Is there a Messinian unconformity in the Central Paratethys?

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ABSTRACT: Since the conception of the Mediterranean Messinian Salinity Crisis model in the 1970s, regional unconformities as candidates for indicators of a correlative base level drop have been sought in the neighbouring Paratethyan basins. Some authors have suggested that seismic sections and borehole profiles from the Late Miocene to Pliocene lacustrine to fluvial succession of the Central Paratethyan Pannonian Basin include such unconformities. We argue that none of these unconformities evidence a significant drop in water-levels. One type of such unconformities is marked by the onlap of seismic reflections onto the lower portion of the shelf-edge clinoforms, a feature repeatedly observed in the eastern Hungarian part of the basin. This geometry, however, resulted from strike variability of the sediment feeder system, thus it is a local phenomenon which does not necessarily justify general base level drops. The only regional unconformity was observed on the shelf, not on the slope. It separates originally flat-lying Messinian deltaic-fluvial deposits from the overlying Pliocene fluvial-terrestrial sediments. This surface can be traced along the entire length of the northern basin margin both in seismic and borehole data. The unconformity is angular and thus has a tectonic origin. It is tilted together with the underlying sediments toward the basin proper, indicating the onset of basin inversion in the latest Miocene or earliest Pliocene. Thus, the seismic and borehole data published so far from the Pannonian Basin do not evidence that the water level of the Central Paratethys was directly influenced by the drawdown of the Mediterranean or the Eastern Paratethys.

INTRODUCTION

The concept of the Messinian desiccation of the Mediterranean was based on the presence of shallow-water sediments (evaporites) in deep basinal settings (Hsü et al. 1977), and coeval regional unconformities in the basin margins (Ryan and Cita 1978). The Messinian Salinity Crisis (MSC) model also involved the drainage of Paratethyan "fresh" waters into the Mediterranean basin during the latest Messinian, causing the migration and dispersal of endemic Paratethyan molluscs, ostracods, fish, and dinoflagellates across the Mediterranean "lagomare" (Orszag-Sperber 2006). These hypotheses triggered a thorough search for unconformities and regional erosional surfaces in the Paratethyan basins at or near the Miocene/Pliocene boundary (Hsü and Giovanoli 1979). Recent studies claim the existence of such erosional surfaces in the Euxinian (Gillet et al. 2007) and Dacian (Clauzon et al. 2005) basins of the Eastern Paratethys, although other papers describe continuous sequences of shallow-water environment in the Dacian basin throughout the entire MSC interval, thus excluding significant (>100m) water level drops (e.g. Vasiliev et al. 2005).

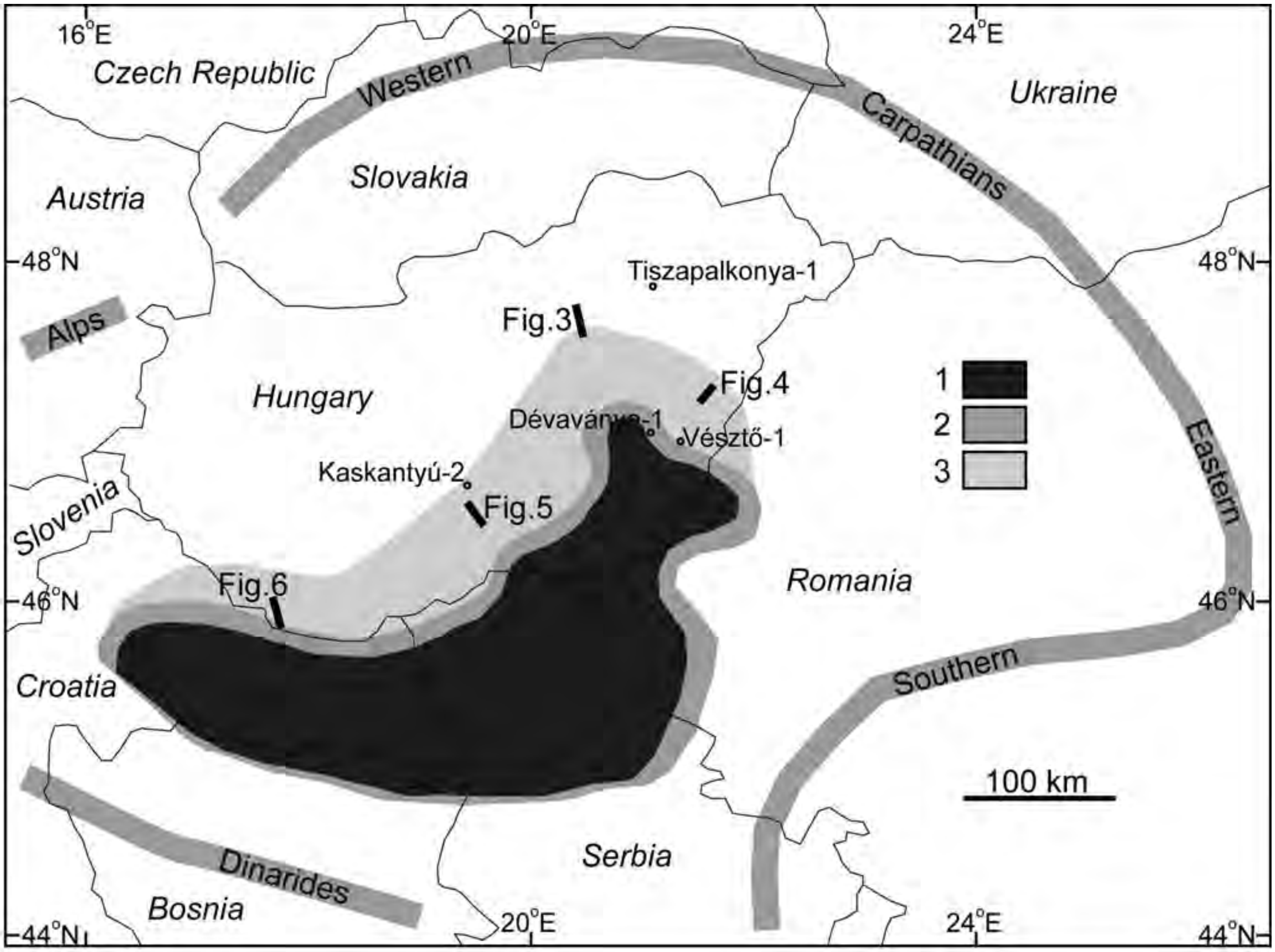
A similar controversy applies to the Central Paratethys as well. On the basis of seismic and borehole data, several authors suggested that the Central Paratethys (the Pannonian basin) also experienced a significant base-level drop during the latest Miocene as a consequence of the drawdown of the Mediterranean and the Eastern Paratethys (Csató 1993; Vakarcs et al. 1994; Juhász et al. 1999; Csató et al. 2007). Others claimed, however, that no such environmental impact is perceptible in the seismic record (Sacchi et al. 1999). The question of whether or not a Messinian unconformity is present in the Central Paratethys is not only of regional importance. If true, it implies that a significant marine connection must have been present between the Pannonian basin and the Mediterranean (or the Eastern Paratethys) in Messinian times, which would be very relevant for budget calculations of salinity and water level changes during the MSC.

