GEOLOGICA CARPATHICA, JUNE 2007, 58, 3, 277–290

Magnetostratigraphic, seismic and biostratigraphic correlations of the Upper Miocene sediments in the northwestern Pannonian Basin System

IMRE MAGYAR[1], MIKLÓS LANTOS[2], KATALIN UJSZÁSZI[1] and LÁSZLÓ KORDOS[2]

[1]MOL Hungarian Oil and Gas Plc., Budafoki út 79, 1117 Budapest, Hungary; immagyar@mol.hu; kujszaszi@mol.hu
[2]Geological Institute of Hungary, Stefánia út 14, 1143 Budapest, Hungary; lantos@mafi.hu; kordos@mafi.hu

(Manuscript received March 30, 2006; accepted in revised form October 5, 2006)

Abstract: Magnetic polarity records from four wells and four surface outcrops from the non-marine Upper Miocene of the northwestern Pannonian Basin System have been correlated with the polarity time scale. Correlation between the wells (Duka-II, Nagylózs-1, Szombathely-II, and Zsira-1) was established by means of seven seismic horizons (A to G), calibrated biostratigraphically in the boreholes. Interpretation of the seismic horizons was extended to about 8000 km^2 in northwestern Hungary. Correlation of the surface outcrops was based on biostratigraphy (Hennersdorf, Pezinok, Sopron) or it was attempted by seismic stratigraphy (Bérbaltavár). Although the Hennersdorf, Sopron, and Pezinok outcrops all belong to C5n (11.04 to 9.78 Ma), the first is biostratigraphically older than the latter ones. This correlation implies that the MN10 rodents of the Pezinok outcrop are older than 9.7 Ma, the presently acknowledged MN9/MN10 boundary. The borehole sections in the western part of the Kisalföld (Danube) Basin (Nagylózs, Zsira, and Szombathely) were correlated with Chrons C5r to C3B (>11 Ma to >7 Ma), whereas the Duka section in the southeastern part corresponded to the interval C4Ar to C4r (>9 Ma to >8 Ma). The Bérbaltavár mammal locality probably correlates with C4n (8.11 to 7.53 Ma). All these data combined with facies interpretation and seismic correlations suggest that the shelf break of Lake Pannon swept across the Kisalföld Basin from NW to S-SE in less than 1 million year (ca. 9.7 to 8.8 Ma).

Key words: Late Miocene, Pannonian Basin, Danube Basin, Lake Pannon, magnetostratigraphy, biostratigraphy, seismic stratigraphy.

Introduction

The thick Upper Miocene sedimentary formations of the Central European Pannonian Basin System were deposited in Lake Pannon, a large, deep, long-lived lake, and in the adjacent fluvial environments. Chronostratigraphic subdivision and correlation of the lacustrine sequence have long posed problems, mostly because of the endemic biota of the lake, the highly diachronous nature of facies units, and the scarcity of reliable geochronometric data. The best method to overcome these difficulties appears to be an integrated approach, that is a combination of all available stratigraphic methods.

This study is based on the magnetic polarity records of 4 boreholes and 4 surface outcrops from the northwestern part of the Pannonian Basin System. The Duka-II, Nagylózs-1, Szombathely-II and Zsira-1 wells and outcrops of Pezinok, Sopron, and Bérbaltavár (=Baltavár) are located in the western and southern margins of the Kisalföld ("Little Hungarian Plain" or "Danube") Basin in Hungary and Slovakia, whereas the Hennersdorf outcrop is located in the Vienna Basin, Austria (Fig. 1). The wells were drilled during the 1980's, when the Geological Institute of Hungary drilled a dozen deep, continuously cored stratigraphic test holes in various parts of the Pannonian Basin. The cores were studied for stratigraphy, sedimentology, paleontology and magnetostratigraphy. The polarity zones of the boreholes were correlated with the geomagnetic time scale of Berggren et al. (1985, 1995), employing radiometric ages and results of litho- and biostratigraphy (Elston et al. 1990, 1994; Kókay et al. 1991; Lantos et al. 1992; Lantos & Elston 1995; Juhász et al. 1999; Magyar et al. 1999). Magnetostratigraphic correlations were commonly anchored to the long normal polarity interval of Chron C5n. No radiometric data were available in stratigraphically higher parts of the sections; the age of the younger strata was thus somewhat uncertain. In the central part of the Pannonian Basin, the boreholes were correlated by means of composite seismic profiles (Horváth & Pogácsás 1988; Pogácsás et al. 1988, 1992, 1994), and the results of magnetostratigraphic interpretations were widely used in dating sequence stratigraphic surfaces and sedimentary cycles (Csató 1993; Ujszászi & Vakarcs 1993; Vakarcs et al. 1994; Sacchi et al. 1995, 1999; Juhász et al. 1996, 1997, 1999; Sprovieri & Sacchi 1999; Korpás-Hódi et al. 2000; Sacchi & Horváth 2002; Sprovieri et al. 2003; Sacchi & Müller 2004).

A recent interpretation of regional seismic horizons in NW Hungary offered a new opportunity for systematic seismic correlations between the magnetostratigraphic test holes. The seismic time-lines, combined with biostratigraphic data, provided constraints for the correlation of the polarity records with the geomagnetic polarity time scale (ATNTS by Lourens et al. 2004). Thus, we propose here an updated correlation of the Pannonian sediments in the Duka-II, Nagylózs-1, Szombathely-II and Zsira-1 bore-

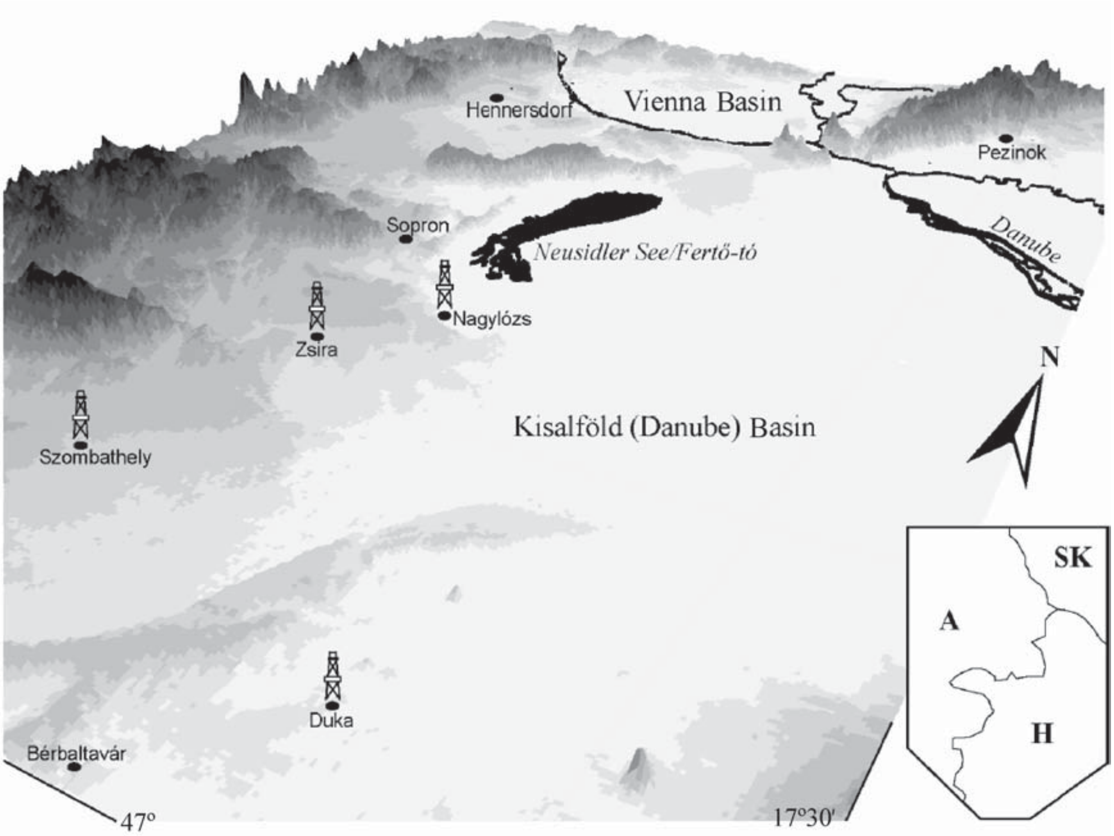

Fig. 1. Digital terrain model of the NW Pannonian Basin System with locations of drill cores and outcrops where magnetostratigraphic studies were performed. Inset map: **A** — Austria, **SK** — Slovakia, **H** — Hungary. The represented area is 150×100 km.

holes, as well as in the outcrops of Hennersdorf, Pezinok, Sopron, and Bérbaltavár (Fig. 1).

Geological setting

The Pannonian Basin is a complex Neogene basin system bordered by the Carpathian Mountains, Alps, and Dinarides. The general subsidence of the area started in the Middle/Late Miocene. The resulting accommodation space was filled by lacustrine, deltaic, and fluvial deposits during the Late Miocene, Pliocene, and Pleistocene. The lacustrine deposits accumulated in Lake Pannon, a large brackish lake. Transition to deltaic and fluvial sedimentation occurred gradually as the shoreline prograded basinward from the northwestern and northeastern margins, and resulted in highly diachronous facies (Juhász 1991; Molenaar et al. 1994).

The northwestern segment of the basin system comprises the Vienna Basin (Kováč et al. 2004; Harzhauser et al. 2004) and the Kisalföld or Danube Basin (Tari 1996; Mattick et al. 1996; Hrušecký 1999; Kováč et al. 2006) (Fig. 1). These depressions, lying close to the sediment sources of the Alps and Carpathians, were among the first to be filled up by siliciclastic sediments. The entire lacustrine, deltaic, and most of the fluvial facies in the Kisalföld Basin represent the Upper Miocene; the relatively thin Pliocene and Pleistocene deposits are confined to the central part of the basin. This pattern is partly due to a tectonic inversion that occurred during the Pliocene (Horváth et al. 1995). As a consequence of this inversion, the littoral and shallow sublittoral facies zones of the Upper Miocene lacustrine deposits are exposed today along the western and eastern margins of the Kisalföld Basin (Jámbor 1980; Magyar et al. 2000). The investigated outcrops and drillings are located in such marginal positions (Fig. 2), where a few tens to a few hundred m thick Pliocene (and Quaternary?) succession is believed to have been eroded (Jámbor 1980; Lantos et al. 1992; Dunkl & Frisch 2002).

