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STRUCTURAL HISTORY OF THE PORVA BASIN IN THE NORTHERN BAKONY MTS (WESTERN HUNGARY): IMPLICATIONS FOR THE MESOZOIC AND TERTIARY TECTONIC EVOLUTION OF THE TRANSDANUBIAN RANGE AND PANNONIAN BASIN

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Abstract: The authors made geological mapping and microtectonic measurements in the Northern Bakony Mts., around the Porva Basin. Using structural observations, a new structural-geological map was made for this area. Four tectonic phases were separated by the analysis of stress field. Map-scale neptunian dikes represent the Jurassic rifting episode. For this phase NNE-SSW tension was estimated. NW-SE compression of Albian (?) age resulted in gently dipping reverse and conjugate strike-slip faults. In the Ottnangian–Sarmatian (18.5–11 Ma) a strike-slip type stress field with NNW-SSE compression developed. This phase formed mainly NW-SE striking dextral and conjugate shorter sinistral strike-slip faults. NW-SE striking half-grabens formed along strike-slip or oblique-slip faults. Motion resulted in post-sedimentary tilting of the Eocene-Oligocene sequences toward the master faults. A late Miocene extensional phase with WNW-ESE tensional directions was also determined. During this phase the earlier half-grabens were reactivated, although with slightly different slip on boundary faults. Some of the young half-grabens are connected by transfer faults, which had a strike-slip character. Ottnangian-Sarmatian strike-slip faults occurred during the rifting phase of the Pannonian Basin, their main activity was coeval with important stretching in the northeastern Pannonian Basin. These relatively local strike-slip faults could accommodate differential extension between the northern and southern Pannonian Basin. On the other hand, the newly recognized Late Miocene tensional phase indicate, that the post-rift evolution of the Pannonian Basin was associated with considerable crustal extension.

Key words: Cretaceous, Miocene, Pannonian Basin, Bakony Mts, structural geology, strike-slip fault, half-graben, stress field.

Introduction

The Bakony Mts are situated in the Transdanubian Range, southeast of the Danube Basin (Fig. 1). According to its Miocene structural setting, the Bakony Mts are on the hanging wall of the detachment fault running down from the Kőszeg-Rechnitz Penninic window (Tari 1996). While modern tectonic analysis has been made in the Danube Basin (e.g. Tari 1994), the northern Bakony is a relatively unknown area in this respect. Here the last systematic structural work was done by Mészáros (1983) describing ESE-WNW oriented Miocene dextral faults. The largest one, the Telegdi Roth Line has a 4.7 km dextral separation (Fig. 1) (Mészáros 1983; Kókay 1976) and runs just south of the studied area.

Although detailed geological maps cover the Northern Bakony Mts (Császár 1982; Gyalog & Császár 1990), the lack of paleostress data prevented the kinematic interpretation of faults. Bergerat et al. (1984) and Maros (pers. commun.) measured only a few sites, while Fodor et al. (1999) reported results from few additional locations. In our paper we present new paleostress data and other observations from the Porva Basin, Northern Bakony. The description of fault pattern, its kinematic character and the structural evolution can be used as analogy in other areas around the Danube Basin. In addition, some of the new data can have implications for the structure of the whole Pannonian region.

Geological setting

In the research area the oldest surface formation is the Upper Triassic dolomite (Hauptdolomit Formation, Fig. 2), showing typical intertidal sedimentary features. Dachstein Limestone, the most frequent Mesozoic sedimentary rock surrounding the basin, was also generated in a shallow marine environment (Haas 1995). Different Lower Jurassic shallow and deep-water limestones follow it. Middle Jurassic to Early Cretaceous limestones mainly represent pelagic sediments. The late Early Cretaceous shallow water crinoidal limestone (Tata Formation) and the Senonian siliciclastic sequence including coal beds (Csehbánya Formation) have very limited extension (Lelkes 1990; Császár & Haas 1984) but an important tectonic role. Middle Eocene sediments are represented by two basic types: (1) the lower, nummulitic Szőc Limestone Formation and (2) the upper, deep water glauconitic Padrag Marl Formation with tuffitic horizon (Fig. 8). These Eocene sediments were formed at increasing water-depth. The thickest Tertiary sedimentary fill of the Porva Basin is the fluvial Csat-

