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Serravallian sequence stratigraphy of the northern Vienna Basin: high frequency cycles in the Sarmatian sedimentary record

MICHAL KOVÁČ, ĽUBOMÍR SLIVA, BOHUSLAVA SOPKOVÁ, JANA HLAVATÁ and ADRIANA ŠKULOVÁ

Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina G, 842 15 Bratislava, Slovak Republic; kovacm@fns.uniba.sk

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Abstract: Middle Miocene global and regional factors affecting the development of depositional systems and sedimentary architecture were studied in the northern Vienna Basin. In the Serravallian sedimentary record (Upper Badenian and Sarmatian, Central Paratethys regional stages) two individual 3rd-order cycles of sea-level changes were confirmed. They can be more or less compared with Haq's Mediterranean cycles TB 2.5 and TB 2.6. The presented sequence stratigraphy approach also proved existence of four 4th-order relative sea-level changes in this time interval here. Furthermore, the late Serravallian (Sarmatian) record documents the strong influence of astronomical forcing on cyclic sedimentation. Detected high frequency cycles are most likely result of climatic (orbital) forcing on the eccentricity band with period of 400 and 100 kyr in a shallow water depositional environment. The sequence stratigraphy scheme of the northern Vienna Basin fits well with development in the whole basin, as well as with development in other basins in the Carpathian-Pannonian region (Styrian and Transylvanian Basins). This fact therefore led to the assumption of an interregional character of the high frequency cycles initiated by impulses common for different basins in the Central Paratethys realm.

Key words: Sarmatian, Upper Badenian, Vienna Basin, sequence stratigraphy, depositional systems, cyclic sedimentation, high frequency cycles.

Introduction

Study of the sedimentary record in the northern Vienna Basin (Slovak part) was focused on the Serravallian basin fill architecture, determination of the depositional environments and cyclicity of the sedimentary record. The research traces the occurrence of global events in the Vienna Basin (e.g. global 3rd-order sea-level changes) known from the whole Central Paratethys domain (Vakarcs et al. 1994, 1998; Pavelić et al. 1998; Kováč et al. 2001, 2007; Krézsek & Filipescu 2005; Strauss et al. 2006; Piller et al. 2007), as well as regional events (e.g. 4th-order cycles of relative sea-level changes). Special emphasis was given to detailed study of high frequency cycles as a result of interactions between climatic influence and the dynamics of shallow water sedimentary environments during the late Serravallian (Sarmatian).

Geological setting and outline of the Vienna Basin's paleogeography

The Vienna Basin, situated in the Alpine-Carpathian junction, covers parts of three states. Its north-western part extends into the Czech Republic, the southern part, representing more than 50% of the basin is situated in Austria, whereas its north-eastern part lies in Slovakia (Fig. 1).

The Vienna Basin was described as a typical pull-apart basin (Royden 1985; Fodor 1995), nevertheless the tectonic history also documents an Early Miocene evolutionary stage of piggy-back basins and wrench fault furrows and a Middle to Late Miocene extensional basin development of graben and horst structures (Kováč 2000; Kováč et al. 2004). The basin is superimposed on tectonic units of the Flysch Zone (Rhenodanubian Flysch and Outer Western Carpathians) in the West and North. The pre-Neogene basement in the southern, central and eastern part is built up by units of the Northern Calcareous Alps, Central Eastern Alps and Central Western Carpathians (Fig. 1). Neogene sedimentary fill reaches a thickness of up to 5500 m in the basin's deepest part (Kilenyi & Šefara 1989).

The basin pull-apart depocentres developed at the end of the Early Miocene during the initial rifting stage, which was associated with the extrusion of the Western Carpathians from the East Alpine domain (Ratschbacher et al. 1991a,b). The Middle Miocene basin evolution was overtaken by regional extensional tectonics. The subsidence of the basin depocentres was controlled predominantly by the NE-SW and NNE-SSW oriented normal faults. Grabens, halfgrabens and elevations were formed (Lankreijer et al. 1995).

The Serravalian (Late Badenian and Sarmatian) structural development of the basin, as well as the development of neighbouring mountain ranges, induced important changes in the river drainage system, transport of sediments and formation of deltaic systems (Fig. 2). The older, Early Miocene delta entering the basin from the south (Aderklaa Formation) was replaced by the large Middle Miocene deltaic bodies on the

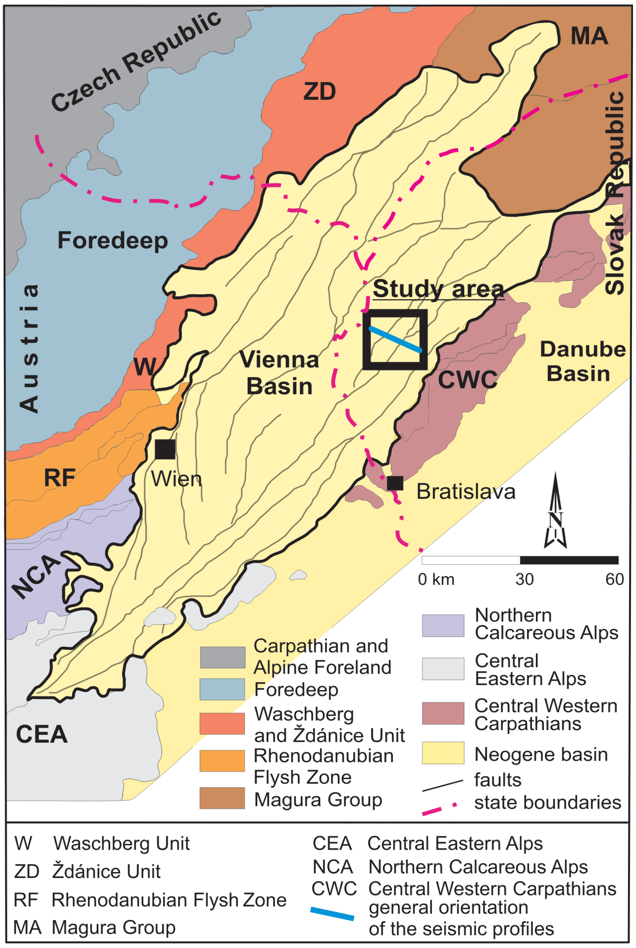


Fig. 1. Simplified geological map of the Vienna Basin, situated at the East Alpine–Western Carpathian junction (modified after Lexa et al. 2000).

western (paleo-Danube river delta) and northern margin of the basin (paleo-Morava river delta). The basin accommodation space was continuously filled up due to intense sediment supply in this time (Jiříček & Seifert 1990; Jiříček 2002).

The Middle Miocene Vienna Basin, with respect to paleogeographical setting, can be regarded as a semi-closed basin, an embayment of the Central Paratethys Sea surrounded by the Alpine-Carpathian-Dinaride mountain chains. The basin, situated on the north-western margin of the Pannonian Basin System (Rögl 1998; Kováč et al. 2004, 2007) was connected with remaining epicontinental sea only through the Eisenstadt Basin and Ödenburg Gate in the SE, further by the Devín-Hainburg and by the Jablonica Gates in the E and NE (Fig. 2). In spite of this, the global and regional sea-level changes traceable in the Vienna Basin are similar to the changes in the Pannonian Basin System, covered by the Central Paratethys Sea during this time (Harzhauser & Piller 2007; Kováč et al. 2007).

The connection of the Central Paratethys Sea with the Mediterranean — via Trans-Tethydian Trench Corridor had already been closed before the Serravallian (in Middle Badenian). Other, disputable sea connections had disappeared during the early Serravallian (in Late Badenian, Rögl 1998; Harzhauser & Piller 2007; Kováč et al. 2007). The late Serravallian (Sarmatian) sedimentary environment of the Central Paratethys already has signs of strong isolation from the open sea areas, which are documented by the specific composition of brine (Pisera 1996) and endemic faunas (Harzhauser & Piller 2007). From the climatic point of view, the Middle Miocene Climatic Optimum ended here in the early Serravallian (Late Badenian, Böhme 2003) and in the late Serravallian (Sarmatian) a shift towards a Mediterranean temperate climate was documented (Kvaček et al. 2006; Harzhauser et al. 2007).

Methods

The presented research was supported by study of archive materials of the Oil and Gas Exploration Company NAFTA, comprising 89 Final reports for individual wells, including well logs for each well (Spontaneous Potential — SP, Resistivity log — RAG; and a limited number of Gamma logs — GKA), seismic profiles and available borehole cores.

The field methods included sedimentological study of borehole cores combined with sampling for micropaleontological high-resolution analysis. Well logs of all boreholes were compared and processed under principles of electro-sequence analysis (Van Wagoner et al. 1990; Rider 1996; Emery & Myers 1996; Catuneanu 2002). The well logs were used to determine general trends of individual parasequences to obtain a general trend for the whole sedimentary record. For comparison, migrated seismic lines were used, to check well log motifs with their responses on the seismic profiles. The acquired data were further confronted with the results of sedimentological and micropaleontological analysis of cores, to provide reliable final information (Kováč et al. 2001, 2005, 2008; Fordinál et al. 2002, 2003, 2006; Bartakovics & Hudáčková 2004; Kováčová et al. 2008).

Time scale

The studied time span covers the Mediterranean stage — the **Serravallian**, with its duration from 13.65±0.05 to 11.608±0.005 Ma, assigned to the Middle Miocene sub-epoch (Gradstein et al. 2004). In the regional Central Paratethys time scale the Serravallian is considered to be the Late Badenian and Sarmatian stage (Table 1).

The **Late Badenian** stage of the Central Paratethys spanning from 13.65 Ma to 12.7 Ma corresponds to the early Serravallian of the Mediterranean, as well as to the Konkian regional stage of the Eastern Paratethys (Papp et al. 1978; Gradstein et al. 2004; Kováč et al. 2007).

