991), whereas the Rába Line is not visible, probably, due to its steep position. The Rába Line, however, is clearly detected by magnetotelluric sounding as a zone which separates two areas of different geoelectric properties and cuts overthrusts detected in seismic sections (Fig. 3).

Overthrust 1 coincides with the top of the Penninic Window at Kőszeg and can be interpreted as the base of the Austroalpine nappes, their contents being not confirmed by drilling data. Overthrust 2 is of opposite sense outlining together with Overthrust 1 something like a synform. Below it, borehole Csapod Cs–1 (Fig. 2) penetrated mica schists with garnet, therefore, Overthrust 2 is not an equivalent of Overthrust 1. Farther southwards, below Overthrust 2, Bük Dolomite (+ slate) appears. It is not correlatable with the Csapod crystalline in a petrographic sense, but both of them may belong to the same nappe (e.g. Upper Austroalpine). Overthrust 3 separates both Csapod crystalline and Bük Dolomite from Mihályi Slate, the latter underlying them in a tectonic sense. That situation would be consistent with the correlation of Mihályi Slate with the Penninics, not with Bük Dolomite. Moreover, it in any case contradicts the view of numerous geologists on the assignmentof the Csapod crystalline to the Lower and Mihályi Slate to the Upper Austroalpine Nappe. The petrographic (and stratigraphic?) heterogeneity of the Nemeskolta basement may be due to its position within the dislocation zone of the Rába Line.

Overthrusts 4–6 do not seriously influence the distribution of the principal stratigraphic sequences (metamorphites, Permian sandstones and Triassic limestones), thus, they cannot bear significant magnitudes. Most probably, they are analogous to the Litér and other thrusts in the Balaton Highland outlining the symmetry of the structure of the Transdanubian Range Syncline (Fig. 4).

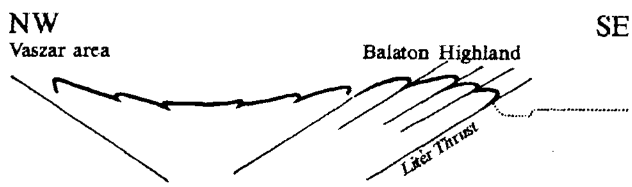

Fig. 4. Symmetric structure of the Transdanubian Range, completed after Schmidt (1961).

Alpine and Carpathian analogs of low-grade metamorphic rocks

Numerous geologists regarded the Graz Paleozoic as the analog of Mihályi Slate, Bük Dolomite and Szentgotthárd Phyllite. The Graz Paleozoic crops out in a 60x30 km area (Fritz et al. 1992) and consists of limestones and calcareous slates as well as dolomites and dolomite sandstones sometimes intercalated by mafic tuffs and lavas. Shaly/silty sequences of significant thickness occur in the deepest horizons mostly intercalated by mafic volcanites and limestones, not dolomites.

The Graz Paleozoic is situated more than 100 km west of the Bük area, and the Arnwiesen Dolomite (Flügel 1988a, b) in the basement of the Styrian Basin forms a link between them. The Blumau Series below the Arnwiesen Dolomite consists of