The objective of this paper is to provide a critical review of earlier interpretations concerning the presence of a Messinian unconformity in the Central Paratethys, and to integrate the sometimes divergent seismic stratigraphic, biostratigraphic and magnetostratigraphic interpretations into a coherent picture. In the course of our work we used the extensive seismic network (2D and 3D) that covers the Hungarian part of the Pannonian basin, and published stratigraphic data from various boreholes in the same area.

PALEOGEOGRAPHIC SETTING

At about the Middle/Late Miocene boundary, the once contiguous Central Paratethyan realm was divided into two units. West of the Carpathians, the Pannonian basin system became effectively separated from the rest of the Paratethys, whereas the fore-Carpathian areas, including the Dacian basin, became part of the Eastern Paratethys (Popov et al. 2006). Following the Middle Miocene back-arc extension, the Pannonian basin system experienced post-rift thermal subsidence during much of the Late Miocene (Horváth et al. 2006). Sedimentation took place in Lake Pannon, a large and deep inland "sea", and in the adjacent deltaic and fluvial environments.

The uplifting Alps and Carpathians shed sediments to the northwestern and northeastern parts of the lake, respectively. By the Late Messinian, the northern half of the Pannonian basin system was converted into alluvial plains, and Lake Pannon was confined to an area what is now the southern part of Hungary, northern parts of Croatia, Bosnia, and Serbia, and easternmost tip of Romania (Vakarcs et al. 1994; Magyar et al. 1999a; text-fig. 1). Southward progradation of the northern shoreline continued in the Early Pliocene. The Late Neogene is character-



TEXT-FIGURE 1
Position of Lake Pannon within the Pannonian basin in the Late Messinian. 1: basin, 2: slope, 3: "shelf" (delta plain). Within the political borders of Hungary the environments were mapped by seismic profiles; beyond those borders they were interpreted based on general paleogeographic trends (Magyar et al. 1999a). Boreholes with magnetic polarity record and the locations of seismic profiles in text-figures 3-6 are also indicated.

ized by accelerated subsidence of the central Pannonian basin and inversion (uplift) in the marginal areas (Horváth and Cloetingh 1996).

Lake Pannon was a site of repeated adaptive radiations in various taxa during the Late Miocene (Geary et al. 2000, Magyar 2006). At the beginning of the Pontian age, dated as 5.9 Ma by Vasiliev et al. (2005), a large number of endemic Lake Pannon molluscan species appeared and dispersed in the Eastern Paratethys. Some paleontologists suggested that this event indicated the formation of a uniform Paratethys, i.e. a connection between the Pannonian and the Dacian basins (e.g. Nevesskaja et al. 2001). Others stressed, however, that this outward dispersal from the Pannonian basin can be explained by an intermittent outflow of Lake Pannon towards the Eastern Paratethys (e.g. Müller and Magyar 1992). The first case implies that a drowdawn in the Dacian basin would have certainly affected the water levels of Lake Pannon. In the latter case, however, no such relationship is necessary; the water level of Lake Pannon in the Late Messinian was regulated by regional tectonics, sediment supply, and hydrological budget, similarly to the preceding Tortonian-Early Messinian interval.

UNCONFORMITIES IN THE UPPER MIOCENE-PLIOCENE SUCCESSION OF THE PANNONIAN BASIN

The Upper Miocene to Pliocene sedimentary succession of the Pannonian basin represents one tectono-stratigraphic cycle, reflecting the "birth, life and death" of Lake Pannon (Kázmér 1990). The major facies units include (from bottom to top): lacustrine hemipelagic marls; sandy turbidites; mudstones deposited on the slope (appearing as shelf-margin clinoforms on seismic profiles); various shallow lacustrine and deltaic sediments deposited on the "shelf"; and eventually fluvial and flood-plain sediments (Juhász 1991). The boundaries between these genetic units are highly diachronous; progradation dominantly from N-NW to S-SE lasted from ca. 10 Ma to 4 Ma, when the deep lacustrine basin eventually infilled (Magyar et al. 1999a).

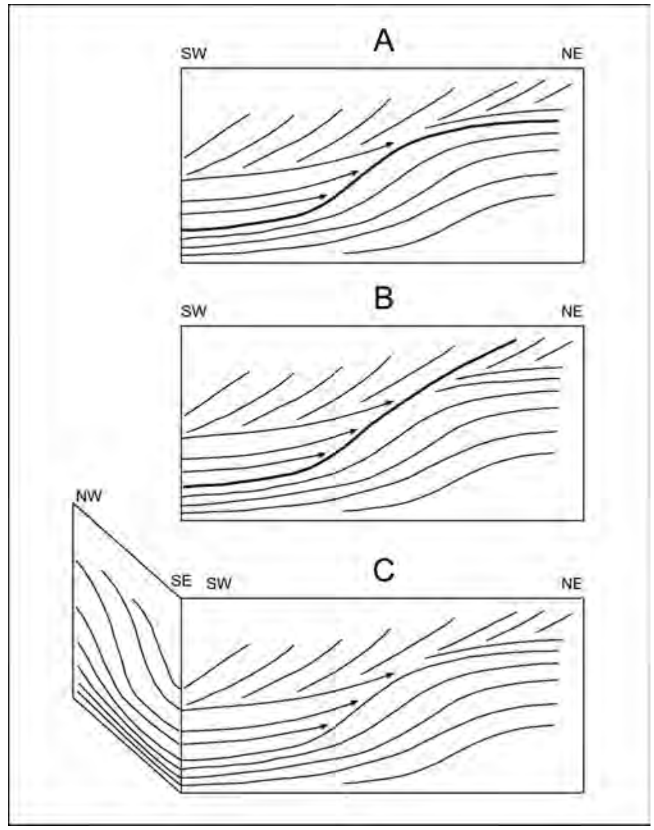
The presence of regional unconformities within this Upper Miocene-Pliocene sedimentary succession have been claimed by various authors, based on either 2D seismic profiles or borehole data. The suggested unconformities, however, have rarely been carefully correlated over significant distances, and never been structure mapped.

