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LATE MIOCENE PALEOENVIRONMENTS AND SEQUENCE STRATIGRAPHY: NORTHERN VIENNA BASIN

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Abstract: Late Miocene sedimentary environments were related to the shallow brackish- to fresh-water lake in the Slovak part of the Vienna Basin. During the Pannonian time, the geological settings gradually changed from deltaic-dominated in Papp's A–C zones, through offshore-dominated (D–E zones), up to coal-bearing, limnic-dominated (F–H zones). The variation in sediment supply, eustatic sea-level oscillations and the subsidence influenced the formation of accommodation space and related geometry and lithology of sedimentary bodies. The sedimentary cycles were characterized by seismostratigraphic, sedimentological methods, well-log data and fossils content and interpreted in terms of sequence-stratigraphic concept. The Pannonian A, B zones of the recognized sedimentary cycle represents a duration of approximately 0.5 Ma, with possible further subdivision into two higher-order cycles. These cycles are regarded as parasequences within the late stage of the 3rd-order sequence, which continued from the Sarmatian. In the Pannonian sediments of the C–H zones, a further four full sequences were determined. The definition of the sequences is based on the recognition of lowstand, transgressive and highstand systems tracts. Erosional surfaces were recognized on seismic sections, and in the sedimentary record they are marked by redeposited older fauna in the lowstand deposits. During the sea-level rise a backstepping reflectors termination pattern is visible on seismic sections and during the transgressions rapid changes of faunal assemblages were also determined. The highstand deposits are often represented by condensed sections and low-aerated conditions in the Vienna Basin centre. The maximum flooding surface within the D zone represents the initial highstand stage and can be indicated by a dinoflagellates-rich horizon.

Key words: Vienna Basin, Late Miocene, sequence stratigraphy, paleoenvironments.

Introduction

The Vienna Basin is situated within the Alpine-Carpathian mountain chain, between the Eastern Alps and the Western Carpathians. It represents a polyhistoric basin with Neogene to Quaternary sedimentary fill, deposited in various types of basins in relation to the paleotectonic development of the orogen.

The Eggenburgian to Ottnangian sedimentation took place in a system of piggy-back basins and intramontane wrench-fault furrows, developing in a compressive tectonic regime, due to the collision of the orogen with the North European Platform (Kováč et al. 1989; Kováč et al. 1997). During the Karpatian and the Early Badenian times the Vienna pull-apart basin was formed, following the lithospheric displacement of the Western Carpathians northeastwards (Royden 1988; Ratschbacher et al. 1991a,b). From the Middle Badenian to the Sarmatian the basin subsidence was controlled by back-arc synrift extension. The post-rift stage of the basin development represents the Pannonian and Pontian evolution of the Vienna Basin, which gradually changed into the tectonic inversion of the area during the Pliocene and Quaternary times (Kováč et al. 1997).

The aim of this paper is to clarify the sequence stratigraphy of the Pannonian basin fill, of the basis of new results obtained by sedimentological and paleontological study of surface outcrops and boreholes, as well as by reinterpretation of seismic sections and well-log data in the Slovak part of the Vienna Basin (Fig. 1).

Stratigraphy

The Late Miocene radiometric dating of the Neogene stage boundaries, carried out on volcanic rocks of the Western Carpathians (Vass et al. 1985) determined: the Sarmatian/Pannonian boundary as 11.5 ± 0.5 Ma, the Pannonian/Pontian boundary as 8.5 ± 0.5 Ma and the Pontian/Pliocene boundary as 5.6 ± 0.2 Ma. According to new data, the boundary between the Pannonian and the Pontian was shifted to 7.1 Ma (Rögl 1996).

The Late Miocene sedimentary environment changes are well reflected in faunal changes in the Vienna Basin deposits. The oldest division of these rocks was based on study of molluscs (Papp 1951, 1985) and subdivided the Pannonian strata into the lower part, containing small *Congeria* of the A, B and C biozones, overlain by a sedimentary succession with large *Congeria* of the D and E biozones. Besides the brackish-water fauna of zone F, the Pontian was characterized by the fresh-water fauna of the G and H biozones (Rögl & Steininger 1990) (Table1, Pl. I).

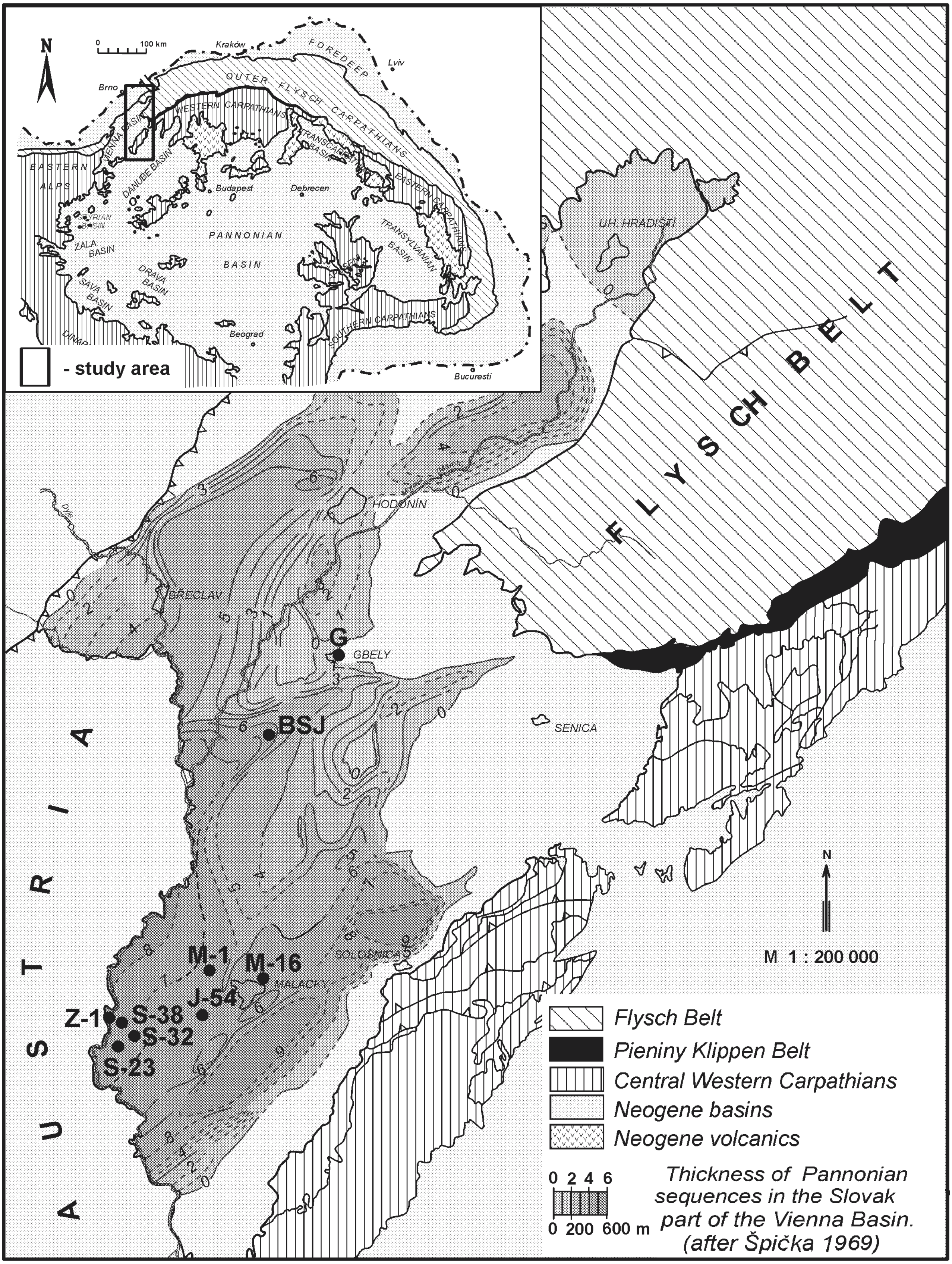


Fig. 1. Situation of the Vienna Basin within the Alpine-Carpathian mountain chain, thickness of the Pannonian strata in the northern part of the basin. The studied boreholes are marked: M — Malacky, J — Jakubov, S — Suchohrad, Z — 1-Suchohrad; outcrops: G — Gbely, BSJ — Borský Svätý Jur.

