GEOLOGICA CARPATHICA, 50, 4, BRATISLAVA, AUGUST 1999
325–338

PALEOGEOGRAPHY, PALEOBATHYMETRY AND RELATIVE SEA-LEVEL CHANGES IN THE DANUBE BASIN AND ADJACENT AREAS

MICHAL KOVÁČ[1], KATARÍNA HOLCOVÁ[2] and ANDRÁS NAGYMAROSY[3]

[1]Department of Geology and Paleontology, Faculty of Science, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovak Republic
[2]Institute of Geology and Paleontology, Faculty of Science, Charles University, Albertov 6, 128 43 Prague 2, Czech Republic
[3]Department of Physical and Historical Geology, Eötvös University, Múzeum krt. 4/a, 1088 Budapest, Hungary

(Manuscript received November 19, 1998; accepted in revised form March 17, 1999)

Abstract: The evolution of the Danube Basin is closely related to the extrusion of the Western Carpathian and Transdanubian Central Range lithospheric fragments from the East Alpine collision zone and to the Middle Miocene back-arc extension, associated with the formation of the Pannonian Basin System. Deposits of the Eggenburgian marine transgression, reaching the Danube Basin broader area through the Alpine and Carpathian Foredeep, can be correlated with transgressive depositional system of the TB 2.1 cycle of Haq (1991). The transgressive sequence passes upwards into highstand, neritic to upper bathyal sedimentation. The Ottnangian marine and part of the anoxic and brackish sediments represent the falling stage deposition. The lowstand deposition which can be correlated with the TB 2.2 cycle of Haq (1991) appeared still in the Ottnangian, during the compressive tectonic event resulting in closure of smaller basins. Later, during the Karpatian, sedimentation of transgressive and highstand depositional systems took place, still on the present Danube Basin northern margin (Blatné Depression, Bánovce Depression). The high energy environment of the basin attained deep neritic to upper bathyal depth. The angular discordance between the Karpatian and Badenian strata, very common absence of the Late Karpatian and Early Badenian deposits (proved by micropaleontological data), as well as the presence of sediments of this age in the Novohrad (Nógrád) Basin and its equivalents in the Želiezovce Depression (Danube Basin) suggest absence of the marine TB 2.3 cycle of Haq (1991) in most of the territory. The whole area of the Danube Basin was flooded by the sea during the Middle to Late Badenian and Sarmatian. The sedimentation in the high energy environment of the neritic zone reflects two depositional cycles, which can be compared with the TB 2.4, TB 2.5 and TB 2.6 cycles of Haq (1991). The Badenian cycle started with the Middle Badenian rush transgression and highstand of the TB 2.4 cycle, followed by the Late Badenian higstand (SB type 2) and falling stage in the Bulimina-Bolivina Zone. The Sarmatian cycle started by a lowstand characterized by Ammonia rich assemblages on the Badenian-Sarmatian boundary and was followed by a transgression and highstand which can be correlated with the TB 2.6 cycle of Haq (1991). The Late Miocene shallow water high energy brackish to delta-lake sedimentation in the north and deep water high energy environment in the central and southern part represent equivalents of the TB 3 Haq (1991) cycles.

Key words: Miocene, Western Carpathians, Danube Basin, paleogeography, relative sea-level changes.

Introduction

The Danube Basin, represented by the Slovak Danube Lowland and its southward continuation the Little Hungarian Plain in Hungary is situated in Alpine-Carpathian-Pannonian junction (Fig. 1). The basin is filled up by Neogene and Quaternary deposits with a thickness of up to 8 km (Steininger et al. 1985; Kilényi & Šefara 1989). Its pre-Neogene basement is built up mainly of Central Alpine and Central Western Carpathian units and a buried part of the Transdanubian Central Range (Fuchs 1985; Fusán et al. 1987; Fülöp et al. 1987; Dank & Fülöp 1990; Balla 1995; Keith et al. 1994). The structural and paleostress analysis points to changes in its structural pattern during the Miocene and defines the type of crustal shortening and/or extension in the area (Kováč et al. 1989a; Nemčok et al. 1989; Neubauer & Gesner 1990; Marko et al. 1990, 1991; Fodor et al. 1991, 1992; Pereszlényi et al. 1993; Fodor 1995; Csontos et al. 1991, 1992; Ratschbacher et al. 1991a,b; Franko et al. 1992; Kováč et al. 1993a,b, 1994; Hrušecký et al. 1996; Milička et al. 1996). On the basis of the above mentioned facts, we can distinquish a change from a transpressional to transtensional tectonic regime during the Early Miocene characterized by NW-SE to N-S oriented axis of the main compression, transtensional to extensional tectonic regime during the Middle Miocene characterized by a NE–SW oriented axis of main compression or a NW-SE to WNW-ESE oriented extension and W-E to NW-SE oriented extension during the Late Miocene.

The structural, sedimentological, biostratigraphical and paleoecological analysis of the basin fill also makes it possible to reconstruct the former shape of basin depocentres (Fig. 2), as well as the paleoenvironment, paleodepth and the possible connection toward the world sea.

Eggenburgian

The Alpine collision led to the eastward extrusion of the Alcapa microplate (Central Western Carpathians and Pelso Unit) and it was accompanied by crustal shortening at the

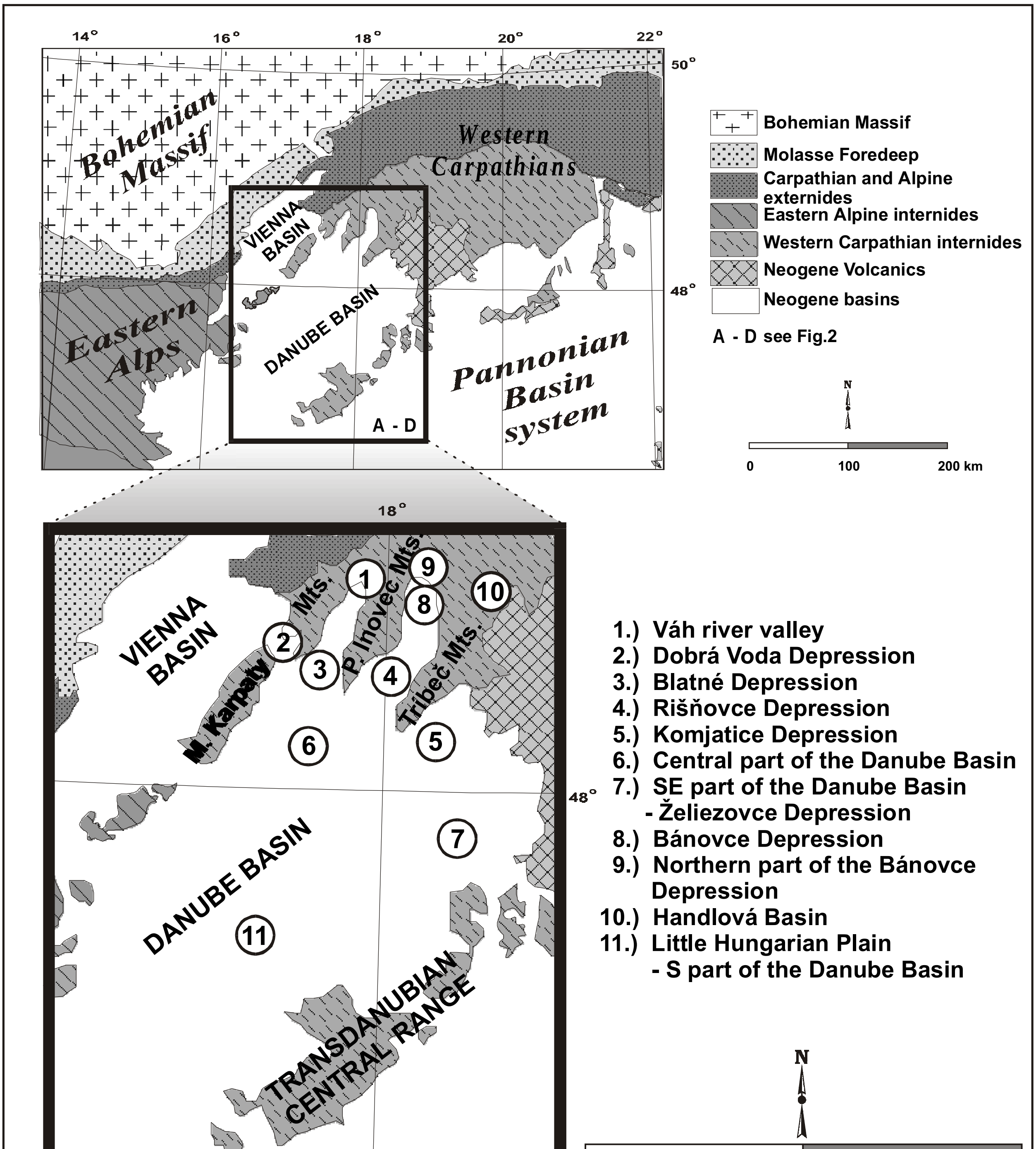


Fig. 1. Geological position of the Danube Basin.

front of the plate (Fig. 2A). Before opening of the present Danube Basin, the dextral shears and reverse faults in compressive tectonic regime formed wrench fault furrow type basins at the eastern margin of the Northern Calcareous Alps, in the marginal part of the Central Western Carpathians and in the Transdanubian Central Range (Kováč et al. 1989a,b, 1997; Marko et al. 1991, 1995; Fodor et al. 1992). The northern part of the area (Váh river valley, Bánovce Depression) was flooded by the sea transgrading from the Alpine and Carpathian Foredeep during the Eggenburgian (Rögl & Steininger 1983), while the southern part of the Danube Basin was an uplifted dryland.

Eggenburgian littoral conglomerates and sandstones deposited in a relatively shallow sea are preserved on the surface in the Dobrá Voda Depression, Váh river valley and Bánovce Depression (Gašparík 1969). Their material was derived mainly from the Mesozoic rocks of the Northern Calcareous Alps and Central Western Carpathians (Baráth 1993). The Tatric crystalline complexes of the Alpine-Carpathian-Pannonian junction were still buried, as is suggested by fission-track data, heavy mineral associations and pebble analyses (Kováč et al. 1994; Uher & Kováč 1993; Baráth & Kováč 1989; Brestenská 1980; Seneš 1959). The basal clastic sequence passes upward into a pelitic, schlier type sequence.

The Eggenburgian in the northern margin of the Danube Basin and adjacent areas is defined biostratigraphically by occurrence of the calcareous nannoplankton species *Discoaster druggii* and *Helicosphaera ampliaperta* (Lehotayová 1977, 1984; Šutovská in Kováč et al.1991b). The first occurrences of both forms characterize the NN 2 Zone (sensu Martini 1971), a time interval aproximatelly from 21 to 19 Ma (Berggren et al. 1995; Fornaciari & Rio 1996). In local Central Paratethys stratigraphy (Cícha et al. 1983a,b) occurrence of *Uvigerina posthantkeni* Papp indicates the Eggenburgian age for example in sediments of the Váh river valley (Salaj & Zlinská 1991).

