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Asymmetric lithospheric stretching in Danube Basin

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Abstract: Danube Basin is a thermal extensional basin which began to open at the end of the Early Miocene. The main part of the initial synrift phase occurred during the Middle Miocene and the thermal postrift phase closed the filling of the basin during the Late Miocene and Pliocene. Asymmetric stretching controlled tectonic development of the basin. In the outer zone, on the northern margin of the basin (Blatne, Rišnov, Komjatice and Želiezovce depressions) prevailed synrift subsidence. Thermal subsidence occurred in this zone only partly or it was missing. In the inner zone (in the partial Gabčíkovo Basin) both phases of subsidence occurred but the synrift subsidence was relatively small. Locally some areas emerged (Kolárovo elevation). On the contrary thermal postrift subsidence was very intensive and determined deposition of several thousand meters thick deposits only slightly deformed by faults. The basin development is consistent with Coward model of heterogeneous lithosphere thinning (1986).

Key words: Danube Basin, non-uniform lithosphere stretching, asymmetrical continental lithosphere stretching, thermal extension, initial tectonic or synrift subsidence, thermal or postrift subsidence.

Introduction

Model of Pannonian or (Carpathian) Basin as one basin unit, presented mostly under the influence of geomorphologists and accepted by Stegena et al. (1975) in the first genetic interpretations of gathered geophysical data, is not valid today. The first objections were risen by Vass (1976, 1979). Later an american-hungarian team of geologists and geophysicists came to the similar conclusion when they characterized Pannonian depression area as a basin system (Royden et al. 1983, 1988, Figs. 6 and 7).

The individual basins in the basin system differ by origin and development even if there is some relation among some of them. More of them are thermal extensional basins originated by lithosphere stretching as a result of rising of astenosphere and subsequent warming and stretching of the upper mantle and crust. But also among thermal basins important genetic differences exist:

- The part of them implies by their position above thinned crust and lithosphere the origin by a pure shear lithopheric stretching (McKenzie 1978, Salveson 1976, 1978) or, perhaps most likely, they originated by non-uniform lithosphere stretching (basins Makó, Békes - Royden and Keen 1980, Beaumont 1982, Hellinger & Sclater 1983).
- Other thermal basins of the Pannonian Basin system were opened as a result of heterogeneous lithosphere stretching. The northern Danube Basin is assigned among such basins.

The Danube basin differs from the other Pannonian thermal basins by:

- fluctuation of the crust and lithosphere thickness in the basin area
- contrasting thickness of syn- and postrift deposits in the central and outer (marginal) part
- contrasting subsidence velocity
- differences in the frequency of the occurrence of synsedimentary faults and in the magnitude of their throws.

The Northern Danube Basin lies on the territory of Slovakia and it is consistent with the Danube Lowland according to the regional geographic divisions of the Slovak Republic. The southern part of the basin lies on the Hungarian territory and it is consistent with the Kiss Alföld (Little Hungarian Plain).

The objective of the work is an analysis of the structure of the Northern Danube Basin with emphasis to untangle the mechanism and the history of its opening and subsidence.

The northern part of the Danube Basin, as said above, is consistent with the Danube Lowland. It extends north of the Danube river, stretching by "bays" between mountains of Malé Karpaty Mts., Považský Inovec, Tríbeč. At the NE it is limited by neovolcanics of Štiavnica stratovolcan and Pohronský Inovec Mts (Fig. 1). The structure and development of the above defined part of the Danube Basin are different in comparison with other

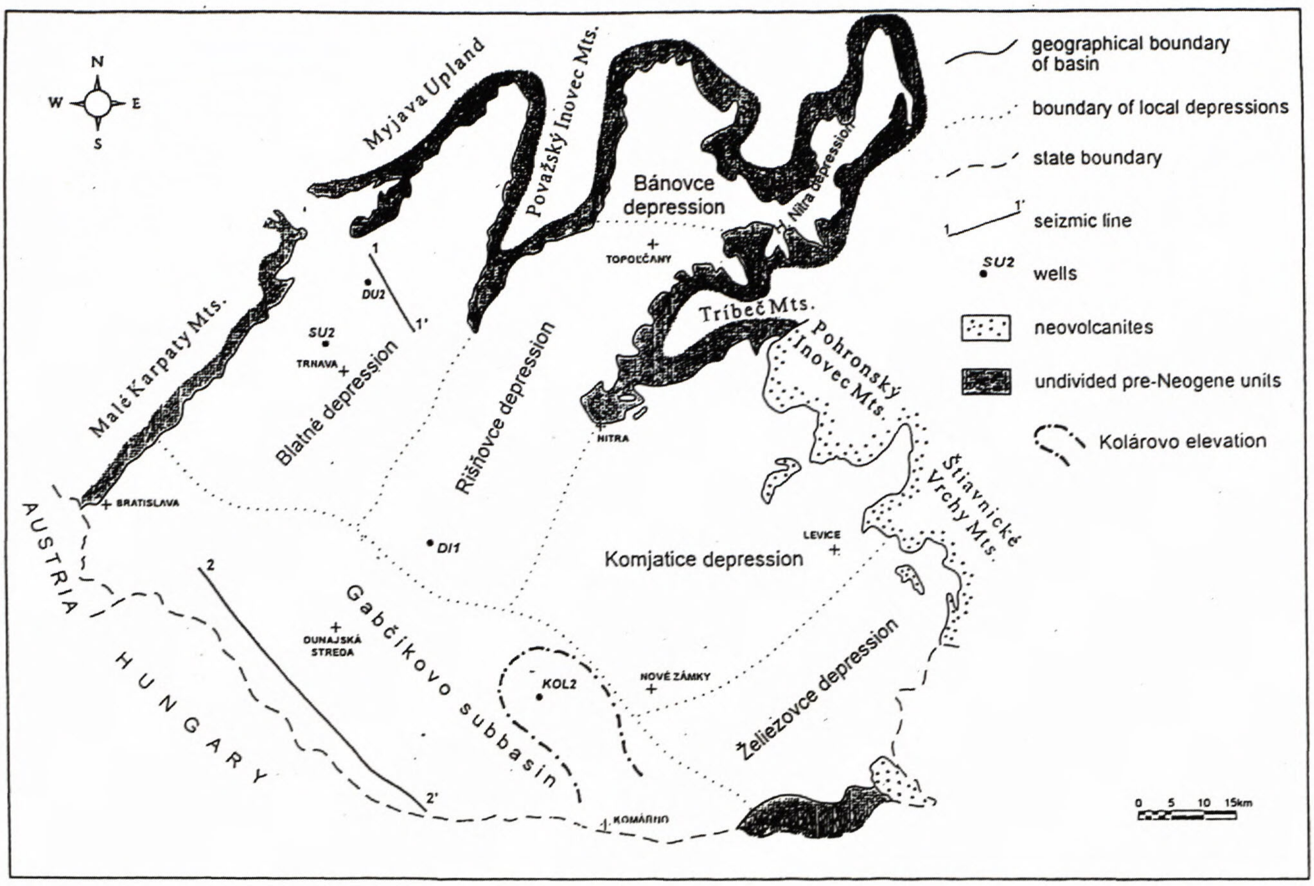

Fig. 1 Northern part of Danube Basin - Situation of seizmic lines, wells used in the model and regional subdivision

extensional basins of the Pannonian area. The basic difference is differentiated structural development of partial depressions in "bays" of the northern margin of the basin on one side and partial Gabčíkovo depression immediately north of Danube river on the other side.

Tectonic history of the area

Numerous important tectonic events preceded the origin of the Danube Basin. During the Paleogene and Early Neogene an extensive lateral movement of elastic lithosphere segments comprising present West Carpathians, Bakonicum and Bükkicum occurred along shear zones or transcurrent faults. This movement occurred contemporaneously with the thrusting of the Outer Flysch Carpathians. Extrusive tectonics as a driving mechanism for the final location of the East Alpine and West Carpathians tectonic units was proposed by Ratschbacher et al. (1991). Extrusive tectonics is defined as a synchronous interaction between tectonic escape (Burke & Sengor 1986) and extension colaps (Deway 1988). It is necessary to emphasize that the structure of the West Carpathians was mainly formed in the Late Cretaceous (Mediterranean phase of thrusting sensu Andrusov 1967). The Eocene or post-Eocene thrusting already was more or less synergic with extensive lateral translation. The process of lateral translation had a character of tectonic escape of lithospheric fragments from the area south of the Northern Alps as a result of continent - continent collision between Apulian promotory and Bohemian Massif. The amplitude of the lateral movement of the lithospheric blocks is on the basis of Bakony unit (Kazmer & Kovacs 1985) assumed to be 500 km. The direction of tectonic escape was toward the south-east although the today's position of the escaped blocks is north-east in relation to the original home area. The reasons for today's position will be explained below.

Contemporary thrusting in the Outer Carpathians helped at least partly to solve the problem of space necessary for escaping lithospheric blocks. The thrusting mainly occurred in the innermost and southermost e.g. Magura Flysch unit, but also in the Dukla and Silezian units (e.g. Stránik in Vass et al. 1987).