Table 1: Neogene chronostratigraphy and sequence boundary ages.

Geochronometric scale in Ma.	Chronostratigraphy and sequence boundary ages: Period	Mediterranean stages	Systems tracts (Haq 1991)	Central - Paratethys stages	Biozones (Papp 1951)		Systems tracts (Pogácsás & Seifert 1991)	VIENNA BASIN (Kováč et al. in this paper): Biozones (Rögl et al. 1993)	Systems tracts 3-rd order (this paper)
4	PLIOCENE	ZANCLEAN	TS, LS	ROMAN.		fresh water fauna			
4.4			HS	DACIAN					
5									
5.3			TR, LSW						
5.6	LATE MIOCENE	MESSINIAN	HS	PONTIAN					
6			TR, LSW		GH				
6.5			HS		F				
7 / 7.1		TORTONIAN		PANNONIAN					
8			SMW			large congeria	?	GH	HS, TR
9			HS		E			F	SMW
								E	HS, mfs
10			TR, LSW		D		HST	D	TS
11			HS		C	small congeria	TST	C	LS
11.5					AB			AB	HS
12	MIDDLE MIOCENE	SERRAVALIAN	TR, LSW	SARMAT.			LST		HS

The first appearance of *Hipparion* is recorded from the base of Pannonian zone C (Papp 1951; Rögl et al. 1993; Steininger et al. 1996). This appearance is correlated throughout Europe with the base of the MN 9 mammal zone (Mein 1975; Rögl et al. 1993; Rögl 1996). The finding of *Hipparion* sp.*, Ictitherium viverrinum, Perunium ursogulo, Monosaulax* sp. and *Lagomerix* sp. in deposits of the Papp´s zone E at Borský Svätý Jur indicate the presence of the MN 10 to MN 11 zones (Lupták 1995a,b; Pipík & Holec 1998).

According to micromammals the boundary between the zones MN 9 and MN 10 (Mein 1975; Steininger et al.1990, 1996) is based on the first appearance of murids. The first *Progonomys* is recorded from the locality Neusiedl am See from fluvial sands of the "zone G" (sensu Papp 1951) and the famous freshwater section of the Eichkogel at the western border of the Vienna Basin has a very rich fauna of the MN 11 zone (Mein 1975; Steininger et al. 1990, 1996).

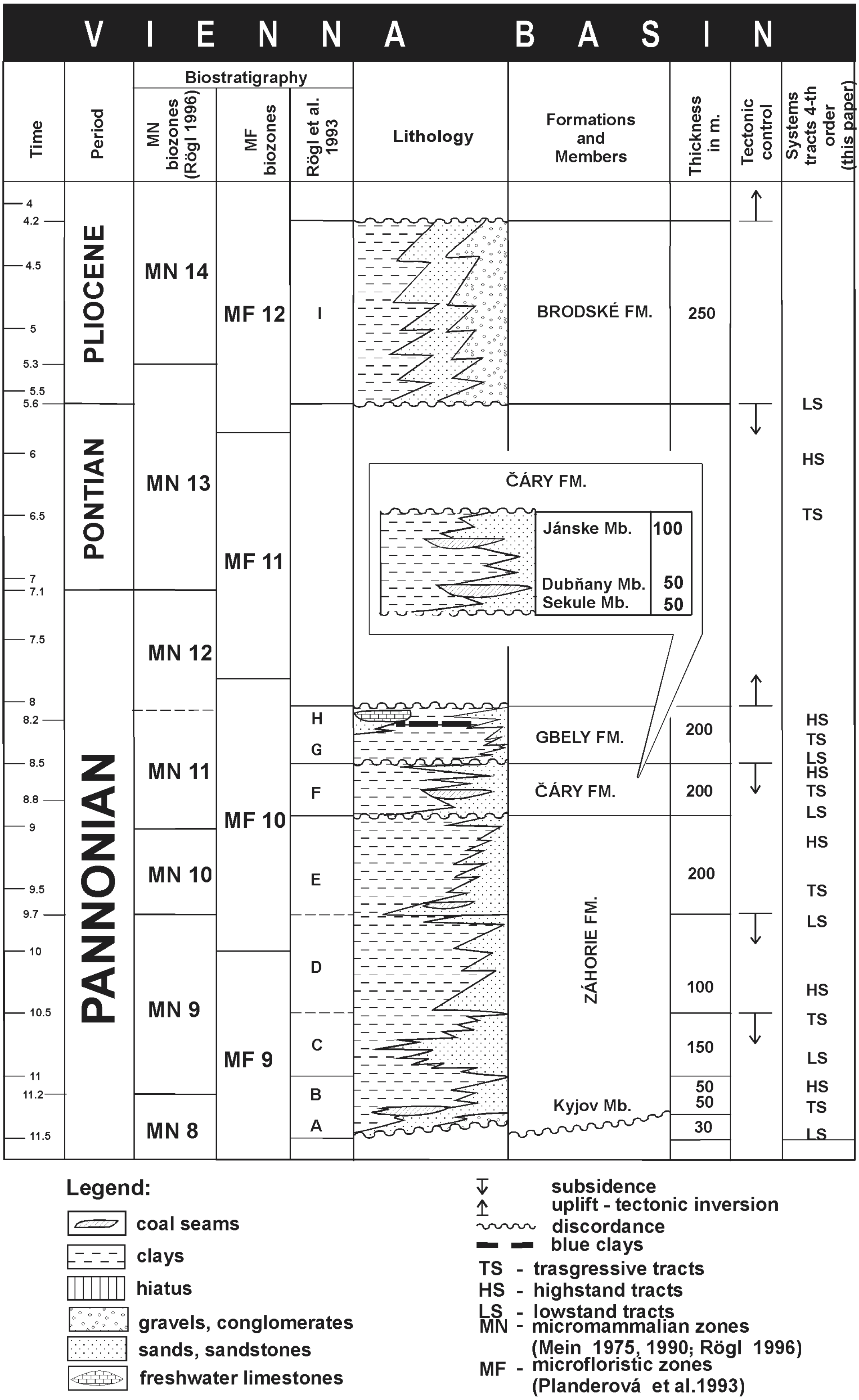
Deposits of the G–H zones (Papp et al. 1985) represented in the northern part of the Vienna Basin by the Gbely Fm., were correlated with the Early Pliocene (Bartek 1989). We incline to the opinion, that the formation represented a deposition below the boundary of 7.1 Ma, during late Pannonian times (Table 2). The Pliocene sedimentation started with deposition of the Brodské Fm. (Bartek 1989).

Paleoenvironments and sea-level oscillations

The end of the Middle Miocene (Late Sarmatian) was characterized by sea-level fall in the Vienna Basin. A shallow brackish-marine environment in the basin is documented by the *Elphidium hauerinum* biozone (Grill 1943). The results of pollen analysis indicate a subtropical, warm and humid climate of the MF-9 biozone (Planderová et al. 1993).

At the beginning of the Pannonian stage — **A zone** (11.5–11? Ma) (Papp 1951, 1985), the higher-order lowstand sea-level fall led both to the erosion of older sediments and to deposition of a prograding lowstand wedge (Table 2). In the study area it is documented by an unconformity between the Sarmatian and Pannonian strata (Jiříček 1985a), above which

Table 2: Late Miocene biozones, lithology and sequence stratigraphy of the Vienna Basin.



a delta front facies was deposited. The sandstones of the delta front contain water-escape structures and synsedimentary slump deformations and become finer upwards into laminated sandy-clayey prodelta facies (Pl. II). The heavy minerals association indicates a transport mostly from the Outer Carpathian Flysch zone.

A brackish-water sedimentary environment with decreased salinity (15–10 ‰) is documented by ostracods, e.g. *Cyprideis pannonica* Mehes, *C. tuberculata* Mehes, *Hungarocypris auriculata* (Reuss) etc. The erosion of older sediments and their transport basinwards is reflected by the redeposited Sarmatian, Badenian and Karpatian macro- and microfauna during this time.

The offshore facies consists of hemipelagic laminated and homogenous clays and silty clays with abundant plant debris and infaunal bioturbation.

