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Climatically influenced interactions between the Mediterranean and the Paratethys during the Tortonian

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[1] The Paratethys was a separate branch of the Tethys Ocean that developed as a series of inland seaways, brackish lakes, and wetlands within the interiors of central-eastern Europe and western Asia during the Oligocene-Neogene. A short-lived connection between the Mediterranean Sea and the Paratethys continental realm toward the very end of the Messinian salinity crisis is documented on the basis of the Paratethyan affinity of the brackish shallow water faunas in several Mediterranean localities. Nevertheless, there are at present only a few comparative studies on stratigraphy paleobiogeography and paleoceanography of these two contiguous Neogene provinces [e.g., *Benson*, 2000]. In this study we compare and integrate different stratigraphic data sets from middle-upper Miocene sequences of the central Mediterranean and the western Pannonian basins (central Paratethys) that are seen as parts of a complex paleoclimatic and paleoceanographic system. On the basis of this comparison we propose that the Paratethys had a long-lived influence on the large-scale oceanographic circulation of the eastern Mediterranean, at least since the Tortonian (between 9.7 and 7.5 Ma); that is, well before the onset of the Messinian *Lagomare* event (∼5.5 Ma). The integrated stratigraphy of coeval marine (Tortonian) and continental (Transdanubian) strata presented here suggests that mutual interaction and interdependence of climate subsystems ostensibly developed over the Mediterranean area and central-eastern Europe continent and were orbitally forced. Long-eccentricity insolation forcing is hypothesized to have exerted a broad control on the freshwater budget of the brackish Pannonian Basin and the consequent oceanographic setting of the Mediterranean region. *INDEX TERMS:* 4870 Oceanography: Biological and Chemical: Stable isotopes; *KEYWORDS:* Paratethys, Mediterranean, Tortonian, paleoceanography, sequence stratigraphy, stable isotopes

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1. Introduction

[2] The Paratethys was a vast epicontinental basin that extended over 3 million km^2, from the Alpine Molasse foredeep to central Asia during the Oligocene to Pliocene (Figure 1). Major relics of the ancient Tethys-Paratethys Basin system are represented by the present-day Mediterranean Sea, the Black Sea, the Caspian Sea, and the Aral Sea. Post Oligocene faunal associations of this province were characterized by increasing endemism that mirrored a progressive separation of the Paratethys epicontinental basin from the open ocean [*Cicha and Seneš*, 1968; *Steininger and Nevesskaya*, 1975; *Rögl and Steininger*, 1983; *Papp et al.*, 1985; *Stevanović et al.*, 1990; *Rögl*, 1998; *Magyar et al.*, 1999a; *Müller et al.*, 1999].

[3] The transition of the restricted marine Sarmatian (Serravallian) deposits to the Pannonian *sensu lato* (s.l.) (Tortonian-Messinian) continental strata of the central Paratethys occurred at about 12 Ma [*Kokay et al.*, 1991; *Sütő-Szentai*, 1991; *Pécskay et al.*, 1995]. By the early Tortonian, isolation of the Paratethys from the Mediterranean was complete and an extraordinarily rich, endemic, brackish/freshwater mollusk faunal association flourished in the various basins of the Paratethys realm [*Magyar et al.*, 1999a, 1999b; *Müller et al.*, 1999].

[4] A short-lived connection between the Paratethys and the Mediterranean at the end of the Messinian salinity crisis has been documented on the basis of Paratethyan affinity of the brackish, shallow water fauna (particularly ostracods and mollusks) [*Cita and Ryan*, 1973; *Hsü et al.*, 1973; *Ruggieri and Sprovieri*, 1967; *Cita et al.*, 1978; *McKenzie et al.*, 1999]. *Ruggieri* [1967] first used the term *Lagomare* to describe the depositional setting and the typical faunas of the Mediterranean during this distinct period of "Paratethyan influence". According to most authors, the onset of the *Lagomare* during the late Messinian was caused by a "capture" of Paratethys waters toward a lowstanding base level in the Mediterranean [*Hsü*, 1983]. However, the cause of the change in the drainage system and the processes involved in the capture remain elusive [e.g., *Cita*, 1991; *Tari*, 1994; *McKenzie et al.*, 1999].

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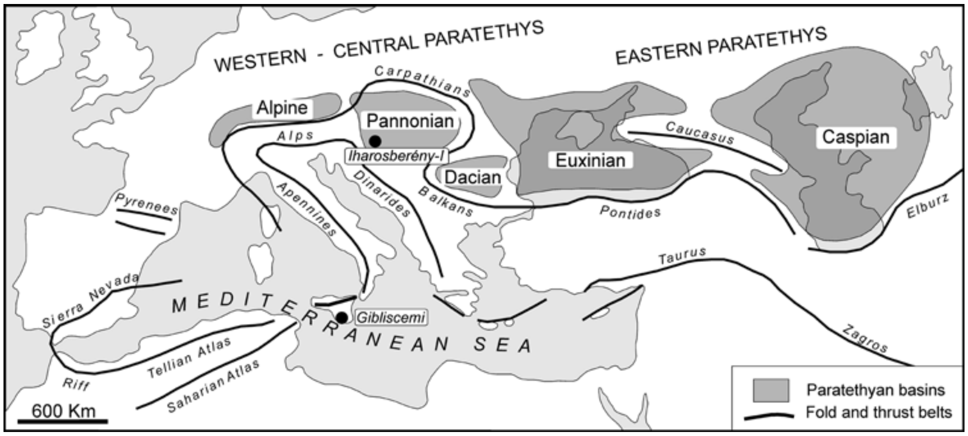

Figure 1. Location map of the studied sections and outline of the Paratethys Basin system during the late Miocene [after *Müller et al.*, 1999].