Kretzoi and Krolopp (1972) were first to suggest regional unconformities and hiati between biostratigraphically dated intervals in borehole profiles. They used mammals and freshwater and terrestrial molluscs for dating the Upper Miocene to Holocene interval in the central Pannonian basin, and found that the longest hiatus spanned the Miocene-Pliocene boundary, between ca. 6 Ma and 4 Ma.

Beginning with the 1980s, recognition of onlap surfaces on seismic reflection profiles led many seismic interpreters to identify unconformities (e.g. Pogácsás 1987; Pogácsás et al. 1988, 1994; Tari et al. 1992; Mattick et al. 1994; Sacchi et al. 1999). Some of these researchers applied Vail`s model (Vail et al. 1977) to the lacustrine-deltaic-fluvial basin fill, thus several third-order sequence boundaries were designated and interpreted as a result of significant lake level drops. In particular, Vakarcs and Várnai (1991), Csató (1993), Vakarcs et al. (1994), and Csató et al. (2007) observed seismic onlaps onto shelf-margin clinoforms in Eastern Hungary and interpreted this feature as evidence of a several-hundred-meter relative water-level drop and consequent basinward shift of facies. Although their interpretation on the landward continuation of the unconformity surface was not unanimous (text-fig. 2A,B), they all agreed that this was the most prominent seismic unconformity in the Pannonian basin, and proposed that the phenomenon was connected to the MSC of the Mediterranean.

In contrast, Juhász et al. (1996), who investigated a number of boreholes with full core recovery from the Hungarian part of the Pannonian basin, concluded that there was only one significant unconformity within the Upper Miocene through Pliocene succession that was obvious from sedimentological observations. This unconformity separated grey, fine-grained sediments, deposited on delta plain or flood plain environments, from the overlying variegated, coarse channel sands and flood plain marls. Subaerial exposure of the lower unit was indicated by the presence of paleosols, calcareous nodules, and abundant root casts. The authors suggested that the unconformity corresponded to the MSC (Juhász et al. 1999).

In the same volume, Sacchi et al. (1999) argued that based on their seismic stratigraphic studies, "no major paleoenvironmental impact was perceptible in the western Pannonian basin during the MSC." They conceded, however, that "a significant change in the regional stratigraphic patterns is observed since earliest Pliocene, possibly associated with the very beginning of a large-scale tectonic inversion within the intra-Carpathian area."



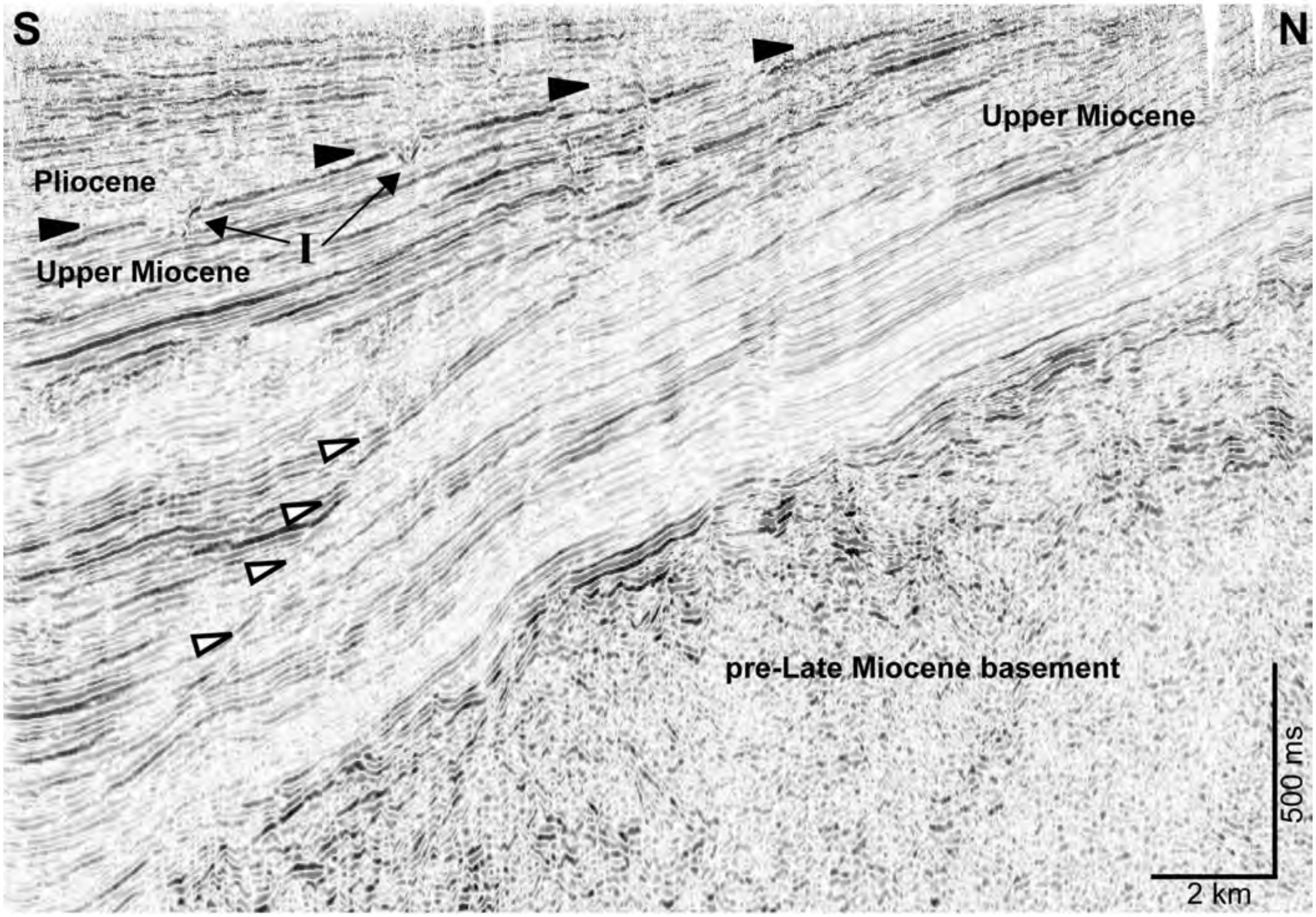
TEXT-FIGURE 2
Various interpretations of the same seismic pattern (onlaps onto shelf-margin clinoforms, indicated by arrows) in eastern Hungary. Interpretations by Vakarcs and Várnai (1991) and Csató (1993), as represented in cartoon A, and by Vakarcs et al. (1994), cartoon B, equally imply a significant base-level drop (the associated third-order sequence boundary is indicated by thicker line), whereas our interpretation (cartoon C) does not.