The arctotertiary elements of geoflora, predominantly *Abies*, *Tsuga, Picea* and *Cedrus*, indicate a temperate and humid climate at the Sarmatian/Pannonian boundary. The lowstand period with marshes and lagoons at the basin margins caused the increased pollen portion of *Chenopodiaceae* and *Taxodium,* less *Myrica* and *Nyssa* (swamp vegetation elements) in the palynospectra. The increased pollen portion of *Ericaceae* points to a fluvial influence. The accumulation of *Chenopodiaceae* in the interfluve areas probably indicates a local saline swampy environment during the sea level fall (Pl. III).

In the Early Pannonian strata — **B zone** (11.5?–11 Ma) (Papp 1951), two horizons of prodeltaic and basinal sediments are separated by delta-front sandy and gravelly facies with an erosive base. The prograding delta-front facies can be interpreted as deposited during a higher order lowstand period within the lower frequency transgressive systems tract (Fig. 2). The clastic material was transported from the northwest, as it is visible in seismic sections.

The offshore facies is represented by grey calcareous clays with typical small congerias (*Congeria ornithopsis* Brusina) and gastropods *Melanopsis impressa bunellii* Manyoni, *Melanopsis impressa posterior* Papp. The ostracods *Cyprideis, Amplocypris* sp. and *Hungarocypris auriculata* (Reuss) document a still brackish-water sedimentary environment with the salinity of 15–10 ‰ (Tables 1, 2, Pl. IV).

The vegetation assemblage of MF-9 biozone (Planderová et al. 1993) (Pl. III) with dominating *Pinus* and *Alnus–Ulmus–Myrica* subdominance on the basin margin indicates a temperate climate. The near-shore facies at the base of the Pannonian zone B is represented besides brackish-water also by freshwater lagoonal coal bearing sediments (Kyjov Mb.), representing the initial transgressive stage (Table 2).

During the Middle Pannonian — **C zone** (11–10.5? Ma) (Papp 1951; Rögl et al. 1993), the shelf-margin wedge (or lowstand wedge) development was followed by transgression. Incised valleys in deposits of the A and B zones were filled by conglomerates, passing upwards into coarse-grained sands (Fig. 2). During this time a sandy sedimentary body up to 150 m thick was deposited, containing a rich mollusc fauna with *Melanopsis fossilis* Martini-Gmelin, *M. bouei* Ferussac, *Dreissena turislavica* Jekelius, *Theodoxus intracarpathicus* Jekelius, *Congeria hoernesi* Brusina. Basinwards, the upper part of the sands passes into calcareous clays with *Congeria partschi* Papp, documenting still brackish environment with the salinity of 15–10 ‰.

During the Pannonian — **D zone** (10.5?–9.7? Ma) (Papp 1951; Rögl et al. 1993), the basin subsidence accelerated and about 100 m of grey calcareous clays were deposited, containing large congerias *Congeria partschi partschi* Czjzek, *C. globosatesta* Papp (Pl. I), as well as *Melanopsis fossilis pseudoimpressa* Papp and *Limnocardium ornatum ornatum* Pavlovic (Jiříček 1985a). The marginal sandy facies contains *Melanopsis fossilis coaequata* Handmann and *M. fossilis constricta* Handmann. The rapid change of the faunal assemblage is considered to be related to the 3rd -order eustatic-controlled transgression (Table 2).

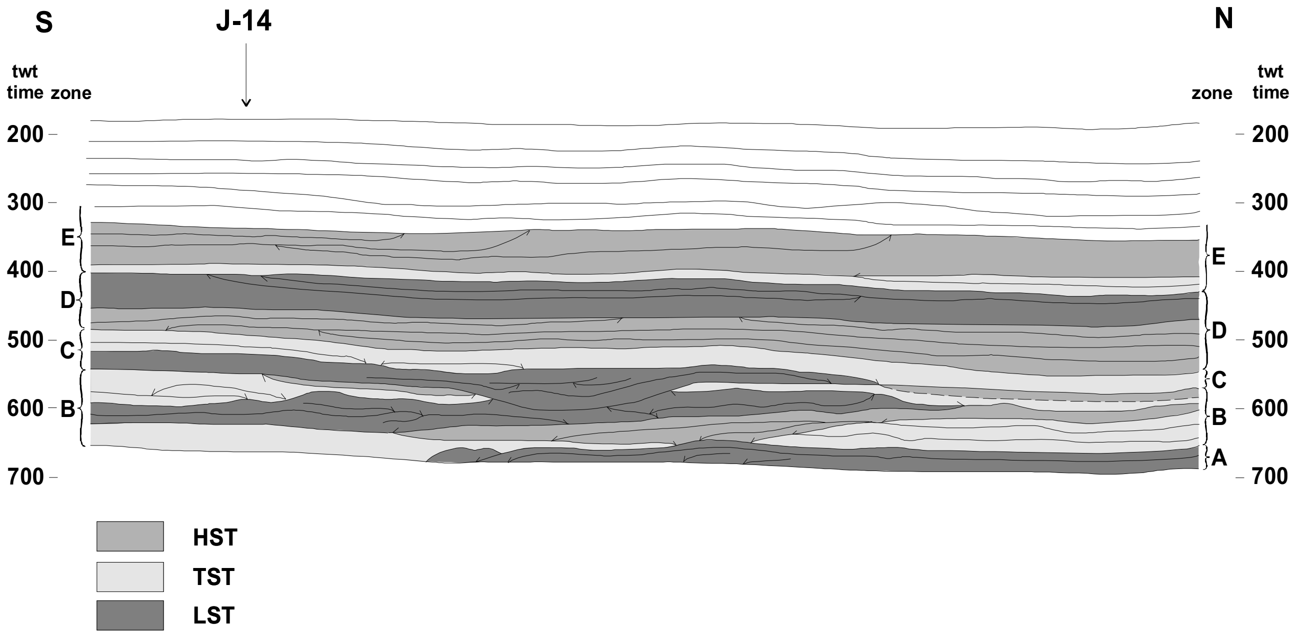


Fig. 2. Seismic sequence stratigraphy from the Jakubov area.

