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# Late Miocene sequence stratigraphy of the Pannonian Basin fill (Kiskunhalas–Mélykút region, Hungary): how core, electric log and seismic data fit together?

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**Abstract:** In the area of the Danube–Tisza Interfluve, Pannonian Basin, Hungary, sedimentological, paleontological and well log interpretations of fully cored boreholes made it possible to establish the sequence stratigraphic subdivision of the Upper Miocene lacustrine and fluvial sections of boreholes Kaskantyú Kas-2, Jánoshalma J-1 and Bácsalmás Bá-1, of which Kas-2 is paleomagnetically dated. 8 sequences were determined in borehole Kas-2 and 6–6 ones in the boreholes J-1 and Bá-1 respectively. The correlation of the sequences was made along two independent composite seismic lines with the help of cross seismic profiles and well logs of 29 boreholes. 11 sequences were marked out in the Upper Miocene basin fill. The areal distribution of the sequences reflects the NW–SE direction of the sediment transport. By the time of maximum flooding surface (MFS) 2, the area was almost completely flooded. The oldest 4 sequences were identified in a seismically observable thickness in the NE Kiskunhalas depression. Their condensed layers are present in the well Bá-1 in the SE part of the area, revealed by dinoflagellates. Sequences 5 to 11 are present in well-observable thickness in the study area. The thickest part of the successive sequences is shifting towards the SE. Sequences 8 and 10 are developed only in the eastern part of the area. The basin evolution had two major phases: from 10.2 Ma to approximately 7.6 Ma the sequences 1–4 were characterized by local sediment accumulation despite their complete water cover, while between 7.6 and 6.6 Ma (sequences 5–10) regional sedimentation occurred.

**Key words:** Upper Miocene, Pannonian Basin, paleogeography, biostratigraphy, magnetostratigraphy, sequence stratigraphy, delta progradation.

## Introduction and research history

The Late Neogene Pannonian Basin and its subbasins has been in the centre of interest of stratigraphers, sedimentologists and paleontologists for decades. Being an approximately 12–13 million-year-old disconnected Paratethyan depository, the facies dependent and low diversity brackish water endemic fauna has caused serious correlation problems both in the basin, and in the remaining connected parts of the Paratethys. In the present era of integrated stratigraphy however, many former unanswered questions turned out to be less important, for example, the overemphasized elaboration and refinement of the Paratethyan (local) Late Miocene stages and substages or the urge to find more and more — not properly supportable — biostratigraphic subdivisions in the Pannonian Basin.

After the decades governed by the concept of static and basin-wide contemporaneous lacustrine infilling, a model of fluvial-dominated delta systems prograding mainly from NW to SE has been established offering a new explanation for the development of the infilling of the Pannonian Basin (Bérczi & Phillips 1985). Magnetostratigraphic data proved the protracted character of the infilling and the duration of the whole process was determined (Elston et al. 1985, 1990, 1994; Csató 1993; Juhász E. et al. 1997).

By the second half of the 1980s, many papers were published on the seismic facies of the different deep Pannonian subbasins of medium size. Later, using composite seismic sections, sequences according to the concept of Vail and co-authors (e.g. Posamentier & Vail 1988) were outlined and correlated to the 'global' system (Mattick et al. 1985; Pogácsás & Völgyi 1987; Pogácsás & Révész 1987; Pogácsás et al. 1987, 1988, 1989, 1992; K. Juhász Gy. et al. 1989; Korpás-Hódi et al. 1992; Csató 1993). In the early 1990s a new generation of seismic stratigraphers as well as sedimentologists made an effort to complete the missing parts and construct a unified system both in space and time (Vakarcs & Várnai 1991; Tari et al. 1992; Vakarcs et al. 1993, 1994).

Many problems and questions arose during this 20 years of manifold studies, for example regarding synchronism of the sea-level (SL) rise-and-fall and the water-level changes in a detached part of a previously interconnected brackish water sea system (Paratethys), the ordering (3$^{rd}$, 4$^{th}$ or 5$^{th}$-6$^{th}$) of the independent sequences (Juhász E. et al. 1994a, 1996), finding out whether these sequences are mostly climatic or tectonics related (Juhász E. et al. 1997) or whether they are the results of complex and/or feedback-type mechanisms.

By the middle of the 1990s, each working group established a series of sequences coherent to their disciplines but not matching the others. The aim of this paper is to give an example for gathering multidisciplinary (sedimentological, ecological, lithological and seismic) data in a study area of the eastern central part of the Pannonian Basin to evaluate them in their interdependence.

Summarizing the above mentioned facts, the infill model of the Pannonian Basin has been developed from a static one — lower finer grained and upper cyclically sandy series — through a lithostratigraphic one — based on the moving delta facies-system — to a recent sequence stratigraphic model based on the relative lake level changes and the balance between the overall subsidence and sediment influx. According to this model, ca. 6–12 elongated sigmoid-shaped bodies, piled on each other and slipped by their geometric centre toward the accumulation direction, constitute the Upper Miocene infilling of the basin. This model, by its geometry, certainly outlines the possible direct correlation of conductive coarser grained sand bodies important from the underground streaming fluids (water, oil and gas) and fluid movement modelling points of view.

## The study area

The study area lies in the central and southern part of the Danube–Tisza Interfluve, where three fully cored boreholes were drilled in the 1980s (Kaskantyú Kas-2, Jánoshalma J-1 and Bácsalmás Bá-1) cutting through the whole Upper Miocene (Fig. 1). There are paleomagnetic data from Kas-2, and biostratigraphic data based on dinoflagellates from Kas-2 and Bá-1 available. Due to former hydrocarbon exploration, the area was properly investigated and a large number of seismic lines were shot, however, no seismic lines go exactly through the wells J-1 and Bá-1.

All of the studied boreholes are situated above basement highs. The composite seismic sections are going through the Kiskunhalas depression located SE of Kas-2 and E of J-1. The Mélykút depression lies between the wells J-1 and Bá-1. Both depressions are relatively shallow parts of the basin system with undulating paleotopography that link to the Makó–Hód Trough E and SE of the Tisza river.

The cores of Kas-2, J-1 and Bá-1 were described minutely resulting in dm-scale resolution of the sedimentological, ecological and biostratigraphical data, while the 2D correlation of the seismic sections reflects 30–50 m resolution of the acoustic waves. Since the Upper Miocene formations here have a relatively limited thickness (400–1500 m) compared to the 5000–6000 m of those in the deepest basins to the SE (Makó–Hód Trough, Békés Basin) (Bérczi & Philips 1985; Bérczi 1988; Révész et al. 1989), the use of all the advantages of disciplines besides seismics was necessary.

## Methods

In order to gain at least two series of data, two different composite sections were compiled, a shorter one near the shallower part of the sub-basin and a longer one closer to the deeper areas crossing or approaching local basement highs. To improve the results 12 additional crossing seismic sections were used (from 'a' to 'l', in Fig. 1). Close to the borehole Jánoshalma J-1 the two composite sections are running together. The necessary number of the sections was determined by the reliable tracing of the systems tracts.

Between 1992 and 1996 the detailed sedimentological supervision of the cores and data available of the fully cored boreholes was carried out in the course of the Basin Analysis Project of the Geological Institute of Hungary (MÁFI) (Juhász E. et al. 1993, 1994b, 1996). This work was completed in the framework of a joint Hungarian–US governmental project between 1994 and 1997 by the USGS and the MÁFI (U.S.–Hungarian Science & Technology Joint Fund, JFNo. 329. Juhász E. et al. 1997, 1999, final report: Juhász E. & Phillips 1998). As a part of this project, the sedimentological data sheets of these three boreholes were also completed by detailed environmental interpretation. The ecological interpretation of the mollusc fauna was made by Pál Müller (personal communication), the biostratigraphic zonation from the wells Kas-2 and Bá-1 was performed by Sütő-Szentai (1982, 1983, 1991, 2003 pers. comm.). All these data were evaluated to establish sequences and systems tracts. Well log (electric and nuclear) interpretations were made to complete the sedimentological framework regarding cyclicity ("parasequences") and upward coarsening or fining trends of the series. On Fig. 2 a part of the data sheet of the well Bácsalmás Bá-1 demonstrates the elaboration.

On the figure, two seguence boundaries can be seen. The lower one is characterized by gradual upward coarsening of the deposited material, with a definite m-scale thick sandy bed, littoral clams together with slight upward coarsening trend visible on gamma and resistivity logs, followed by a sharp decrease in the average grain size of the sediment. The transgressive systems tract is dominanted by silts. Some sublittoral faunal elements show the deepening of the water cover. The maximum flooding surface is below the horizon where the upward coarsening trend of the cyclicity of fourth- or fifth-order occurs together with littoral shell fragments. The shallowing of the facies may also be indicated by the disappearance of the dinoflagellates. Approaching the upper sequence boundary the lagoonal fossils also disappear. At the top root casts, calcareous concretions and variegated sediment colour are also characteristic.

## Results and discussion

### *Correlation of the sequence stratigraphic units*

#### *Sequence stratigraphic outline*

The Upper Miocene series was divided into sequences in all the three boreholes. In the deepest Kas-2 well 8 complete sequences appear, while in the shallower wells (J-1 and Bá-1) 5-5 can be identified. In Fig. 3 the general outline of the systems tracts can be seen. At the base there is a basin-wide erosional contact between the Middle Miocene and Upper Miocene series with significant time gap in the study area. At the top there is a subaerial unconformity between the Pliocene and Miocene strata.