The **Sarmatian** stage covers a time span of 12.7–11.6 Ma and corresponds to the late Serravallian of the Mediterranean and to the Volhynian and early Bessarabian stages of the Eastern Paratethys (Papp et al. 1974; Gradstein et al. 2004). According to Abreu & Haddad (1998), the lower boundary of the Sarmatian fits very well with the glacio-eustatic isotope event MSI-3 at 12.7 Ma and its upper boundary corresponds to the glacio-eustatic sea-level lowstand of cycle TB 3.1 at 11.6 Ma,

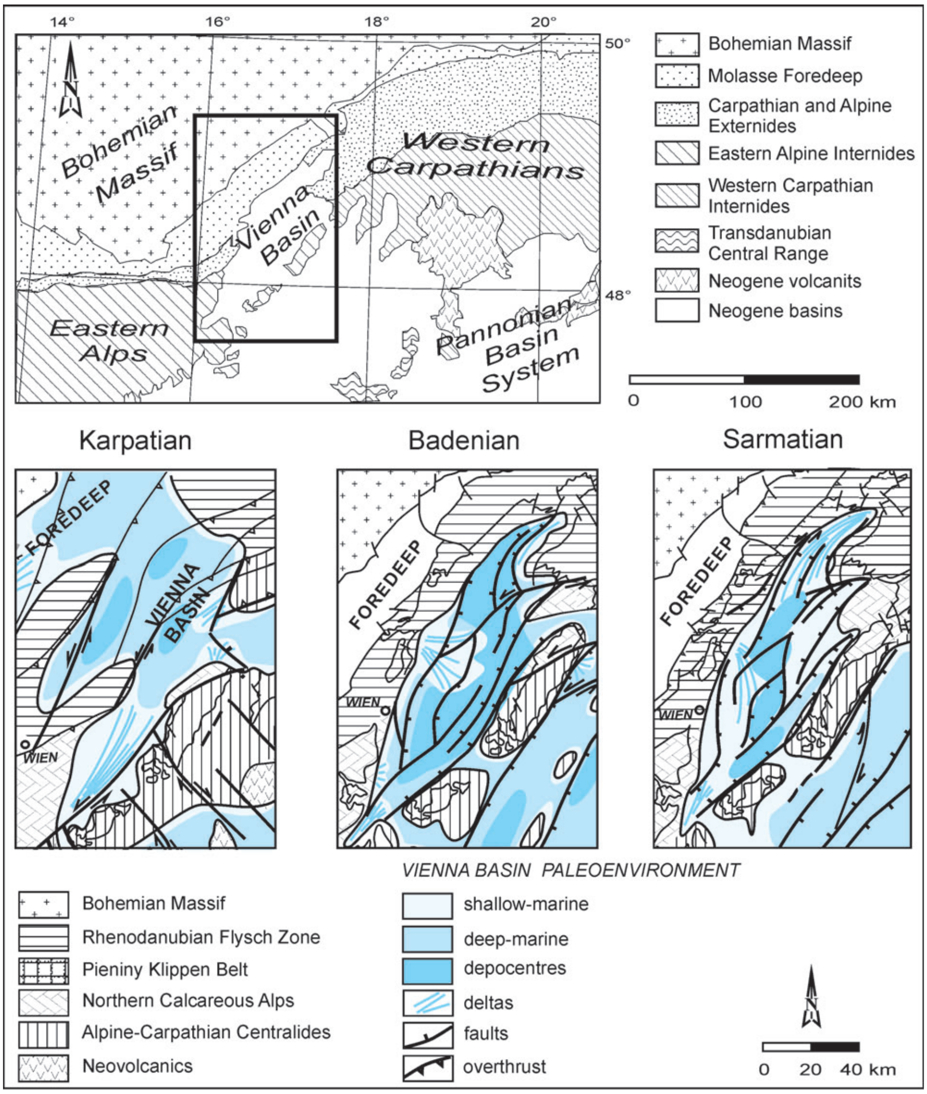


Fig. 2. Paleogeographical development of the Vienna Basin from Lower to Middle Miocene documenting change in the position and development of prograding delta bodies entering the basin (modified after Kováč 2000).

although no absolute dating of these boundaries is available up to now (Harzhauser & Piller 2004).

Chrono- and biostratigraphy

The base of the **Serravallian** was defined by the last occurrence (LO) of the nannofossil *Sphenolithus heteromorphus* within the magnetic polarity Chronozone C5ABr. The end is characterized by the last common occurrence of the calcareous nannofossil *Discoaster kugleri* and the planktonic foraminifer *Globigerinoides subquadratus.* Assosiated with the short normal polarity Subchron C5r.2n (Gradstein et al. 2004).

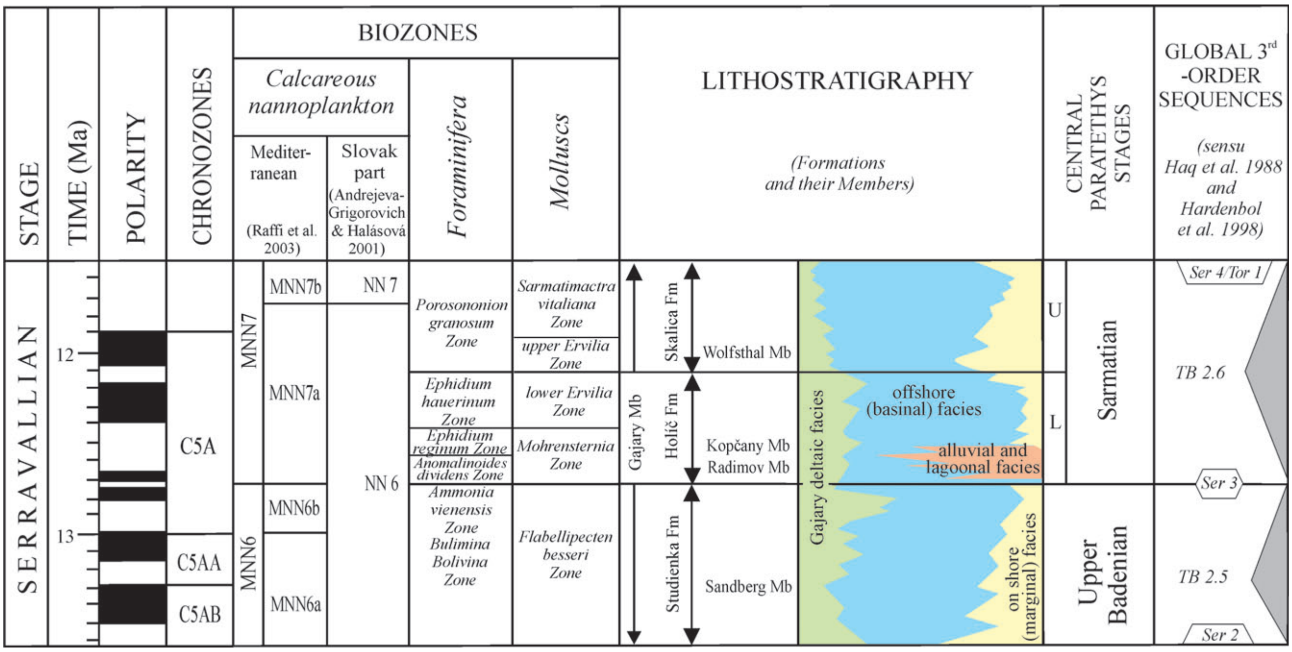
The base of the **Late Badenian** was defined by the onset of the planktonic foraminiferal *Velapertina indigena* Zone as well as by the extinction of the *Sphenolithus heteromorphus,* referring to the NN5c Zone and the first occurrence of *Discoaster exilis* that falls within the calcareous nannoplankton NN6 Zone (Andrejeva-Grigorovich et al. 2001). Further, according to Grill (1941, 1943) the Late Badenian can be characterized by foraminiferal associations of the *Bolimina/Bulivina* Zone, whereas in marginal parts of the basin depleted brackish *Ammonia beccarii* associations often prevails.

The previous three-fold biozonation of the **Sarmatian** stage (according Grill 1941, 1943) using the foraminiferal assemblages: *Elphidium reginum* Zone, *Elphidium hauerinum* Zone and *Nonion granosum* (= *Porosononion*) Zone has recently been revised into a two-fold division (Table 1); the **Early Sarmatian** comprising foraminiferal *Anomalinoides dividens*, *Elphidium reginum* and *Elphidium hauerinum* Zones and the **Late Sarmatian** containing the *Porosononion granosum* Zone (Harzhauser & Piller 2004). Beside the zonation based on foraminifera, molluscs also provide reliable biostratigraphic markers. The Early Sarmatian spans the *Mohrensternia* Zone and the lower part of the *Ervilia* Zone and the Late Sarmatian comprises the upper part of the *Ervilia* Zone and the *Sarmatimactra vitaliana* Zone of Harzhauser & Piller (2004). Jiříček (1970, 1972) divided the Sarmatian according ostracodes into the Early Sarmatian with A–B Zones represented by *Aurila mehesi* and the Late Sarmatian with the C–E Zones with occurrence of *Aurila notata* (Jiříček 2002).

Sedimentary record

The **Upper Badenian** sediments are represented by the **Studienka Formation** in the Slovak part of the Vienna Basin (Table 1). The offshore facies consist mostly of fine-grained greenish-grey calcareous clays/claystones reaching a thickness of up to 400–600 m (Špička 1969). The *Bulimina-Bolivina* Zone foraminiferal associations indicate stratification of the water column with low oxygen content near the basin bottom (Hudáčková & Kováč 1993). Towards the basin margins the marine calcareous clays ("marls") and siltstones are replaced by more sandy onshore facies. In the uppermost part of the sequence dark clays with coal beds occur in some places.

Table 1: Chronostratigraphy and biostratigraphy of the Serravallian (Late Badenian and Sarmatian) sediments of the Vienna Basin: calcareous nannoplankton (Martini 1971; Raffi et al. 2003), foraminifera (Grill 1941, 1943), molluscs (Harzhauser & Piller 2004); litostratigraphy (Vass 2002); Mediteranean sea-level changes (sensu Haq et al. 1988 and Hardenbol et al. 1998, modified after Gradstein et al. 2004.)