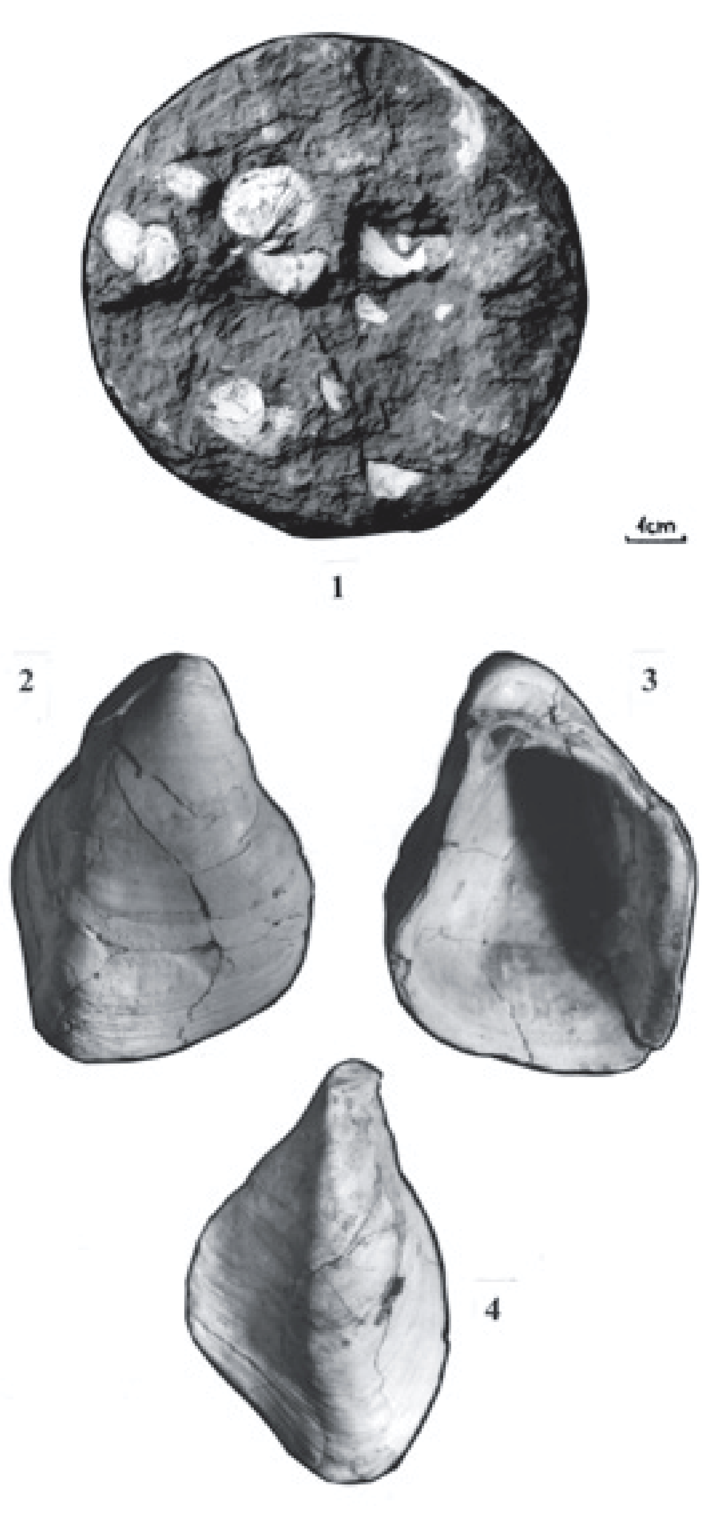


Plate I: Fig. 1. *Ervilia dissita* Eichwald and fragments of small congeria, S-38 borehole. Large congeria: **Figs. 2, 3.** *Congeria subglobosa subglobosa* Partsch. **Fig. 4.** *Congeria ungulacaprae* Münster.

The deposition of fine-grained prodeltaic sediments continued in the study area. Synsedimentary siltstone intraclasts in clays point to sea-level fall in the upper part of the D zone. Ostracods *Amplocypris recta* (Reuss), *A. abscissa* (Reuss) point out to the lowered salinity of sedimentary environment ranging from 15–10 ‰ (Pl. IV).

Pollen analysis data with prevailing *Alnus–Betula–Myrica–Nyssa* coastal vegetation on the basin margin, indicate a temperate climate during the lower part of the MF-10 biozone (Planderová et al. 1993) (Pl. III).

During the Pannonian — **E zone** (9.7?–9? Ma) (Papp 1951; Rögl 1996; Sacchi et al. 1997), the accelerated sea-level rise is reflected by blooms of the dinoflagellate species *Spiniferites bentori oblongus* Suto & Szemlai, with which enrichment indicates an increased depth of sedimentation (maximum flooding surface) (Pl. VI). The ostracods also indicate the best migration conditions. Approximately 20 of the 57 Upper Pannonian species found in Mt. Medvednica (Croatia) are present in the Vienna Basin. Rundić (1991) described very similar ostracods from the area around Belgrade (Yugoslavia). During the highstand stage, a retreat of deltaic sedimentation from the study area is visible, being followed by an onset of shallow-water basinal facies of bioturbated clays.

The palynospectrum corresponds to the MF-10 biozone (Planderová et al. 1993) and contains a dominance of coniferous woody plants of mountain vegetation (*Pinus, Picea, Abies, Tsuga)* (Pl. V) and *Salix*. The mountain vegetation may document a sea-level rise and a flooding of the basin coastal plain. The subdominance of various herb species in the upper part of the E zone can be regarded as a consequence of sea-level fall and widening of steppe environment on the basin margins.

The offshore clays of the E zone are rich in large *Congeria* (*Congeria subglobosa* Partsch, *Congeria pancici* Pavlovic*)*, as well as in *Congeria zsigmondyi* Halavats*, Psilunio atavus* Partsch*, Melanopsis vindobonensis* Fuchs, *Dreissenomya piriformis* Papp, *Limnocardium conjungens* Partsch*, L. brunnense* Andrusov. The salinity of the sedimentary environment can be determined as 3–15 ‰, on the basis of the presence of the ostracods *Cyprideis heterostigma* (Reuss*), C. obesa* (Reuss) and a large number of *Candoninae* (e.g. *Candona unguicula* (Reuss), *Candona mutans* Pokorný).

During the Pannonian — **F zone** (9?–8.5? Ma) (Papp 1951; Rögl 1996; Sacchi et al. 1997), the sedimentary succession of the Čáry Fm. was deposited.

The succession started by the Sekule Beds (Bartek 1989) transgressive sandy-clayey deposits

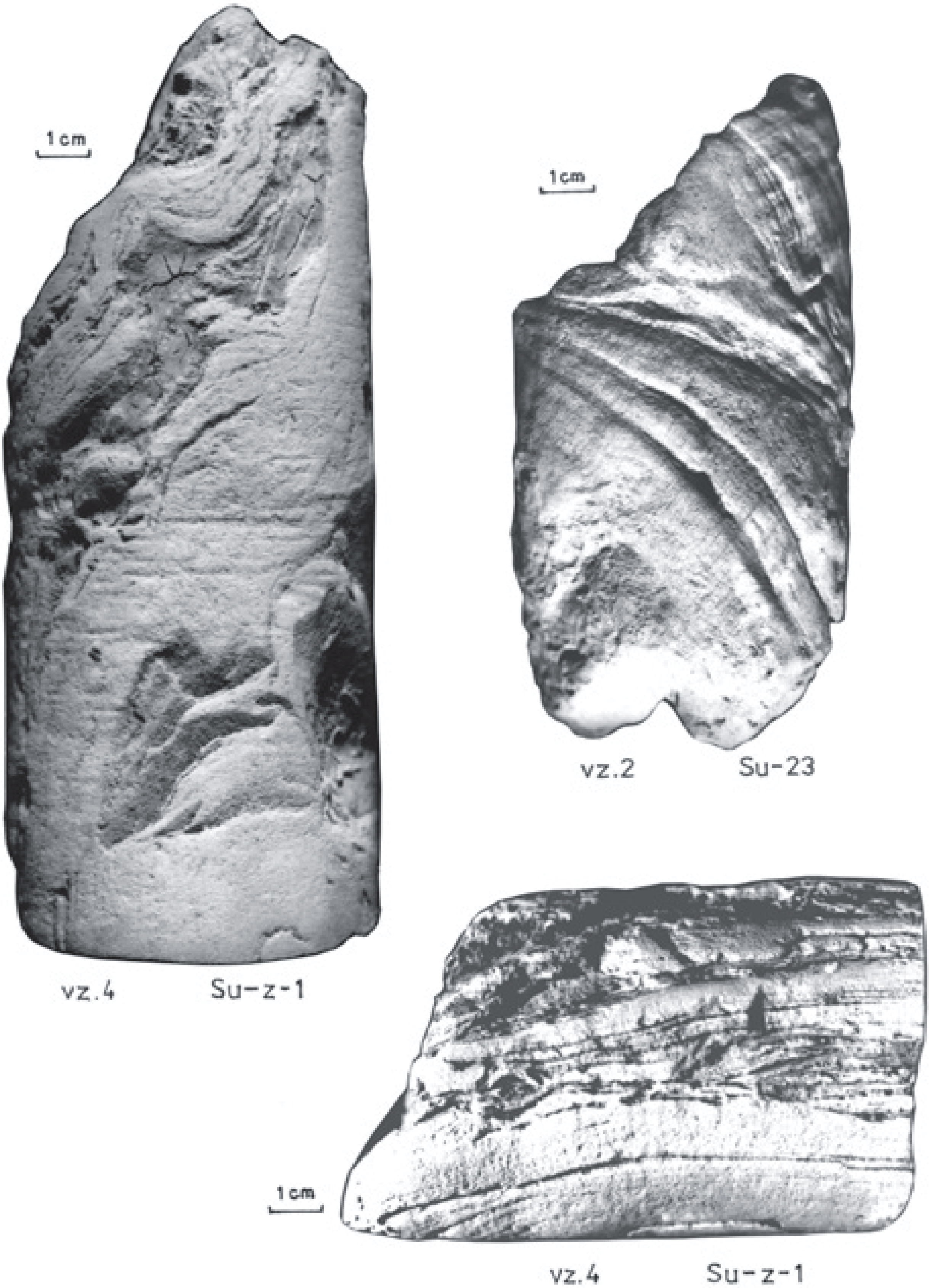


Plate II: Soft-sediment deformations in the delta front facies from the boreholes Z-1 and S-23.