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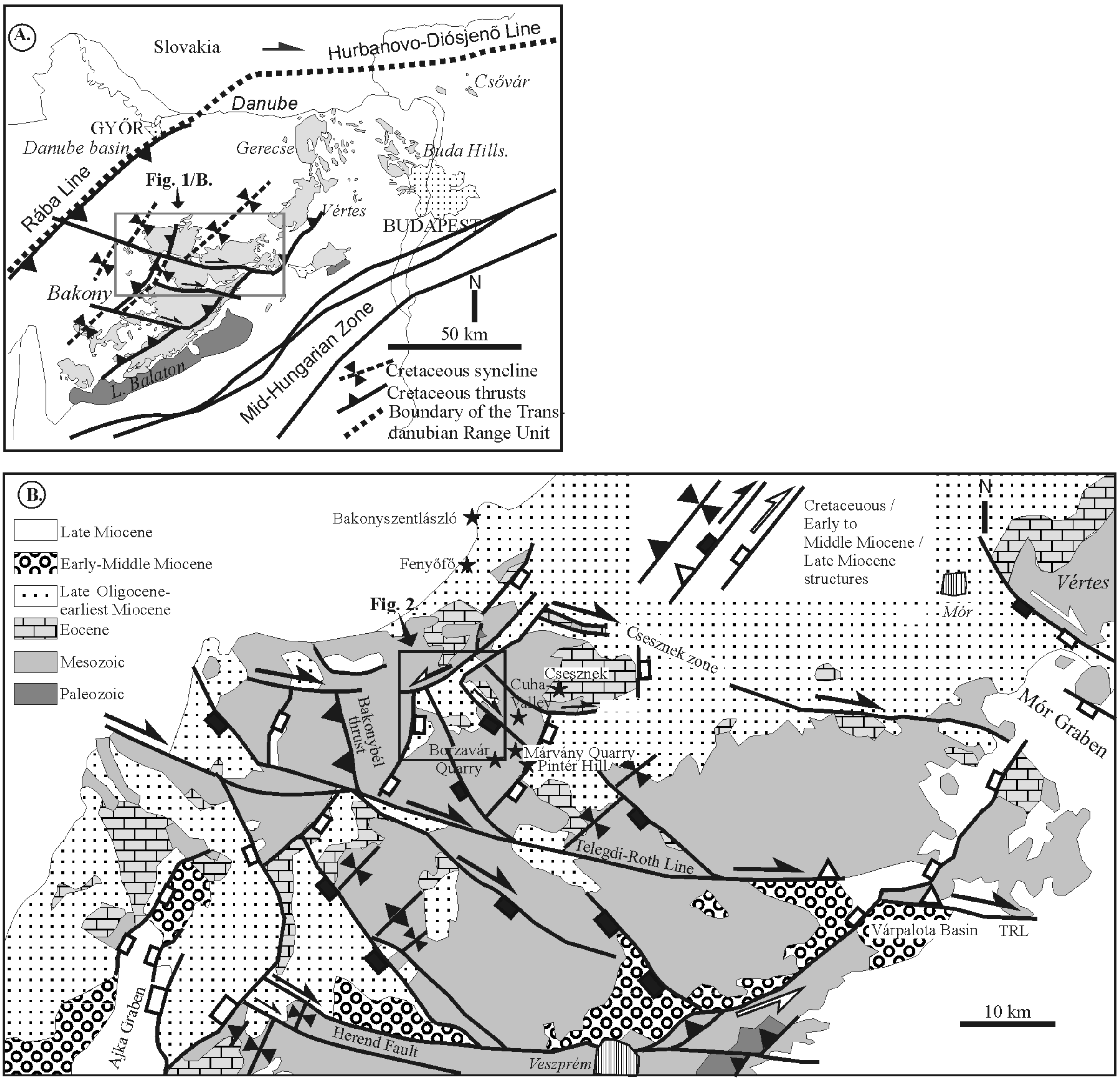

Fig. 1. The study area, the Porva Basin is situated in the Northern Bakony Mts. Pre-Tertiary formations are shown.

ka Formation (Fig. 2). The detrital succession contains siltstone, sandstone and conglomerate with predominantly exotic quartz and metamorphic pebbles (Korpás 1981). The age of these strata is Upper Oligocene–Early Miocene (Egerian–?Eggenburgian), accumulated as sediments of alluvial and/or torrent rivers. Loess, slope and alluvial sediments were formed in the Quaternary (for clarity, they are not shown in Fig. 2).

Methods

Structural mapping included the control or modification of faults shown by earlier maps (Gyalog & Császár 1990). We modified the location, connection, and, if it was possible to determine, the kinematics of faults. During this step, a digital terrain model was applied for better resolution of morphotectonic elements.

Microtectonic measurements represented an important part of the fieldwork. Microtectonic data was evaluated by the method of Angelier (1984). Stereograms drawn by the software show the measured data and also the calculated principal stress axes. Outcrop-scale observations, the determined stress axes and the apparent map offset of formations were used to determine the kinematics of faults (Fig. 2). We also used borehole data to construct a new geological map without Quaternary formations.