Figure 3 also illustrates the following most common features of the Upper Miocene series on the Great Hungarian Plain: the monotonous, cyclic alternation of sandy and muddy layers, the shallowing and/or upward coarsening

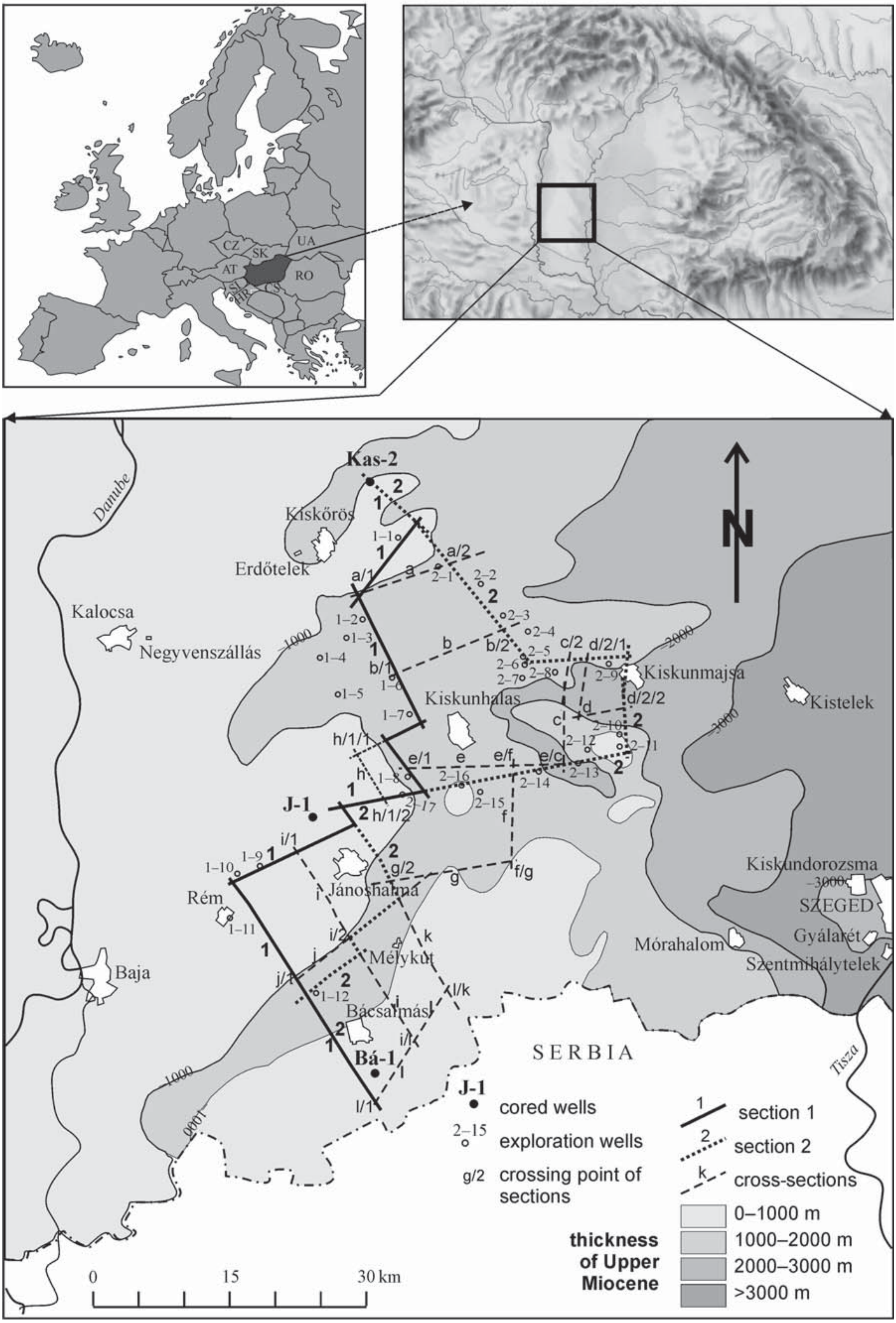


**Fig. 1.** Location map with the three cored wells, composite seismic sections #1 and #2, additional crossing seismic sections above the thickness contour map of the Upper Miocene (Pannonian) series.

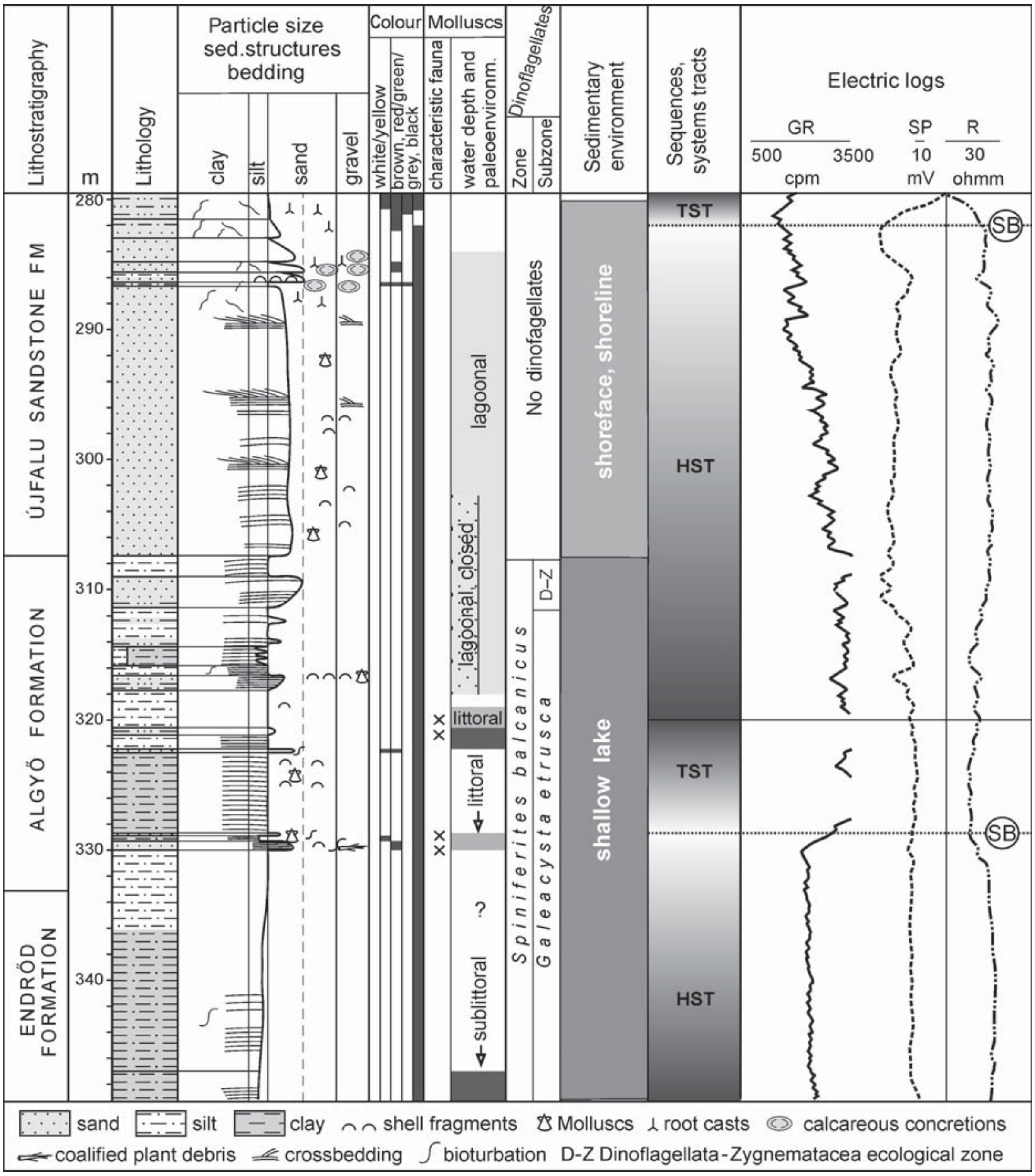


**Fig. 2.** Sedimentological chart of Bácsalmás-1 borehole section and systems tracts interpretation (sedimentology: Juhász et al. 1994b; molluscs: Müller P. in Juhász et al. 1994b and pers. comm. 2002; dinoflagellates: Sütőné Szentai M. 1982, 2003, pers. comm.).

character of the complete Upper Miocene series (see also Juhász E. et al. 1996) and the significant (here: 150–200 m) thickness of the basal silty clay–clayey silt set of strata regardless of the relative closeness of the elevated background or the thickness of the covering littoral sediments. The development of this fine-grained basin unit is primarily the result of the quick and significant incipient deepening of the Pannonian Basin (starving basin era). The rapid infilling process here could have been started not before 9.8 Ma (see Fig. 3, Kas-2 well).

### *Correlation*

The location of the already performed fully cored wells limited the possibility of choosing seismic sections with numerous diagnostic terminations of the reflectors. To make a well-established net of sequence stratigraphic horizons, the well logs of 29 additional hydrocarbon exploration wells were also used (see Fig. 1). In order to correlate these logs with the pattern of the systems tracts detected along the seismic sections, the general upward coarsening