The shallow water sedimentation at the basin margin is represented by the transgressive Sandberg Member to the East and the deltaic Gajary Member to the West (Table 1).

The **Sandberg Member** (Baráth et al. 1994) lies discordantly on the underlying pre-Neogene basement and is formed mainly by cross-bedded yellow-grey sand with intercalation of gravel and sandy-clays layers. Algal biostromes occur as well. The thickness of the deposits does not exceed 100 m.

The **Gajary Member** (Vass 1989) consists mainly of sandy sediments interbedded with calcareous clays and silts, reaching a thickness of about 100 m. The member is especially distributed along the Slovak-Austrian boundary and refers to a large delta entering the basin from the West.

The Upper Badenian sediments in the study area, in the north-eastern offshore zone of the Vienna Basin, belong to Studienka Formation. The cores (Table 3) are composed mainly of grey calcareous clays/claystones, often bioturbated, containing molluscs fragments (Fordinál et al. 2002, 2003; Bartakovics & Hudáčková 2004; Kováč et al. 2008). Towards the overlying strata calcareous clays pass into sands and silts deposited in a shallow, brackish environment (Table 3). In the western part of study area, the clays are locally substituted by deltaic sands of the Gajary Member (Kováč et al. 2005, 2008).

The **Sarmatian** sediments of the Vienna Basin can be subdivided into two parts — the Holíč and Skalica Formations (Tables 1, 2).

The Lower Sarmatian, **Holíč Formation** is represented by grey calcareous clay, silt and rare acidic tuff layers (Vass 2002). According to Elečko & Vass (2001) fluvial gravels representing the Radimov Member in the northern tip of the basin and the Kopčany Member, consisting of variegated and spotted pelites with scattered lenses of sand represent the lowermost Sarmatian deposits in the northern part of the Vienna Basin, in the Kúty and Kopčany grabens. The Kopčany Member has also been known as the *Carychium* beds (Jiříček 1973). The next informal lithostratigraphic term the "Beds of Hölles" was introduced by Brix & Plöchinger (1988) within the central and southern part of the basin, composed mainly of coarse-grained sediments on the margins, whereas in basinal settings predominantly marls with coarse intercalations are present. In marginal settings bryzoan-serpulid-algae bioconstructions and several meters thick pale limestones are situated (Harzhauser & Piller 2004).

The Upper Sarmatian **Skalica Formation** displays various lithologies, ranging from marl and silt to sandstone and gravel with various siliciclastic and carbonatic deposits such as oolites, rock-forming coquinas and foraminiferal bioconstructions (Elečko & Vass 2001; Vass 2002). The Wolfsthal Member is wide-spread along margins of the basin and includes the rock-forming oolitic coquinas (Harzhauser & Piller 2004). In basinal settings, carbonate facies are replaced by fossiliferous sandy to clayey marls, which have been named in the central and southern Vienna Basin as the "Beds of Kottingbrung" by Brix & Plöchinger (1988).

Sarmatian strata in the study area comprise predominantly grey clays and silts along with sands of the Lower Sarmatian Holíč Formation (Table 3). In cores foraminiferal assemblages of *Anomalinoides dividens* Zone, *Elphidium reginum* Zone and *Elphidium hauerinum* Zone were detected (Kováč et al. 2005, 2008). Upwards, the Skalica Formation represents the Upper Sarmatian fill, built up by clays, silts and sandstone layers (Table 3) with occurrences of foraminiferal assemblages of the *Porosononion granosum* Zone (Kováč et al. 2005, 2008; Fordinál et al. 2006).

Depositional environment

The **Upper Badenian** sedimentary record in the study area, in the north-eastern part of Vienna Basin (Fig. 1) shows a gradual transition from the offshore environment to the environment of a distal delta setting (prodelta). Toward the overlying strata the depositional environment became shallower and shallower. The foraminiferal associations of the *Bulimina-Bolivina* Zone are replaced here by assemblages with prevalence of *Ammonia beccarii* (Kováč et al. 2005, 2008). Shoaling was caused by the eastward progradation of delta lobes (Figs. 3, 4). Increased sediment supply also led to the onset of forced regression. Summarizing the evolution of the depositional environment in the Upper Badenian sequence within the studied area, the following changes could be established: offshore–prodelta–delta slope–delta front with prograding mouth bars — delta plain with distributary and interdistributary areas displaying common distributary channel avulsion (based on detailed descriptions of seismic lines (Figs. 3, 4), well logs (Fig. 5) and cores (Table 3) which follow in the next part of this paper, dealing with sequence stratigraphy).

The **Sarmatian** sedimentary record reveals deposition in a shallow marine, near shore deltaic environment. The Lower Sarmatian sedimentation starts with a muddy sequence, deposited in a relatively quiet environment of the distal area of deltaic lobes. Towards the overlying strata, transition from clays to sandy clays and silts is documented (Fig. 5) and it is interpreted as a continual change from basinal environment to the environment of delta plain (Table 3). In the middle part of the sedimentary column increased input of clastic material was observed, which can be connected with regional tectonics inducing paleogeographical changes of depocentres as well as shift of the deltaic lobes (Kováč et al. 2004, 2008). The sediments in the uppermost part of sequence, containing common plant detritus, were deposited in an environment of shallow marshes or hyposaline lagoons, frequently foraminiferal assemblages with *Ammonia beccarii* (Linné) were found (Kováč et al. 2008). Study of borehole cores point to the environment of muddy tidal flats. The silts and sands often comprise flaser and lenticular beddings; thus, we suppose deposition mainly in the subtidal to intertidal zone (Table 3).

Study of cores and well logs enabled consideration, that the sedimentary environment on the north-eastern margin of the Vienna Basin was composed of distributary channels and interdistributary areas, represented by swamp and marsh systems (Table 3, Figs. 5, 6). Distributaries are designated by the number of leveed channels, passing basinward to mouth bars, yielding clastic material derived from NW–N. Evident fluctuations recorded between the stacked parasequences in well logs can be related to the distributary channels/mouth bars shifts (Fig. 5). Upwards, we suggest increased sediment load to be reworked by coastal currents in the form of individual, laterally extensive sand bodies, distinguishable in well logs (Fig. 6). According to the sedimentological and micropaleontological study of borehole cores (Kováč et al. 2008), a gradual shift was recorded from a subtidal to an intertidal environment, ranging from the tidal flats to vegetated marshes. Micropaleontological study (occurrence of miliolids association) and rich plant detritus also points to the very shallow water environment of the intermediate, hyper or hyposaline marshes overgrown by vegetation (Tables 2, 3). The character of marsh and very shallow water sedimentation continued till the end of the Early Sarmatian.

The onset of the Upper Sarmatian environment, interpreted from cores and well logs, can be characterized by the presence of sand ridges and sandy bodies reworked by coastal currents and occasionally by shallow incised tidal channels on the coastal plain (Table 3, Figs. 5, 6). The clastic material transported by along-shore coastal currents, formed some kind of barriers triggering the sedimentation in protected bays or lagoons. Furthermore, continual shallowing upward was accompanied by the onset of the foraminiferal assemblages with *Porosonion granosum* (d'Orbigny) monoassociations, typical for the brackish shallow environment (Fordinál et al. 2006; Kováč et al. 2008). The environment of marshes was recorded in cores by occurrence of seed remnants of the *Glyptostrobus europaeus* (Brongniart). At the end of the Late Sarmatian even deposition of lignite layers within the coastal flats was proved.

Seismic profiles

On the interpreted NWW-SEE oriented seismic profiles in the northern Vienna Basin (Fig. 1) distinct basinward prograding clinoform bodies belonging to the Badenian record (Figs. 3, 4) can be recognized. The lower clinoform is assigned to the Middle Badenian; the upper clinoform was deposited during the Late Badenian sub-stage. Recognition of delta topsets, foresets and bottomsets is based on the configuration of reflections.

The lower wedge-shaped body reflectors downlap onto more or less horizontal reflections of underlying strata, which refer to the maximum flooding surface (mfs) in the sedimentary record of the Middle Badenian. The upper boundary of the clinoform represents a sequence boundary of type 2 (SB 2). Onlapping reflexes onto the foreset of the Middle Badenian clinoform body most likely indicate the Late Badenian transgression.

The overlying Upper Badenian clinoform is characterized by a sigmoidal configuration of seismic responses, which pass eastward into flat laying parallel responses referring to a prodelta sedimentary environment. The sigmoidal configuration of seismic reflexes points to quiet, undisturbed depositional conditions with continuous sediment supply (sensu Mitchum 1977; Vail et al. 1977; Miall 2000).