According to foraminiferal assemblages of the Eggenburgian (dominating taxa are mentioned on Fig. 3) the deepest paleoenvironment took place in the Vienna Basin (Cícha 1957; Kováč & Hudáčková 1997) and in the Bánovce Depression, in an upper bathyal facies (Brestenská 1975, 1977). A neritic environment prevailed in the basin of the Váh river valley (Cícha & Brestenská in Steininger & Seneš 1971), where the deepest assemblages from lower neritic to upper bathyal zone were described by Salaj & Zlinská (1991). The Handlová and Horná Nitra Depressions represent a marginal part of the Eggenburgian sea with an upper neritic, partly hyposaline environment (Gašparíková 1972).

Sediments in the Váh river valley contain only calcareous nannoplankton assemblages with *Discoaster druggii, Helicosphaera scissura, Reticulofenestra pseudoumbilica* and can refer to the lower part of the NN 2 Zone (Šutovská et al. 1993; Zlinská 1993b, 1995). However, the presence of *Chlamys gigas* in the mollusc assemblages points to the upper part of this zone and refers to the Eggenburgian transgression. The Eggenburgian schlier sediments in all of these basins, with their highly diversified, relatively deep-water faunas can be interpreted as highstand deposits. Therefore, we correlate this sea level rise with the TB 2.1 cycle of global sea level change (sensu Haq 1991) which continued into the Ottnangian (Fig. 4) and is well documented in the Vienna Basin (Kováč & Hudáčková 1997), in the Dobrá Voda Depression and in the Bánovce Depression.

Ottnangian

Remnants of marine Ottnangian sediments on the eastern flank of the Transdanubian Central Range (Várpalota Basin, Kókay 1971) were regarded as relicts of a new marine seaway from the Mediterranean via the "trans-Tethyan-Dinaride corridor" (Rögl & Steininger 1983), but we cannot exclude still existing marine connection with the Alpine foredeep. In this case, sediments deposited during the Early Ottnangian occurring only as remants in the NE part of the Vienna Basin, near to Senica, where bryozoa-rich deposits of the NN 3 Zone similar to deposits in the Transdanubian Central Range were found (Zágoršek et al. in press) and represent the deposits of the same sedimentary basin.

The Ottnangian marine ingressions in the NN 3 nannoplankton zone also reached the area of the Novohrad (Nógrad) Basin in the South Slovakia. The ingressions with the same depocentres as in the Late Eggenburgian can be characterized by upper to lower neritic foraminiferal assemblages (Figs. 3, 4) and occurrence of nannoplankton species *Sphenolithus belemnos* (Vass et al. 1987; Šutovská 1993). This marine event can be regarded as a maximum flooding in the Eggenburgian-Ottnangian sedimentary cycle.

In the Vienna Basin, Dobrá Voda, Blatné as well as in the Bánovce depressions the sedimentation continued in partly isolated basins, as is documented by the anoxic sandy, clayey Planinka Formation (Kováč et al. 1991b; Kováč et al. 1992) and anoxic and brackish aleuropelitic sequence in the Bánovce Depression (Brestenská 1975, 1977, 1980; Milička et al. 1994). Occurrence of fish remains and thecamoebs characterizes these deposits. The age of both formations (NN 3 Zone, sensu Martini 1971) is well-documented by the occurrence of the calcareous nannoplankton species *Sphenolithus belemnos* (Lehotayová 1977; Šutovská in Kováč et al. 1991b) and represents starved highstand and falling stage conditions.

The Late Ottnangian compression in the front of the Alps caused gradual desintegration of the western marine seaway. In the southernmost part of the Vienna Basin brackish and also terrestrial Ottnangian deposits occur along the south-eastern flanks of the Eastern Alps, where gradual extension initiated the subsidence (present Sopron Mts.). The coal-bearing Brennberg Formation was deposited in the Landsee Gulf on the western margin of the basin (Fülöp 1983; Ebner & Sachsenhofer 1991; Pereszlényi et al. 1993).

The above mentioned facts make it possible to correlate the marine Ottnangian sediments with the falling stage of the cycle TB 2.1 of global sea-level changes (Haq 1991) and the latter lowstand period of the cycle TB 2.2 (Haq 1991), which led to shallowing of the basin. The low oxic environment in addition to the relative sea-level fall may reflect humid climatic conditions.

Karpatian

The Karpatian change of the structural pattern and paleogeography (Fig. 2B) was accompanied by displacement and tectonic subsidence along NE–SW oriented sinistral strike-slip faults, which opened the present Vienna Basin and Blatné Depression in the NE part of the Danube Basin (Kováč et al. 1993b, 1997a).

A transtensional tectonic regime widened the Blatné Depression southwards. The principal source of clastic material of the Karpatian basal conglomerates (Biela 1978) and Jablonica deltaic gravels were the Mesozoic rocks of the Northern Calcareous Alps and Central Western Carpathian

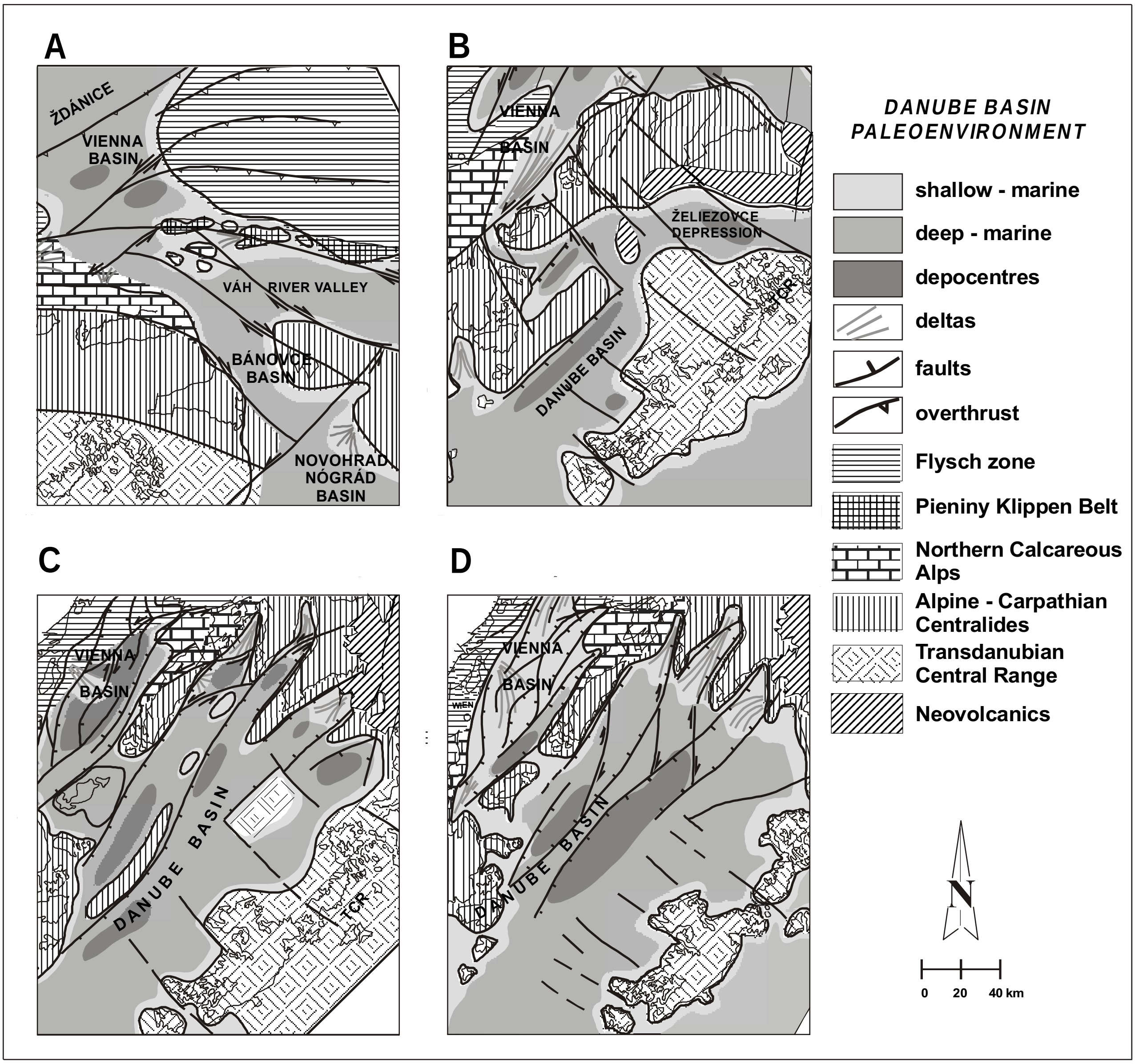


Fig. 2. Paleogeography and palinspastic reconstruction of the Danube Basin development during the Neogene. A — Eggenburgian, B — Karpatian–Early Badenian, C — Late Badenian–Sarmatian, D — Pannonian.

nappes. At the same time, the unroofed Central Carpathian crystalline complexes also started to be eroded (Kováč 1986; Mišík 1986; Uher & Kováč 1993).

As a consequence of the Eastern Alps uplift and initial rifting on the western margin of the Danube Basin coarse clastic fans appeared in the Hungarian Sopron area, in the Austrian Landsee Gulf and Styrian Basin margins. They are represented by the alluvial Ligeterdö or Auwald gravels in the Landsee–Sopron area (Tollmann 1985; Fülöp et al. 1983), while in the Styrian Basin the deltaic and coal-bearing limnic Upper Eibiswald Member as well as the fluviatile Sinnersdorf conglomerates were deposited (Kollmann 1965; Ebner & Sachsenhofer 1991).

Further to the east–southeast, in the Hungarian part of the Danube Basin non-marine clastic depocenters appear during the pre-Badenian period. Two branches of depocenters can be traced. One along a NNE-SSW strike, parallel to the Mihályi Ridge (Nemeskolta, Csapod), another along a NE-SW strike, parallel to the Rába lineament (Ikervár, Celldömölk, Vaszar). A further major terrestrial depocenter can be traced by seismic measurements below the Badenian deposits in the central part of the Danube Basin, along NE-SW strike, from Mosonszolnok to Šurany (Hrušecký et al. 1996). The sediment thicknesses in these little subbasins rarely exceed 400 metres, but exceptionally in its northern branch can reach a thickness of 1000 metres.