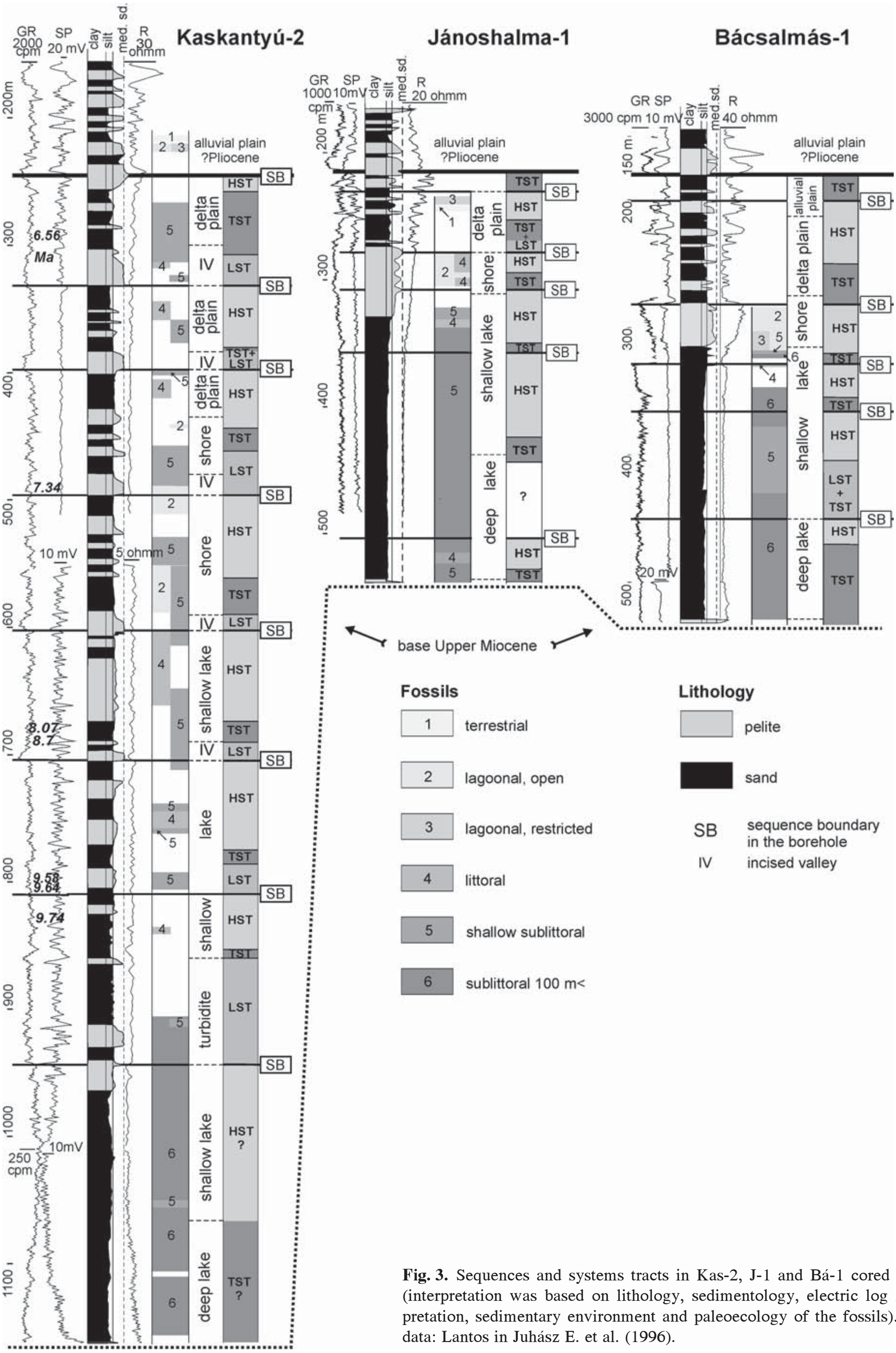


**Fig. 3.** Sequences and systems tracts in Kas-2, J-1 and Bá-1 cored wells (interpretation was based on lithology, sedimentology, electric log interpretation, sedimentary environment and paleoecology of the fossils). Age data: Lantos in Juhász E. et al. (1996).

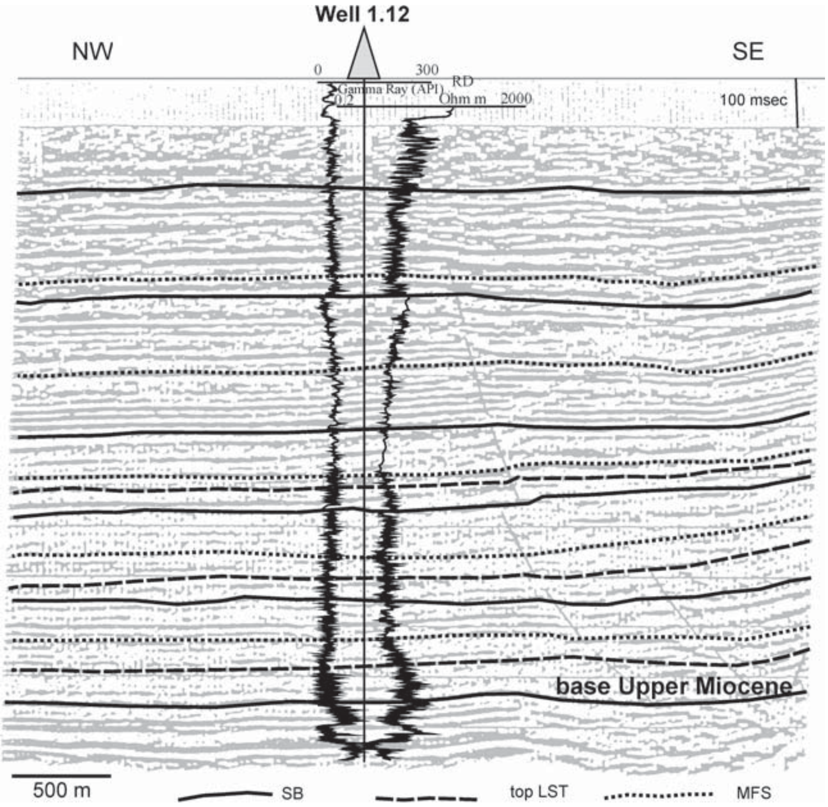


**Fig. 4.** The electric logs (GR and resistivity) of well numbered 1.12 along seismic section #2. Sequence boundaries, top lowstand surfaces and maximum flooding surfaces were identified and correlated with joint interpretation of well log shapes and seismic reflection configuration.

or fining trends of the approximately 100 m thick bedsets, parasequence sets were depicted, thus improving the reliability of the comparison. In Fig. 4 a well log of a borehole located in the Mélykút local depression is presented. With the help of the crossing seismic sections, stepping from well to well on the composite seismic lines of #1 and #2, the correlation of the sequence stratigraphic units was successfully achieved.

*The sequence stratigraphy of the study area*

As a result of correlation 11 complete sequences were traced (Fig. 5). The previously stated (Bérczi & Phillips 1985; Mattick et al. 1985; Pogácsás & Révész 1987; Bérczi 1988; Juhász Gy. 1992; Vakarcs et al. 1994) NW–SE direction of accumulation also governs the sedimentation here. The area of the successive sequences advances to the SE and the position of their greatest thickness progresses into the same direction. In the vicinity of Kaskantyú and in the Kiskunhalas local depression the sequences 1–7 are fully developed. The bulk of the material of the first 4 sequences was deposited in the northeastern Kiskunhalas depression (see Fig. 5). The fifth sequence is the first such sequence with a thickness greater than the average resolving power of the seismics in the whole study area; nevertheless it is eroded near Kas-2 by sequence boundary (SB) 6. Sequence 8 is also missing in the relatively flat, gently dipping indented rim of the elevated western part of the Danube–Tisza Interfluve (see Fig. 1). The possible reasons for this absence are to be discussed in the next part.

*Paleogeography of the sequences*

The area of the individual successive sequences reveals the main NW–SE direction of the accumulation at the investigated sites. In Fig. 6 the area of maximum flooding surface (MFS) 1 and MFS2 show the steps of the flooding process while the area of SB1 and SB2 show the maximum extent of sediment accumulation detectable by acoustic waves. Notice that in the well J-1 and in its vicinity, as well as to the SE, near the crossing of the f and g lines (f/g crossing point, see also Fig. 1) there is an area without sedimentation due to elevated position and/or underwater erosion.

The water cover of the area is also confirmed and dated by the dinoflagellate data since the *Spiniferites bentorii-oblongus* and the *Pontiadinium pecsvaradensis* Biozones are also present in the near bottom layers of the wells Kas-2 and Bá-1 (Sütő-Szentai 1991; Magyar et al. 2001).

The infilling process was continuing slowly; Fig. 7 shows the area of the 3–5 sequences. As it can also be seen in Fig. 5, the bulk of the material of the first 4 sequences was kept in the Kiskunhalas depression, thus the areas of these sequences do not differ significantly. Note that sequence 5 is missing in Kaskantyú-2 and in its close vicinity probably due to the erosive character of sequence 6 in this small region.

Sequences 6, 7 and 9 are thick and widely extended all over the whole area (see Fig. 5). In accordance with the NW–SE accumulation direction, the thicknesses of sequence 5 and 6 are greater in the NW (Kiskunhalas depression) while sequences 7 and 9 are thicker in the SE (Mélykút depression).

The area of sequences 8 and 10 is somewhat different from all the others (Fig. 8). Both are mainly developed in the eastern part of the Kiskunhalas depression according to composite line #2 and the crossing a–g lines. Since the thickness of these two sequences is gradually decreasing towards the W and S, their absence in the three cored wells can be explained rather by reworking during the next transgression than by underwater erosion and removal. The simplest explanation could be the actual change of the direction of the feeding channel.

In Table 1 the identified sequences are listed in the three master-cored wells with the thicknesses of the individual systems tracts.

