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Neogene tectono-sedimentary megacycles in the Western Carpathians basins, their biostratigraphy and paleoclimatology

NATÁLIA HUDÁČKOVÁ[1], MICHAL KOVÁČ[1], VILIAM SITÁR[1], RADOVAN PIPÍK[1], KAMIL ZÁGORŠEK[1] & ADRIENA ZLINSKÁ[2]

[1]Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, Bratislava
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava

Abstract: Sedimentary fill of the Western Carpathians Neogene basins was deposited during four main tectono-sedimentary megacycles. The Eggenburgian - Ottnangian marine to terrestrial megacycle could be characterized by transpressive tectonic regime in the frontal part of the orogen and transtensive tectonic regime in the back arc region. During the Karpatian - Lower Badenian and Middle Badenian - Sarmatian megacycles the transtensive basin formations were controlled by the Western Carpathians active elongation. The sedimentary environment was dominantly marine during the Karpatian and Badenian and mainly brackish during the Sarmatian due to isolation from the Mediterranean. The brackish to lacustrine sediments of the younger megacycle (Upper Sarmathian - Pannonian) were deposited during the back arc thermal collapse in extensive regime.

Key words: Neogene megacycles, tectonic regime, biostratigraphy environment, climate,.

Introduction

The development of intramontane basins in the Western Carpathians was influenced by compressional tectonic regime connected with subduction of the basement of Carpathian externides and the formation of an accretionary prism of the flysch zone, as well as by extensional tectonic regime of back-arc rifting and subsequent thermal subsidence.

The sedimentary history of Western Carpathian intramontane basins during the Neogene may be divided, based on tectono-sedimentary megacycles, into four stages: Eggenburgian - Ottnangian, Karpatian - Lower Badenian, Middle Badenian - Lower Sarmatian, Upper Sarmatian - Pannonian (Pontian).

Eggenburgian - Ottnangian stage

Tectonic regime: In view of the continuing tectonic extrusion of the lishospheric Western Carpathian fragment from the area of Alpine collision, and of the subduction in front of the orogen, a considerable role in the formation of Lower Miocene basin systems of the Central Carpathians played the transpressional tectonic regime. This regime controlled the sedimentation in relic fore-arc basins and wrench-fault furrow type basins in the front of the orogen. On the other hand, transtensional regime predominated in the back-arc area (southern Slovakia).

Environment: The Lower Miocene transgression from the Mediterranean area intruded through the Alpine and partly Carpathian foredeep into the area of the Vienna Basin. From there, sea progressed later into the Váh Valley (SALAJ & ZLINSKÁ 1991), flooding also the areas of the Bánovce Depression (BRESTENSKÁ 1980), Turiec and Horná (Upper) Nitra (GAŠPARÍKOVÁ 1972, KOVÁČ et al. 1989). The Eggenburgian transgression into the Western Carpathian area is characterised by calcareous nannoplankton associations of the NN2 zone, where *Discoaster druggi* appears for the first time and, at the end of the zone, the species *Triquetrohadulus carinatus* became extinct (STEININGER et al. 1985). The Eggenburgian age of the transgression in the area of the Carpathian foredeep is documented by shallow-water sediments with foraminifer thanatocenoses with the genera *Planulina and Cibicidesoides*.

Deep-water Eggenburgian sediments of the Lužice Fm. lower partin the Vienna Basin are characterised by communities of foraminifers *Batysiphon - Cyclammina*, with predominant agglutinated foraminifer species, such as: *Cyclammina praecancellata* VOLOSH., *C. rotundidorsata* (HANTK.), *Haplophramgomides vasiceki vasiceki* C.-Z., *Bathysiphon taurinense* SACCO and *Textularia gramen abbreviata* ORB., which, acccording to MURRAY (1991), lived in ecologic niches of the outer shelf to upper bathyal, in areas of cool, in nutriments rich currents.

In the Považie and Bánovce Depression region, sediments with equivalent age contain a deep neritic thanatocenosis, with *Marginulina - Lenticulina*, along with *Bolivina antiqua* ORB., *Lenticulina meznericsae* (CICHA), *Marginulina fragaria* GUMBEL, *Tenuitellinata angustiumbilicata* (BOLLI), *G. praebulloides occlusa* BLOW-

BANNER, *Cassigerinella boudecensis* POKORNÝ and *Cribrononion hiltermanni* HAGN (STEININGER & SENEŠ 1971 and BRESTENSKÁ 1980).

In the East Slovakian Basin, in the the Prešov Formation, we can find neritic foraminifer thanatocenoses, characterised by the genera *Bolivina, Bulimina, Valvulineria* and *Marginulina*, which in the west of the area pass into shallow-water, hyposaline communities with various species of the genera *Ammonia, Elphidium* and *Porosononion.* The Čelovce Formation, of Eggenburgian age, contains also foraminifer communities with *Uvigerina posthantkeni* PAPP, *Cibicidoides budayi* (C.-Z.) and *Bolivina tumida* CUSH., indicating insufficient aeration of marine water at the bottom (MURRAY 1991). Sediments of Ottnanngian age are missing in the East Slovakian Basin.

In the Novohrad - Nógrad Basin, in the orogene hinterland, we may observe desalination and shallowing of the sedimentary basin even to brackish development of the sediements in the Ottnangian. This environment is characterised by the occurrence of *Cribrononion hiltermani* (HAGN), *Lobatula lobatula* (WALKER ET JACOB) and *Melonis soldanii* (FICHT. et MOLL.). The emergence is documented here by Ottnangian deposition of terrestrial or lake sediments without foraminifers (ČECHOVIČ 1952, VASS et al. 1979). Marine ingression in the uppermost Ottnangian (VASS et al. 1987), which is well correlable with the global curve of sea level changes - the onset of the TB2 pericycle (HAQ et al. 1988) - documents opening of the Mediterranean sea ways. A sign of the ingression in southern Slovakia is the occurrence of marine nannoplankton species - *Cricolithus jonesi* COHEN, *Discoaster aulacos* GARNTER, *Helicosphaera ampliaperta* BRAMLETTE et WILCOXON and *Sphenolithus pacificus* MARTINI, further the occurrence of neritic types of benthic foraminifers, such as *Pappina parkeri breviformis* (PAPP et TURN.), *Cibicidoides borislavensis* (AISENSTAT), *Lenticulina cultrata* (MONTFORT), *Bolivina hebes* MACFAD., as well as the occurrence of planktonic foraminifer species *Globigerina praebulloides* Blow, *Globigerina woodi woodi* JENKINS and *Globigerinoides primordius* BLOW et BANNER.