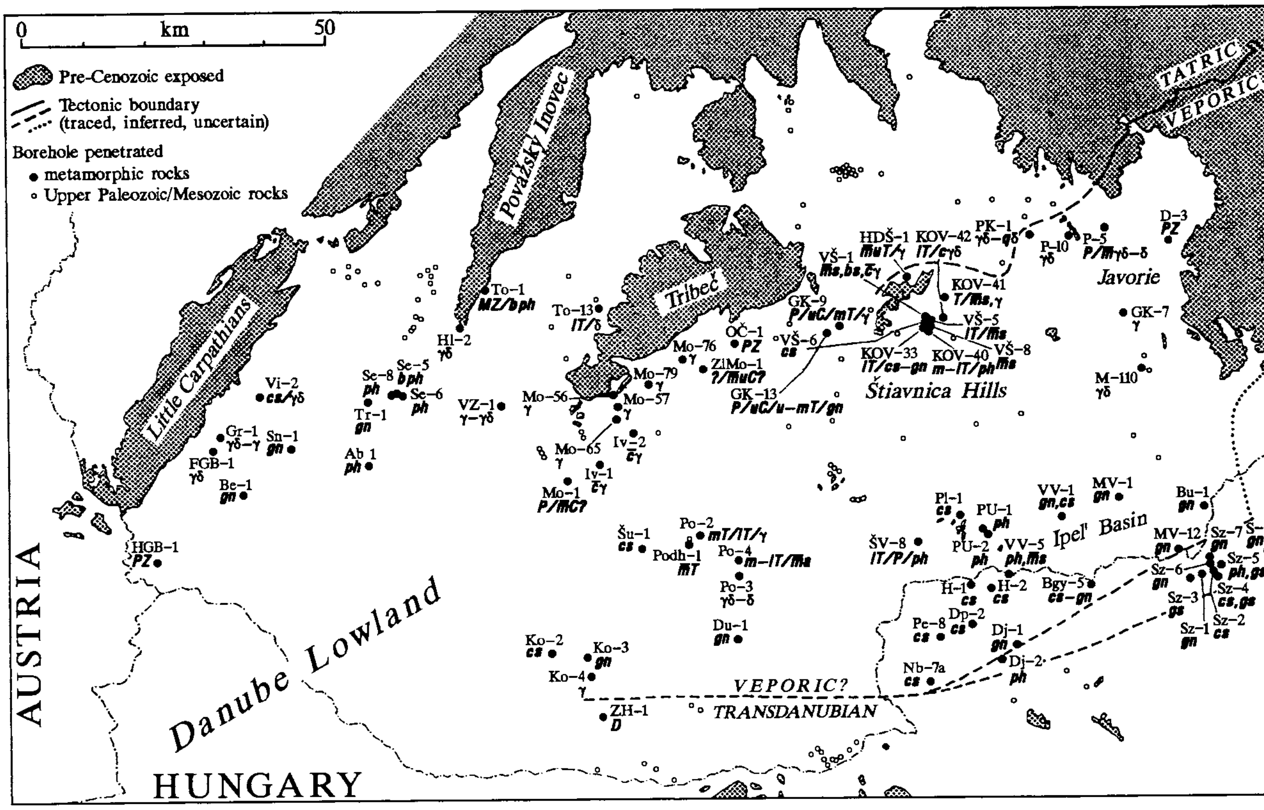

Fig. 5. Boreholes with metamorphites in the Slovakian Danube Lowland, after Biela 1978a-b and Fusán et al. 1987b, completed from Balla et al. 1978, Balla 1989 and Kilényi & Šefara 1989. **D, C, P, T, PZ, MZ** = standard age codes; **b ph** = biotite phyllite; **cs** = crystalline schist; **gn** = gneiss; **gs** = greenschist; **ma** = metasandstone; **ms** = metamorphic schist; **ph** = phyllite; γ = granite; $\gamma\delta$ = granodiorite; δ = diorite. Adjectives: *c* = cataclastic; *l* = lower; *m* = middle; $\overline{m}$ = metamorphic; *u* = upper.

phyllites with limestone and dolomite intercalations, and thus, may be correlated with the deeper levels of the Graz Paleozoic and, perhaps, of the Bük Dolomite. Sausal Series south of Graz consists of greenschists, phyllites and sericite slates with limestone intercalations (Schönlaub 1980), in boreholes it is traceable towards the east up to the Hungarian border (Flügel 1988a, b). Szentgotthárd Phyllite was drilled in about 15 km of the last occurrence, and its correlation with the Graz Paleozoic is problematic.

Mihályi Slate is isolated from the Styrian Basin by the Bük-Arnwiesen Series. No quasi-homogenous slate fields of comparable size exist in the area of the Graz Paleozoic on the surface. In that sense, Sausal Series would be similar, the presence of limestone intercalations in it, however, makes the correlation doubtful.

The metamorphism of the Graz Paleozoic ranges from late diagenetic through anchi- and up to epizonal (Hasenhüttl & Russegger 1992). The number of K/Ar ages is limited and ranges between 80 and 238 Ma (Becker et al. 1987; Fritz & Neubauer 1990). Nappes of deeper position display younger (98 - 133 Ma for 6 and 80 Ma for 1 sample), and those of higher position, older (150 - 200 Ma for 10 and 121, 138 and 238 Ma for other 3 samples) ages due to increasing with the burial depth of Alpine thermal influence (Fritz & Neubauer 1990). From that point of view, Mihályi Slate would be correlatable with the deeper, and Bük Dolomite, with the higher nappes.