This initial point of the subsidence in the Hungarian part of the Danube Basin is not well determined. While some authors suggest a full-marine sedimentation during the Karpatian (Hámor 1988), others (Körössy 1987; Nagymarosy in

Kováč et al. 1997a) described only terrestrial deposits beneath the marine Badenian. Unpublished micropaleontological data of Nagymarosy and Horváth show, that no marine microfossils older than Badenian occur beneath the Hungarian part of the Danube Basin.

Between the Ottnangian and Karpatian in the Vienna Basin (Kováč & Hudáčková 1997), Dobrá Voda and Bánovce depressions the anoxic environment changed rapidly to a well aerated one. The Karpatian transgression is marked here by a shallow-water hyposaline environment characterized by *Ammonia–Porosononion* assemblages (Kováč et al. 1991a; Brestenská 1977). This horizon may be correlated with the Medokýš Mb. (earlier name Rzehakia or Oncophora Beds) in the Novohrad (Nógrád) Basin in South Slovakia, which also contains *Ammonia* and *Porosononion* in indigenous assemblages (Holcová 1996). The "Oncophora Beds" can be correlated generally with the Late Ottnangian (Papp et al. 1973), but the coexistence of *Rzehakia socialis-* and *Uvigerina graciliformis*-marker of the Karpatian time-interval in the Central Paratethys is a specific feature of the Medokýš Mb. (Cícha et al. 1983). The common occurrence of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* in calcareous nannoplankton assemblages indicates the time interval 18.3–16.4 Ma (Berggren et al. 1995). The Medokýš—"Oncophora Beds" thus represent transgressive depositional system of the cycle TB 2.2 (sensu Haq 1991).

The statistical evaluation of the Karpatian foraminiferal assemblages (Šutovská et al. 1993) points to marine connection between the Outer Western Carpathian basins and Inner Carpathian basins (Kováč et al. 1993a) during the migration of *Uvigerina graciliformis* within the NN 4 nannoplankton zone (sensu Martini 1971). This form occurs in the Várpalota Basin (Transdanubian Central Range), Styrian Basin, Slovenia and represents evidence of a marine seaway via trans-Tethyan-Dinaride corridor (Rögl & Steininger 1983).

The continuing subsidence of the Western Carpathian basins led to the evolution of a deep water environment during the Early Karpatian. In the Novohrad (Nógrád) Basin, the deepest upper bathyal assemblages have been found in the Strháre-Trenč graben (Zlinská & Šutovská 1990). The Karpatian deposits with the upper bathyal assemblages overlie the deepest Eggenburgian ones. Therefore, no shift of the basin depocentre from Eggenburgian to Karpatian is suspected.

Similarly, deep water-bathyal environment was documented in the Bánovce Depression and Vienna Basin belonging to the same water circulation system in this time (Brzobohatý 1987; Brestenská 1980; Kováč et al. 1993a; Kováč & Hudáčková 1997). In the northern part of the Bánovce Depression assemblages with rotalids dominate (Fig. 3), where Karpatian sediments overlie the Ottnangian ones. Lower neritic agglutinated assemblages dominate in the southern part of the Bánovce Depression, where the Karpatian sediments are transgress on the pre-Neogene basement. The Karpatian fill of the Blatné Depression is also represented mostly by lower neritic sediments. Most of the assemblages contain a large amount of reworked Cretaceous and Paleogene foraminifers.

It is supposed that the Karpatian foraminiferal assemblages with agglutinated taxa indicate similar paleoecological conditions to the Eggenburgian *Cyclammina–Bathysiphon* assemblages of the Vienna Basin (Kováč & Hudáčková 1997). According the data from the recent seas (Murray 1991), ecological interpretation of these assemblages is not fully clear: cold, well-aerated condition may be expected probably caused by transgression and highstand. Coexistence of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* and the absence of *Praeorbulina* in the time interval 18.3–16.4 Ma, sensu Berggren et al. (1995), enables us to correlate Karpatian transgression with the global sea-level rise in the cycle TB 2.2 (Haq 1991). Foraminiferal assemblages in all basins (with schlier sediments) record accelerated deepening and represent transgressive to highstand depositional systems.

The upper part of the Karpatian strata are missing because the analysed sections in both the Danube and Novohrad (Nógrád) basins do not include the "transgressive phase" with *Globigerinoides sicanus (=bisphericus)* typical of the Carpathian foredeep during the Late Karpatian (Rögl 1986; Cícha 1995; Andreyeva-Grigorovich et al. 1997). The same horizon was also not found in the Vienna Basin (Kováč & Hudáčková 1997), but it is present in the East Slovak Basin in pelites overlying the Karpatian salt deposits (Kováč & Zlinská 1998). The above mentioned facts refer to erosion or a hiatus during the Late Karpatian and the lowermost Badenian (see below) in the Vienna, Danube and Novohrad (Nógrad) basins during the TB 2.3 cycle (Haq 1991).

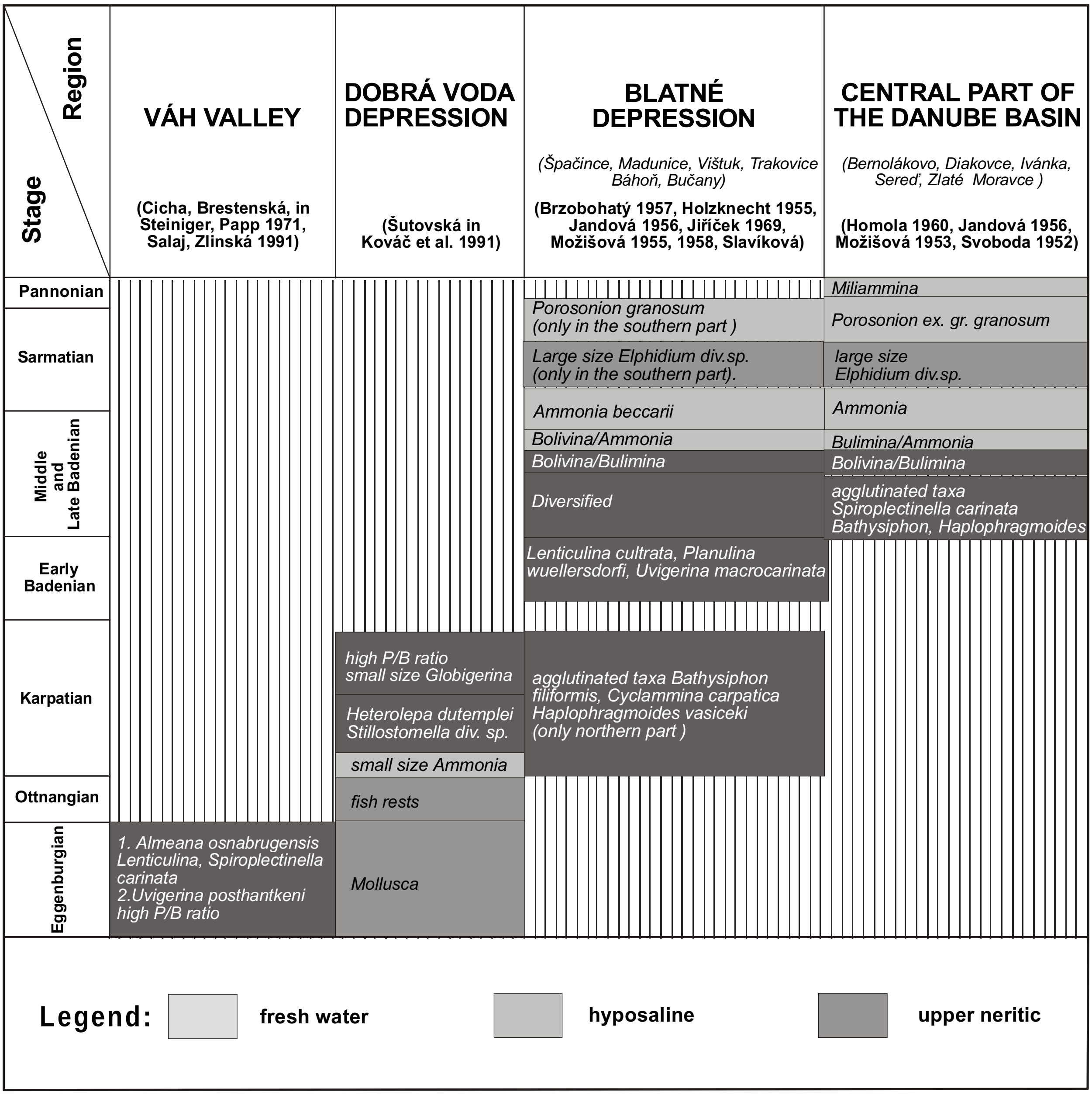
Early Badenian

The Early Badenian paleogeographical situation reflects the Karpatian structural event (Fig. 2B). The steepening of relief on the Danube Basin's western margin was connected with the uplift of the Central Alpine and Central Carpathian units along the western part of the Pericarpathian lineament (Leitha wrench zone). The Leitha Mts. and Malé Karpaty Mts. became part of an uplifted horst structure in the East Alpine–Western Carpathian transition zone, partly disintegrated by NW-SE dextral strike-slips and N-S normal faults (Marko & Uher 1992).

The Early Badenian (or Karpatian?) synrift extension in the northern part of the Danube Basin was accompanied by volcanic activity (Gnojek & Heinz 1993). The belt of buried volcanic bodies extends from the Styrian Basin along the Rába lineament up to the Central Slovak Volcanic area (Lexa et al. 1993).

In the Danube Basin, the oldest Badenian marine faunas and biozones are not present (upper part of NN 4, Lower Lagenid Zone, Praeorbulina glomerosa Horizon), that is the first marine beds belong to the Upper Lagenid Zone (Grill 1941) with orbulinas, that is to the younger part of the Early Badenian. This means, that not only the pre-Badenian (Karpatian?), but also the earliest Badenian deposits are missing or are of non-marine origin in the central part of the basin.

