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# BIOSTRATIGRAPHIC REVISION OF THE HÓD-I WELL: HUNGARY'S DEEPEST BOREHOLE FAILED TO REACH THE BASE OF THE UPPER MIOCENE PANNONIAN STAGE

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**Abstract:** Hungary's deepest borehole, Hód-I, was drilled in 1969–71 SE of the town of Hódmezővásárhely, in order to explore one of the thickest Neogene basin fills of the entire Pannonian Basin (the Makó Trough). The final depth of the well was 5842.5 m. According to earlier analyses of 45 core samples taken from the borehole, the lowermost 700 m was thought to belong to the Middle Miocene (Badenian and, possibly, Sarmatian Stages), whereas the overlying part was believed to belong to the Upper Miocene (deposits of Lake Pannon, Pannonian Stage), Pliocene, and Quaternary. In order to establish a more precise position of the Neogene stage boundaries, we carried out micropaleontological investigations on the 4100 to 5823 m interval (cores 25 to 45). Ostracods have been prepared by solution of the samples in acetic acid. Dinoflagellates were investigated in palynological preparations and in petrographic thin sections. It was found that core 34 (5070–5074 m), earlier thought to represent the base of the Pannonian Stage, in fact belongs to the younger part of the Lake Pannon sequence (*Spiniferites validus* Zone). Downwards to the base of the borehole, the *Spiniferites paradoxus, Pontiadinium pecsvaradensis*, and *Spiniferites bentorii oblongus* Zones were found, all belonging to the Pannonian. Accordingly, ostracods indicated the younger part of the Upper Miocene lacustrine sequence for the upper samples of the investigated interval, and older Upper Miocene down to core 44. Thus, the drilling failed to reach the base of the Pannonian Stage. The huge thickness (>6 km) of the postrift sediments above the relatively thin synrift stages (Badenian and ?Sarmatian) in the Makó Trough corroborates the notion that simple rifting models are not sufficient to adequately describe basin evolution in the central part of the Pannonian Basin.

**Key words:** Upper Miocene, Pannonian Basin, Lake Pannon, biostratigraphy, Ostracoda, Dinoflagellata.

## Introduction

Prior to the recognition of basin-centred gas plays in the late 1990's, the central, deepest parts of sedimentary basins were rarely probed by drilling. State-owned oil companies, especially under the circumstances of a "planned economy", however, may be governed by other factors than strictly commercial ones in their decisions. The borehole Hódmezővásárhely-I (Hód-I) was drilled by the Hungarian Oil and Gas Trust in 1969–71 in order to explore the stratigraphic, sedimentological, tectonic, petroleum geological and organic geochemical conditions in one of the deepest Neogene subbasins of the entire Pannonian Basin. The Makó (or Makó-Hódmezővásárhely) Trough is a northwest–southeast trending, slightly asymmetric extensional graben in southeast Hungary (Grow et al. 1994; Fig. 1). It was formed in the Middle Miocene as a result of metamorphic core complex style extension (Tari et al. 1997, 1999; Fig. 2) and subsequently filled with more than 6000 m of Neogene and Quaternary sedimentary rocks (Mattick et al. 1985, 1988; Bérczi & Phillips 1985; Bérczi 1988). The well is located some 10 km SE of the town of Hódmezővásárhely, close to the axis of the trough (Gajdos et al. 1983; Fig. 1).

The drilling had been planned to penetrate the entire Neogene fill and to hit the Paleozoic metamorphic basement before reaching its final depth of 6000 m. The following unbroken stratigraphic column was expected above the crystalline basement: Lower Miocene (and possibly Paleogene), 1300 m; Middle Miocene (including two Central Paratethyan regional stages, the marine Badenian and the restricted marine Sarmatian), 600 m; Upper Miocene (comprising deposits of the brackish Lake Pannon and the adjacent fluvial plains, and synonymized in this study with the Pannonian Stage), 2600 m; Pliocene (predominantly fluvial and freshwater lacustrine sediments), 700 m; Quaternary, 700 m. Each of the three Miocene stages mentioned above has a characteristic fossil fauna and flora, so in most cases they are easily distinguishable by paleontological investigations (Table 1).

Although the drilling was abandoned due to technic problems at 5842.5 m without reaching the base of the Neogene formations, it is still the deepest well ever drilled in Hungary. Information obtained from this well is commonly referred to in sedimentological, geochemical, mineralogical, structural geological and geophysical studies (e.g. Szemethy 1977; Szalay & Szentgyörgyi 1979, 1988; Sajgó 1980; Kőrössy 1981; Gajdos et al. 1983; Bérczi & Phillips 1985; Sajgó et al. 1988; Bérczi 1988; Dövényi & Horváth 1988; Horváth et al. 1988; Mattick et al. 1985, 1988; Royden & Dövényi 1988; Szalay 1988; Hámor-Vidó & Viczián 1993; Clayton et al. 1994; van Balen et al. 1999).

The Neogene sequence of the well has been sampled with 45 cores, numbered in descending order (Fig. 3). The samples were subjected to routine biostratigraphic investigations (Csongrádi et al. 1971). According to these investigations,