Structural description and kinematic analysis

The oldest structural phase known from this area belongs to the Jurassic (Fig. 3A). The interpreted NNE-SSW oriented tensional stress field induced the development of neptunian dikes filled by Lower Jurassic crinoidal (Hierlatz) limestone

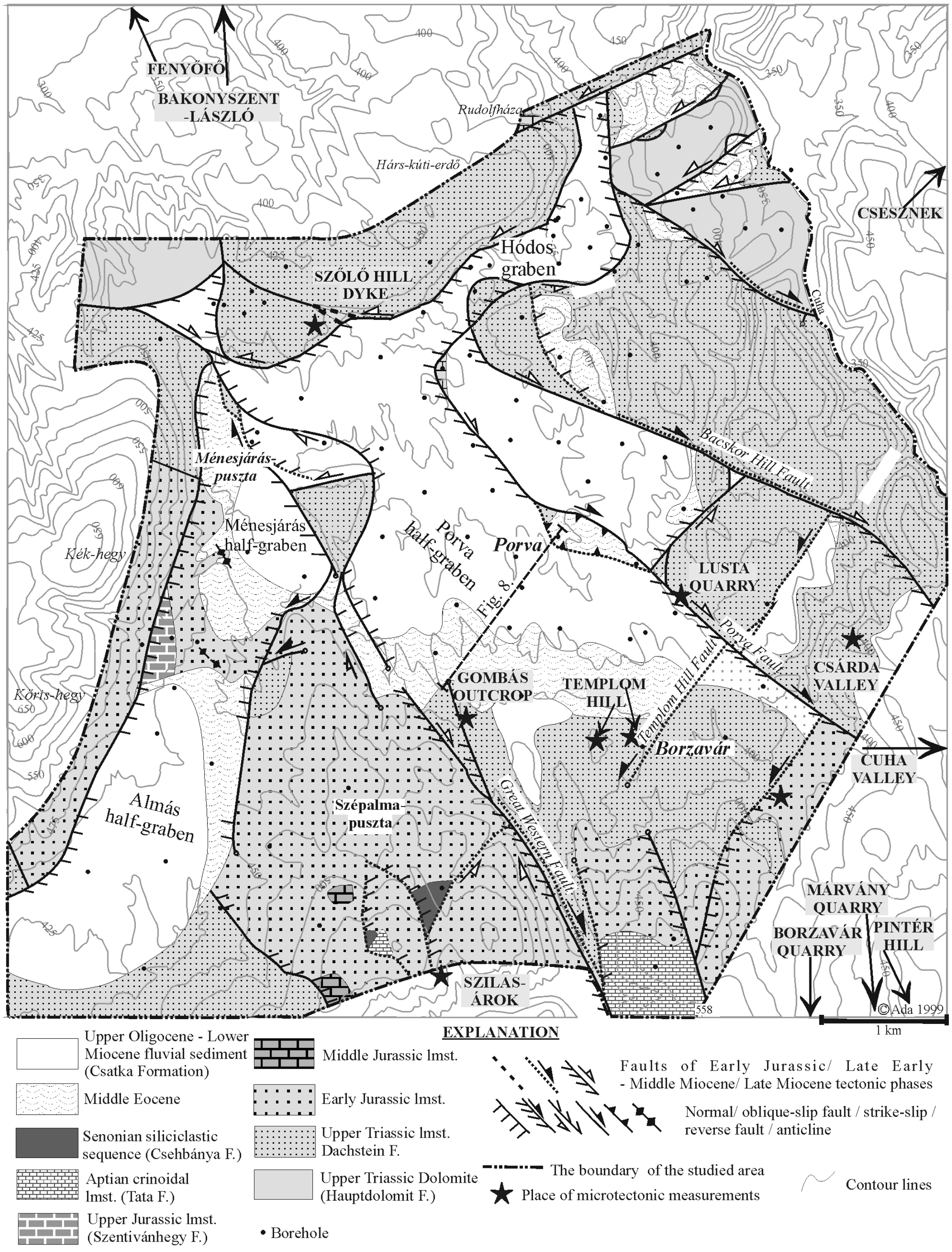

Fig. 2. Geological map of the Porva Basin in the Northern Bakony Mts. Based on maps of Császár (1982), Gyalog & Császár (1990) and own data.

perpendicular to the tension (Fig. 3B). The largest dike is 300 m wide and it is accompanied by smaller (1–10 cm) dikelets in the surroundings (they are schematically shown on Fig. 3).