The closing of Lower Miocene marine sea connections is in the Vienna Basin documented by shallow brackish environment characterised in the upper part of the Lužice Formation (Eggenburgian-Ottnagnian) by a typical euhaline foraminiferal community, with predominance of the *Cibicides* and *Elphidium* genera. An equivalent of the upper part of the of the Lužice Formation are in the Austrian part of the Vienna Basin the "Rzehakia (Onkophora) Beds" of Ottnangian age. In the western part of the Western Carpathians (Dobrá Voda, Bánovce Depression), dark, laminated clays sedimented in the Ottnangian, with remnants of fish, displaying considerably limited oxygen - content at the bottom (PAPP et al. 1973, KOVÁČ et al. 1991).

The marine transgression into the Carpathian foredeep and Vienna Basin in the Eggenburgian is documented by a mollusc association typical for the sublittoral zone. They are especially the species *Turritella turis, Pitar lilacinoides, Pholadomya alpina* and various species of the genera *Teredo, Balanus* and *Ficus* (STEININGER et al., 1971). Later on, with progressing transgression, there started to appear species characteristic for neritic parts: *Chlamys gigas* and *Aturia aturi.* The decrease of salinity in the Vienna Basin during the Ottnangian is documeted by remnants of mollusc shells of the genera *Rzehakia* and *Congeria*, occurring in the upper part of the Lužice Formation. In foredeep sediments of Ottnangian age, there are also mollusc species characteristic of an evironment with lower salinity: especially *Limnocardium moravicum* and various species of the genera *Rzehakia, Congeria* and *Melanopsis* (STIENINGER et al. 1971).

In the Váh Valley and in the Horná Nitra area, the Eggenburgian transgression is well documented by mollusc fauna. The earliest transgression period is characterised by brackish mollusc associations of the genera *Tympanotonus, Melanopsis* and *Clithon*, and sometimes by the occurrence of *Crassostrea gryphoides* in the Horná Nitra area. Later on, predominant are species characteristic of shallow, normally saline sublittoral zone: *Pecten hornensis, Pitar lilacinoides* and *Taras rotundatus.* In the Váh Valley the succession ends with shallow-neritic sediments with the mollusc association of the *genera Astarte, Leda, Solen* and *Tellina.* After neritic sediments with *Panopea* and *Tellina planata*, the highest member of the succession of Eggenburgian age in the Horná Nitra area are again sublitoral sediments with *Turritella eryna*, proving the onset of sea regression from this area (STIENINGER et al. 1971). During the Ottnangian, the whole area was situated in brackish conditions, documented by the occurrence of molluscs *Limnocardium moravicum, Cardium sociale* and various species of the genus *Rzehakia* (STIENINGER et al. 1973).

Eggenburgian sea transgression in the South Slovakian Basin is supported by the occurrence of molluscs from the genera *Flexopecten, Calyptrea, Turritella, Ficus* and *Fussus*, characterising sublittoral to supralittoral zone (STIENINGER et al. 1971). Later on, bryozoan genera typical of deeper parts of the littoral - *Shizoporella* and *Retepora* - occur along with them. Early Ottnangian sediments of the South Slovakian Basin formed in the environment of limno-brackish to limnic basins, which is documented by the occurrence of molluscs *Limnocardium moravicum*, species of the genus *Rzehakia* and later limno-brackish to limnic species of the genera *Planorbis* and *Unio* (STIENINGER et al. 1973).

In the Fiľakovo Formation, at the village Mučín, there was found a rich fauna of sharks and whales of Lower Miocene age. The majority of species indicates sublittoral zone in a tropical to subtropical climate, but pelagic

species are common too; deep-water species are rare. The most frequently occurring were teeth of the *Synodontaspis acutissima*, *S. cuspidata* and *Isurus hastalis*, which are typical representatives of the near-shore zone in a warm sea. The more rare species *Isurus desori*, *Aetobatis aruatu* and *Squatina* sp. may be assigned to the same niche. In the transitional zone between the sublittoral and deeper littoral there lived *Carcharocles chubutensis*. Typical pelagic species found in this area are *Notidanus primigeneraus*, *Carcharoides catticus*, *Galeocerdo aduncus*, *Esistius triangularis*, *Squalus* sp. and the whale *Squalodon* sp. On the other hand, there are present also species living near the bottom, adjusted rather to cool water, especially in a greater even bathyal depth. A rarely occurring species is here the Lower Miocene shark *Mitsukurina lineata*, further *Carcharoides catticus* and the very rare *Isurus benedeni* (HOLEC et al. 1995).

In the area of the Ipeľ Basin, in the Dolina mine, in the overlier of the coal seam, there were found fragments of siren ribs of Upper Ottnangian age (HOLEC 1982).

Climate: *Lower Eggenburgian* (subzone MF-2) had a warmer climate than the cool Egerian. This is documented by the scarce occurrence of arctotertiary elements and rich representation of subtropic to tropic species. The micro-flora (spores and pollen grains) as well as macro-flora has tropic to subtropic character (PLANDEROVÁ 1990). The spores are represented by a fern group of the genus *Lygodium* and club-mosses of the genus *Lycopodium*. From coniferous plants there are representatives of the genus *Cathaya* and of angiosperms especially pollen of the family Sapotoaceae, Symplocaceae and Fagaceae. The macro-flora (loc. Veľká Čausa) is charaterised by the genera *Ficus*, *Fagus*, *Castanopsis*, *Laurus*, *Engelhardia*, *Daphnogene*, *Quercus* and *Persea*, from arctotertiary elements there are only *Ulmus* and *Zelkova* (NĚMEJC 1967). The landscape was in this time richly overgrown with xerophilous forests, except for areas near rivers and lakes, with hydrophilous or even morass flora.

Upper Eggenburgian - Lower Ottnangian (community subzone MF-3). In sediments of this zone, there occur pollen grains of angiosperms plants, such as *Carya*, *Myrica* and Sapotaceae, which are clearly tropical elements, along with *Magnolia*, Nyssaceae and Cyrillaceae, typical for tropics to subtropics. Macroremnants of flora, assigned to this zone, are known from the locality Lipovany. From this locality there are known plant impressions characteristic for hydrophilous tropical-subtropical plants, especially Lauraceae, further *Magnolia*, *Engelhardia*, *Quercus*, *Platanus*, from unigerminate palm trees (*Calamus*, *Chamemaerops*) and from conifers *Tetraclinis* and *Pinus*.