[5] In this paper, we compare and integrate different stratigraphic data sets of two selected upper Miocene sequences, namely from Sicily (central Mediterranean) and the western Pannonian basins (central Paratethys). On the basis of this comparison we propose that the Paratethys influenced oceanic circulation in the eastern Mediterranean since at least the Tortonian and we develop arguments regarding the nature of this interaction.

2. Materials and Methods

2.1. Central-Eastern Mediterranean

[6] High-resolution planktonic and benthic oxygen isotope records have been generated from the Gibliscemi sequence that crops out along the southern margin of Sicily, Italy (Figure 1). Lithostratigraphy, integrated calcareous plankton biostratigraphy, and astronomical calibration of the section (Figure 2a) are based on previous studies of *Hilgen et al.* [1995] and *Sprovieri et al.* [1999].

[7] Oxygen isotope data, obtained by the Department CFTA-University of Palermo, come from analyses of well-preserved monospecific samples of about 20–25 specimens of the planktonic foraminifer *Globigerinoides obliquus* and the benthic foraminifer *Cibicidoides pachyderma* from the $\geq$125 μm fraction. A total of 423 planktonic foraminiferal samples were analyzed with a sample spacing of 30 cm (corresponding to an average time interval of 5 kyr). Seventy-eight benthic foraminiferal samples were analyzed with an average sampling spacing of 1.5 m (corresponding to an average time periodicity of 25 kyr). Isotopic values are expressed in δ‰ units and reported with respect to the PDB-1 standard. The reproducibility of the isotopic determinations was 0.1‰. We assume the oxygen isotope values of *G. obliquus* and *C. pachyderma* to be indicative of surface and deep water isotope composition, respectively, with a constant offset from oxygen isotopic equilibrium for each species.

2.2. Central Paratethys

[8] The upper Miocene (Pannonian s.l.) succession of the Iharosberény-I well in southwest Hungary, western Pannonian Basin, has been selected as a continental reference section for the central Paratethys (Figures 1 and 3a). The Pannonian s.l. strata cored at Iharosberény-I occupy the interval between 1377 m and 24 m beneath the surface and consist of a regressive succession of continental deposits (Figures 3a and 3c), evolving from open lacustrine to delta plain settings.

[9] Iharosberény-I is one of a series of continuously cored exploratory wells in the Hungarian part of the Pannonian Basin that have been published [*Lantos et al.*, 1992; *Juhász et al.*, 1994, 1999; *Magyar et al.*, 1999a]. The study section has been correlated with the Global Polarity Timescale (GPTS) [*Hilgen et al.*, 1995; *Shackleton and Crowhrust*, 1997] by *Sacchi* [2001] on the basis of the original interpretation of *Lantos et al.* [1992] (Figure 3d).

[10] Variations of the mean grain size of sediments against depth have been used as cyclostratigraphic proxies, as they mirror changes of basic properties of sediment texture through time. The grain-size curve of Iharosberény-I well (Figure 3b) has been constructed by digitalization at a 0.2 m sampling rate (corresponding to an average time interval of 1.5 kyr) of the original analogue grain-size log compiled in the field during drilling operations by the Geological Institute of Hungary. Mean grain size of sediments was measured across the cored sequence by estimates based on visual comparison charts and calibrated by laboratory analysis [*Juhász et al.*, 1994]. The horizontal scale of the curve represents the mean grain-size of the sediment at a given depth, according to the classic Udden-Wentworth scale for clastic sediments [*Wentworth*, 1922].

[11] The general stratigraphic framework adopted for the upper Miocene succession of the central Paratethys in Hungary synthesizes the recent studies of *Gyalog* [1996], *Vakarcs* [1997], *Magyar et al.* [1999a, 1999b], *Müller et al.* [1999]; *Sacchi et al.* [1997, 1999a, 1999b], *Sacchi and Horváth* [2002]. Sequence stratigraphic interpretation of the Iharosberény-I well is based on the results of *Sacchi* [2001] (Figure 3c).

2.3. Numerical Methodologies

[12] Spectral analysis and filtering procedures were applied to both the Mediterranean and Paratethyan data sets discussed in this study. These methodologies are based on