To summarize, the Bük Dolomite is correlatable with the Graz Paleozoic through the Arnwiesen(-Blumau) link, and Szentgotthárd Phyllite, with the Sausal Series of uncertain stratigraphic and tectonic position. It is worth mentioning that both the Szentgotthárd and Bük sequences are still behind the Alpine section, not the Alpine-Carpathian transition. Correlation of the Mihályi Slate, situated already behind the transition section, with any of the Austroalpine sequences seems to be unconfirmed although not excluded.

Carpathian analogs of Mihályi Slate are difficult to search for. In overviews for the Slovak Danube Lowlands (Fusán et al. 1972a, 1987a), no distinction is made between the epi- and mesozonal metamorphites, all of them being ranged into the "crystalline basement". Since detailed petrographic descriptions are usually unavailable, the low-grade metamorphic rocks have been selected mainly by names of rocks and lists of minerals (Biela 1978a, b). "Phyllites" and "sericite-chlorite slates" have been regarded low-grade (epizonal) although obvious uncertainty remains with the content of the terms "phyllite" and "sericite" which may influence validity of the definition "low-grade".

In the Slovakian Danube Lowlands, "low-grade" metamorphic rocks have been mentioned from three areas (Fig. 5): (1) southeastern foreland and buried southwestern continuation of the Považský Inovec Mts. (biotite phyllite in Topoľčany To–1, quartz-biotite phyllite and phyllite in Sereď Se–5, phyllite and quartz phyllite in Sereď Se–6, phyllite in Sereď Se–8 and sericite phyllite in Abrahám Ab–1), (2) Štiavnica Hills (quartz-sericite-chlorite slate in KOV–39, phyllite in KOV–40, sericite-chlorite slate in KOV–41, sericite-chlorite slate, partly influenced by contact metamorphism, and biotite slate in VŠ–1, sericite-chlorite slate with quartz lenses and greenschists in VŠ–5, sericite-

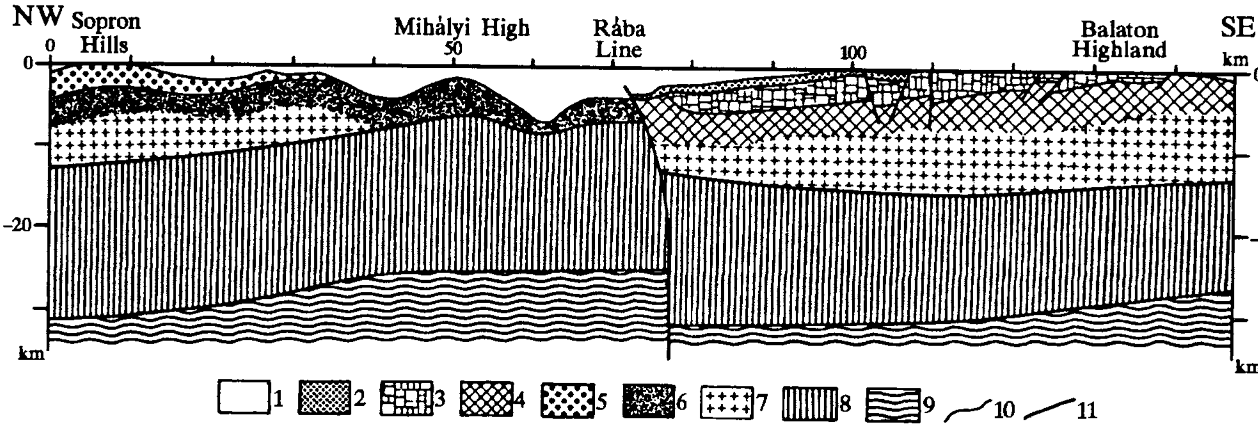

Fig. 6. Crustal section across the Mihályi High, after Balla et al. (1991). **1** - Cenozoic (mainly Neogene) sediments; **2** - Upper Cretaceous (Senonian) sediments; **3** - Permian to Lower Cretaceous sequences; **4** - anchimetamorphic Paleozoic of the Transdanubian Range; **5** - Lower Austroalpine nappe; **6** - Penninics; **7** - normal crustal complexes ("granitic layer"); **8** - high-density crustal complexes ("basaltic layer" etc.); **9** - upper mantle; **10** - geological boundary; **11** - intracrustal boundary.