CORRELATION AND INTERPRETATION OF THE UNCONFORMITIES

In order to resolve all the controversy described in the previous chapter, we attempted to correlate the unconformities and some of the wells that had been identified and involved, respectively, by the above studies. For the correlation we used the extensive network of industrial seismic reflection profiles that covers the southern and eastern parts of Hungary. The results of our investigations can be summarized in three points.

1. The most conspicuous seismic unconformity, where shelf-margin clinoforms are onlapped by high-amplitude, horizontal strata, is a local sedimentary phenomenon and does not imply a basin-wide fall of water-level. Our regional seismic studies, including 3D volumes, revealed that these onlaps on the shelf-margin clinoforms were caused by strike variability of the sediment supply rather than a lake-level drop. What appear as onlapping reflections in dip-oriented sections of the shelf-margin clinoforms are in fact turbidites that arrived from strike direction, from another source (text-fig. 2C). This pattern appears in various parts of the basin where direction of progradation changed (text-fig. 3), but it is always a local phenomenon (Martinsen and Helland-Hansen 1995). Consequently, such onlaps observed on two-dimensional depositional-dip seismic sections do not evidence lake-level drops.

2. There is only one unconformity that attains regional distribution. It can be more or less continuously traced on seismic sections along the northern shelf of Lake Pannon (text-figs. 3-6), and it corresponds to the unconformity observed in fully cored wells. This surface was identified as the base of seismic facies "F" of Pogácsás (1984) and Marton (1985), it was the only "prominent unconformity" in the composite section connecting magnetostratigraphically dated master wells of Pogácsás et al. (1988), it was designated "SBIV" by Vakarcs and Várnai (1991), "SBVII(5.5Ma)" by Ujszászi and Vakarcs (1993), "SB#9(5.5Ma)" by Vakarcs et al. (1994), "non-depositional period between 5.4-4.6 Ma" by Pogácsás et al. (1994), and "Pan-4" by Sacchi et al. (1999). It also corresponds to the



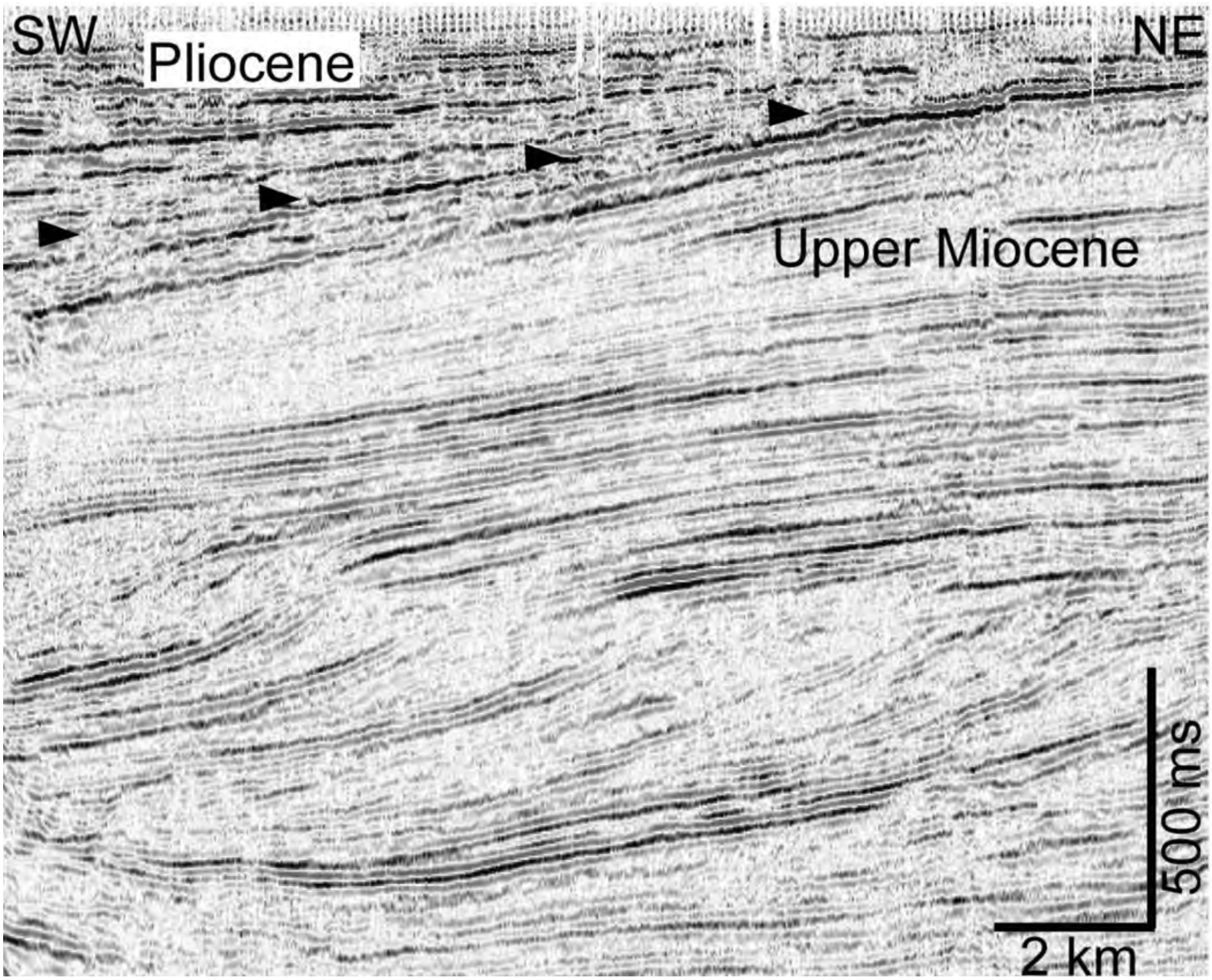
TEXT-FIGURE 3
A seismic profile across the northern shelf of Lake Pannon. White arrows: reflections onlapping onto a shelf-margin clinoform as a consequence of change in sediment supply direction; black arrows: onlapping of Pliocene layers on the tilted and locally eroded Upper Miocene; I: incisions. For location of the profile see text-figure 1.

shelfal part of the "Intra-Messinian Unconformity" of Csató et al. (2007). Although generally acknowledged, this unconformity received relatively little attention from seismic stratigraphers, because it is not associated with onlapping terminations on the shelf-margin clinoforms, therefore it could not be interpreted as a product of a large-scale basin-wide water-level drop. It was observed and described in a number of wells, however, as the most important unconformity within the Upper Miocene to Pliocene basin fill ("SB2" by Juhász et al. 1996). This unconformity always separates deltaic sediments, sometimes with obviously eroded or exposed surface, from onlapping fluvial deposits. Towards the interior of the basin, well before reaching the shelf edge, the unconformity becomes a conformable surface, impossible to distinguish from the under- and overlying seismic reflections.