The non-marine pre-Badenian (Hungarian part of the Danube Basin) can be characterized by red beds, coarse conglomerates indicating an anchi-metamorphic crystalline source area. The occurrences are arranged into two zones,



▲▶

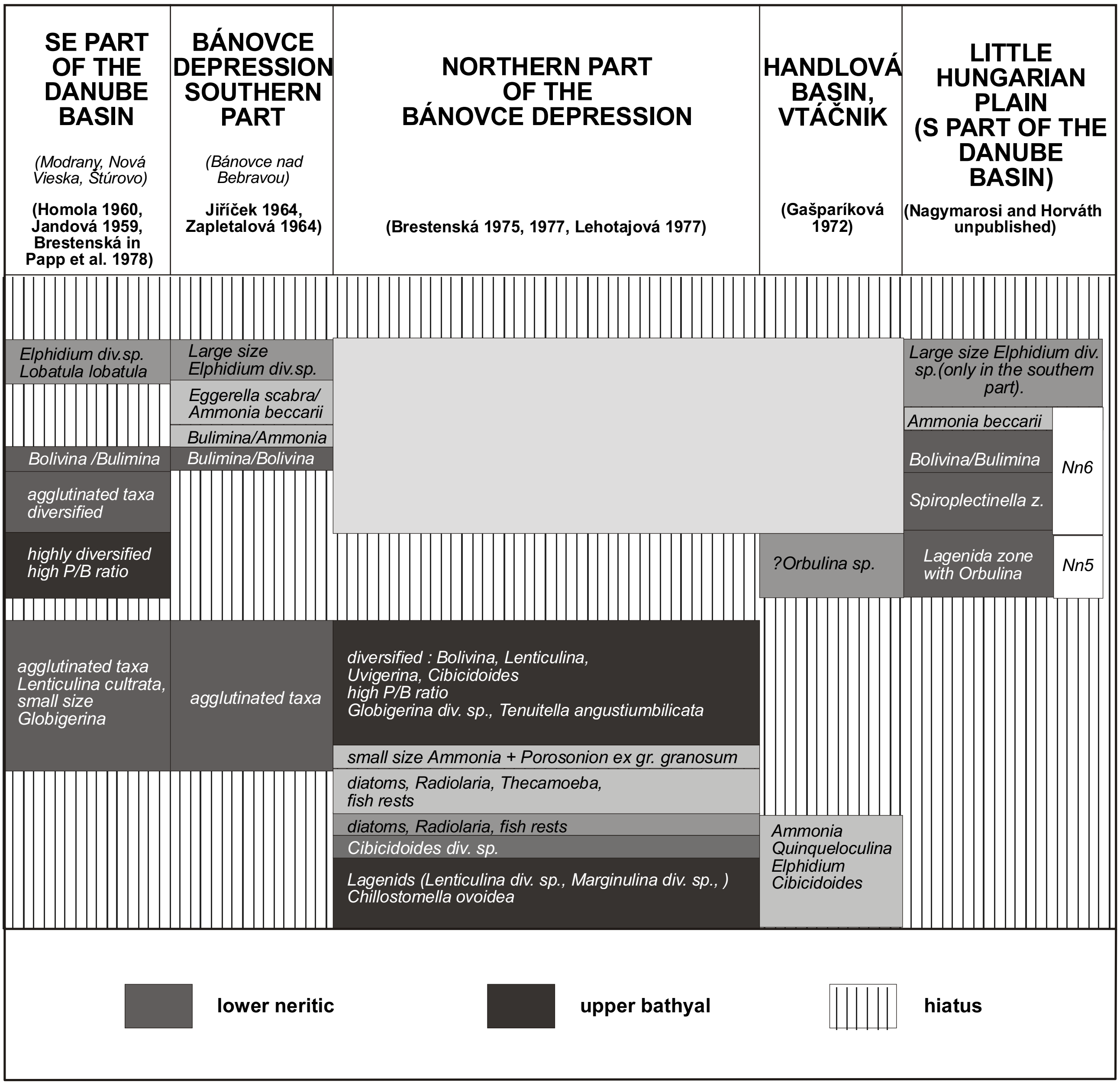
Fig. 3. Species dominating in foraminiferal assemblages and their paleoecological interpretations in the Danube Basin.

similarly to the older Karpatian ones: one near to the northern periphery of the Transdanubian Central Range, south of the Rába lineament, and the other north of the Répce lineament (Kováč et al. 1997a).

In the Danube Basin's northern part, the late Early Badenian marine paleoenvironment was documented only in western and eastern margin of the Blatné Depression, where the Ratkovce littoral sands, gravels and sandy clays deposited (Fig. 2).

From the late Early Badenian on, the subsidence of the southern and central part of the Danube Basin accelerated and the Badenian sea invaded a huge area, from the Bakony Mts. to the elevated crystalline ridge at the Sopron Mts. The Mihályi Ridge and its uplifted adjacent parts might have formed a row of cliffs or a minor archipelago. The basin margins, at the northern flanks of the Bakony Mts. can be characterized either by algal limestone or by coarse-clastic sedimentation.

The late Early Badenian sedimentary and volcanoclastic sequence of the Želiezovce Depression situated in front of the Transdanubian Central Range, might have been deposited on a circalittoral open shelf plain (Seneš & Ondrejičková 1991). The basin form, as well as the rapid tectonic subsidence (Vass et al. 1993), proved by the results of foreward modelling (Lankreijer et al. 1995), suggest the activity of the NW–SE oriented dextral and normal faults (Fig. 2).



Continuation of Fig. 3.

The Early Badenian littoral sediments of the Styrian and Eisenstadt basins, situated towards the west, belong to former shallow sea embayments with algal and coral reef system (Kollmann 1965; Tollmann 1955). In the intrabasinal parts siltstone and shale deposited (Körössy 1987).

In the Danube Basin, foraminiferal assemblages with *Praeorbulina* occur only together with *Orbulina* (Fig. 3) in the Želiezovce Depression (Zlinská 1992a; Zlinská et al. 1997). The assemblages indicate lower neritic to upper bathyal paleoenvironments (Jandová 1959a,b). Reworked Early Badenian foraminifers were also determined in the southern part of the Bánovce Depression (Brestenská & Lehotayová in Papp et al.1978). Occurrence of the Early Badenian sediments with *Orbulina* sp. was also described from the Nováky Basin by Gašparíková (personal communication), but the sediments may be younger than the Early Badenian.

The late Early Badenian fill of the Želiezovce Depression, containing well diversified foraminiferal assemblages with high P/B ratio refer to the re-opening of the seaway (during the migration of *Orbulina*) via trans-Tethyan-Dinaride corridor (Rögl & Steininger 1983).

On the basis of the age of FAD of *Praeorbulina* (16.4–16.5 Ma) and *Orbulina* (15.1 Ma) in the Mediterranean and Central Paratethys (Berggren et al. 1995; Fornaciari & Rio 1996), only sediments with *Praeorbulina* can be clearly cor-

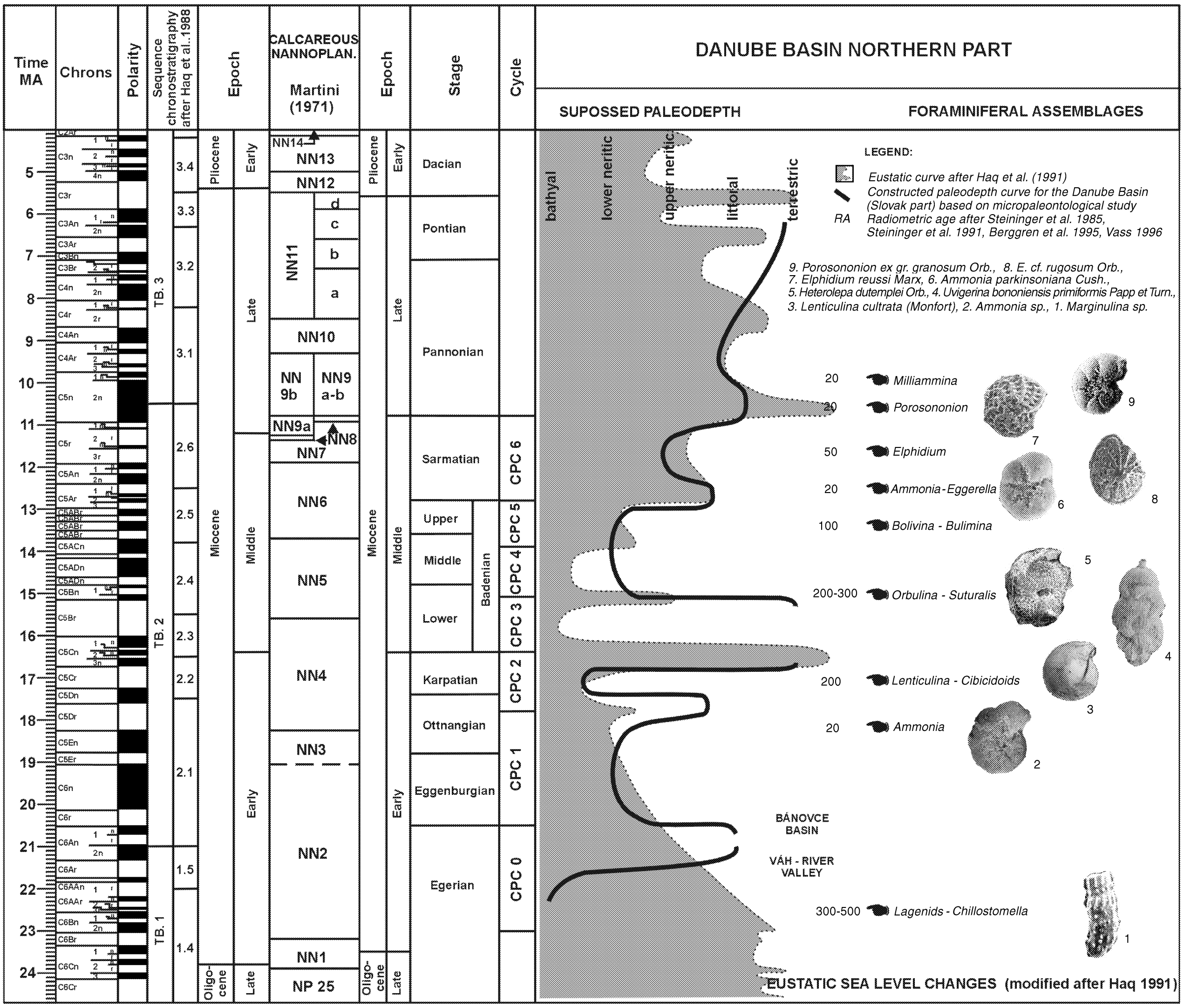


Fig. 4. Comparison of global sea-level changes (after Haq 1991) with paleodepth changes (dark curve), interpreted for the Slovak part of the Danube Basin. Interruption of the curve represents erosion periods and the absence of the given sediments.

related with the transgression of the cycle TB 2.3 of global sea-level changes (sensu Haq 1991). Due to the absence or very rare occurrence of *Praeorbulina* in the Danube Basin and surrounding areas, in the biostratigraphical recognition of the Early Badenian deposits, occurrences of *Orbulina* or *Uvigerina macrocarinata* as well as some ecostratigraphical criteria were often used (Jiříček 1969; Cícha et al. 1983b; Homola 1960; Jandová 1959a,b). Although *Orbulina* refers already to the transgression of the TB 2.4 cycle (sensu Haq 1991).

Middle–Late Badenian

The Middle and Late Badenian development of the Danube Basin (Fig. 2C) was characterized by a wide synrift subsidence controlled by whole lithospheric extension (Kováč et al. 1993b, 1997; Lankreijer et al. 1995; Lankreijer 1996). In the northern part of the basin embayments of the Blatné, Rišňovce and Komjatice depressions subsided or opened, controlled mainly by activity of the NE–SW oriented normal faults at this time (Kováč et al. 1993b, 1997a,b; Keith et al. 1995).

