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SHORT NOTE

MEDITERRANEAN AND PARATETHYS. FACTS AND HYPOTHESES OF AN OLIGOCENE TO MIOCENE PALEOGEOGRAPHY (SHORT OVERVIEW)

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Abstract: Paleogeographical considerations on the development of the Paratethys and the Mediterranean during Oligocene and Miocene are presented in twelve time-slices. Plate tectonic activities and the collision of India with Asia caused the destruction of the Western Tethys Ocean in the Late Eocene. The Mediterranean and the intracontinental Paratethys basins came into existence as new marine realms. In the Mediterranean Basin open oceanic connections existed throughout the Oligocene and most of the Miocene. The Eastern Paratethys and the Central to Western Paratethys showed different marine conditions and changing connections most of the time. A first period with reduced salinity, anoxic bottom conditions, and strong endemisms occurred throughout the Paratethys in a short period of the Lower Oligocene (Solenovian, NP 23). It was followed by more open marine conditions with wide-spread clastic sedimentation (Upper Kiscellian, Kalmykian, NP 24). By the collision of Africa and Arabia with Eurasia, the seaway between the Mediterranean Sea and the Indian Ocean was closed in Burdigalian time, but a new landbridge enabled a distinct mammal migration between the continents (*Gomphotherium* Landbridge). During the Middle Miocene marine seaways between the Indian Ocean, the Mediterranean, and the Paratethys opened and closed intermittently. Finally, the marine connections of the Paratethys were strongly reduced, and gave way to the endemic faunal development during the later Miocene (Sarmatian to Pontian).

Key words: Oligocene, Miocene, Paratethys, Mediterranean, paleogeography.

Introduction

The past few years have seen a flood of new information on the paleogeography, paleobiogeography, and tectonic development of the circum-Mediterranean region during the later Cenozoic. This short overview is a result of some current publications (e.g. Rögl 1998) on the subject of continental and marine migrations and emphasizes the development of the Paratethys. The paleogeographical reconstructions must be regarded as only sketches that can help to explain migration possibilities; many parts raise more questions than they answer. The continent positions are based on the plate tectonic reconstructions of Scotese et al. (1988). Important information has been revealed by the recent paleogeographical studies of Hamor & Halmai (1988), Kováč et al. (1989), Boccaletti et al. (1990), Popov et al. (1993), Jones & Racey (1994), Goff et al. (1995), Jones & Simmons (1996), and Studencka et al. (1998). The most problematic period is the middle Miocene, with its rapidly changing paleobiogeographical conditions and strong tectonic activity. Only intensive investigations in the problematic tectonic regions from the south-eastern end of the Carpathians, along the Balkanides to Northern Anatolia can solve some of the questions. Another problem is the different opinion in the correlation of stages between Central and Eastern Paratethys. The recent correlations are based on nannoplankton and planktonic foraminifers in comparison with the chronostratigraphic table of Berggren et al. (1995).

A vanishing Tethys Ocean in the late Eocene

Continents in motion, the dispersal of the Pangean continent, and the northward drift of India and Australia ended the period of the Mesozoic Tethys Ocean. These changes in the configuration of land and sea altered the pattern of oceanic circulations, the climate, and the faunal exchanges on the continents and in the sea. By the end of the Eocene the Tethys Ocean had nearly vanished. A new Indian Ocean was born, and the western end of the Tethys was reduced to a Mediterranean Sea (Fig. 1). Europe was still an archipelago. Intercontinental seas covered large areas of the European platform and of western Asia. A mammal exchange between Asia and Europe was not possible. Between the stable Eurasian platform and the relics of the western Tethys, elongated deep basins had formed. North of India a marine connection stretched to the West Pacific. An important connection of the Tethys with the Polar Sea existed via the Turgai Strait, on the far side of the Ural Mts. These seaways around Asia and the connections with the Polar Sea enabled warm-water exchanges and probably explain the sustained warm climate during the Late Eocene.

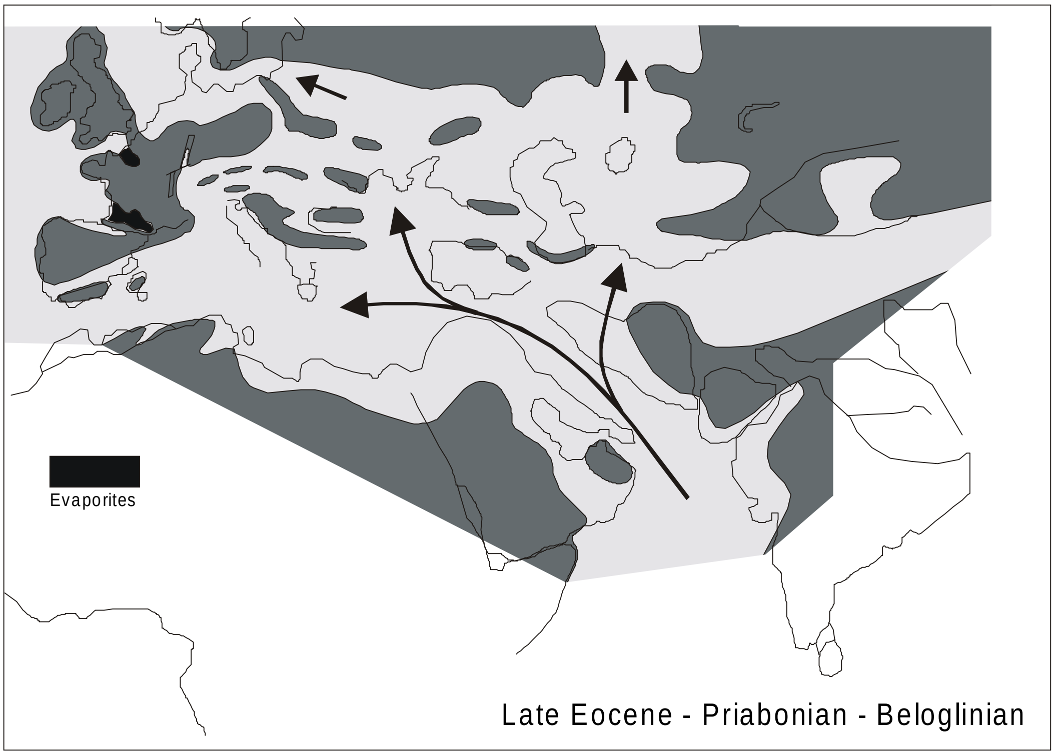

Fig. 1. By the northward movement of India the Tethys Ocean vanished. The western end of the relic Tethys connected the Indo-Pacific and the Atlantic Ocean. Northward the Turgai Strait opened to the Polar Sea, and hindered an intracontinental mammal migration. Europe was still an archipelago in the Eocene.