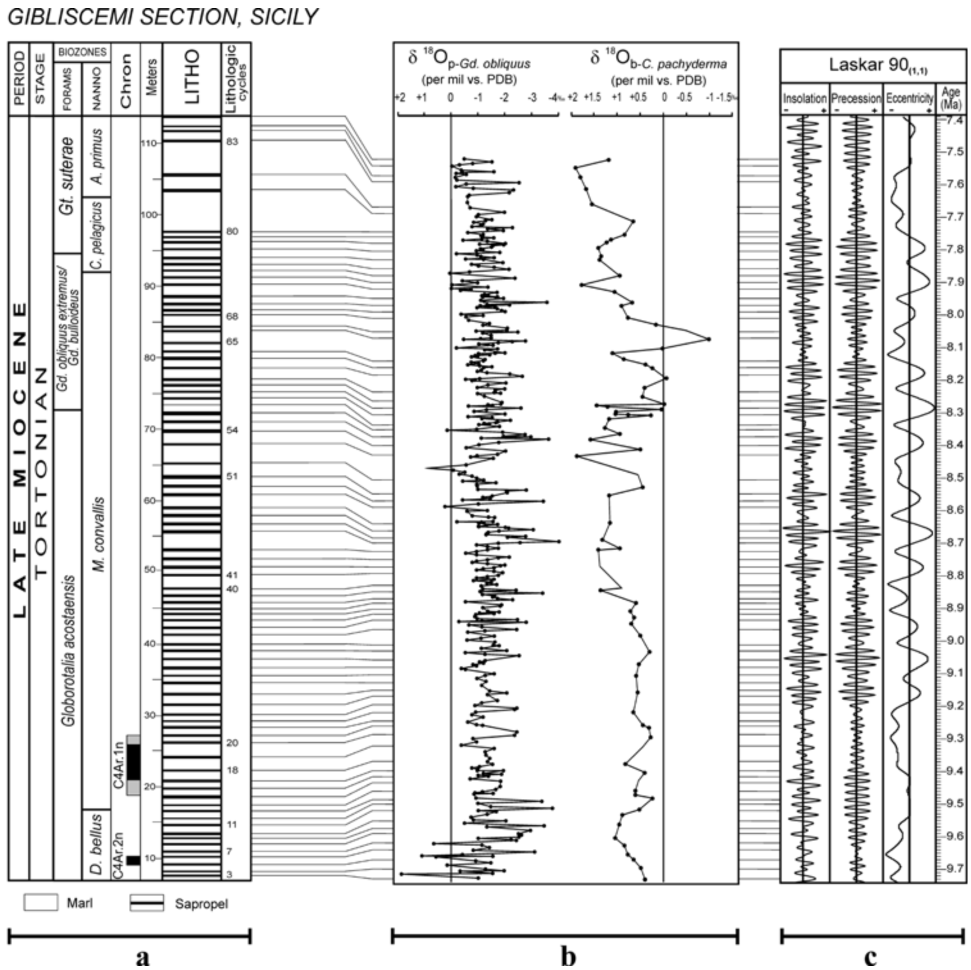

Figure 2. (a) Lithostratigraphy, integrated calcareous plankton biostratigraphy, and astronomical calibration of the Gibliscemi section are based on previous studies of *Hilgen et al.* [1995] and *Sprovieri et al.* [1999]. (b) Oxygen isotope data of planktonic ($\delta^{18}O_p$) and benthic ($\delta^{18}O_b$) foraminifera from the Gibliscemi section. (c) Correlation with the insolation, precession, and eccentricity curves based on the solution $La90_{1,1}$ of *Laskar et al.* [1993].

the standard approach of *Jenkins and Watts* [1968] that deconvolves the frequency structure of the studied signals and filters the original time series in selected representative periodicity bands. Time series have been interpolated using a Gaussian weighting method.

3. Oxygen Isotope Records of the Gibliscemi Section

[13] The oxygen isotope composition of the planktonic foraminifer *Gd. obliquus* ($\delta^{18}O_p$) exhibits high-frequency ~2‰ variations superimposed on longer-term ~±0.3 to 0.7‰ oscillations around an average of −1.3‰ (Figure 2b). The most negative anomalies in this record correspond to the abundant sapropelitic layers.

[14] The oxygen isotope record of the benthic foraminifer *C. ungerianus* ($\delta^{18}O_b$) (Figure 2b) is characterized by an initial positive excursion (~0.2‰) from the base of the section (~9.75 Ma) to about 9.62 Ma (~1‰) followed by a sharp return to average values of about 0.2% up to 8.85 Ma. At that level, the record abruptly shifts to an average of ~1.5‰ up to about 8.22 Ma, where a negative trend starts that culminates in a peak value of ~−0.9‰ at about 8.00 Ma. This peak is followed by a final positive excursion recorded up to the top of the section where $\delta^{18}O_b$ reaches values of ~1.5‰.

[15] We transformed the two isotope records into the time domain using the astronomically tuned Geomagnetic Polarity Timescale of *Hilgen et al.* [1995]. The $\delta^{18}O_p$ and $\delta^{18}O_b$ records were then linearly detrended and re-sampled at constant time intervals of 5 and 30 kyr, respectively, prior to spectral analysis. Power spectra (Figures 4a and 4b) show high values of variance in the $\delta^{18}O_p$ and $\delta^{18}O_b$ time series associated to the long and short orbital eccentricity components (~400 and ~100 kyr, respectively). The higher sampling resolution of the $\delta^{18}O_p$ record also allows registration of the 19–23 kyr precession period. We then used a Tukey band pass filter with a central frequency of 0.0025 cycles/kyr and a bandwidth of 0.055 cycles/kyr to extract the 400 kyr astronomical component from both records. As previously discussed by *Sprovieri et al.* [1999], highs in the $\delta^{18}O_p$ 400 kyr cycles correspond to minima in the long-