The Middle Badenian subsidence in the Blatné Depression was followed by accumulation of huge talus cones of conglomerates and breccias in the western and eastern part of the depression (Baráth 1993). The Doľany conglomerates consist mostly of crystalline clastic material and were deposited in alluvial to fluvial environments (Kováč et al. 1991). The subsiding central part of the depression was filled up mainly by the pelitic Špačince Fm. passing northwards into deltaic brackish Madunice sands deposited during the Late Badenian (Vass et al. 1990; Jiříček 1990).

The subsidence of eastward situated grabens of the Rišňovce and Komjatice depressions was followed by deposition of sandy-clayey marine strata of the Pozba Formation. The Middle to Late Badenian infill of the Komjatice Depression contains frequent tuffaceous admixture, tuffs, sandstones and algal limestones, similar to the fill of the Želiezovce Depression (Vass et al. 1988, 1990; Nagy 1998).

The subsidence of the central part of the Danube Basin also reflects the NE-SW to NNE-SSW oriented fault systems (Gaža 1984; Pěničková & Dvořáková 1985). Southwards, the activization of low-angle listric faults in extensional tectonic regime led to widespread synrift subsidence (Tari et al. 1992; Horváth 1993). The whole Transdanubian Central Range Mesozoic nappe system moved back from above the Lower and Middle Austroalpine nappes, along a set of minor displacement zones parallel to the Rába lineament (rejuvenated former compressional thrust plains), thus causing basin widening.

The Middle to Late Badenian paleogeography shows the same features as in the Early Badenian (Fig. 2C). However, some trends of filling up of the basin can be observed at the end of the Badenian epoch, such as the frequent occurrence of sandstone bodies interfingering into pelagic siltstones, or the formation of two belts of algal (rarely reef) limestone patches along the margins of the basin (Friebe 1990). The volcanoclastics of trachytic alkaline volcanism in the Pásztori region (central part of the basin) also played an important role in filling up the basin, from the Late Badenian until the Early Pannonian. Maximum sediment thicknesses of up to 400 to 500 metres can be observed in the Szigetköz area, near to the Hungarian-Slovak border, and in the Nemeskolta and Csapod subbbasins.

Microbiostratigraphy of the Middle to Late Badenian in the Danube Basin is based either on calcareous nannofossils, or on the ecostratigraphical principles using Grill biozones (Grill 1941; Jandová 1955, 1956, 1959a,b; Homola & Slavíková 1955; Cícha 1958; Homola 1960a,b; Zapletalová & Jiříček 1964; Jiříček 1969). The good applicability of ecostratigraphy reflected stable paleoenvironmental conditions in whole Central Paratethys during this time.

The Middle Badenian Spiroplectammina (Spiroplectinella) carinata Biozone (Grill 1941; Zlinská & Čtyroká 1993; Zlinská 1996a) corresponds to the top part of the nannoplankton zone NN 5 and lower part of the NN 6 (sensu Martini 1971) and is overlain by the Late Badenian Bolivina-Bulimina Biozone (Grill 1941) corresponding to the upper part of NN 6 and maybe to the basal part of NN 7. The sediments of Bolivina-Bulimina Biozone (Grill 1941) reflect stratification of water masses in the Danube Basin and are regarded as highstand deposits partly correlated to cycle TB 2.5 (sensu Haq 1991). The highstand system is characterized by low-oxic environment similar to the Eggenburgian higstand depositional system of the TB 2.1 cycle in the Danube Basin's northern part.

Between the Early and Middle Badenian moderate shallowing was interpreted for the SE part of the Danube Basin (Homola & Slavíková 1955; Zlinská 1993). Therefore, two cycles of sea-level changes of the 4th-order may be interpreted: the lower for the uppermost part of the Early Badenian to early Middle Badenian; the upper cycle for the late Middle Badenian.

The Middle–Late Badenian sedimentation in the Danube Basin mostly finishes with deposition of hyposaline strata with *Ammonia*. These assemblages developed gradually from the assemblages of the Bolivina-Bulimina Zone. In the Bánovce Depression, instead of *Ammonia*, *Eggerella* dominates in hyposaline assemblages (Zapletalová & Jiříček 1964).

The *Ammonia* rich strata containing reworked species from the underlying Late Badenian sediments of the Bulimina-Bolivina Zone also appear at the base of the Sarmatian in all the Western Carpathian intramountane basins (Zlinská & Fordinál 1992; Zlinská 1992b, 1997, 1998a; Hudáčková 1995; Kováč & Hudáčková 1997; Kováč & Zlinská 1998) and therefore may represent lowstand depositional systems of cycle TB 2.6 (Haq 1991).

Sarmatian

The brackish character of the Sarmatian sea was a consequence of disintegration and closing of the Badenian seaways toward the Mediterranean and Indopacific ocean (Rögl & Steininger 1983). The Sarmatian sea might have been shallow, reaching upper neritic depth as maximum (Fig. 4).

In the southern and part of the central part of the Danube Basin (Little Hungarian Plain) narrow belt of brackish fish-scale bearing shale, *Elphidium*- and *Nonion*-bearing schlier represent the Sarmatian sedimentation. At the basin margins sandy limestones and coarse clastics was deposited. The Sarmatian deposits show a less areal distribution here than the Badenian ones. The sporadic distribution and extremely small thickness of the Sarmatian strata refers to basin inversion in its southern part and as a consequence of this, to selective erosion during the Late Sarmatian. Due to this erosional period, the thickness of Sarmatian deposits rarely exceeds 200 metres.

Although it is not visible on seismic sections, a minor sedimentary gap needs to be supposed between the Badenian and Pannonian deposits in the bulk of the area. Not postulating an uplift and sub-aeric erosion one may suggest a slight submarine uplift and erosional effect combined with a low rate of deposition, since no clear evidence of sub-aeric erosion exists.

In opposite to the central and southern parts of the basins, an accelerated synrift subsidence characterized the evolution of the subbasins, situated above the external zone of the back-arc asthenosphere updoming (Kováč et al. 1997b). The subsidence in partial depocentres (Rišňovce Depression) in the northern margin of the Danube Basin reflected the active elongation of the Western Carpathians due to a subduction roll-back effect in front of the Eastern Carpathians (Vass et al. 1990; Royden 1993; Lexa et al. 1993, 1995; Csontos & Horváth 1995). The paleostress field with a NE–SW oriented axis of the principal compression activized NE-SW to NNE-SSW normal faults and the WSW–ENE oriented sinistral strike slips allowing accelerated subsidence in the northern embayments of the basin (Hók et al. 1995), where mostly pelitic to sandy sedimentary sequences were deposited during the TB 2.6 cycle of global sea level changes (Haq 1991).

Microbiostratigraphy of the Sarmatian period is based on the ecostratigraphic principles using Grill biozones (Grill 1941). As in the Badenian, good applicability of ecostratigraphy reflected stable paleoenvironmental conditions in all the

Western Carpathian intramountane basins during this time (Zlinská 1993a; Fordinál & Zlinská 1994; Zlinská & Fordinál 1995; Hudáčková & Kováč 1993; Kováč & Hudáčková 1997).

The Early Sarmatian sediments contain large-size *Elphidium* div. sp., and sometimes *Lobatula lobatula* (transgressive tract of TB. 2.6 cycle). The Middle Sarmatian is characterized by the dominance of *Elphidium hauerinum* and the Late Sarmatian deposits are characterized by *Porosononion granosum* (highstand of TB 2.6. cycle). Sarmatian can be well interpreted as one cycle of sea-level change, with a maximum paleodepth of 20–50 m. The shallowing of the marine basin was connected with a further decrease of salinity in the Late Sarmatian.

Pannonian–Pontian

During the Late Miocene a rapid subsidence took place only in the axial part of the Danube Basin, represented by Komjatice and Gabčíkovo depressions (Fig. 2D). The sedimentation might have been connected with a second phase of rifting and following thermal postrift subsidence of the back-arc area, without a significant role for fault activity (Horváth et al. 1986; Tari et al. 1992; Horváth 1993; Hrušecký et al. 1993; Lankreijer et al. 1995; Lankreijer 1998).

During the Pannonian and Pontian (10.5–7.1 Ma), brackish to lacustrine water masses invaded all previously emerged areas in the central and southern part of the Danube Basin, including the previously uplifted Mihályi Ridge. Some considerations show, that most of the Transdanubian Central Range was probably flooded by the Pannonian lake. In the central part of the brackish basin (Gabčíkovo Depression) an alternating clayey sandy sedimentation continued, reaching a maximum thickness of 4000–5000 metres (Buday et al. 1962; Körössy 1987). It was filled up by sediments transported by the rivers from the northern and northeastern periphery.

The sedimentation in the extensional grabens at the northern margin (Slovakia) of the Danube Basin was influenced by deltaic environment, forming marshes in the Blatné Depression, a limnic estuaryum in the Rišňovce Depression and a delta-influenced embayment in the Komjatice Depression (Jiříček 1990). Brackish sediments contain practically monospecific *Miliammina* assemblages. The water depth did not exceed 20 m (Fig. 4).

On the western edge of the Danube Basin (Sopron Mts.) Gilbert-type deltas developed, gradually filling up the deep basin depocentres with coarse clastic sediments. Seismic sections prove that the paleodepth in the basin centre (Hungary) might exceed several hundred metres. Due to basin isolation, only a very poor correlation with global sea level changes can be presented: the lowstand depositional system and transgressive depositional systems of the TB 3 cycle (Haq 1991) can be supposed at the base of the Pannonian, Zone A–B of Papp (1951; Papp & Steininger 1979); highstand depositional system may represent the Pannonian Zone E (Papp 1951). By the beginning of the Pontian most of the Danube Basin had been filled up by sediments.

Near to the boundary of the Late Miocene and Early Pliocene, a rapid inversion took place in almost the whole Alpine-Carpathian-Pannonian junction area, except the Pliocene Gabčíkovo and Komjatice depressions (Adam & Dlabač 1969; Gaža 1984; Baráth & Kováč 1995). In this time large accumulations of fluviatile and limnic gravels originated due to differences in the vertical movements of the Western Carpathian orogene belt.

Conclusions

Danube Basin represents a polyhistoric basin, with its Neogene fill deposited in various depocentres, differing in origin and paleoenvironment. The basin development and subsidence was strongly influenced by local tectonics but also by relative and global sea-level changes (Haq 1991).