Description of the investigated boreholes and outcrops

Boreholes

Each borehole penetrated the usual tripartite litho- and biofacies associations of the Upper Miocene. The fine-grained Lake Pannon deposits (Peremarton Group) are overlain by variable deltaic sediments, which in turn are followed by purely fluvial and terrestrial deposits (Dunántúl Group). The Peremarton Group consists of mudstone, marl, and silty clay, whereas the Dunántúl Group consists of grey, fine-grained sand, silt, clay, siltstone, clayey marl, and locally lignite. For details on lithology

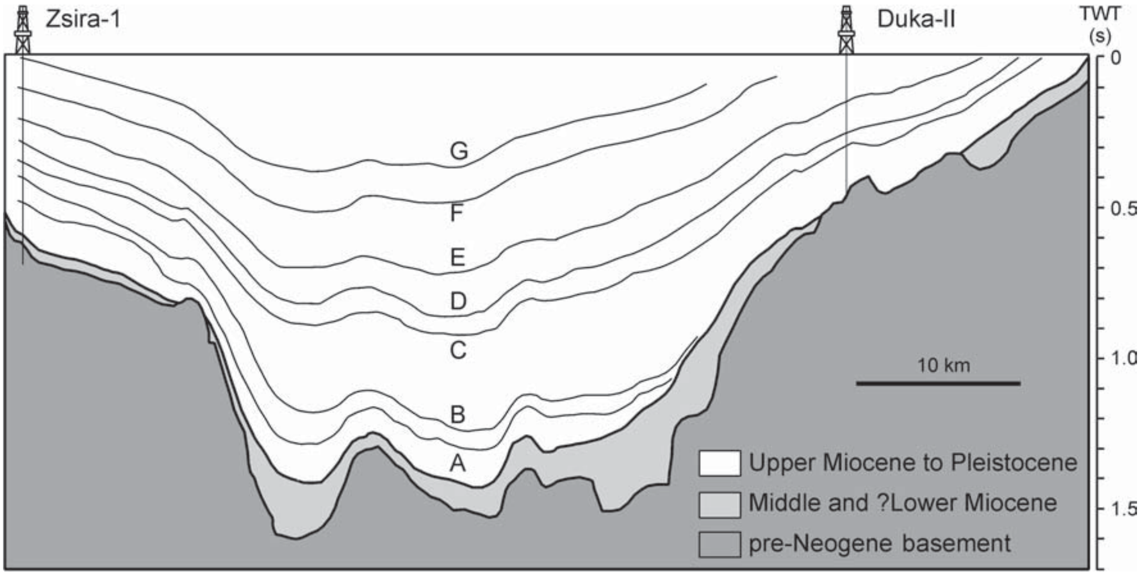

Fig. 2. A NW to SE transect across the southern Kisalföld Basin with the correlated seismic horizons. Line drawing based on a composit seismic profile. The location of the profile is shown in Fig. 7.

of the individual sections, see the references. Biostratigraphic subdivision and correlation of the Upper Miocene is based on endemic dinoflagellates (deep water facies), endemic molluscs (deep lacustrine to littoral facies), and mammals (littoral to fluvial facies) (Fig. 3).

The **Szombathely-II** borehole (Fig. 4) penetrated the Upper Miocene between 23 and 1811 m. The Lake Pannon sediments overlie Middle Miocene Sarmatian deposits with an apparent unconformity. The top of the Peremarton Group is at 1042 m (Korpás-Hódi 1992; Lantos et al. 1992; Juhász et al. 1996, 1997; Korpás-Hódi et al. 2000). In terms of mollusc biostratigraphy, the "*Lymnocardium*" *praeponticum* Zone, the *Congeria banatica* Zone, the "*Dreissenomya*" *digitifera* Zone, and the *Lymnocardium ponticum* Zone (Fig. 3) were identified (from bottom to top; Korpás-Hódi 1992; Magyar et al. 1999). The overlying deposits contain purely freshwater and terrestrial molluscs. In the deep water facies, the *Mecsekia ultima*,

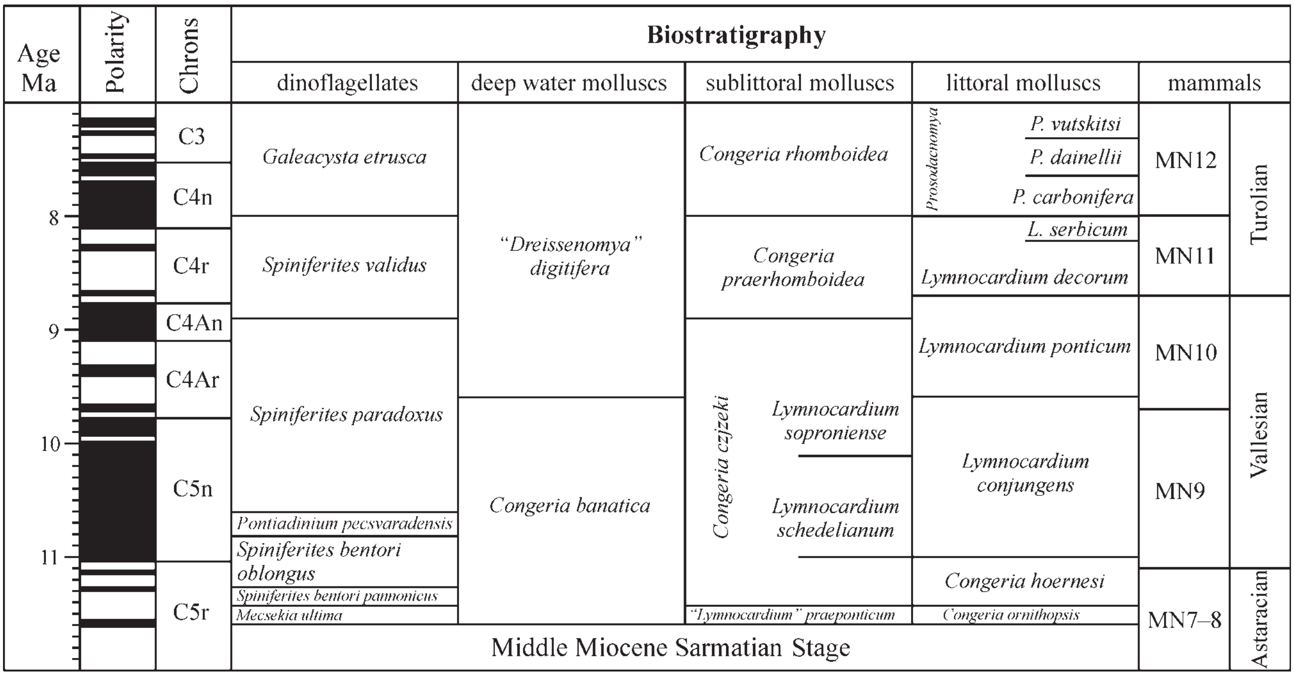

Fig. 3. Biostratigraphic correlation chart for the Upper Miocene Lake Pannon deposits (after Magyar et al. (1999), modified with the results of this study). The Sarmatian-Pannonian boundary is according to Harzhauser et al. (2004). Mammal zone boundaries follow Daxner-Höck (2001). The polarity time scale is after Lourens et al. (2004).

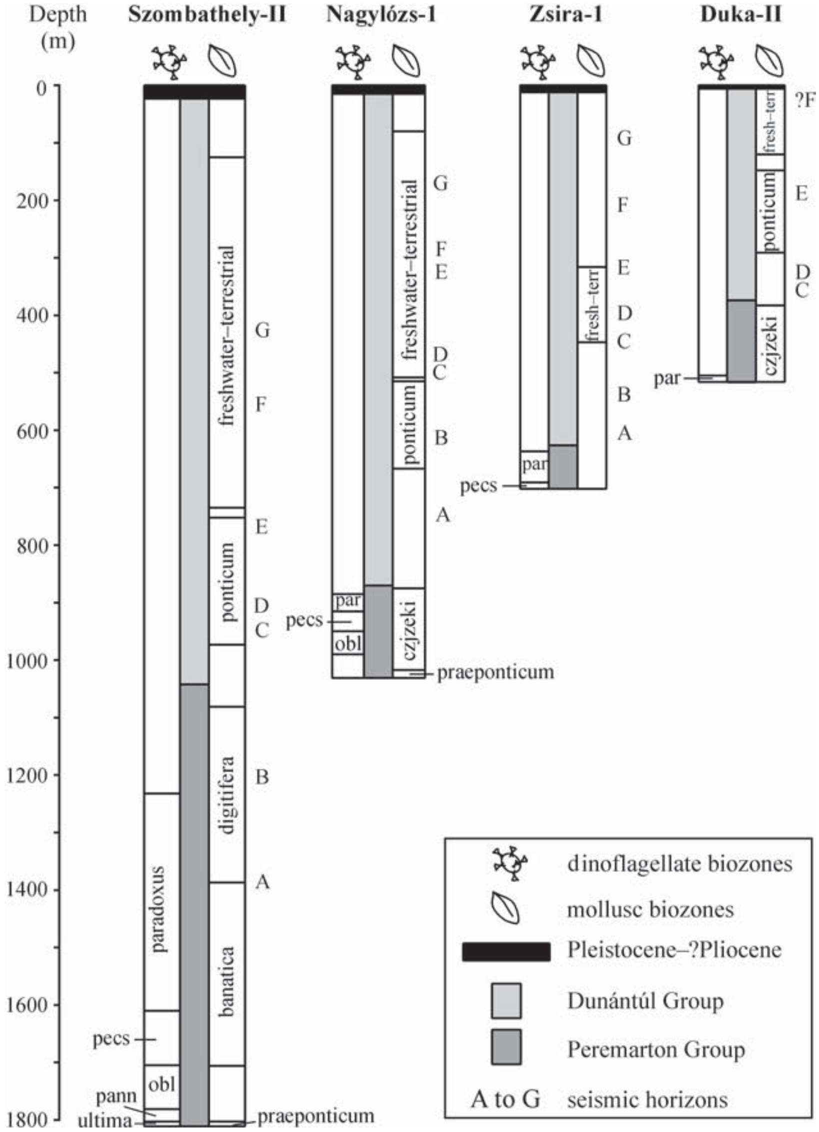

Fig. 4. Sketch of the biostratigraphic and lithostratigraphic units (Upper Miocene to Pleistocene) in the studied boreholes. Pann — *pannonicus*, obl — *oblongus*, pecs — *pecsvaradensis*, par — *paradoxus* Zones, fresh-terr — freshwater and terrestrial molluscs.

the *Spiniferites bentorii pannonicus*, the *Spiniferites bentorii oblongus*, the *Pontiadinium pecsvaradensis*, and the *Spiniferites paradoxus* dinoflagellate Zones (Fig. 3) were identified (Sütő-Szentai in Magyar et al. 1999).