3. The major unconformity described in the previous paragraph is angular in nature. Such an angular unconformity between originally flat-lying deltaic-fluvial and purely fluvial sequences must have had a tectonic origin. Indeed, the seismic reflectors of the sequence above the unconformity diverge towards the basin centre in a fan-shaped manner, indicating that the tectonic tilting of the Upper Miocene to Pliocene sequence was a longer process which may be active even today. Thus, although base-level obviously lowered in the relatively uplifted and subaerially exposed part of the shelf, this does not necessarily involve a drop in the level of Lake Pannon.

DATING OF THE MAJOR UNCONFORMITY

The means to correlate the Upper Miocene-Pliocene sedimentary succession of the closed Pannonian basin with the coeval marine deposits are rather limited. Biostratigraphic subdivision of the basin fill is based on endemic species in the lacustrine facies and on more widespread freshwater species in the fluvial facies. This basin-specific stratigraphy can be chronologically calibrated by correlations with European mammal stratigraphy, magnetostratigraphy, and radioisotopic age determinations from interbedded volcanic layers (Magyar et al. 1999b). Both age-diagnostic mammal fossils and unaltered volcanics, however, are rare within the lacustrine-fluvial sequence, and interpretation of the polarity records is often challenging due to mineral alterations and secondary magnetization (Vasiliev et al. 2006, Magyar et al. 2007, Babinszki et al. 2007). In the lack of more straightforward methods, however, we assess the age of the major unconformity described in the previous chapter by

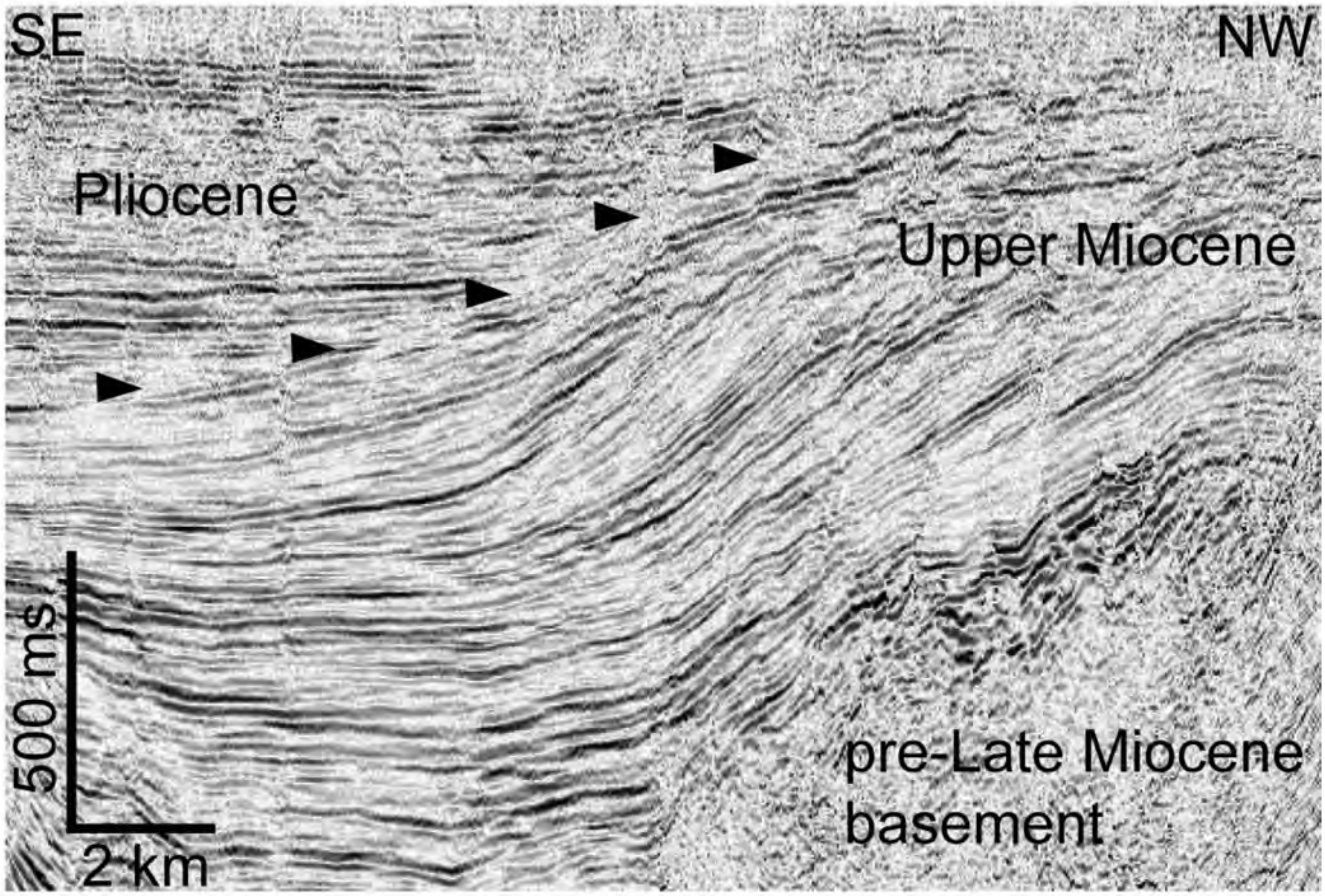


TEXT-FIGURE 4
The Miocene/Pliocene unconformity in eastern Hungary (location indicated in text-fig. 1). The unconformity, together with the underlying deltaic deposits, is tilted basinward, arguing for a tectonic origin.

reviewing the relevant biostratigraphic and magnetostratigraphic data from various boreholes.