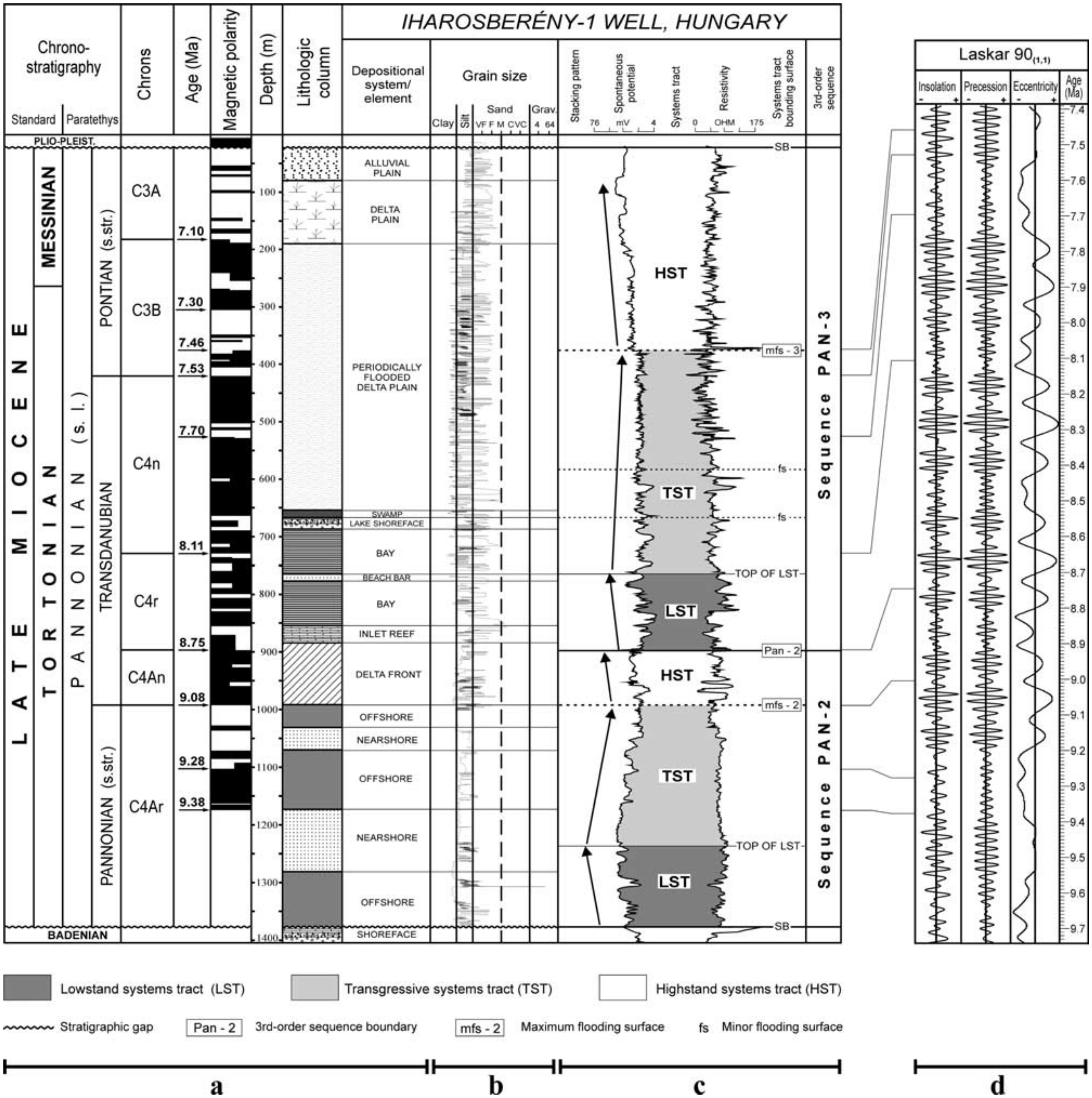

Figure 3. (a) Interpretation of the Pannonian s.l. (upper Miocene) succession cored at Iharosberény-1 well site, western Pannonian Basin, Hungary. Chronostratigraphic subdivision of Pannonian s.l. strata is after *Sacchi et al.* [1999a, 1999b] and *Sacchi* [2001]. Magnetic polarity zones have been calibrated according to *Hilgen et al.* [1995] and *Shackleton and Crowhrust* [1997]. (b) Grain-size curve recorded from the studied core. (c) Synthesis of sequence stratigraphy of the well. (d) Correlation with the insolation, precession, and eccentricity curves based on the solution $La90_{1,1}$ of *Laskar et al.* [1993].

eccentricity component of the insolation curve of *Laskar et al.* [1993], and minima in the 400 kyr $\delta^{18}O_p$ cycles to highs in the astronomical signal.

4. Sedimentary Record of Iharosberény-I Well

[16] The upper Miocene (Pannonian s.l.) succession cored at Iharosberény-I has been analyzed to evaluate lake level fluctuations for comparison with orbital climate cycles. Sediments of large lacustrine realms are sensitive indicators of changes in climate and its influences on weathering, sediment transport, and depositional settings. Notably, changes in the water budget of hydrologically closed basins cause pronounced lake level fluctuations [e.g., *Scholz et al.*, 1998]. Long-term changes of relative lake level, with non-periodic cyclicity in the order of a few to several hundred