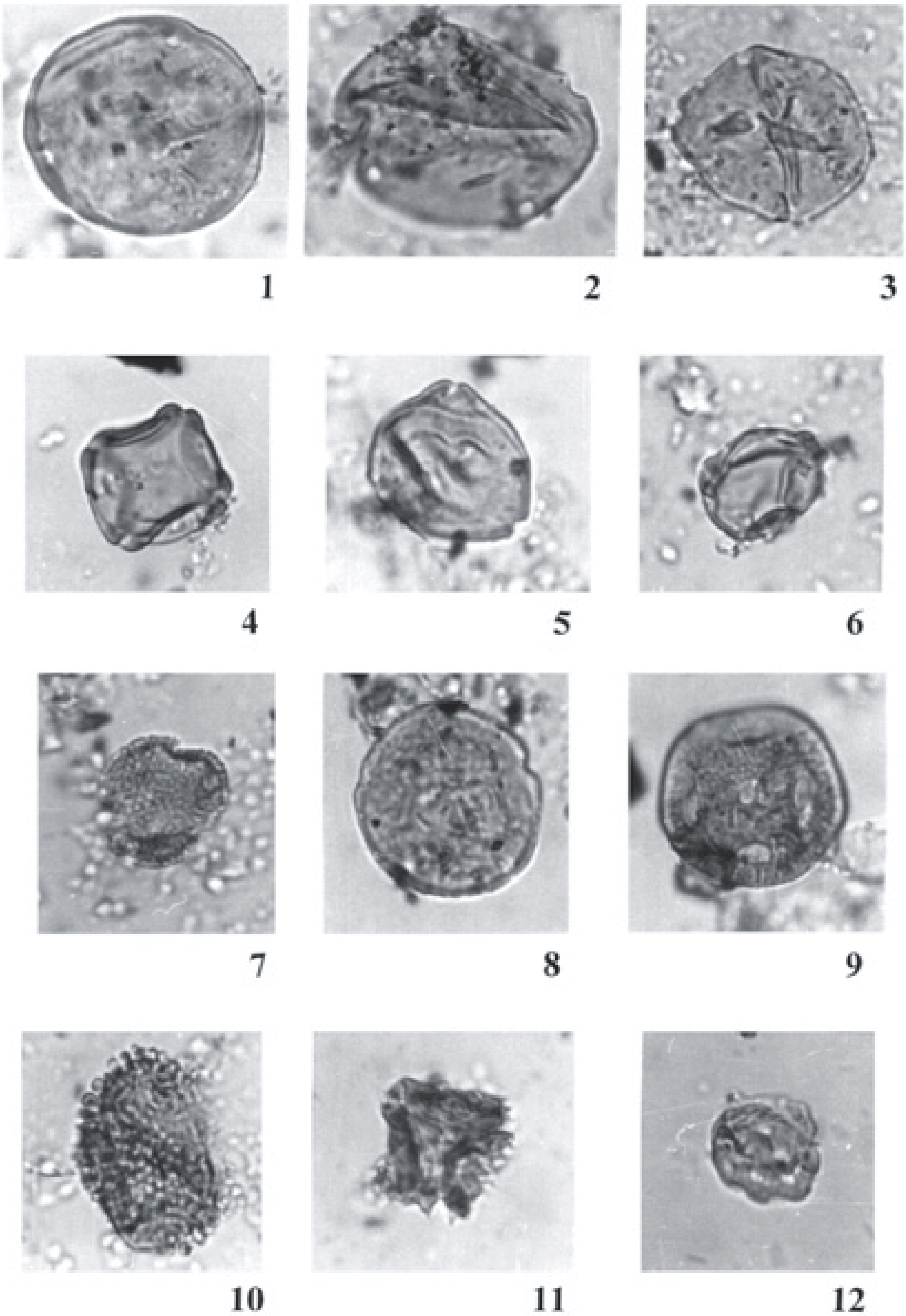


Plate III: All photographs enlarged ×1000. **Fig. l.** *Caryapollenites simplex* (Potonié) Raatz, G outcrop. **Fig. 2.** *Carpinipites carpinoides* (Pflug) Nagy, G outcrop. **Fig. 3.** *Pterocaryapollenites stellatus* (Potonié) Thiergart, S-32 borehole. **Fig. 4.** *Alnipollenites verus* Potonié, S-32 borehole. **Fig. 5.** *Myricipites rurensis* (Pflug & Thomson) Nagy, S-38 borehole. **Fig. 6.** *Betulaepollenites betuloides* (Pflug) Nagy, S-32 borehole. **Fig. 7.** *Salixipollenites* sp., S-32 borehole. **Fig. 8.** *Ulmipollenites undulosus* Wolff, S-38 borehole. **Fig. 9.** *Liquidambarpollenites* sp., G outcrop. **Fig. 10.** *Ilexpollenites margaritatus* (Potonié) Raatz, G outcrop. **Fig. 11.** *Cichoreacidites* sp., G outcrop. **Fig. 12.** *Chenopodipollis multiplex* (Weyland & Pflug) Krutzsch, S-32 borehole.