The escape of large lithospheric mass triggered a change of the equilibrium state in the asthenosphere. The removal of lithospheric or crustal masses on the surface generates a horizontal stress gradient in the mantle if it is sufficiently rapid. The horizontal stress gradient in the mantle creates, in turn, an elastic mantle mass flow. The mantle mass escapes from areas of increased crust or lithospheric weight into areas of lower crust or lithosperic pressure (Allen & Allen 1992). This is the forming mechanism for convective flows which generate astheno-

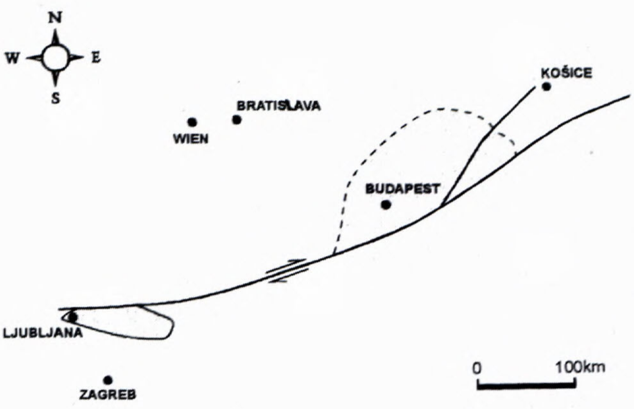

Fig. 2 Lateral displacement of the Slovenian (Lubljana) and Hungarian Paleogene Basins after the Egerian (according to Csontos et al., 1992)

sphere rising and thinning of lithosphere. A similar model - the model of extensional colaps introduced by Deway (1988), Molnar & Lyon-Cean (1988) has been applied for the extension in intra-Carpathian space, where extension is explained as a result of thickened and therefore gravititionally not stable crust (Horváth & Berkhemer 1982, Tari et al. 1992).

Warming by convection and conduction heat transfer through lithosphere caused its thinning. If heat flow from the astenosphere was big enough, relatively fast thinning of continental lithosphere and its isostatic uplift occurred (active rifting, Sengor & Burke 1978, Baker & Morgan 1981, Turcotte 1983, Morgan & Baker 1983, Keen 1985, fide Allen & Allen 1992). The condition of sufficiently high heat flow transferred by astenosphere convection as well as the condition of the rapid lithosphere thinning was fulfilled. The escape of lithospheric masses was realized during ca. 12 - 15 Ma (Oligocene - Earliest Miocene) when the rash translation documented by the spatial redistribution of Slovenian Paleogene in relation to the Hungarian Paleogene basins occurred. This translation, which occurred after the Eggerian e. g. after 22 Ma B.P. (Csontos et al. 1992), was carried out by the dextral strike slip along the Balaton line in the range about 300 km (Fig. 2). The first surface manifestation of the uplift phase of the active rifting are dated to the end of Eggenburgian e.g. to the time span ca. 20 - 19 Ma B.P. The proves of prerift uplift are Bukovina (southern Slovakia), Zagyvapalfalva (northern Hungary), Sásvár (Mecsek and surroundings, Zala and Dráva Basins), Madaras (Alföld) and Brenberg (surroundings of Šopron) Formations (Fig. 3). They consist of continental deposits (fluvial etc.) discontinuously spread in the entire modern Pannonian Basin, including depressions of southern Slovakia. They lie on the either marine deposits of

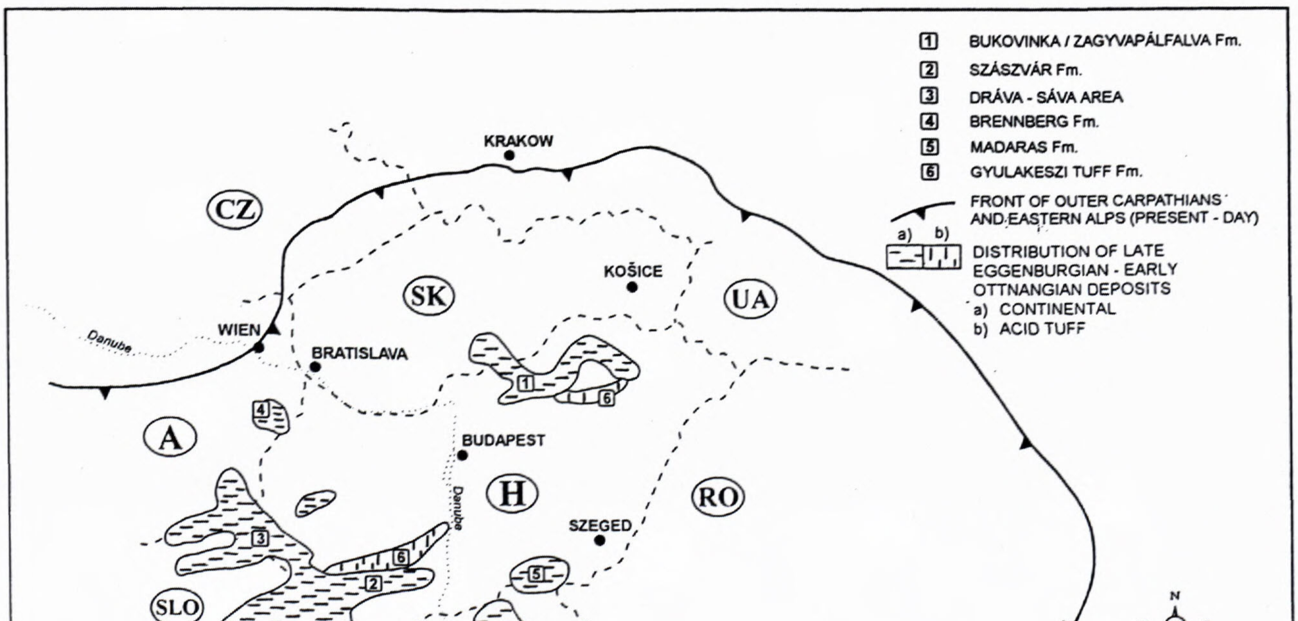

Fig. 3 Continental formations Late Eggemburgian – Early Ottnangian in age, distributed in the „Pannonian area". Areas in between are assumed to have been exposed to erosion. The picture clearly documents the regional uplift in the whole area of present-day Pannonian Basin (according to Hámor et al., 1988, modified and completed by authors).

Early Eggenburgian (on Fiľakovo and Pétervásar Formations) or older rocks (e.g. Čechovič 1952, Seneš 1951, Vass et al. 1979, 1989, 1992, Csasar & Haas 1983).

The continental formations document a change from marine depositional environment to continental environment, thus an uplift and sea regression in the Pannonian space inspite of the global sea level rise trend in the time span 21 - 17.5 Ma (Techas TB 2.1, Haq et al. 1987).

The continental deposits are accompanied by rhyodacite/rhyolite tuffs of areal extent (Lexa et al. 1993) with radiometric ages 19.7 and 20.1 Ma in the southern Slovakia (Kantor et al. fide Vass et al. 1992, Repčok 1987) and 17 - 19 Ma in the north-eastern Hungary (Hámor et al. 1980).

The uplift lasted from the end of Eggenburgian to the Early Ottnangian representing time span 1-2 Ma. The prerift uplift is also recorded in the East-Slovakian Basin which is evidenced by the lack of the Ottnangian deposits (Fig. 4).

The own rifting followed the uplift phase. The first subsidence, controled by faults, already commenced during Ottnangian in the Pannonian area. The result of the subsidence is a sea incursion into surroundings of Várpaloty (Bántapusta Formation, Kokai in Papp et al. 1973). Indication of the beginning of the marine transgression is also a paralic coal sedimentation in Borsode area (north-eastern Hungary, Bohn-Havas 1985) and marine ingressions into fluvial-palustrine environment (into coal-bearing Pôtor Member) and later into lacustrine environment (Plachtince Member) of Ottnangian age in the southern Slovakia (Vass et al. 1987, Škvarka et al. 1991). In this period, extension controlled palaeostress field (Vass et al. 1993, Márton & Fodor 1995). On the contrary in the Carpathian front next thrust phase of Flysch Carpathians and their overthrusting on the Carpathian foredeep occurred (e.g. Jiříček 1979, Vass et al. 1983, Oszypko and Slaczka 1985).