Ottnangian microflora is rich in genera as well as species, pointing to an optimum climate. The plants indicate the existence of large marshes in the south of Slovakia, overgrown with flora requiring humid soil.

Upper Ottnangian - Karpatian (zone MF-4). The terminal part of the Ottnangian differs by its plant cover. There disappeared especially tropical elements and they were replaced by elements of coastal mixed forests, with alders, oaks and chestnut trees. From this time, there are available only palynologic data (PLANDEROVÁ 1990). According to the occurrence of palynomorphs we may assume a cooler climate than in the preceding zone. The number of subtropical-tropical elements decreased, both of spore and seed plants. The percentage of arctotertiary species increased (*Ulmus*, *Carpinus*, *Betula*), as well as of intermediary species, especially conifers (*Pinus*, *Picea*, *Cedrus*) and deciduous trees (*Alnus*, *Carya*, *Ostrya*).

Volcanism: This time is characterised by rhyodacite volcanism in the back-arc area and basalt volcanism in the foredeep (Northern Moravia).

Karpatian - Lower Badenian stage

Tectonic regime: Transpressional tectonic regime continued to accompany the forming of the Outer Western Carpathian accretionary prism. The marginal parts of the Central Western Carpathians were zones of transition from a transpressional to transtesional tectonic regime. In the Vienna Basin and in the Transcarpathian Basin, a sinistral and dextral system of strike slips formed, controlling the opening of basins deposition centres of pull-apart type.

In the hinterland of the orogen, the back-arc extension continued with its syn-rift stage in a transtensional regime.

The uplift of centralids led to the formation of a river network, oriented predominatly towards the externids in the Karpatian. Rapid subsidence of deposition centres of the basins led to deposition of clastics, frequently by grain-flow of material and turbiditic mechanism of transport.

Environment: During the uppermost Ottnangian (zone NN4 of calcareous nannoplankton) marine transgression progressed from the orogene hinterland (southern Slovakia), through the Bánovce area to the Vienna Basin and to the Carpathian foredeep. In the southern Slovakia, similarly as in Hungary, some Ottnangian uvigerina faunas may be regarded as already Karpatian. On the base of the Karpatian, however, some typical Lower Miocene species disappeared (such as *Almaena osnabrugensis* (MUNSTER), *Cyclammina praecancellata* VOLOSH., *Planulina wuellerstorfi* (SCHW.) and *Uvigerina hantkeni* (CUSH.-EDW.). Renewed communication with the Mediterranean in the Karpatian has been confirmed by the occurrence of the largest amount of new Neogene foraminiferal species and high diversity of their communities. The typical neritic microfauna

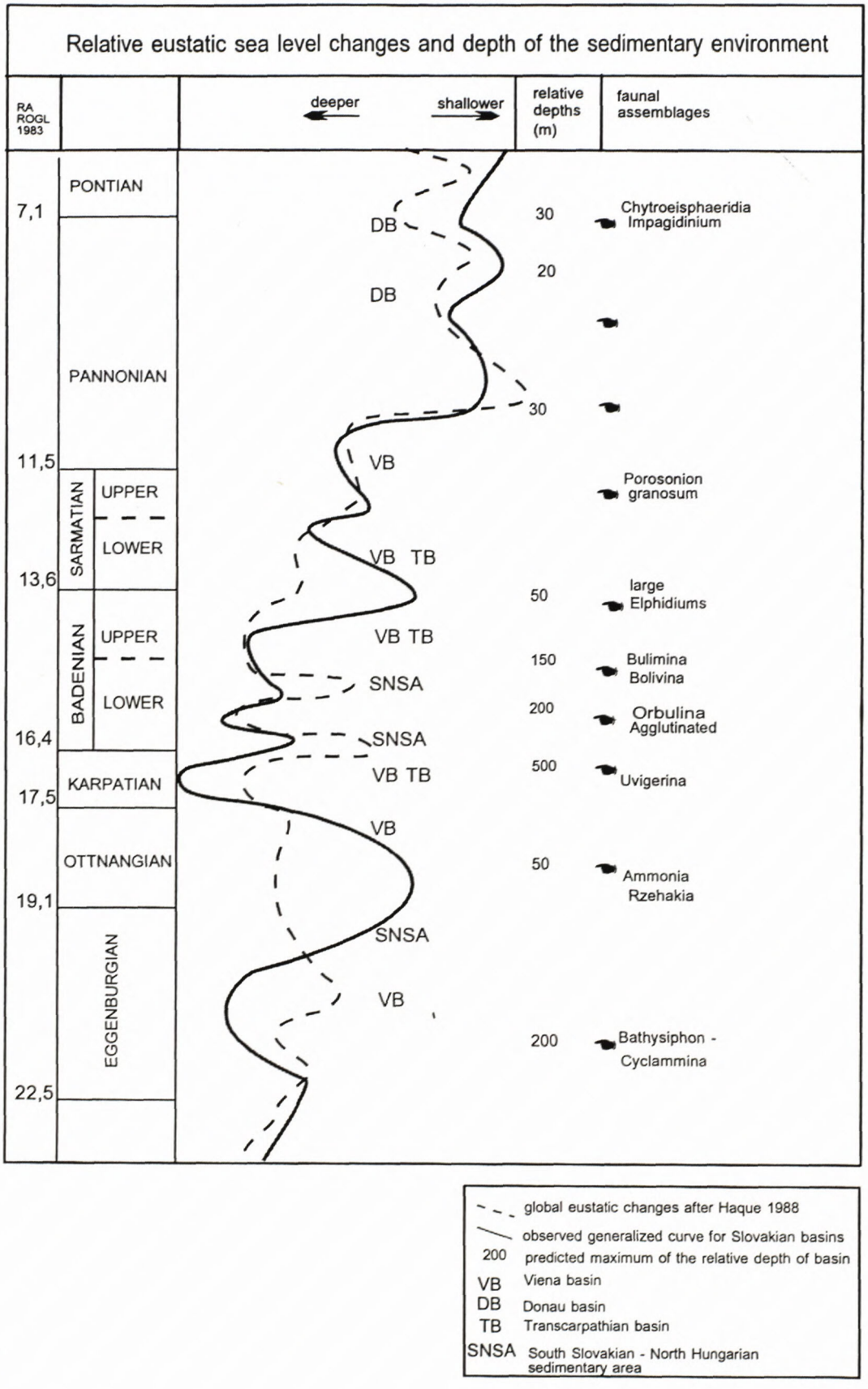

Fig. 1: Relative changes of sea level and paleodepth of the Western Carpathians Neogene basins.