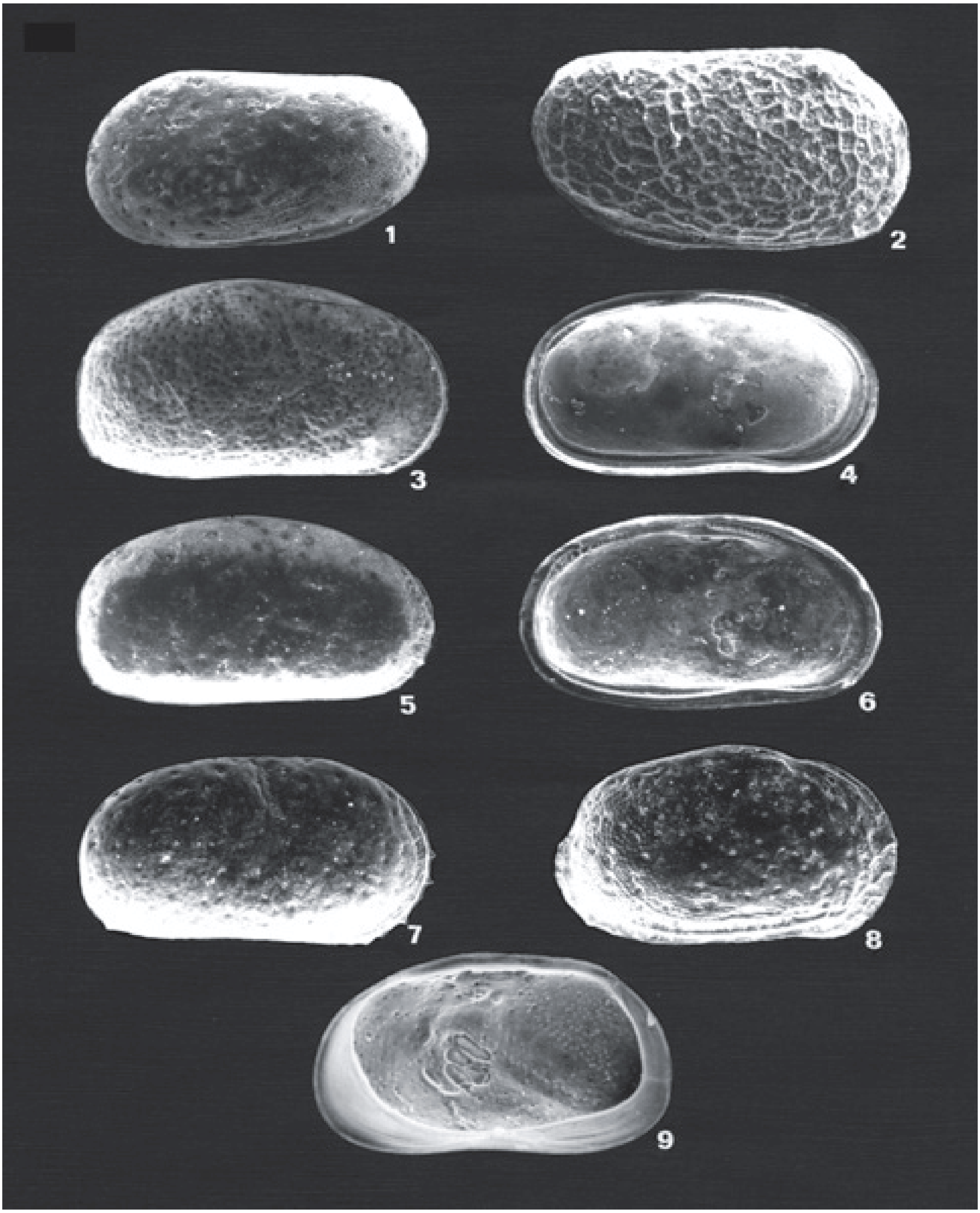


Plate IV: Fig. 1. *Loxoconcha muelleri* (Mehes), Lv, outside, 107×, M-16 borehole. **Fig. 2.** *Loxoconcha kochi* (Mehes), Rv, outside, 111×, M-16 borehole. **Fig. 3.** *Cyprideis tuberculata* (Mehes), Rv, outside, 81×, S-32 borehole. **Fig. 4.** *Cyprideis tuberculata* (Mehes), Lv, inside, 70×, S-32 borehole. **Fig. 5.** *Cyprideis pannonica* (Mehes), Rv, outside, 81×, M-16 borehole. **Fig. 6.** *Cyprideis pannonica* (Mehes), Lv, inside, 70×, M-16 borehole. **Fig. 7.** C*yprideis heterostigma* (Reuss), Rv, outside, 57×, J-54 borehole. **Fig. 8.** *Hemicyteria reniformis* (Reuss), Rv, outside, 67×, J-54 borehole. **Fig. 9.** *Amplocypris recta* (Reuss), Rv, inside, 73×, BSJ outcrop. Lv — left valve. Rv — right valve.

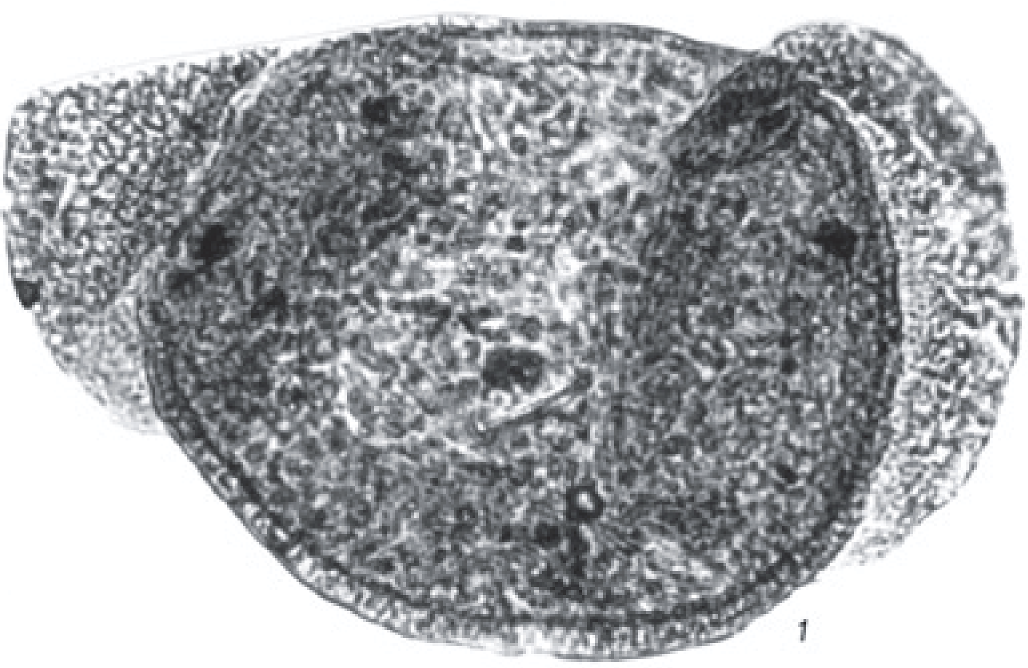
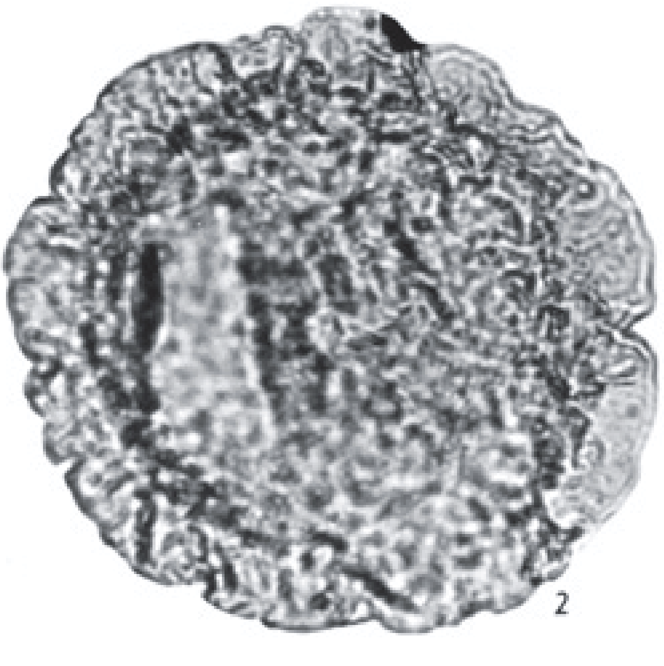
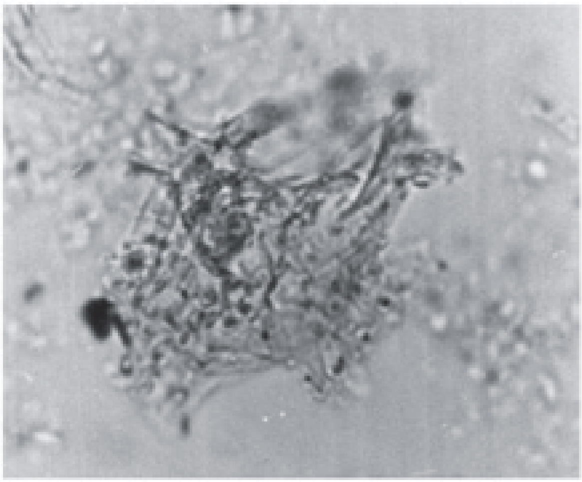




Plate V: All photographs enlarged ×1000. **Fig. 1.** *Abiespollenites maximus* Krutzsch*, G outcrop.* **Fig. 2.** *Tsugaepollenites rueterbergensis* (Krutzsch) Nagy, G outcrop. **Fig. 3.** *Inaperturopollenites* cf. *hiatus* (Potonié) Thomson & Pflug, S-32 borehole.

with coquinas of *Congeria zahalkai* Spalek*, Congeria neumayri* Andrusov and *Limnocardium,* as well as molluscs *Dreissena* and *Valvata* (Tables 1, 2). Later the Dubňany lignite beds were deposited, being than overlain by fine-grained sandstones with coquinas. The ostracods *Cyprideis seminulum* (Reuss), *Cypria abbreviata* (Reuss), *Candona neglectan* Sars*, Darwinula stevensoni* Brady & Robertson document the 0–15 ‰ salinity of the sedimentary environment (Pl. IV). The east-Serbian ostracod assemblages determining the Novorossian and Portaferian stages (Krstić & Stancheva 1989) have no analogy in the Vienna Basin. The only common species seems to be *Caspiolla venusta* (Zalanyi). The paleobotanical data point to swamp vegetation with *Glyptostrobus, Nyssa, Phragmites* (Knobloch 1963).