chlorite slate with sillimanite, andalusite and biotite in VŠ–6 and sericite-chlorite slate with quartz lenses in VŠ–8) and (3) western Ipeľ Basin (sericite and sericite-chlorite phyllite with intercalations of epidote amphibolites and sericite-quartz phyllites, fine-grained quartzite and sericite-quartz phyllite, sericite, calcite-sericite and graphite-calcite-sericite phyllite in Dolné Semerovce ŠV–8, crystalline schist/slate in Plášťovce Pl–1, phyllite with quartzite intercalations in Plášťovce PU–1, phyllite in Plášťovce PU–2 and sericite-chlorite and chlorite phyllite and schist in Ipeľské Predmestie VV–5).

The Sereď area is open to the south, but, for about 80 km towards the Mihályi area, no borehole reached the basement.

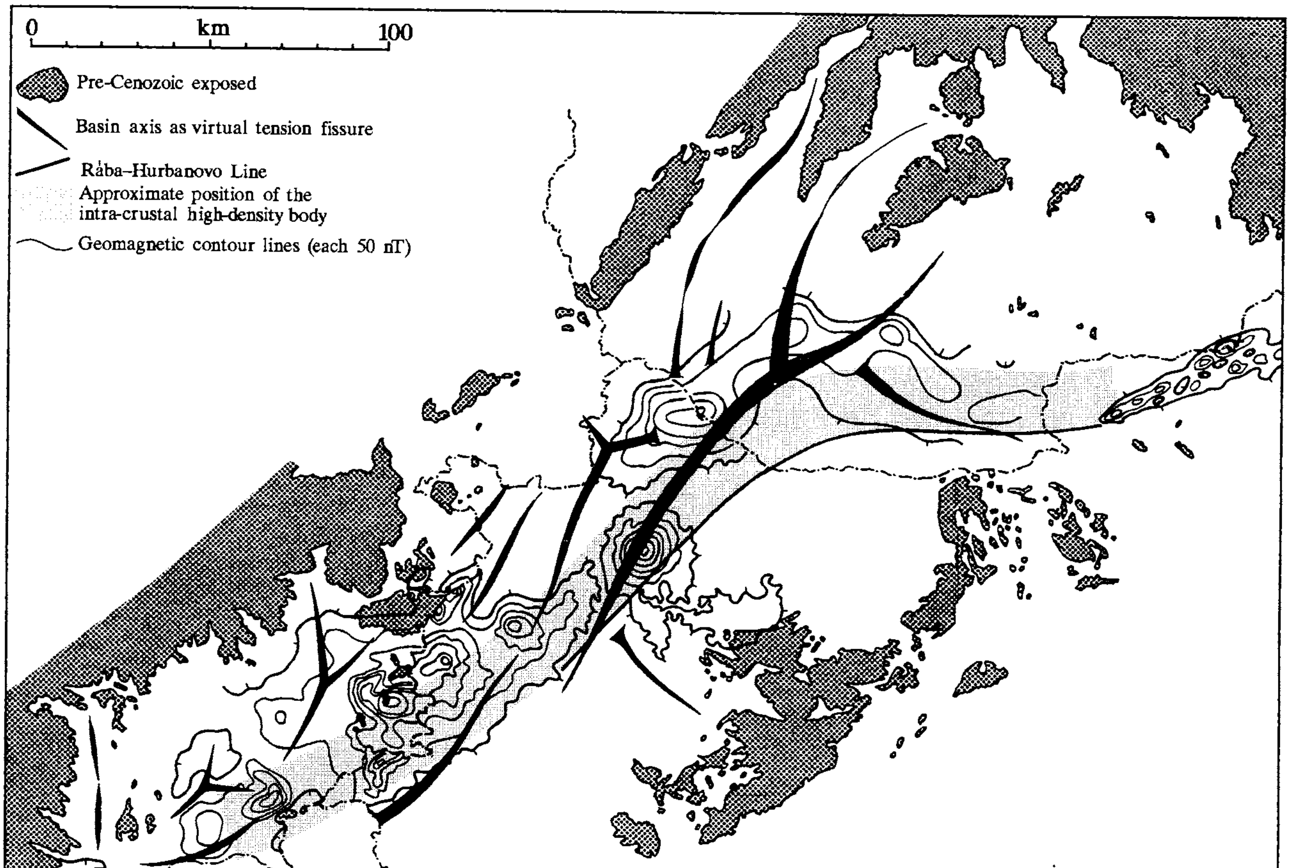

Fig. 7. High-density intra-crustal body in relation to geomagnetic anomalies and Neogene basins. *Magnetic anomalies*, after Haáz & Komáromi (1967), Kubeš & Filo (1987) and Seiberl (1988). Austrian, Hungarian and Slovakian data are not exactly comparable due to differences in survey methods and in measurement objects (airborne T in Austria, field Z measurements in Hungary and Slovakia) as well as in accepted regional fields. Basin axes outlined using Kilényi & Šefara (1989).