We interpret compressional (strike-slip) type stress field with NW-SE σ_1 in the late Early Cretaceous (Early Albian?) phase. This stress field was identified from microtectonic data of 6 quarries (Fig. 4). In the Szilas-árok outcrop reverse faults and associated folds (ramp anticline) also occur. In most of the outcrops gently dipping reverse faults occur, often with reactivated bedding planes.

Early timing of these structures can be established by the data of Márvány quarry and especially Templom Hill. The strike-slip striae are situated parallel to the bedding-fault plane intersection line. This geometry is probable when tectonic tilting occurred after the faulting (Fig. 5). If the strike-slip is of post-tilt age, slickenside lineations would be horizontal de-

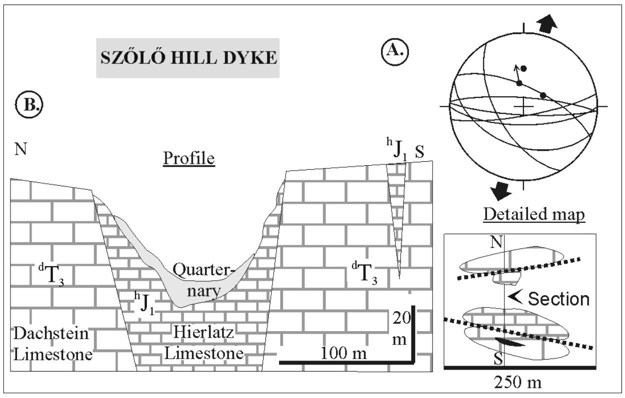

Fig. 3. A — Jurassic brittle deformation is represented by a map-scale neptunian dike (location in Fig. 2, cross section — **B**). Here Jurassic limestone (${}^{h}J_1$) occurs as a sedimentary dike in Upper Triassic Dachstein Limestone (${}^{d}T_3$). For this phase NNE-SSW tension was estimated.

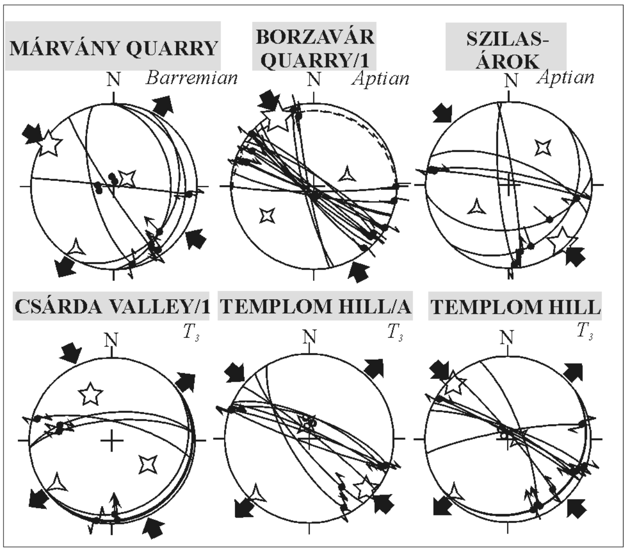

Fig. 4. Microtectonic measurements in lower Cretaceous limestones (upper 3 diagrams) and Dachstein Limestone (the lower 3). During middle Cretaceous deformation, gently dipping thrust and strike-slip faults were generated due to NW-SE compression. Stereographic projections use Schmid net, lower hemisphere. Arrows on fault projections correspond to sense of shear, strike-slip (double), away and toward circle centre (normal, reverse faults). Stars with five, four, three branches are σ_1, σ_2, σ_3. Black arrows out of the circle are projections of σ_1 and σ_3 to horizontal.

spite tilted beds. There was an important tilting event during the late Early Cretaceous, when the synform structure of the Transdanubian Range was formed (Tari 1995). The striae developed before (or during) this tilting event, so they can belong to an early deformational phase.

Along the Great Western Fault (Fig. 2) there is map-scale argument for pre-Tertiary (probably mid-Cretaceous) deformation. On the eastern block Middle Eocene (and Egerian?) sediments directly cover the Upper Triassic Dachstein Formation, while the western block contains the complete Jurassic-Cretaceous sequence. Relative vertical motion and erosion occurred before the Eocene.

Probably the most significant structural phase occurred during the Ottnangian–Karpatian–Badenian–Sarmatian in the Bakony Mts including the Porva Basin. The stereogram belonging to this phase shows that the direction of maximal horizontal stress is, NNW-SSE (Fig. 6). This stress field formed mainly NW-SE striking dextral and conjugate shorter sinistral strike-slip faults. These faults are several km long (Bacskor Hill Fault, Porva Fault, Great Western Fault, Fig. 2), are trending NW-SE, and are partly running out of this area. Shorter sinistral fault is present at the Templom Hill Fault (Fig. 2). NW-SE striking dextral faults, which are important structural elements also in the next phase, could have been generated as early as during this phase, on the basis of the stress field.