The **Nagylózs-1** borehole (Fig. 4) penetrated the Upper Miocene between 15 and 1031 m. The Upper Miocene overlies Middle Miocene Sarmatian deposits with a probable unconformity. The top of the Peremarton Group is at 870 m (Juhász et al. 1996; Korpás-Hódi et al. 2000). In the mollusc record, the "*L.*" *praeponticum*, *Congeria czjzeki* (?), and *L. ponticum* Zones (Fig. 3) were identified (based on data received from Korpás-Hódi in 1997, Magyar et al. 1999), underlying freshwater and terrestrial associations. In dinoflagellates, the *S. b. oblongus*, *P. pecsvaradensis*, and *S. paradoxus* Zones (Fig. 3) were identified (Sütő-Szentai in Magyar et al. 1999).

In the **Zsira-1** borehole (Fig. 4), the Upper Miocene sequence overlies the Middle Miocene Sarmatian deposits with an unconformity at 702 m, and the top of the sequence is at 12 m. The top of the Peremarton Group is at 626 m. Freshwater and land molluscs were recorded between 316 and 447 m. In terms of dinoflagellate biozonations, the *P. pecsvaradensis* and the *S. paradoxus* Zones (Fig. 3) were identified in the deep water facies of the sequence.

The **Duka-II** borehole (Fig. 4) penetrated the Upper Miocene between 6 and 516 m. The Lake Pannon deposits overlie Cretaceous rocks. The top of the Peremarton Group is at 374 m (Lantos et al. 1992). In the mollusc record, the sublittoral *C. czjzeki* Zone and the littoral *L. ponticum* Zone (Fig. 3) were identified; these are overlain by freshwater and terrestrial faunas (Korpás-Hódi 1989). In the dinoflagellates, only the *S. paradoxus* Zone (Fig. 3) was identified in the bottom of the Upper Miocene.

Outcrops

Hennersdorf is located some 10 km south of Vienna, close to the western margin of the Vienna Basin. The thickness of the outcropping sublittoral clay and silty clay is about 15 m. The lower two third of the sequence is bluish grey, the upper third is yellowish grey in colour (Harzhauser & Mandić 2004). The uppermost fossiliferous layer in the claypit is silty and contains a variety of littoral molluscan shells, probably indicating a storm- or gravity-induced redeposition from a littoral environment. A common mollusc species in the sublittoral facies is *Lymnocardium schedelianum* (Fig. 5A), indicating the *L. schedelianum* Subzone of the sublittoral *Congeria czjzeki* Zone (Magyar et al. 1999; Harzhauser & Mandić 2004; Fig. 3). Molluscs in the littoral facies include *Lymnocardium conjungens*, marking the *L. conjungens* Zone (Fig. 3). The mammal fauna is interpreted as representing the middle part of MN9 (Daxner-Höck 1996a; Harzhauser et al. 2004; Fig. 3).

In **Sopron**, fossiliferous sublittoral bluish-grey clay and claymarl are exposed in a thickness of about 20 m in the Balfi út claypits. Coarser-grained sediments, such as silt, sand, and gravel, occur in the upper part of the sequence, often containing shells of littoral molluscs (Korpás-Hódi 1994). One of the most common fossils in the sublittoral facies is *Lymnocardium soproniense* (Fig. 5B), a probable descendant of *L. schedelianum*. Its presence defines the *L. soproniense* Subzone of the sublittoral *Congeria czjzeki*

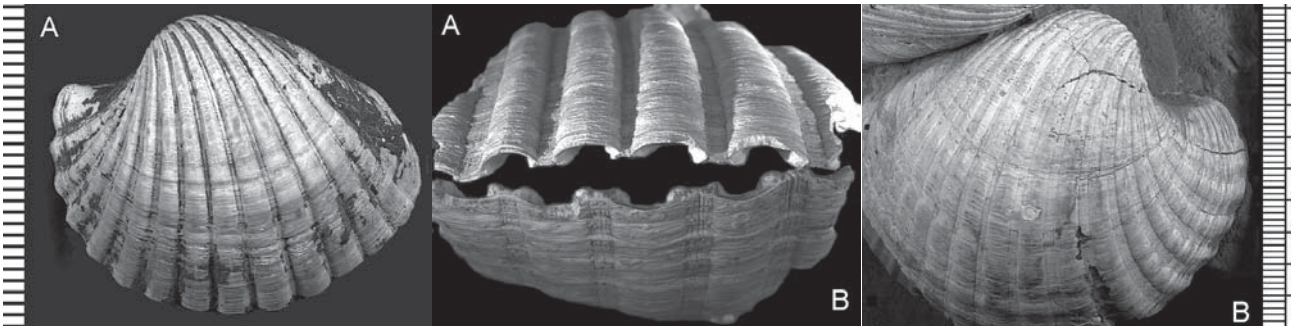

Fig. 5. A common bivalve in the Hennersdorf outcrop is *Lymnocardium schedelianum* (A); in Sopron, however, it is substituted by *L. soproniense* (B). Compare the prominent ribs of A and the almost smooth shell of B. *L. soproniense* is considered a descendant of *L. schedelianum*. Scales in mm.

Zone. The littoral molluscs, occurring in the upper part of the outcrops, include *Lymnocardium conjungens*, thus indicating the *L. conjungens* Zone (Fig. 3).

The **Pezinok** claypit in the eastern foreland of the Malé Karpaty Mts exposes an alternation of sand, silt, clay, and lignite layers about 40 m thick (Baráth et al. 1999). These sediments and the embedded fossils indicate a littoral depositional environment (Fordinál 1997). The presence of *Lymnocardium conjungens* indicates the *L. conjungens* Zone (Fig. 3). The uppermost sand beds may be fluvial in origin. Mammal remains from right below the uppermost coal seam included the murid rodent *Progonomys* sp., indicating the lower part of MN10 Zone (Sabol et al. 2004; Fig. 3).

The village of **Bérbaltavár** (formerly Baltavár) is located 35 km SE of Szombathely. This locality is the only outcrop in this study which is not an actively exploited brickyard claypit. The outcrop, originally a road cut, was first recorded by Suess (1861) as a valuable treasury of fossil mammals. Later Pethő (1885), Kormos (1914), and Benda (1927) excavated the bone-bearing layers, describing and depicting the exposed sequence as well as the fossil finds. The sequence consisted of fluvial sands overlying clayey floodplain sediments, and the lower part of the sand contained the bones. Kretzoi (1969) considered Baltavár as the type locality of the relatively impoverished, large mammal-dominated steppe fauna of the Turolian, and coined the term "Baltavarium" to designate a distinct phase in the western Eurasian faunal succession. Halaváts (1925) reported a rich freshwater and terrestrial mollusc fauna from the locality. Recent cleaning of the exposure in the framework of an international project provided an opportunity for magnetostratigraphic sampling in a 4 m high section, including the sand above the black, red, and brown-coloured bone-bearing layer as well as the underlying clay.

Seismic correlations

Correlation of 7 seismic horizons (A to G) was carried out in the NW-Hungarian part of the Kisalföld Basin, between the four investigated boreholes. Five horizons (A to E) were selected arbitrarily; we were looking for well discernible (high amplitude) and well traceable (horizontally continuous) reflections (although these properties are usually geographically restricted in each horizon). Horizons F and G were introduced into the study area from the south, where they represented biozone boundaries (see in the next chapter).

The selected horizons were interpreted in ca. 6000 km 2D industrial seismic reflection profiles. These correlations show the large-scale geometry of the basin fill and thus reflect the depositional processes. A sigmoidal pattern in horizons A to E (Fig. 6) represents the coeval morphology of the basin slope. The boundary between the flat-lying shallow-water deposits and the dipping slope deposits (i.e. between the Peremarton and Dunántúl Groups) is indicated as the "shelf break" in this study (Fig. 6). The major sediment transport direction was from the N-NW, thus the slope, together with the shelf break, gradually moved towards the S-SE (Fig. 7).

Because of the lack of vertical seismic profiling (VSP) in the investigated boreholes, the time-depth conversion between the seismic profiles and the wells introduced at least several tens of meters uncertainty into the correlation, which has to be taken into account when correlation options are analysed. Tracing of seismic horizons became difficult and uncertain in many profiles close to the surface, in the uppermost 100–300 ms.

Biostratigraphic assessment of the seismic horizons

Horizon A — In the Nagylózs and Zsira wells, this horizon corresponds to fossil-free delta front deposits. Below the horizon, the last (uppermost) dinoflagellates in both boreholes indicate the *Spiniferites paradoxus* Zone. In the Szombathely-II borehole, however, the horizon is within the deepwater facies (*Spiniferites paradoxus* Zone), somewhat below the first occurrence of "*Dreissenomya*" *digitifera* (marking the "*D*". *digitifera* Zone). The horizon is older than the base of well Duka-II (Figs. 2, 4).