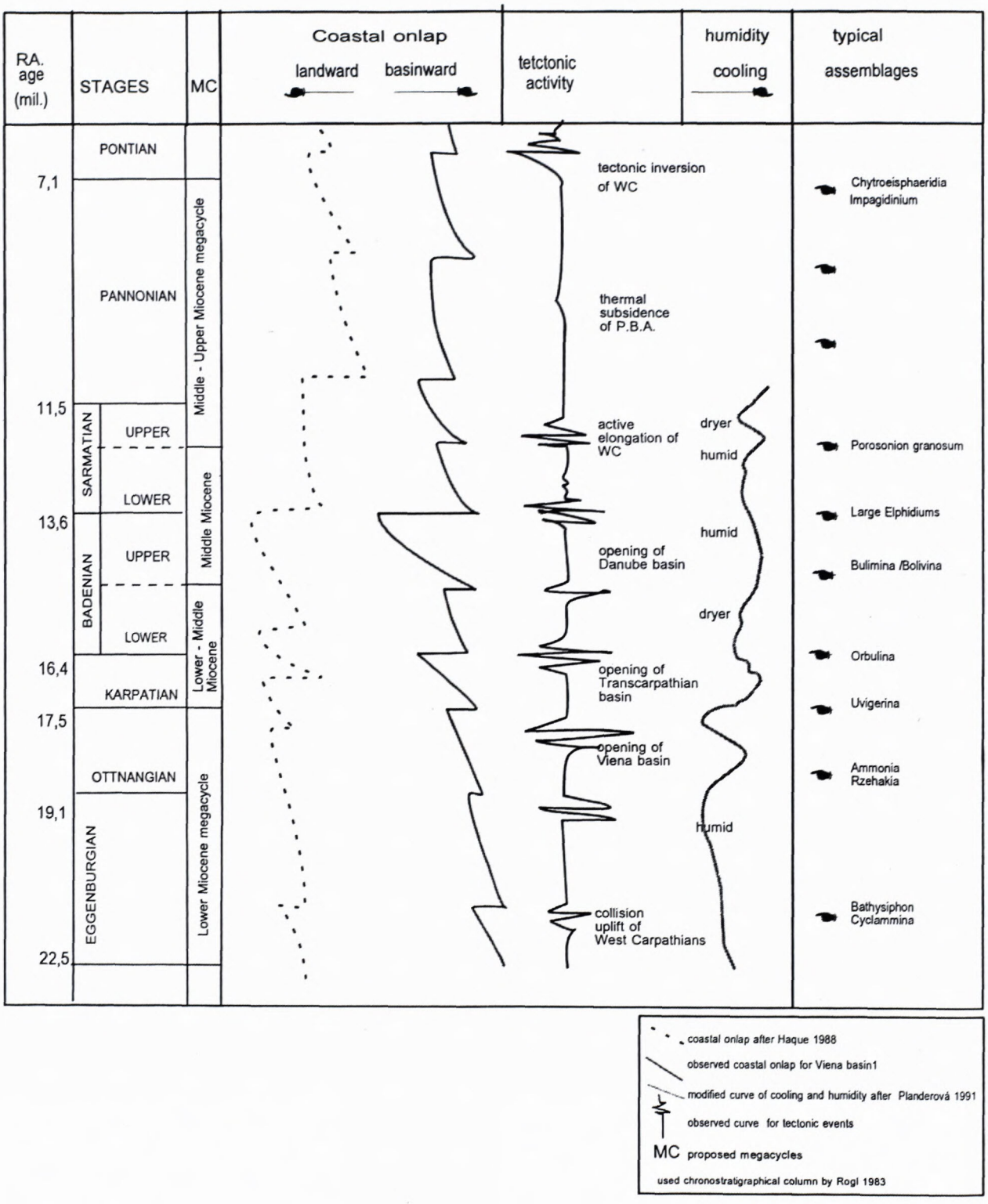

Fig. 2: Transgresive - regresive cycles, tectonic activity, climatic changes and faunal assemblages depending on opening or closisng of the Paratethys marine sea connection with the Mediteranean.

(even bathyal in the Bánovce Basin and in the northern part of the Vienna Basin) is euhaline and tolerant to oxygen depletion at the bottom. In thanatocenoses there are mostly *Uvigerina graciliformis* (PAPP et TURN.) *Pappina bononiensis primiformis* (PAPP et TURN.), *P. parkeri breviformis* (PAPP et TURN.), *Cyclammina karpatica* C.-Z. and *Reticulophragmium karpaticum* C.-Z. (CICHA et al. 1983).

In the Eastern Slovakia, hypersaline facies sedimented with very poor microfauna consisting of representatives of the genera *Elphidium, Melonis* and *Nonion*, sporadically also with *Uvigerina graciliformis* P.-T., *Ammonia beccarii* (L.) and *Bolivina dilatata* RSS. above neritic facies. The development of the East Slovakian Basin points to partial isolation from the intracarpathian sea, containing euryoxibiont communities, with predominant *Lenticulina inornata* (ORB.), *Dentalina intermedia* (ORB.), *Pappina bononiensis primiformis* (PAPP et TURN.) and numerous *Bulimina* species.

Stabilised marine environment along with ideal climate led to the appearance of new fauna groups during the Lower Badenian. This time is characterised by maximum number of foramininferal species, especially agglutinated and lagenerad forms. This fact was probably caused by subtropical climate in the Western Carpathian region and global sea level rise, which may be correlated with the short-term curve TB2-2.5 in the global marine level changes supercycle (HAQ et al. 1988).

Lower Badenian nannoplankton communities (zone NN5) are in all basins almost identical - they contain 39 nannoplankton species, such as *Braarudosphaera bigelowi* (GRAN et BRAARRUD) DEFLANDRE, *Coccolithus pelagicus* (WALLICH) SCHILLER, *Cyclococcolithus leptoporus* (MURRAY et BLACKMANN) KAMPTNER, *C. rotula* (KAMPTNER) KAMPTNER, *Discoaster aster* BRAMLETTE et RIEDES and *D. druggi* BRAMLETTE et WILCOXON. More diversified communities have been found at localities in southern Slovakia, with *Helicosphaera wallichi* LOHMANN.