The Late Miocene stress field shows predominantly extensional features (Fig. 7). The direction of minimal stress axis was WNW-ESE. Normal faults were associated with oblique-slip faults. Most of the determined map-scale faults reactivate older strike-slip faults with oblique-slip kinematics.

Half-graben tectonics belongs to the last two phases (Fig. 8). Half-grabens were controlled by normal-dextral (like Porva

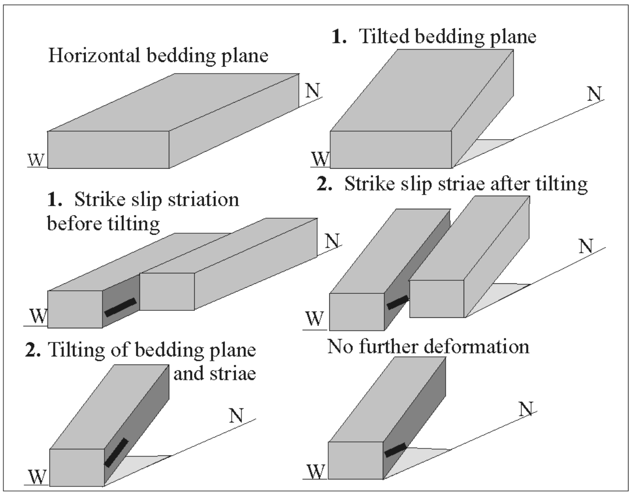

Fig. 5. Relation between striae and bedding. On the left side model tilting occurred after the faulting so the striae are parallel with the bedding plane. That is, what we can observe on the stereogram of the Cretaceous phase (Fig. 4). On the right side tilting happened before the faulting thus the striae and bedding plane are not parallel.

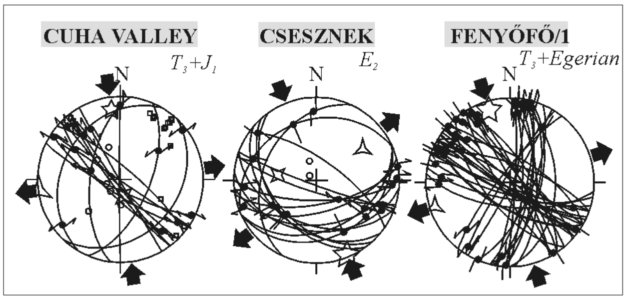

Fig. 6. Microtectonic data of the early to Middle Miocene phase. Measurements were made on Dachstein Limestone (Cuha Valley), Eocene Szőc Formation (Csesznek) and Oligocene Csatka Formation (Fenyőfő/1). Data of the site Cuha Valley are from Gyetvai et al. (1997), reinterpreted.

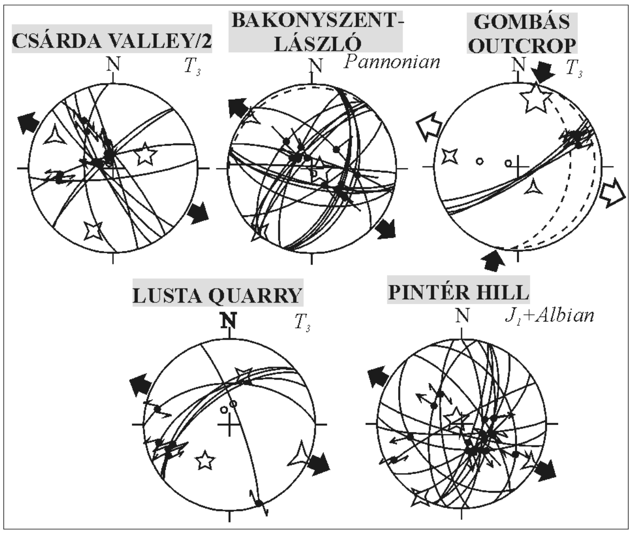

Fig. 7. Microtectonic measurements of Late Miocene phase. The youngest affected rock is Pannonian. A WNW-ESE tension direction was determined.