Horizon B — In the Nagylózs well this horizon is within the shallow-water facies, and correlates with the lower part of the *L. ponticum* Zone. In the Szombathely-II bore-

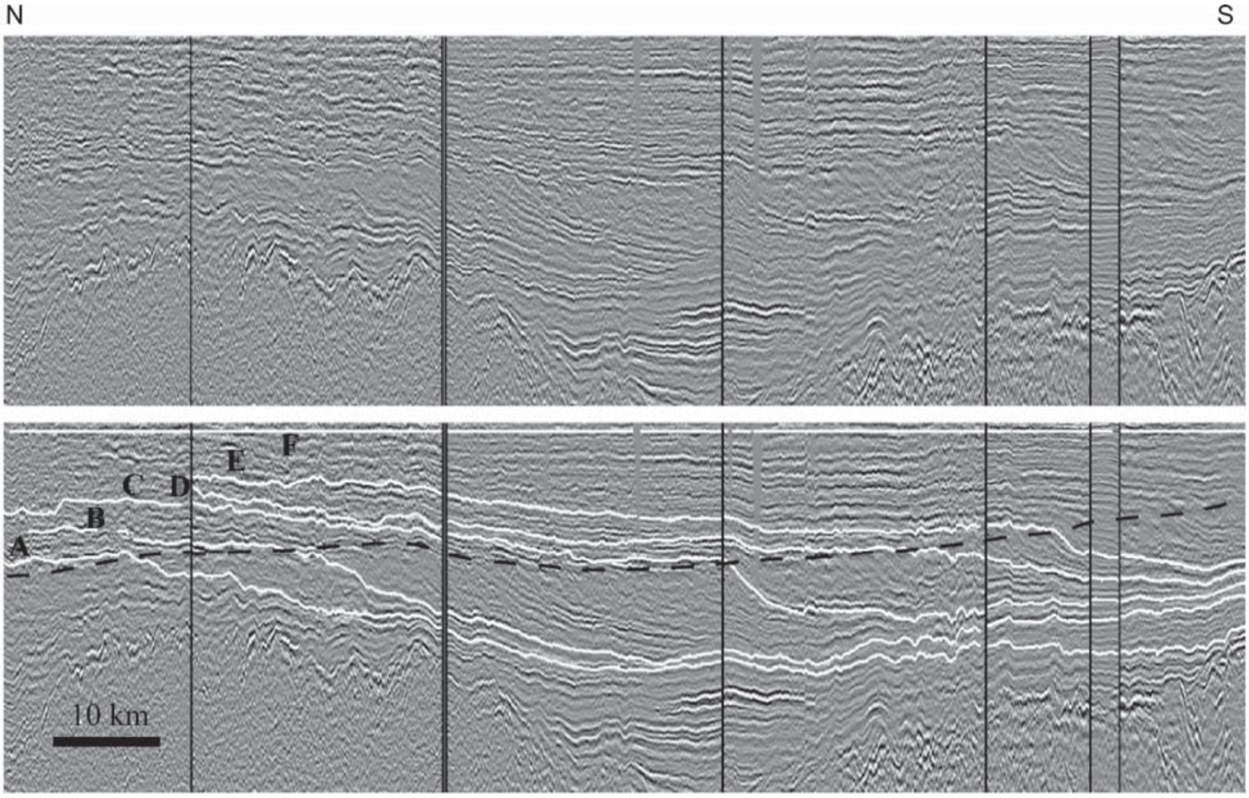

Fig. 6. Uninterpreted (above) and interpreted (below) versions of a N-S composite seismic profile across the Kisalföld Basin with seismic horizons A to E. The profile is flattened to horizon F, thus reflecting the basin morphology at the time when F represented an almost horizontal, flat-lying fluvial plain (ca. 8.6 Ma ago). Dashed line indicates the shelf break, corresponding to the lithostratigraphic boundary between the Peremarton and Dunántúl Groups. Slope height indicates a paleo-waterdepth of ca. 300 m. For location of the profile see Fig. 7.

hole, the horizon is within the deep-water facies (*Spiniferites paradoxus* Zone, "*D*". *digitifera* Zone) (Korpás-Hódi 1992). The horizon is somewhat older than the base of well Duka-II (Figs. 2, 4).

Horizon C — This horizon seems to correspond to biofacies boundaries in all four boreholes. In the Nagylózs and Zsira wells, the horizon approximately correlates with the biofacies boundary between the shallow-lake and the exclusively freshwater, alluvial plain facies. In the Duka and Szombathely wells, however, the horizon is within or close to the 100 m fossil-free interval that separates the sublittoral and shallow-lake facies. Thus, it cannot be younger than the littoral *L. ponticum* Zone identified in Duka-II (Figs. 2, 4).

Horizon D — In the Nagylózs and Zsira wells, the horizon is already within the freshwater alluvial plain facies. In the Szombathely borehole it is within the *L. ponticum* Zone, whereas in Duka it still corresponds to the fossil-free interval (Figs. 2, 4).

Horizon E — In the Nagylózs and Zsira wells the horizon is within the freshwater alluvial plain facies, whereas

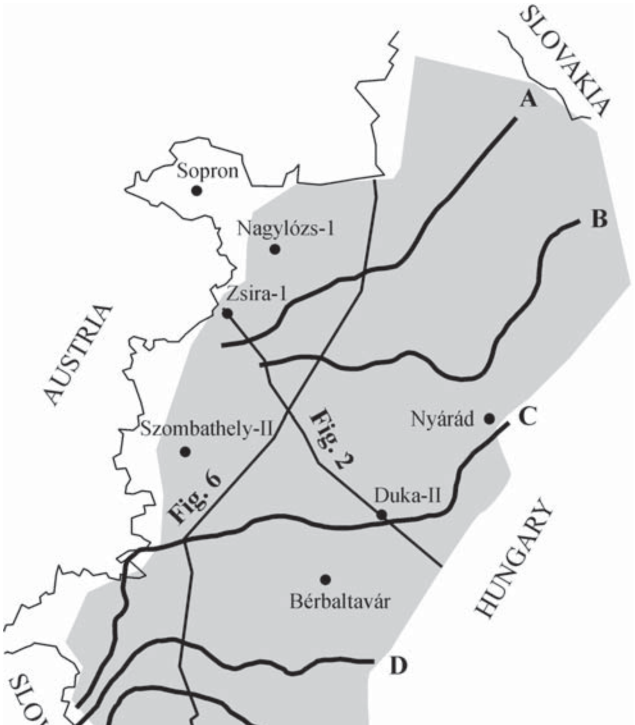

Fig. 7. The western part of the Kisalföld Basin with subsequent shelf break lines belonging to seismic horizons A to E. Seismic correlations were performed in the shaded area (ca. 6000 km 2D profiles covering ~8000 km^2). Note the gradual south-southeastward progradation.

in Szombathely and Duka it is within the *L. ponticum* Zone, close to the shallow-lake/freshwater alluvial plain facies boundary (Fig. 4).

Horizon F — This horizon is within the freshwater alluvial plain biofacies in all the four wells (Fig. 4). (In Duka-II, it may overlie the entire sequence of the well, coming to the surface west of the borehole; correlation is rather ambiguous here (Fig. 2).) The horizon represents the basal part of the *Spiniferites validus* Zone south of the study area (e.g. in Iharosberény-I borehole, see Magyar et al. 1999). As a consequence of the Pliocene or Quaternary uplift of the Transdanubian Central Range, this horizon emerges onto the surface east of the study area, in the vicinity of Nyárád (for its location see Fig. 7). A surface outcrop in Nyárád yielded a fossil rodent, *Allospalax petteri* (Bachmayer et Wilson) (Kordos 1987). The same form is known from Sümeg (MN10, according to, among others, Daxner-Höck 1996b; Mészáros 1999), Kohfidisch (late MN10, Daxner-Höck 1996a), Eichkogel (MN11, Daxner-Höck 1996a), and Tihany (Kordos 1987, 1989). Thus, the temporal range of this species seems to be late MN10 to early MN11. The MN10/MN11 boundary was magnetostratigraphically dated in Spain as 8.7 Ma (Krijgsman et al. 1996). These data suggest that the age of Horizon F may be approximated with this number.

Horizon G — This horizon is estimated to be at about 150 m depth in Nagylózs, 100 m in Zsira, and 400 m in Szombathely, in fluvial facies (Fig. 4). The horizon is definitely younger than the top of borehole Duka-II (Fig. 2). Horizon G represents the base of the littoral *Prosodacnomya* Zone south of the study area (e.g. in Iharosberény-I borehole, see Magyar et al. 1999). The youngest possible age of Horizon G is determined by the K/Ar dating of the Tihany volcano (Magyar et al. 1999). An isochron age of 7.92 ± 0.22 Ma has been obtained recently for the onset of volcanic activity in Tihany (Balogh & Németh 2005). The underlying Tihany-Fehérpart outcrop belongs to the *Lymnocardium decorum* Zone (Müller & Szónoky 1990), and yielded *Allospalax petteri*, correlated with MN11 (Kordos 1989). Thus the age of the horizon can be estimated as 7.9 Ma to ~8.3 Ma.

Magnetostratigraphy

Sampling and laboratory procedures

Details of the paleomagnetic studies have been published elsewhere (Lantos et al. 1992; Lantos & Elston 1995; Juhász et al. 1999); a short summary is given here.

Samples were collected from undisturbed, unaltered and wet sediments. Modifications due to weathering were observed in several beds but these were not sampled. Samples were taken from the central parts of the borehole cores at 0.5 m interval. The upper part of the surface exposures commonly consists of coarse-grained, oxidized or dry, friable sediments that were not sampled. Dry and weathered materials were removed from the wall of the exposures, and the samples were collected at 10 cm stratigraphic intervals from outcrops at Hennersdorf and Sopron, 30 cm at Bérbaltavár, and 1 m intervals at Pezinok. The cubic samples were cut from the unconsolidated sediments with a brass knife and were placed in plastic boxes, which then were sealed and stored in a refrigerator to inhibit desiccation. Altogether, slightly more than 7600 samples were collected from the four holes and the four exposures.

The samples were processed at the joint laboratory of the Geological Institute of Hungary and Eötvös Loránd Geophysical Institute. Laboratory measurements employed a two-axis CCL (Cryogenic Consultants Limited) magnetometer. Following measurement of the natural remanent magnetization, a series of pilot samples representing different lithologies, depths, and inclinations were selected for progressive alternating field (AF) demagnetization. These pilot samples were demagnetized in a one-component Schoenstedt demagnetizer up to 90 mT or until the intensity decreased below the noise level of the magnetometer. The demagnetization behaviour of the pilot samples is depicted in orthogonal demagnetization diagrams (Fig. 8a–d). Additional demagnetization diagrams from the Szombathely section can be found in Lantos & Elston (1995). Most samples exhibited two components of magnetization, and the relatively soft secondary magnetizations disappeared at 10–20 mT in the samples from boreholes and at 20–30 mT from outcrops. A few samples exhibited disturbed demagnetization behaviour above 50–60 mT, where a third component of magnetization, a gyroremanence, was probably acquired during demagnetization (Fig. 8b). Most pilot samples displayed no changes in polarity with demagnetization, only about 20 percent of the inclinations changed polarity. The majority of inclinations thus exhibited no hint of different polarities near the threshold level of stability.