4 m brecciated "Lower Triassic" shale and sandstone (Se–5) and 36 m "Mesozoic" calcareous sandstone and arenaceous limestone (To–1) in the top of the metamorphites cannot be regarded as a normal stratigraphic cover, thus, the phyllite sequence is not necessarily Paleozoic in age. Thus, a re-evaluation of the phyllite sequence with consideration of the possibility of its Mesozoic age and tectonic position below the crystalline and granite complexes in the surroundings (Senec Sn–1, Trnava Tr–1, Hlohovec Hl–2, Kubeš & Filo (1987), Veľké Zálužie VZ–1 etc.) seems to be useful.

The two other areas seem to be "closed" towards the southwest by boreholes with mesometamorphic or granite basement (Kolárovo Ko, Šurany Šu, Podhájska Podh, Pozba Po). The density of boreholes, however, is insufficient for excluding possibilities for correlations, and about 80 km towards the Mihályi area remain completely without any borehole data on the basement composition.

The presence of a distinct low-grade metamorphic sequence of Paleozoic age in the Štiavnica area is doubtful due to similar names for Lower Triassic rocks (KOV–39 and –40), on one hand, and to presence of gneisses, migmatites and cataclastic granitoids (KOV–33, –39, –41 and VŠ–1), on the other. On the contrary, biotite was not mentioned even in detailed descriptions of the basement rocks from the western Ipeľ Basin (ŠV–8: Reichwalder 1981; VV–5: Klinec 1976), thus, the presence of a low-grade metamorphic sequence in that area seems to be very probable. Permian to Lower Triassic (low-metamorphic) sediments in the top (ŠV–8) confirm its Paleozoic age.

To summarize, the presence of low-grade metamorphic slate sequences can be supposed in two areas of the Slovakian basement, in the Sereď area and in the western Ipeľ Basin. The age of the slate sequence can be both Mesozoic or Paleozoic in the first area and is Paleozoic in the second.

Taking into account the absence of any boreholes in the central Danube Lowlands (60 x 80 km) and limited amount of them in most of the basin areas, the existence of still unknown low-metamorphic basement sequences is not excluded. They could partly correspond to Paleozoic slate sequences of the exposed areas (Pezinok, Pernek and Harmónia: Plašienka et al. 1991; Jánov Grúň: Miko 1981; Predná Hoľa: Bajaník et al. 1979; Gelnica and Rakovec: Grecula 1982), but may be completely new as well.

Crustal structure

Crustal structure is frequently discussed in terms of basement and Moho topography as well as fault and block delineation. Here, another aspect of the crustal structure, viz. composition heterogeneity recorded in magnetic and gravity anomaly pattern will be discussed.

Intense magnetic anomalies are characteristic of the Hungarian Danube Lowlands (Haáz & Komáromi 1967), the sources of them being within the pre-Cenozoic basement (Posgay 1967a, b). They are situated in the immediate neighbourhood of the Rechnitz-Kőszeg Penninic Window, and that fact induced relating the anomalies to the mafic and ultramafic magmatites of the Rechnitz-Kőszeg Series (Varrók 1963; Balla 1982). Magnetic anomalies have also been traced in the Styrian Basin (Seiberl 1988) and interpreted together with those in Hungary the same way (Hoffer et al. 1991).

It is remarkable, however, that intense magnetic anomalies both in Hungary and Austria are restricted to basins and suddenly diminish in exposed areas of the Penninics. Moreover, mafic and ultramafic magmatites rest in nappes above the Penninic sediments (Pahr 1980a) whereas the intense magnetic anomalies come from sources within the pre-Cenozoic basement (Posgay 1967a, b). That is why doubts remained concerning the origin of the anomalies (Oberladstädter et al. 1979).