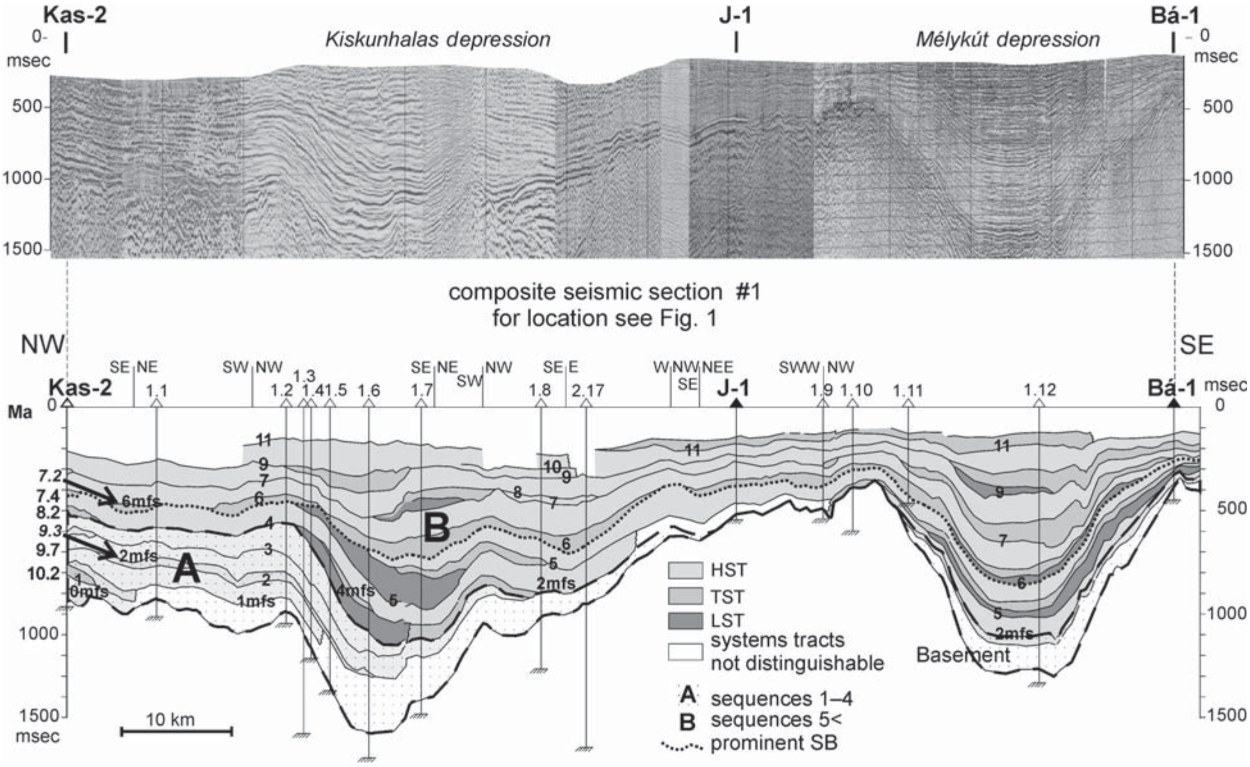


**Fig. 5.** Composite master seismic line # 1, and sequence stratigraphic interpretation. On the left magnetostratigraphic data from Kaskantyú-2 borehole (the breaks of the systems tracts' boundaries mark the position of the faults which were not illustrated because of the significant vertical exaggeration).

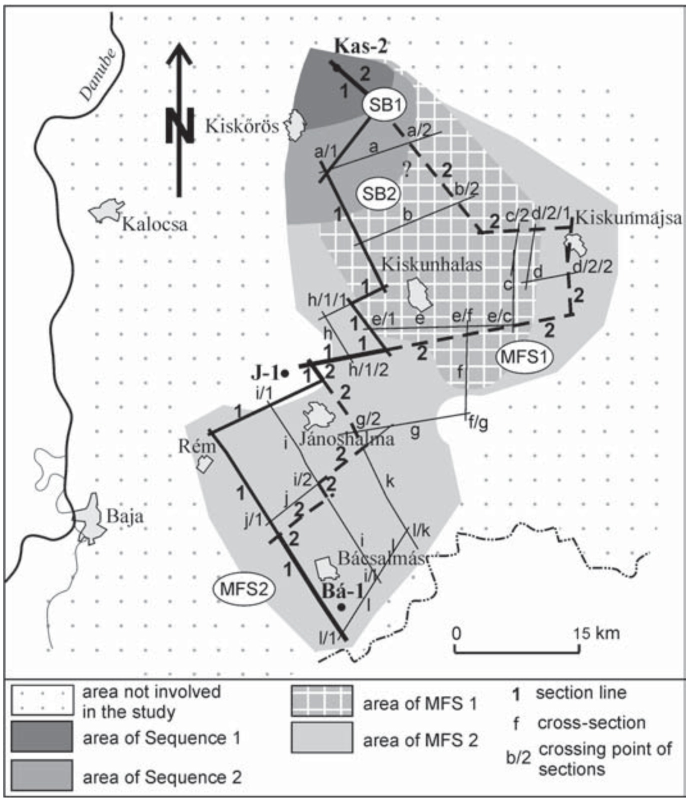


**Fig. 6.** Area of SB1, MFS1, SB2 and MFS2. Note the missing sequences in the vicinity of well J-1 and crossing point f/g.

### *Chronostratigraphic calibration of the sequences*

*Biochronostratigraphy: Dinoflagellate biozones*

In the wells Kas-2 and Bá-1, Sütő-Szentai (1982, 1983) has carried out detailed investigations referring to the dinoflagellate flora and summarized them together with the available data from the boreholes of the whole Pannonian Basin, differentiating biozones, subzones, as well as associations and correlating them to the flora of the Mediterranean Late Miocene (Sütő-Szentai 1991; Magyar et al. 2001). Sütő-Szentai updated the biostratigraphic subdivision of these two boreholes in 2003 (pers. comm.). These data are shown in Fig. 9 together with the latest version of the sequence stratigraphic division. There are two biozones, A: *Spiniferites bentorii* and B: *Spiniferites balcanicus* present in the time spans represented by the samples. The boundary between the two biozones is situated near the base of the thick, oldest clayey sediments of both boreholes, thus zone B covers almost the whole series. Regarding biozones, the correlation is perfect, however considering subzones the partly unfavourable ecological conditions are reflected in the changes of the frequency and the number of the species so strongly, that ecological Dinoflagellata-Zygnemataceae assemblages (marked by D-Z 1, -2, -3 in Fig. 9) break the succession of the subzones. This also means that the boundaries of the *Spiniferites*

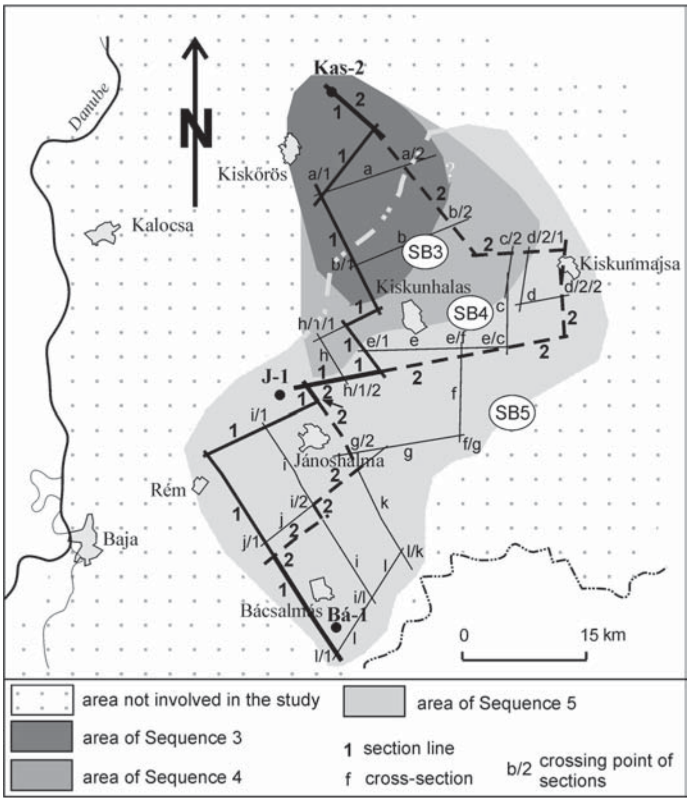


**Fig. 7.** Area of SB3, SB4 and SB5. Note the relatively slow advance of the sedimented material in seismically observable thickness.

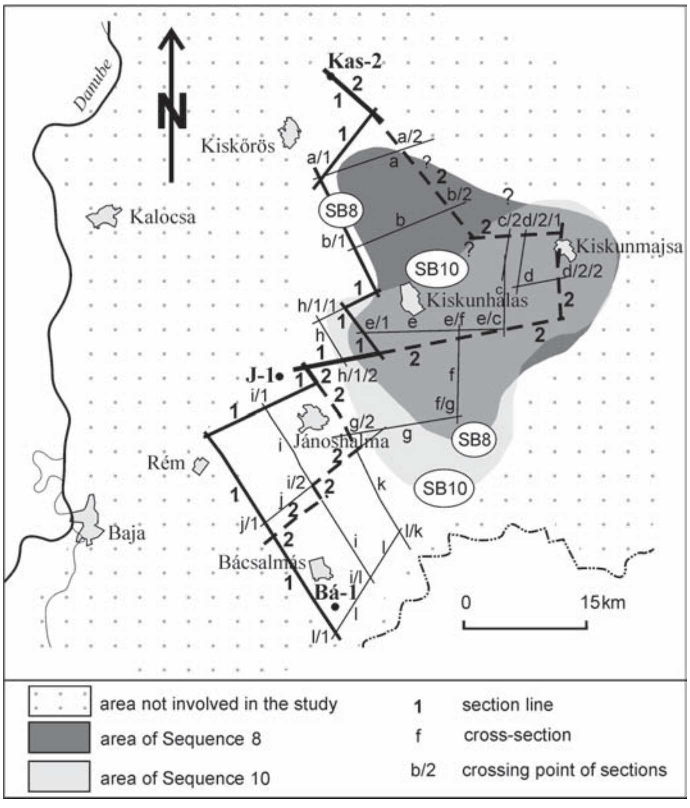


**Fig. 8.** Area of sequence boundaries 8 and 10. Note their similar contours and the absence or thinning out of their sediments toward the West and South.

Subzones can be extended probably through the D-Z zones (dashed lines on Fig. 9).

The correlations of the 4 subzones are as follows: *Spiniferites paradoxus*' is good but the upper boundary is too high in Bá-1, *Galeacysta etrusca*' is approximately acceptable, while *Spiniferites validus* and *Sp. tihanyensis* Subzones are uncorrelatable. Nevertheless the thicknesses of the zones in Kaskantyú-2 show excellently that the sedimentation rate was higher here in the first 4 sequences than during the sequences 6 and 7. Up to now, the contradictory results have not been solved.

One possible cause of the contradictions is the significantly elevated synsedimentary position of the place exposed by borehole Bá-1, so the thicknesses of the developed individual sequences are near or partly below the seismic resolution of the acoustic waves. Therefore below SB5 all the sequence boundaries must be considered here as approximations. As mentioned above, the bottom layers of the Upper Miocene in vast territory of the Pannonian Basin are rather fine-grained, as it can be seen in Fig. 2, so this lithology is unfavourable for distinguishing sequences both from seismic and sedimentological aspects.