Furthermore, in the very eastern part of some seismic sections a third sedimentary body was identified (Fig. 3). This body shows strong (sharp) seismical responses, what can be related to sedimentation of coarser material. These seismic reflections show a typical onlap pattern, what is presumably caused by the subsequent compaction, and therefore — because of their uncertain original position — such sedimentary package could represent fluvial lowstand deposits of the fol-

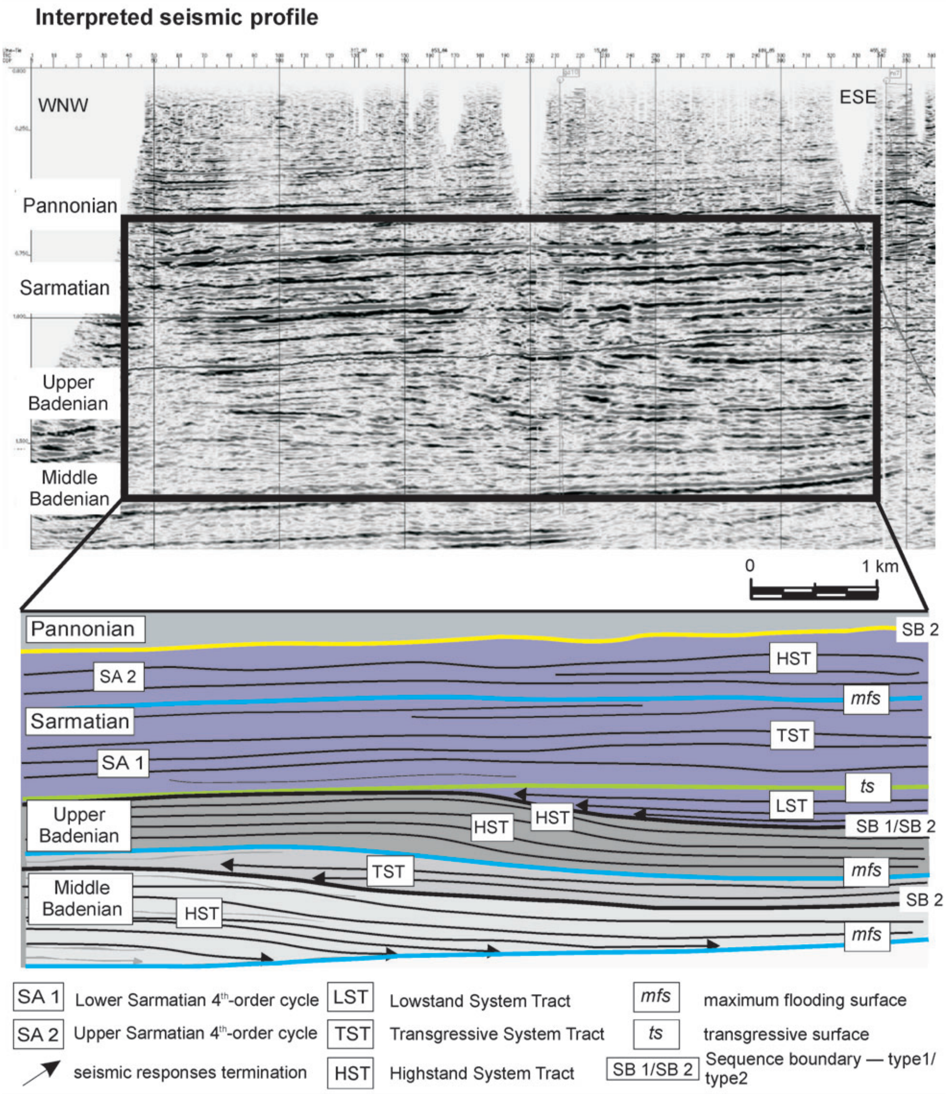


Fig. 3. Interpreted seismic profile of the Badenian and Sarmatian (Serravallian) sedimentary record (profile location see Fig. 1). Notice the Sarmatian fluvial lowstand deposits (LST) in the eastern section of the seismic profile.

lowing cycle of relative sea-level change (sensu Catuneanu 2002). A lowstand system tract (LST), with fluvial character of sedimentation, defined by strong seismic responses was also confirmed on well logs by typical prograding funnel-shaped pattern, related to the deposition in mouth-bars (Fig. 5). Even though the sediments are dated by biostratigraphy as Late Badenian (Fordinál et al. 2002, 2003; Kováč et al. 2008) they are associated with the sedimentary architecture of the next Sarmatian cycle of relative sea-level change. Consequently, we propose to interpret this boundary as SB 2/SB 1 at the base of following cycle (Fig. 3). The observed phenomenon — e.g. beginning of the "Sarmatian cycle in terminology of the Sequence stratigraphy" already during the termination of the "Late Badenian in terminology of the Biostratigraphy" — is comparable to a similar development of the Late Badenian and Sarmatian 3rd-order cycles in the Transylvanian Basin (sensu Krészek & Filipescu 2005).

Other seismic profiles from the studied area reveal different configurations of seismic responses. On these profiles the above mentioned lowstand deposits (LST) are missing (Fig. 4). The presence of an erosional unconformity was documented on the basis of toplap termination of the Late Badenian reflexes. The identified erosional surface is also well observable on the well logs as a new onset of channel fill sands (Fig. 5). This datum most likely represents an erosional surface, which originated after a considerable sea-level drop at the turn of the Late Badenian and Sarmatian. The identified unconformity is assigned to a sequence boundary of type 1 (SB 1), which continuously passes eastward into a sequence boundary of type 2 (SB 2). The explanation of this fact is that the Upper Badenian highstand deltaic sediments underwent erosion before they were overlain (covered) by the Sarmatian deposits. The onset of the next sequence is marked not only by an erosive discordance, but also by partly chaotic reflectors with downlaps in the western part of some seismic profiles (Fig. 3).

From the lithological point of view the Badenian clinoform bodies on the eastern margin of the Vienna Basin are composed mainly of pelitic material. Clays prevail particularly in the depositional enviroment of topsets and bottomsets. The area of deltaic foresets shows a sharpening of seismic responses, which could indicate increased sedimentation of coarser material (sands and silts) referring to the presence of mouth bars.

The Sarmatian sediments are marked by an absence of distinct clinoforms caused by shallow accomodation space of the Sarmatian sea in the studied area (Fig. 1). These deposits are recorded by relatively subhorizontal to horizontal seismic reflectors, which point to the trends of high frequency cycles, represented by planar sand bodies alternating with fine-grained clays and silts (Figs. 3, 4). The distribution and bedding of sediments indicates slight differences within the Lower and Upper Sarmatian strata.

When tracing seismic responses as well as the well log motifs, it is possible to observe that the bio- and sequence stratig-

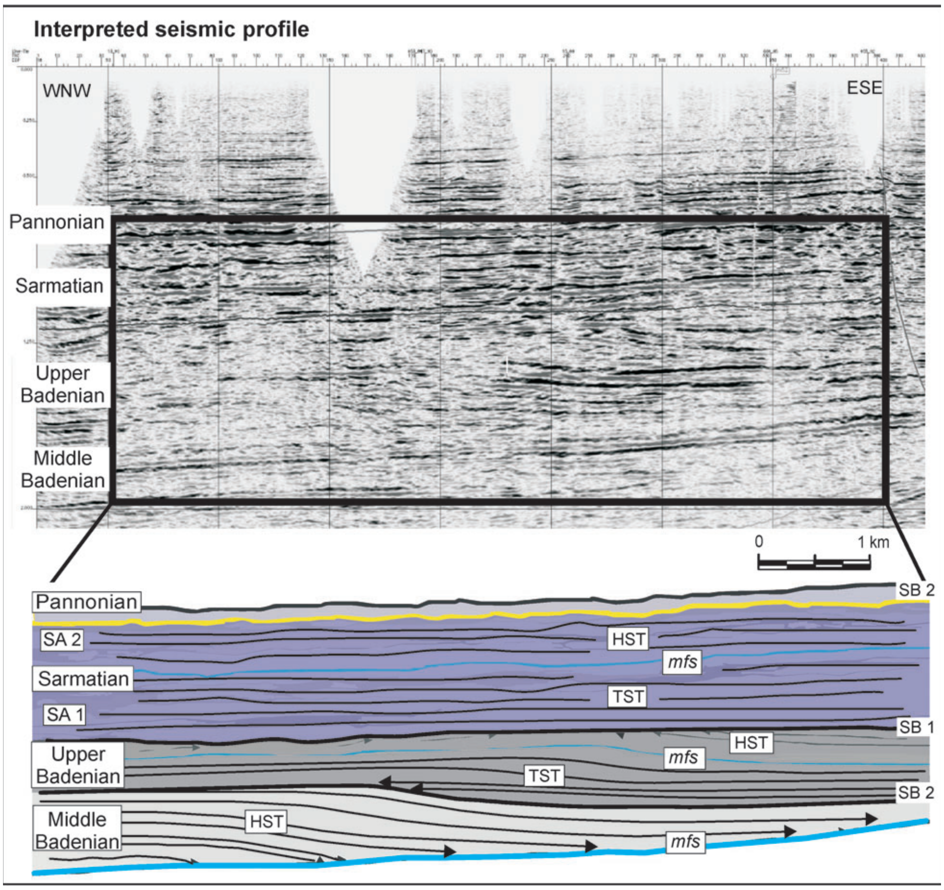


Fig. 4. Interpreted seismic profile of the Badenian and Sarmatian (Serravallian) sedimentary record (profile location see Fig. 1). Notice the distinct erosional surface on the Late Badenian/Sarmatian boundary.

raphy boundaries do not match exactly. The explanation of this fact is easy. In our case, it is generally accepted, that at the Badenian/Sarmatian boundary there was a considerable sea-level drop, what is recognized as a SB 1 (Kováč et al. 2004; Strauss et al. 2006). Erosion and transport of the Upper Badenian sediments is associated with the redeposition and enrichment of the deposits by the Late Badenian foraminiferal associations. Therefore, their following deposition during the Sarmatian LST of the 3rd-order cycle apparently started at the termination of the "Late Badenian" and the Early Sarmatian transgression can be clearly documented first of all by biostratigraphy.

The same is considered for the Sarmatian/Pannonian boundary, where the Pannonian cycle also seems to start at the end of the Sarmatian stage deposition, which is shown by the easily identifiable transgressive surface (Figs. 3, 4).

Sequence stratigraphy

The sequence stratigraphy framework was applied for the first time within the area of the northern part of the Vienna Basin in the 90's (Kováč et al. 1998). The studies represent an attempt to resolve the influence of relative sea-level changes on sedimentation and paleoenvironment as well as their influence on the sedimentary record of the basin. The mutual interplay between global sea-level changes, tectonics and sediment supply were taken into account as well. The following works of Kováč et al. (2001, 2004), Harzhauser & Piller (2004), Strauss et al. (2006) have recognized in the Miocene sedimentary fill of the basin nine 3rd-order cycles, composing the sedimentary architecture. From those cycles, one individual cycle of relative sea-level change belongs to the Late Badenian and one cycle represents the Sarmatian sedimentary record.