Gravity anomalies both in Austria and Hungary were interpreted in terms of basement and Moho topography (Renner & Stegena 1966; Walach & Weber 1987; Posch et al. 1989). The intense Kolárovo gravity high in Slovakia was also primarily related to a hypothetical basement high (Gaža & Beinhauerová 1977) but in the light of seismic and drilling data was re-interpreted and connected with an intra-crustal high-density mass (Bielik et al. 1986). An analysis of gravity anomalies along a seismic section revealed the presence of a similar mass below the Mihályi area (Fig. 6), and analogous evaluation of a gravity profile across the Styrian and Zala Basins allowed the author to continue that mass towards the southwest (Balla 1993). Altogether, the intra-crustal high-density mass has become traceable for more than 200 km covering the zone of the intense magnetic anomalies (Fig. 7). In the first approximation, coincidence of the magnetic and gravity anomalies is explicable in terms of mafic/ultramafic composition of the intra-crustal source.

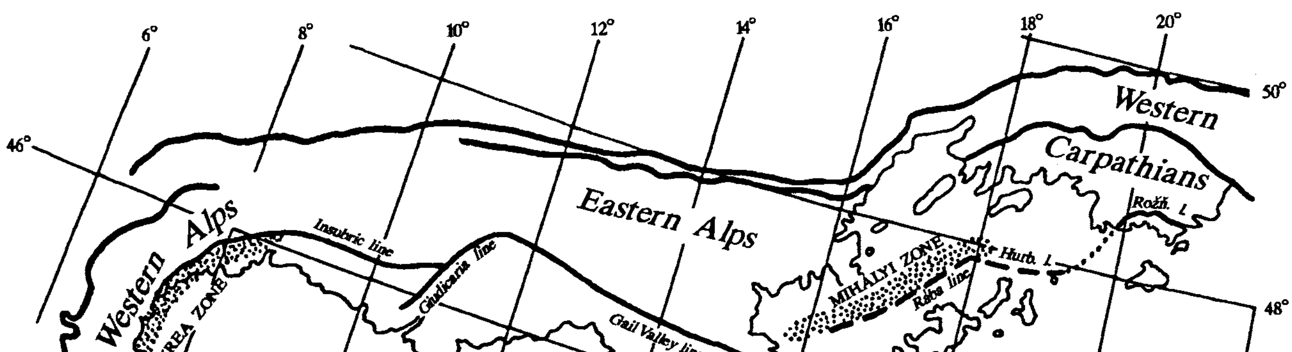

Fig. 8. Correlation of the Mihályi intra-crustal high-density body with Ivrea Zone, after Balla (1992a, b).

The position of the intra-crustal high-density mass in the general structure of the Alps induced an idea of correlating it with the well-known Ivrea Zone of the Western Alps and to outline a possibility of an about 500 km dextral offset upon the Insubric-Periadriatic Lineament (Fig. 8). The absence of high-grade metamorphism above the high-density mass, however, is a significant difference from the Ivrea Zone. It might be explicable in terms of the much deeper position of the top of the mass below the Danube Lowlands area as compared with that in the Ivrea Zone, but no comparisons of the expectable and observable metamorphic zonation and no computations of the corresponding thermal models have been performed to support that concept.

Three alternative explanations for the intra-crustal high-density mass can be outlined as follows: (1) an intrusion connected with the Miocene volcanism (Bielik et al. 1986), (2) an inclusion within the continental crust of a piece of the oceanic lithosphere which arose due to the Penninic basin not being completely closed and (3) a protrusion of the upper mantle in connection with the Miocene extension. In the frame of the intrusion model, the size of the mass in question and, in the frame of the intrusion and inclusion models, its linear shape are incomprehensible. In the context of the inclusion and protrusion models, asymmetry of the mass in vertical cross section (Fig. 6) and, in the context of the protrusion model, the discordant position of the mass in maps relative to the basement topography (Fig. 7) would be inexplicable. As seen, even in the first approximation, no real alternative for the Ivrea model can be offered although mantle protrusions in the axial zones of the deepest partial basins may complicate the picture due to additional high-density masses.