Lower Badenian foraminiferal species, due to higher water temperatures in the sedimentation area, are more developed and richly ornamented (e.g. *Lenticulina echinata*). For the first time there occurred the plankton genera *Orbulina* and *Praeorbulina,* from benthos *Heterostegina.*

Foraminifer communities in the Vienna Basin indicate a bathyal sea depth, with a well aerated bottom, with typical occurrence of the genera *Orbulina* and *Praeorbulina* in the lagenerad zone (GRILL 1943). Along with them, there occur the species: *Lenticulina echinata* (ORB.), *L.. cultrata* (MONTF.), *Planularia antillea ostraviensis* VAŠÍČEK, *P. dentata* KARRER, *Vaginulina legumen* (L.) and *Uvigerina macrocarinata* PAPP et TURN..

Only the eastern part of the present Danube Basin area was flooded (the Želiezovce Depression), which communicated with the sea at the southern margin of the Central Slovakian neovolcanics. The sea attained locally (Bajtava, Modrany) neritic depth (PAPP et al. 1978), Marine sedimentation was frequently interrupted by the accumulation of volcanic material. The most frequently occurring foraminifers are *Valvulineria complanata* (ORB.), *Heterolepa dutemplei* (ORB.), *Globigerinoides trilobus* RSS. and *Orbulina suturalis* (BRONN.) along with the communities *Ammonia beccarii* (L.), *Asterigerinata planorbis* (ORB.) and *Nonion sp..*

In southern Slovakia, the basins attained sublittoral, at most shallow neritic depth. After the Lower Badenian, this area became a dry land (KOVÁČ et al. 1993).

In the East Slovakian Basin, in sediments of Lower Badenian age, marine foraminifer communities with *Orbulina suturalis* Bronnimann and *Orbulina universa* (Jedlitschka) occur rarely, indicating by their large lagenerad forms an autonomy of the basin, with a weakly aerated shallow neritic sedimentation environment.

The sedimentatry environment in the foredeep is characterised especially by rich associations of sublittoral marine mollusc species, with typical stenovalent species of the genera *Pecten, Chlamys. Teredo* and *Turritella* during the Karpatian. There are known also remnants of corals (especially the genera *Flabellum and Turbellastrea),* ciripedians (genus *Balanus)* and ostracods (e.g. *Cytheridea (C) paracuminata*), CICHA et al. (1967). In the Lower Badenian the depth of the sea slightly increased, the environment became circalittoral, with typical species such as *Aporrhais pespelecani* and *Nassa dujardiny* (SENEŠ et al. 1978).

In the Vienna Basin, neritic environment with well aerated bottom predominated during the Karpatian, characterised by frequent finds of mollusc, sea urchins and ostracod shells. From molluscs, the most typical representatives of neritic associations are the species *Solemya doderleini* and *Aturia aturi,* from sea urchins especially *Brissopsis ottnangiensis* and the genus *Schizaster,* and from ostracods especially *Loxoconcha hastata* (CICHA et al. 1967).

During the Lower Badenian, terrestrial material along with remnants of land vertebrates entered locally the marine environment in the Vienna Basin. In the area of the Štokerau lime works (Devínska Nová Ves), there has been found a rich fauna of mammals which inhabited the steppe-forest and several species of small rodents. There are frequent finds of the species *Palaeoerinaceus* sp., *Sorex gradilidens, S. dehmi, Heterosorex sansaniensi* and *Seaptouyx edwardsi.* Further there have been found remnants of the bats *Rhinolophus delfinensis, R. similis, Pareptesicus priscus* and *Miniopetrus fossilis,* of the carnivores *Trocharion albanense, Amphicyon maior, Alopecondon leptorhynus, Hemicyon sansaniensis, Ursavus brevirhinus, Ailurictis jourdani* and *Pseudailurus* cf. *turnausensis,* the mastodonts *Zygolopnodon turicensis* and the odd-toed *Chalicotherium grande.* Rarely there have been found also fragments of primates - *Proplio-*

pithecus vindobonensis, fragments of the hornless rhinoceros *Aceratherium* cf. *tettradactylum* and of the nomad which had immigrated from America across the Bering Strait - *Anchitherium* (HOLEC 1978).

The marine connection renewed during the Karpatian is characterised by a communication with the Mediterranean, especially through the back-arc basin. A typical feature of this sedimentary environment is the occurrence of more deep-water neritic mollusc species, such as *Nuculana fragilis, Solemya dodorleini, Euspira catena helician* and *Aturia aturi* (SENEŠ et al. 1978). Normal salinity is proved by the presence of corals (frequent is especially *Flabellum senesi*) and sea urchins (common are species of the genus *Brissopsis)*, CICHA et al. (1967).

In Eastern Slovakia, a rich mollusc association of Karpatian age is found, represented especially by species and genera which are relatively rare in other basins, e.g. *Chlamys zitteli, Pinna squamosa, Ammussium, Aloidis* and *Thracia,* along with common species typical of the shallow neritic: e.g. *Solemyia doderleini* and *Nuculana fragilis* (SENEŠ et al. 1978). Very rich is the association of sea urchins (predominant species are those from the genera *Schizaster, Brissopsis* and *Trachyaster*) and ostracods, frequent are especially *Cytheridea (C.) paracuminata* and *Hemicytherura*), proving circalittoral to neritic zone of a normally saline sea.

Climate: This stage is characterised by frequent oscillations of the climate, warming on the base of the Karpatian, replaced by subsequent cooling and repeated warming at the end of the Karpatian, which led to the return of warm-subtropic flora after the cooling in the Ottnangian-Lower Karpatian time. The dry land was covered by xerothermic plants, indicating an absence of morasses. New increase in thermophilous elements is obvious especially in comparison with the preceding zone, however, they are not as abundant as in the zone MF3. The proportion of arctotertiary elements remains the same. Microflora is represented by pollens - Cyrillaceae (ericoid forms), Schizeaceae (ferns with large spores) and palm trees, which is evidence of a warm subtropic climate. Macroflora (locality Stredné Plachtince) is known by the abundacy especially of Lauraceae, Myricaceae and *Engelhardia,* from conifers there is *Glyptostrobus* (NĚMEJC 1967).

Volcanism: The time of the Karpatian and Lower Badenian is characterised by volcanism which changed gradually from acid in the Lower Miocene, to intermediary and to basic during the Middle Miocene, reflecting the process of the contamination of magma by mantle masses in the back-arc area. Intensive dacite and rhyolite volcanism was active especially in the area of Central Slovakian Neovolcanics, Eastern Slovakuia and in the Danube Basin.