Third-order cycles of relative sea-level changes in the sedimentary record of the northern Vienna Basin

In the Vienna Basin, the Late Badenian sedimentation represents an individual 3rd-order cycle of relative sea-level change, that is comparable to the TB 2.5 cycle according to Haq et al. (1988) or it corresponds to the time span between the sequence boundaries Ser-2 (13.65 Ma) and Ser-3 (12.7 Ma) identified by Hardenbol et al. (1998). The Sarmatian, spanning the time interval from 12.7 to 11.61 Ma, also comprises in the Vienna Basin a single 3rd-order cycle, which is comparable to the TB 2.6 cycle of relative sea-level changes according Haq et al. (1988) and the Ser-3 (base) and Ser-4/Tor-1 (top) boundaries of Hardenbol et al. (1998).

In general, the **Late Badenian 3rd-order cycle** starts after a relative sea-level drop in the Vienna Basin (Kováč et al. 2004; Strauss et al. 2006). The most representative evidence of the following transgression is the Sandberg Member on the eastern margin of the Vienna Basin (Baráth et al. 1994; Holec & Sabol 1996). Here the Upper Badenian strata directly overlie the pre-Neogene basement of the Western Carpathians, representing a distinct unconformity (SB 1). In the central part of the basin the sedimentation continued without apparent evidence of subaerial erosion. Thus, for the eastern offshore zone of the basin, a conformable sequence boundary of type 2 (SB 2) was proposed (Kováč et al. 2004).

The Late Badenian sedimentation was strongly influenced by a deltaic system, entering the basin from its western margin since the Early-Middle Badenian (Jiříček & Seifert 1990). This large delta belonging to the paleo-Danube river (in oil and gas prospecting slang called the Suchohrad-Matzen-Gajary delta) strongly influenced the development of the Vienna Basin depositional environments. The majority of seismic lines document continual deposition from the Middle to Late Badenian. The deltaic lobes — clinoforms moved generally from the West toward the East (Figs. 3, 4). The present study focuses particularly on the north-eastern margin of the basin, where distal facies of the deltaic body were deposited (Figs. 1, 5)

The Late Badenian **lowstand system tract (LST)** is detectable only on well log profiles and was defined on the basis of a prograding parasequence set above the identified sequence boundary between the Middle and Upper Badenian strata (Fig. 5). The lowstand system tract deposits are represented by

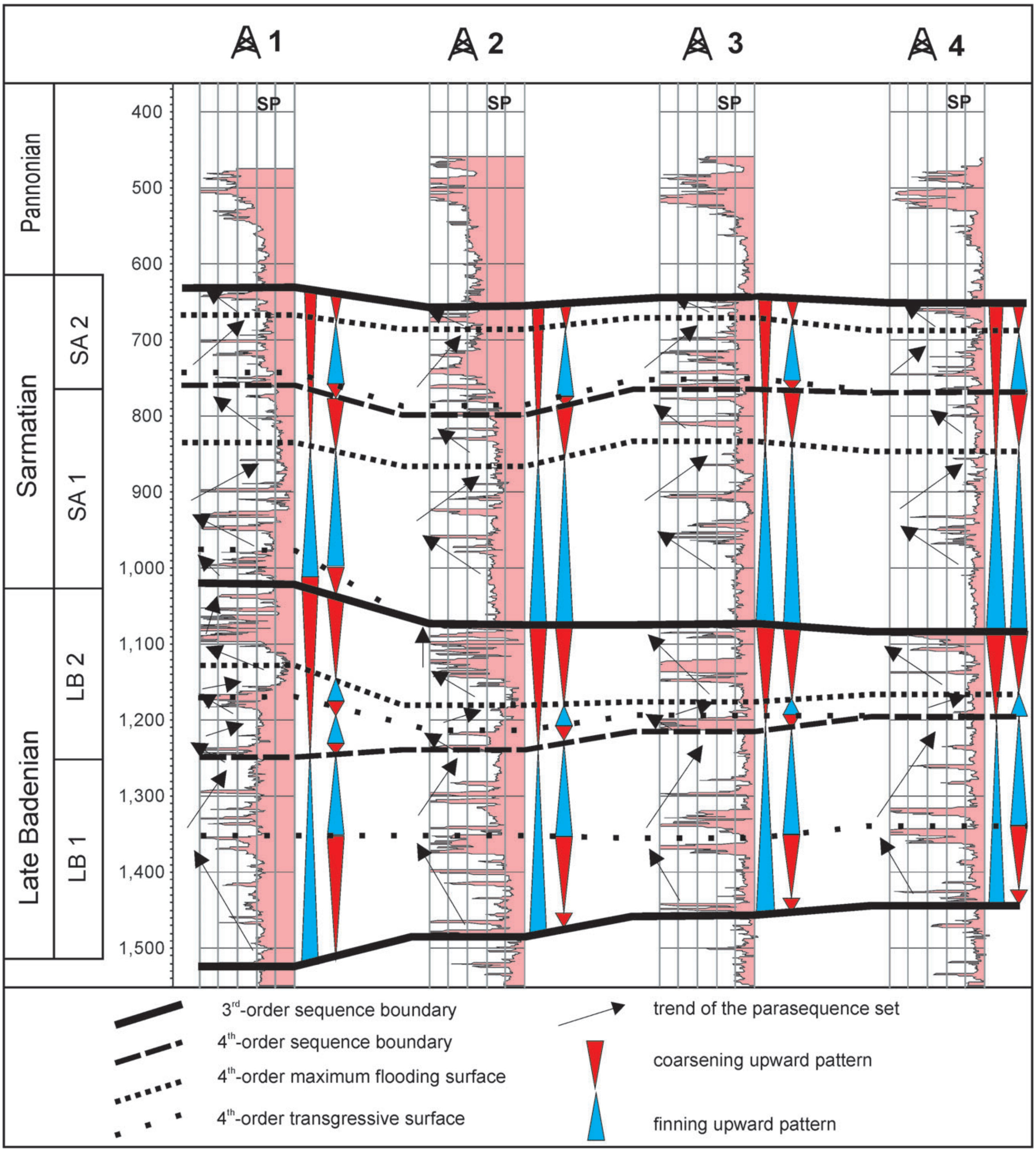


Fig. 5. Well logs interpretation based on Van Wagoner et al. (1990), Posamentier & Allen (1999) and Emery & Myers (1996); boreholes 1–4 = M1, M27, M47, M49; Individual trends of the parasequence sets refer to the sea-level changes. Coarsening and fining upward patterns reflect the identified 3rd- and 4th-order cycles of relative sea-level change.

coarser material (silts, sands) supplied from the West. The **transgressive systems tract (TST)** could generally be identified on the basis of retrogradational parasequence stacking pattern trend on well logs (Fig. 5), that refers to gradual deepening of the depositional environment. In the studied area the TST is formed mainly by delta front sandy mouth bars. The **highstand system tract (HST)** is characterized by the eastward progradation of deltaic clinoforms as a result of forced regression (Figs. 3, 4). These progradational clinoforms show sigmoidal seismic responses on the seismic sections. They refer to sedimentation in the lower delta plain environment, with common channel avulsion and alternation of distributary and interdistributary depositional settings.

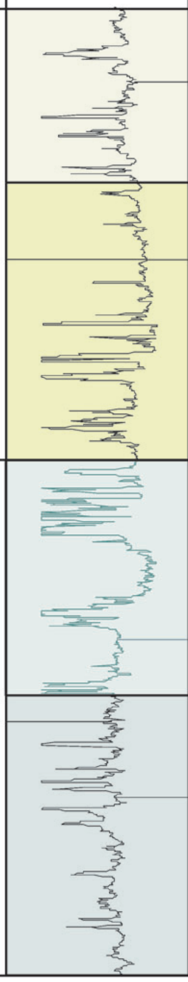
The **Sarmatian 3rd-order cycle** of relative sea-level changes is restricted by the lower boundary of SB type 1 or SB type 2 (Harzhauser & Piller 2004; Kováč et al. 2004; Straus et al. 2006). The erosional unconformity (SB 1) has been registered only in the north-western part of the study area. It is documented on well logs by isolated channel fill composed of coarse-grained sediments. The sediments of incised channels represent the **lowstand system tract (LST)**. However, the beginning of Sarmatian deposition in other places, situated eastwards, is characterized only by a distinct transgressive surface (ts) overlying the Upper Badenian strata (Table 1, Figs. 3, 4, 5). This key surface in an offshore setting coincides with the concordant sequence boundary (SB 2). In spite of this, the transgressive character of the entire Sarmatian sedimentation is perfectly documented in the Vienna Basin paleogeography, by gradual flooding of the northern Vienna Basin during this time (Jiříček 1988; Kováč et al. 2004).

The Sarmatian **transgressive system tract (TST)** displays a general fining-upward trend in the well-log response and it is characterized by a relatively thick development of fine-grained sediments, represented mainly by clays and silts (Fig. 5). The transgressive deposits often contain foraminiferal assemblages of the *Elphidium reginum* Zone, sometimes also the lowermost part of the *Elphidium hauerinum* Zone (Kováč et al. 2008). The TST terminates below the 3rd-order maximum flooding surface (mfs) situated in the lower/middle part of the Sarmatian sedimentary record in clays of the *Elphidium hauerinum* Zone (sensu Grill 1941, 1943). The 3rd-order **highstand system tract (HST)** is registered by the coarsening-upward trend on the well-logs. The sediments contain predominantly foraminiferal association of the *Porosononion granosum* Zone (Kováč et al. 2008). Increased sediment input of coarser sandy sediments can be observed on well logs, the sands were deposited in flat channels, mouth bars and sand waves (Fig. 6). The top of the Sarmatian strata is bounded by the SB 2 or SB 1. The "Sarmatian/Pannonian" cycles transition in the sense of sequence stratigraphy, represented by distinct erosional unconformity of SB type 1, is frequently located in the lower Pannonian sedimentary record, between the B–C Zones (sensu Papp 1951; Kováč et al. 1998).