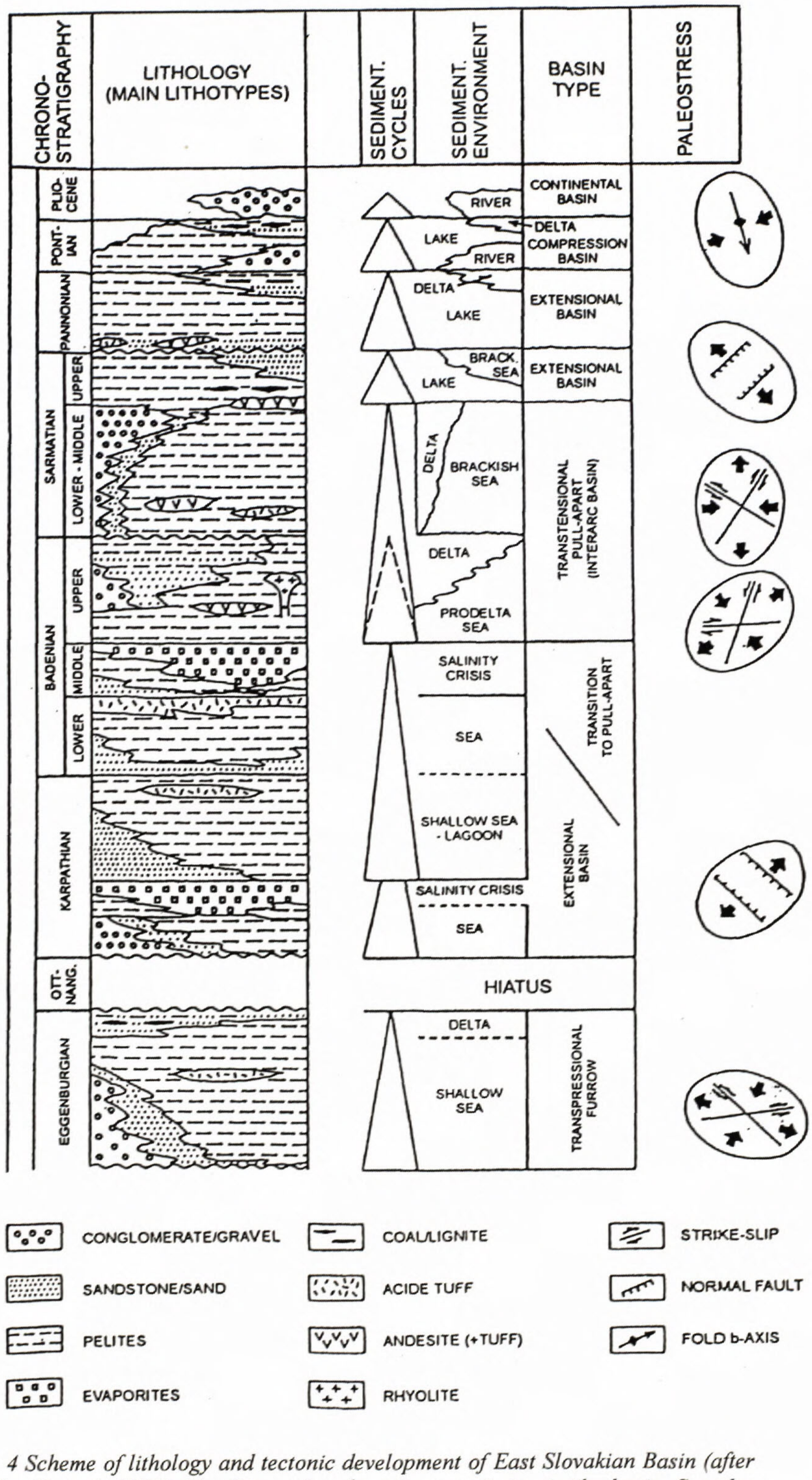

Fig. 4 Scheme of lithology and tectonic development of East Slovakian Basin (after P. Kováč et al. 1994). The Ottnangian deposits are missing in the basin. See also the extension during the Karpathian.

On this tectonic background an extensive 50° anticlockwise rotation of the North Pannonian - West Carpathian block or partial blocks occurred. An another rotation in ca. 30° contributed to the first rotation in the Karpatian or during the Early Badenian. The total movement of blocks affected by rotation might be 500 - 1000 km toward the north (Márton et al. 1995, 1996). This mechanism was responsible for today's position of the units which originally tectonically escaped toward the south-east. The units are now located north-east of the original home area in the Alps and Dinarides. It is necessary to say that the rotational transport of the Inner Carpathian units from the south to the north is supported by shallow inclination of remanent palaeomagnetism. Thrusting in the Carpathian front, which means space shortening in the front of the Outer Carpathians and space widening in the inner part in ca. 500 km (Oszczypko & Slaczka, 1985) compensated by anticlockwise (e.g. toward the north) rotational movement of the Inner Carpathian units contributed by a decisive role to the formation of the Carpathian loop (Vass et al. 1988).

The rifting and crustal extension continued in the Karpatian. The relevant style of the crust extension was described by Tari et al. (1992). In the southern part of the Danube Basin (e. g. in the Small Hungarian Plain) an ex tension controlled by normal listric fault which originally represented a detachment plane of pre-Tertiary units was described on the basis of seismic profile. The sinking movement on the fault opened an asymmetric trough restricted by faults in the north-western part and without fault restriction in the south-eastern part (Fig. 5). The oldest deposits of the trough fill are Ligeterdö conglomerates of Karpatian age (17.5 - 16.5 Ma, Steininger et al. 1988). A similar contemporary (e.g. Karpatian) style of opening is preserved in the East-Slovakian Basin. In the pre-Tertiary basement, tectonically formed in the Paleogene (after

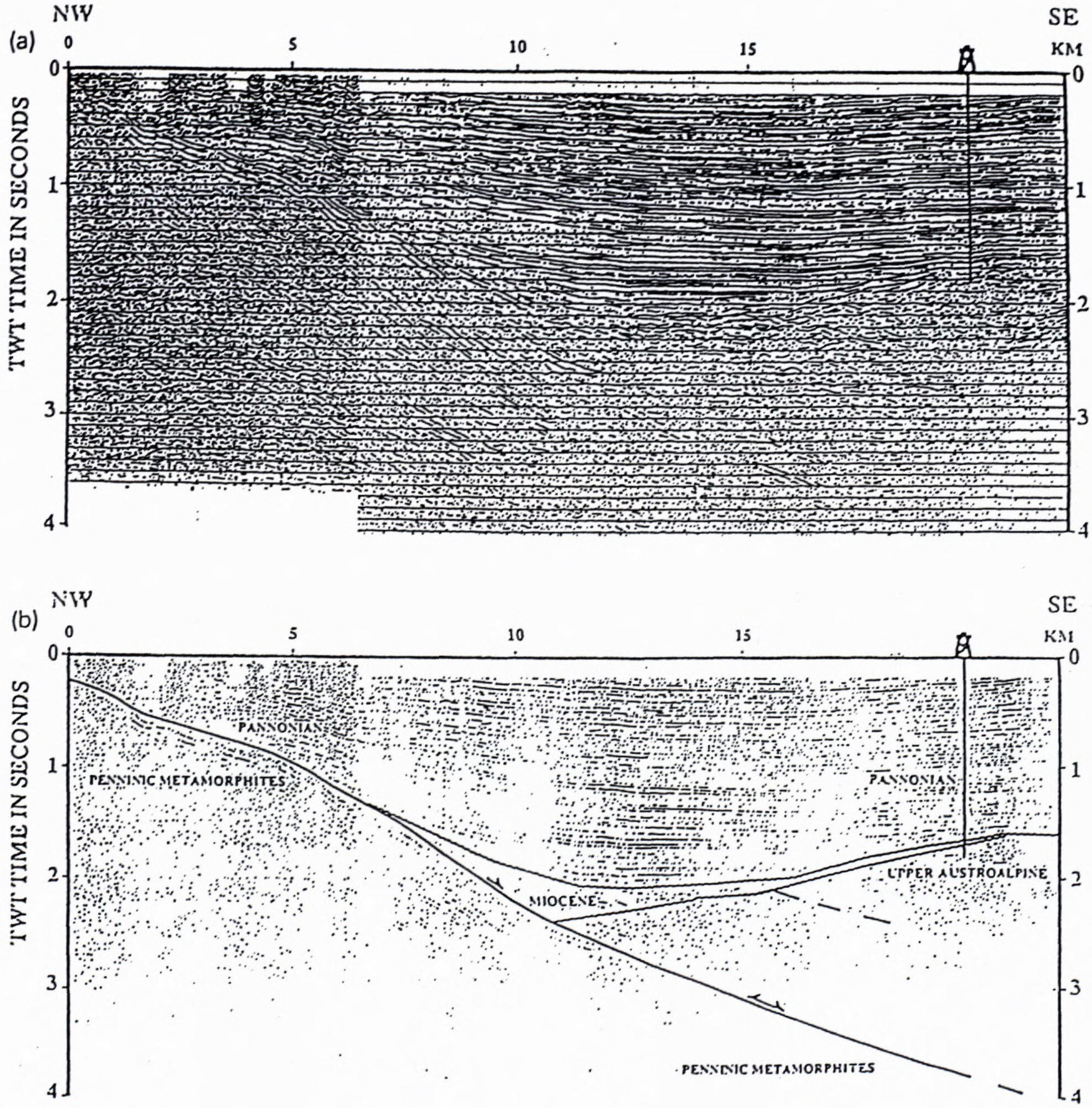

Fig. 5 Migrated sesmic section (a) and its interpretation (b). The basement consists of epimetamorphic greenschists on the northwestern side of the section, representing the subsurface continuation of Jurassic – Early Cretaceous rocks outcropping in the Penninic window of Rechnitz. The well on the souteastern side of the profile bottomed in anchimetamophic Paleozoic rocks (Graz Paleozoic). The low-angle tectonic contact between these tectonic unit corresponds to a Cretaceous major overthrust plane. During the Middle Miocene the same fault plane reactivated as an extensional detachment fault, along which the metamorphic core complex of Rechnitz was uplifted and the asymmetric graben of middle Miocene through Pliocene in age subsided (after Tari et al., 1992)

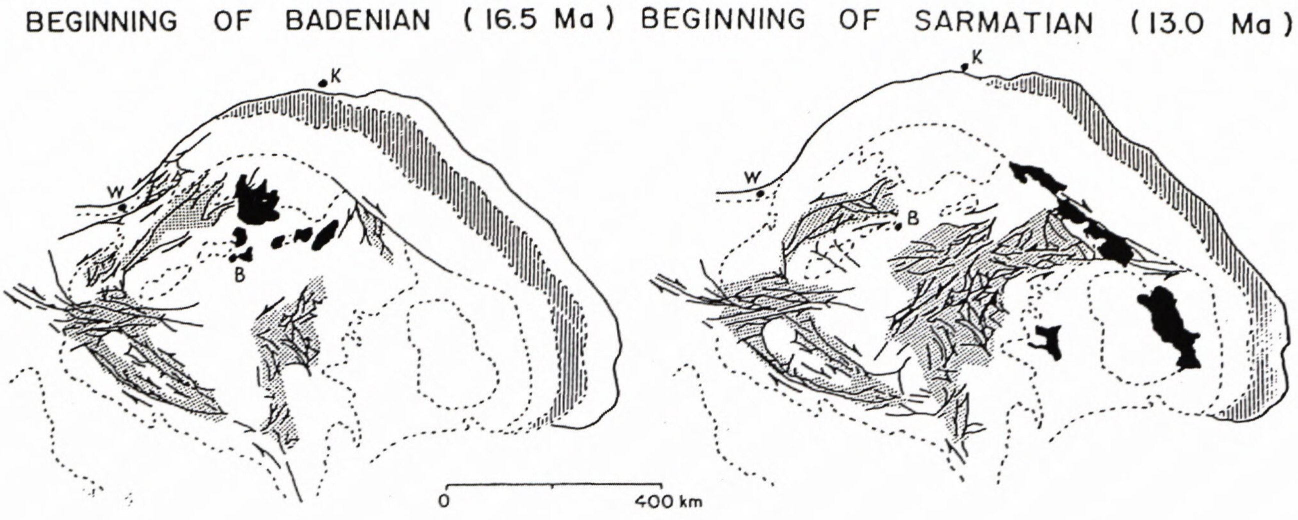

Fig. 6 Palinspastic reconstruction of the Carpathian – Pannonian region at beginning of Badenian time and beginning of Sarmatian time showing the areas of synrift extension and sedimentation. Solid line shows present external limit of Carpathian flysh and is fixed with respect to Europe. Shaded areas show region af active extension during each time stage (Badenian and Sarmatian); vertical lines indicate areas of shortening; small arrows indicate direction of motion inferred along strike-slip fault zones. Black indicates areas of andesitic volcanism. There are show only the areas of extension, compression and transcurrent faulting which have been identified and are know to belong to the time periods indicated (after Royden et al., 1982).
W – Wien, K – Krakow, B – Budapest