The deltaic layers beneath the unconformity contain elements of the endemic fauna and flora of Lake Pannon. The molluscs, ostracods, and dinoflagellates of these deposits have been described from several boreholes (e.g. Széles 1977, Sütõ-Szentai 2000). In all known cases the mollusc fauna indicated the *Prosodacnomya vutskitsi* zone, which in turn correlates with the European mammal zone MN13 (Müller and Magyar 1992), that is, with the Messinian (text-fig. 7). The dinoflagellates indicated the *Galeacysta etrusca* zone, which spans the latest Tortonian through Messinian time interval (Magyar et al. 1999b).

Although the fluvial and terrestrial layers above the unconformity are notoriously poor in fossils, some boreholes and outcrops yielded molluscs and mammals that unanimously indicated their Pliocene age. The mollusc fauna from these deposits is distinctly different from both the Miocene fluvial fauna and from the Pleistocene molluscs (Krolopp 1970). It includes *Dreissena polymorpha* (Pallas 1771), sculpted *Unio* sp., *Theodoxus* cf. *semiplicatus* (Neumayr 1875), *Valvata* cf. *obtusaeformis* Lõrenthey 1905, *Viviparus dezmanianus* (Brusina 1874), *V. mazuranici* (Brusina 1902), sculpted *Bithynia* sp., *Emmericia* sp., *Lithoglyphus* sp., *Melanopsis* cf. *lanceolata* Neumayr 1875, *Melanopsis* sp., *Carychiopsis* sp., *Azeca* sp., *Gastrocopta* sp., *Triptychia* sp., *Goniodiscus* sp., *Helicigona* cf. *wenzi* Soós 1934, and *Tropidomphalus doderleini* (Brusina 1897) (Kretzoi and Krolopp 1972). This association was found above the unconformity and below the Pleistocene in a number of boreholes (e.g. Krolopp 1976, Tanács and Barabás 1981, Franyó 1979, Bartha 1962). Similarly, mammal remains of the Early Pliocene Ruscinian stage (MN14-15) were recovered from above the unconformity in several boreholes (Kretzoi 1984, Rónai 1972, Kretzoi and Krolopp 1972) and outcrops (Jaskó and Kordos 1990).



TEXT-FIGURE 5
The Miocene/Pliocene unconformity in central Hungary (location indicated in text-fig. 1). Note the significant angular aspect of the unconformity.

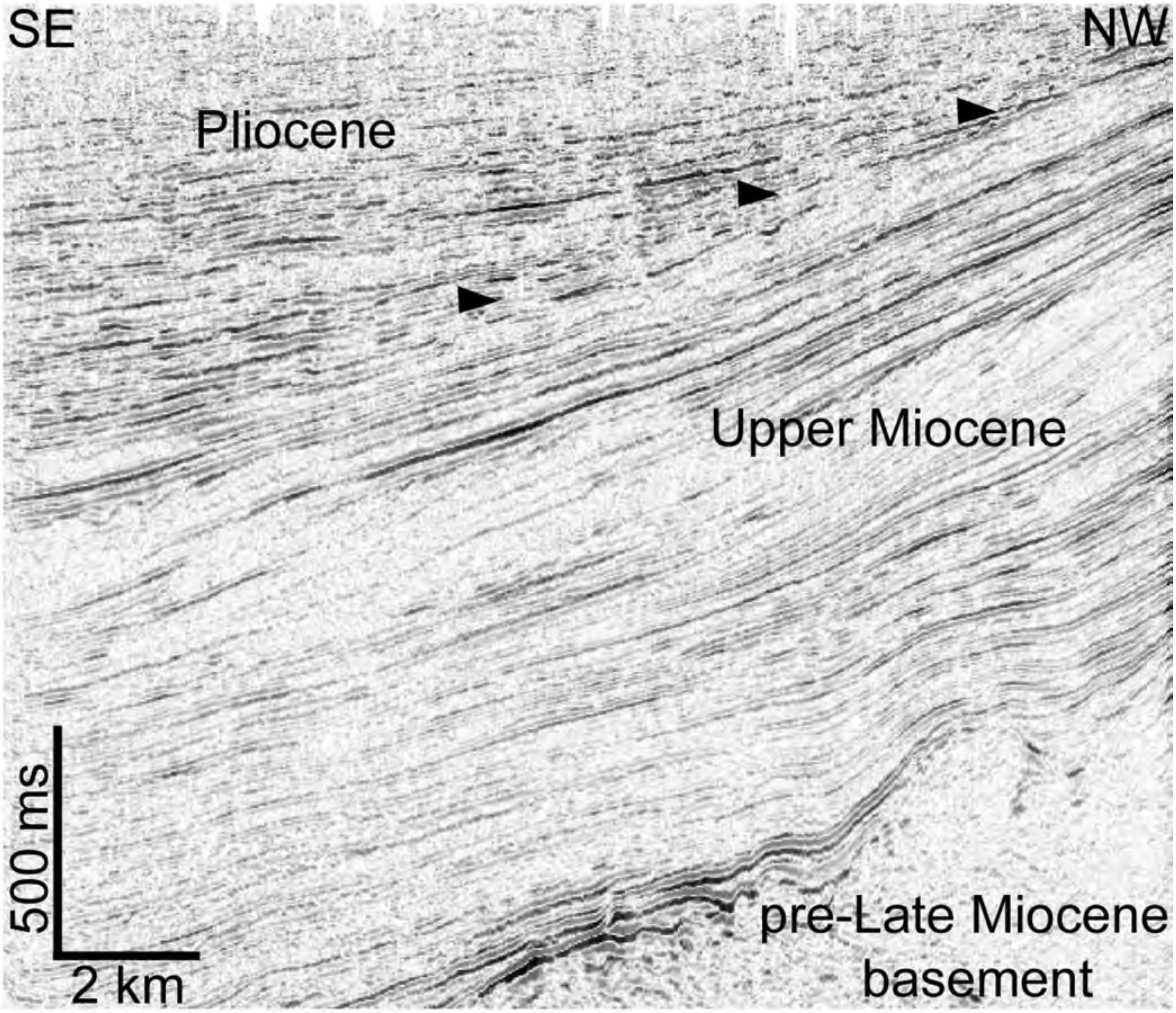
There are two magnetostratigraphic test holes that penetrated the unconformity: Tiszapalkonya-1 and Kaskantyu-2 (text-fig. 1). The magnetostratigraphic interpretation of these profiles was based on the long normal polarity interval observed in the lower part of the Lake Pannon succession and correlated with chron C5n. The youngest polarity change identified in the Tiszapalkonya well was the beginning of C3Ar (7.15 Ma), some 150 m below the unconformity surface. In the Kaskantyú well, the youngest identified event was the beginning of C3An2n (6.8 Ma), about 50 m below the unconformity (Elston et al. 1994; text-fig. 7). Unfortunately, these interpretations have little support from radiometric age determinations; the youngest reliably dated volcanics that can be correlated to these wells through seismic sections are as old as 9.6 Ma (Balogh et al. 1986; Pogácsás 1987).