Middle Badenian- Lower Sarmatian stage

Tectonic regime: Middle Miocene transpressional regime accompanied only the forming of the Outer Carpathian accretionary prism, while the last thrusting of nappes on the foredeep took place in the Lower Sarmatian (JIŘÍČEK 1979). The forming of the Western Carpathian basin structure was affected by the steepening of the subducted plate in front of the Eastern Carpathians, causing active elongation of the Western Carpathian internids in north-eastern and later eastern direction.

The forming of basins in the back-arc area was controlled by extensional regime. In the west, in the marginal part of the Western Carpathians, there predominated normal faults of NE-SW direction and ENE-WSW sinistral strike slips compensating the active elongation. Their influence was reflected in formation of partial depressions in the northern part of the Vienna Basin and northern embayment of the Danube Basin. The Transcarpathian Basin acquired in this time the character of an inter-arc basin, where sedimentation was controlled by NW-SE longitudinal faults and NE-SW to ENE-WSW transversal faults.

Deposition centres of Western Carpathian intramontane basins displayed a marked subsidence in the Upper Badenian to Lower Sarmatian.

Due to the elevation of the externids, as well as of the central part of the orogen, the orientation of the river network changed in this time, acquiring predominantly the direction towards the back-arc basin.

Environment: During the Middle Badenian, sea flooded the whole area of the Vienna and Danube Basins. The sediments contain diversified communities of nannoplankton (32 species) with discoasters (zone NN6) with long processes, such as *Discoaster deflandrei* BRAMLETTE. et WILCOXON and *D. aulacos* GARTNER, *D. nephados* HAY, *D. variabilis* MARTINI et BRAMLETTE. Foraminifer communities with *Spiroplectinella carinata* (so called *Spiroplectammina carinata* zone, GRILL 1941), *Cyclammina pleschakowi* PISCH., *Martinotiella communis* (ORB.), *Spiroplectinella (=Spiroplectammina) carinata* (ORB.), *Textularia gramen* ORB. and *Haplophragmoides vasiceki vasiceki* C.-Z. are documenting a neritic environment with euhaline conditions. Noteworthy in this zone is the occurrence of the genus *Pseudotriplasia,* the vertical range of which in the Carpathian basins is very narrow. Typical for plankton there are *Globigerina nepenthes* TODD, *G. decoraperta* TAKAYANAGI et SAITO, *Globoturborotalita druryi* (AKERS). The sedimentatry area is locally desalinated in the upper part (Molčíková 1960).

In the East Slovakian Basin, shallow, hypersaline environment predominated during the Middle Badenian, with sporadic occurrence of poor marine communities of small foraminifers - *Globigerina* aff. *bulloides* ORB.,

Globorotalia scitula BRADY, *Globigerinoides trilobus* (RSS.) and *Uvigerina aff. aculeata* ORB.

In the Upper Badenian, the Vienna, Danube and EasSlovakian Basins had almost the present shape and they were the marginal bays of a relatively shallow sea in the back-arc area. A general feature of these basins is the development of the *bulimina-bolivina* biozone (GRILL 1941) as a reaction to oxygen deficit. The above biozone is characterised especially by the species: *Bolivina dilatata dilatata* Rss., *B. dilatata maxima* C.-Z., *B. dilatata brevis* C.-Z., *Bulimina elongata* ORB., *Praeglobobulimina pupoides* (ORB.) and *Pappina neudorfensis* (TOULA). The marginal parts of the bays with marine-brackish environment (ammonia zone, GRILL 1941) is documented by foraminifer communities containing miliolid types: species of the genera *Quinqueloculina, Triloculina* and the species *Ammonia beccarii* (L.), which, in near-shore facies, pass isochronally into shallow-water brackish mono-communities with *Ammonia* (Čierna 1974). On the basis of lateral and vertical isochronal changes of communities we may assume the stratification of the water column, with a lower - anoxic and upper - hyposaline layer. The anoxia is however not present in all of the area.

During the Upper Badenian, some species of agglutinaged foraminifers became extinct and in the Lower Sarmatian they were substituted by miliolid foraminifers. The reduction in the number of benthic foraminifers may have been caused by the deterioration of the life conditions, related to the gradual interruption of marine connections at the end of the Badenian. The above mentioned changes were a reflection of the global lowering of the sea level in the TB2-2.4 cycle (HAQ 1988).

In the Sarmatian, due to the interruption of marine communication with the Mediterranean, gradual desalination took place, documented by a marked change in the communities of nannoplakton, organostenic plankton and foraminifers. Nannoplankton , exept for the borehole SŠ 37 at Pavlová, has been found only rarely - the species were *Cyclococcolithus leptoporus, Cyclococcolithus rotulus.* In the borehole SŠ 37 Pavlová, north of Štúrovo, rich nanoplakton communities have been found, containing, besides the already mentioned *Cyclococcolithus leptoporus* and *Cyclococcolithus rotulus*, many other species.

In the Lower Sarmatian, shallow-marine to brackish environment with decreased salinity (zone *Elphidium reginum* GRILL 1941) predominanted in all basins of the Western Carpathians, the typical species being *Anomalinoides badenensis* (ORB.), *Articulina sarmatica* (KARRER), *Elphidium acuelatum* (ORB.), *E. reginum* (ORB.), *E. macellum* (F.-M.), *E. crispum* (L.), *E. samueli* ZLINSKÁ. Locally, the tectonically affected deepening of the sedimentation area (e.g. in the Vienna Basin and the Mukachevo area) with manifestations of anoxia at the bottom, is documented by the developkent of mono-communities with *Anomalina badenensis* (HUDÁČKOVÁ - KOVÁČ 1993). In the Lower Sarmatian of the Vienna Basin we may observe mass occurrences of algae *Leiosphaera* sp. and *Mecsekia incrassata* S. - Szentai, which may be considered the result of a stress factor.