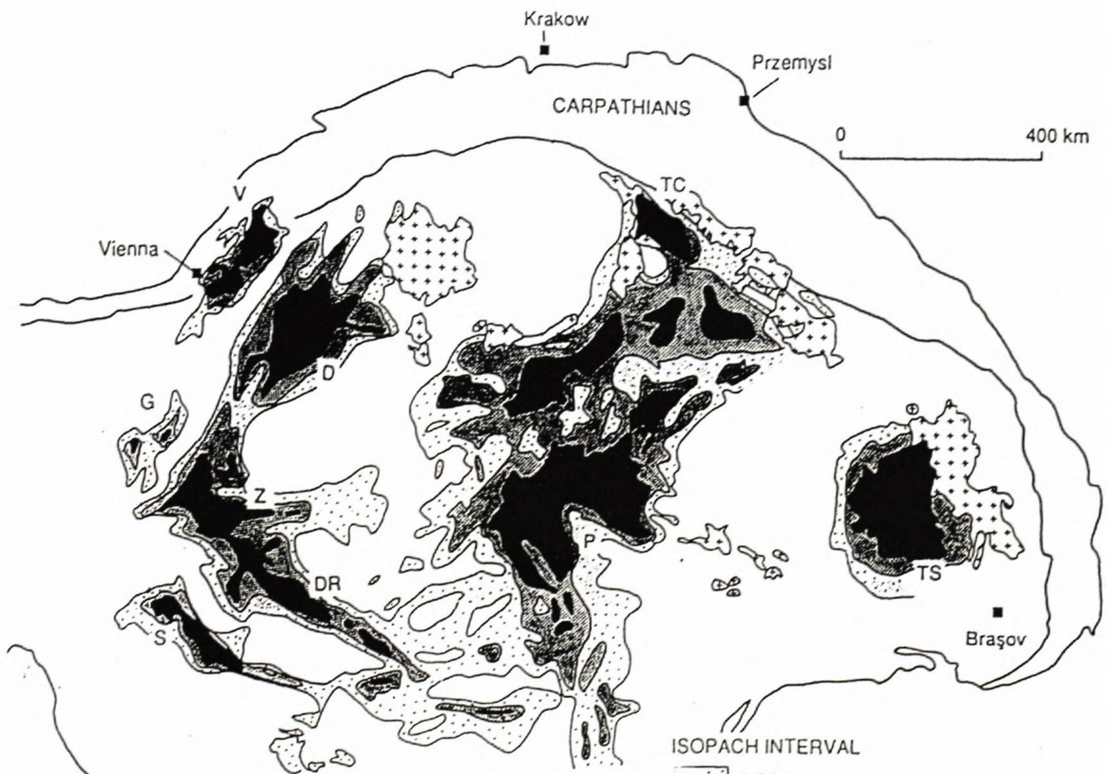

Fig. 7 Izopachyte map of the Pannonian Basin system with subdivision into partial basins: S - Sava; Dr – Drava B; Z – Zala B; G – Graz B; D - Danube B; V - Vienna B; P - Pannonian s.s. B (Mako and Bekes Basins); Tc – Transcarpathian B; Ts - Transylvanian B (Royden et al., 1983)

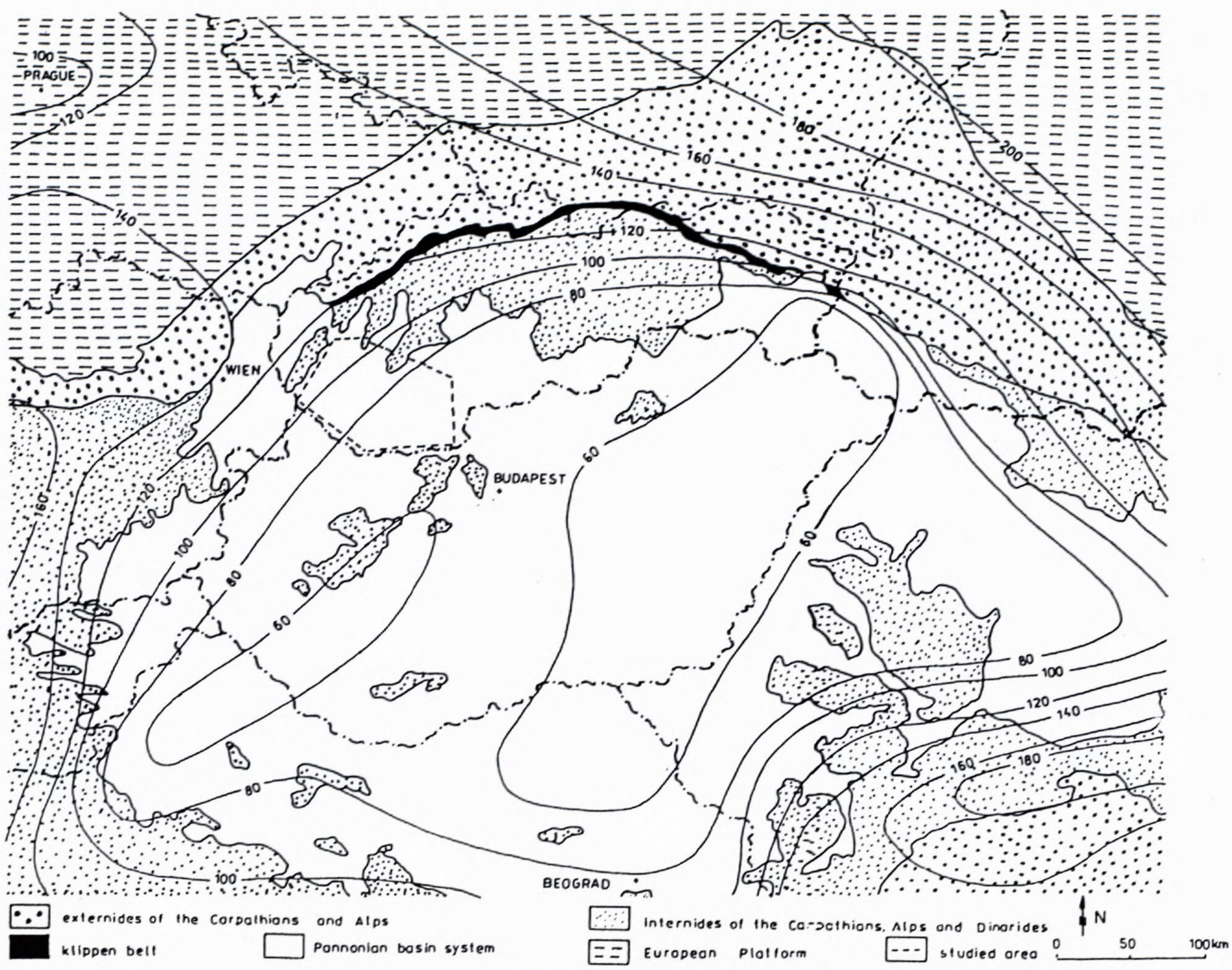

Fig. 8 Lithospheric thickness map of the Pannonian Basin and surrounding territories (according to Horváth, 1993). Thicknesses are given in km.

Eocene, Sotak et al. 1993), partial thrust planes are indicated on seismic profiles as subhorizontal or low-angle inclined conspicuous reflectors (Vozárová et al. 1993). During the Early and Middle Karpatian, when extension predominated in the East-Slovakian Basin (Fig. 4) at least a part of these thrust planes could act as listric faults along which partial tectonic units or slices of pre-Neogene basement were slided. As a result the East - Slovakian Basin had been opened and filled up by marine Teriakovce Formation, later by marine-lagoon evaporites of Soľná Baňa Formation (P. Kováč et al. 1994).

In the following process of rift stage and crustal extension next faults were activated. Conjugated systems of horizontal strike slips were opening smaller basins in the framework of the Pannonian area (Horváth and Royden 1981, Royden et al. 1982, Tari et al. 1992). Extension reaches 50% to 200% and it was a response of crust thinning when asthenosphere rising, rifting and postrift stage were situated more or less above each other.

Discussion

Model of asymmetric opening of the Danube Basin

Knowledge on structure of the northern part of the Danube Basin suggests different mechanism of the basin origin and basin filing as in other partial depressions of the Pannonian area. The substance of the difference is in fluctuation of crust and lithosphere thickness in the area of the Danube Basin. It also lies in contrasting thickness of syn- and postrift deposits, in subsidence velocity, in frequency of synsedimentary faults and size of their throw. In the area of Gabčíkovo Depression, e.g. in the central part of the Danube Basin, the crust thickness or the depth of MOHO is 27.5 km or less (Fig. 9) and the lithosphere thickness is about 80 km (Fig. 8). The thickness of Middle Miocene deposits of synrift stage (Badenian and Sarmatian) is several hundred meters (Adam and Dlabač 1969), maximum 1500 m as is confirmed also by later seismic profiles (Fig. 13), synrift sediment thickness distribution (Fig. 10) and subsidence curves of selected boreholes (Diakovce-1 and Kolárovo-2, Fig. 14). The greater part of deposits from the synrift stage is absent on the Kolárovo elevation: Sarmatian deposits lie on metamorphous rocks and granitoids of Veporicum. In places, where synrift deposits are thinned on the seismic profile we assume only Sarmatian deposits (Fig. 13). The density of mostly synsedimentary faults deforming synrift deposits is relatively lower comparing to the northern part of the basin. Higher throw amplitudes are rare. On the contrary the deposits of postrift or thermal stage (Pannonian to Pliocene) reach considerable thickness, e.g. the thickness south of Dunajská Streda is up to 5000 m (Fig. 11). It is mainly proved by seismic profiles because none of boreholes penetrated postrift deposits in places of their maximum accumulation. An important difference of subsidence during the deposition of syn- and postrift sediments are also proved by subsidence curves (Fig. 14). The postrift deposits are only slightly deformed by faults and throw amplitudes are small (Fig. 13).