The Pliocene age of the deposits overlying the unconformity was corroborated by magnetostratigraphic investigations from two other boreholes. Dévaványa-1 and Vésztõ-1 (text-fig. 1) were drilled in the deep basin where "continuous" sedimentation took place through the Late Miocene to present, thus the unconformity did not develop in this area (text-fig. 8). The polarity zones were interpreted from the Brunhes Chron back to the beginning of the Nunivak subchron of the Gilbert Chron close to the bottom of the boreholes (C3n2n, 4.6 Ma; Elston et al. 1994; text-fig. 7). The seismic horizon that corresponds to the bottom of the boreholes onlaps northward onto the unconformity surface (Pogácsás et al. 1994), indicating that the base of the Pliocene is younger than 4.6 Ma north of the onlap, and older than 4.6 Ma south of it (text-fig.8).

DISCUSSION AND CONCLUSIONS

The Upper Miocene to Pliocene sedimentary succession of the Pannonian basin contains stratigraphic unconformities of various ranks and types. A lot of minor, higher-order unconformities can be identified on seismic profiles, first of all along shelf-edge clinoforms. These are geographically restricted and delineate individual sedimentary lobes (Mattick et al. 1994, Tóth-Makk 2007). In the cross-over zones of different progradation directions, seismic onlaps on the shelf-margin clinoforms may be especially conspicuous, but misleading in depositional-dip sequence stratigraphic interpretation. This phenomenon, although repeatedly interpreted as a sequence boundary associated with the MSC (Csató 1993, Vakarcs et al. 1994, Csató et al. 2007), does not necessarily involve a change in lake level.

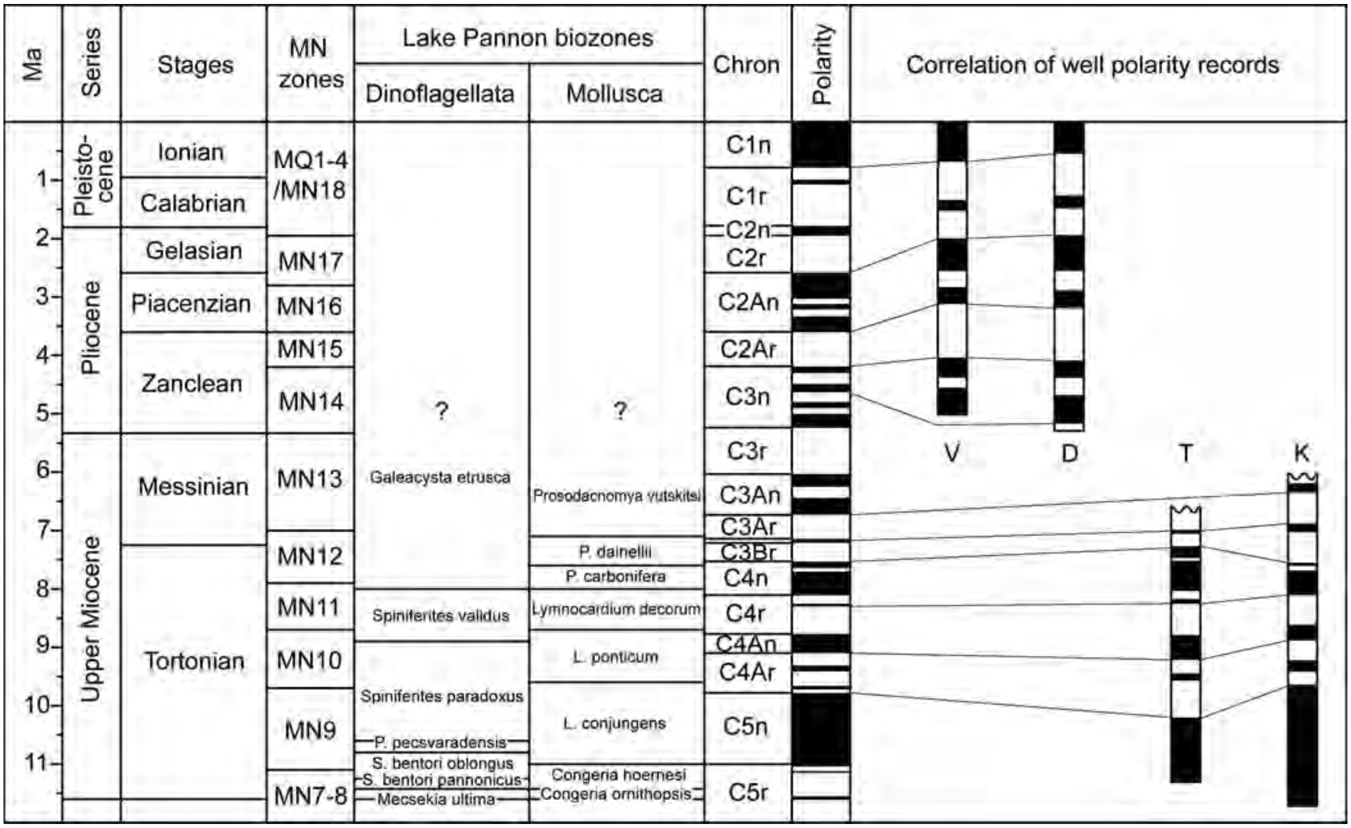
That the water level of Lake Pannon fluctuated is clearly evidenced by the cyclic architecture of the shallow lacustrine to deltaic facies (Juhász et al. 1997, Korpás-Hódi et al. 2000, Harzhauser et al. 2004). Incisions of various size into the delta plain deposits can be observed on seismic profiles at various stratigraphic levels (Juhász et al. 2006). They appear to have a



TEXT-FIGURE 6
The Miocene/Pliocene unconformity in southwestern Hungary (location indicated in text-fig. 1). For earlier interpretations of the phenomenon in this area see Ujszászi and Vakarcs (1993) and Sacchi et al. (1999).

random distribution, probably controlled by the local interplay of sediment supply, subsidence, and lake level. The most outstanding erosional feature is a deep canyon in the central Pannonian basin, the formation of which was probably triggered by intense strike-slip faulting and local tectonic uplift (Juhász et al. 2007). A systematic analysis of these erosional features may bring new arguments into the Messinian unconformity debate. It is important to note, however, that evidence of a lake-level falling below the shelf edge has not been found along the northern slope of Lake Pannon so far.