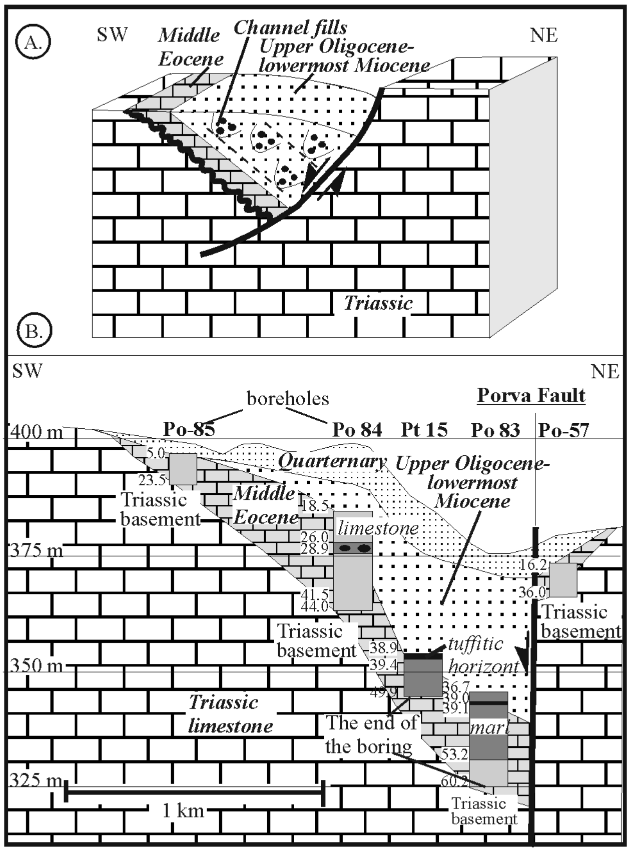

Fig. 8. **A** — Ideal block diagram of post-Oligocene half-grabens. **B** — Cross section of the Porva half-graben with fifteen-fold vertical exaggeration (location on Fig. 2).

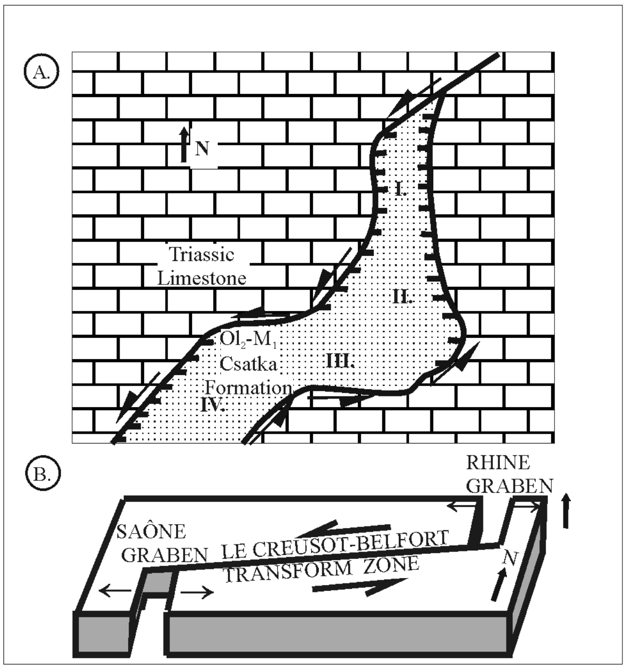

Fig. 9. **A** — The Hódos graben was formed during the last (Pannonian) tectonic phase on the northern part of the research area. **B** — shows the idealized block diagram of a similar transfer zone, which connects the Rhine and the Saône grabens (Bergerat 1977).

and Ménesjárás half-grabens), as well as by ”pure” normal faults (like Almás half-graben). The generated basinal domains are asymmetrical, dipping toward the master faults. No major sediment thickening occurs toward the faults either in the Eocene or in the Upper Oligocene–lowermost Miocene formations, suggesting post-sedimentary formation of half-grabens.

In the Late Miocene phase the complex Hódos graben was formed (Fig. 9). It can be divided into 4 parts. Graben domains I., II. and IV. were bounded by normal faults or oblique faults with sinistral component. These domains are connected to each other and limited on the north by E-W striking transfer zones of the segment III. and I. (Fig. 9). These transfer faults were formed because of geometric reasons.

Discussion and conclusion

Early Jurassic deformation is represented by a NNE-SSW tension. The stress axis is similar to the supposed stress field that can be deduced from the paleogeographical elements described by Vörös & Galácz (1998) for the whole Bakony Mts or documented in the Gerecse (Fodor & Lantos 1998). We can connect this Early Jurassic tectonic event with the disruption (rifting) of the Upper Triassic carbonate platform of the Transdanubian Range.