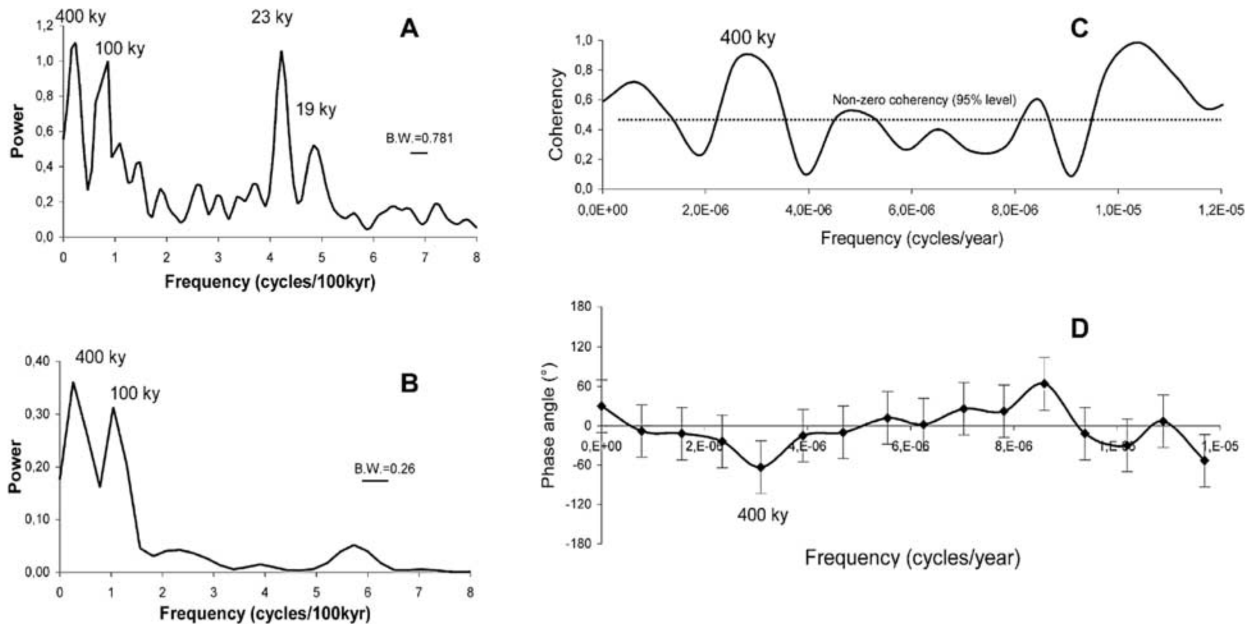

Figure 4. Spectral analysis of the (a) $\delta^{18}O_p$ and (b) $\delta^{18}O_b$ signals. Power spectra were calculated by Spageos software package [*Bonanno et al.*, 1997] using the numerical procedure reported by *Jenkins and Watts* [1968]. BW, bandwidth. Spectral densities are plotted on linear scale. (c) Coherence analysis and (d) phase lag results obtained between the $\delta^{18}O_p$ and $\delta^{18}O_b$ signals. The coherency spectrum is plotted on hyperbolic arctangent scale. The dashed horizontal line indicates confidence at the 95% level.

thousand years have been documented for the middle-late Miocene history of Pannonian lake [*Vakarcs et al.*, 1994; *Juhász et al.*, 1997; *Sacchi et al.*, 1999a]. These fluctuations, on the order of a few tens up to several tens of meters, have been interpreted in terms of interplay among sediment supply, local tectonics, and water budgets within the basin and/or interference of these factors with third-order (10^6 years duration) eustatic cycles [*Csató*, 1993; *Tari*, 1994; *Vakarcs*, 1997; *Juhász et al.*, 1999; *Sacchi*, 2001].

[17] Stratigraphic evidence for Pannonian lake fluctuations with cyclicity in the Milankovitch frequency bands has been documented by *Juhász et al.* [1997, 1999] and *Sacchi and Müller* [2003]. Particularly, thickness changes of sand and coal layers seem to be controlled by precession and short eccentricity, while variations in grain-size reflect precession and long-eccentricity forcing. Here we focus on the grain-size record of Iharosberény-I well as a proxy of lake level (i.e., water budget) oscillations.

[18] The grain-size curve of the Iharosberény-I well is characterized by high-frequency oscillations, mostly between 3,9 μ (very fine silt) and 500 μ (medium sand) (Figure 3b). Gravel (up to 4 cm) only occurs in one distinct turbidite layer (1304 m) interbedded within open lacustrine strata in the lower part of the section. A significant clay fraction occurs in the upper part of the section between 900 and 24 m (beach-foreshore and delta plain settings).

[19] Frequency analysis of the grain-size signal of the Iharosberény-I well has been performed after its transformation into a time-dependent record using the chron boundary ages of *Hilgen et al.* [1995] and *Shackleton and Crowhrust* [1997]. The power spectrum (Figure 5a) shows two main frequency peaks (at 0.0025 and 0.01 cycles/kyr) corresponding to the classic Milankovitch periodicity bands of long- and short-eccentricity, respectively. Filtering of the original signal at a central frequency of 0.0025 cycles/kyr with a bandwidth of 0.055 cycles/kyr shows the periodicity cycles of 400 kyr throughout the record (Figure 6e).

[20] Cross spectral analyses performed between the 65°N summer insolation curve (La $90_{1,1}$) of *Laskar et al.* [1993] [cf. *Lourens et al.*, 1996] and the grain-size record of the Iharosberény-I well, shows high values of coherence (Figure 5b) at the periodicity of about 400 kyr and 100 kyr with calculated phase lags (Figure 5c) showing a phased response of the sedimentary record to the astronomical forcing at those frequency bands. Thus, in the periodicity band of 400 kyr and 100 kyr, coarser sediments correspond to highs in the insolation forcing, and finer sediments to lows.