The crust thickness toward the north from Gabčíkovo Depression increases from 27.5 km to 30 km (Fig. 9) and the lithosphere thickness is about 100 km (Fig. 8). The synrift stage sediment thickness in partial depressions, namely in Blatné Depression and Rišnovce Depression, exceeds 2 500 m and 2 000 m respectively (Fig. 10). Synrift deposits are deformed by a dense system of synsedimentary faults with high throw amplitudes (in order of hundred meters - Fig. 12). Postrift deposits are developed only rudimentary. Their thickness abruptly decrease toward the north. The thickness is several tens, maximum several hundreds meters on the northren margins of depression (Figs. 11 and 12).

The above mentioned evidence about structural heterogenity of the Northern Danube Basin suggests that it is possible to apply Coward model of heterogeneous lithosphere thinning (Coward 1986) to elucidate the basin genesis. This model is a modified model of a simple shear (Wernicke 1981, 1985). According to Coward model stretching of the lower part of the lithosphere is concentrated beneath the much more extensive zone of upper crust extension (Fig. 15). New fault generation can diffuse to the area of the initial rift zone and in this way it can widen the zone of the stretching of the upper crust. The fault expansion or uppercrust stretching can be supported by older, slightly waning anizotropy or compositional layering within the crust. Old fault systems or thrust planes are rejuvenated.

The sedimentary basin originating by asymmetric crust extension has outer zone with the extension only in the upper part of the crust and inner zone, where the upper crust is extended by a factor β, while the lower crust is extended by a factor β + β′ to balance the extension of the upper crust on the basin margin. The extension and fault development are not symmetric. In the zone of the upper crust thinning initial e.g. synrift subsidence carries

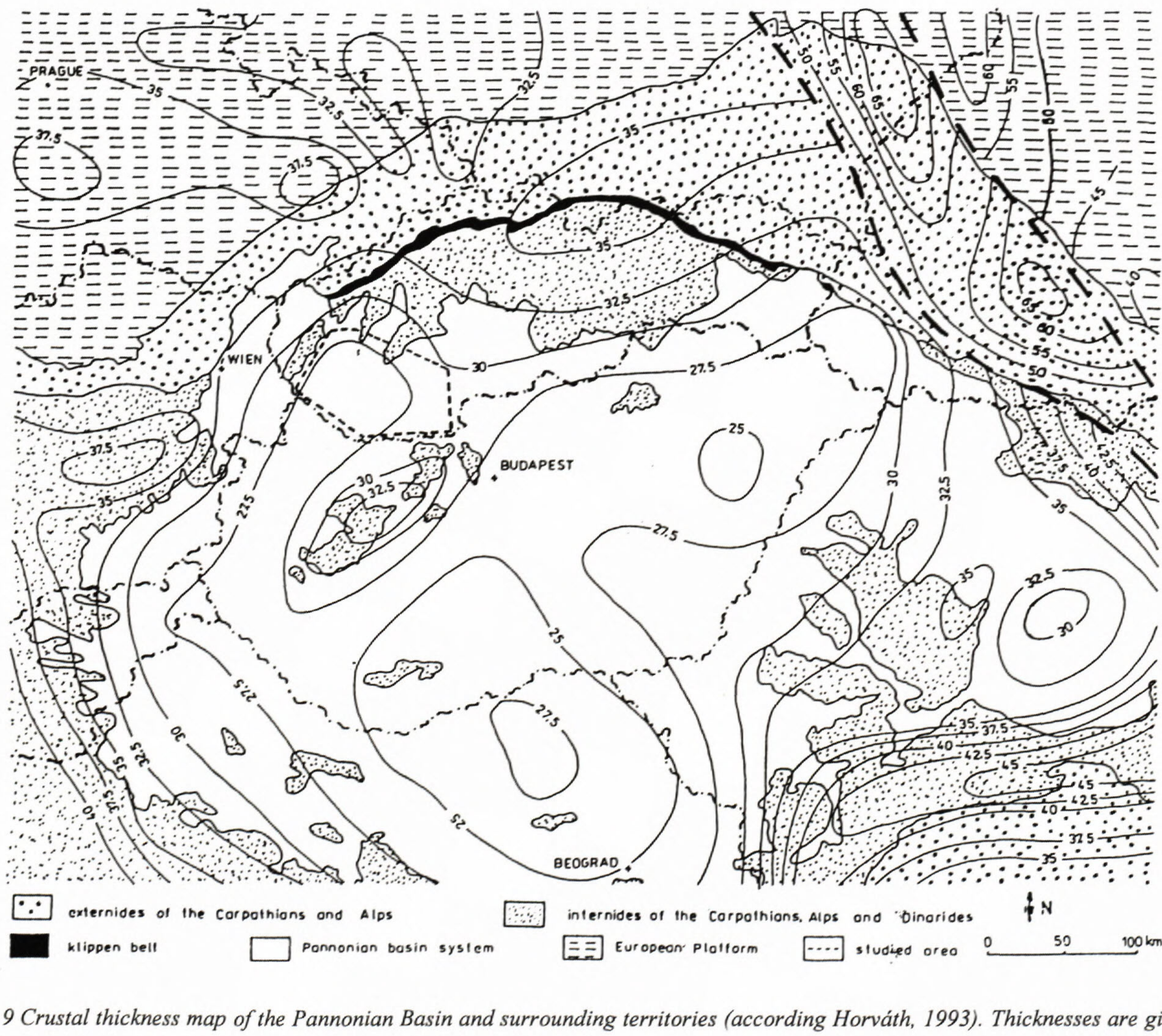

Fig. 9 Crustal thickness map of the Pannonian Basin and surrounding territories (according Horváth, 1993). Thicknesses are given in km.

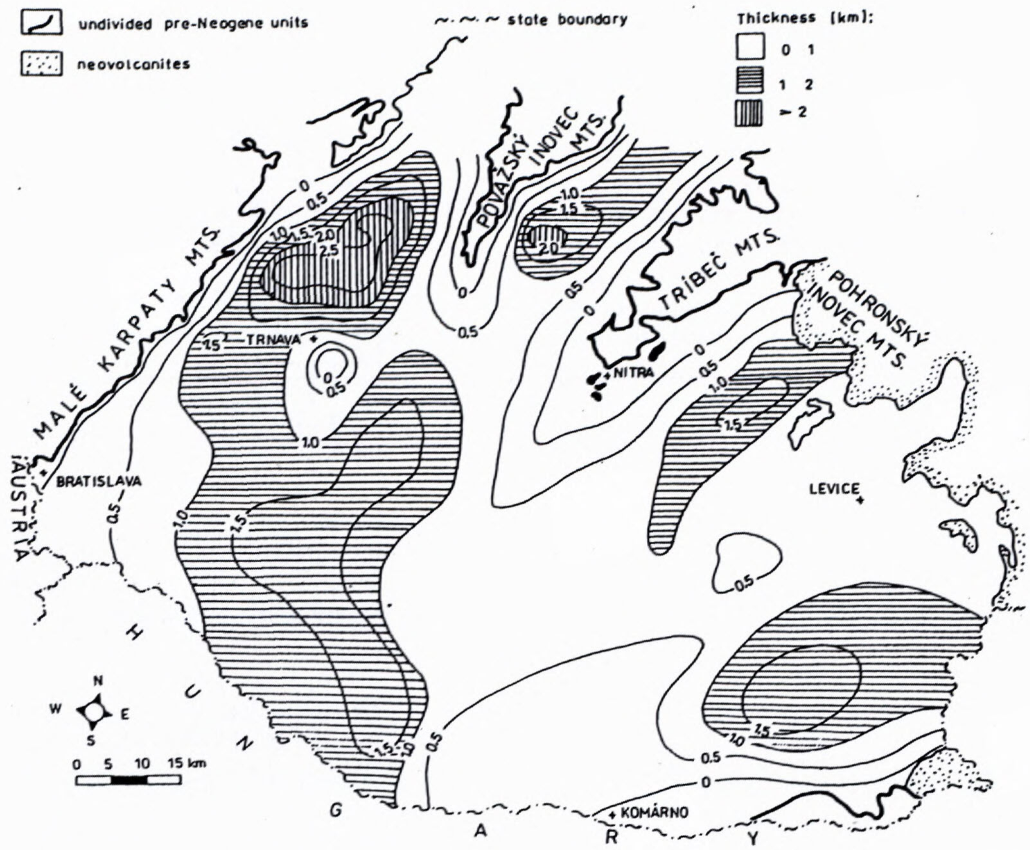

Fig. 10 Northern part of the Danube Basin - Thicknesses are given in km. Maximal thickness is in the partial depressions near the northern Basin margin. See the area of Kolárovo elevation where the synrift sediments are thin and uncomplete