Fourth-order cycles of relative sea-level changes in the sedimentary record of the northern Vienna Basin

The 4th-order cycles of relative sea-level change mirror regional or local impulses, which affected the sedimentary record (climate, sediment supply, local tectonics). Nevertheless, the changes of depositional environment in the sedimentary record of the Vienna Basin can be traced and even correlated with other basins of the Central Paratethys (see Kováč et al. 2001, 2007; Harzhauser & Piller 2004, 2007; Krészek & Filipescu 2005)

Table 2: 3rd- and 4th-order cycles of relative sea-level changes, well log record referring to changes in depositional environment (borehole M1) on the Vienna Basin north-eastern margin.

Stage	Global cycles sensu Haq et al. 1989	3rd-order cycles	Electrosequences	4th-order cycles in this paper		Depositional environment	Formation
Sarmatian	TB 2.6	HST		HST, mfs, TST, LST	SB 1/2, SA 2, SB 1	upper delta plain or coastal plain	Skalica Fm
		mfs, TST, LST		HST, mfs, TST, LST	SA 1, SB 1/2	lower delta plain to upper delta plain	Holíč Fm
Late Badenian	TB 2.5	HST		HST, mfs, TST, LST	LB 2, SB 1	delta slope to lower delta plain	Studienka Fm
		mfs, TST, LST /		TST, ts, LST?	LB 1, SB 2	prodelta to delta slope	

and so they will be an important tool in future for high resolution study of the basin architecture.

According to well log analysis, the presence of two 4th-order cycles within the Late Badenian and two 4th-order cycles within the Sarmatian were recognized. The entire record exhibits signs of deposition in a delta system with mixed fluvial to coastal flat environments. Generally a gradual shallowing upward trend is observable.

The first Late Badenian 4th-order cycle (LB 1) is of transgressive character, followed by an upper one (LB 2) with regressive features. Similarly, the following Early Sarmatian 4th-order cycle (SA 1) is mainly of transgressive character, whereas the upper one (SA 2) accounts for the regressive phase of the 3rd-order cycle of relative sea-level changes (Table 2).

The lower part of the **first 4th-order Late Badenian cycle (LB1)** possesses prograding parasequence sets, situated above the conformable sequence boundary (SB 2). This can be interpreted as an increase of sediment supply during the sea-level lowstand. Coarser material represents delta front mouth bars which show a typical funnel-shaped coarsening upward pattern (Table 2). These sandy deposits are overlapped by transgressive calcareous clays, which are bounded at the base by a transgressive surface. Fine-grained sediments often alternate with relatively thick sand horizons. Sands on the well logs reveal a funnel-shaped motif that also points to the deposition in the form of mouth bars (Fig. 5). The log record of the transgressive deposits is generally characterized by a retrogradational parasequence set trend, which indicates decreasing sediment supply (or widening of accommodation space). Based on the well log study, the prevalence of retrogradational trend and any evidence of aggradation or progradation in overlying strata let us assume that within the LB 1 cycle the highstand deposits were missing or they are not preserved. The LB 1 4th-order cycle upper boundary is emphasized locally by an unconformity (Fig. 5).

Second Late Badenian 4th-order cycle (LB 2) starts on well logs with infill of small incised distributaries that indicate presence of erosional surfaces at their base. Sands display on the logs cylindrical pattern with sharp boundaries at the base and top (Fig. 5). Sandy deposits could be assigned to the lowstand deposition of this second 4th-order cycle. The sedimentation continues onwards into deposition of clays, which represent transgressive sediments. Above the maximum flooding surface (mfs) progradational (funnel-shaped) and aggradational (serrated) stacking pattern log motifs prevail. Serrated patterns indicate the high-energy environment of existing interdistributary areas (Fig. 5). Both of these log motifs show gradual delta front progradation into the basin and shallowing of the depositional environment during the highstand conditions. At the end of the Late Badenian, sedimentation took place in the studied area more likely in a lower delta plain environment with distributary channels (sandy units), channel-levee complexes, crevasse splays and interdistributary areas — lagoons, marshes and coastal flats (Table 3, Figs. 6, 7).

Presence of two 4th-order cycles of relative sea-level change was also recognized within the sedimentary fill of the Transylvanian Basin, which are equivalent to Haq's TB 2.5 cycle (Krézsek & Filipescu 2005), which points to a rather more than local character of these two cycles. Moreover, we expect to be able to trace both cycles within a wider area. This suggestion of course, has to undergo further precise investigation.

The **Early Sarmatian 4th-order cycle (SA 1)** lower boundary, at the Badenian/Sarmatian transition, is represented by the SB type 1 or SB type 2 (Table 2). The sequence boundary of type 1 was recorded only in several well logs by the presence of incised channels filled up by coarse-grained sediments, prevailingly in the western part of the studied area (Fig. 1). The well logs display here distinct boxcar-shaped successions with serrated patterns characteristic for the channels with no uniform current velocities, resulting in contiguous deposition of sand and silts. Occurrences of serrated funnel shaped curves of progradational character refer to the existence of sand ridges and bars and suggest a basinward development of the SB 2 boundary. They exhibit laterally synchronous deposition with an hour-glass shape pattern toward east (Fig. 5, well 1) and correspond to the lowstand deposits (LST).

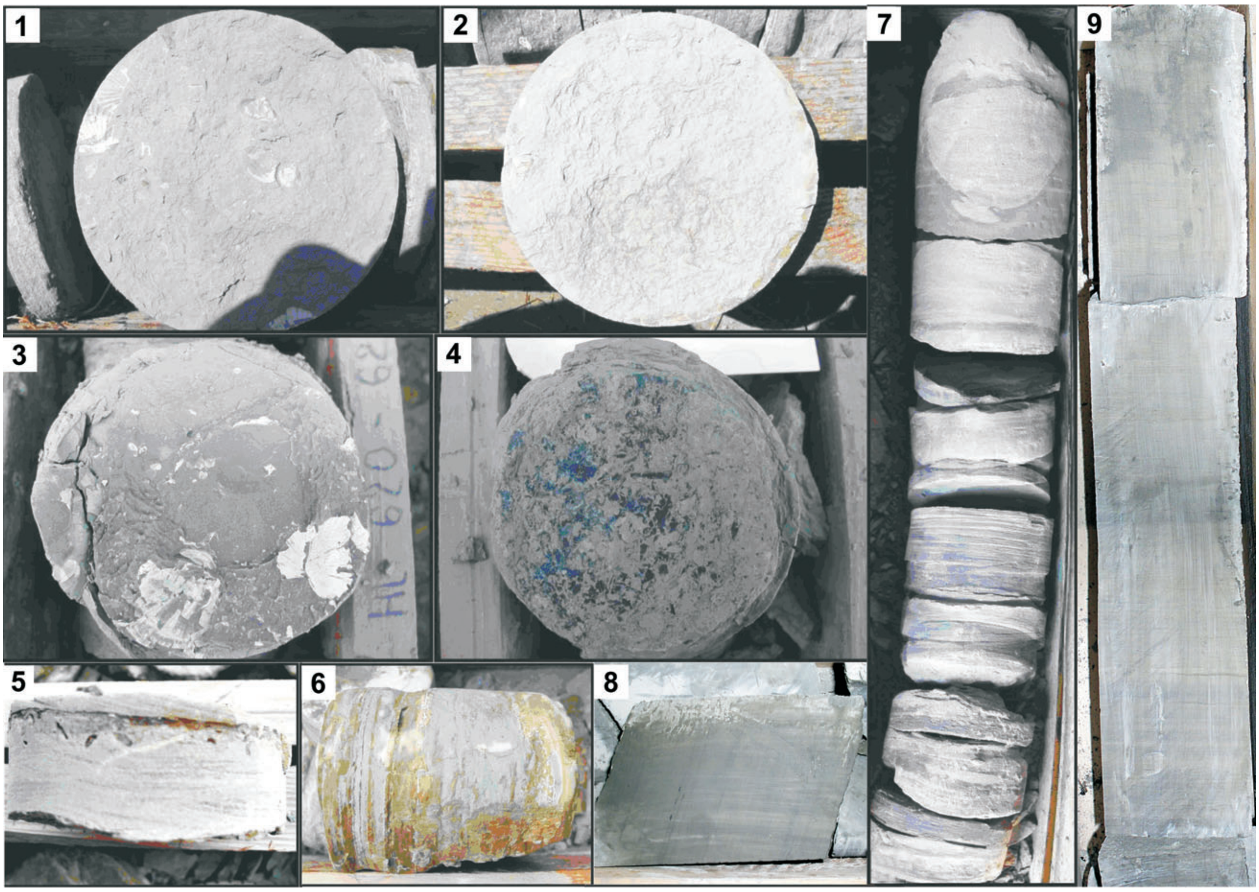
However, the onset of the first 4th-order cycle in the majority of wells situated in the eastern part of the study area (Fig. 1) is specific by a distinct transgressive surface (ts) and therefore identical with the SB 2 at the Badenian/Sarmatian transition (Fig. 5). Transgression has been registered in processed well logs by development of fine-grained sediments attaining relatively considerable thicknesses. The mainly massive and laminated clays alternating with silt layers are related to the transgressive deposits (TST). According to analysis of the borehole cores, the sediments contain flaser and lenticular bedding with non-cyclic trends, typical for tidal flats, estuaries or tidal influenced delta plains (Table 3). Therefore, the 4th-order transgressive deposits can be considered to be deposited in the tide-influenced delta or coastal flats.

Transgressive deposits (TST of the 4th-order) display increased input of clastics, comprising numerous redeposits of the Cretaceous and Paleogene microfossils (Kováč et al. 2008). This depositional pattern was registered by funnel-shaped parasequences and coarsening upward trends on the well logs (Fig. 5), which is in contradiction to the supposed deepening attributed to the sedimentation during relative sea-level rise. This event can be related to possible changes of climate or local tectonics, connected with increased erosion. On the basis of sedimentological analysis of cores (Table 3), situated on the top of progradational sandy units, we are able to determine the sedimentary environment of the intertidal zone to subtidal zone.

The maximum flooding surface (mfs) of the 4th-order cycle of relative sea-level change (identical with the mfs of the 3rd-order cycle as well), is relatively well recognizable in the well logs in the sedimentary record of the *Elphidium hauerinum* Zone (Table 1, Fig. 5).