The remaining samples were demagnetized mainly in two or three steps in 15–30 (40) mT. Samples from the Zsira-1 borehole were demagnetized in 10–15 mT because the magnetic intensity decreased near the noise level of the magnetometer in a higher demagnetization field. About 10 percent of the samples did not contain stable directions and were discarded. Most of these samples were collected from the shallow-lake and the alluvial plain facies.

A lack of cementation precluded thermal demagnetization of the sediments. Several pilot samples from more consolidated rocks from the Szombathely-II borehole were progressively demagnetized thermally in a Schoenstedt demagnetizer. Differences in inclination between the thermal and AF demagnetization averaged 3° (Lantos & Elston 1995).

Geological studies and subsurface correlations indicate that the Lake Pannon sediments accumulated rapidly and were buried promptly, and have remained undisturbed and unexposed since burial. The sediments also remained wet. Most strata exhibited rather uniform grey colours representing unoxidized sediments, and modifications due to weathering were observed commonly near the top of the sections. X-ray diffraction analysis, micromineralogical and rock magnetic studies indicate that detrital magnetite is the principal carrier of stable magnetization in the sedi-

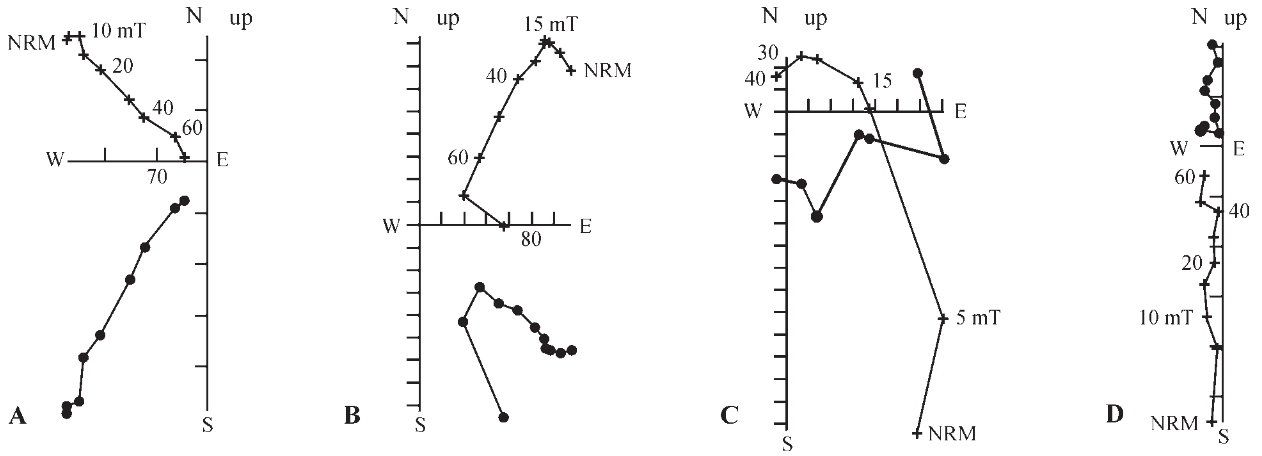

Fig. 8. Diagrams of demagnetization for samples: **A** — drillhole Duka-II, at a depth of 284.5 m, **B** — drillhole Nagylózs-1, 910.4 m, **C** — drillhole Zsira-1, 492.5 m, **D** — outcrop of Sopron, 9.75 m. + — vertical plane, • — horizontal plane.

ments (Lantos & Elston 1995; Thamó-Bozsó 2002). The only exception is Pezinok, where hematite was identified as the principal carrier (Kovács-Pálffy, pers. comm). All studies indicate minor weathering, therefore the stable directions are considered to reflect original magnetization acquired during deposition. However, several short intervals of normal polarity may be related to post-depositional magnetizations. Such intervals occur mainly in the delta front deposits at Nagylózs-1 and Zsira-1 sections, and in nearshore sands above 194 m in Duka-II borehole.

Correlation with the geomagnetic polarity time scale (GPTS)

The biostratigraphically calibrated seismic framework establishes a ca. 4 million year temporal window that allows the polarity records to be correlated with the polarity time scale. All magnetostratigraphic records were re-examined and re-correlated with the ATNTS (Astronomically Tuned Neogene Time Scale) by Lourens et al. (2004) (although differences between ATNTS2004 and the formerly used GPTS of Berggren et al. (1995) are insignificant at the level of our correlations).

The lowermost long interval of normal polarity in the Szombathely-II section coincides with the deep water *C. banatica* molluscan Zone, representing the basal Upper Miocene in the Pannonian Basin (Korpás-Hódi 1992; Magyar et al. 1999). Therefore, the basal long normal polarity interval in the Szombathely, Nagylózs, and Zsira boreholes correlates with Chron C5n (Figs. 9, 10 and 11). Seismic horizons C and D are within a predominantly normal polarity interval in the Nagylózs-1, Zsira-1 and Duka-II boreholes, and this normal polarity interval was correlated with Chron C4An. The Nagylózs-1 section appears to be complete from Chron C5n to C4n (Fig. 10).

The seismostratigraphic correlation suggests that the sediments at the base of the Duka-II sequence accumulated during Chron C4Ar (Fig. 12). The magnetostratigraphic correlation above 194 m is uncertain, because the seismic correlation is rather ambiguous here and post-depo-

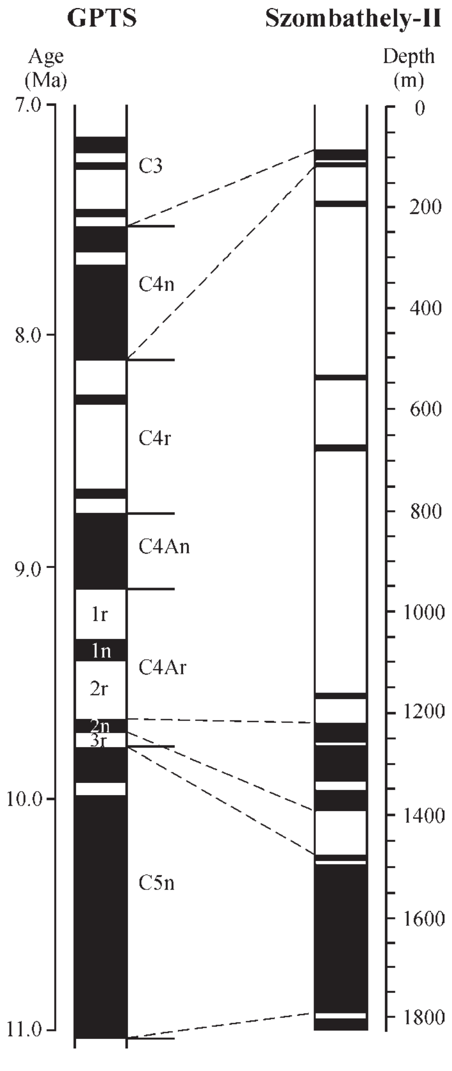

Fig. 9. Correlation of polarity zones in Szombathely-II core section with the geomagnetic polarity time scale (GPTS) of Lourens et al. (2004). Correlation modified from Lantos & Elston (1995). Black — normal polarity; white — reversed polarity; black and white — mixed polarity; grey — no sample.

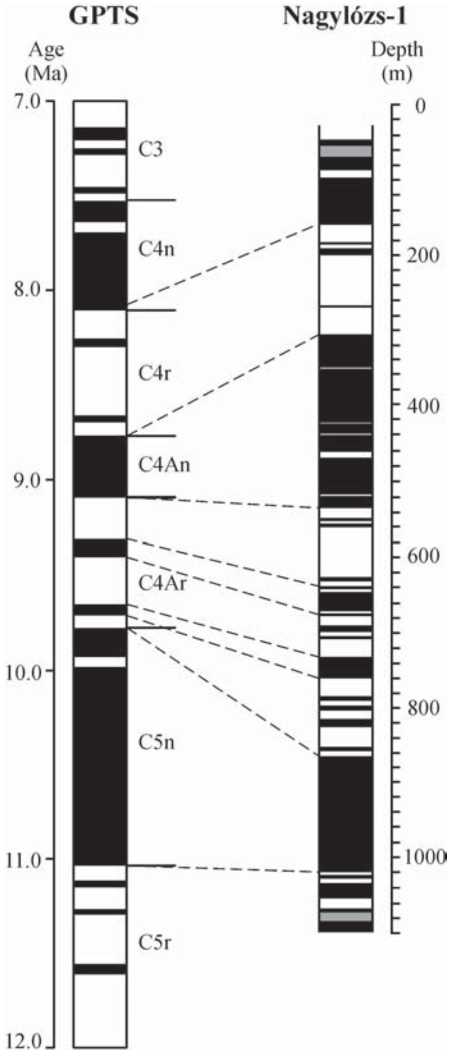

Fig. 10. Correlation of polarity zones in Nagylózs-1 core section with the geomagnetic polarity time scale (GPTS) of Lourens et al. (2004). For legend see Fig. 9.

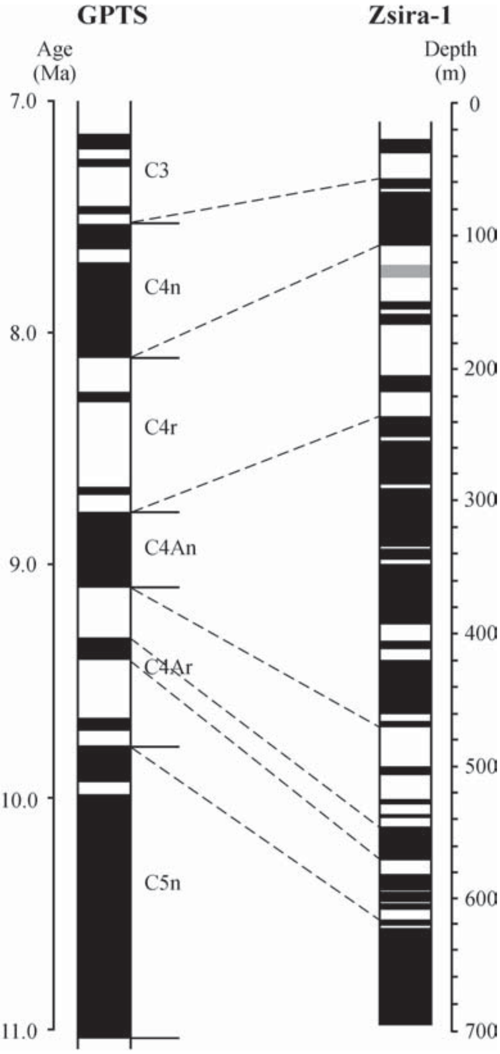

Fig. 11. Correlation of polarity zones in Zsira-1 core section with the geomagnetic polarity time scale (GPTS) of Lourens et al. (2004). For legend see Fig. 9.

sitional processes might have overprinted the original directions.