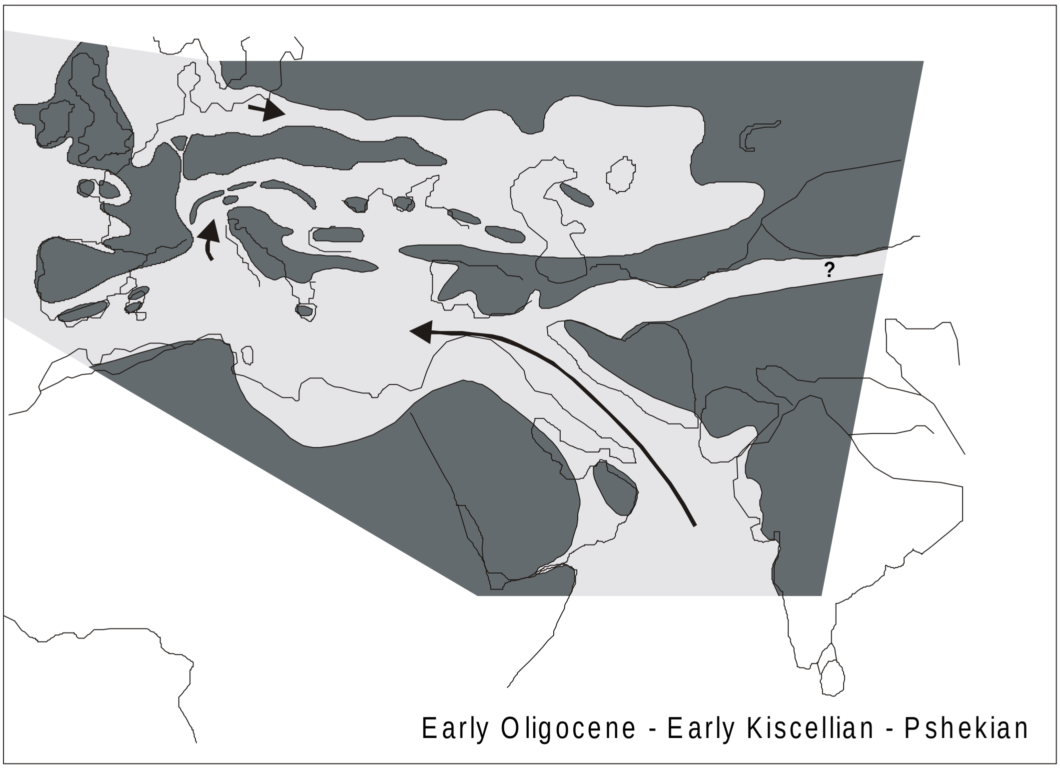

Fig. 2. The birth of the Paratethys Sea. Tectonic activities along the Alpine front and the collision of India with Asia created the intercontinental Paratethys Sea, and south of the orogene the Mediterranean Sea. Continentalization increased, the Turgai Strait closed and the new oceanic circulation supplied water from the North Sea to the Paratethys.

Birth of the Paratethys Sea

In contrast to Laskarev's (1924) definition of a Neogene Paratethys, the investigations of the Oligocene sequences have demonstrated that the formation of an isolated Paratethys Sea had started around the Eocene-Oligocene boundary (Baldi 1980; Rusu 1988). Strong tectonic activities changed the Eurasian configuration (Fig. 2). The Tethys finally vanished by the collision of the Indian continent with Asia. Continentalization of Europe increased, the Turgai Strait became dry land, and the Bering Bridge opened and enabled a mammal migration from North America to Asia and further to Europe. The Paratethys Sea was separated from the Mediterranean. Elongated deep troughs stretched from the Western Alps to the Transcaspian Basin. The Danish-Polish Strait enabled Latdorfian mollusc faunas to migrate from the North Sea to the southern Ukraine and the shores of the Transcaspian Basin, within nannoplankton zone NP 21 (Popov et al. 1993). In the west a shallow seaway, the Rhine Graben opened to the north, whereas deep marine troughs stayed open in the Prealps and in the Slovenian corridor. The first isolation of the Paratethys produced dysaerobic bottom conditions documented by the sedimentation of black shales. In the upper NP 22 Zone, widespread pteropod horizons (*Spiratella/Limacina* marls) form a distinct marker level. In the Eastern Paratethys the subsidence was associated with uncompensated sedimentation of dark shales (Khadum facies), hydrogen sulfide contamination and an event of sedimentary manganese ore formation. The hydrogen sulfide contamination continued in the deep Eastern Paratethys basins throughout the Oligocene and early Miocene.

First Paratethys isolation

The closure of marine seaways culminated with the onset of nannoplankton zone NP 23 (Fig. 3). Dysaerobic bottom conditions spread in the basins. Dark laminated clays ("Meletta shales"), monospecific nannomarls (Dynow Marlstone), and diatomites with brackish to freshwater influences (Haczewski 1989; Krhovsky et al. 1991; Krhovsky 1995) occurred from the Molasse Basin throughout the Carpathians to the Caspian Basin. The strongest endemism developed with a uniform fauna of small-sized (1–2 cm) bivalves, for example *"Cardium" lipoldi, Janschinella, Korobkoviella, Urbnisia,* and *Ergenica* (Baldi 1986; Popov et al. 1993; Rusu et al. 1996). This horizon is accompanied by ostracod layers. Marine faunas existed only in the westernmost part of the Paratethys (Lindenberg 1981; Ujetz 1996).