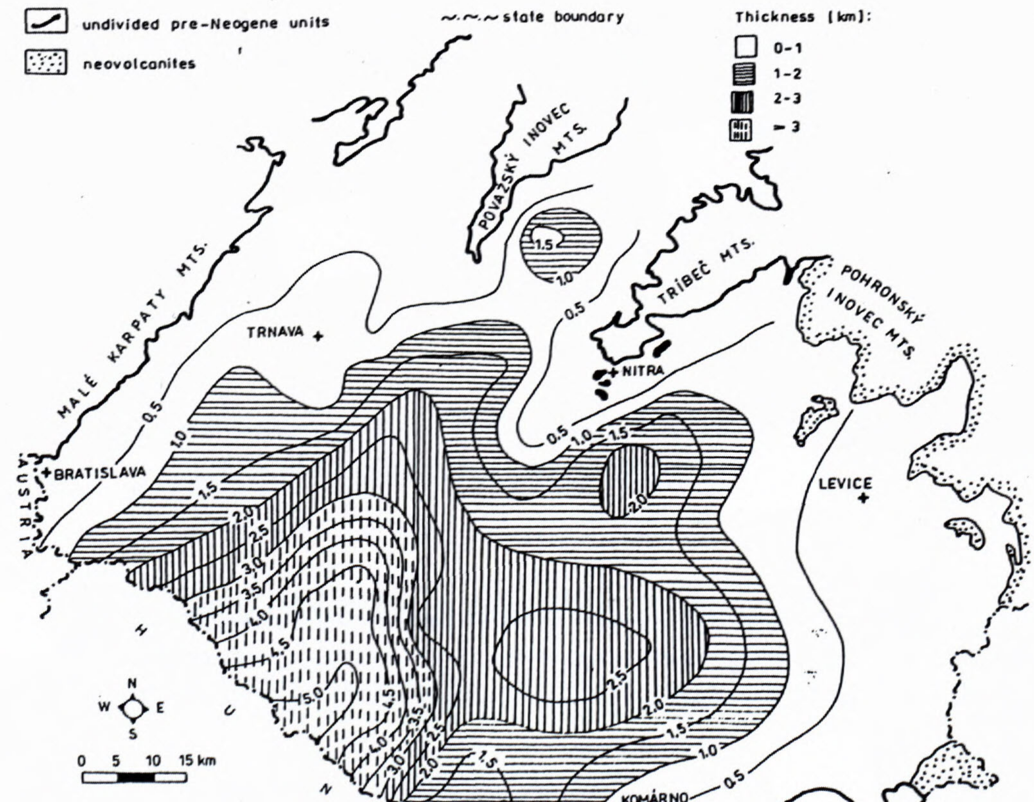

Fig. 11 Northern part of the Danube Basin - Thickness map of the Pannonian, Pontian and Pliocene postrift deposits. Thicknesses are given in km. Maximal thickness is in Gabčíkovo depression.

out. Thermal and/or postrift subsidence does not develope there (Fig. 15).

In the basin inner part where the entire lithosphere (inner zone) is thinning, both initial tectonic and subsequent thermal subsidence occur. The stretching of the whole crust by factor β triggers subsidence but the supplementary factor β′ in the lower crust and in the lithosphere mantle determines a slight uplift of lithosphere. If in the lower crust the density is variable, the total uplift occurs resulting in the emergence of the extensional upper crust above the sea level. In these conditions, initial subsidence of the inner zone has to be necessarily lower than in the outer zone. Besides, a discordance occurs between deposits of the initial subsidence and subsequent thermal subsidence. This discordance is often hidden and not conspicuous.

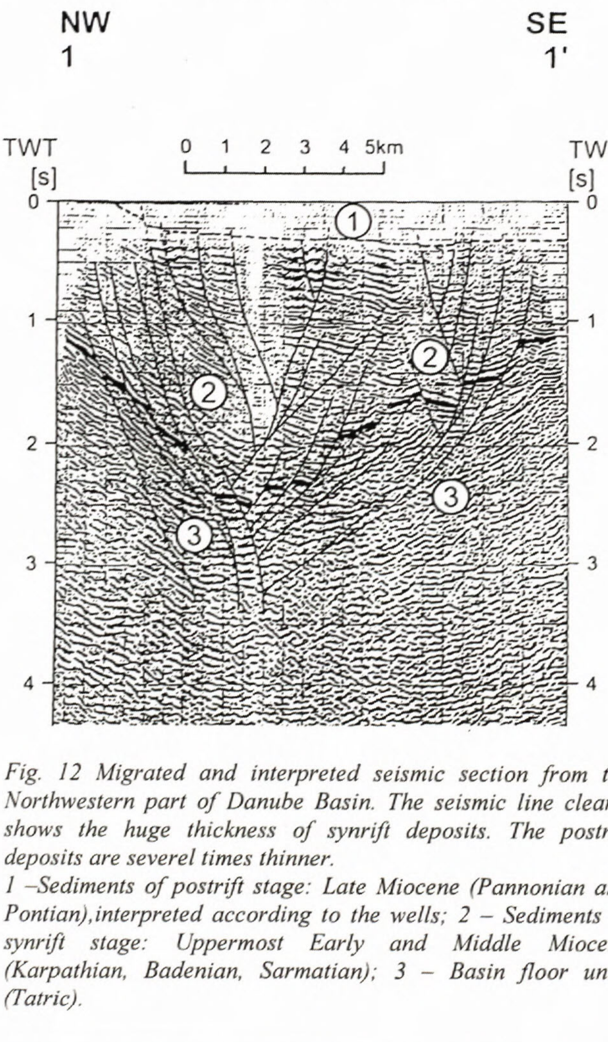

Fig. 12 Migrated and interpreted seismic section from the Northwestern part of Danube Basin. The seismic line clearly shows the huge thickness of synrift deposits. The postrift deposits are severel times thinner.

1 –Sediments of postrift stage: Late Miocene (Pannonian and Pontian),interpreted according to the wells; 2 – Sediments of synrift stage: Uppermost Early and Middle Miocene (Karpathian, Badenian, Sarmatian); 3 – Basin floor units (Tatric).

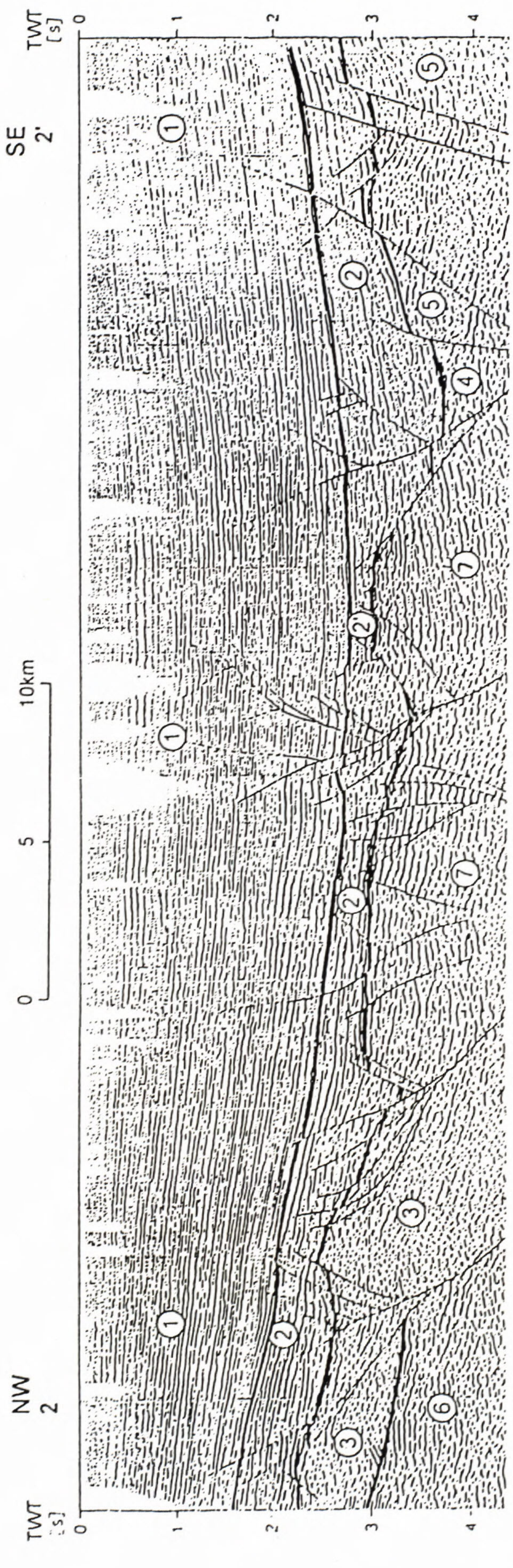

Fig. 13 Migrated and interpreted seismic section from the Central part of Danube Basin. Seismic line shows reverse situation as Fig. 11. The postrift sediments are thick and synrift deposits several time thinner.

1 – sediments of postrift stage: late Miocene (Pannonian and Pontian), Pliocene (Dacian and Romanian), Quternary; 2 – sediments of synrift stage: middle Miocene (Badenian and Sarmatian); 2′–reduced thickness - Sarmatian only?; 3–7 – tectonic units of the basin floor; 3 – Tatric, 4 – Veporic, 5 – Bakony, 6 – Penninic?, 7 – Unknown.

In the Danube Basin, the partial Blatné, Rišňovce, Komjatice or also Želiezovce depressions located in the northern part of the basin (Fig. 1) are consistent with the outer zone. In these depressions, asymmetric extension of the outer crust resulted in reactivation of faults active in the older depression structure. It determined tectonic subsidence governing a thick synrift pile of deposits. The later thermal subsidence was applied in very restricted extent. The postrift deposits occur only rudimentary.

Gabčíkovo Basin (Fig. 1) is consitent with the inner zone where synrift deposits of initial phase are substantially less thick than postrift deposits of thermal phase. Kolárovo anomaly suggests that in the beginning of the initial subsidence a local energic uplift occurred in the inner zone and crystalline rocks of basin basement were denuded. Only at the end of this phase elevation sank down and the deposits of the final part of the initial phase (Vrábel Formation - Sarmatian age) lie on it transgressively (Fig.13). In the thermal (postrift) subsidence stage the entire partial Gabčíkovo Basin subsided uniformly.