The overlying Jánske Beds are composed of grey clays, sandy clays with plant debris, sands and thin lignite seams in the lower part (Table 2). The beds were deposited partly in a fresh-water environment, which is documented by the mollusc fauna, e.g. *Unio* sp*., Planorbis confusus* Soos*, Planorbis grandis* (Halavats)*, Viviparus* and *Anodonta.*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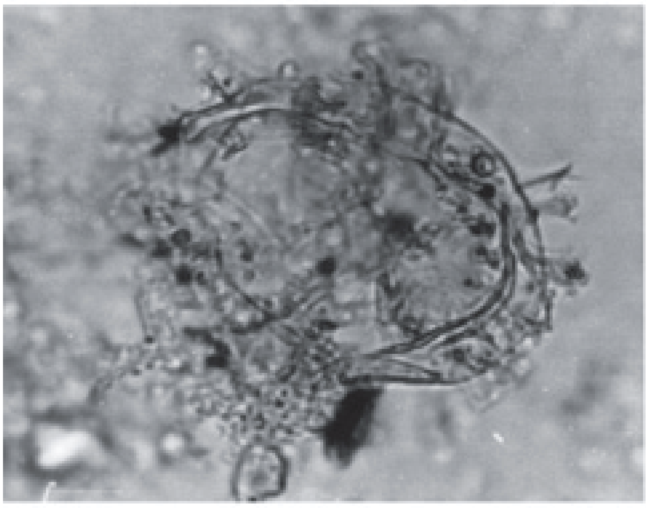

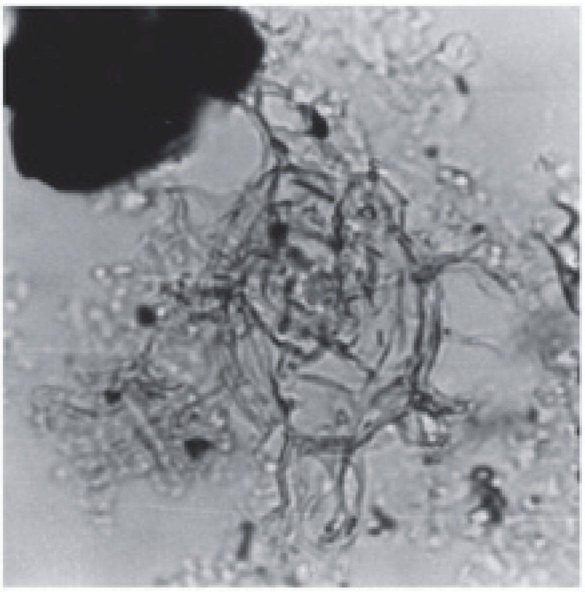
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Plate VI: All photographs enlarged ×1000. **Fig. 1.** *Spiniferites bentorii oblongus* Suto Szentai, G outcrop. **Fig. 2.** *Spiniferites* sp., G outcrop. **Fig. 3.** *Achomosphaera* cf. *andalusiense*, G outcrop.

The Pannonian **G–H zones** (8.5?–7.1? Ma) (Papp 1951; Rögl et al. 1993) are represented by fresh-water sediments of the Gbely Fm.

The G zone is represented by sands, sandy clays with plant debris and typical blue clays. A fresh water environment is documented by the mollusc fauna e.g. *Viviparus, Valvata* and ostracod fauna *Darwinula stevensoni* Brady & Robertson, *Candona candida* (O. F. Müller), *Pseudocandona marchica* Hartwig etc.

The H zone is represented by variegated clays and fresh-water limestones with *Valvata, Planorbis, Pisidium* and *Characeae* orogens.

The overlying Pliocene Brodské Fm. was deposited in a fluvial environment and consists of gravels, sandy clays and sands with redeposited lignite fragments (Jiříček 1975; Bartek 1989).

Sedimentary cycles and sequence stratigraphy

On the basis of detailed reflection-seismic data with interpreted reflectors-termination patterns, completed by original and regionally correlatable electric well-log data (such as SP and R curves), sedimentological well-core interpretations and paleontological environmental and biostratigraphic analysis from both wells and outcrops we interpreted sedimentary cycles in terms of the sequence-stratigraphic concept (Figs. 2, 3, 4, Table 2).

The seismostratigraphic interpretation (Fig. 2) enabled us to recognize four sedimentary cycles within the Pannonian A–E zones. The younger cyclicity (Pannonian E–H) was interpreted from sedimentological and paleontological results.

The geological settings changed upwards from deltaic-dominated (A–C zones), through offshore-dominated (D, E zones), up to coal-bearing, limnic-dominated (F–H zones). The paleoenvironmental transformation is considered to be caused by eustacy and later by gradual extinction of sedimentary accommodation place in the Vienna Basin during the Late Miocene and Pliocene times.

The first Pannonian sedimentary cycle has a duration of 0.5 Ma (Pannonian A, B zones) and represents probably the 4th-order parasequence (Table 2). It can be further subdivided into two higher-frequency parasequences (PS 1, PS 2), based on the seismostratigraphic record (Fig. 2). These fine-scale cycles probably belong to the late 3rd -order highstand systems tract or falling-stage systems tract.

The higher-order parasequences originated under the influence of changing sediment supply and related available accommodation space in the deltaic-dominated setting (Jiříček 1985b).

The PS 1 parasequence has an erosive base, correlated with the Sarmatian/Pannonian boundary. The delta-front progradation and redeposition of sediments with older fauna into the basin centre created a lowstand wedge and basin-floor fans during the Pannonian A zone. The delta-front facies is covered by backstepping sandy facies of the transgressive systems tract with characteristic filling

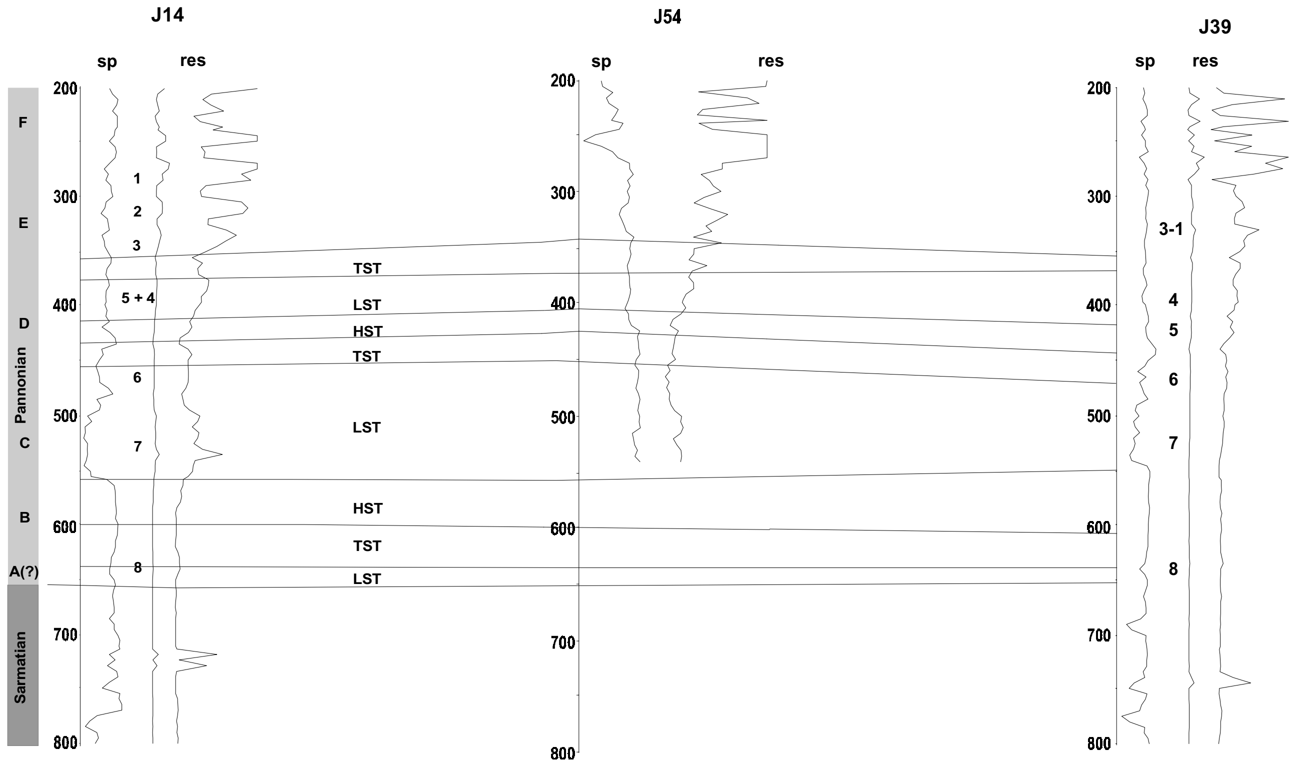

Fig. 3. Sequence stratigraphic interpretation of the well logs (SP and R curves) data from the Jakubov boreholes.