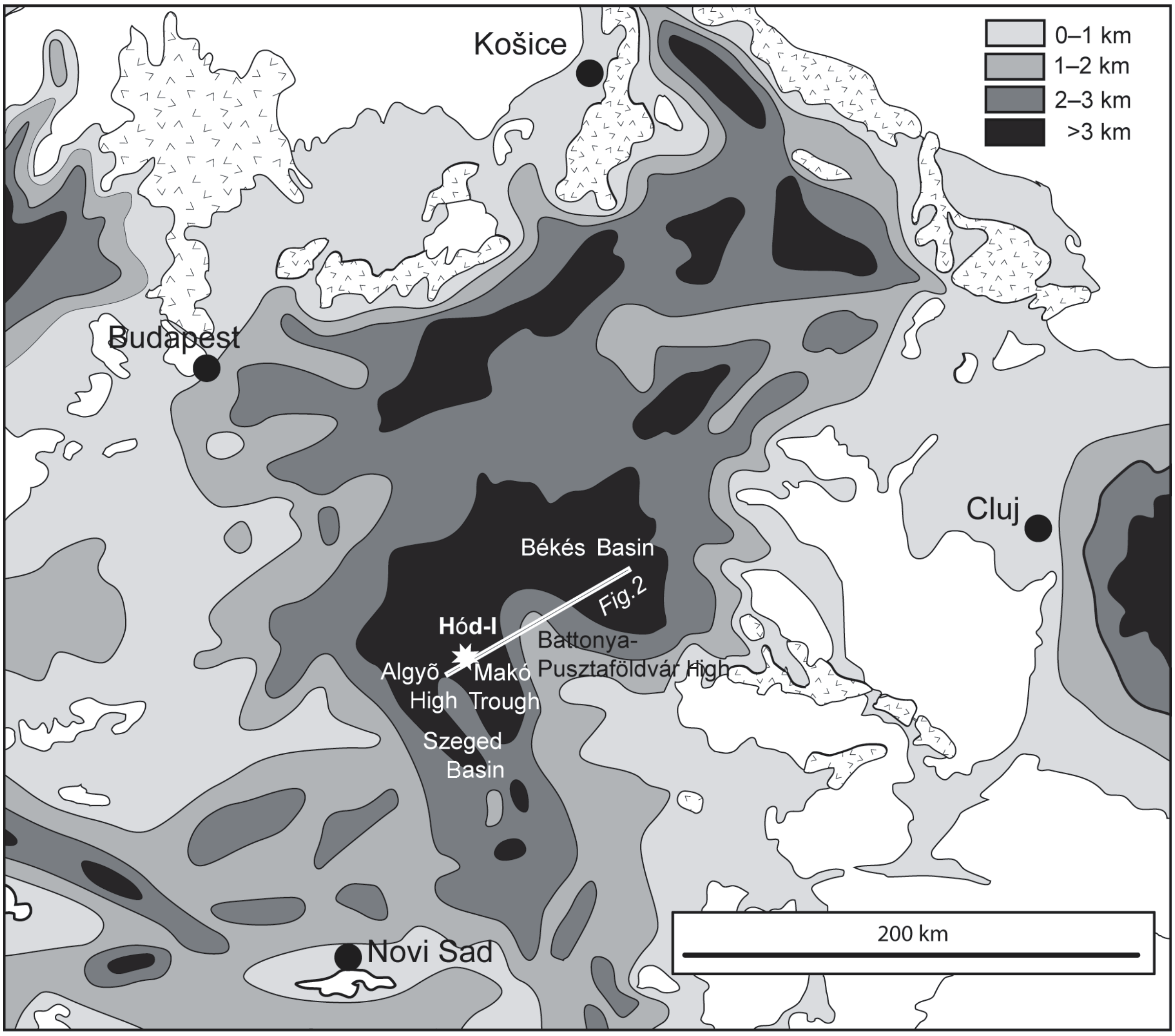


**Fig. 1.** Thickness of the Neogene basin fill in the central Pannonian Basin with location of Hód-I well (asterisk) in the NW–SE trending extensional Makó Trough. V-pattern indicates Neogene volcanics at the surface. Location of the seismic profile presented in Fig. 2 is also indicated.

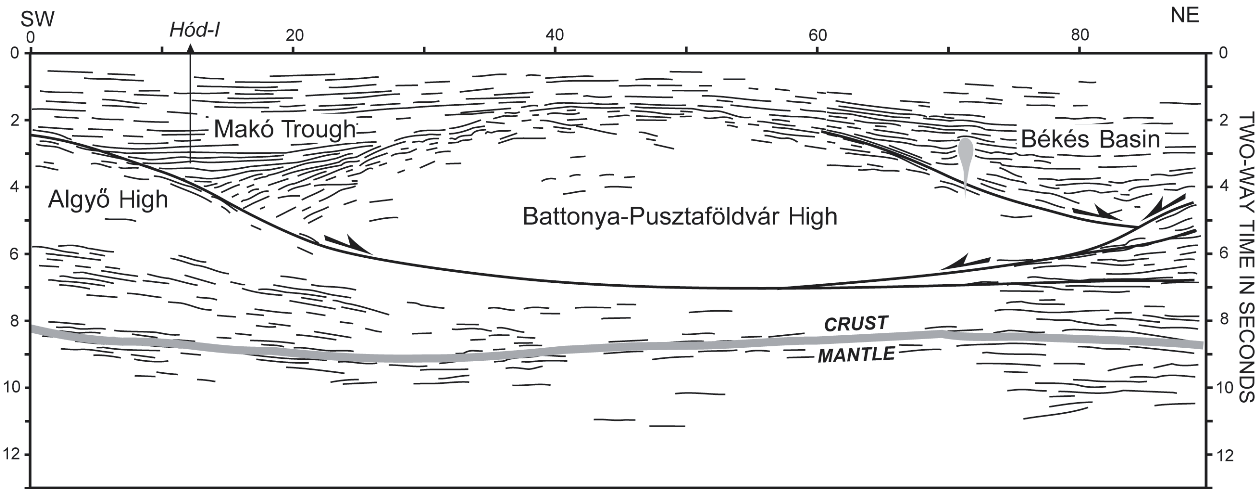


**Fig. 2.** Line drawing of a seismic profile across the Algyő High, Makó Trough, Battonya-Pusztaföldvár High, and Békés Basin. Location of the profile in Fig. 1. According to the interpretation of Tari et al. (1999), the Makó Trough formed as the mass of the Battonya-Pusztaföldvár High slid eastwards from above the emerging Algyő metamorphic core in the Middle Miocene (from Tari et al. 1999, modified).

**Table 1:** The Middle and Upper Miocene regional stages of the Central Paratethys: their ages (according to Vakarcs et al. 1999 and Magyar et al. 1999a) prevailing depositional environments, and characteristic fossils.

| Stage | Age (beginning) | Prevailing environment | Nannoplankton | Dinoflagellates | Foramini-fers | Ostracods | Molluscs | Other characteristic fossils |
|---|---|---|---|---|---|---|---|---|
| Pannonian | ca. 12.0 Ma | brackish lacustrine | strongly impoverished relict with endemics | caspibrackish, endemic | no | caspibrackish, endemic | caspibrackish, endemic | |
| Sarmatian | ca. 13.7 Ma | restricted marine | impoverished relict | marine | only benthic, with eurytopic genera | eurytopic marine genera with endemic species | eurytopic marine with endemics | |
| Badenian | ca. 16.5 Ma | normal marine | normal marine | marine | normal marine, incl. planktonic | normal marine | normal marine | echinoids, red algae |

core 34 belonged to the Pannonian Stage, since it contained the endemic Lake Pannon bivalve *Paradacna abichi* (R. Hörnes), whereas core 35 already represented the marine Badenian Stage with the appearance of planktonic foraminifers (Fig. 3). Badenian foraminifers were washed from cores 35 to 45, together with a few ostracod fragments which were too poorly preserved for determination. Thin sections, mostly made of hard sandstone layers, showed an increasing amount of marine fossils indicating Badenian age from core 35 downwards; these included planktonic and benthic foraminifers and fragments of red algae and echinoderms (Fig. 3). The majority of the foraminifers were small, poorly preserved, and had pyritic incrustations. Palynological investigations had also been carried out on several samples of this interval, but yielded no conclusive biostratigraphic results. Although it was a widely held view that there was no significant hiatus in the Neogene sequence of the basin, the restricted marine Sarmatian Stage, sandwiched between the marine Badenian and the lacustrine Pannonian, was not identified in the borehole. The boundary between the "Middle Miocene" and the Pannonian was marked at the top of core 35, at 5167 m. The final well report did not even mention the apparent absence of the Sarmatian Stage.

The conviction that the Sarmatian Stage must be present in the well was strong. Royden & Dövényi (1988), for example, re-evaluated the stratigraphy of the well (on unknown grounds) so that the upper 160 m of the earlier "Badenian" represented the Sarmatian. To clarify the position of Neogene stage boundaries, Báldi-Beke (1995) investigated nannoplankton from cores 33 to 45. Only a few samples yielded stratigraphically interpretable fossils. Typical Badenian associations with *Sphenolithus heteromorphus* Deflandre, *Sphenolithus* aff. *moriformis* (Brönnimann et Stradner), etc., were found in cores 44 and 43; an impoverished Badenian(?) flora with *Cyclococcolithus rotula* (Kamptner), *Cyclococcolithus leptoporus* (Murray et Blackman), *Cyclicargolithus floridanus* (Roth et Hay), etc., in cores 40 and 42; and an association of eurytopic species, such as *Coccolithus pelagicus* Wallich, *Reticulofenestra pseudoumbilica* (Gartner), etc., in core 35 (Fig. 3). Báldi-Beke (1995) thought that the latter might have represented the Sarmatian Stage, although she asserted that this stage has no diagnostic nannoflora. Several years later Kollányi (2000) published her results on Pannonian nannoplankton investigations from various boreholes. She concluded that many species, which inhabited brackish waters in the Badenian and Sarmatian ages, survived into the Pannonian, and, consequently, the Badenian/Sarmatian and Sarmatian/Pannonian boundaries cannot be readily marked by nannoflora (although endemic Pannonian species do exist).