The polarity zones in the Zsira-1 borehole were correlated with the polarity time scale mainly on the basis of seismic time lines between the Nagylózs-1 and Zsira-1 boreholes. The normal polarity zones have been assigned to Chrons C5n, C4Ar.1n, C4An and C4n but deposits corresponding to Chron C4Ar.2n (and large part of Chron C4Ar.3r) appear to be missing (Fig. 11). The secondary magnetization was not completely removed in low demagnetization field between 570–615 m, thus spurious polarity reversals may occur here and the polarity record is not reliable.

The polarity zones below 1220 m in the Szombathely-II section correlate with Chrons C5n–C4Ar.2n (Fig. 9). Above 1220 m, an extremely long interval of reversed polarity extends to 117 m. The negative inclinations must reflect original directions because progressive AF and thermal demagnetizations, rock magnetic and mineralogic studies indicate that the stable magnetization resides in magnetite aligned with the ambient field during deposition (Lantos & Elston 1995). Additionally, the general lack of iron hydroxides indicates a lack of alteration of the magnetite. Moreover, a similar, overly thick interval of reversed polarity was encountered in a borehole at Torony, located about 15 km west of Szombathely. Although the base of the reversed polarity interval was not encountered at Torony, similarities in stratigraphy and polarity between the drill core sections indicate a stratigraphically reproducible thick interval of reversed polarity.

Seismic horizons in the normal polarity interval, assigned to Chron C4An in the other sections (horizons C, D, and E), correlate with horizons at a depth of between 770 and 950 m in the Szombathely-II drill site. As no interval of normal polarity was encountered here, Chrons C4An and C4Ar.1n are not represented in the Szombathely-II record (Fig. 9). Within the Dunántúl Group, Phillips et al. (1992) recognized an erosional surface at

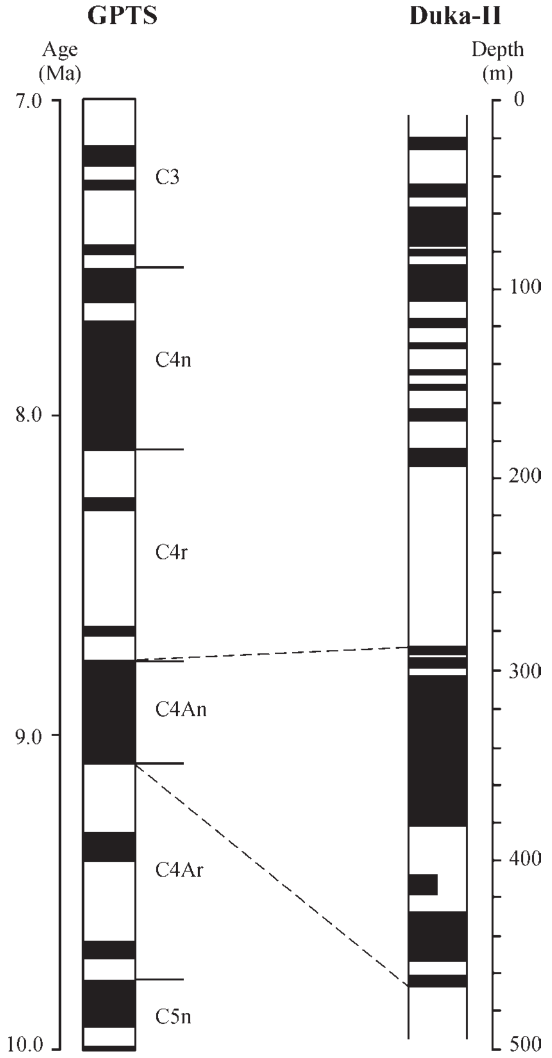

Fig. 12. Correlation of polarity zones in Duka-II core section with the geomagnetic polarity time scale (GPTS) of Lourens et al. (2004). For legend see Fig. 9.

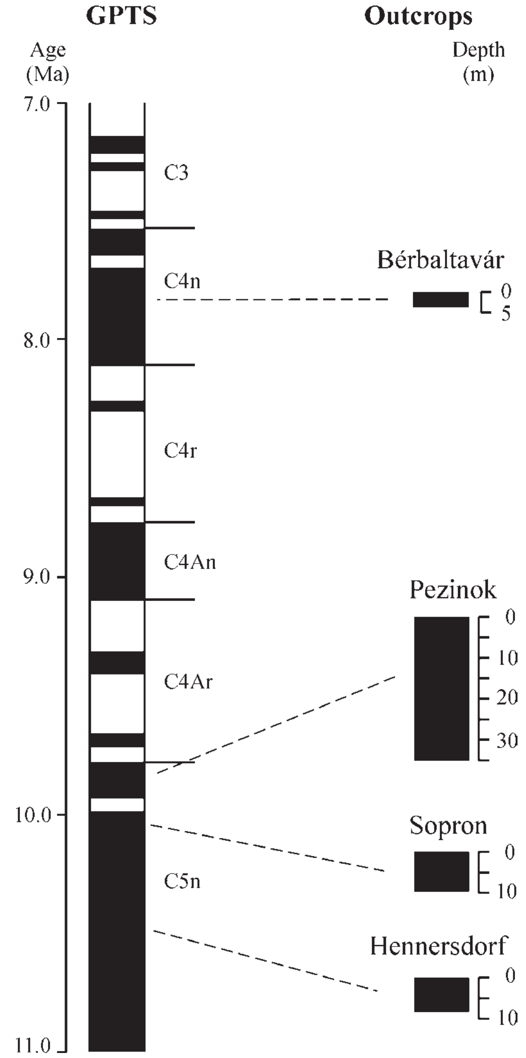

Fig. 13. Correlation of polarity zones in the outcrops at Hennersdorf, Pezinok, Sopron, and Bérbaltavár with the geomagnetic polarity time scale (GPTS) of Lourens et al. (2004). For legend see Fig. 9.

1003 m, and this may represent at least some of the loss of geological and paleomagnetic record.

The seismic horizon F at Nagylózs-1 drill site is in a reversed polarity interval, correlated with Chron C4r. This horizon was traced to the Szombathely-II site where it lies at a depth of 530 m. Therefore the upper part of the long reversed polarity interval in Szombathely-II has been assigned to Chron C4r, and the relatively narrow normal polarity zone between 76 and 117 m may correlate with Chron C4n.

In the claypits of Hennersdorf, Sopron, and Pezinok, the entire sections display an interval of normal polarity. These localities all yield *Lymnocardium conjungens*, and the *Lymnocardium conjungens* Zone is considered to coincide with Chron C5n (Magyar et al. 1999; Fig. 3). Therefore the normal polarity interval of these claypits correlates with Chron C5n (Fig. 13).

If the lower part of MN10 mammal Zone in the upper part of the Pezinok section is valid (Sabol et al. 2004), the MN9/MN10 boundary must be older than 9.78 Ma, the end of Chron C5n. Krijgsman et al. (1996) put the MN9/MN10 boundary at 9.7 Ma, which is less inconsistent with our data than the 9.5 Ma datum proposed by Steininger et al. (1996).

The inclinations show an interval of normal polarity in the Baltavár section. A seismic horizon in the Iharosberény-I borehole at 700 m (*P. dainellii* Subzone; see Magyar et al. 1999) emerges to ~100 m below the surface in the vicinity of Baltavár. The *P. dainellii* Subzone corresponds to Chron C4n (Magyar et al. 1999), thus the normal polarity record in Baltavár is inferred to represent this chron (8.11 to 7.53 Ma; Fig. 13).

Discussion

Base of the Pannonian stage

There seems to be a wide consensus that the age of the Sarmatian/Pannonian boundary is between 11 and 12 Ma

(Vass et al. 1987; Vass 1999; Magyar et al. 1999; Harzhauser et al. 2004), although a few outlying interpretations also occur (Kókay et al. 1991; Vakarcs et al. 1999). Within this 1-million-year interval, however, the data and interpretations widely scatter. Recently Harzhauser et al. (2004) proposed an astronomically estimated age model which dates the beginning of the Pannonian at 11.6 Ma, corresponding to the Middle/Late Miocene boundary (Fig. 3). The magnetostratigraphic interpretation of the Szombathely and Nagylózs polarity records indicates that the base of the Lake Pannon sequence is indeed older than Chron C5n (i.e. belongs to C5r, 12.01 to 11.04 Ma). Although both profiles contain the lowermost biozones of the Pannonian (*Mecsekia ultima* and *Lymnocardium praeponticum* Zones), a hiatus is supposed to be present between the Pannonian and the underlying Sarmatian, because the long reversed polarity interval of Chron C5r is poorly represented in both boreholes (Figs. 9 and 10). The hypothetical 11.6 Ma datum cannot be tested in the investigated sections.

Dating the seismic horizons and biozone boundaries

On the basis of the integrated interpretation, the following chrons and approximate ages can be assigned to the seismic horizons: A: C4Ar.2n, 9.7 Ma; B: C4Ar.1r, 9.2 Ma; C: C4An, 9 Ma; D: C4An, 8.9 Ma; E: C4An, 8.8 Ma; F: lower part of C4r, 8.6 Ma; and G: lower part of C4n or upper part of C4r, 8.0 Ma. These results indicate that the upper boundary of the *Spiniferites paradoxus* dinoflagellate Zone and that of the *Congeria czjzeki* Zone are both younger than 9.2 Ma (in Duka-II, they are younger than horizon B; Fig. 4). The boundary between the *Congeria banatica* and "*Dreissenomya*" *digitifera* deep water molluscan Zones is around 9.6 Ma (approximately corresponding to horizon A in Szombathely-II; Figs. 4 and 9). Finally, deposition of the littoral *Lymnocardium ponticum* molluscan Zone lasted from at least 8.8 to 9.2 Ma (in Duka-II it is younger than horizon E, whereas in Nagylózs-1 it is older than horizon B; Fig. 4). The biostratigraphic chart in Fig. 3 was already edited in accord with these data.