The gently dipping thrust and strike-slip faults formed by NW-SE compression are syn- or pre-tilting structures. These small-scale structures can correspond to the main phase of Cretaceous structural evolution of the Transdanubian Range, when the Permo-Mesozoic succession was folded, and detached from its pre-Alpine basement (Tari 1995). The resulting synclines and reverse faults occur all around the Porva Basin (Fig. 1A), north and east of it (Gyalog & Császár 1990), west of the basin (Bakonybél thrust, Tari 1994), south of the Herend fault (Mészáros 1968). The estimated compressional direction (NNW-SSE) of Tari (1995) and also the measured data

(WNW-ESE) of Fodor & Koroknai (2000) in the southern Bakony correspond to our computed data. Similar a late Early Cretaceous stress field was recorded in the Balaton Highland by Dudko (1991) where compression created large thrust faults (Fig. 1A).

We observed one Baremian and two Aptian sites deformed during this phase. This shows that at least part of the (tilting) folding is clearly post-Aptian. Combining with the upper time constraint (Mészáros 1968), the deformation could be placed in the early Albian (Fodor & Koroknai 2000). However, an early Aptian event is not excluded (e.g. Haas 1996), because the Aptian crinoidal limestone contains clasts from different Jurassic and Upper Triassic formations (Lelkes 1990).

One of the most important phases of structural evolution of the Porva Basin happened in the late Early to Middle Miocene. In this phase a strike-slip stress field developed with NNW-SSE compression and perpendicular tension.

This stress field operated other map-scale strike-slip faults, such as the Telegdi Roth Line (Fig. 1), which has 4.7 km dextral separation. It corresponds to a stress field estimated from the fault pattern of Mészáros (1983) and the few published stress field data (Bergerat et al. 1984; Fodor et al. 1999). Transpressional dextral faults were described on the northern edge of the Bakony (Csesznek Zone, Fig. 1B, Kiss & Gellért 2000) and on the south (Herend fault, Mészáros 1968). Dextral faulting could be associated with domino-type rotation of blocks (Tari 1991). Numerous measurements have been made in the Oligocene–Early Miocene Csatka Formation at Fenyőfő, thus the tectonic phase can be specified as post-Egerian. This wrenching probably started in the Ottnangian in the Várpalota Basin (Fig. 1B, Kókay 1996). Displaced Badenian strata indicate, that the main period could be Sarmatian (Mészáros 1983).

These structures are difficult to interpret and put in the Carpathian geodynamic framework, because they are very scarce in other parts (see Fodor et al. 1999). Dextral strike-slip faulting in the Porva Basin, particularly, the main Badenian-Sarmatian activity was coeval with important extension in the northeastern Pannonian Basin (e.g. East Slovak Basin, Kováč et al. 1995). One alternative explanation is that dextral faults accommodate differential extension between the northeastern and southern Carpathian-Pannonian area (Fig. 10A). The other