The Late Eggenburgian transgression can be observed in the northern periphery of the basin, where a shallow water, high-energy environment is passing to a deep water environment. It can be correlated with the global sea-level rise during the **TB 2.1 cycle** of global sea level changes (sensu Haq 1991)**.** The maximum paleodepth can be estimated as lower neritic to upper bathyal zone. Highstand conditions also document the Early Ottnangian marine flooding of the area from the Alpine foredeep, through the Transdanubian Central Range to the Novohrad (Nógrád) Basin in South Slovakia and North Hungary (the present Danube Basin was practically not present, because it opened during the Early Badenian).

The Late Ottnangian sea-level fall is documented by gradual shallowing and isolation of the basins which caused an anoxic and partly brackish environment. The Ottnangian lowstand deposition was followed by the Late Ottnangian–Early Karpatian global sea-level rise during the **TB 2.2 cycle** (sensu Haq 1991). The development of a deep water, high-energy paleoenvironment was a result of sea-level rise and tectonically controlled subsidence in the Blatné Depression of the Danube Basin. The paleodepth has been estimated as neritic to shallow bathyal zone here.

The absence of the Late Karpatian and Early Badenian marine strata in most of the Danube Basin territory, as well as the angular unconformity betwen the Karpatian and Badenian strata in the northern part of the basin (Blatné Depression) led us to postulate, that the deposits corresponding to the **TB 2.3 cycle** (sensu Haq 1991) are partly missing and its sediments of the falling stage are present only in restricted areas (e.g. Jablonica Conglomerates).

The late Early Badenian transgressive deposits corresponding to the **TB 2.4 cycle** rest directly on the Karpatian highstand deposits of the TB 2.2. cycle (Haq 1991) or on the pre-Neogene basement of the basin. Relative sea level rise during the Middle Badenian Spiroplectammina Biozone (Grill 1941) can be correlated with the transgression and maximum flooding surface of the TB 2.4 cycle of global sea-level changes (Haq 1991). The sedimentary environment can be characterized by maximum paleodepth of neritic zone.

The Late Badenian highstand and falling stage during the Bulimina-Bolivina Biozone (Grill 1941) can be correlated with the **TB 2.5 cycle** (SB type 2) and shows deep neritic, low oxic conditions with stratified water column pronounced in the whole Danube Basin. The following *Ammonia* rich beds reflect partial isolation and slightly brackish conditions.

The nest cycle of relative sea level change started at the Badenian-Sarmatian boundary and is characterized by a hyposaline paleoevironment. The Sarmatian strata show a coastal onlap northwards, with a shallowing upward trend and can be correlated partly with the **TB 2.6. cycle** of global sea-level change (Haq 1991). The paleodepth did not exceed the neritic zone.

The Pannonian isolation of the Danube Basin led to the development of a brackish to lacustrine lake system. The global sea level changes of the **TB 3 cycle** (Haq 1991) cannot be correlated properly with the local water level oscillations.

Acknowledgements: The authors express their gratitude to the Grant 12172/97 and 407697 of the Slovak Academy of Sciences and to the Institutional Project of the Department of Geology and Paleontology of Comenius University, Bratislava, as well as to the Grant 266/96/B-Geo of Charles University Prague and OTKA T-017009 of the Hungarian goverment for the financial support in the preparation of this paper.

References

Adam Z. & Dlabač M., 1969: Erklärungen zur Mächtigkeitskarte und zur lithofaziellen Entwicklung der Donau-Niederung. *Západ. Karpaty, ZK,* 11, 156–171.

Andreyeva-Grigorovich A.S., Kulchytsky Y.O., Gruzman A.D., Lozonyak P.Y., Petrashkevich M.I., Portnyagina L.O., Ivanina A.V., Smirnov S.E., Trofimovich N.A. & Savitskaya N.A. et al., 1997: Regional stratigraphic scheme of Neogene formations of the Central Paratethys of Ukraine. *Geol. Carpathica*, 48, 2, 123–136.

Balla Z., 1995: Basement tectonics of the Danube Lowlands. *Geol. Carpathica*, 45, 5, 271–281.

Baráth I. & Kováč M., 1989: Sedimentation conditions and source areas of the Eggenburgian clastics in the western part of the Western Carpathians. *Knihovnička ZPN*, 9, *Misc. Micropalaent.,* IV, 55–86 (in Slovak).

Baráth I. & Kováč M., 1995: Sedimentology and paleogeography of the Pliocene Hron river delta in the Komjatice depression (Danube Basin). *Miner. slovaca,* 27, 4, 236–242.

Baráth I., 1993: Sedimentary conditions and source areas of Lower and Middle Miocene coarse clastics in the Alpine-Carpathian junction zone. *Manuscript, Geofond,* Bratislava (in Slovak).

Berggren W.A., Kent D.V., Swisher III. C.C. & Aubry M.P.A., 1995: Revised Cenozoic geochronology and chronostratigraphy. In: Berggren W.A., Kent D.V. & Hardenbol J. (Eds.): Geochronology, Time scale and Global stratigraphic correlations: A unified temporal framework for an historical geology. *Soc. Econ. Paleontol. Miner., Spec. Publ.*, 54, 129–212.

Biela A., 1978: Deep drillings in the Western Carpathian basins. *Reg. Geol.,* 10, 224.

Brestenská E., 1975: Microbiostratigraphy of sediments of the DB-15 borehole, Horňany, Bánovce basin. *Manuscript, Geofond,* Bratislava (in Slovak).

Brestenská E., 1977: Microbiostratigraphy of the Miocene of the Bánovce basin. *Manuscript, Geofond,* Bratislava (in Slovak).

Brestenská E., 1980: Geological map and explanatory notes to region of the Bánovská kotlina Basin 1:50,000. *Manuscript, Geofond*, Bratislava (in Slovak).

Brzobohatý R., 1987: Comments on the Palaeogeography of the Miocene basins of the Central Paratethys from the viewpoint of otolit faunas. *Knihovnička ZPN*, 6b, *Misc. Micropalaent.,* II/2., 101–111.

Buday T., Cambel B. & Maheľ M. (Eds.), 1962: Explanations to the geological map of ČSSR 1:200,000 Wien–Bratislava M-33-XXXV, M-33-XXXIV. *Geofond,* Bratislava, 122–151 (in Slovak).

Cícha I., 1957: Microbiostratigraphical investigation of Burdigalian and Helvetian from intra-Alpine Vienna Basin. *Zpr. Geol. Výzk. v r. 1956,* Praha , 26–28 (in Czech).

Cícha I., 1958: Microbiostratigraphical conditions of Neogene from drillhole Cf in the Lakšárská N. Ves area. *Geol. Práce, Zpr.,* 14, 92–106 (in Czech).

Cícha I., 1995: Development of the Neogene sediments in Central Paratethys, new results. *Knihovnička ZPN*, 16, 67–72 (in Czech).

Cícha I., Krhovský J., Brzobohatý R., Čtyroká J., Daniel von C.H., Haunold Th., Horvath M., Luczkowska E., Reiser H., Rupp Ch., Rijavec R. & Ewnger W., 1983a: Oligocene and Miocene *Uvigerina* from the Western and Central Paratethys. *Utrecht Micropaleont. Bull.,* 35, 121–181.

Cícha I., Zapletalová I., Molčíková V. & Brzobohatý R., 1983b: Stratigraphical range of Eggenburgian-Badenian Foraminifera in West Carpathian Basins. *Knihovnička ZPN*, 4, 99–144.

Csontos L. & Horváth F., 1995: Tertiary structural evolution of the Intra-Carpathian area: A report on integrated basin studies, Pannonian Basin E.C. Project. *Geol. Soc. Greece, Spec. Publ.,* 4, 12–17.

Csontos L., Tari G., Bergerat F. & Fodor L., 1991: Evolution of the stress fields in the Carpatho-Pannonian area during the Neogene. *Tectonophysics,* 199, 73–91.

Csontos L., Nagymarosy A., Horváth F. & Kováč M., 1992: Tertiary evolution of the Intra-Carpathian area: A model. *Tectonophysics*, 208, 221–241.

Dank V. & Fülöp J., 1990: Map of the pre Tertiary basement of the Hungary. *Geol. Surv. Budapest,* Hungary.

Ebner F. & Sachsenhofer R.F., 1991: Die Entwicklungsgeschichte des Steirischen Tertiärbeckens. *Mitt. Abt. Bergb. Geol. Paläont. Landesmus. Joanneum (Graz),* 49, 5–96.

Fodor L., 1995: From transpression to transtension: Oligocene–Miocene structural evolution of the Vienna basin and the East Alpine-Western Carpathian junction. *Tectonophysics,* 242, 151–182.

Fodor L., Marko F. & Nemčok M., 1991: Evolution microtectonique et paleó-champs de constraines du Basin de Vienna. *Geodyn. Acta*, 4, 3, 147–158.

Fodor L., Magyari A., Kázmér M. & Fogarasi A., 1992: Gravity flow dominated sedimentation on the Buda paleoslope: records of the Late Eocene escape tectonics of the Bakony unit. *Geol. Rdsch.,* 81, 797–816.

Fordinál K. & Zlinská A., 1994: Sarmatian Fauna from the Stretava and Kochanovce formations in the Sečovce area (Albínovská Hôrka, Eastern Slovak Basin). *Geol. Práce, Spr.,* 99, 77–82 (in Slovak).

Fornaciari E. & Rio D., 1996: Latest Oligocene to early middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology,* 42, 1, 1–36.

Franko O., Vass D., Franců J., Král M., Pereszlényi M. & Milička J., 1992: First occurrence of oil in the Slovak part of the Danube lowland. *Miner. slovaca,* 24, 453–460 (in Slovak).

Friebe J.G., 1990: Lithostratigraphische Neugliederung und Sedimentologie der Ablagerungen des Badenium (Miozän) um die Mittelsteirische Schwelle (Steirisches Becken, Österreich). *Jb. Geol. B-A,* 133, 223–257.

Fülöp J. (Ed.), 1983: Lithostratigraphic Formations of Hungary. *MÁFI,* Budapest, 1–285 (in Hungarian).

Fülöp J., Bresznyánszky K. & Haas J., 1987: The new map of the Pannonian basin basement in the Hungary. *Acta Geol. Hung.*, 30, 1-2, 3-20.

Fusán O., Biely A., Ibrmajer J., Plančár J. & Rozložník L., 1987: Basement of the Tertiary of the Inner West Carpathians. *GÚDŠ,* Bratislava, 1-103.

Fuchs W., 1985: Geologische Karte der Republik Österreich 1 : 50,000, 61—Hainburg an der Donau. *Geol. Bundesanst.,* Wien.

Gašparík J., 1969: Paleogeography and widening of the Horná Nitra Basin Neogene. *Zbor. Geol. Vied, Západ. Karpaty, Rad ZK*, 11, 172-181 (in Slovak).

Gašparíková V., 1972: Microbiostratigraphy of the Paleogene and Lower Miocene sediments of the Vtáčnik. *Manuscript, Geofond,* Bratislava (in Slovak).