Depositional history

Average rates of accumulation for different time intervals in the borehole sections were calculated from the magnetostratigraphic correlations (Fig. 14). These estimates are average minimum rates of accumulation and do not take into account the effects of compaction.

Accumulation of Lake Pannon deposits began somewhat before 11 Ma (Szombathely-II, Nagylózs-1) or later (Zsira-1, Duka-II) in the studied sections (Figs. 9–12). The time interval of Chron C5n (11.04 to 9.78 Ma) is represented by thick deposits in the Szombathely-II, Nagylózs-1 and Zsira-1 boreholes. The accumulation rates indicate an increase in the sedimentary input and subsidence of the basin between 9.78 and 8.77 Ma, however, there are significant differences between the drill sites (300–600 m/Myr, Fig. 14). The inferred gaps in sedimentary records at Szombathely-II and Zsira-1 (Figs. 9 and 11) suggest a temporary loss of accommodation space rather than a lack of transport capacity of rivers, because the deposition was continuous in the Nagylózs-1 and Duka-II boreholes at the same time. The accumulation rates after 8.77 Ma (above seismic horizon F) indicate a slower and more uniform subsidence in the area (ca. 200 m/Myr, Fig. 14). The youngest Miocene sediments in the investigated borehole sections may be ca. 7.4–7.2 Ma old.

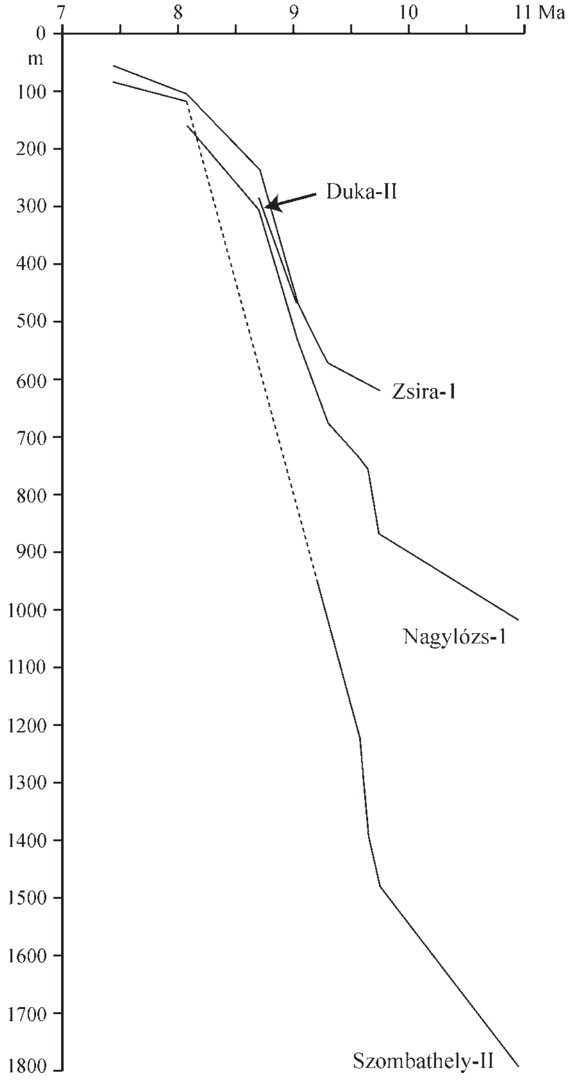

Fig. 14. Accumulation vs. time (without compaction) diagram for the Szombathely-II, Nagylózs-1, Zsira-1 and Duka-II wells.

Horizon C corresponds to biofacies boundaries in all four boreholes. Moreover, this horizon approximately corresponds to a sequence boundary in Vakarcs et al. (1994), at the base of a normal polarity interval at 8.2 Ma by the polarity time scale of Berggren et al. (1985). The age of this horizon (base of Chron C4An) is 9.10 Ma in the ATNTS2004. Vakarcs et al. (1994) suggested a depositional hiatus associated with this sequence boundary in more easterly parts of the Pannonian Basin. Horizon C is at 900–950 m depth in the Szombathely well (Fig. 4), relatively close to the unconformity surface observed at 1003 m. Although the seismic profiles do not provide evidence of the presence of a significant sequence boundary and associated hiatus in the studied area, such phenomena might well influence the sedimentation in the investigated borehole sections.

Patterns of progradation

The shelf break swept across the Kisalföld Basin in less than 1 Myr, turning the lacustrine basin into fluvial plains. The shelf break ran parallel with the basin margin along the eastern foot of the Alps and Carpathians at 9.7 Ma (horizon A in Fig. 7). The area behind the shelf break line had been transformed to shallow lacustrine and fluvial environments by this time; the offshore sediments at Hennersdorf and Sopron must have been deposited earlier. The shelf break line had already passed Zsira, Nagylózs, and Pezinok, where shallow lacustrine and deltaic sedimentation took place at this time.

Progradation continued east- and southward into the central part of the Kisalföld Basin. According to the thickness of the sigmoid patterns on seismic profiles, the water depth in the basin was ca. 300 m. By 9 Ma (horizon C in Fig. 7) the shelf break line had passed Szombathely and Duka, replacing the sublittoral environment with shallow lacustrine and deltaic conditions. Some 50 km behind the shelf break, at Zsira and Nagylózs, the temporary influence of Lake Pannon ceased forever, and freshwater and terrestrial environments prevailed.

The shift of the shelf break line then was slow in the western part of the basin relative to the basin proper. As a result, the subsequent shelf break lines display a fan-shaped pattern, the "rotation centre" being in the Őrség region of western Hungary or in northeastern Slovenia. At 8.8 Ma (horizon E in Fig. 7), the deltaic influence was about to end at Szombathely and Duka, ca. 50 km behind the shelf break, whereas deltaic and shallow lacustrine environment still prevailed around Bérbaltavár, about 30 km behind the shelf break. The Baltavár mammals and terrestrial and freshwater molluscs lived some time later, when the delta system moved further to the south.

Acknowledgments: The cleaning and magnetostratigraphic investigation of the Bérbaltavár locality was sponsored by the National Geographic Society in the framework of Project 6210-98, Evolution of Central Paratethys (Hungary) Miocene Vertebrate Communities, with R.L. Bernor and L. Kordos as principal investigators. The authors thank R.L. Bernor and MOL Hungarian Oil and Gas Co. for permitting the publication of the Bérbaltavár magnetostratigraphic data and the Kisalföld seismic materials, respectively. F.F. Steininger, I. Baráth and K. Fordinál are thanked for making available the Hennersdorf and Pezinok claypits for sampling and investigations. We also thank I. Baráth and M. Harzhauser for their careful review and useful comments on the earlier version of this paper. This study was supported by the Hungarian Scientific Research Fund (OTKA) Project No. T 035168.

References

Balogh K. & Németh K. 2005: Evidence for the Neogene small-volume intracontinental volcanism in Western Hungary: K/Ar geochronology of the Tihany Maar Volcanic Complex. *Geol. Carpathica* 56, 91–99.

Baráth I., Fordinál K. & Pipík R. 1999: Lacustrine to alluvial sedimentary cyclicity (Pannonian zone E, Danube Basin). *Geol. Carpathica, Spec. Issue* 50, 14–16.

Benda L. 1927: The history of the paleontological excavations at Baltavár in the course of seventy years 1856–1926. *Joint Stock Company*, Szombathely, 1–64.

Berggren W.A., Kent D.V., Flynn J.J. & Van Couvering J.A. 1985: Cenozoic geochronology. *Geol. Soc. Amer. Bull.* 96, 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., Aubry M.-P. & Hardenbol J. (Eds.): Geochronology time scales and global stratigraphic correlation. *SEPM Spec. Publ.* 54, 129–212.

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

Daxner-Höck G. 1996a: Faunenwandel in Obermiozän und Korrelation der MN-Zonen mit den Biozonen des Pannons der Zentralen Paratethys. *Beitr. Paläont.* 21, 1–9.

Daxner-Höck G. 1996b: Middle and Late Miocene Gliridae of western, central, and southeastern Europe. In: Bernor R.L., Fahlbusch V. & Mittmann H.-W. (Eds.): The evolution of western Eurasian Neogene Mammal Faunas. *Columbia University Press*, New York, 261–263.

Daxner-Höck G. 2001: Early and Late Miocene correlation (Central Paratethys). *Ber. Inst. Geol. Paläont. K.-F.-Univ. Graz* 4, 28–32.

Dunkl I. & Frisch W. 2002: Thermochronologic constraints on the Late Cenozoic exhumation along the Alpine and West Carpathian margins of the Pannonian basin. *European Geosci. Union Stephan Mueller Spec. Publ. Ser.* 3, 135–147.

Elston D.P., Lantos M. & Hámor T. 1990: Magnetostratigraphic and seismic stratigraphic correlations of Pannonian (s.l.) deposits in the Great Hungarian Plain. *Ann. Rep. Hung. Geol. Inst.* 1988, 109–134 (in Hungarian with English abstract).

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. A case study from the Békés basin, Hungary. *Kluwer Academic Publishers*, Dordrecht, 111–142.

Fordinál K. 1997: Molluscs (Gastropoda, Bivalvia) from the Pannonian deposits of the western part of Danube Basin (Pezinok clay pit). *Slovak Geol. Mag.* 3–4, 263–283.

Halaváts J. 1925: Die oberpontische Molluskenfauna von Baltavár. *Mitt. Jb. Kgl. Ungarischen Geol. Anstalt* 24, 167–180.

Harzhauser M. & Mandić O. 2004: The muddy bottom of Lake Pannon — a challenge for dreissenid settlement (Late Miocene; Bivalvia). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 204, 331–352.

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.

Horváth F. & Pogácsás Gy. 1988: Contribution of seismic reflection data to chronostratigraphy of the Pannonian basin. In: Royden L.H. & Horváth F. (Eds.): The Pannonian basin. A study in basin evolution. *Amer. Assoc. Petrol. Geol., Memoir* 45, 97–105.

Horváth F., Cloetingh S. & Tari G. 1995: Stress-induced late stage subsidence anomalies of the Pannonian Basin. In: Horváth F., Tari G. & Bokor Cs. (Eds.): Hungary: Extensional collapse of the Alpine orogene and hydrocarbon prospects in the basement and basin fill of the western Pannonian Basin. *AAPG International Conference and Exhibition, Nice, France, Field Trip Notes* 6, 47–60.