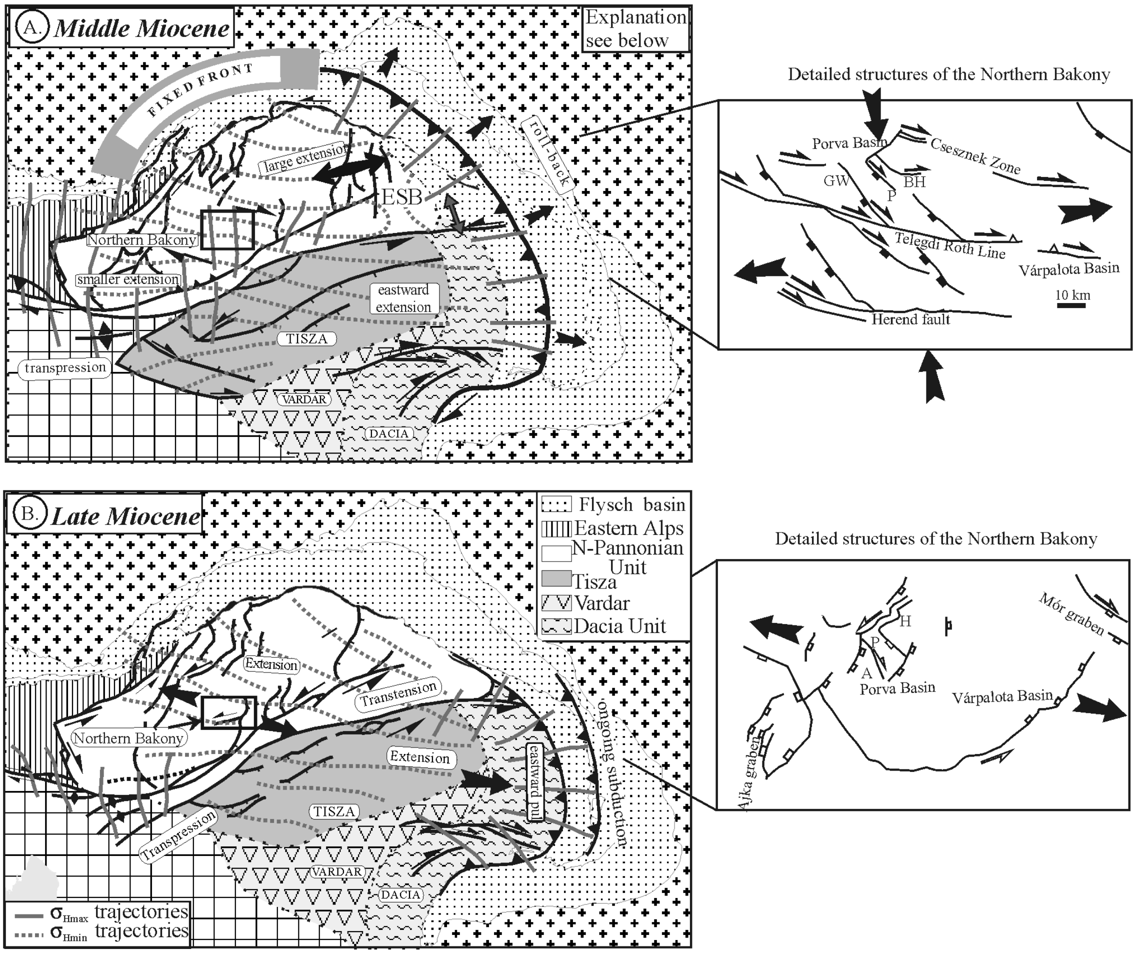

Fig. 10. Main Miocene structures, stress trajectories (main figures), structures and stress axes (insets) for the Pannonian-Carpathian region and for the northern Bakony, respectively; after Fodor et al. (1999) and this work (see also Figs. 1, 2). **A:** Middle Miocene phase; note parallel dextral faults in the Bakony Mts. **ESB** — East Slovak Basin; **BH** — Bacskor Hill; **GW** — Great Western, **P** — Porva dextral faults. **B:** Late Miocene phase; note normal or oblique normal faults with ESW-NW tension in the Bakony Mts., probably due to continuing eastward pull in the Eastern Carpathians. **H** — Hódos; **P** — Porva; **A** — Almás half grabens.

possible scenario is that NNW-SSE compression is the far-field sign of compression and dextral transpression in the southern Alps (Castellarin & Cantelli 2000) and in the southern Eastern Alps (Nemes et al. 1997; Polinski & Eisbacher 1992), in Slovenia (Fodor et al. 1998) or in Croatia (Tomljenović & Csontos 2001).

During the Late Miocene period long normal and dextral-normal faults were working. They controlled the development of half-grabens, and the tilting of the Eocene-Oligocene sequence. This phase activated the fault pattern of the Hódos graben which is very similar (in geometry) to the Le Creusot-Belfort transform zone, which connects the Saône and Rhine grabens (Bergerat 1977).

This significant extension phase can be extended to the entire Northern Bakony Mts (Fig. 1B). West and northwest from the Porva Basin, maps (Gyalog & Császár 1990) indicate Pannonian sediments bounded by E-W to NNE-SSW trending faults (Fig. 1B). On the southwest, the Ajka graben is limited by en echelon, NNE oriented normal faults. Between the Bakony and Vértes Hills, the dextral-normal boundary fault of the Mór graben displaces Pannonian rocks (Kóta 2001). At the southern wing of Northern Bakony Mts Kókay (1996) reported a late normal fault displacing the Telegdi Roth Line in the Várpalota Basin (Fig. 1B). All these NNE-SSW trending faults could have been generated by ESE-WNW tension. Kókay (1996) has dated the Várpalota fault as middle Pannonian. This is in good agreement with our relative chronology while the youngest affected rock is Pannonian (Bakonyszentlászló, Fig. 7).

This post-Middle Miocene extension phase has already been determined in the vicinity of the Bakony. A stress field with pure NW-SE minimal axes was measured in the Gerecse (Bada et al. 1996) and in the Buda Hills (Fodor et al. 1994).

Altogether, ESE-WNW to SE-NW oriented tension seems to be present in a considerable part of the Pannonian Basin (Fig. 10B). The Late Miocene period is traditionally regarded as a post-rift phase marked only by thermal subsidence (Royden & Horváth 1988). Our data indicate noticeable crustal extension, which could be connected to final thrusting in the Carpathians (Fodor et al. 1999). The direction of trajectories of σ_3 are oriented to the Eastern Carpathian thrust front which was still active at the beginning of the Late Miocene (Maţenco 1997).

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