### *Radioisotope data*

In the borehole Bácsalmás-1, at a depth of 485 m, 9.6 ± 1 Ma age was measured on biotites of dacite tuff forming a few cm thick layer (Balogh 1983). In the Kiskunhalas region (Kiha-Ny-3 well) below the fine-grained sediments belonging to the *Spiniferites paradoxus* Dinoflagellate Subzone, radioisotope ages ranging from 9.35 ± 0.68 to 9.77 ± 0.71 Ma (4 samples) were determined from basalts (Cserepes-Meszéna 1978; Balogh et al. 1986).

### *Magnetostratigraphy*

Vertically oriented samples were taken from every 0.5–1 m, for magnetic measurements, from the well Kaskantyú-2. The polarity zones were correlated to the polarity/time scale of Berggren et al. (1985) (Elston et al. 1990). As Kas-2 was the first section measured for paleomagnetic purposes in the Pannonian Basin, its magnetic profile may hold more uncertainties than the younger ones (Elston et al. 1990, pp. 113, 116) due to sampling methods and the rate of demagnetization. Lantos (in Juhász E. et al. 1996) adjusted the polarity zonation of numerous wells including Kas-2, to the new polarity/time scale of Berggren et al. (1995).

For dating the sequence stratigraphic units of the study area, mainly the paleomagnetic data of the well Kas-2 were used. The ages of SB2, 3, 4, 6, 7 and 9 are linearly interpolated from the next two ages of the reversals, SB1 is extrapolated (as the first measurable reversal was the C5n to C4Ar at the age of 9.74 Ma). The obtained data are listed in Table 2.

**Table 1:** Depth position and thickness of the systems tracts in the cored wells.

| Sequence stratigraphic levels | Kaskantyú-2 | | | Jánoshalma-1 | | | Bácsalmás-1 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Depth m | Thickness m | | Depth m | Thickness m | | Depth m | Thickness m | |
| | | **syst. tracts** | **sequence** | | **syst. tracts** | **sequence** | | **syst. tracts** | **sequence** |
| **Base Upper Miocene** | **1162** | 95 | 218 | **538.4** | | | **531.5** | | |
| MFS 0 | 1067 | 123 | | | | | | | |
| **SB 1** | **943.7** | 84 | | | | | | | |
| Top of LST 1 | 859.6 | 8 | 134 | | | 10 | | | 61 |
| MFS 1 | 852.0 | 42 | | | | | | | |
| **SB 2** | **810.0** | 24 | | | | | | | |
| Top of LST 2 | 786.0 | 10 | 105 | | | | | | |
| MFS 2 | 776.2 | 71 | | 528.0 | | | 470.0 | | |
| **SB 3** | **704.9** | 15 | 102 | | | | | | |
| Top of LST 3 | 690.4 | 16 | | | | | | | |
| MFS 3 | 674.0 | 71 | | | | 12 | | | 20 |
| **SB 4** | **602.7** | 13 | | | | | | | |
| Top of LST 4 | 590.0 | 28 | | | | | | | |
| MFS 4 | 562.0 | | | | | | | | |
| **SB 5** | **eroded** | | | **516.0 ?** | 92 | 159 | **450.0** | 46 | 84 |
| MFS 5 | | | | 424.0 | 67 | | 404.0 | 38 | |
| **SB 6** | **495.0** | 33 | 99 | **357.0** | 7 | 50 | **366.0** | 12 | 37 |
| Top of LST 6 | 461.8 | 19 | | 350.0 | 43 | | 354.0 | 25 | |
| MFS 6 | 443.0 | 47 | | | | | | | |
| **SB 7** | **396.3** | 13 | | **307.4** | 12 | | **328.7** | 9 | |
| Top of LST 7 | 383.4 | 3 | | 295.0 | | | 320.0 | | |
| MFS 7 | 380.0 | | | | | | | | |
| SB 8. LST. TST. HST | not present/condensed in the master-cored wells | | | | | | | | |
| **SB 9** | **322.0** | 15 | | **278.0** | 8 | | **282.0** | 32 | |
| Top of LST 9 | 307.2 | 51 | | 269.7 | 16 | | 250.0 | | |
| MFS 9 | 256.0 | | | 253.0 | | | | | |
| SB 10. LST. TST. HST | not present/condensed in the master-cored wells | | | | | | | | |
| **SB 11** | | | | **229.0** | 8 | | **200.5** | | |
| MFS 11 | | | | 221.0 | 4 | | | | |
| **Base Nagyalföld Formation** | **245.3** | | | **217.3** | | | **180.2** | | |

**Table 2:** Paleomagnetic ages of the sequences detected in well Kaskantyú-2.

| Sequence boundary | Depth/time relations* correlated to Berggren et al. (1995) polarity/time scale | | | Interpolated paleomagnetic ages | | Duration of the sequence (Myr) |
|---|---|---|---|---|---|---|
| | (m) | Reversals | (Ma) | (m) | (Ma) | |
| Base Upper Miocene | 1162 | | | 1162 | | |
| **SB1** | | | | 943.7 | **10.2** (extrapol.) | 0.5 |
| | 833.9 | C5n.1n/C4Ar.3r | 9.74 | | | |
| **SB2** | | | | 810.0 | **9.7** | 0.8 |
| | 808.5 | C4Ar.3r/ C4Ar.2n | 9.64 | | | |
| | 800.9 | C4Ar.2n/ C4Ar.2r | 9.58 | | | |
| | 791.8 | C4Ar.2r/ C4Ar.1n | 9.3 | | | |
| | 765.3 | C4Ar.1n/ C4Ar.1r | 9.2 | | | |
| | 730 | C4Ar.1r/ C4An | 9.03 | | | |
| **SB3** | | | | 704.9 | **8.8** | 0.6 |
| | 690.4 | C4An/C4r.2r | 8.7 | | | |
| **SB4** | | | | 602.7 | **8.2** | 0.8/2=0.4 |
| | 579.3 | C4r.1r/ C4n.2n | 8.07 | | | |
| **SB6** | 490.4 | C3Br.2n/C3Br.2r | 7.34 | 495.0 | **7.4** | 0.4 |
| **SB7** | | | | 396.3 | **7.0** | 0.3 |
| **SB9** | | | | 322.0 | **6.7** | |
| | 294.7 | C3Ar/C3An.2n | 6.56 | | | |

*Lantos, in Juhász et al. (1996)

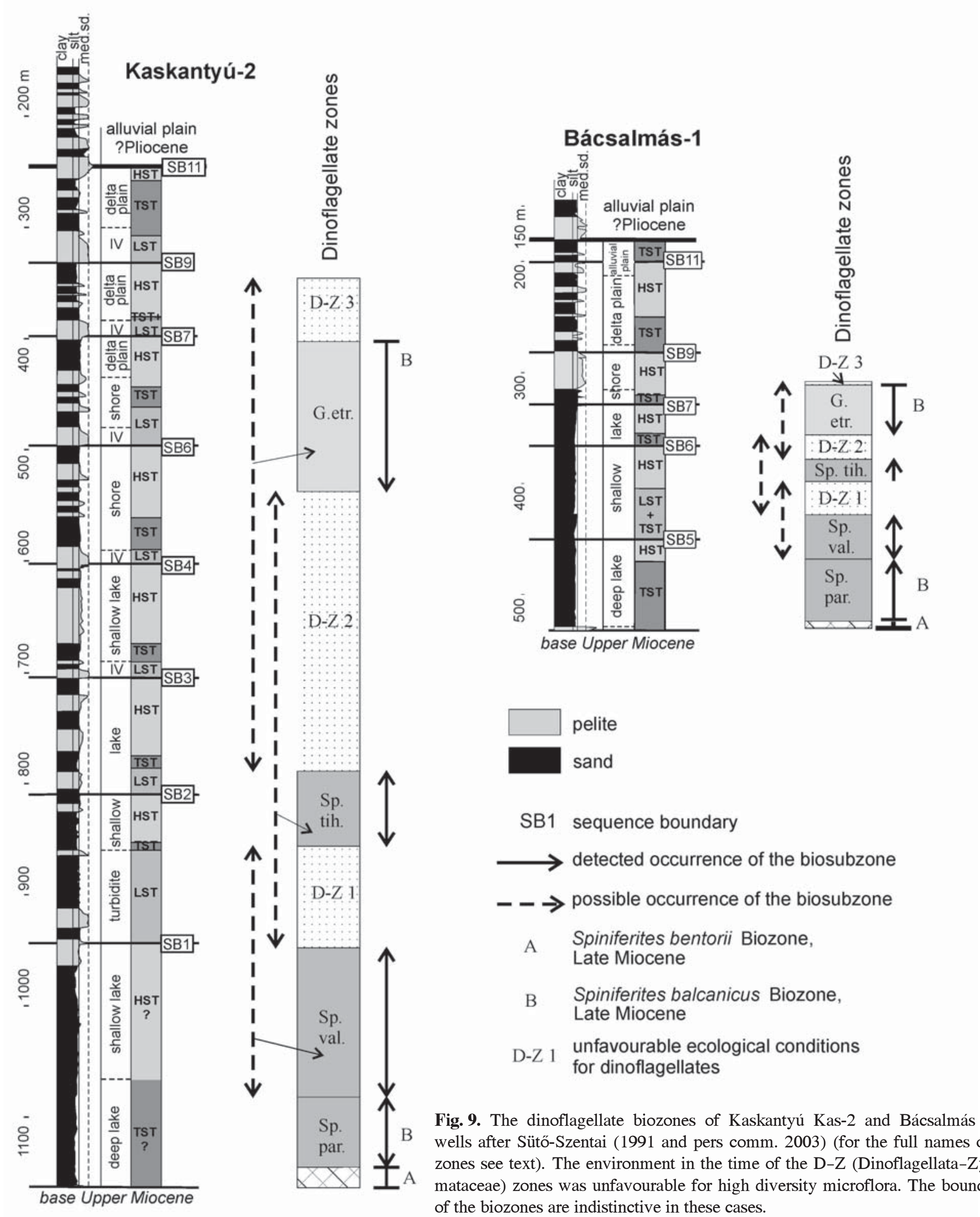


**Fig. 9.** The dinoflagellate biozones of Kaskantyú Kas-2 and Bácsalmás Bá-1 wells after Sütő-Szentai (1991 and pers comm. 2003) (for the full names of the zones see text). The environment in the time of the D–Z (Dinoflagellata–Zygnemataceae) zones was unfavourable for high diversity microflora. The boundaries of the biozones are indistinctive in these cases.