Return to open marine conditions in the Paratethys

During the middle part of the Oligocene (NP 24) well oxygenated bottom conditions were re-established throughout the Paratethys. This corresponds with the period of sedimentation of the Kiscell Clay. Deposition of clastic sediments and turbidites increased in all Paratethys basins. The "Rupelton" was deposited in the Rhine Graben (Huber 1994), the Slovenian seaway broadened. A connection from the Indian Ocean to the Transcaucasian and Transcaspian basins is strongly debated. A possible connection is supported by recently studied sections in the Zagros Mts. with thin-bedded limestones and marls of

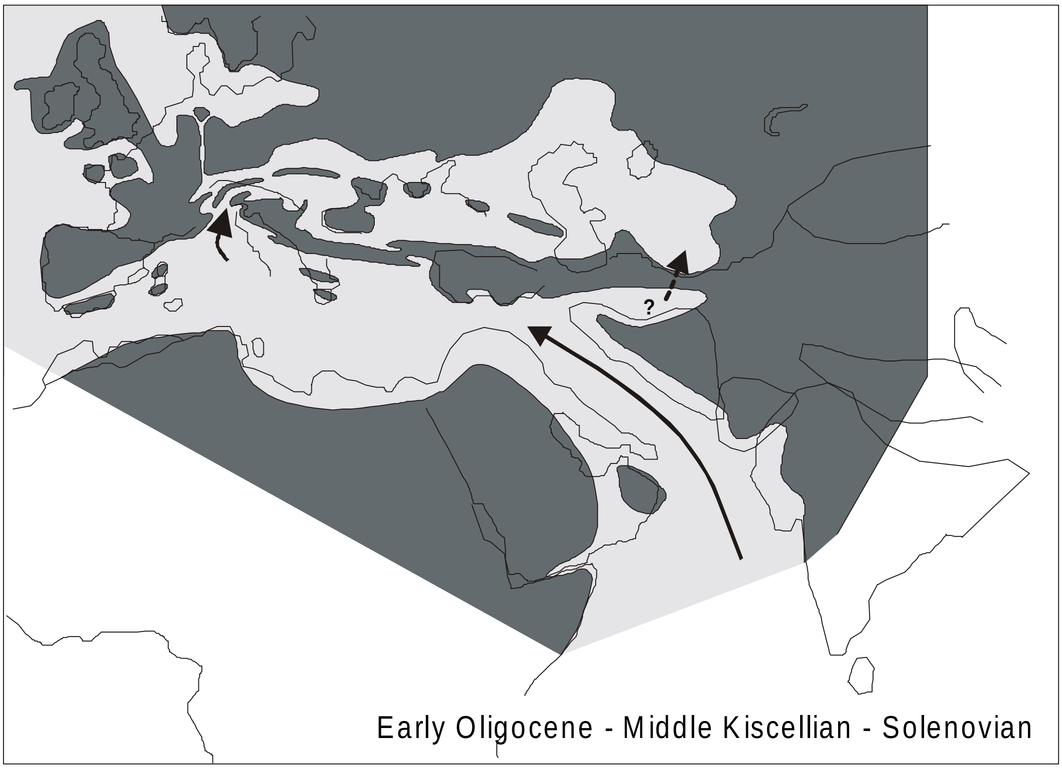

Fig. 3. A closure of open seaways caused the first isolation of the Paratethys. Dysaerobic conditions at the bottom of the basins, reduced salinity, and strong endemism are observed. The only marine connections existed in the far west with the Mediterranean and via the Rhine Graben with the North Sea.

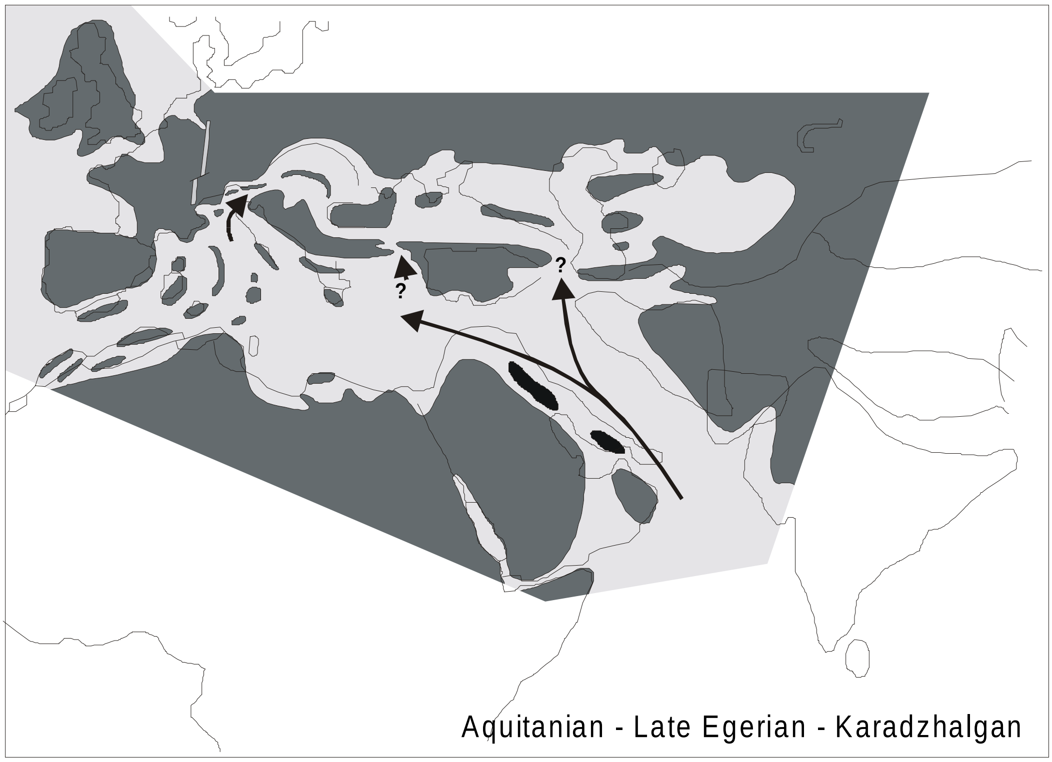

Fig. 4. During the middle part of the Oligocene the Paratethys returned to open marine conditions. The peri-Alpine seaway closed in the upper Oligocene. Around the Oligocene-Miocene boundary (Aquitanian) tropical incursions from the Indian Ocean increased. The circulation from the Indian to the Atlantic Ocean remained open. In the western Mediterranean the spreading of the Balearic Sea started.