This was when we launched our search for the Sarmatian Stage in the Hód-I well, invoking new methods of micropaleontological preparation. Our investigations led to an unexpected result: the Sarmatian Stage is missing from the explored succession, because the drilling failed to reach the bottom of the Pannonian Stage.

## Methods

### *Sampling*

For micropaleontological investigations we sampled the lower third of the Hód-I well, from core 25 downward (Fig. 3). There was no recovery from cores 29 and 31, and we had access to only a small chunk of core 42. In each core, the most fine-grained intervals available were sampled and sandy layers rejected. Where quality and recovery of the core allowed, we collected larger amounts of sediments (500–1000 g) for treatment with acetic acid.

### *Preparation of ostracods*

Our investigation marks the first time that acetic acid treatment has been applied to Pannonian rocks in order to obtain calcitic fossils from them. The samples were broken into small pieces and bathed in concentrated solution of acetic acid (96% $C_2H_4O_2$) until the sediment was entirely soaked and disintegrated (about two weeks). Acetic acid dissolves cement of the rock faster than it does the crystalline $CaCO_3$ of the fossil shells. With this method, we were able to free intact ostracod shells even from the hardest sample. Traditional preparation with peroxide of hydrogen from the same samples yielded

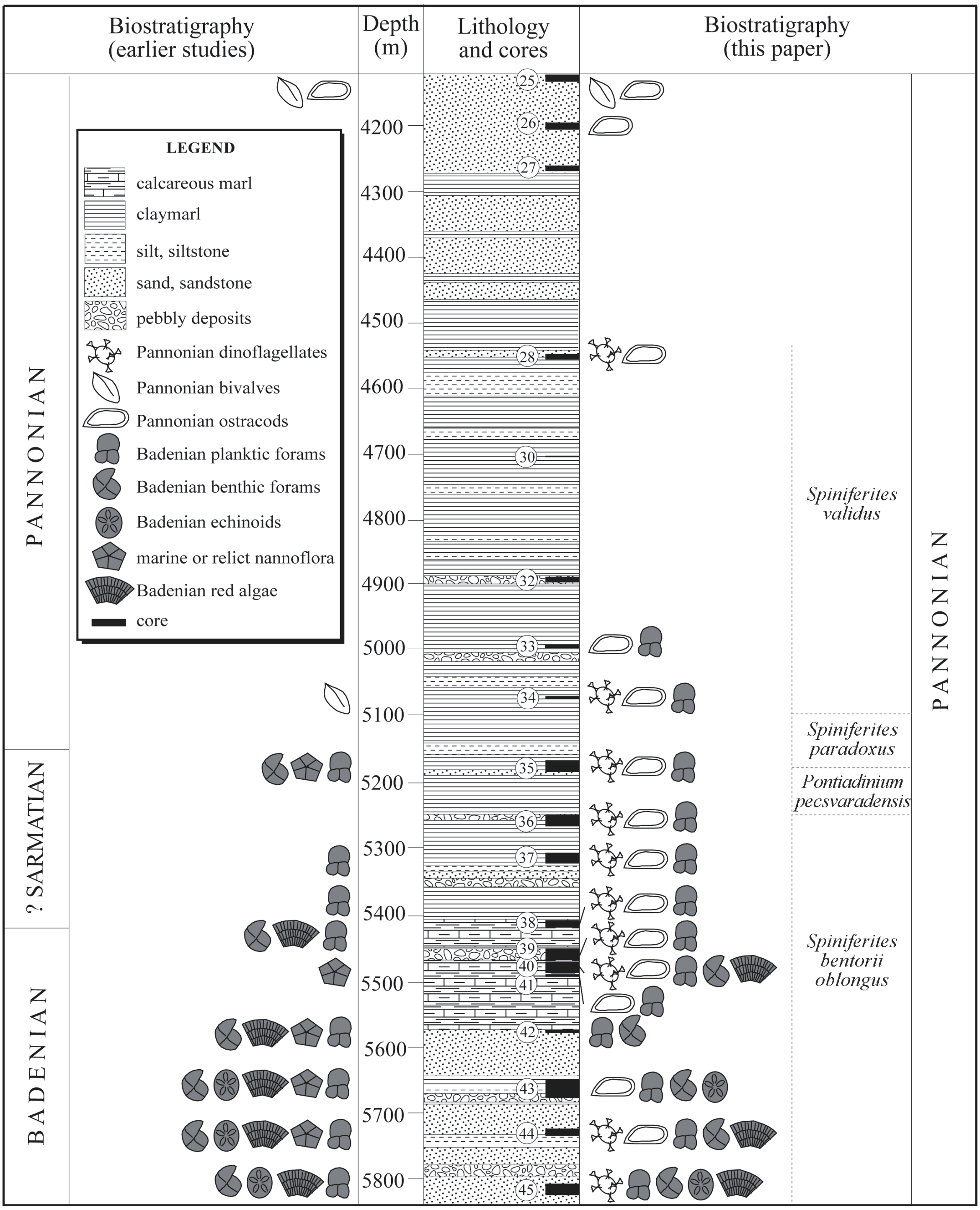


**Fig. 3.** Stratigraphic column of the lower section of well Hód-I, showing the results of earlier biostratigraphic investigations (Csongrádi et al. 1971; Báldi-Beke 1995; left side) and the results of our study (right side). Symbols of Badenian (marine) fossils are grey-filled, those of Pannonian are empty.

only a few indeterminable fragments, so we soon abandoned the latter method altogether.

### *Preparation of dinoflagellates*

In addition to traditional palynological preparations, dinoflagellates were also observed in normal (30 μm thick) petrographical thin sections. During the first description of the Hód-I core samples thirty years ago, paleontologist J. Kőváry (in Csongrádi et al. 1971) recorded dinoflagellates in a thin section from core 35. This thin section was reexamined now, and a rich association of determinable dinoflagellates was recognized in it. Encouraged by this success, we systematically investigated both old and freshly made thin sections of each sample. Dinoflagellates have been found in many of the sections. Their size varied, however, and they were not always as conspicuous as in the first section where they could be easily recognized with 100 times magnification.

Traditional palynological preparations from cores 25 to 33 yielded only black, amorphous fragments and a few, poorly preserved sporomorphs. Samples from cores 34 to 45, however, contained dinoflagellates.

## Results of paleontological investigations

### *Dinoflagellata*

Thin sections from cores 28 and 34 contained dinoflagellate associations including the species *Spiniferites validus*, indicating the *Spiniferites validus* Zone (Table 2, Figs. 3, 4). This zone belongs to the upper part of the Lake Pannon sequence; core 34 was thus far too young to represent the base of the Pannonian, as the stratigraphic position of the core had been interpreted originally (Fig. 3).

Samples from the top of core 35 (35a) yielded *Spiniferites paradoxus* in both thin sections and palynological preparations, indicating the *Spiniferites paradoxus* Zone (Table 2, Fig. 3); dinoflagellates from this sample are depicted in Figs. 5 and 6A–C. Thin sections from deeper parts of the core (35b) contained *Pontiadinium pecsvaradensis*, indicating the *Pontiadinium pecsvaradensis* Zone (Table 2, Fig. 3). The boundary between the *paradoxus* and *pecsvaradensis* Zones is thus interpreted to run within core 35.

Palynological preparations from cores 37 and 44 gave dinoflagellate associations that indicate the *Spiniferites bentorii oblongus* Zone. In accordance with these results, thin sections of cores 36, 37, 40, 44, and 45 also yielded fossils belonging to the *oblongus* Zone (Table 2, Figs. 3, 6D).