### *The order of the sequences*

The age calibration of the sequence boundaries implies a possible duration of the confined sequences. As Table 2 shows, the duration of the individual sequences lies between 300 and 800 kyr. According to the original definitions of Mitchum et al. (1977) and Van Wagoner et al. (1990), the formation of the third-order sea-level change sequences lies between $10^5$ to $(1–2)\times10^6$ years, the thickness varies between 20 to 400 m. The 4$^{th}$-order sequences are of $10^4$ to $(1–4)\times10^5$ years, the average thickness varies between 10 to 100 m (by order of magnitude). In our case it means, that sequences 6 to 11 can be regarded as fourth-order, sequences 1–6 can be regarded as third-order sequences on the basis of their duration and thickness. Taking into account that the larger values: 500 kyr, 600 kyr and 800 kyr, belong to the older sequences where either the seismic or the sedimentological evidence is weak, there is an increased possibility of finding one or two undifferentiated sequences.

Vakarcs (1997) evaluated the order of the Upper Miocene sequences all over the Hungarian part of the Pannonian Basin. The sequence boundaries at 10.8 (Pa2), 9.15 (Pa3), 6.85 (Pa4) and 4.4 (Pa5) were marked as 3$^{rd}$-order ones by him. There are several 4$^{th}$-order sequences building up the 3$^{rd}$-order ones. The number of these sequences varies between 3 and 15.

In the Vienna Basin Harzhauser et al. (2004) marked as third-order SB the one at the Serravallian/Tortonian boundary at 11.6 Ma, and considered that the whole Lower and Middle Pannonian lake deposits belong to one 3$^{rd}$-order sequence.

Kováč et al. (1998) marked one 3$^{rd}$-order SB near the base of the Pannonian series in the northern Vienna Basin, and a second one near the top of the D zone *sensu* Papp. Kováč et al. (2006) approved a 3$^{rd}$-order sequence boundary of SB1 type at Late Serravalian to Early Tortonian (Sarmatian to Early Pannonian) at the northwestern basin margin. The next 3$^{rd}$-order cycle belonging to the Middle Tortonian is characterized there by caspibrackish Lake Pannon sequences. The last Late Pannonian (Late Tortonian) 3$^{rd}$-order cycle includes freshwater lake and alluvial plain deposits and are characterized by SB1 and SB2 type sequence boundaries. Correlation of the Danube Basin cycles of relative water level changes with global sea-level fluctuations (*sensu* Haq et al. 1988 and Hardenbol et al. 1998) documents an indirect connection of the Lake Pannon with the world sea during the Pannonian time interval.

Juhász Gy. et al. (2006) underline the role of tectonics in the formation of the 3$^{rd}$-order sequences on the Great Hungarian Plain.

In a detached part of a former inland sea (Paratethys) mainly climate and tectonics can cause water level fluctuations. The ~400 kyr periodicity of the identified cycles in the study area suggests climatically driven cyclicity in Late Miocene time. This idea was first published concerning the Hugarian part of the Pannonian Basin by Juhász E. et al. (1996). Sacchi & Müller (2004) reported 400 kyr cyclicity in the Upper Miocene of the Transdanubian part of the Pannonian Basin. Juhász Gy. et al. (2006) regard 4$^{th}$- and higher order cycles driven by large-scale climatic cycles of the Milanković band (100, 200 and 400 kyr) or their multiples.

Harzhauser & Piller (2004) identified and documented 400 kyr period time cyclicity in the Sarmatian series of the Western Central Paratethys.

### *Sequence stratigraphic correlations*

It is possible to compare the results of this study with previously published data and results of Pogácsás et al. (1988), Vakarcs (1997), Vakarcs et al. (1997) and Sacchi et al. (1999, 2004). Without having a common data set, the comparison can only involve the number, the order and the age of the sequences.

Ages of sequence boundaries were first published from the Late Miocene of the Pannonian Basin by Pogácsás et al. (1988). These data were based on radioisotope and paleomagnetic data. In Fig. 10 the available data with the reference scales of Berggren et al. (1985, 1995) can be seen. Since Vakarcs (1997) studied the latest filled and deepest two sub-basins (Békés and Makó Grabens), his data involve the youngest ages. Nevertheless, in the majority of the territory of the Pannonian Basin, in the Late Miocene, sedimentation occurred between 10.8 and 6.3 Ma. Older strata were deposited in the deepest subbasins and marginal subbasins (due to tectonic reasons; Vakarcs et al. 1993). Strata younger than 5.4 Ma occur only in the SE part of the Great Hungarian Plain.

SB2 at 9.7 Ma of the study area may coincide with Vakarcs's (1997) Pa3 at 9.15 Ma. Kiskunhalas–Mélykút region being a "starving basin" in the time of SB2 the deposited sediments were condensed and as a consequence, on the seismic sections, the surfaces SB2 and MFS2 cannot be distinguished, they are represented by the same seismic event. Moreover, the extension of sequence 1 is much more limited than the area of sequence 2 (see Fig. 6). This fact underlines the significance of SB2, and gives an intention to correlate it with a 3$^{rd}$-order SB of Vakarcs (1997) Pa3, 9.15 Ma. MFS2 of the study area at 9.3 Ma and MFS2 of Sacchi & Müller (2004) at 9.075 Ma also seems to be correlative.

The first hiatus of Pogácsás et al. (1988) was dated between 7.6 and 7.9 Ma. Projecting it to the Berggren (1995) scale, this SB (or boundaries) can be correlated to either SB3 (8.8 Ma) or SB4 (8.2 Ma) of the study area. One of them can be compared to Pan2 at 8.75 Ma (Sacchi & Müller 2004). The big hiatus in the Messinian, involving perhaps more than one sequence boundary between 5.7–6.8 Ma (Pogácsás et al. 1988), can be correlated to Pa4 of Vakarcs (1997) at 6.85 Ma and to SB6 of the study area at 7.4 Ma. Fig. 5 and Fig. 6 show the significance of this surface all over the study area. Note the erosive character of this surface in relation to SB5.

The reason to connect MFS3 of Sacchi et al. (1999) at 7.455 Ma and MFS6 of the study area at 7.2 Ma is that both are situated above a significant, correlated SB (see also Fig. 6) and both can be traced well in their study areas.

## Conclusions

This work is an attempt to make a synopsis of seismic, well log and fully cored borehole investigations in a particular study area in order to match the results of different disciplines.

In the area of the Danube–Tisza Interfluve sedimentological, paleoecological and well log interpretations of fully cored boreholes enabled the establishment of a sequence stratigraphic subdivision of the Upper Miocene (Pannonian s.l.) section of the boreholes Kaskantyú Kas-2, Jánoshalma J-1 and Bácsalmás Bá-1. Not considering the unconformity at the base of the Pliocene Nagyalföld Formation (*sensu* Császár 1997, which is present in all of the three studied boreholes), 8 complete sequences were identified in the Kaskantyú Kas-2 borehole and 5–5 sequences in the Jánoshalma (J-1) and the Bácsalmás (Bá-1) boreholes.

On the basis of joint interpretation of two independent composite seismic lines, 12 cross seismic profiles and well logs of 29 boreholes, sequence stratigraphic units were correlated along the composite seismic lines between the master cored boreholes. 11 sequences were observed in the Upper Miocene basin fill complex of the study area, apart from the regional erosional unconformity at the base of the Upper Miocene.

The oldest four sequences were identified in a seismically observable thickness only in the borehole Kaskantyú Kas-2 and in its surroundings. Its condensed layers were identified in the borehole Bácsalmás Bá-1 on the basis of micropaleontological studies (Sütőné Szentai 1982). Sequences 5, 6 and 7 are widespread in the study area. Sequence 5 is eroded along SB6 near the borehole Kas-2, at the northern margin of the Kiskunhalas sub-basin. Sequences 8 and 10 are well-developed in the eastern and south-eastern part of the area. According to the cross-sections, they gradually thin towards the West and North.

In the study area sequence 6 is the most important. It levelled off significant differences in basin topography. It has a considerable thickness in the majority of the study area, its lower sequence boundary is a remarkable onlap surface, and it erosionally truncates sequence 5 in the North. Sequence 7 displays similar features, however, its thickness is significant only in the South and south-east.

The time duration of the sequences ranges between 0.3 and 0.8 Myr, older sequences 0.8 to 0.6 Myr, while younger sequences were deposited during a shorter period, of 0.3 to 0.4 Myr. Most of the observed sequences are in the range of the 4$^{th}$-order sequences based on their duration, thickness and extension. The longer periods may hide undifferentiated cycles due to condensed sedimentation in the silty-marly lithofacies.