The following highstand of the 4th-order cycle (HST) is clearly marked on well logs by the onset of sandy bodies with sporadic occurrences of incised flat channels. These sandy layers are commonly stacked as progradational high-frequency parasequence sets and refer to the changes in dynamics of the depositional environment, possibly to the transition from lower delta plain to intertidal or supratidal zone of coastal flats.

Table 3: Vienna Basin Serravallian sedimentary fill in selected borehole cores: **1** — greenish clay with bivalve remnants, Sarmatian; **2** — greenish clay with gastropod remnants, Sarmatian; **3** — greenish clay with bivalve remnants in original position, Sarmatian; **4** — grey clay with rich plant fragments, Sarmatian; **5** — silt with ripple cross lamination — flaser bedding, Sarmatian; **6** — alternating silt and clay laminas, Sarmatian/Badenian boundary; **7** — clays and silts with lenticular and flaser bedding, on top (right) is scoured fine-grained sand with load cast at base, Badenian; **8** — laminated clay, Sarmatian; **9** — fine laminated offshore clay, Badenian. (*Borehole cores have diameter 10 cm, except core No. 7 with diameter 7 cm.)*



The second **Late Sarmatian 4^th^-order cycle (SA 2)** lower boundary (SB 1) is marked by an abrupt change from fine- to coarse-grained sediments on well logs, or locally by the presence of flat incised channel filled up by sand and silts (Fig. 5). Channels are indicated on the well logs as boxcar-shaped successions within clays pointing to deposition on a coastal flat. Other recognized well log curves, predominantly of serrated funnel shaped responses representing contemporaneous sedimentation, refer to the sand ridges (Fig. 5, well 1–3). These represent the sea-level lowstand deposits (LST), which are overlain by the transgressive surface. The following transgressive desposits (TST) are designated by the general fining-upward trend of sediments and characterized by the hour-glass to bell-shaped parasequences (Fig. 5). These represent sandy bodies, reworked by tidal or coastal currents more likely of along shore character. Storm events and wave erosion cannot be excluded. According to the paleoecology of the foraminiferal associations which are recorded in the cores, situated on top of these sand units, the lower delta plain, coastal plain or tidal flats environment were registered (occurrence of *Ammonia/Haynesina*, Kováč et al. 2008). Within these transgressive deposits well log record, an increased amount of sands and silt has been observed, which can be explained by local tectonics or climatic changes of a higher order. The transgressive sediments are restricted by the mfs of the 4th-order of relative sea-level change, placed in the clays of the upper part of the Late Sarmatian record (Table 2). The highstand deposits (HST) record is represented by serrated funnel shaped successions on the well logs, referring to prograding sand bodies. An evident shift of environment from delta to coastal plain has been recognized by the borehole cores studies with very shallow water to subaerial paleoenvironment (lignite layers). The Sarmatian strata terminate either by the SB 1 or SB 2 boundary at the Sarmatian/Pannonian transition (Fig. 5).

High frequency cycles in the sedimentary record of the north-eastern Vienna Basin

The Middle Miocene sedimentary record as well as well log motifs reveals the presence of distinct cyclic deposition in offshore and onshore environments of the Vienna Basin. From the Late Badenian towards the Sarmatian the periodical repetition of coarse-grained and fine deposits becomes a more and more typical feature of sedimentation. Sands, silts

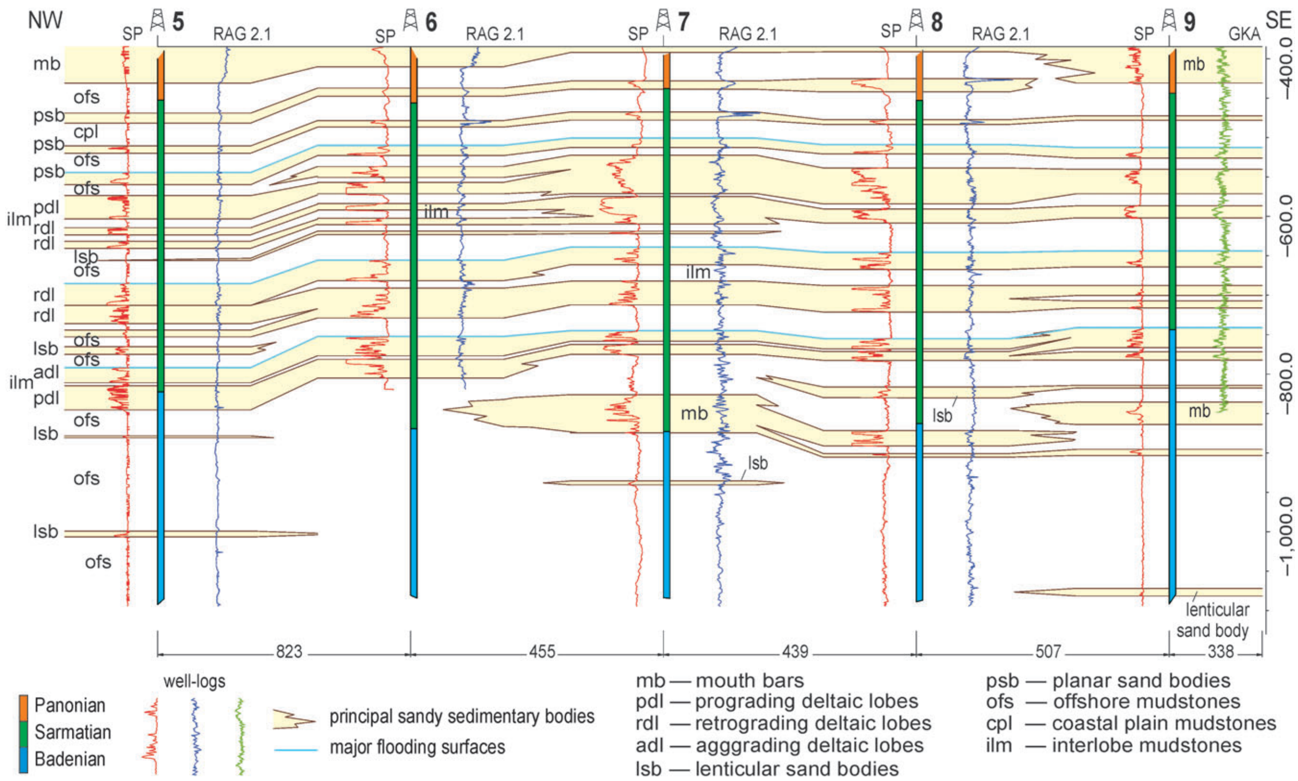


Fig. 6. Sarmatian parasequence sets — high frequency cycles identified in the sedimentary record of the study area; boreholes 5–9 = J26, J20, J25, J23, L76; Sarmatian sand bodies of varied origin (see explanatory notes to Fig. 6) are traceable across the entire littoral zone of the northern Vienna Basin eastern margin.

and clays in various parasequence sets refer to increase of most likely paleogeographical and climatic influence on deposition, above all in shallow water environments.

On the basis of the well log analysis, several parasequences were distinguished within the **Late Badenian** record, and they are bounded by distinct flooding surfaces. The parasequence sets of the lower part of the Upper Badenian strata assigned to the 1st Late Badenian 4th-order cycle — LB 1 generally display a fining upward trend. In the studied area, parasequences with serrated funnel-shape of well logs prevail. This is characteristic for small sand bar bodies (Fig. 5). This fact suggests the landward shift of the shoreline, decreased sediment supply and preferential deposition of pelitic material (calcareous clays) during the 3rd-order transgression. On the other hand, the 2nd Late Badenian 4th-order cycle, with progradational coarsening upward trend of the well logs, refers to the deposition during the sea-level high stand in the onshore settings influenced by deltaic deposition. Individual parasequences exhibit clear funnel shaped log motif, which can, after the correlation with obtained drill cores, be described as progradational mouth bars developing in the shallow water environment of the lower delta plain.

The recognized parasequence sets are presumably of local character and might represent a sedimentary record documenting a shift in the direction of the distributary channels, development of crevasse splays and deltaic to alluvial plain depositional settings. Sandy accumulations are accompanied by fine, pelitic deposits of interdistributary areas, which are suddenly eroded and filled with coarser sandy sediments. Besides this fact, individual parasequence sets are not traceable across the whole studied area and the number of these cycles is highly changeable. Hence, it is not possible to find (specify) any principal regularity of their origin. We suppose the identified Upper Badenian parasequences and parasequence sets to be more likely a result of frequent shifting of distributaries rather than orbital forcing.

The presence of repeating sand-clay cycles is very typical for the **Sarmatian** sedimentary record of the Vienna Basin in general (Harzhauser & Piller 2004). This regularity of the appearance of sand bodies also led to their numbering: 1–10 sandy beds (horizons) by the Czech and Slovak oil and gas industry employers in the past (Kreutzer & Hlavatý 1990). Within our studied area 8 horizons were generally identified (Table 5).

The ***high frequency cycles*** (*parasequence sets or cycles of the 5th-order of relative sea-level changes*) reveal a distinct arrangement; they are composed of sandy bodies interbedded by fine-grained sediments, mainly clays (Fig. 6). The cycles represent either stacked parasequence sets (separated from each other by flooding surfaces) or the parasequences are a part of 5th-order cycles of relative sea-level changes, separated from each other by sequence boundaries.

Exact recognition of the 5th-order cycles in very shallow marine environments is a challenge, because the record of sedimentary surfaces is often discontinuous due to frequent sea-level changes and the composite characteristics of sedimentation. That is also a reason, why these surfaces are not always easily assessed and usually it is also difficult to recognize the hierarchy of the sequence boundary, indicating the 5th-order cycle of relative sea-level change. Nevertheless, subdividing the Sarmatian sedimentary record into 5th-order cycles was attempted, but no distinct sequence boundaries correlative within the whole area were detected. Only very few sequence boundaries appear to represent an erosional type, but even those display obscured patterns on well logs. Furthermore, the structure and character of stacking patterns of individual genetically related parasequences vary from well to well, reflecting the high-energy dynamic shallow marine-deltaic environment. This variety also caused difficulties with tracking the continuity of sedimentary surfaces and thus it would be highly speculative and inappropriate to regard these high frequency cycles as formal 5th-order sequence units. Henceforward, the Sarmatian cycles of less than the 4th-order of relative sea-level changes will be described as the high frequency cycles stacked into parasequence sets.