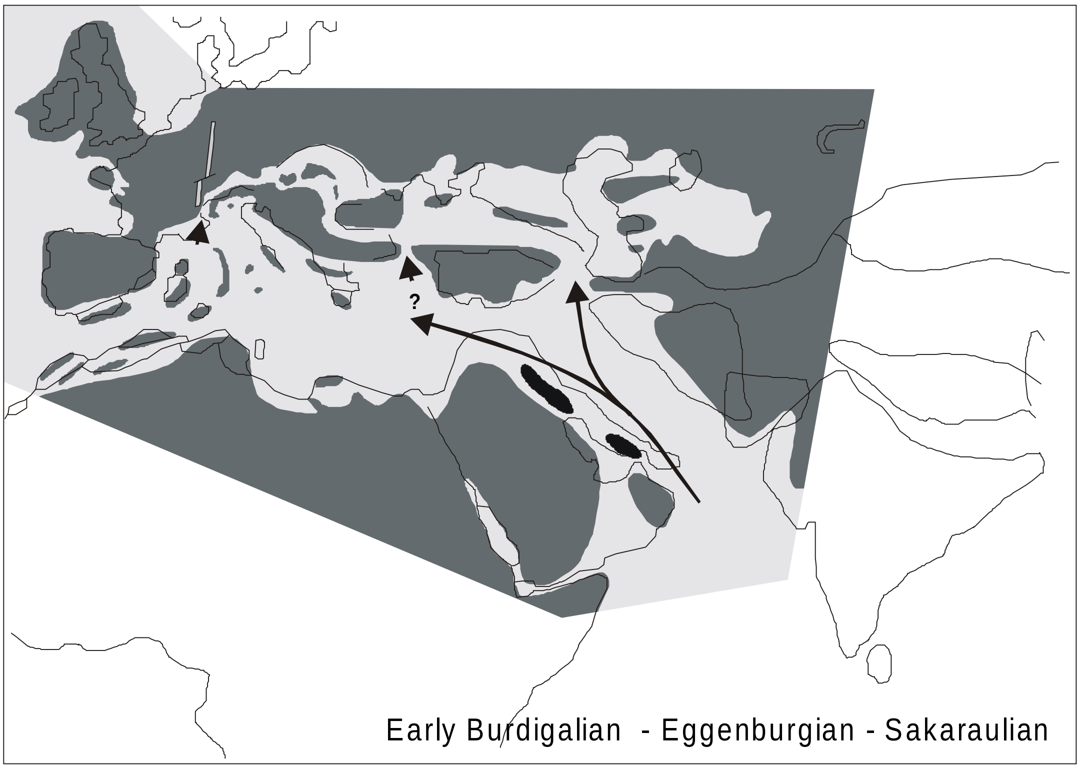

Fig. 5. In the Lower Burdigalian, the Molasse trough along the Alpine Foredeep re-opened, the Slovenian corridor between Mediterranean and Central Paratethys closed. The extent of the marine realm in the area of the later Pannonian Basin was strongly reduced. Distinct similarities of mollusc faunas between Eastern and Central Paratethys point to open circulation and Indo-Pacific influences.

NP 24 age, and specific nanno-floras similar to those of the Paratethys (pers. comm. of B. Hamršmíd, Hodonín, and provision of material by A. Hamedani, Isfahan).

In the Late Oligocene, tectonic activities also increased in the Mediterranean. In the west, the opening of the Balearic Basin started with the formation of oceanic crust. The nappes of the Apennines were thrust northeastwards and started their counterclockwise rotation (Boccaletti et al. 1990). The sea regressed from the western Alpine Foredeep to a line east of Munich–Salzburg. Limno-fluviatile sedimentation of Lower Freshwater Molasse started. Otherwise the open seaways to the Paratethys broadened (nanno-zone NP 25), and connections from the Mediterranean existed also in Thrace. These paleogeographical configurations (Fig. 4) continued in the lowermost Miocene (Aquitanian/Egerian/NN1-lower NN2). Similar mollusc faunas and assemblages of larger foraminifers (*Miogypsina, Lepidocyclina*) spread from the Qum Basin in Iran to the Mediterranean and to the Central Paratethys.

The Lower Burdigalian (upper NN 2 Zone) had extensive Indo-Pacific connections. Tropical-subtropical faunal elements continued to migrate to the Mediterranean and Paratethys. A horizon of giant pectinids and other “giant“ mollusc taxa is known from California to the Bavarian Molasse (Addicott 1974; Steininger et al. 1976; Rusu 1996). The main paleogeographical difference from the Aquitanian is the re-opening of the Mediterranean-Paratethys seaway along the Alpine Foredeep, and the closure of the seaway in Slovenia (Fig. 5). The marine area between the Dinarides and the outward moving Carpathian nappes was strongly reduced (Halásová et al. 1996).

The Gomphotherium landbridge

The counterclockwise rotation of Africa and Arabia resulted in a collision with the Anatolian plate (Fig. 6). For a first time the Mediterranean was cut off from the Indian Ocean. The Mediterranean became an embayment of the Atlantic Ocean. A newly formed landbridge connected Africa and Eurasia and enabled a remarkable mammal exchange at the base of mammal zone MN 4. The most impressive African immigrants were the Proboscidea with *Gomphotherium*.