According to the sequence stratigraphic subdivision, established in this work, the basin evolution had two major phases. The first phase terminates with sequence 4 (the top is identical with SB5). Despite the total water coverage (known from dinoflagellate zones), this first phase was characterized by local sediment accumulation, in which

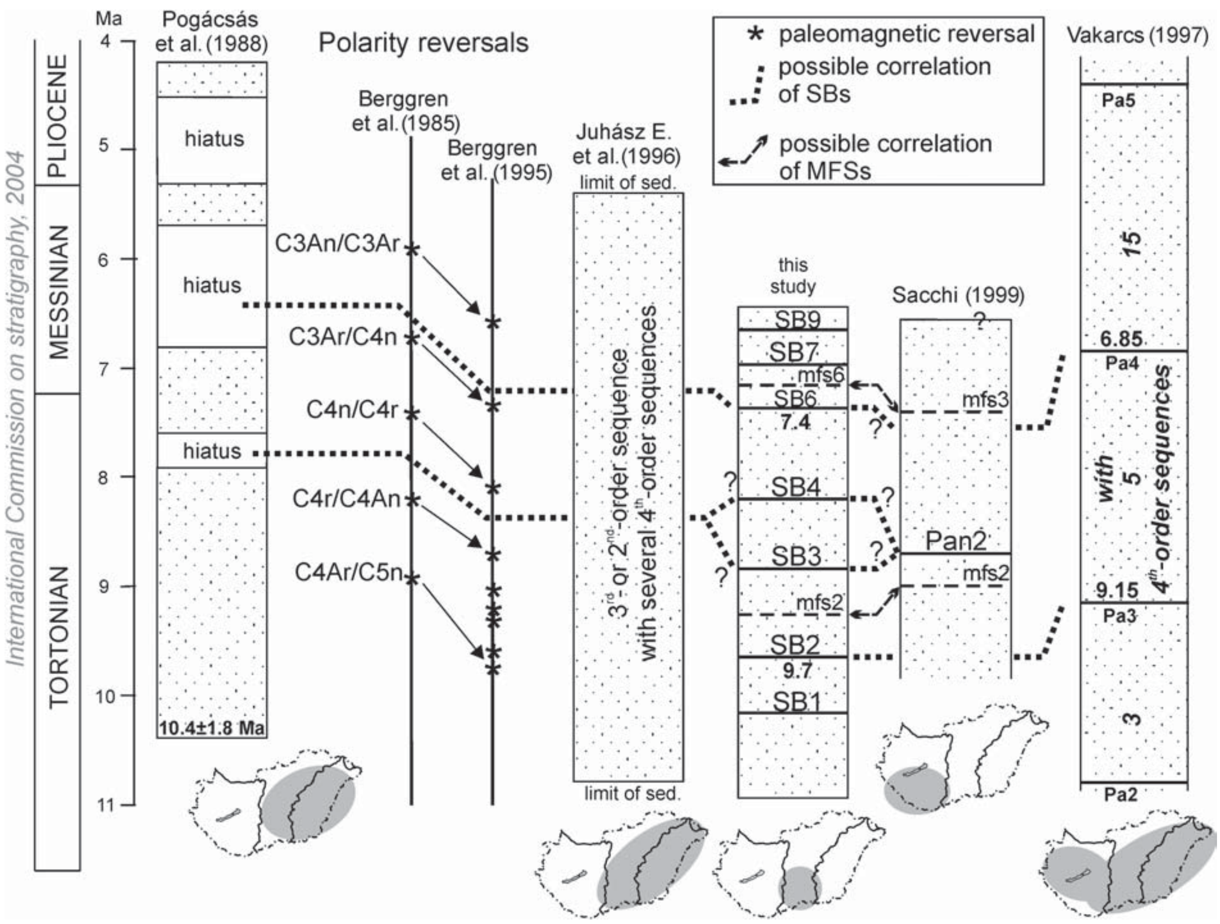


**Fig. 10.** Chronology correlation chart of sequences, established by authors for different subbasins of the Pannonian Basin system. Age data of Pogácsás et al. (1988) were correlated to Berggren et al. (1985) time scale (on the left) all the others are related to Berggren et al. (1995) time scale (on the right). For discussion see text.

sediments were not able to fill the available accommodation space completely but they were trapped in the Kiskuhalas depression. The second phase of basin development (sequences 5–10 between 7.8 and 6.6 Ma) was characterized by a regional, widespread sedimentation. Moreover, sequences 1–4 have similar thickness in the basin areas and above basement highs, which shows a uniform subsidence. On the contrary, sequences younger than sequence 5 are thicker in the depressions. This may reflect to differential basin subsidence.

The dated sequence boundaries of this work have been compared to previous results of other authors as well. It is quite likely, that the hiatus between 5.7 and 6.8 Ma, described by Pogácsás et al. (1988) can be identified with the Pa4 sequence boundary of Vakarcs (1997) at 6.85 Ma and also with SB6 at 7.4 Ma of this work. Based on the previously listed evidence and endorsing Vakarcs's (1997) classification, this SB can be regarded as a 3$^{rd}$-order one. The hiatus between 7.6 and 7.9 Ma of Pogácsás et al. (1988) can be identified with the SB4 at 8.2 Ma or SB3 at 8.8 Ma of this work (Fig. 10).

Considering that SB2 (9.7 Ma) and its maximum flooding surface (9.3 Ma) can be followed in an extended area from Kaskantyú to Bácsalmás, it could be identified with the Pa3 3$^{rd}$-order sequence boundary at 9.15 Ma of Vakarcs (1997), despite the age differences. In the study area this can also be classified as a 3$^{rd}$-order one.

Sacchi followed and dated primarily the maximum flooding surfaces in his sections. The age of the maximum flooding surface of sequence 2 in the borehole Kas-2 at 9.3 Ma, and the 7.2 Ma age of the maximum flooding surface of sequence 6, can be correlated with the MFS ages of Sacchi & Müller (2004) at 9.075 and 7.455 Ma respectively.

The extension of the study area, the location of the fully cored boreholes, the relative scarcity of fossils, and thickness variability of the observed sequences did not allow further conclusions based on evidence referring to synchronism with the global sequence stratigraphic system.

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## References

Balogh K. 1983: The results of K/Ar radiometric geological age determination in Hungary. *Thesis C. Sc., Hung. Acad. Sci.*, Budapest.

Balogh K., Árva-Sós E., Pécskay Z. & Ravasz-Baranyai L. 1986: K/Ar dating of post-Sarmatian alkali basaltic rocks in Hungary. *Acta Mineral. Petrogr. Szeged* 28, 75–93.

Bérczi I. 1988: Preliminary sedimentological investigation of a Neogene depression in the Great Hungarian Plain. In: Royden L.H. & Horváth F. (Eds.): The Pannonian Basin. A study in basin evolution. *AAPG Memoir* 45, 107–116.

Bérczi I. & Phillips R.L. 1985: Process and depositional environments within Neogene deltaic-lacustrine sediments, Pannonian Basin, Southeast Hungary. *Geophys. Trans.* 31, 1–3, 55–74.

Berggren W.A., Kent D.V., Flynn J.J. & Van Convering J.A. 1985: Cenozoic geochronology. *Geol. Soc. Amer. Bull.* 96, 2, 1407–1418.

Berggren W.A., Kent D.V., Swisher C.C. & Aubry M.-P. 1995: A revised Cenozoic geochronology and chronostratigraphy. In: Berggren W.A., Kent D.V. & Hardenbol J. (Eds.): Geochronology, time scales, and global stratigraphic correlations: A unified temporal framework for a historical geology. *SEPM Spec. Publ.* 54, 129–212.

Csató I. 1993: Neogene sequences in the Pannonian basin, Hungary. *Tectonophysics* 226, 377–400.

Császár G. (Ed.) 1997: Basic lithostratigraphic units of Hungary. *Geol. Inst. Hung.*, Budapest, 1–114.

Cserepes-Meszéna B. 1978: Proterozoic migmatite and Lower Pannonian basalt cut by Kiskunhalas-Ny 3. CH exploratory well (in Hungarian). *Földt. Közl.* 108, 53–64.

Elston D.P., Hámor G., Lantos M., Rónai A. & Hámor T. 1985: Magnetostratography of Neogene strata penetrated in two deep core holes in the Pannonian Basin: Preliminary results. *Geophys. Trans.* 31, 75–88.

Elston D.P., Lantos M. & Hámor T. 1990: Magnetostratigraphic and seismic stratigraphic correlations of Pannonian (s.l.) deposits in the Great Hungarian Plain. *Ann. Report Geol. Inst. Hung. 1988,* 109–135 (in Hungarian).

Elston D.P., Lantos M. & Hámor T. 1994: High resolution polarity records and the stratigraphic and magnetostratigraphic correlation of Late Miocene and Pliocene (Pannonian, s.l.) deposits of Hungary. In: Teleki P.G., Mattick R.E. & Kókai J. (Eds.): Basin analysis in petroleum exploration. *Kluwer Academic,* Dordrecht, 111–142.

Haq B.U., Hardenbol J. & Vail P.R. 1987: Chronology of fluctuating sea levels since the Triassic. *Science* 235, 1156–1167.

Hardenbol J., Thierry J., Farley M.B., Jaquin T., Gracinasky P.-C. & Vail P.R. 1998: Mesozoic and Cenozoic Sequence chronostratigraphic framework of European basins. *SEPM Spec. Publ.* 60, 3–13.

Harzhauser M. & Piller W.E. 2004: Integrated stratigraphy of the Sarmatian (Upper Middle Miocene) in the western Central Paratethys. *Stratigraphy* 1, 65–86.

Harzhauser M., Daxner-Höck G. & Piller W.E. 2004: An integrated stratigraphy of the Pannonian (Late Miocene) in the Vienna Basin. *Austrian J. Earth Sci.* 95/96, 6–19.

Juhász E. & Phillips L. 1998: Miocene sequence-stratigraphy. *U.S.–Hungarian Science & Technology Joint Fund, JF No. 329 — Activity Report 1998,* 154–155.

Juhász E., Farkas-Bulla J., Hámor T., Korpás-Hódi M., Müller P., Ricketts B.D. & Tóth-Makk Á. 1993: High-resolution sequence stratigraphy of Late Miocene and Pliocene sediments in the Pannonian Basin, Hungary. *8th Meeting of the Association of European Geological Societies, Budapest,* Abstracts, 28.

Juhász E., Farkas-Bulla J., Hámor T., Korpás-Hódi M., Müller P., Ricketts B.D. & Tóth-Makk Á. 1994a: Sequence stratigraphy and subsidence history of Neogene lake deposits, Pannonian basin, Hungary. *14th IAS, Recife, Brazil, August 1994,* Abstracts S 6–7.