Hrušecký I. 1999: Central part of the Danube basin in Slovakia: Geophysical and geological model in regard to hydrocarbon prospection. *Exploration Geophysics, Remote Sensing and Environment* 6, 2–55.

Jámbor Á. 1980: Pannonian in the Transdanubian Central Mountains. *Ann. Hung. Geol. Inst.* 62, 1–259 (in Hungarian).

Juhász E., Müller P., Ricketts B.D., Tóth-Makk Á., Hámor T., Farkas-Bulla J. & Sütő-Szentai M. 1996: High-resolution sequence stratigraphy and subsidence analysis of the Late Neogene in the Pannonian Basin, Hungary. *Acta Geol. Hung.* 39, 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., 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.* 156, 335–356.

Juhász Gy. 1991: Lithostratigraphical and sedimentological framework of the Pannonian (s.l.) sedimentary sequence in the Hungarian Plain (Alföld), Eastern Hungary. *Acta Geol. Hung.* 34, 53–72.

Kókay J., Hámor T., Lantos M. & Müller P. 1991: The paleomagnetic and geological study of borehole section Berhida 3. *Ann. Rep. Hung. Geol. Inst.* 1989, 45–63 (in Hungarian with English abstract).

Kordos L. 1987: Neogene vertebrate biostratigraphy in Hungary. *Ann. Hung. Geol. Inst.* 70, 393–396.

Kordos L. 1989: Anomalomyidae (Mammalia, Rodentia) remains from the Neogene of Hungary. *Ann. Rep. Hung. Geol. Inst.* 1987, 293–311.

Kormos T. 1914: Über die Resultate meiner Ausgrabungen im Jahr 1913. *Jb. Königlich Ungarischen Geologischen Reichsanstalt für 1913*, 559–604.

Korpás-Hódi M. 1989: Molluscs in borehole Duka-II. *MS MÁFI,* 1–10 (in Hungarian).

Korpás-Hódi M. 1992: The Pannonian (s.l.) molluscs of borehole section Szombathely II. *Ann. Rep. Hung. Geol. Inst.* 1990, 505–525 (in Hungarian with English abstract).

Korpás-Hódi M. 1994: The Neogene of the Sopron Mts. Claypit, Sopron, Balfi street, Pannonian. In: Nagymarosy A. (Ed.): IGCP 329 Project "The Neogene of the Paratethys". *Workshop Meeting 1994, Sümeg, Excursion Guide,* 34–36.

Korpás-Hódi M., Nagy E., Nagy-Bodor E., Székvölgyi K. & Ó. Kovács L. 2000: Late Miocene climatic cycles and their effect on sedimentation (west Hungary). In: Hart M.B. (Ed.): Climates: Past and present. *Geol. Soc. London, Spec. Publ.* 181, 79–88.

Kováč M., Baráth I., Harzhauser M., Hlavatý I. & Hudáčková N. 2004: Miocene depositional systems and sequence stratigraphy of the Vienna Basin. *Cour. Forsch.-Inst. Senckenberg* 246, 187–212.

Kováč M., Baráth I., Fordinál K., Grigorovich A.S., Halásová E., Hudáčková N., Joniak P., Sabol M., Slamková M., Sliva L. & 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, 32–52.

Kretzoi M. 1969: Sketch of the late Cenozoic (Pliocene and Quaternary) terrestrial stratigraphy of Hungary. *Földrajzi Közlemények* 93, 179–204 (in Hungarian with English summary).

Krijgsman W., Garcés M., Langereis C.G., Daams R., van Dam J., van der Meulen A.J., Agustí J. & Cabrera L. 1996: A new chronology for the middle to late Miocene continental record in Spain. *Earth Planet. Sci. Lett.* 142, 367–380.

Lantos M., Hámor T. & Pogácsás Gy. 1992: Magneto- and seismostratigraphic correlations of Pannonian s.l. (Late Miocene and Pliocene) deposits in Hungary. *Paleontologia i Evolució* 24–25, 35–46.

Lantos M. & Elston D.P. 1995: Low- to high-amplitude oscillations and secular variation in a 1.2 km late Miocene inclination record. *Phys. Earth Planet. Inter.* 90, 37–53.

Lourens L.J., Hilgen F.J., Shackleton N.J., Laskar J. & Wilson D. 2004: The Neogene period. In: Gradstein F., Ogg J. & Smith A.G. (Eds.): A geologic time scale 2004. *Cambridge University Press*, 469–471.

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

Magyar I., Müller P., Geary D.H., Sanders H.C. & Tari G.C. 2000: Diachronous deposits of Lake Pannon in the Kisalföld basin reflect basin and mollusc evolution. *Abh. Geol. Bundesanst.* 56, 669–678.

Mattick R.E., Teleki P.G., Phillips R.L., Clayton J.L., Dávid Gy., Pogácsás Gy., Bardócz B. & Simon E. 1996: Structure, stratigraphy, and petroleum geology of the Little Plain basin, northwestern Hungary. *Amer. Assoc. Petrol. Geol. Bull.* 80, 1780–1800.

Mészáros L. 1999: Taphonomical observations on Late Miocene soricids (Mammalia). *Földt. Közl.* 129, 159–178 (in Hungarian with English abstract).

Molenaar C.M., Révész I., Bérczi I., Kovács A., Juhász Gy.K., Gajdos I. & Szanyi B. 1994: Stratigraphic framework and sandstone facies distribution of the Pannonian sequence in the 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, 99–110.

Müller P. & Szónoky M. 1990: Faciostratotype the Tihany-Fehérpart (Hungary) ("Balatonica Beds", by Lőrenthey, 1905). 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*, Zagreb–Belgrade, 427–435.

Pethő Gy. 1885: Über die fossilen Säugethier-Überreste von Baltavár. *Jb. der k. u. Geologischen Anstalt für 1884*, 63–73.

Phillips R.L., Jámbor Á. & Révész I. 1992: Depositional environments and facies in continuous core from the Szombathely-II well (0–2150 m), Kisalföld Basin, western Hungary. *U.S. Geol. Surv. Open File Report* 92–250, 14.

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

Pogácsás Gy., Szabó A. & Szalay J. 1992: Chronostratigraphic relations of the progradational delta sequence of the Great Hungarian Plain. *Acta Geol. Hung.* 35, 311–327.

Pogácsás Gy., Mattick R.E., Elston D.P., Hámor T., Jámbor Á., Lakatos L., Lantos M., Simon E., Vakarcs G., Várkonyi L. & Várnai P. 1994: Correlation of seismo- and magnetostratigraphy in Southeastern Hungary. 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, 143–160.

Sabol M., Joniak P. & Holec P. 2004: Succession of mammalian assemblages during the Neogene — a case study from the Slovak part of the Western Carphatians. *Scripta Fac. Sci. Nat. Univ. Masaryk. Brunensis, Geol.* 31–32, 65–84.

Sacchi M. & Horváth F. 2002: Towards a new time scale for the Upper Miocene continental series of the Pannonian basin (Central Paratethys). In: Cloetingh S.A.P.L., Horváth F., Bada G. & Lankreijer A.C. (Eds.): Neotectonics and surface processes: the Pannonian Basin and Alpine/Carpathian System. *European Geosci. Union, Stephan Mueller Spec. Publ. Ser.* 3, 79–94.

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 A.G., Premoli Silva I., Weissert H. & Ferreri V. (Eds.): Cyclostratigraphy: Approaches and case histories. *SEPM Spec. Publ.* 81, 275–294.

Sacchi M., Horváth F. & Magyari O. 1995: High resolution seismics in the Lake Balaton: insights into the evolution of western Pannonian Basin. In: Horváth F., Tari G. & Bokor Cs. (Eds.): Extensional collapse of the Alpine orogene and hydrocarbon prospects in the basement and basin fill of the western Pannonian basin. *AAPG International Conference and Exhibition, Nice, France, Field Trip Notes* 6, 171–185.

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.

Sprovieri M. & Sacchi M. 1999: Correlation between Paratethys and Mediterranean events during the Tortonian: a working hypothesis. *Neogene Newsletter* 6, 60–70.

Sprovieri M., Sacchi M. & Rohling E.J. 2003: Climatically influenced interactions between the Mediterranean and the Paratethys during the Tortonian. *Paleoceanography* 18, 1034.

Steininger F.F., Berggren W.A., Kent D.V., Bernor R. L., Sen S. & Agusti J. 1996: Circum-Mediterranean Neogene (Miocene and Pliocene) marine-continental chronologic correlations of European mammal units. In: Bernor R.L., Fahlbusch V. & Mittmann H.-W. (Eds.): The evolution of western Eurasian Neogene mammal faunas. *Columbia University Press*, New York, 7–46.

Suess E. 1861: Über die grossen Raubthiere der österreichischen Tertiär-Ablagerungen. *Sitz.-Ber. K. Akad. Wiss., Math.-Naturwiss.* 43, 217–235.

Tari G. 1996: Neoalpine tectonics of the Danube Basin (NW Pannonian Basin, Hungary). In: Ziegler P.A. & Horváth F. (Eds.): Peri-Tethys Memoir 2: Structure and prospects of Alpine basins and forelands. *Mém. Mus. Nat. Hist. Natur.* 170, 439–454.

Thamó-Bozsó E. 2002: Mineral composition of Cenozoic sands and sandstones in Hungary and the possibilities of determination of their source. *Ann. Rep. Geol. Inst. Hung.* 1997–1998, 119–134 (in Hungarian with English abstract).

Ujszászi K. & Vakarcs G. 1993: Sequence stratigraphic analysis in the south Transdanubian region, Hungary. *Geophys. Transactions* 38, 69–87.

Vakarcs G., Vail P.R., Tari G., Pogácsás Gy., Mattick R.E. & Szabó A. 1994: Third-order Middle Miocene-Early Pliocene depositonal 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.

Vass D., Repčok I., Balogh K. & Halmai J. 1987: Revised radiometric time-scale for the Central Paratethyan Neogene. *Ann. Hung. Geol. Inst.* 70, 423–434.

Vass D. 1999: Numeric age of the Sarmatian boundaries (Suess 1866). *Slovak Geol. Mag.* 5, 227–232.