The two lowermost dinoflagellate zones of the Pannonian Stage, that is the *Mecsekia ultima* and the *Spiniferites bentorii pannonicus* Zones, have not been identified in the core samples; the well did not reach the base of the Pannonian Stage.

### *Ostracoda*

The interval between cores 25 and 35 yielded relatively poorly preserved and low-diversity ostracod associations (Table 3; Fig. 3). This fauna consisted of various subgenera of the genus *Candona*, such as *Hastacandona, Caspiolla, Bakunella*, and *Thaminocypris*. Only a single specimen from core 25 could be identified on the species level: *Candona (Bakunella) dorsoarcuata*. According to Krstić (1972) and Sokać (1990), this species is characteristic of the "Pontian" (corresponding to the upper part of the Lake Pannon sequence, latest Miocene).

Samples from the deeper part of the well (cores 36 to 44) responded more favourably to solution in acetic acid, and yielded better preserved and richer associations (Table 3; Fig. 7A–G). The fauna is dominated again by *Candona*: *C. (Thaminocypris), C. (Thyphlocypris), C. (Cryptocandona),* and *C. (Lineocypris)*. Apart from *Candona*, specimens of *Amplocypris* sp., *Hungarocypris* sp., and *Xestoleberis* sp. occurred. The following taxa could be determined on the species level (all from cores 39 to 41): *Candona (Typhlocypris) alpherovi, Candona (Typhlocypris)* cf. *fossulata, Candona (Thaminocypris)* cf. *improba, Candona (Lineocypris)* cf. *dorsobrevis.*

According to Krstić (1972, 1985), these species indicate the lower part of the Lake Pannon sequence (Slavonian Sub-

**Table 2:** Dinoflagellates from cores of well Hód-I. For depth intervals of cores, see Fig. 3.

| | 28 | 34 | 35a | 35b | 36 | 37 | 38 | 39 | 40 | 44 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Spiniferites* sp. | × | × | × | × | × | × | | | | | |
| *Spiniferites balcanicus* (Baltes) | × | | × | | | | | | | | |
| *Spiniferites validus* Sütő-Szentai | × | × | | | | | | | | | |
| *Spiniferites maisensis* Sütő-Szentai | | | | | × | | | | | | |
| *Spiniferites bentorii* (Rossignol) | | | × | × | × | × | × | × | × | × | × |
| *Spiniferites bentorii pannonicus* Sütő-Szentai | | | × | | | × | | | | × | |
| *Spiniferites bentorii oblongus* Sütő-Szentai | | | | × | | | | | × | × | × |
| *Spiniferites bentorii coniunctus* Sütő-Szentai | | | × | | | | | | | | |
| *Spiniferites paradoxus* (Cookson et Eisenack) Sarjeant | | | × | | | | | | | | |
| *Pontiadinium* sp. | | × | | × | | × | | | | × | × |
| cf. *Pontiadinium* sp. | | | | × | × | | | | | | |
| *Pontiadinium obesum* Sütő-Szentai | | | | × | | | | | | | |
| *Pontiadinium pecsvaradensis* Sütő-Szentai | | | | × | | | | | | | |
| *Pontiadinium inequicornutum* (Baltes) | | | | × | | | | | | | × |
| *Impagidinium* sp. | × | | × | | | | | | | | |
| *Gonyaulax digitalis* (Pouchet) | | | × | | × | × | | | | × | × |
| *Romanodinium areolatum* Baltes | | | × | | | | | | | | |
| *Nematosphaeropsis balcombiana* (Deflandre et Cookson) | | | | × | | × | | | | | |
| *Millioudodinium* sp. | × | | | | | | | | | | |
| *Millioudodinium pelagicum* Sütő-Szentai | | | × | | | | | | | | |
| *Chytroeisphaeridia* sp. | | | × | | | | | | | × | |
| *Chytroeisphaeridia cariacoense* Wall | | | × | | × | | | | | | |

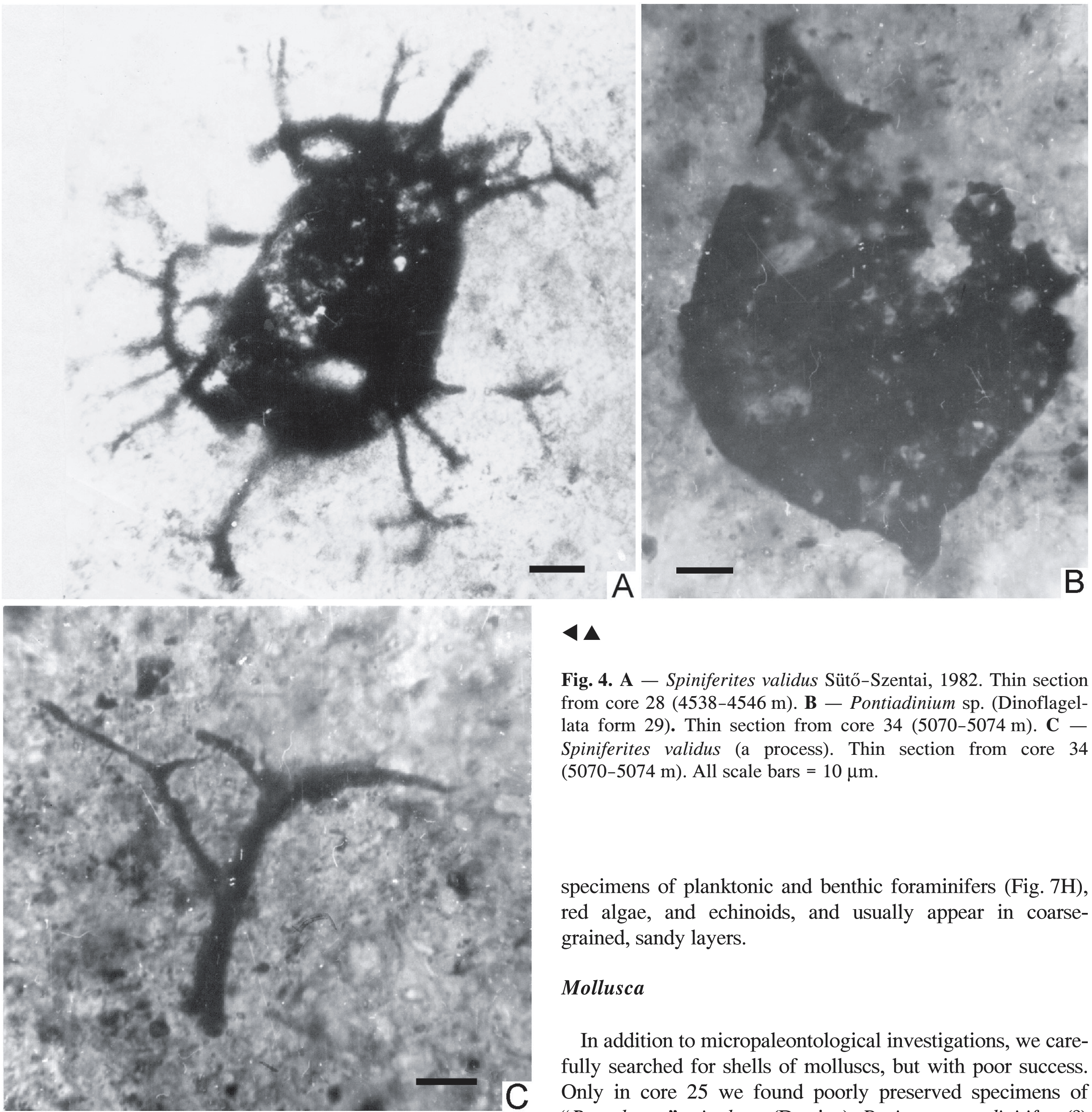


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**Fig. 4.** **A** — *Spiniferites validus* Sütő–Szentai, 1982. Thin section from core 28 (4538–4546 m). **B** — *Pontiadinium* sp. (Dinoflagellata form 29)**.** Thin section from core 34 (5070–5074 m). **C** — *Spiniferites validus* (a process). Thin section from core 34 (5070–5074 m). All scale bars = 10 µm.

stage), more precisely the "*Hemicytheria*" *tenuistriata* Zone. Fossils characteristic of the basal Pannonian ostracod biozones of Krstić (1985), however, have not been found. Core 45 did not yield ostracods.