In sediments of Badenian age in the Vienna Basin there are abundant remnants of vertebrates. Finds of teeth of varius shark and ray species are predominant. The most frequent are shark teeth of the species *Hemispristis serra, Synodontaspis accutissima* and *S. cuspidata,* from rays there are *Aetobatis arcuatus, Miliobatis* sp. and *Dasyatis* sp. , as well as teeth of bony fish of the genera *Sparus, Pagrus, Cymbius, Saurocephalus, Spherodu, Phyllodus, Capitodus, Diplodus* and *Trigondon,* all of them inidcating shallow-water, sublittoral environment. Rarely there have been found remnants of the sea turtles *Trionyx* and *Psephophorus polygonus,* fragments of seals *Pristiphoca vetusta,* of the sirens *Metaxytherium* and *Thalatosirean,* as well as of the whale *Mesocetus hungaricus.* Washed down from dry land into the basin there were remnants of the primates *Sivapithecus (Dryopithecus) darwini,* of large terrestrial mammals *Zygolophodon turicensis, Deinotheriuim levius* (mastodonts), *Brachypotherium* cf. *goldfussi* (rhinoceros), *Amphicyon, Palaeogale* and small even-toed animals - *Hyotherium soemmeringi, Conohyus simmorrensis, Listriodon lockharti, Taucanamo sansaniense, Dorcatherium vindobonendse, Dicroceros elegans, Lagomeryx parvulus* and *Palaeomeryx eminans* (HOLEC 1986). In the central Slovakia (Horná Nitra area), below the coal seams in Nováky, remnants of large mammals have been found, of the species *Aceratherium innccisivum* KAUP. and *Zygolophodon turicensis* (mastodonts) along with bones and teeth of small mammals - *Demoricetodon brevis* SCHAUB., *Sciurus* sp., *Eumyarion latior* SCHAUB. et ZABFE, *Peridyromys hamadryas* (MAJOR), *Neoceometes brunonis* SCHAUB. et ZAPFE, *Glis* sp. and *Mioglis larteti* BAUDELOT (HOLEC 1985).

Mollusc communities are very well diversified in sediments of Middle to Upper Badenian age. A characteristic feature is the presence of stenotype genera, such as *Turritella, Conus, Cypraea, Pecten* et. (Seneš et al. 1978). For the first time, corals occur in greater quantity, especially in the foredeep - above all the genera *Siderastrea, Caryophyllia, Parites* and *Dendrophyllia*, pointing to a very warm, well aerated, normally saline sea in the circalittoral to infralittoral zoe. Remnants of sea urchins are frequent too, especially of the genera *Schizaster* and *Brissopsis,* proving as well the above conditions.

The mollusc thanatocenosis, especially in the Vienna Basin, shows a gradual decrease of salinity from a normally saline sea in the Upper Badenian (characteristic species: *Glycimeris pilosa, Pecten besseri* and *Venus multilamella*) through a slightly brackish environment in the Uppermost Badenian (species typical for such environment are *Corbula gibba, Hinia illovensis* and

Glossus sp.) to the strongly decreased salinity, brackish environment of the Upper Sarmatian (as evidence may be regarded the presence of *Pirenella picta* and various species of the genera *Cerithium* and *Cerastoderma).*

In the Vienna Basin, predominant fossils at the boundary of Badenian/Sarmatian became bryozoans, in some places with the sedentary worms *Serpula.* Bryozoan zoaria of the species *Pentalopora foliacea* (ELLIS et SOL, 1786) form monospecific accumulations, creating thus conspicuous, even reef bodies in the Devínska Kobyla area. Such bodies often consist also of the association *Celleporaria plamata (*MICH.) - *Serpula,* especially in the area of the southern Slovakian sedimentation area.

In the Sarmatian, due to gradual decreasig of salinity a monotype communities of molluscs and ostracods were formed. In the Vienna Basin there predominated molluscs of the genera *Calliostoma* and *Mohrensternia,* more rare are species of the genera *Hydrobia* and *Pirenella.* A simlar mollusc community is known from the sediments of the East Slovakian Basin, where species of the genera *Cerithium, Hydrobia* and *Ervilia* are predominant. In the Danube Basin, sediments of Sarmatian age are known only from boreholes. From molluscs, predominant there are the genera *Cerastoderma, Modiolus* and *Mohrensternia* (SENEŠ edit. 1974).

The marked decrease of salinity is indicated by the ostracod genera *Candona* and *Candoniella.* Later on, species bearing well the lower salinity of the Sarmatian sea appeared as well, such as *Cytheridea hungarica, Aurila méhesi, Loxoconcha fragilis* and *Miocyprideis janoscheki.*

Climate: *Upper Badenian* (subzone MF - 6). In this time, we may observe a decrease in the number of thermophilous elements, but the cooling was less intensive that at the end of the Egerian, or at the end of the Ottnangian. Relatively short intervals of warm humid climate occurred too, with morasses in which the coal seams of Handlová and Nováky deposited. Based on palynomorphs it may be assumed that in the Paratethys area, the era of ferns from the family Shiczeaceae and of the deciduous Sapotaceae (i.e. of clearly tropical elements) ended. PLANDEROVÁ (1990) concluded from palynological data - based on the lower proportion of spore plants - that a more xerophilous flora existed then. In microscopic associations, elements of intermediary flora types are prevalent, such as *Carya, Pterocarya*, Taxodiaceae and Cupressaceae. *Engelhardia (Momipites)* were still abundant. The arctotertiary component started to prevail (*Pterocarya, Ulmus, Alnus, Carpinus*). PLANDEROVÁ (1990) determined a greater proportion of Chenopdiaceae, i.e. of halophytes elements, indicating a generally dryer climate.

Macroflora from this time is characterised especially by the genera *Salix, Alnus, Betula, Quercus* and *Acer.* Lauraceae are represented by the genera *Daphnogene* and *Laurus.* Lauraceae started to recede, replaced by mixed forests of flood plain forrest type. The flora is generally more continental, with predominant mixed forests, which we may find at present in the Balkan peninsula. All above data are evidence of a dryer and cooler climate than in the Lower Badenian.

Boundary Badenian - Sarmatian Zone MF-7. At the end of the Badenian, the proportion of mountain plant species increased. The general character of plants was more xerophilous. Based on predominant species in the pollen range, we may assume a warm, temperate climate with oscillating dry periods, which were dryer than in the late Badenian. In the pollen range, predominant there are the families Polypodiaceae, Cyatheaceae (tree and herb ferns) and Lycopodiaceae. From conifers, *Pinus* and *Picea* are repsented by a lower percentage, more abundant are Cedrus, *Sequuioa* and *Tsuga.* Frequently found angiosperms are the palm *Arecipites* and the genera *Ulmus, Quercus* and *Castanea.* Elements of tropical plants, the spores Symplocaceae (wood plants of present tropics and subtropics) and Sapotaceae are missing.

Macroflora is known from the borehole VT-D-5 in the Nováky Basin (SITÁR et al. 1987) and partly from the inter-seam layers in the Handlová Basin. There are elements of hydrophilous to morass plants, e.g. Sphagnum and Lycopodium, from krytosemenné Byttneriophyllum. Besides these, a large amount of impressions have been found, of the genera *Myrica, Laurophyllum, Daphogene, Acer, Ulmus* and *Magnolia.* Tropical elements are missing, but Lauraceae are still represented, indicating cooling of the climate.