The tectonic activities also closed off the marine realm of the Eastern Paratethys. The Kotsakhurian Sea, with strongly reduced salinity and endemic faunas, came into existence. Characteristic are the bivalve faunas with *Rzehakia, Eoprosodacna, Cerastoderma,* and *Siliqua*. In the western part of the Paratethys the Alpine trough remained open, and a shallow connection existed to the North Sea through the Rhine Graben (Martini 1990). In Slovenia the corridor to the Central Paratethys probably opened again. Strong Atlantic and boreal influences are observed in the Central Paratethys faunas. In the Carpathian Foredeep, the easternmost part in the Ukraine and Romania became an evaporitic basin (e.g. Popescu et al. 1996; Sarata Formation, NN 3).

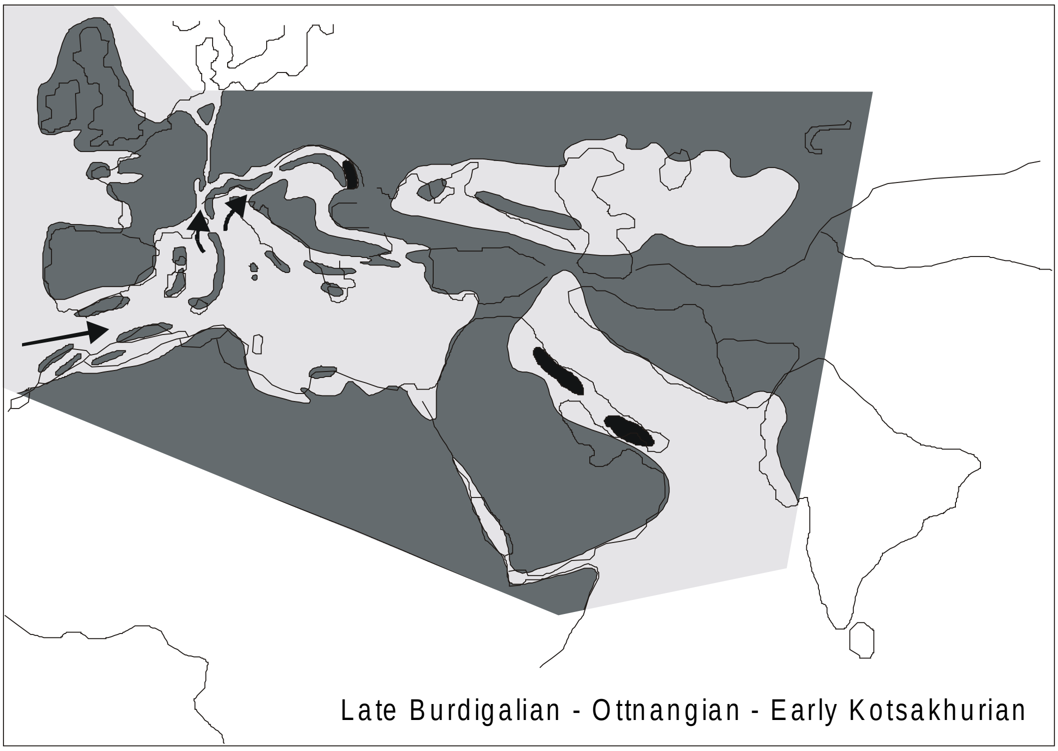

Fig. 6. The rotation of Africa and Arabia, and finally the collision with Eurasia closed the open marine Indo-Pacific connections. The *Gomphotherium* Landbridge connected the continents for a first time. In the Eastern Paratethys the isolated Kotsakhurian Sea came into existence with reduced salinity and strong endemism. The Western and Central Paratethys remained under marine conditions, connected with the Mediterranean and through the Rhine Graben with the North Sea. In the eastern Carpathian Foredeep evaporites were deposited.

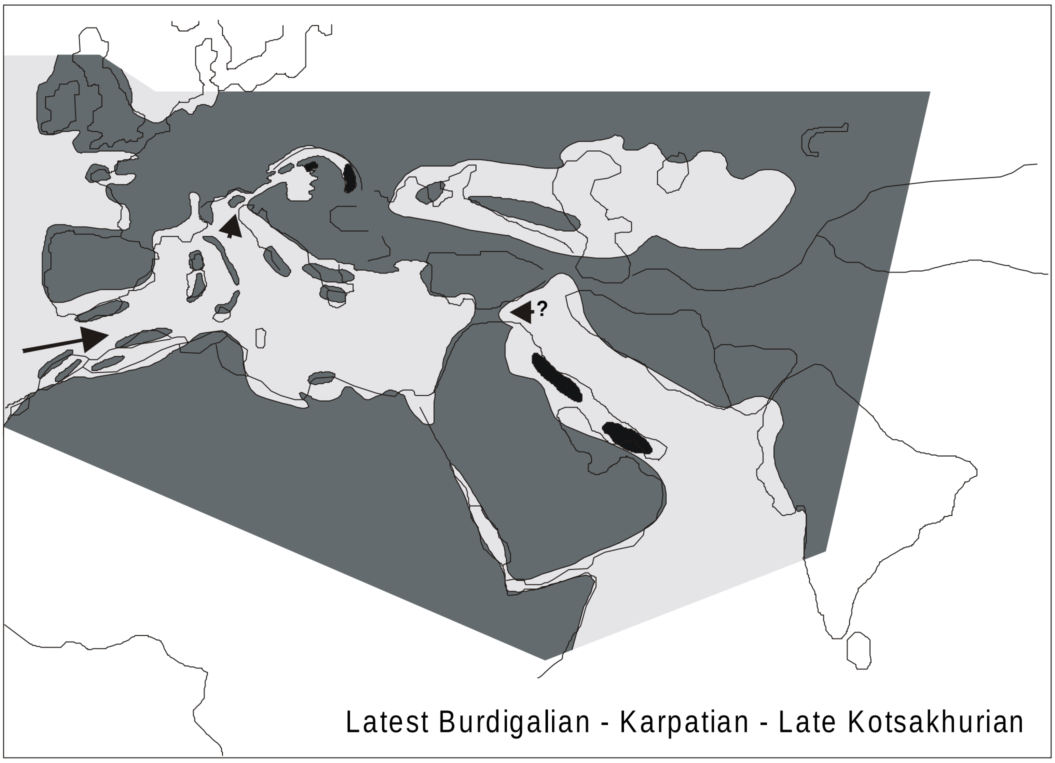

Fig. 7. At the end of Burdigalian (Karpatian) the general configuration remained, but in the more western regions of the Paratethys, the Alpine Foredeep and the Transylvanian Basin became dry land. A small region in the Central Paratethys stayed in connection with the Mediterranean Sea. Evaporites were deposited in the eastern Carpathian Foredeep and in the East Slovak Basin.