### *Foraminifera*

In 1971, core 35 was considered to indicate the top of the Badenian Stage because some planktonic foraminifers were found in the washing residue. We found planktonic foraminifers (*Globigerina* (?) sp.) as high as core 33 (Fig. 3). The amount of reworked marine (Badenian) fossils increases from here towards the bottom of the borehole. They include worn specimens of planktonic and benthic foraminifers (Fig. 7H), red algae, and echinoids, and usually appear in coarse-grained, sandy layers.

### *Mollusca*

In addition to micropaleontological investigations, we carefully searched for shells of molluscs, but with poor success. Only in core 25 we found poorly preserved specimens of "*Pontalmyra*" *otiophora* (Brusina), *Dreissenomya digitifera* (?) (Andrusov), and *Valenciennius* sp., indicating a typical deep-water association of Lake Pannon (Magyar 1995). The fossils are small in size, partly because they are fragmentary, partly because they represent juvenile individuals; their determination is therefore somewhat uncertain.

## Discussion

Lithospheric extension and formation of the Pannonian Basin system is thought to have started in the early Middle Miocene (Badenian) or somewhat earlier, in the late Early Miocene (Ottnangian and Karpatian ages). Various rifting models were proposed for the different basin types. The "peripheral basins", such as the Vienna and Transcarpathian Ba-

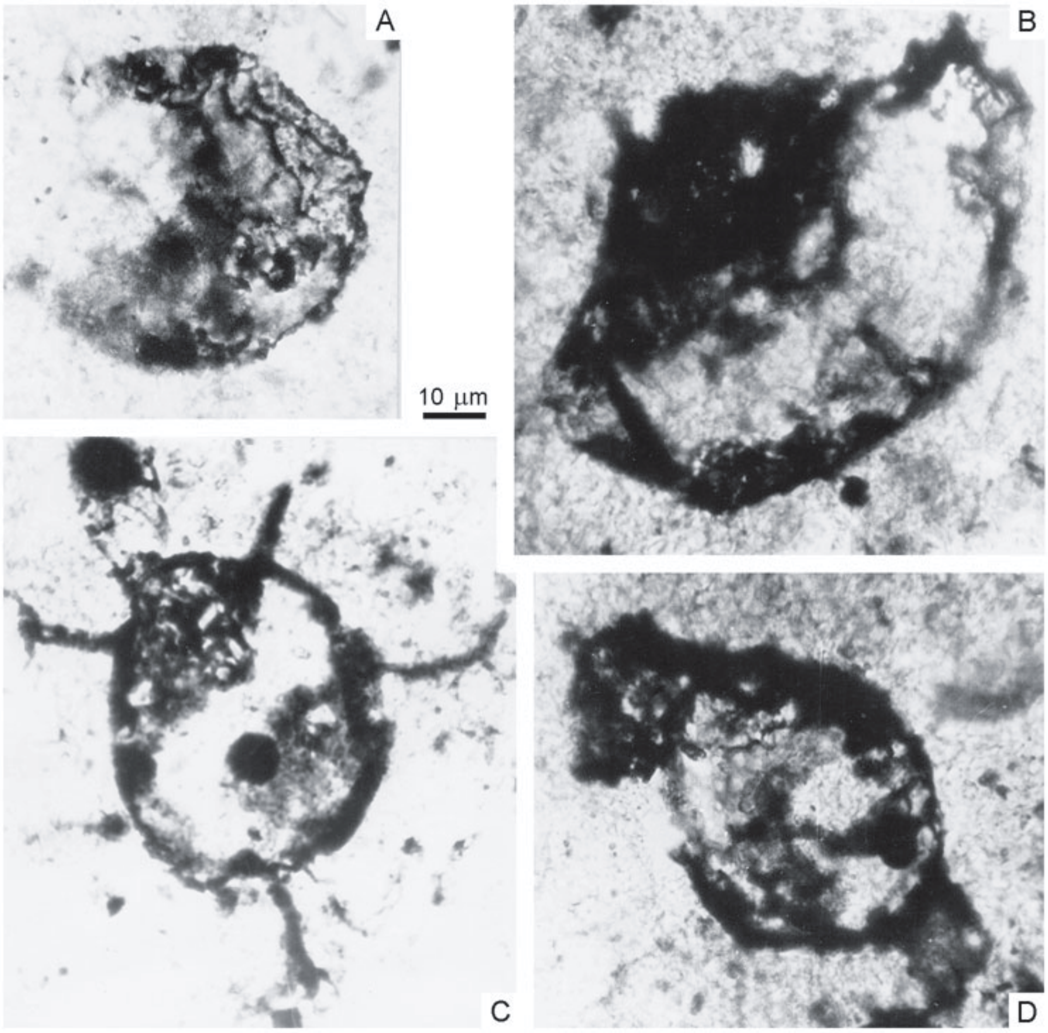


**Fig. 5.** Dinoflagellates in thin sections from core 35a (5167–5183 m, upper part). **A** — *Impagidinium* sp. (Dinoflagellata form 72). **B** — *Spiniferites balcanicus* (Baltes, 1971) Sütő-Szentai, 2000. **C** — *Spiniferites bentorii* (Rossignol, 1964) Wall et Dale, 1970 ssp. *coniunctus* Sütő-Szentai, 1990. **D** — *Spiniferites paradoxus* (Cookson et Eisenack, 1968) Sarjeant, 1970.

**Table 3:** Ostracods from cores of well Hód-I. For depth intervals of cores, see Fig. 3.

| | 25 | 26 | 28 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 43 | 44 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Candona* sp. | × | × | × | × | | × | | × | × | × | × | × | | × |
| *C.* (*Hastacandona*) sp. | × | | | | | | | | | | × | | | × |
| *C.* (*Caspiolla*) sp. | × | | × | | | × | | | | | | | | |
| *C.* (?*Caspiolla*) sp. | | | | × | × | | | | | | | | | |
| *C.* (*Thaminocypris*) sp. | | | | | | × | × | × | × | × | × | × | | × |
| *C.* (?*Thaminocypris*) sp. | | | | × | × | × | | | | | | | | |
| *C.* (*Thaminocypris*) cf. *improbus* Krstić | | | | | | | | | | | × | | | |
| *C.* (*Typhlocypris*) sp. | | | | | | | | × | | | | × | | × |
| *C.* (*Typhlocypris*) cf. *alpherovi* (Schneider) | | | | | | | | | | | × | | | |
| *C.* (*Typhlocypris*) cf. *fossulata* Pokorný | | | | | | | | | | | × | | | |
| *C.* (*Zalanyiella*) sp. | | | | | | | | | × | | | | | |
| *C.* (*Lineocypris*) sp. | | | | | | | | | × | | | | | |
| *C.* (*Lineocypris*) cf. *dorsobrevis* Krstić | | | | | | | | | | × | | × | | |
| *C.* (*Pseudocandona*) sp. | | | | | | | | | | | | | | × |
| *C.* (*Cryptocandona*) sp. | | | | | | | | | | | | | | × |
| *C.* (*Bakunella*) cf. *dorsoarcuata* Zalányi | × | | | | | | | | | | | | | |
| *Amplocypris* sp. | | | | | | | | × | | | × | × | × | × |
| *Xestoleberis* sp. | | | | | | | | | × | | | | | |
| *Hungarocypris* sp. | | | | | | | | | | | × | | | |