[21] Most facies models of lacustrine environments suggest that low lake levels are a response of arid climates which causes coarse beadload at nearshore area, while high lake levels during humid climates lead to less abundant and finer sediments because of the reduction of stream gradients and bedrock stabilization by vegetation [*Swann*, 1964; *Picard and High*, 1972; *McGowen et al.*, 1979; *Galloway and Hobday*, 1983; *Allen and Collison*, 1986; *Talbot and Kelts*, 1989; *Dam and Surlyk*, 1992; *Surlyk et al.*, 1993]. Accordingly, we interpret that the coarse sediment abundance maxima within Pannonian Lake sediments (corresponding to maxima in the in the eccentricity curve)

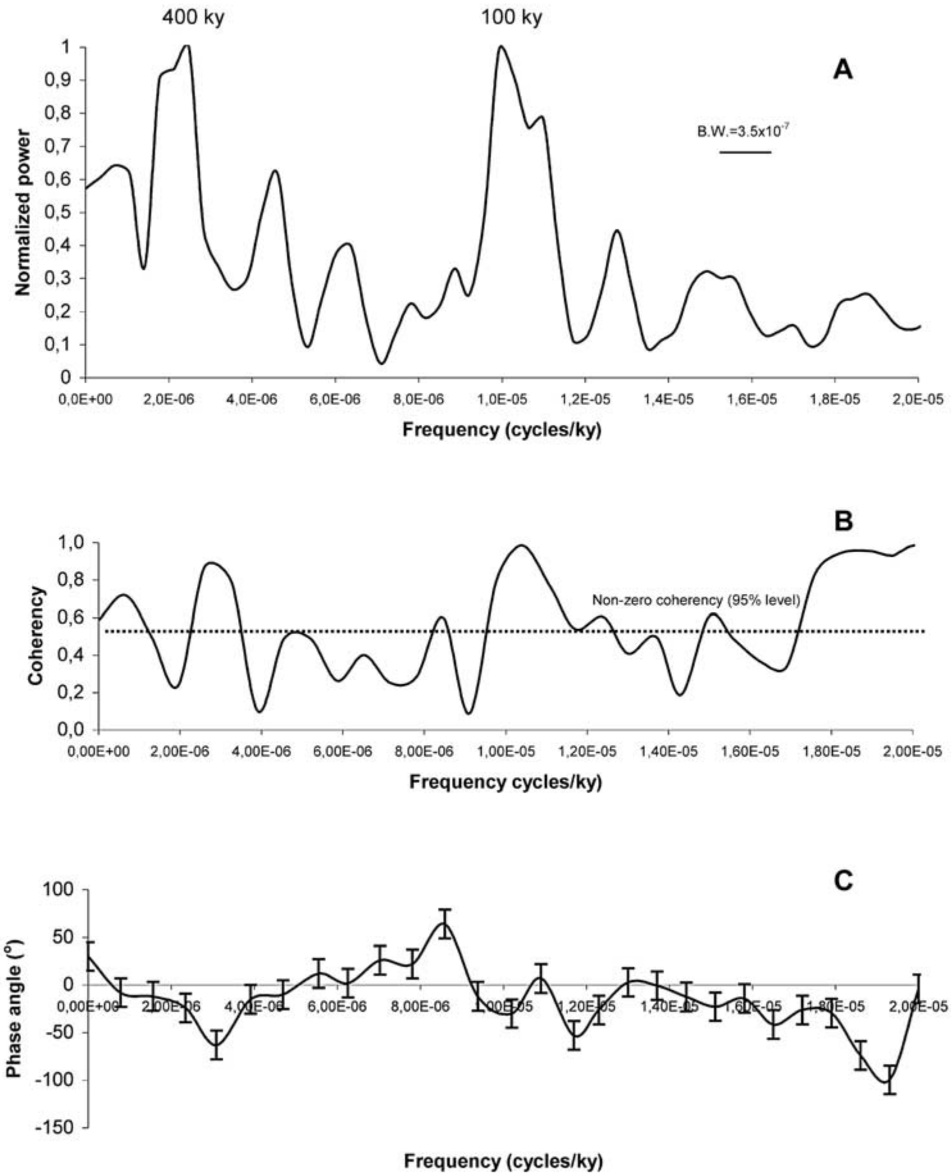

Figure 5. (a) Power spectrum of the grain-size record of the Iharosberény-I well. Power spectra were calculated by Spageos software package [*Bonanno et al.*, 1997] using the numerical procedure reported by *Jenkins and Watts* [1968]. BW, bandwidth. Spectral densities are normalized and plotted on linear scale. (b) Coherence analysis and (d) phase lag results obtained between the grain-size record of the Iharosberény-I well and the insolation curve $La90_{1,1}$. The coherency spectrum is plotted on hyperbolic arctangent scale. The dashed horizontal line indicates confidence at the 95% level.

resulted from low lake level stands during relatively arid conditions.

5. Correlation Between the Gibliscemi Section, Sicily, and the Iharosberény-I Well, Hungary

[22] Comparison between the filtered $\delta^{18}O_p$ and $\delta^{18}O_b$ signals (Figures 6a and 6b) shows a distinct anti-phase response (Figures 4c, 6a, and 6b), with the $\delta^{18}O_p$ 400 kyr cycle minima generally coinciding with relative highs in the $\delta^{18}O_b$ filtered curve (intervals labeled with uppercase letters A to F). Moreover, the astronomical tuning of the Iharosberény-I well to the insolation curve allows us to correlate the A to *F* eccentricity maxima with intervals characterized by long-eccentricity maxima in the grain-size curve (Figure 6e).