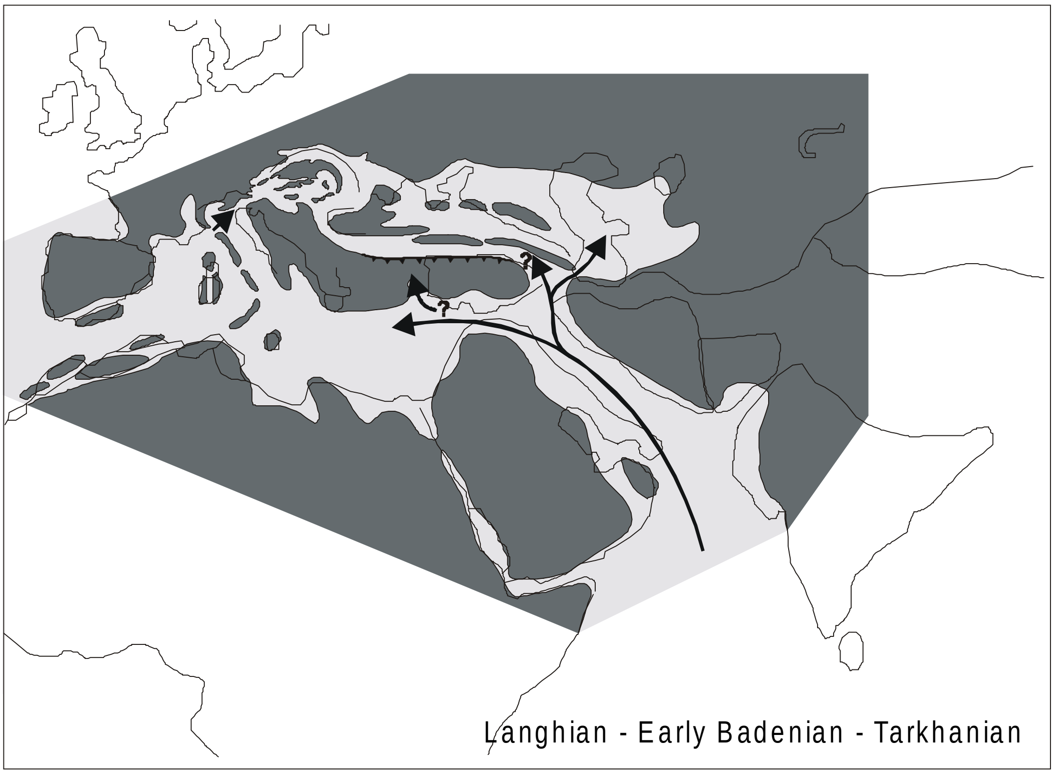

Fig. 8. Indo-Pacific recurrence. For a short time the seaway to the Indian Ocean opened again. The Middle Miocene transgression flooded the entire Mediterranean and Paratethys.

By the end of the Ottnangian a strong regression occurred in the Alpine Foredeep, and in the estuarine areas of the Central Paratethys, *Rzehakia* faunas similar to those of the Kotsakhurian spread. The Transylvanian Basin also became dry land, and in the Karpatian the marine realm was restricted to the Pannonian Basin and the Carpathian Foredeep (Fig. 7). Along the front of the Carpathians sedimentation was dominated by clastics, with evaporites in the eastern part of the basin, dated NN 4 (Kováč et al. 1989; Andreyeva-Grigorovich et al. 1997; Oszczypko 1998). The Kotsakhurian Basin remained endemic, and the stratigraphic correlation between the Karpatian and Tarkhanian seems to be incorrect (see below).

Intermittent seaways and landbridges

A Middle Miocene transgressive highstand at the sequence cycle TB 2.3 of Haq et al. (1988) is correlated with the base of the Langhian (Fig. 8). Stratigraphically it is defined by the FAD (first appearance datum) of the planktonic foraminiferal genus *Praeorbulina* within nanno-zone NN 4. The correlation of the Tarkhanian stage with the Karpatian by nannoplankton zone NN 4 (e.g. Studencka et al. 1998) cannot be followed. This zone is also present at the base of the Langhian. Otherwise, unpublished results (N. Muzylev & C. Müller) from the Tarkhanian at Jurkino near Kertch show already NN 5 at the base of the section, below the *Spirialis* clay.

A seaway re-opened between Arabia and South Anatolia, and a similar event also took place in Eastern Anatolia, as recorded by marine sediments in the Lake Van area (Gelati 1975). The main uncertainty is the highest marine development in the Carpathian Foredeep and in the Transylvanian Basin. Tropical conditions with corresponding larger foraminifers and molluscs were observed in the Paratethys as far north as Poland. In the Eastern Paratethys during the Tarkhanian, poorly developed *Globigerina* assemblages, atypical mollusc faunas, and bottom conditions contaminated by hydrogen sulfide make a full marine connection unlikely.