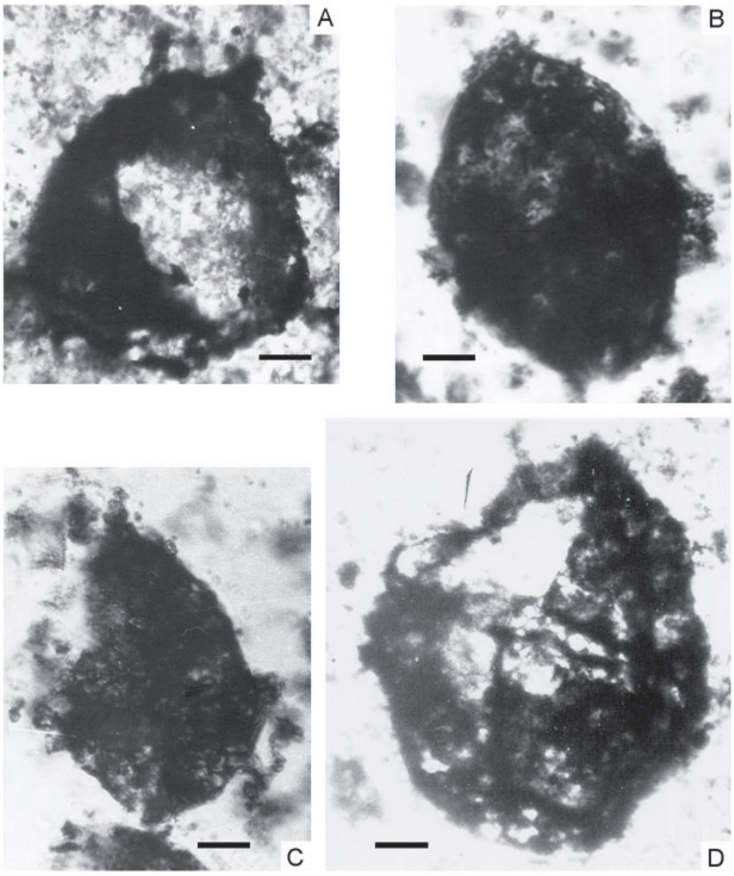

**Fig. 6. A** — *Spiniferites bentorii* (Rossignol, 1964) Wall et Dale, 1970 ssp. *pannonicus* Sütő-Szentai, 1986. Thin section from core 35a (5167–5183 m, upper part). **B–C** — *Spiniferites bentorii* (Rossignol, 1964) Wall et Dale, 1970. Thin section from core 35a (5167–5183 m, upper part). **D** — *Gonyaulax digitale* (Pouchet, 1883) Kofoid, 1911. Thin section from core 36 (5250.0–5267.0 m). All scale bars = 10 μm.

sins, seem to have obeyed the model of uniform lithospheric stretching (Sclater et al. 1980). The thermal subsidence of most parts of the Pannonian Basin system can be satisfactorily explained by mid-Miocene regional rifting and subsequent cooling of the lithosphere (Tari et al. 1999). In the deep subbasins of the central Pannonian Basin, including the Makó Trough, however, unrealistically excessive stretching would have been required to cause the observed thermal subsidence (Sclater et al. 1980). Additional subcrustal thinning (Horváth et al. 1988) and intraplate stress associated with a recent compressional inversion of the Pannonian Basin (Horváth & Cloetingh 1996) were considered as possible explanations for this subsidence anomaly. Tari et al. (1999) suggested that basin evolution in the area started with a metamorphic core complex extension in the Karpatian as the modern Battonya-Pusztaföldvár High slid eastwards from above the modern Algyő High along a NE-dipping detachment fault (Figs. 1, 2). This initial stage was followed by a wide rift style extension in the Badenian and eventually by local rifting (narrow rift style) that extended well into the Sarmatian and Pannonian (Tari et al. 1997, 1999). However, our results indicate that old (though not basal) Pannonian strata are not tilted and thus apparently were not affected by extension. We also found that the postrift sedimentary cover is even thicker here than was thought before; future models have to accomodate a >6 km postrift sedimentary pile in the centre of the Makó Trough.

The statement that thin synrift sediments have been deposited in locations of the Pannonian Basin situated far from the Carpathian thrust belt and, consequently, far from sediment sources (Royden 1988; Grow et al. 1994), applies particularly well to the Makó Trough. Supposing an unbroken sedimentary cycle beginning as early as the Badenian, the Badenian and Sarmatian Stages as well as the two lowermost Pannonian dinoflagellate zones must exist in the <800 m gap between the metamorphic basement and the bottom of the Hód-I well (Fig. 2). This arrangement allows only relatively thin synextensional Badenian and Sarmatian sediments to be present in the axis of the trough (although tilted synrift strata may be somewhat thicker to the east, in the Middle Miocene axis of the basin; Fig. 2). Thus, the Makó Trough was probably a starved basin during the Middle Miocene.

Sediment supply from outside the basin was scarce even during the Early Pannonian. The investigated interval of Hód-I was interpreted by Bérczi (1988) as a superposition of three main facies, such as "coarse-grained basal turbidites, deep-basin fine-grained sediments, and distal prodelta sediments". The lower part of the well contains a quantity of reworked Badenian fossils and pebbly horizons (Fig. 3). This is in accord with the sedimentological interpretation of Bérczi (1988), who thought that the >300 m basal series in Hód-I consisted of sediment gravity flow deposits. Patchy occurrences of the Badenian and Sarmatian Stages (erosional fragments?) have been explored by drillings on the eastern flank of the Makó Trough, whereas they are not known on the western flank. Heavy reworking of Badenian sediments indicates steep slope morphology.

The original goal of the study, that of determining Sarmatian boundaries, was not achieved; however, Pannonian biozones were identified in the Hód-I sequence. Chronostratigraphic interpretation of these biozones, according to Magyar et al. (1999a), is given in Table 4. The thickness of the biozones (Table 4) reflects various stages of sedimentation. The *Spiniferites bentorii oblongus* Zone is at least 600 m thick in the Hód-I well, whereas it rarely exceeds 100 m in other areas of the Pannonian Basin. During the deposition of this zone, the shoreline of Lake Pannon ran close to the margins of the Pannonian Basin (Magyar et al. 1999b), thus no significant fluvial sediment transport could reach the Makó Trough from the basin margins. The sources of the anomalously thick sediment pile in the Makó Trough must have been the surrounding highs (islands), as indicated by the high ratio of reworked material in these deposits.