Gaža B., 1984: in: Bednaříková J. & Thon A. (Ed.): Hydrocarbon exploration in Czechoslovakia. *Knihovnička ZPN,* 5, 290-298.

Gnojek I. & Heinz H., 1993: Central European (Alpine-Carpathian) belt of magnetic anomalies and its geological interpretation. *Geol. Carpathica*, 44, 3, 135-142.

Grill R., 1941: Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen in Wiener Becken und den benachtbarten Molasse - Anteilen. *Öl und Kohle*, 37, 595-602.

Hámor G. (Ed.), 1988: Neogene palaeographic atlas of Central and Eastern Europe. *Hung. Geol. Inst.,* Budapest, 7 maps.

Haq B.U., 1991: Sequence stratigraphy, sea-level change and significance for the deep sea. *Spec. Publs. int. Ass. Sed.*, 12, 3-39.

Hók J., Šimon L., Kováč M., Elečko M., Vass D., Halmo J. & Verbich F., 1995: Tectonics of the Hornonitrianska kotlina Depression in the Neogene. *Geol. Carpathica,* 46, 4,191-196.

Holcová K., 1996: Determination of transport of foraminiferal tests in the fossil record (the South Slovak Basin, Middle Miocene). *Neu. Jb. Geol. Paleont., Mh.,* 4, 193-217.

Homola V., 1960a: Borehole Nová Vieska-1 in the Danube basin. *Manuscript, Geofond,* Bratislava (in Czech).

Homola V., 1960b: Borehole Diakovce 1 in the Danube Basin. *Manuscript, Geofond,* Bratislava (in Czech).

Homola V. & Slavíková K., 1955: Results of analysis of the borehole Báhoň-1 in the NW part of the Danube basin. *Manuscript, Geofond,* Bratislava (in Czech).

Horváth F. & Royden L., 1981: Mechanism for the formation of the intra-Carpathian basins: A review. *Earth Evol., Sci.,* 3/4, 307-316.

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

Horváth F., Szalay A., Dövényi P. & Rumpler J., 1986: Structural and thermal evolution of the Pannonian basin. In: Burns J. (Ed.): Thermal modelling in sedimentary basins. *Tecnip.,* Paris, 339-358.

Hrušecký I., Pereszlényi M., Hók J., Šefara J. & Vass D., 1993: The Danube Basin geological pattern in the light of new and reinterpretation of old geophysical data. In: Rakús M. & Vozár J. (Eds): Geodynamical model and deep structure of the Western Carpathians. *GÚDŠ,* Bratislava, 291-296 (in Slovak).

Hrušecký I., Šefara J., Masaryk P. & Lintnerová O., 1996: The structural and facies development and exploration potential of the Slovak part of the Danube Basin. In: Wessely G. & Liebl W. (Eds): Oil and Gas in the Alpidic Thrust Belts and Basins of Central and Eastern Europe. *EAGE Spec. Publ.*, 5, 417-429.

Hudáčková N., 1995: Ecotype variability of genus *Ammonia* Brunnich 1772 in the Neogene of Paratethys and their paleoecological significance. *Miner. slovaca*, 27, 133-144.

Hudáčková N. & Kováč M., 1993: Sedimentary environment changes in the eastern part of the Vienna Basin during Upper Badenian and Sarmatian. *Miner. slovaca*, 25, 3, 202-210.

Jandová V., 1955: Foraminifers from the borehole Vráble 1. *Manuscript, Geofond,* Bratislava (in Czech).

Jandová V., 1956: Foraminifers from the boreholes Madunice 1, 2, 4. *Manuscript, Geofond*, Bratislava (in Czech).

Jandová V., 1959a: Foraminifers from the borehole Modrany 1. *Manuscript, Geofond,* Bratislava (in Czech).

Jandová V., 1959b: Foraminifers from the borehole Modrany 2. *Manuscript*, *Geofond,* Bratislava (in Czech).

Jiříček R., 1969: Stratigraphical sections of the boreholes Trakovice. *Manuscript*, *Geofond,* Bratislava (in Czech).

Jiříček R., 1990: Fluvial and deltaic systems of Neogene Paratethys. In: Sedimentologiccal problems of the Western Carpathians. *Konferencie-sympózia-semináre, GÚDŠ*, Bratislava, 79-88 (in Slovak).

Keith J. F., Vass D. & Kováč M., 1994: The Danube Lowland Basin. *ESRI, Occasional Publ. 11A, Slovak Geology,* 63-87.

Kilényi E. & Šefara J. (Eds.), 1989: Pre-Tertiary basement contour map of the Carpathian basin beneath Austria, Czechoslovakia and Hungary. *Eötvös Lóránd Geophysical Institute*, Budapest, Hungary.

Kókay J., 1971: Das Miozän von Várpalota. *Bull. Hung. Geol. Soc.*, 101, 217-224.

Kollmann K., 1965: Jungtertiär im Steirischen Becken. *Mitt. Geol. Gesell. (Wien),* 57, 479-632.

Körössy L., 1987: Hydrocarbon geology of the Little Plain of Hungary. *Gen. Geol. Rev.*, 22, 99-174 (in Hungarian).

Kováč M., 1986: Lower Miocene sedimentation in the area of Jablonica depression—a model bound to oblique slip mobile zone. *Geol. Zbor. Geol. Carpath*., 37, 1, 3-15.

Kováč M. & Hudáčková N., 1997: Changes paleoenvironment as a result of interaction of tectonic events with sea level changes in the northeastern margin of the Vienna Basin. *Zbl. Geol. Palaeont*., *Teil I,* 5-6, 457-469.

Kováč M. & Zlínská A., 1998: Change of paleoenvironment as a result of interaction of tectonic events and sea level oscillation in the east Slovak Basin. *Przegl. Geol*., 46, 5, 403-409.

Kováč M., Baráth I., Holický I., Marko F. & Túnyi I., 1989a: Basin opening in the Lower Miocenen strike-slip zone in the SW part of the Western Carpathians. *Geol. Zbor. Geol. Carpath*., 40,1, 37-62.

Kováč M., Cícha I., Krystek I., Slaczka A., Stráník Z., Oszczypko N. & Vass D., 1989b: Palinspastic maps of the Western Carpathian Neogene. Praha, 31.

Kováč M., Michalík J., Plašienka D. & Putiš M., 1991a: Malé Karpaty Mts. —Geology of the Alpine-Carpathian Junction. Excursion guide. *Konferencie, sympóziá, semináre, GÚDŠ*, Bratislava, 1-82.

Kováč M., Baráth I., Šutovská K. & Uher P., 1991b: Changes in the sedimentary records in the Lower Miocene of the Dobrá Voda Depression. *Miner. slovaca*, 23, 201-213 (in Slovak).

Kováč M., Šutovská K., Nemčok M. & Fordinál K., 1992: Planinka Formation—Ottnangian to Lower Badenian sediments in the northern part of the Malé Karpaty Mts. *Geol. Práce, Spr.,* 96, 47-50 (in Slovak).

Kováč M., Nagymarosy A., Soták J. & Šutovská K., 1993a: Late Tertiary paleogeographic evolution of the Western Carpathians. *Tectonophysics,* 226, 401-415.

Kováč M., Marko F. & Nemčok M., 1993b: Neogene structural evolution and basin opening in the Western Carpathians. *Geophysical Trans. (Budapest)*, 37, 297-309.

Kováč M., Kráľ J., Márton M., Plašienka D. & Uher P., 1994: Alpine Uplift History of the Central Western Carpathians: Geochronological, paleomagnetic, sedimentary and structural data. *Geol. Carpathica*, 45, 2, 83-96.

Kováč M., Baráth I. & Nagymarosy A., 1997a: The Miocene collapse of the Alpine-Carpathian-Pannonian junction—an overwiev. *Acta Geol. Hung*., 40, 3, 241–264.

Kováč M., Bielik M., Lexa J., Pereszlényi M., Šefara J., Túnyi I. & Vass D., 1997b: The Western Carpathian intramountane basins. In: Grecula P. et al. (Eds.): Geological evolution of the Western Carpathians. *Miner. slovaca, Spec. Publ.,* 43–64.

Lankreijer A., 1996: Rheology and basement control on extensional basin evolution in Central and Eastern Europe: Variscan and Alpine-Carpathian-Pannonian tectonics. *Vrije Universiteit*, *NSG Publ. no. 980101,* 1–158.

Lankreijer A., Kováč M., Cloetingh S., Pitoňák P., Hlôška M. & Biermann C., 1995: Quantitative subsidence analysis and forward modeling of the Vienna and Danube Basins. *Tectonophysics*, 252, 433–451.

Lehotayová R., 1977: Calcareous nannoflora of the Miocene of the Bánovce depression. *Manuscript, Geofond*, Bratislava (in Slovak).

Lehotayová R., 1984: Miocene nannoplankton zones in west Carpathians. *Západ. Karpaty, Ser. Paleont*., 8, 91–110.

Lexa J., Konečný V., Kaličiak M. & Hojstričová V., 1993: Temporal and spatial distribution of volcanics of the Carpathian-Pannonian region. In: Rakús M. & Vozár J. (Eds.): Geodynamical model and deep structure of the Western Carpathians. *Konferencie, Sympózia, Semináre, GÚDŠ,* Bratislava, 57–70 (in Slovak).

Lexa J., Konečný V., Kováč M. & Nemčok M., 1995: Relationship among convergence, back-arc extension and volcanism in the Western Carpathians during Neogene. *Europrobe Workshops —PANCARDI*, *Abstracts.* Stará Lesná, Slovakia, 65–66.

Marko F. & Uher P., 1992: Postintrusive deformation from southern border of Bratislava granitoide massif. *Miner. slovaca*, 24, 367–379 (in Slovak).

Marko F., Kováč M., Fodor L. & Šutovská K., 1990: Deformations and kinematics of a Miocene shear zone in the northern part of the Little Carpathians (Buková Furrow, Hrabník Formation). *Miner. slovaca*, 22, 5, 399–410.

Marko F., Fodor L. & Kováč M., 1991: Miocene strike-slip movement, faulting and block rotation in Brezovské Karpaty Mts. *Miner. slovaca*, 23, 189–200.

Marko F., Plašienka D. & Fodor L. 1995: Meso-Cenozoic stress fields within the Alpine-Carpathian transition zone: A review. *Geol. Carpathica, 46*, 1, 19–27.

Martini E., 1971: Standard Tertiary and Quaternary calcareous nanoplankton zonation. *Procceding of 2-nd planktonic conference, Roma 1970,* 739–785.

Milička J., Pereszlényi M. & Masaryk P., 1989: Natural gas seepage from a dug well in Gemerská Panica. *Acta Geol. Univ. Comen*., 52, 39–46.