Juhász E., Budai T., Farkas-Bulla J., Hámor T., Lantos M., Müller P. & Tóth-Makk Á. 1994b: The comprehensive sedimentologic facies interpretation and evaluation of the Neogene series of the Pannonian Basin. *Manuscript, OFGA Geol. Inst. Hung.,* Budapest, 1–32 (in Hungarian).

Juhász E., Müller P., Ricketts B., Tóth-Makk Á., Hámor T., Farkas-Bulla J. & Sütő-Szentai M. 1996: High resolution sedimentological and subsidence analysis of the Late Neogene in the Pannonian Basin, Hungary. *Acta Geol. Hung.* 39, 2, 129–152.

Juhász E., Ó. Kovács L., Müller P., Tóth-Makk Á., Phillips L. &

Lantos M. 1997: Climatically driven sedimentary cycles in the late Miocene sediments of the Pannonian Basin, Hungary. *Tectonophysics* 282, 257–276.

Juhász E., Phillips L., Müller P., Ricketts B.D., Tóth-Makk Á., Lantos M., Ó. Kovács L. 1999: Late Neogene sedimentary facies and sequences in the Pannonian Basin, Hungary. In: Durand B., Jolivet L., Horváth F. & Séranne M. (Eds.): The Mediterranean Basins: Tertiary extension within the Alpine Orogen. *Geol. Soc. London, Spec. Publ.* No. 156, 335–356.

Juhász Gy. 1992: Pannonian (s.l.) lithostratigraphic units in the Great Hungarian Plain: distribution, facies and sedimentary environment (in Hungarian). *Földt. Közl.* 122, 2–4, 133–165.

Juhász Gy., Pogácsás Gy., Magyar I. & Vakarcs G. 2006: Integrated stratigraphy and sedimentary evolution of the Late Neogene sediments of the Hungarian Plain, Pannonian Basin. *Földt. Közl.* 136, 1, 51–86 (in Hungarian).

K. Juhász Gy., Molenaar C.M., Bérczi I., Révész I., Kovács A. & Szanyi B. 1989: Stratigraphy of the Pannonian (s.l.) sedimentary succession in the Békés Basin. *Magyar Geofizika* 30, 4–5, 129–145 (in Hungarian).

Korpás-Hódi M., Pogácsás Gy. & Simon E. 1992: Paleogeographic outlines of the Pannonian s.l. of the southern Danube–Tisza Interfluve. *Acta Geol. Hung.* 35, 2, 145–163.

Kováč M., Baráth I., Kováčová-Slamková M., Pipík R., Hlavatý L. & Hudáčková N. 1998: Late Miocene paleoenvironments and sequence stratigraphy: Northern Vienna Basin. *Geol. Carpathica* 49, 6, 445–449.

Kováč M., Baráth I., Fordinál K., Grigorovich A.S., Halásová E., Hudáčková N., Joniak P., Sabol M., Slamková M., Sliva Ľ. & Vojtko R. 2006: Late Miocene to Early Pliocene sedimentary environments and climatic changes in the Alpine–Carpathian–Pannonian junction area: a case study from the Danube Basin northern margin (Slovakia). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 238, 1–4, 32–52.

Magyar I., Juhász Gy., Szurominé Korecz A. & Sütőné Szentai M. 2001: The Tótkomlós Calcareous Marl Member of the Lake Pannon sedimentary sequence in the Battonya–Pusztaföldvár region, SE Hungary. *Földt. Közl.* 133, 4, 521–540 (in Hungarian).

Mattick R.E., Rumpler J. & Phillips R.L. 1985: Seismic stratigraphy of the Pannonian Basin in southeastern Hungary. *Geophys. Trans.* 31, 1–3, 13–54.

Mitchum R.M.Jr., Vail P.R. & Thompson S.I. 1977: Seismic stratigraphy and global changes of sea level. Part 2. The depositional sequence as a basic unit for stratigraphyic analysis. In: Payton C.E. (Ed.): Seismic stratigraphy — application to hydrocarbon exploration. *Amer. Assoc. Petrol. Geol. Mem.* 26, 53–62.

Pogácsás Gy. & Révész I. 1987: Seismic stratigraphic and sedimentological analysis of Neogene deltaic features in the Pannonian Basin. *Ann. Geol. Inst. Hung.* 70, 267–273.

Pogácsás Gy. & Völgyi L. 1987: Korrelation der ostungarischen Pannonian s. str. (Kunság-Stufe) un jüngeren Schichtenverbände aufgrund von für Kohlenwasserprospektion errichteten seismische und borlochgeophysikalischen Profile. *Ann. Geol. Inst. Hung.* 69, 213–228 (in Hungarian).

Pogácsás Gy., Jámbor Á., Mattick R., Elston D.P., Várkonyi L., Lantos M., Simon E., Várnai P., Hámor T. & Lakatos L. 1987: Correlation of seismo- and magnetostratigraphy: Chronostratigraphy and the evolutionary sequence of rock units in the Pannonian Basin. *COGEODATA International Workshop on Computerized Basin Analysis, Szeged, Sept. 1987*, Abstracts, 1–13, 7–11.

Pogácsás Gy., Jámbor Á., Mattick R.E., Elston P., Hámor T., Lakatos L., Lantos M., Simon E., Vakarcs G., Várkonyi L. & Várnai P. 1989: Chronostratigraphic framework of Noegene formation in the Great Hungarian Plain as revealed by combination of seimo&magnetostratigraphy. *Magyar Geofizika* 30, 2–3, 41–62 (in Hungarian).

Pogácsás Gy., Lakatos L., Révész I., Újszászi K., Vakarcs G., Várkonyi L. & Várnai P. 1988: Seismic facies, electro facies and Neogene sequence chronology of the Pannonian basin. *Acta Geol. Hung.* 31, 3–4, 175–207.

Pogácsás Gy., Szabó A. & Szalay J. 1992: Chronostratigraphic relationships of the prograding delta series of the Great Hungarian Plain. *Magyar Geofizika* 33, 1, 1–13 (in Hungarian).

Posamentier H.W. & Vail P.R. 1988: Eustatic controls on clastic deposition I. Conceptual framework. In: Wilgus C., Hastings B., Ross C., Posamentier H., Van Wagoner J. & Kendall C. (Eds.): Sea level changes: An integrated approach. *SEPM Spec. Publ.,* Tulsa 42, 125–154.

Révész I., Bérczi I. & Phillips R.L. 1989: Lower Pannonian sedimentation in the Békés Basin. *Magyar Geofizika* 30, 2–3, 98–113 (in Hungarian).

Sacchi M. & Müller P. 2004: Orbital cyclicity and astronomical calibration of the Upper Miocene continental succession cored at the Iharosberény-I well site, western Pannonian Basin, Hungary. In: D'Argenio B., Fischer B., Silva A.G., Weissert H. & Ferreri V. (Eds.): Cyclostratigraphy: approaches and case histories. *SEPM Spec. Publ.* 81, 275–294.

Sacchi M., Horváth F. & Magyari O. 1999: Role of unconformity bounded units in the stratigraphy of the continental record: a case study from the Late Miocene of the western Pannonian Basin, Hungary. In: Durand B., Jolivet L., Horváth F. & Séranne M. (Eds.): The Mediterranean Basins: Tertiary Extension within the Alpine Orogen. *Geol. Soc. London, Spec. Publ.* 156, 357–390.

Sütőné Szentai M. 1982: Microplanctonic investigations of Pannonian sedimentary successions of key wells (Bácsalmás-1. well). In: Lenner S. 1985 (Ed.): Analytical and testing results of Bácsalmás-I. Neogene borehole samples and their geological evaluation. *Unpublished report. Geol. Inst. Hung.,* Budapest, 1–55 (in Hungarian).

Sütőné Szentai M. 1983: Microplanctonic investigations of Pannonian sedimentary successions of key wells (Kaskantyú-2. well). In: Szántó Z. 1984 (Ed.): Final report on key borehole Kaskantyú-2 of 1387.5 m depth. *Unpublished report. Geol. Inst. Hung.,* Budapest, 1–55.

Sütő-Szentai M. 1991: Organic walled microplancton zones of the Pannonian in Hungary. *Őslénytani Viták (Discussiones Palaeontologicae)* 36–37, 157–200 (in Hungarian).

Tari G., Báldi T., Báldi-Beke M., Horváth F., Kovács A., Lakatos L., Nagymarosy A., Pogácsás Gy., Sztanó O., Vail P.R. & Vakarcs G. 1992: Tertiary sequence stratigraphy of the Pannonian Basin. *Conference of sequence stratigraphy of European Basins, Dijon,* Abstracts, 90–91.

Vakarcs G. 1997: Sequence stratigraphy of the Cenozoic Pannonian Basin, Hungary. *Manuscript, PhD Thesis,* Rice University, Houston, Texas, 1–386.

Vakarcs G. & Várnai P. 1991: The seismostratigraphic model of the Derecske trough area. *Magyar Geofizika* 32, 1–2, 38–51 (in Hungarian).

Vakarcs G., Vail P.R. & Tari G. 1993: Middle Miocene–Pliocene sequence stratigraphic model of the Pannonian Basin, Hungary. *8th Meeting of the Association of European Geological Societies, Budapest,* Abstracts, 39.

Vakarcs G., Vail P.R., Tari G., Pogácsás Gy., Mattick R.E. & Szabó A. 1994: Third order Middle Miocene–Early Pliocene depositional sequences in the prograding delta complex of the Pannonian Basin. *Tectonophysics* 240, 81–106.

Vakarcs G., Abrieu V.S. & Vail P.R. 1997: Integrated stratigraphic correlation, a tool to increase stratigraphic resolution. *Amer. Assoc. Petroleum Geol. Ann. Meeting, Dallas,* Abstracts, A119.

Van Wagoner J.C., Mitchum R.M., Campion K.M. & Rahmanian V.D. 1990: Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high-resolution correlation of time and facies. *AAPG Methods in Exploration Series* No. 7, 1–55.