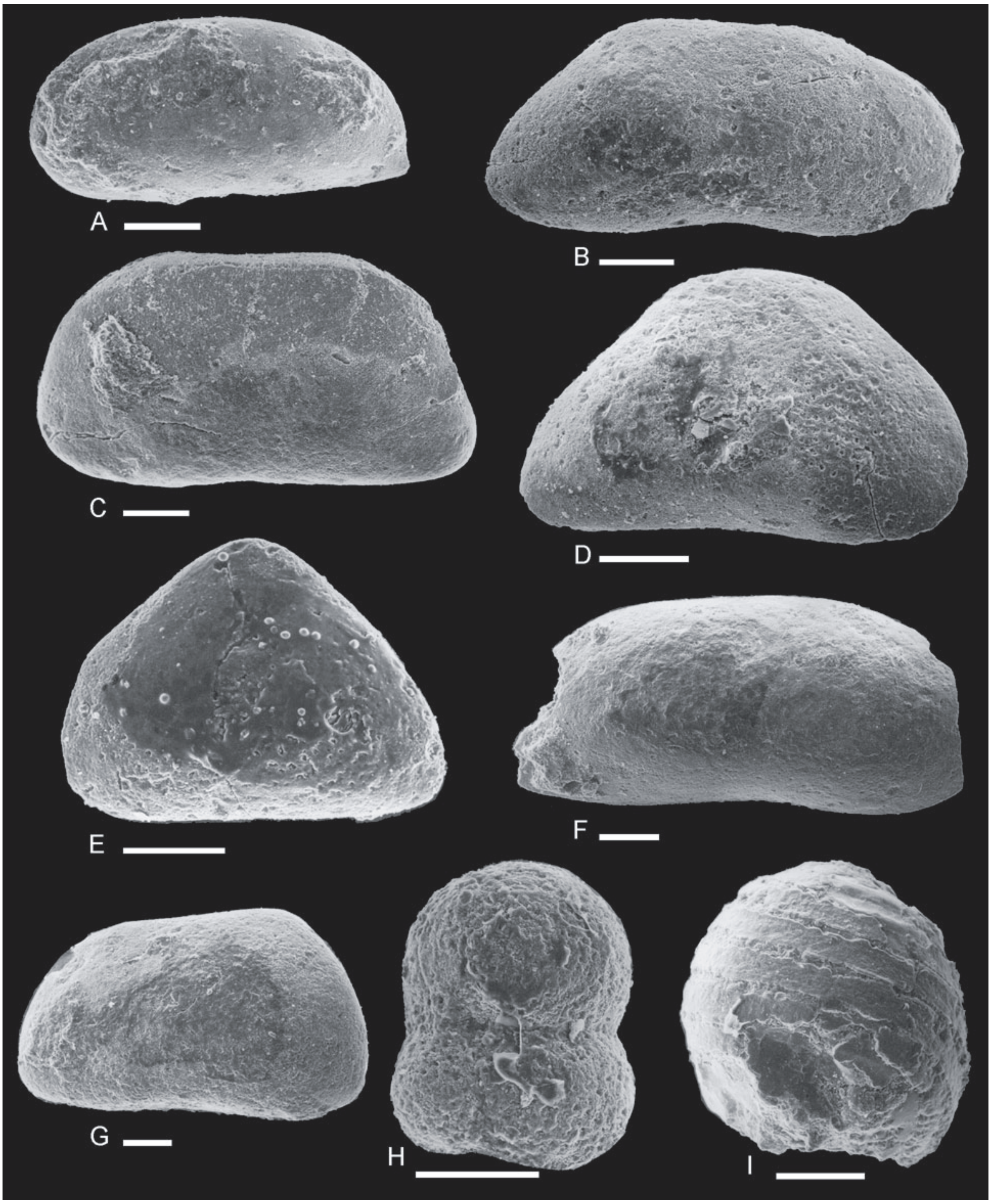


**Fig. 7.** **A** — *Candona* (*Zalanyiella*) sp. Core 38 (5405.5–5418.0 m). Lv, outside. **B** — *Candona* (*Hastacandona*) sp. Core 40 (5468.0–5486.0 m). Rv, outside. **C** — *Candona* (*Thaminocypris*) sp. Core 40 (5468.0–5486.0 m). Lv, outside. **D** — *Candona* (*Typhlocypris*) cf. *fossulata* Pokorný. Core 40 (5468.0–5486.0 m). Rv, outside. **E** — *Candona* (*Typhlocypris*) cf. *alpherovi* (Schneider). Core 40 (5468.0–5486.0 m). Lv, outside. **F** — *Amplocypris* sp. Core 41 (5486.0–5489.0 m). Rv, outside. **G** — *Candona* (*Thaminocypris*) cf. *improba* Krstić. Core 40 (5468.0–5486.0 m). Rv, outside. **H** — *Globigerina* (?) sp. Core 40 (5468.0–5486.0 m). **I** — A charophyte gyrogonite. Core 44 (5727.0–5738.0 m). All scale bars = 100 μm.

On the contrary, the *Spiniferites paradoxus* Zone, representing more than 1 million years, is surprisingly thin (less than 100 m) in the Hód-I sequence. Coeval sediments in NW Hungary may exceed 500 m, and have a strong transgressive character in many parts of the Pannonian Basin (Sütő-Szentai 1991; Szilaj et al. 1999). Seismic sequence stratigraphic studies also established a rising lake level for much of this interval in various parts of the basin (Vakarcs et al. 1994; Sacchi et al.

**Table 4:** Dinoflagellate biozones and their estimated ages (based on Magyar et al. 1999a) and depths in the Hód-I well.

| Zone | Age (beginning) | Estimated depth (m) in Hód-I |
|---|---|---|
| *Spiniferites validus* | 9.2 Ma | 5100 |
| *Spiniferites paradoxus* | 10.5 Ma | 5170 |
| *Pontiadinium pecsvaradensis* | 10.8 Ma | 5250 |
| *Spiniferites bentorii oblongus* | 11.6 Ma | > 5840 |

1999). According to Magyar et al. (1999b), Lake Pannon reached its largest geographic extension at about the end of this biochron. The rise of relative lake level and inundation of vast areas in the basin margins as well as in the surrounding highs may have caused a decrease in sediment supply and sedimentation rate in the deep Makó Trough.

## Conclusions

Preparation of ostracods with acetic acid and investigation of dinoflagellates in thin sections revealed that the deepest borehole in Hungary, Hód-I, failed to reach the base of the Lake Pannon sediments (= Pannonian Stage, Upper Miocene) in one of the deepest subbasins of the entire Pannonian Basin system. This subbasin, the Makó Trough, was considered to be Middle Miocene in age; however, much of the basin is filled with horizontal, relatively undisturbed Lake Pannon sediments, whereas synrift sediments are relatively thin between the base of the well and the supposedly Paleozoic metamorphic basement. The vast thickness of the postrift sequence indicates that mechanisms other than pure shear must be invoked to assess basin evolution in the central Pannonian Basin.

In the beginning of Pannonian sedimentation, Middle Miocene marine deposits and the metamorphic basement were eroded and reworked — probably by wave action — in the steep flanks of the basin and redeposited in the axis of the trough (*Spiniferites bentorii oblongus* and *Pontiadinium pecsvaradensis* Zones). Although a better understanding of paleobathymetry would be crucial for structural evolution interpretations, neither the lithology nor the fossils provide conclusive evidence concerning the paleo-waterdepth of the Makó Trough in the Early Pannonian. Later the rate of sedimentation decreased, probably due to a relative lake level rise (*Spiniferites paradoxus* Zone). Reworked Badenian fossils and pebble layers disappear from the stratigraphic column of Hód-I within the overlying *Spiniferites validus* Zone.

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## References

Báldi-Beke M. 1995: Nannoplankton investigations on core samples of Derecske-I and Hódmezővásárhely Hód-I wells. *MS OGIL,* 1–22 (in Hungarian).