The only regionally traceable unconformity in the Pannonian basin is an angular unconformity, separating originally flat-lying upper delta plain from fluvial deposits. The unconformity can be identified along the northern perimeter of the "shelf" of Lake Pannon in Hungary. Towards the basin proper but well before reaching the shelf edge, the unconformity changes into a conformable surface. The angular nature of the unconformity argues for tectonic origin. The phenomenon cannot be causally linked to the total or partial desiccation of the Mediterranean or the Eastern Paratethys. A common tectonic trigger for the isolation of the Mediterranean and subsidence anomalies in the Paratethyan basins, however, is conceivable. The Messinian unconformity in the Mediterranean basins is often an angular discordance (e.g. Roveri et al. 2003; Lofi et al. 2005). Tectonic inversion in the Western Paratethys started at about the Miocene/Pliocene boundary (Cederbom et al. 2004). Accelerated subsidence in the Eastern Paratethyan Dacian basin began in the Pontian, i.e. Late Messinian (Vasiliev et al. 2004). The angular unconformity in the Central Paratethys indicates the onset of late-stage subsidence anomalies and basin inversion (Horváth and Cloetingh 1996; Sacchi et al. 1999; Horváth et al. 2006). This inversion was associated with ~30° CCW rotations in the southern parts of the Pannonian basin, caused by the northward



TEXT-FIGURE 7
Stratigraphic chart for the Upper Miocene to Pliocene sedimentary succession of the Pannonian basin and correlation of four well polarity records with the Global Polarity Time Scale as established by Elston et al. 1994 (the GPTS modified according to Lourens et al. 2004). The polarity records are generalized, and the thickness of individual sections is not to the same scale. Wells: V: Vésztő-1, D: Dévaványa-1, T: Tiszapalkonya-1, K: Kaskantyú-2

drift and rotation of the Adriatic microplate (Márton et al. 2002, 2006; Lesić et al. 2007). All these events might be the result of increased tectonic activity along the African/European convergence zone in the terminal Miocene (for alternate views see Meulenkamp and Sissingh 2003, Cederbom et al. 2004, Willett et al. 2006).

The age of the Pannonian Basin unconformity could be assessed by biostratigraphic and magnetostratigraphic data. The sediments below the unconformity are Messinian in age (*Prosodacnomya vutskitsi* zone, *Galeacysta etrusca* zone, MN13), the youngest polarity zone was interpreted – with much uncertainty – as 6.8 Ma. The sediments above the unconformity belong to the Pliocene, as indicated by molluscs and mammals of MN14-15. The oldest polarity zone in this sequence was interpreted, with great confidence, as 4.6 Ma. Therefore, we reiterate the point of Sacchi et al. (1999) and partly that of Csató et al. (2007) in that the regional unconformity of the Pannonian basin is a consequence of tectonic inversion that began sometime in the late Messinian or in the earliest Pliocene, and has no direct hydrological relationship with the Messinian drawdown of the Mediterranean and Eastern Paratethyan basins.

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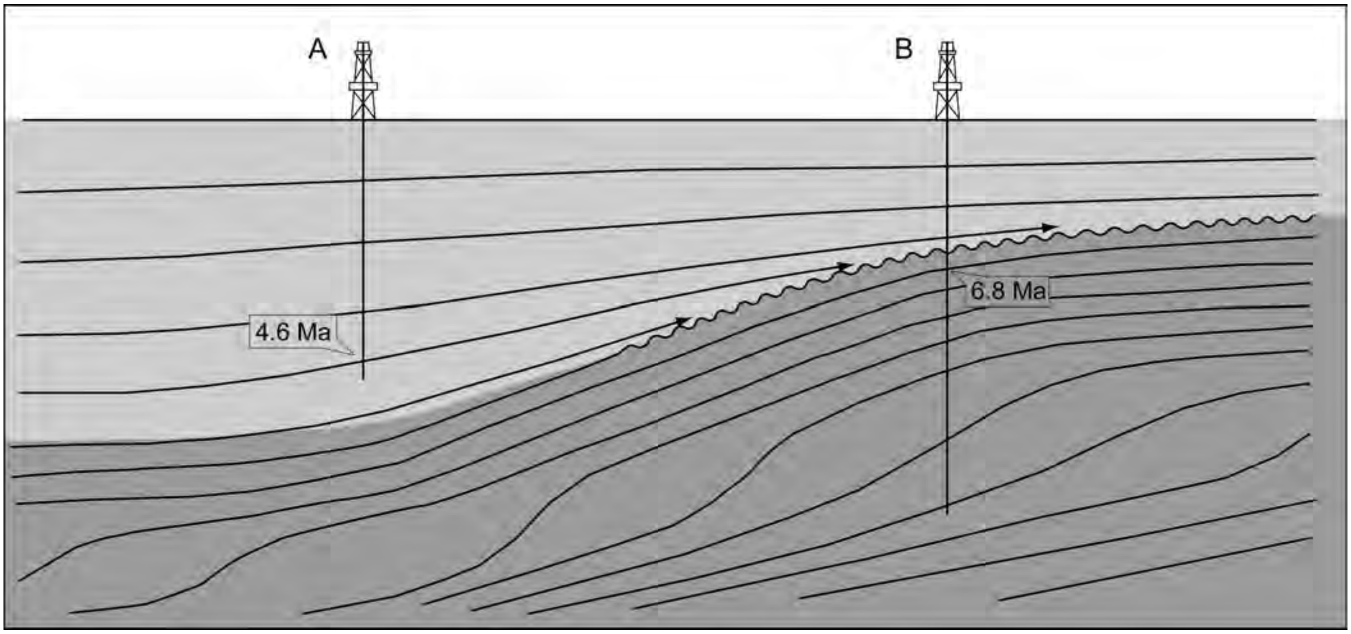

TEXT-FIGURE 8
Generalized stratigraphic position of the Miocene/Pliocene unconformity in the Pannonian basin with locations of the key magnetostratigraphic wells (A: Dévaványa-1 and Vésztő-1; B: Tiszapalkonya-1 and Kaskantyú-2). Dark grey: lacustrine and deltaic facies, pale grey: fluvial and terrestrial facies. Note that the facies boundary crosses the seismic horizons; therefore we predict that the Pliocene horizons continue further to the south (beyond the borders of Hungary) in shelf-edge clinoforms.

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