The Sarmatian record on well log curve enabled the identification of several higher order shifts of the relative sea level. Three relative sea-level falls and two sea-level rises of the 4th-order show a possibility to be correlated with maxima and minima on the eccentricity band (the last minimum is at the end of Sarmatian strata and continues into the Pannonian). The position of two maximum flooding surfaces of the 4th-order cycles can be assigned to maxima on the eccentricity band with a period of 400 kyr (Table 4, after Laskar 1990). This possible climatic (orbital) forcing of the Sarmatian high frequency sedimentary cycles was also proposed by Harzhauser & Piller (2004) in the Austrian part of the Vienna Basin.

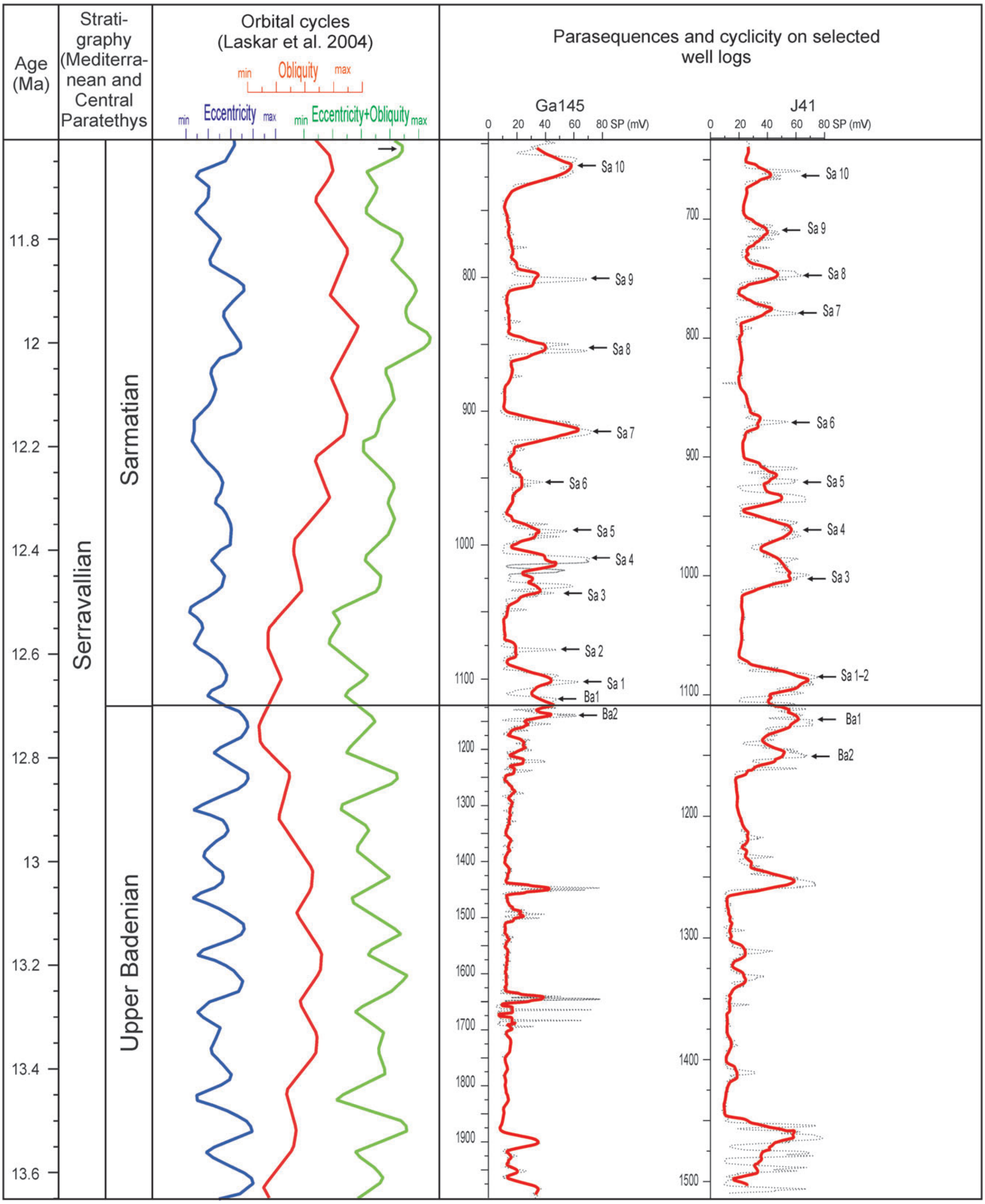
In the scope of well log study, we were able to detect within the Sarmatian record parasequences stacked into 8–12 parasequence sets (sandy horizons), with progradational or retrogradational trends. The number of parasequences is pointing to a highly dynamic changeable environment of a very shallow costal flat area (Fig. 6). These trends in sedimentary fill, on well log record, indicate changes in the depth and dynamics of the depositional environment and can be regarded as a result of climatic (orbital) forcing on an eccentricity band with a period of 100 kyr (Table 4).

The first two parasequence sets in the lower part of the Sarmatian record generally represent a funnel-shaped pattern, documenting increased input of clastic material into the environment of the upper delta plain with the possible pres-

Table 4: Astronomically forced cyclic sedimentation on the Vienna Basin eastern margin (eccentricity component 400-kyr and 100-kyr), Sarmatian depositional environment, lithology and well log trends are marked. Correlation was done on the basis of Laskar (1990) and Harzhauser & Piller (2004). SP log from MZ42 borehole.

			Eccentricity component 400 kyr	Eccentricity component 100 kyr	SP log	Trends of sedimentary fill	Lithology	Depositional environment
SARMATIAN	SA 2	HST	11.6 Ma			Progradation	silty clays to very fine-grained sands	shallow water to subaerial environment, lagoon and vegetated marshes of coastal plain
SARMATIAN	SA 2	mfs, TST				Retrogradation	fine-grained sands to silty clays	coastal plain sedimentary environment, lagoon or sheltered bay
SARMATIAN	SA 2 / SA 1	LST, SB, HST, mfs				Progradation	silty clays to laminated or massive sands	coastal plain, brackish sheltered bay or lagoon
SARMATIAN	SA 1	LST/TST				Retrogradation	sands, silts to laminated clays	delta to coastal plain reworked sand bars
SARMATIAN	SA 1	LST/TST	12.7 Ma			Progradation	laminated silts, clays to laminated fine-grained sands	lower to upper delta plain (brackish to fresh water)

Table 5: Comparison between amplitude modulation of the Serravallian eccentricity and obliquity curve (according to Laskar 1990 and Westerhold et al. 2005) and high frequency cycles of selected well logs. The uppermost part of the Late Badenian and Sarmatian cycles match well with the eccentricity and obliquity curve. The matching points are marked as Ba1–Ba2 and Sa1–Sa10 (Ba1–Ba2 as well as Sa1–Sa10 are the technical names of sandy horizons in the study area).



ence of tidal flats (Figs. 5, 6). In contradiction, the overlying two parasequence sets with bell-shaped patterns designate relative deepening of the sedimentary environment and decreased input of clastic material (Figs. 5, 6). Likewise, the upper part of the Sarmatian record, with 3 to 4 parasequence sets, refers to similar features of sedimentation (funnel-shaped and bell-shaped pattern). However, in the upper part a larger amount of sandy material is present in contrast to the lower one. The sands are related to the regression at the end of the Sarmatian. The sedimentary environment fits coastal plain flats with a tidal influence, including flat channels, interdistributary areas, levee and crevasse splays components. The last Sarmatian parasequence set was probably deposited in a sheltered lagoon with swamp and marsh vegetation (presence of *Glyptostrobus europaeus* (Brongniart)).

In contradiction to the Late Badenian sedimentary record, the Sarmatian record clearly documents the influence of astronomical forcing on cyclic sedimentation. High frequency cycles of 100 kyr component can be clearly correlated with the Laskar (1990) and Westerhold et al. (2005) eccentricity curve (Table 5).

Conclusions

Research into the Serravallian (Late Badenian and Sarmatian) sedimentary architecture, changes of depositional systems and paleoenvironments recorded in sediments of the northern Vienna Basin led to the following results:

- Two previously identified cycles of relative sea-level changes of the 3rd-order (Kováč et al. 2004) referring to the Haq's cycles TB 2.5 and TB 2.6 were again confirmed.
- The existence of four 4th-order cycles of relative sea-level changes was proved. Whereas the 2 lower cycles — LB 1 and LB 2 are assigned to the Late Badenian, the 2 upper ones — SA 1 & SA 2 embody the Sarmatian deposits.
- Both types of cycle — of the 3rd-as well as the 4th-order — fitt well with the development of other basins in the wider area (Styrian and Transylvanian Basins). This fact lets us assume, that they are of interregional character and their development was initiated by impulses common to the entire area of the Central Paratethys.
- Upper Badenian as well as Sarmatian sediments comprise several parasequence sets. Whereas the Upper Badenian parasequences do not show any possibility to correlate them across a larger region, the Sarmatian parasequence sets — high frequency cycles — are detectable over a wider area. However, the number of recognized cycles differs from one basin margin to another (see Austrian and Slovak parts of the Vienna Basin). Interregional correlation of high frequency cycles is not possible due to the restricted extent of the sedimentary bodies and due to discontinuous bounding surfaces.
- The Sarmatian (late Serravallian) shallow water sedimentary record documents a stronger influence of astronomical forcing on cyclic sedimentation. High frequency cycles, documented in the Vienna Basin, show similar development to other basins of the Central Paratethys region and are most likely the result of climatic (orbital) forcing on eccentricity bands with periods of 400 and 100 kyr (Table 5).

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