[23] The observed generally opposite trends between the 400-kyr filtered signal in $\delta^{18}O_p$ and $\delta^{18}O_b$ suggest a fundamental decoupling of the surface and deep water $\delta^{18}O$ signatures in the Mediterranean. It argues in favor of a hydrographic regime that differs considerably from the present. Today, substantial local deep water formation in

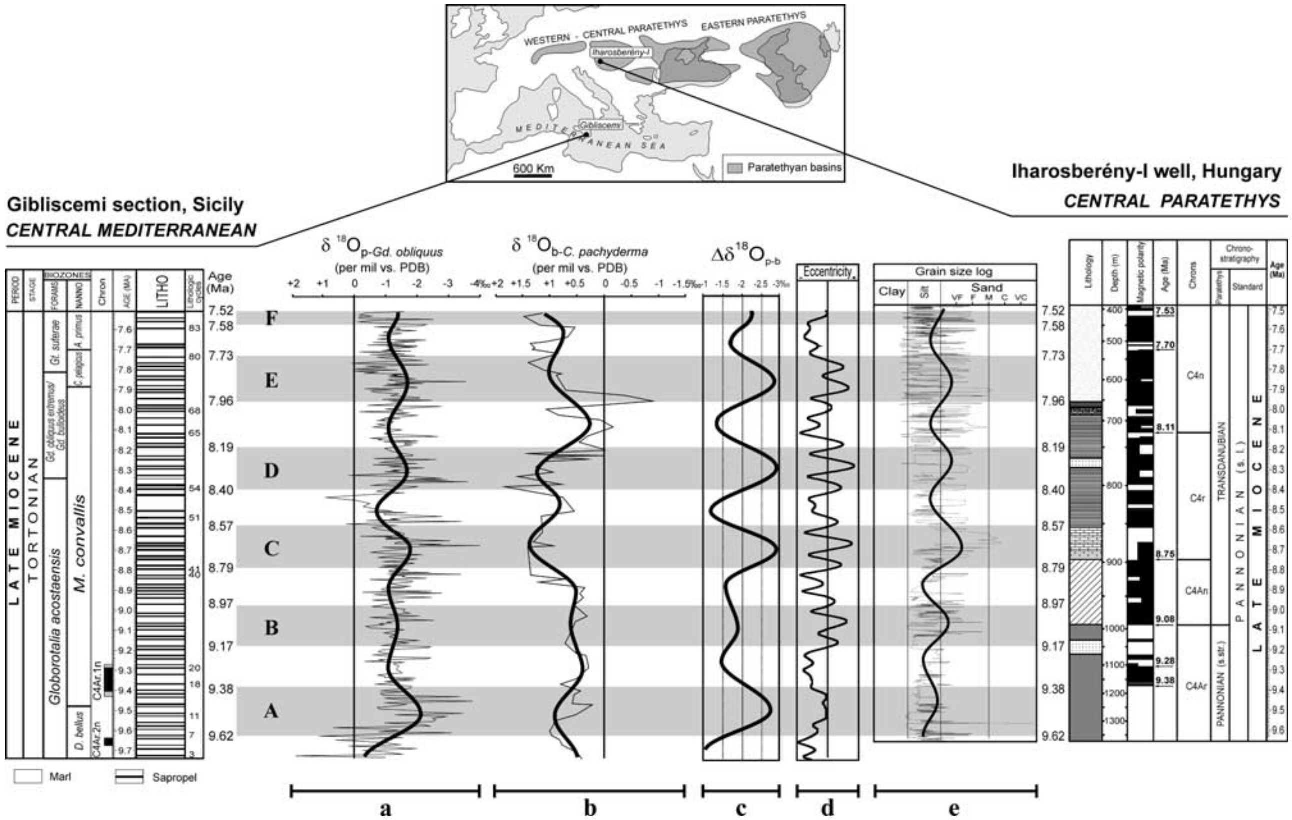

Figure 6. Original (thin lines) and filtered (thick lines) (a) planktonic and (b) benthic oxygen isotope curves and related (c) oxygen isotope gradient from the Gibliscemi section compared to the (e) estimated Pannonian lake base level oscillations at the Iharosberény-I well (Hungary, central Paratethys) for the Tortonian. Uppercase letters (A–F) show the correlations between the two studied sedimentary records. (d) Insolation, precession, and eccentricity curves based on the solution $La90_{1,1}$ of *Laskar et al.* [1993]. Symbols for lithologies of the Gibliscemi section and the Iharosberény-I well as in Figures 2 and 3, respectively.

the Mediterranean is conducive of rapid signal (e.g., $\delta^{18}O$ change) transfer from surface to subsurface waters [e.g., *Wüst*, 1961; *Ozsoy*, 1981; *Ovchinnikov and Plakhin*, 1984; *POEM group*, 1992; *Pierre*, 1999; *Rohling*, 1999]. On the long timescales considered here, which exceed deep and intermediate water advection and mixing times, such signals transferred from surface to subsurface waters would be transmitted throughout the basin's subsurface waters [cf. *Rohling*, 1999]. Hence the observed type of decoupling long-term changes in quasi-conservative properties is a strong indication of sustained changes in the mechanisms of deep ventilation.

[24] The record of oxygen isotope gradients between surface and deep waters ($\Delta\delta^{18}O_{p-b}$), determined by subtraction of the filtered records (Figure 6c), shows minima at times of highs in the 400 kyr eccentricity cycles and highs at times of minima in the 400 kyr cycles. We propose that, during the warmer eccentricity semicycle, increases in central Mediterranean sea surface temperatures (negative shift in $\delta^{18}O_p$) coincided with decreases in continental runoff into sites of deep water formation, causing heavier $\delta^{18}O$ values of intermediate/deep waters (hence $\delta^{18}O_b$), and vice versa. Here, we consider a freshwater forcing on the $\delta^{18}O_b$ record because of the coincidence of long-term periods of light $\delta^{18}O_b$ with long-term lows in the grain-size curve at the Iharosberény-I well, interpreted as tracers of relative highs in the Pannonian lake level record (Figure 6e).