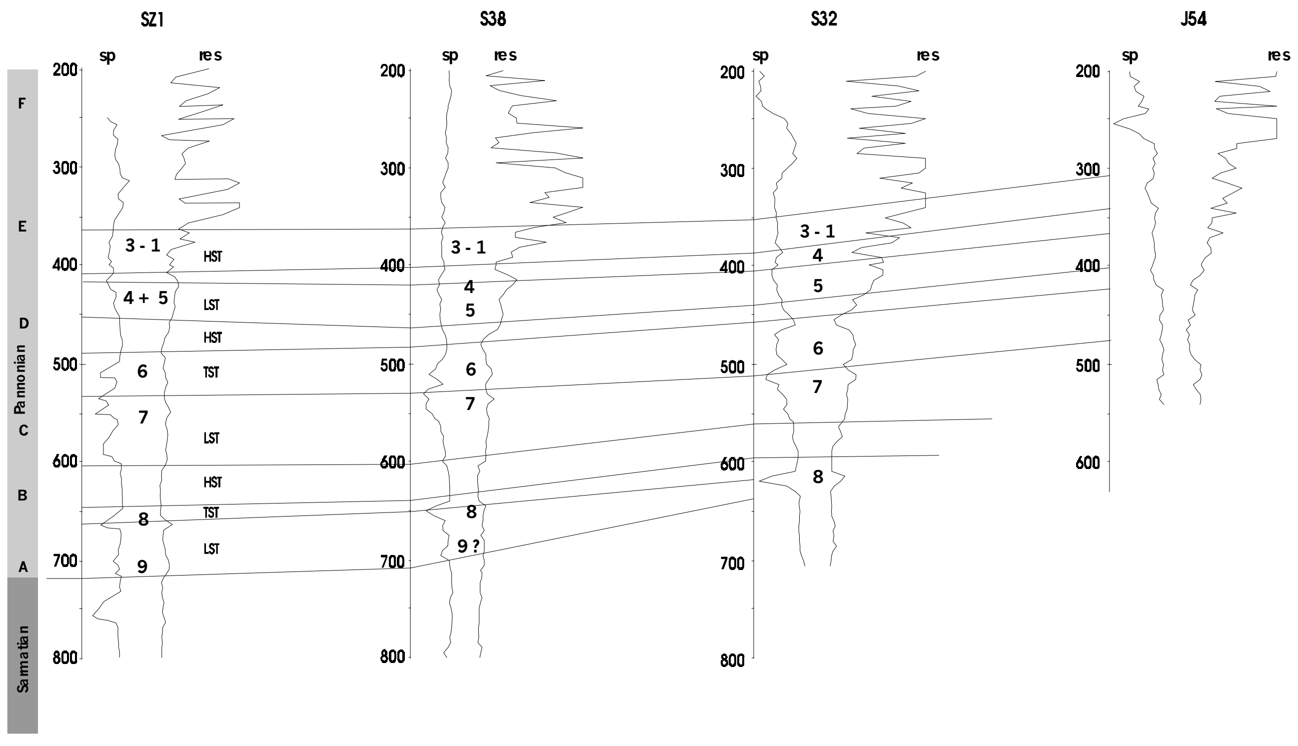

Fig. 4. Sequence stratigraphic interpretation of the well logs (SP and R curves) data from the Jakubov and Suchohrad boreholes.

of increased accommodation place, passing upwards into downlapping highstand systems tract (Fig. 2).

During the Pannonian zone B an onlapping sandy and gravelly sedimentary body represents the lowstand wedge at the base of the PS 2 parasequence. The wedge is covered by finer-grained prodeltaic and basinal facies.

The sedimentary succession of this parasequence is locally deeply eroded and covered by a thick deltaic sand body of the next-sequence lowstand systems tract, stratigraphically correlated with the Pannonian C zone (Fig. 2).

A minor erosive surface within the Pannonian D zone represents the base of the next sequence. The lowstand prodeltaic sediments pass upwards into basinal transgressive and thick highstand clays of the E zone. The upper surface of prograding highstand deposits is truncated by a major erosive surface (Fig. 2), thus marking the 3rd-order sequence boundary.

The sedimentary succession of the E zone was described also from outcrops in the Hodonín brick-yard (Jiříček 1985a). These sandy-clayey sediments can be divided into three parts (E1, E2 and E3).

E1 consists of transgressive facies with a thin coal seam on the basis, passing upwards into dark gray clays with *Limnocardium schedelianum* and *L. conjugens.* E2 is built by variegated (yellowish) clays with very poor fauna content, representing the highstand low-aerated conditions. The overlying sandy sediments of the E3 part containing coquinas with *Congeria spatulata,* alternate with calcareous clays with *Congeria subglobosa, Limnocardium brunnense, Dreissenomya primiformis, Caspiolla unguicula* and *Cyprideis,* and represent deposition under lowstand conditions. These data are in a good correspondence with the seismostratigraphic division (Fig. 2).

The sedimentary succession of the F zone contains four coal-bearing cyclothemes (Jiříček 1985a). They consist of lignite, overlying sands and clays.

F1 — Dubňany lignite seams and clays with *Congeria neumayri* were interpreted as transgressive deposits, F2 — Jánske lignite seams 1 and clays with *Congeria zahalkai*, as well as F3 — Jánske lignite seams 2 and clays with *Congeria zahalkai* represent highstand deposits. F4 — Jánske lignite seams 3 and clays with *Congeria neumayri* were regarded as lowstand deposits.

The limnic Gbely Fm. (G, H zones) can be interpreted as an individual sequence with an erosive base and eroded upper part (Table 2). The highstand stage is considered to be correlatable with the anoxic blue clays without faunal remnants.

Discussion and conclusions

The Late Miocene sedimentary environment in the Northern Vienna Basin was a shallow brackish- to fresh-water inland sea to lake at the northwestern margin of the Pannonian basin system.

The geological settings were changed upwards from deltaic-dominated during Papp's A–C zones, through offshore-dominated (D, E zones), up to coal-bearing, limnic-dominated (F–H zones). The overlying Pliocene deposits show an alluvial dominance during sedimentation. The dominant geological settings have a strong influence on the rate of deposition, due to the sediment supply and related formation of available accommodation place.

From the sequence-stratigraphical point of view, Pogácsás & Seifert (1991) considered relating the Late Sarmatian sediments to the lowstand period of sedimentation. On the basis of sedimentological studies, a 3rd-order transgressive systems represented by typical limestone facies was identified, at the beginning of the Late Samartian (Nagy et al. 1993). Its continuation is represented by fining-upwards sandy and clayey facies of a highstand systems tract. According to correlation with another study of Plint & Nummedal (in press) the partial erosion at the Sarmatian/Pannonian boundary can be explained also during the late 3rd-order highstand period, thus representing a falling stage systems tract.

The finer-scale parasequences, recognized in the Early Pannonian strata (A, B zones), are interpreted as local relative sea-level variations during the late 3rd-order highstand systems tract or falling-stage systems tract, which continued from the Sarmatian (Table 1).

On the base of Papp's C zone a distinct erosive surface marks the next 3rd-order sequence boundary, covered by a thick delta-front-related lobatic system, representing a lowstand systems tract. The following transgression influenced the new faunal migration and significant faunal change from the small congerias to the large congerias at the base of zone D. The following highstand deposits show a gradual decrease of thickness basinwards (to the SE), which can be related to the synsedimentary normal tectonics on the western margin of the basin (Table 2).

A minor erosive surface within the D zone indicates the base of the next sequence with lowstand-related prodeltaic sediments, passing upwards into zone E, where the thin transgressive systems tract is covered by a thick highstand-related silty-clayey facies. The maximum flooding surface is well indicated by a horizon, rich in dinoflagellates (Table 1).

In the upper part of Papp's E zone an erosive surface with distinct hiatus at the basin margin points to a significant relative sea-level fall. The lowstand deposits are passing upwards into the coal-bearing transgressive deposits at the basin margins during the F zone in which a 4th-order relative sea level change was observed. The transgression caused a change in the ostracod faunal assemblages and appearance of their dinaric forms. The highstand deposits at the northwestern margin of the basin are also coal-bearing and gradually disappear, due to the decreasing accommodation place and at the end of the F zone deposits of falling stage to lowstand systems tracts are preserved (Table 2).

After a hiatus the Pannonian fresh-water sediments of zones G–H (Rögl et al. 1993) were interpreted as a succession of transgressive, highstand and lowstand systems tracts, where the highstand stage is correlated with the anoxic blue clays without faunal remnants.

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