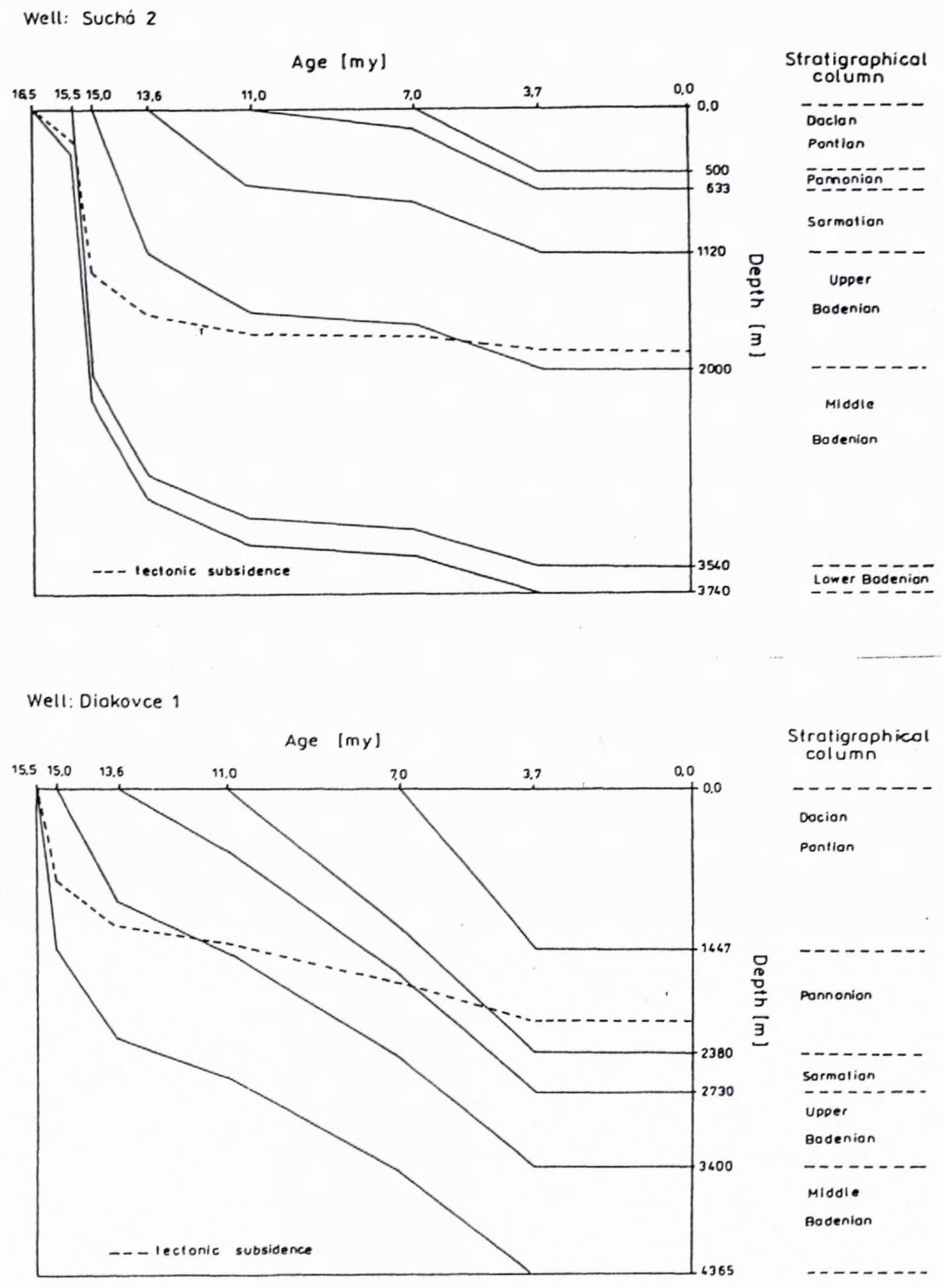

Fig. 14

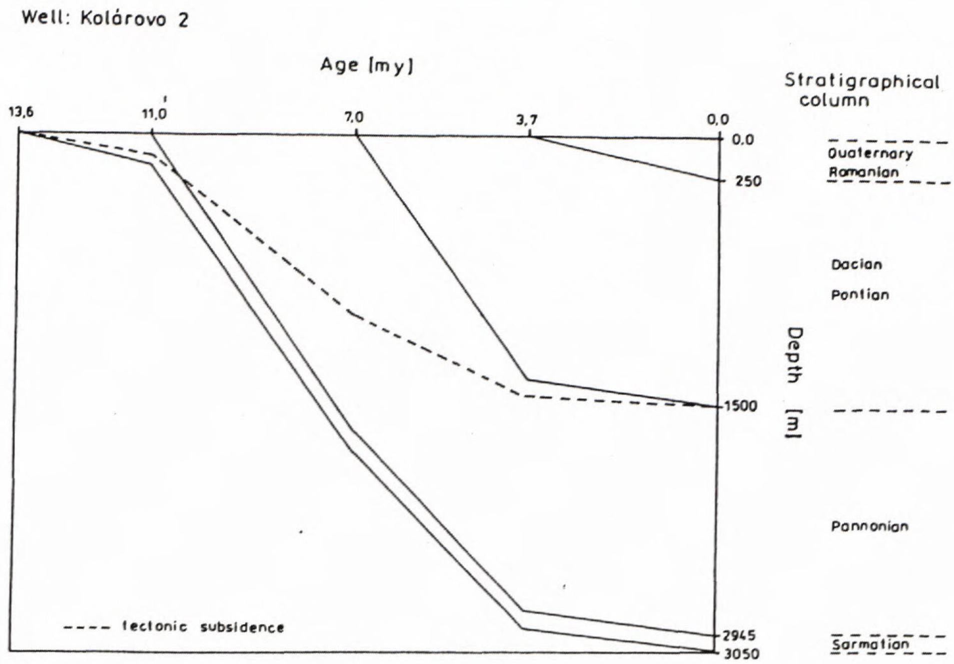

Fig. 14 Burial history curves and tectonic subsidence in Northern part of Danube Basin. Modeled tectonic subsidence is the sum of initial and thermal subsidence. See well expressed initial subsidence in the well Suchá-2 and partly Diakovce-1 (Badenian and Sarmatian); in the well Kolárovo-2 initial subsidence is missing. Contrary, the thermal subsidence (Pannonian – Quaternary) is well expressed in the well Kolárovo-2, less expressed in the well Diakovce-1 and only rudimentary in the well Suchá-2.

The difference between Coward model of asymmetric crust stretching and Wernicke model of lithosphere extension by simple shear

Coward model of asymmetric crust stretching or heterogeneous stretching descends from Wernicke model of lithosphere extension by a simple shear but it is not entirely consistent with this model. The subsidence in Wernicke model is associated with slightly inclined shear zone penetrating the whole crust and stretching out as far as to mantle. The extension from the upper crust in one area should be transferred to the lower crust and lithospheric mantle in the other area by the shear zone. The extensional basin is developing on the site of the upper crust extension controlled by faults. Thus, Wernicke model in contrast to the Coward model and structure of the northern part of the Danube Basin assumes upper crust thinning and subsequent initial tectonic subsidence only in the outer zone. In places where the lower crust and mantle lithosphere undergoe thinning and is not affected by faults the uplift occurs (discrepancy zone). The asthenosphere cooling beneath the zone of discrepancy induces return of the crust into initial position. The discrepancy zone sank below the original level in older zones of the crust extension by a simple shear. This results in formation of shallow, simple sag basin type without interaction of extension faults (Fig. 16).

On the contrary, Coward model does not assume huge shear penetrating the entire lithosphere and reaching the mantle.

The thinning of the upper crust and subsequent initial tectonic subsidence occurred in the whole area under extension e.g. in both outer and inner zones, even if in the inner zone it was less intensively. The subsequent thermal subsidence affected by a significant extent the central zone, resulting in several thousand meters thick pile of deposits in the case of the Danube Basin.

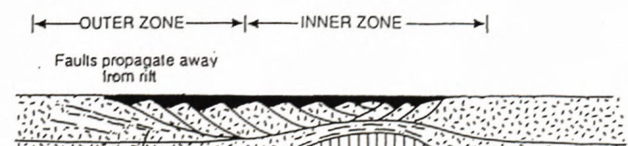

Fig. 15 Heterogeneous thinning of the lithosphere (after Coward, 1986). The upper crustal extension spread outwards asymmetrically over a wide region, possibly reactivating previous tectonic fabrics. The lower crust and subcrustal lithosphere, however, are shown extendind over a much smaller region. This lower crustal/subcrustal thinning may produce thermal domes and erosional unconformities and older extensional faults may be inverted.

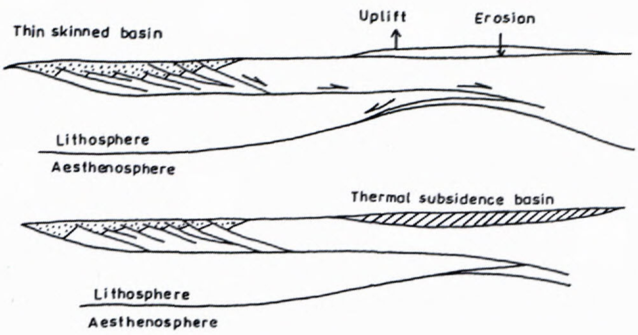

Fig. 16 The model for crustal stretching on a low angle shear zone (after Wernicke, 1981, 1985 – modified).

Conclusion

Coward model of heterogeneous lithosphere thinning most conspicuously elucidates mechanism of the openning and filling of the Northern Danube Basin or its northern part. The basin has two conspicuously separated zones:

- Outer zone with the initial subsidence determined by the upper crust thinning. The important role played rejuvenated or new formed faults. The thermal subsidence was unconspicuous, substantially lesser than preceding initial subsidence.