In the context of the Ivrea model, the Rába Line is accompanied from the northwest by the most elevated in a structural sense zone which suffered the most intense erosion before the Miocene subsidence. In other words, the deepest tectonic units, the Penninics or even its foot, are expectable in that zone. In the Western Alps and the Tauern Window, the foot consists of continental series metamorphosed in high greenschist and/or low amphibolite facies. From that point of view, Mihályi Slate might belong to the Penninic series, and its analogs might cover large areas in the central Danube Lowlands with no boreholes in a 60 x 80 km area. The Sereď phyllites may form an apophysis of that Penninic field. Within the zone of the gravity high, continental basement of the Penninic Nappe might occur in the foot of the Miocene basin fill as well, the Kolárovo granites and metamorphites being possible candidates.

Conclusions

The pre-Cenozoic basement of the Danube Lowlands is divided into two parts by the Rába-Hurbanovo Line. Southeast of the Line, the Transdanubian Range Unit is situated (Fig. 3), with anchimetamorphic Paleozoic sequences and overlying them Permian and Triassic sediments. Northwest of the Rába Line, the pre-Cenozoic basement consists of Alpine-Carpathian metamorphic series which are only covered by Upper Paleozoic and Mesozoic sediments in the peripheral areas.

Mesozonal metamorphites belong to the Austroalpine or Tatroveporic nappes with no real possibility for further subdivision on the basis of composition features of the drill cores. Ranging all the mesometamorphites east of the Sopron area into the "Lower Austroalpine Unit" in Hungary as well as distinction between the "Tatric" and "Veporic" crystalline south of the Tribeč–Štiavnica area in Slovakia seems to be groundless.

Epi- to anchizonal Paleozoic metamorphites are known in the surroundings of Graz, then in the basement of the Styrian Basin (Arnwiesen, Blumau and Sausal Series) and in southwestern Hungary (Szentgotthárd Phyllite = probable equivalent of the Sausal Series, Bük Dolomite-Slate = probable equivalent of the Arnwiesen (+Blumau?) Series and the Graz Paleozoic). Similar rocks may also be constituents of the dislocation zone of the Rába Line (Nemeskolta area). In Slovakia, epizonal metamorphites of Paleozoic age can be supposed in the western Ipeľ Basin (Dolné Semerovce, Plášťovce, Ipeľské Predmestie) surrounded by boreholes with mesometamorphic basement. They are in about 280 km of the Graz Paleozoic (Upper Austroalpine) and in 160 km of its Hungarian equivalents, and are traditionally ranged into the Veporic crystalline.

Epizonal Mesozoic metamorphites, products of Tertiary metamorphism, crop out in the Rechnitz-Kőszeg Penninic Window. In principle, eastern closure of the Penninic basin and eastern termination of the Tertiary metamorphism do not necessarily coincide, thus, it seems possible that, in the Alpine-Carpathian transition zone (Rosalia Mountains through Little Carpathians and Danube Lowlands areas behind them, Fig. 1), Penninic sediments with no Tertiary, only Cretaceous, metamorphism occur.

In the Hungarian Danube Lowlands, Mihályi Slate emerging from-below the overthrust Upper Austroalpine Bük Dolomite-Slate is analogous to the Kőszeg Series in a lithological sense, the only difference consisting in the Cretaceous, not Tertiary, age of its metamorphism. Thus, Mihályi Slate might be a representative of the Penninic series with no Tertiary metamorphism, its Paleozoic age, however, is also not excluded. In Slovakia, 80 km north of the Mihályi Slate but with no borehole data on the basement between them, the Sereď phyllites emerge from-below the overthrust Tatric Mesozoic. The age of them is unconstrained, so Mesozoic is not excluded, and an analogy with the Mihályi Slate seems to be possible although not confirmed.

The Rába Line is accompanied from the northwest by a zone of intra-crustal high-density mass. The latter can be regarded as similar to the Ivrea Zone of the Western Alps (Fig. 8), alternative explanations (Miocene volcanism-related intrusion, oceanic lithosphere inclusion and upper mantle protrusion) being inconsistent with the size, shape or position of the zone in question. In the context of the Ivrea analogy, tectonic units of deepest position would be expected in the basement above the high-density mass. The Penninic provenance of the Mihályi Slate would be in harmony with that expectation, and it seems possible that in the central Danube Lowlands with no borehole data on the basement composition in a 60 x 80 km area, mostly Penninic sequences with no Tertiary metamorphism, not "Tatric" and "Veporic" mesometamorphites and granites, underlie the Neogene basin fill. Kolárovo granites and mesometamorphites do not necessarily overlie those Penninics but perhaps underlie them.

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