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

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

Clayton J.L., Koncz I., King J.D. & Tatár É. 1994: Organic geochemistry of crude oils and source rocks, Békés basin. In: Teleki P.G., Mattick R.E. & Kókai J. (Eds.): Basin analysis in petroleum exploration. A case study from the Békés basin, Hungary. *Kluwer Academic Publishers*, Dordrecht, 161–185.

Csongrádi I., Széles M., Bérczi-Makk A., Sztrákos K., Kőváry J. & Hutter E. 1971: Core analysis report on exploration well Hód-I. *MS OGIL,* 1–30 (in Hungarian).

Dövényi P. & Horváth F. 1988: A review of temperature, thermal conductivity, and heatflow data for the Pannonian basin. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 195–233.

Gajdos I., Pap S., Somfai A. & Völgyi L. 1983: Lithostratigraphic units of the Pannonian (s.l.) Stage in the Great Hungarian Plain. *Magy. Áll. Földt. Intéz.*, Budapest, 1–70 (in Hungarian).

Grow J.A., Mattick R.E., Bérczi-Makk A., Péró Cs., Hajdú D., Pogácsás Gy., Várnai P. & Varga E. 1994: Structure of the Békés Basin inferred from seismic reflection, well and gravity data. In: Teleki P.G., Mattick R.E. & Kókai J. (Eds.): Basin analysis in petroleum exploration. A case study from the Békés basin, Hungary. *Kluwer Academic Publishers*, Dordrecht, 1–38.

Hámor-Vidó M. & Viczián I. 1993: Vitrinite reflectance and smectite content of mixed-layer illite/smectites in Neogene sequences of the Pannonian Basin, Hungary. *Acta Geol. Hung.* 36, 197–209.

Horváth F. & Cloetingh S. 1996: Stress-induced late-stage subsidence anomalies in the Pannonian basin. *Tectonophysics* 266, 287–300.

Horváth F., Dövényi P., Szalay Á. & Royden L.H. 1988: Subsidence, thermal, and maturation history of the Great Hungarian Plain. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 355–372.

Kollányi K. 2000: New data to the distribution of Pannonian nannoplanctonic flora. *Földt. Közl.* 130, 497–527 (in Hungarian with English abstract).

Kőrössy L. 1981: Regional geological profiles in the Pannonian basin. *Earth Evolution Sci.* 3–4, 223–231.

Krstić N. 1972: Genus *Candona* (Ostracoda) from Congeria Beds of Southern Pannonian Basin. *Serb. Acad. Sci. Arts, Monographs*, CDL, 39, 1–146.

Krstić N. 1985: Ostracoden im Pannonien der Umgebung von Belgrad. In: Papp A., Jámbor Á. & Steininger F.F. (Eds.): Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys, VII, M6 Pannonien (Slavonien und Serbien). *Akadémiai Kiadó*, Budapest, 103–143.

Magyar I. 1995: Late Miocene mollusc biostratigraphy in the eastern part of the Pannonian basin (Tiszántúl, Hungary). *Geol. Carpathica* 46, 29–36.

Magyar I., Geary D.H., Sütő-Szentai M., Lantos M. & Müller P. 1999a: Integrated biostratigraphic, magnetostratigraphic and chronostratigraphic correlations of the Late Miocene Lake Pannon deposits. *Acta Geol. Hung.* 42, 5–31.

Magyar I., Geary D.H. & Müller P. 1999b: Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 147, 151–167.

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

Mattick R.E., Phillips R.L. & Rumpler J. 1988: Seismic stratigraphy and depositional framework of sedimentary rocks in the Pannonian basin in southeastern Hungary. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 117–145.

Royden L.H. 1988: Late Cenozoic tectonics of the Pannonian basin system. In: Royden L. & Horváth F. (Eds): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 27–48.

Royden L.H. & Dövényi P. 1988: Variations in extensional styles at depth across the Pannonian basin system. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 235–255.

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, 357–389.

Sajgó Cs. 1980: Hydrocarbon generation in a superthick Neogene sequence in south-east Hungary: A study of the extractable organic matter. In: Douglas A.G. & Maxwell J.R. (Eds.): Advances in geochemistry 1979. *Pergamon Press*, New York, 103–113.

Sajgó Cs., Horváth Z.A. & Lefler J. 1988: An organic maturation study of the Hód-I borehole (Pannonian basin). In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 297–309.

Sclater J.G., Royden L., Horváth F., Burchfiel B.C., Semken S. & Stegena L. 1980: The formation of the intra-Carpathian basins as determined from subsidence data. *Earth Planet. Sci. Lett.* 51, 139–162.

Sokać A. 1990: Pontian ostracod fauna in the Pannonian basin. In: Stevanović P., Nevesskaja L.A., Marinescu Fl., Sokać A. & Jámbor Á. (Eds.): Chronostratigraphie und Neostratotypen, Neogen der Westlichen ("Zentrale") Paratethys, VIII, Pl1 Pontien. *JAZU and SANU*, Beograd–Zagreb, 672–721.

Sütő-Szentai M. 1991: Organic-walled microplankton zones of the Pannonian in Hungary. New data on the zonation and dinoflagellate evolution. *Őslénytani Viták (Discussiones Palaeontologicae)* 36–37, 157–200 (in Hungarian with English abstract).

Szalay Á. 1988: Maturation and migration of hydrocarbons in the southeastern Pannonian basin. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 347–354.

Szalay Á. & Szentgyörgyi K. 1979: Contribution to the knowledge of lithologic subdivisions of Pannonian basin formations explored by hydrocarbon drilling: reconstructions based on trend analyses. *Geonómia és Bányászat* 12, 401–423 (in Hungarian with English abstract).

Szalay Á. & Szentgyörgyi K. 1988: A method for lithogenetic subdivision of Pannonian (s.l.) sedimentary rocks. In: Royden L. & Horváth F. (Eds.): The Pannonian Basin: A study in basin evolution. *Amer. Assoc. Petrol. Geologists, Memoir* 45, 89–96.

Szemethy A. 1977: X-ray analysis of carbonate minerals in Neogene sedimentary rocks. *Ann. Rep. Hung. Geol. Inst.* 1975, 303–314 (in Hungarian with English abstract).

Szilaj R., Szónoky M., Müller P., Geary D.H. & Magyar I. 1999: Stratigraphy, paleoecology, and paleogeography of the "*Congeria ungulacaprae* beds" (= *Lymnocardium ponticum* Zone) in NW Hungary: study of the Dáka outcrop. *Acta Geol. Hung.* 42, 33–55.

Tari G., Horváth F., Oprea D., Stefanescu M., Dunkl I. & Tóth T. 1997: Modes of Neogene extension in the SE Pannonian basin (Hungary, Romania and Serbia). *Geol. Soc. Amer., Ann. Meeting*, Salt Lake City, Abstracts A-319.

Tari G., Dövényi P., Dunkl I., Horváth F., Lenkey L., Stefanescu M., Szafián P. & Tóth T. 1999: Lithospheric structure of the Pannonian basin derived from seismic, gravity and geothermal data. 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, 215–250.

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., Hardenbol J., Abreau V.S., Vail P.R., Tari G., Várnai P. 1999: Correlation of the Oligocene–Middle Miocene regional stages with depositional sequences, a case study from the Pannonian Basin, Hungary. In: DeGraciansky P.-C., Hardenbol J., Jacquin T., Vail P.R. & Farley M.B. (Eds.): Mesozoic-Cenozoic sequence stratigraphy of European basins. *SEPM Spec. Publ.* 60, 211–233.

Van Balen R.T., Lenkey L., Horváth F. & Cloething S.A.P.L. 1999: Two-dimensional modelling of stratigraphy and compaction-driven fluid flow in the Pannonian Basin. 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, 391–414.