A marine seaway from the Albanian Korca Graben and the Mesohellenic Basin to the Central Paratethys—as proposed by Studencka et al. (1995, 1998)—did not exist. In the Mesohellenic Basin, marine sedimentation ended in the Globigerinoides bisphericus Zone (Fermeli 1997), and to the north the “Serbian Lake“ extended onto the Dinarides (Krstić et al. 1996). Such connections were also absent in the Aegean region (Pollak 1979). Therefore a highly speculative seaway is proposed here. It may have extended along the suture between the Balkanides and the Rhodopes, and continued along the North Anatolian Fault Zone between the Black Sea plate and the Pontides. Further insight is expected by studies of the

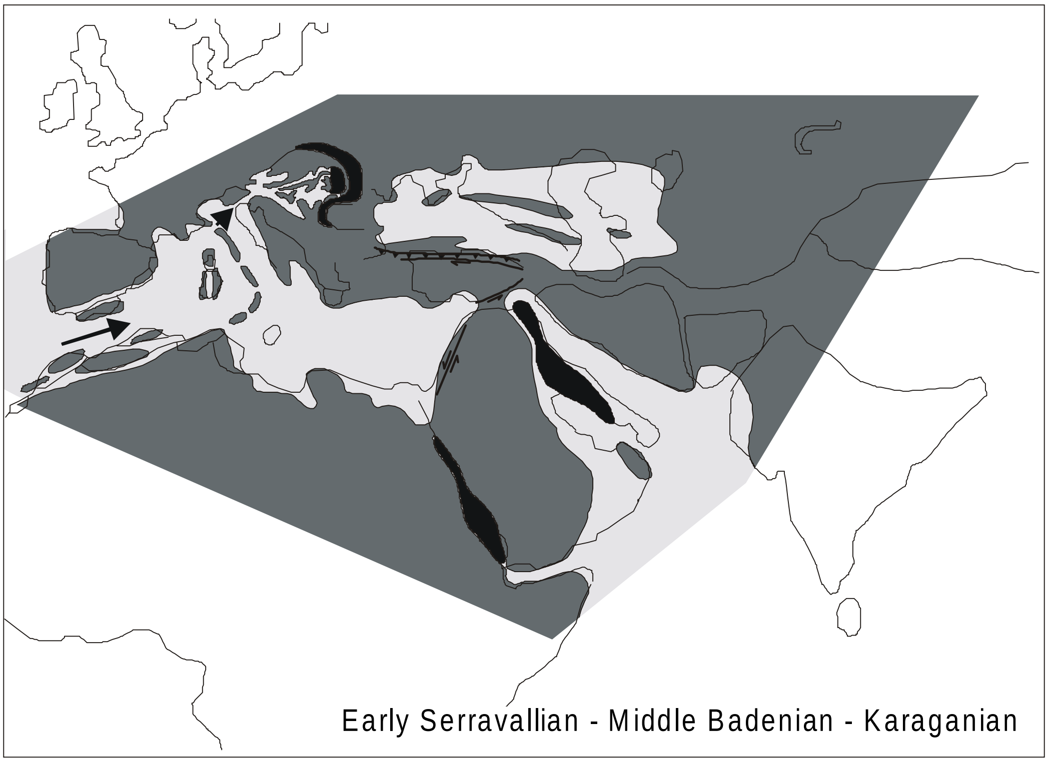

Fig. 9. The Paratethys salinity crisis. With the Serravallian regression and by the tectonic translations along the Levante Fault, the Mediterranean-Indian Ocean seaway ceased finally. The Eastern Paratethys again became an isolated basin with reduced salinity and endemic faunas of the Karaganian Sea. In the Central Paratethys, all the Carpathian Foredeep and the Transylvanian Basin became isolated basins with thick evaporite sedimentation. A reduced area around the Pannonian Basin remained marine.

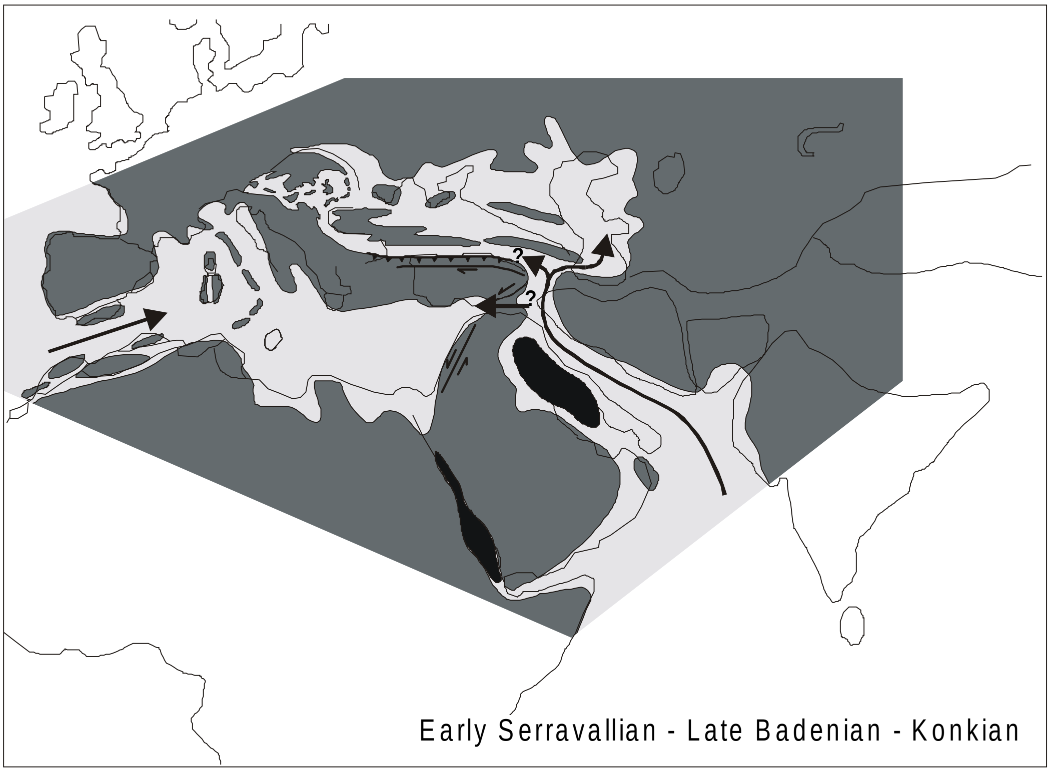

Fig. 10. In Late Badenian/Konkian time a final flooding of the Paratethys occurred. Marine microfaunas and radiolaria marls point to a renewed Indo-Pacific connection. The Mediterranean remained an Atlantic embayment.