Milička J., Pereszlényi M., Šefara J. & Vass D., 1994: Organic geochemical study of the junction zone of the Danube Basin and Inner West Carpathians, Slovakia. *First Break*, 12, 11, 571–574.

Milička J., Pereszlényi M., Franců J. & Vitáloš R., 1996: Organic geochemical appraisal of hydrocarbon potential in the Danube Basin, Slovakia. In: Wessely G. & Liebl W. (Eds.): Oil and Gas in the Alpidic Thrust Belts and Basins of Central and Eastern Europe. *EAGE Spec. Publ*., 5, 431–439.

Mišík M., 1986: Petrographic-microfacial analysis of pebbles and interpretation of sources areas of the Jablonica conglomerates (Lower Miocene of the NW margin of the Malé Karpaty Mts.). *Geol. Zbor. Geol. Carpath*., 37, 4, 405–448.

Murray J.W., 1991: Ecology and paleoecology of benthic Foraminifera. *Longman Scientific & Technical,* London, 1–397.

Nagy A., 1998: A review of the geological structure of the Eastern part of Podunajská nížina. In: Nagy A. (Ed.): Explanatory notes to the geological map of the Danube Basin eastern part 1 : 50,000. *GSSR*, Bratislava, 182–187.

Nemčok M., Marko F., Kováč M. & Fodor L., 1989: Neogene tectonics and paleostress changes in the Czechoslovakian part of the Vienna Basin. *Jb. Geol. Bundesanst. (Wien),* 132, 443–458.

Neubauer F. & Genser J., 1990: Architektur und Kinematik der oestlichen Zentralalpen, eine Ubersicht. *Mitt. Naturwiss. Ver. Steiermark*, 120, 203–219.

Papp A., 1951: Das Pannon des Wiener Becken. *Mitt. Geol. Gesell. (Wien),* 39–41.

Papp A. & Steininger F., 1979: Die Äquivalente des Tortonian und Messinian in der Zentralen Paratethys. *Verh. Geol. Bundesanst. (Wien),* 161–170.

Papp A., Rögl F. & Seneš J., 1973: Chronostratigraphie und Neostratotypen 3. Ottnangien. *Vydav. Slov. Akad. Vied,* Bratislava, 1–841.

Papp A., Cícha I., Seneš J. & Steininger F., 1978: Chronostratigraphie und Neostratotypen Miozän der Zentralen Paratethys M4 Badenien. *VEDA,* Bratislava, 1–593.

Pereszlényi M., Milička J. & Vass D., 1993a: Results of geochemical investigations and hydrocarbon generation modelling in the Danube Basin. In: Rakús M. & Vozár J. (Eds.): Geodynamical model and deep structure of the Western Carpathians. *GÚDŠ*, Bratislava, 201–206 (in Slovak).

Pereszlényi M., Milička J. & Vitáloš R., 1993b: Bericht 1993 ueber Aufnahmen auf OK Nr. 107 Mattersburg, im Gebiet von Brennberger Blockschotter. *Jb. Geol. Bundesanst. (Wien),* 137/3, 412.

Pěničková M. & Dvořáková V., 1985: Fault structure of the Danube Basin. In: Gaža et al. (Ed.): Final report of the hydrocarbon prospection in Danube basin during 1973-1983. *Manuscript, Geophys. Inst.,* Brno (in Czech).

Ratschbacher L., Merle O., Davy Ph. & 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., Lintzer H.G. & Merle O., 1991b: Lateral extrusion in the Eastern Alps, Part 2: Structural analysis. *Tectonics*, 10, 2, 257–271.

Rögl F., 1986: Late Oligocene and Miocene planktic Foraminifera of the Central Paratethys. In: Bolli H.M., Saunders J.B. & Perch-Nielsen K. (Eds.): Planktonic stratigraphy. *Cambridge Univ. Press,* Cambridge, 315–328.

Rögl F. & Steininger F., 1983: Von Zerfall der Tethys zu Mediterran und Paratethys. *Ann. Naturhist. Mus. (Wien),* 85A, 135–163.

Royden L., 1993: The tectonic expression slab pull at continental convergent boundaries. *Tectonics*, 12, 2, 303–325.

Salaj J. & Zlinská A., 1991: Early Miocene planktonic foraminifers of marly facies from Považská Teplá (West Carpathians). *Miner. slovaca*, 23, 2, 173–178.

Seneš J., 1959: Biotop und Entwicklungbedingungen der unterburdigalischen Ablagerungen im Oberneutra-Tal in der Intrakarpatischen Depression. *Geol. Práce, Zoš.,* 53, 65–88.

Seneš J. & Ondrejičková A., 1991: Proposal for the terminology of fossil marine benthic shelf ecosystems. *Geol. Carpathica*, 42, 4, 231–240.

Steininger F.F. & Seneš J., 1971: Chronostratigraphie und Neostratotypen Miozän der Zentralen Paratethys, M1 Eggenburgian. *Vydav. Slov. Akad. Vied,* Bratislava, 1–827.

Steininger F., Seneš J., Kleeman K. & Rögl F., 1985: Neogene of the Mediterranean Tethys and Paratethys. Vol. 2. *Inst. of Paleont. Univ. Vienna,* Vienna, 1–536.

Šutovská K., 1993: Marine Ottnangian in the Ipeľ Basin. *Sbor. VII. Uhel. Konf. Prirodov. Fak.,* Praha, 201–202 (in Slovak).

Šutovská K., Maslowská H. & Bezvoda V., 1993: Analysis of foraminiferal assemblages from the Western Carpathian Lower Miocene using special statistical methods. *Geol. Carpathica*, 44,3, 189–200.

Tari G., Horváth F. & Rumpler J., 1992: Styles of extension in the

Pannonian Basin. *Tectonophysics,* 208, 203–219.

Tollmann A., 1955: Das Neogen am Nordwestrand der Eisenstädter Bucht. *Wiss. Arb. Burgenland, (Eisenstadt)*, 10, 75.

Tollmann A., 1985: Geologie von Österreich. Band 2. Ausserzentralalpiner Anteil. *Franz Deuticke*, Wien, 1–710 .

Uher P. & Kováč M., 1993: Heavy mineral associations in the Neogene sequences of the Malé Karpaty Mts.—paleogeographic evolution of the source areas. *Geol. Práce, Spr.*, 98, 85–100.

Vass D., Elečko M., Kantorová V., Lehotayová R. & Klubert J., 1987: The first finding of marine Ottnangian in the South Slovak Basin. *Miner. slovaca,* 19, 5, 417–422 (in Slovak).

Vass D., Kováč M., Konečný V. & Lexa J., 1988: Molasse basins and volcanic activity in West Carpathian Neogene—its evolution and geodynamic character. *Geol. Zbor. Geol. Carpath.,* 39, 5, 539–562.

Vass D., Pereszlényi M., Kováč M. & Král M., 1990: Out-line of Danube basin geology. *Földt. Közl.*, 120, 193–214.

Vass D., Hók J., Kováč P. & Elečko M., 1993: The Paleogene and Neogene tectonic events of the Southern Slovakia depressions in the light of the stress-field analyses. *Miner. slovaca*, 25, 79–92.

Zágoršek K., Hudáčková N. & Kováč M., in press: Marine Ottnangian in the NE part of the Vienna Basin (Slovakia), *Slov. Geol. Mag.*

Zapletalová I. & Jiříček R., 1964: Foraminifers from the boreholes Bánovce 1–5. *Manuscript, Geofond,* Bratislava (in Czech).

Zlinská A., 1992: Microfaunistical evaluation of drillhole VTB-1 (Bruty, Danube Basin) on the basis of foraminifers. *Manuskript*, *Archív GSSR,* Bratislava (in Slovak).

Zlinská A., 1992b: Mikrofaunistische Bewertung der Bohrung Devínska Nová Ves auf Grund der Foraminiferen und ihre Revision, *Geol. Práce, Spr*., 94, 31–34 (in Slovak).

Zlinská A., 1993: Badenian microfauna from village Malá n/Hronom area (southeastern Danube Lowland), *Geol. Práce, Spr.,* 97, Bratislava, 73–78 (in Slovak).

Zlinská A., 1993a: New species of the genus Elphidium (Foraminifera) from the Sarmatian of the Eastern Slovakian Lowland. *Západ. Karpaty, Sér. Paleont*., 17, 85–87 (in Slovak).

Zlinská A., 1993b: Biostratigraphical evaluation of samples from Chvojnícka pahorkatina Upland. *Manuskript, Archív GSSR,* Bratislava (in Slovak).

Zlinská A., 1995: Biostratigraphic study of Miocene sediments from Modra nad Cirochou based on foraminifers. *Geol. Práce, Spr.*, 100, 53–56 (in Slovak, English summary).

Zlinská A., 1996: Micropaleontological evaluation of the drillhole HGŽ-3 (Želiezovce, Danube Basin) on the basis of foraminifers. *Manuscript, Archív GSSR,* Bratislava (in Slovak).

Zlinská A., 1996a: Microfauna of the Vranov Formation—drill hole BB-1 (Byšta, Eastern Slovak Basin). *Geol. práce, Spr.,* 102, 37–40 (in Slovak, English abstract).

Zlinská A., 1997: Biostratigraphical evaluation of samples from Danube Basin-east. *Manuscript, Archív GSSR*, Bratislava (in Slovak).

Zlinská A., 1998a: Microbiostratigraphy of the Badenian sediments from East Slovak Basin on the basis of foraminifers. *Zem. Plyn Nafta,* 43, 1, 11–152 (in Slovak).

Zlinská A. & Šutovská K., 1990: Biostratigraphical and paleoecological evaluation of the LKŠ-1 borehole on the basis of foraminifera (the Lučenec basin). *Miner. slovaca*, 22, 335–343 (in Slovak).

Zlinská A. & Fordinál K., 1992: Biostratigraphische und Paleoöekologische Bearbeitung der Badenian - Ablagerungen in der Umgebung von Smolenice. *Geol. Práce, Spr.,* 96, 69–73 (in Slovak).

Zlinská A. & Čtyroká J., 1993: Some remarks to the taxonomy of genera Spiroplectammina Cushman, 1927 and Spiroplectinella Kiselman, 1972 from the Badenian of the Vienna Basin. *Západ. Karpaty, Sér. Paleont.*, 17, 89–97.

Zlinská A. & Fordinál K., 1995: Lower Sarmatian fauna from Drillhole K-3 (Eastern Slovak Basin). *Geol. Práce, Spr*., 100, 71–76 (in Slovak, English summary).

Zlinská A., Halásová E. & Antolíková S., 1997: Evaluation of foraminiferal and calcareous nannoplankton assemblages from drillhole VTB-1 (Bruty, SE part of the Danube Basin). *Knihovnička ZPN,* 42, 2, 157–167 (in Slovak).