[25] An alternative explanation would be that the long-term benthic $\delta^{18}O_b$ variations reflect temperature changes that are completely out of phase with surface temperature changes of similar magnitude ($\delta^{18}O_p$). Following a fractionation effect of 0.2–0.3‰ $°C^{-1}$ [*O'Neil et al.*, 1969; *Kim and O'Neil*, 1997], the long-term variability in both records reflects temperature changes up to $\sim$3°C. Assuming that the planktonic record likely reflects summer temperatures and the benthic record records the temperatures in the overturning season (winter), this alternative explanation would imply variations in seasonal temperature contrast of up to 6°C around the mean, which seems unrealistic for a period lacking large-scale glaciation cycles in the Northern Hemisphere.

[26] Although further investigation, spanning longer time intervals, is needed to assess the long-term synchroneity between changes in the Paratethys and the Mediterranean inferred for a period of 2 million years in the present paper, our observations suggest an interdependence between the two environments during the middle Tortonian, well before

the Messinian *Lagomare* episode. What mechanisms could underlie this interdependence?

6. A Climatic Teleconnection Between the Mediterranean and the Paratethys During the Tortonian?

[27] Here, we present a hypothesis to explain the apparent synchroneity between the Mediterranean and Paratethys isotopic and sedimentary records in terms of a common climatic origin. General atmospheric circulation models suggest that the basic climate zonation in the Northern Hemisphere had been established before the late Miocene, with an intensified Indian monsoonal system and stabilization of the Antarctic ice cap [e.g., *Ruddiman and Kutzbach*, 1989; *Ruddiman et al.*, 1989]. This would imply that the planetary wave configuration in the atmospheric circulation over the European/Mediterranean area was roughly comparable to the interglacial state of today, with the westerly wind belt carrying Atlantic-sourced moisture that causes precipitation over most of Europe, including its eastern sector (the geographic area corresponding to the Miocene Pannonian Basin) [e.g., *Rozanski et al.*, 1993].

[28] The recorded 400 kyr $\delta^{18}O_p$ minima were found to correlate to long-eccentricity (insolation) maxima. As argued above, the amplitude of the long-term variability in $\delta^{18}O_p$ reflects sea-surface temperature changes of $\sim$2–3°C. Today, there is a 4–6°C N-S gradient in annual mean temperatures over the Mediterranean Basin. Since the modern Mediterranean spans $\sim$10° of latitude, sustained 2–3°C long-term positive SST shifts witnessed in $\delta^{18}O_p$ could be viewed as the result of northward shifts of $\sim$5° of the main zonal climate structure over the basin. If during the warm phases of the cycle the subtropical climate belt extended $\sim$5° further north than today, then a similar shift might possibly be inferred for the axis of the westerlies to the north of this system. The inferred magnitude of these shifts on 400 kyr timescales is comparable to modern seasonal variability. In view of their long-term sustained nature, such shifts would cause decreased precipitation over the Pannonian lake, because of a northward shift of the main moisture supply away from the Anatolian and Caucasus highlands, where orographic effects today cause extreme runoff. By eliminating/reducing this runoff, more moisture would have been allowed to escape the Pannonian catchment by continued eastward transport deeper into Asia. Reduced precipitation into the Pannonian catchment would cause reduction in the Paratethys overspill into the Mediterranean. Although tentative, and subject to future validation, we suggest that such a climate shift may represent a primary mechanism responsible for coupled changes between the Mediterranean and Paratethys realms, indirectly forcing the observed $\delta^{18}O$ variability between surface and deep waters in the Mediterranean.

[29] Although the proposed working hypothesis is based only on first-order correlation between a limited set of sedimentary sequences and a preliminary synthesis of climate-ocean interaction, it opens an intriguing new avenue for research into the final evolution of the Tethyan region during the late Miocene. Recent paleogeographic reconstructions [e.g., *Rögl*, 1998] suggest the possible occurrence of a seaway, located near the present Black Sea that connected the Mediterranean Basin and the Paratethys during the late Miocene. Future research on a wide geographic network of high-quality sedimentary sequences is needed to test our working hypothesis that climatic developments over the Paratethys area exerted a direct and primary influence on Mediterranean hydrography, and that this influence started long before the late Messinian *Lagomare* episode.

7. Conclusions

[30] We present a high-resolution correlation of isotope data from a Tortonian sedimentary sequence of the central Mediterranean and sequence stratigraphic and magnetostratigraphic data from coeval strata in the western Pannonian Basin, Hungary. On the basis of this correlation we infer that the continental area of the Parathetys exerted a long-term influence on the oceanographic conditions in the eastern Mediterranean at least since the Tortonian, well before the onset of the *Lagomare* event.

[31] A climatically influenced interaction is proposed to have induced important changes in the Paratethys continental area and in the Mediterranean Basin. Northward shifting of the westerly belt could have periodically reduced the moisture supply to the Paratethys region and consequently reduced spillover into the Mediterranean Basin. Associated northward shifting of the subtropical climatic belt would have caused the concomitant rises of Mediterranean sea surface temperature inferred from the surface/planktonic $\delta^{18}O$ record. Thus it is proposed that climatically induced changes in the continental water budgets of the Paratethys realm represented the primary mechanism for modification of large-scale oceanographic features of the Mediterranean.

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