Lower Sarmatian (zone MF-8). In the pollen range, some conifers as well as angiosperms are predominant. From conifers there are mostly *Sequoia.* Representatives of krytosemenné may be regarded as the most important component of the flora. They are above all Juglandaceae, Oleaceae and Betulaceae. The spore-pollen community was very rich in species, therefore we may assume that in this time there existed an optimum climate for the development of thermophilous vegetation of mixed deciduous-coniferous forest type.

The richness of flora is documented by the abundant finds of leaf impressions. The impressions of Fagaceae, Juglandaceae and Betulaceae are predominat, however, freqent are also *Parrotia* and *Platanus.* Although representatives of Taxodiaceae or *Byttneriophyllum,* i.e. elements of hydrophilous plants, occur in this flora as well, we may conclude that this flora indicates rather a dry and warm climate.

Volcanism: The time of the Upper Badenian and Lower Sarmatian is characterised by a very intensive stage of andesite volcanism, especially in the area of the Central Slovak Neovolcanics and in the Transcarpathian

Depression. Besides intermediary volcanism, acid - rhyolite volcanism type was present in the back-arc basin as well.

Upper Sarmatian - Pannonian (Pontian) stage

Tectonic regime : The syn-rift stage of back-arc extension was replaced by thermal subsidence of post-rift stage. At the end of this time (in the Pontian), as well as later in the Pliocene and Quaternary, there followed a period of tectonic inversion of the back-arc area, accompanied by the elevation of the Western Carpathian orogen. Intramontane basins became a part of the Pannonian basin system, in which, in spite of its isolation from the Mediterranean, we still feel the influence of global eustatic changes.

The central part of the Danube Basin (the Gabčíkovo and Komjatice depression) still diplays a marked subsidence. Intramontane basins (the Vienna and Eastern Slovakian Basins) display a relative decrease of subsidence, controlled mostly by normal faults.

Environment: The decrease of salinity in Sarmatian sedimentation areas is proved by a marked depletion of calcareous nannoplankton communities of the genus *Coccolithophoridae* and, on the othern hand, enrichment of communities of flagellate algae with an organic cell wall. In sediments of the Vienna Basin we may record, after the Lower Sarmatian mass occurrence of the algae *Leiosphaera* sp., the occurrence of tiny algae *Mecsekia incrassata* and the dinocysts *Spiniferites bentori* (Ross.), which live in delta areas. From dinoflagellates, predominant communities are those of the zone *Spiniferites bentori* (Szuto & Szentai 1988), with a 60% proportion of the genus *Spiniferites (Spiniferites bentori* S.-Szentai, *s. bentori pannonicus* S.-Szentai).

Planktonic dinoflagellates of the genera *Chytroeisphaeridia* and *Gaonyaulax*, as well as others, prove the communication of the Vienna Basin area with a more open-sea environment and the existence of near-bottom currents (Hudáčková, Kováčová, in press).

The Middle and Upper Sarmatian was in all basins on the Slovak territory in brackish development (zone with *Elphidium hauerinum,* Grill 1941), typical species being *Elphidium aculeatum* (Orb.), *E. reginum* (Orb.), *E. samueli* Zlinská, *E. hauerinum* (Orb.). The Upper Sarmatian is almost in freshwater development (zone *Nonion granosum,* Grill 1941) documented by shallow-water brackish species - *Porosononion* ex gr. *granosum* (Orb.) and rarely with *Ammonia parkinsoniana tepida* (Cush.), *Elphidium hauerinum* (Orb.) and *Miliolina* sp.

Brackish to lacustrine sedimentation area during the Upper Sarmatian is characterised also by in species poor, in some places even monotype, but in specimens very rich mollusc associations. In the Western Carpathian basins, there gradually predominated *Melanospis impress, Congeria ornithopsis, Theodoxus intracaraticus* and *Congeria partschi* (Papp et al. 1985). From ostracods, there are present monospecific accummulations of the species *Cyprideis tuberculata.*

The lake-river environment of the Pannonian is characterised above all by the occurrence of a bivalvian from the genus *Unio,* a gastropod of the genus *Planorbis* and the caspic-brackish ostracods *Cyprideis tuberculata, Cyprideis pannonica, Cyprideis sublittorali, Cyprideis heterostigma, Cyprideis obesa, Hemicytheria lorentheyi, Hemicytheria folluculosa, Amplocypris recta, Amplocypris abscissa, Caspiolla unguiculus* and *Caspiolla preabalcanica.*

In Pannonian sediments near Pezinok there was found a remnant of *Trogontberia* and the ancient horse *Hipparion,* belonging to the biozone MN 11. *Hipparion* was found also in Topoľčany and Slepčany, and as a rarity on the boundary Pliocene/Pleistocene also in Nová Vieska in southern Slovakia (Holec 1981).

Climate: *Upper Sarmatian - Lower Pannonian* Zone MF-9. Pollen ranges from sediments of the Upper Sarmatian point to a depletion of spore plants from the families Polypodiaceae and Cyatheaceae and increase in the number of representatives from the families Lycopodiacea and Osmundaceae. From conifers, Pinus is especially abundant. angiosperms are represented by a large amount of grasses - Gramineae (*Typha*), further *Juglans* and *Betula* (Planderová 1990).

From leaf remnants there are predominant leaves of the genera Betulaceae, Ulmaceae and Cornaceae, from spore plants *Equisetum* and *Osmunda.* Some oak species receded - *Quercus* (Sitár 1994). Based on the occurrence of pollen grains of Chenopodiaceae, the small proportion of *Byttneriophyllum* and *Glyptostrobus*, we may assume a more dry and moderately warm climate.

Upper Pannonian - Pontian. In the pollen range, there are represented the spores *Equisetum* and abundant *Gramineae, Pinus, Fagus, Ulmus* and *Alnus.* macroflora is represented mostly by krytosemenné, above all the genera *Carpinus, Betula, Alnus* and *Quercus.* From more thermophilous plants, we may mention *Ginkgo adiantoides* and *Cercidiphyllum crenatum.* From conifers there occur species of the genera *Torreya, Picea* and *Juniperus.* The forests had the character of mixed deciduous forests with prevalent beeches, oaks and parotias.

Volcanism: Alkaline-basalt to basanite volcanism of Pontian to Quaternaty age occurs mostly at the margins of the Pannonian back-arc area.

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