- Inner zone with manifestation of initial and thermal subsidence. The initial subsidence was less intensive than thermal one. Uplift occurred locally during the subsidence. The thermal subsidence took relatively large area of the basin where it enables formation of several meters thick sediment pile but it stretched into the outer zone only marginally.

References

Adam Z., Dlabač M., 1969: Vysvětlivky k mapám mocnosti a litofaciálního vývoje Podunajské nížiny. *Záp. Karpaty* 11, Bratislava, 156-172

Andrusov D., 1968: Grundriss der Tektonik der Nördlichen Karpaten. Slov. Akad. vied, Bratislava, 1-187

Allen Ph.A., & Allen J.R., 1992: Basin analysis, principles and applications. Blackwell Scient. Publ., London, 1-451

Beaumont C., Keen C.E., & Boutilier 1982: On the evolution of rifted continental margins, comparison of models and observations for Nova Scotia margin. *Geophys. J. R. astr.* Soc. 70, 667-715

Burke K., & Sengör A.M.C., 1986: Tectonic escape in the evolution of the continental crust. In M. Barazangi & L. Brown (edts.): Reflection Seismology a global perspective. Amer. Geophys. union *Geodynamics* Series 14, 41-53

Csontos L., Nagymarosy A., Horváth F. & Kováč M., 1992: Tertiary evolution of the Intra-Carpathian area: a model. *Tectonophysics* 208, 2221-2241

Coward M.P., 1986: Heterogenous stretching, simple shear and basin developement. Earth planet. *Sci Letters* 80, 325-336

Császar G., & Haas J., (edts.) et al., 1983: Magyarország litosztratigráfiai formációi. Hung. Geol. inst. Budapest

Čechovič V., 1952: Geológia juhoslovenskej panvy. *Geol. Práce, Zoš.* 33, Bratislava, 1-53

Dewey, J.F., 1988: Extension collapse of orogens. *Tectonics* 7, 1123-1139

Hámor G., Ravaszné Baranyai L., Balogh K., Árva Soós E., 1980: A magyarországi miocén ryolittufa-szintéK radiometrikus kora. *Évi jelentése* 1978, Hung. Geol.Inst., Budapest, 65-72

Hámor G., et al., 1988: Neogene paleogeographic Atlas of Central and Easterm Europe. Hung. Geol. Inst. Budapest

Haq B.U., Hardenbol J. & Vail P. R., 1987: Chronology and fluctuationg sea levels since the Triassic. *Science*, v. 235, 1156-1167

Heilinger S.J. & Sclater J.G., 1983: Some comments on two - layer extensional models for the evolution of sedimentary basins. *J. geophys.* Res. 88, 8251-8270

Horváth F., & Royden L., 1981: Mechanism for the formation of the Intra - Carpathian Basin: A review. *Earth Evol. Sc.* 3-4/1981, Vieweg, Braunschweig, 307-316

Horváth F., 1993: Towards a mechanical model for the formation of the Pannonian basin. *Tectonophysics*, 226, 333-357

Horváth F. & Brckhemer H., 1982: Mediterranean backarc basins. In: H. Berckhemer and K. Hsú (edts.), Alpine-Mediterranean Geodynamics. AGU *Geodyn.* Ser., 7: 141-173

Jiříček,R. 1979: Tektogenetický vývoj karpatského oblouku během oligocénu a neogénu. In: Mahel', M. (edt.): Tektonické profily Západných Karpát. GÚDŠ, Bratislava, 205-214.

Kázmér M.& Kovács, S., 1985: Permian-Paleogene paleogeography along the Eastern part of the Insubric-Periadriatic Lineament system: evidence for continental escape of the Bakony-Drauzug Unit. *Acta geol. Acad. Sci. hung.* (Budapest),.281/2), 71–84.

Kováč P., Vass D., Janočko J., Karoli S.& Kaličiak M., 1994: Tectonic history of the East Slovakian Basin during the Neogene. ESRI Occasional Publication, New Series No.11 A-B, Columbia SC., 1-15

Lyon - Caen H., & Molnár P., 1989: Constrains on the deep structure and dynamics processes beneath the Alps and adjacent regions from an analysis of gravity anomalies. *Geophys.* J. Int. 99, 19-32

Márton E., Vass D., & Túnyi I., 1995: Mladoterciérne rotácie megajednotky Pelso a priľahlých častí Západných Karpát. *Knihovička Zemní plyn a Nafta* 16, Hodonín, 97-108

McKenzie D. P., 1978: Some remarks on the developement of sedimentary basins. *Earth planet. Sci Letters* 40, 25-32

Molnar P.& Lyon-Caen H., 1988: Some simple physical aspects of the support, structure, and evolution of mountain belts. In: S.P.Clark Jr., B.C.Burchfiel & J.Suppe (edts): Processes in continental lithospheric deformation. *Geol. Soc. Am. Spec. Pub.*, 218, 179-207.

Osczcypko N. & Slaczka A., 1985: An attempt to palimspastic reconstruction of Neogene basins in the Carpathian Foredeep. Ann. societ. Geologorum Poloniae, rocn. Polsk. Towar. *Geologiczsnego.* 55-1/2, Kraków, 55-75

Ratschbacher L., Merle O., Davy P. & Cobbold P., 1991a: Lateral extrusion in the Eastern Alps, Part 1: boundary conditions and experiments scaled for gravity. *Tectonics*, 10 (2): 245-256

Ratschbacher L., Frisch W., Linzer H.G. & Merle O., 1991b: Lateral extrusion in the Eastern Alps. Part 2: structural analysis. *Tectonics,* 10 (2): 257-271

Royden L. & Keen C.E., 1980: Rifting proces and thermal evolution of the continental margin of Eastern Canada determinated from subsidence curves. *Earth planet. Sci. Letters* 51, 343-361

Royden L.H., Horváth F. & Burchfiel B.C., 1982: Transform faulting, extension and subduction in the Carpathian Pannonian region. *Geol. Soc. Am. Bull.* 93, 717-725

Royden L., Horváth F. & Rumpler J., 1983: Evolution of the Pannonian basin system 1. Tectonics. *Tectonics* 2/1, 63-90

Royden L.H. & Horváth F.,(edts.) 1988: The Pannonian Basin, study in Basin evolution. *Am. Ass. Petrol. Geol. Mem.* 4-5, Tulsa, U.S.A. 1-394

Seneš J., 1952: Štúdium o akvitánskom stupni. *Geol. Práce, Zoš. 31,* Bratislava, 1-75

Steininger F.F., Műller C. & Rögl F., 1988: Correlation of Central Paratethys Eastern Paratethys and Mediteranean Neogene stages. *Am. Ass. Petrol. Geol. Mem.,*45:79-88

Soták J., Rudinec R. & Spišiak J.,1993: The Penninic "pull-apart" dome in the pre-Neogene basement of the Transcarpathian depression (Eastern Slovakia). *Geol. carpathica* 44, Bratislava, 11-16

Škvarka Ľ., Vass D., Ondrejičková A. & Elečko M., 1989: Nové poznatky o južnej časti strhársko-trenčskej prepadliny. *Správy o geol. výskumoch* 25, Geol. Úst. D. Štúra, Bratislava, 65-69

Tari G., Báldi T. & M. Báldi-Beke 1992: Paleogene retroarc flexural basin beneath the Neogene Pannonian Basin: A geodynamic model. *Tectonophysics* 226, 433-455

Tari G., Horváth F. & J.Rumpler 1992: Styles of extension in the Pannonian Basin. *Tectonophysics* 208, 203-219

Vass D., 1976: Molasové panvy a globálno-tektonický model Karpát. Zborník referátov vedeckej konferencie: Československá geológia a globálna tektonika (Smolenice 1976). Edičné stredisko Geol. Úst. D. Štúra, Bratislava, 111-117

Vass D., 1979: Genesis of innermolasse basins in West Carpathians in light of leading function of mantle in earth's crust development. In M. Maheľ & P. Reichwalder (edts.): Czechoslovak geology and global tectonics, Veda SAV, Bratislava, 183-197

Vass F., Konečný V. & Šefara J., et al., 1979: Geologická stavba Ipeľskej kotliny a Krupinskej planiny. GÚDŠ, Bratislava, 1-280

Vass D., Elečko M., Kantorová V., Lehotayová R. & Klubert J., 1987: Prvý nález morského otnangu v juhoslovenskej panve. *Mineralia slov.* 19/5, Bratislava, 417-422

Vass D., Stránik Z., & Krystek I., 1987: Tectonomagmatic activity in the West Carpathians (Czechoslovak part) from Pyrenean to Rhodanian epochs.

Yu. G. Leonov & V.E.Khain: Global correlation of tectonic movements. J. Wiley & sons Chichester., 159-171

Vass D., Kováč M., Konečný V. & Lexa J., 1988: Molasse basins and volcanic activity in West Carpathian neogene - its evolution and geodynamic character. *Geol. Zborník - Geol. carpathica* 39/5, Bratislava, 539-561

Vass D. & Elečko M., et al., 1992: Vysvetlivky ku geologickej mape Lučenskej kotliny a Cerovej vrchoviny 1:50 000 Geol. Úst. D. Štúra, Bratislava, 1-196

Vass D., Hók J., Kováč P. & Elečko M., 1993: Sled paleogénnych a neogénnych tektonických udalostí v juhoslovenských kotlinách vo svetle napäťových analýz. *Mineralia slovaca* 25, Bratislava, 79-92

Vozárová A., Vozár J., Tomek Č., Rakús M. & Kováč P., 1993: Reinterpretácia podložia Východoslovenskej panvy a jej korelácia s jednotkami Karpát. Manuskript, GS SR, Bratislava

Wernicke B., 1981: Low-angle normal faults in the Basin and Range Province - nappe tectonics in an extending orogen. *Nature* 291, 645-648

Wernicke B., 1985: Uniform sense simple shear of the continental lithosphere. *Can. J. Earth* Sci 22, 108-125