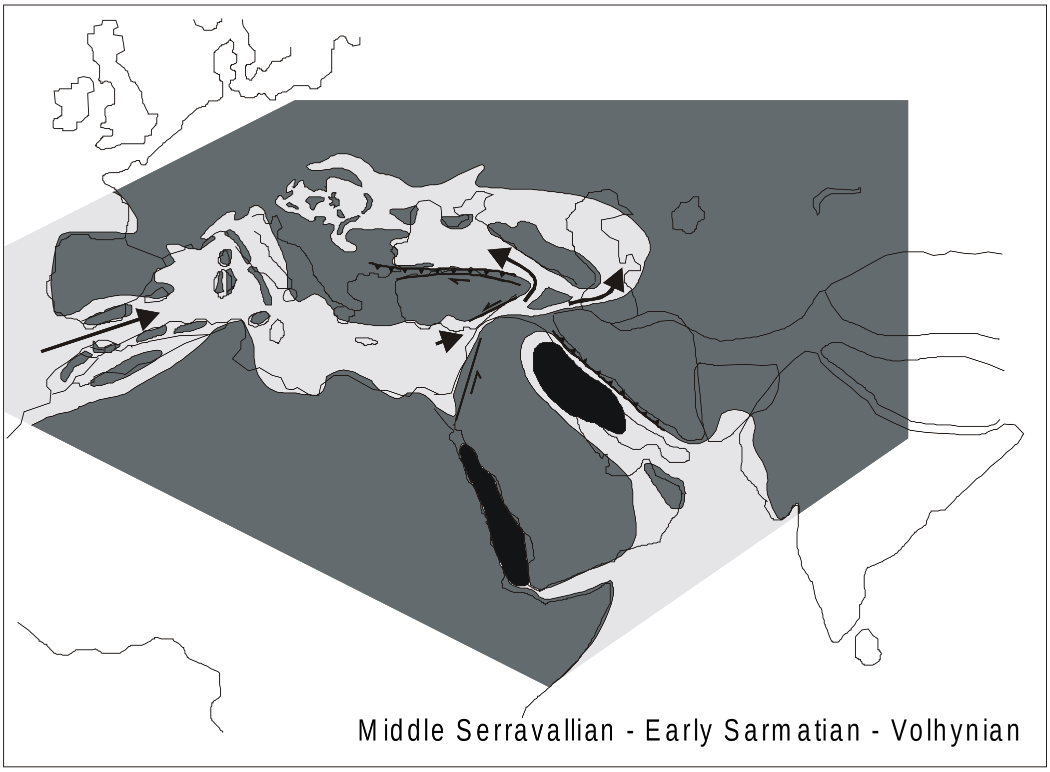

Fig. 11. The end of marine Paratethys environments was caused by the closure of open seaways. A reduced connection opened only along the Bitlis and Eastern Anatolian Fault zones. The Sarmatian Sea turned to reduced salinity conditions and strong endemism.

southward movement of the Rhodopes block (Kazmer & Dunkl 1998). The Aegean region underwent a shortening of 10° latitude and an inward rotation of both sides of 50° since the Lower Miocene (Kissel et al. 1989). This leaves enough space for such a hypothetical seaway. Another possibility, following slightly the proposed direction of Studencka et al. (1998) would be along western Anatolia, and would avoid the complicated structures for northern Anatolia. But this way cannot explain the conditions of the Late Badenian/ Konkian.

The seaways of the Middle Miocene were short-lived. At the beginning of the Serravallian, coinciding with the sea level drop of cycle TB 2.3/TB 2.4 (Haq et al. 1988), tectonic movements along the Levant Fault Zone again closed the seaway between the Mediterranean and Indian Ocean. The landbridge between Africa and Eurasia emerged for a second time (Fig. 9). The realm of the Eastern Paratethys developed into the endemic Karaganian Sea. The mollusc fauna was dominated by *Spaniodontella*, accompanied by *Solen* and *Pholas*. In the Central Paratethys, uplifts in the Carpathians sealed off the foredeep and the Transylvanian Basin. Extensive evaporites with gypsum and halite were deposited. Only the area of the Pannonian Basin retained a marine connection with the Mediterranean through the so-called "Trans-Tethyan-Trench-Corridor" in Slovenia. There are different interpretations by Oszczypko (1998) of the stratigraphic position of this evaporitic event, who regards it as Late Badenian or even Early Sarmatian, within a two-folded Badenian. In the Vienna and Transylvanian Basins nannoplankton determinations give a youngest biostratigraphic datum of NN 6 or NN 6/7 for the Upper Badenian sediments (comp. Chira 1995; Rögl 1996; pers. comm. of M.P. Aubry), and the evaporites or regressive sediments of the "Sandschalerzone" are below radiolaria- or pteropod-marls with this nanno-zonation.

From the Serravallian, the oceanic circulation between the Indian and Atlantic Oceans was interrupted. A worldwide temperature drop, also reflected in benthic oxygen isotope values around 15 Ma, is correlated to this event (Flower & Kennett 1993). The seaway from the Mediterranean to the Central Paratethys in Slovenia was closed in the Late Badenian. On the other hand, the Eastern Anatolian seaway opened again as shown by Indo-Pacific microfossil assemblages in the Central Paratethys (Fig. 10). Also according to Studencka et al. (1998) the seaway in Eastern Anatolia reopened (Araks Strait), but the authors demand two additional independent connections for the Central and Eastern Paratethys with the Mediterranean. All over the Paratethys, from the Transcaspian to the Vienna Basin, a final marine transgression covered all the different facies ar-

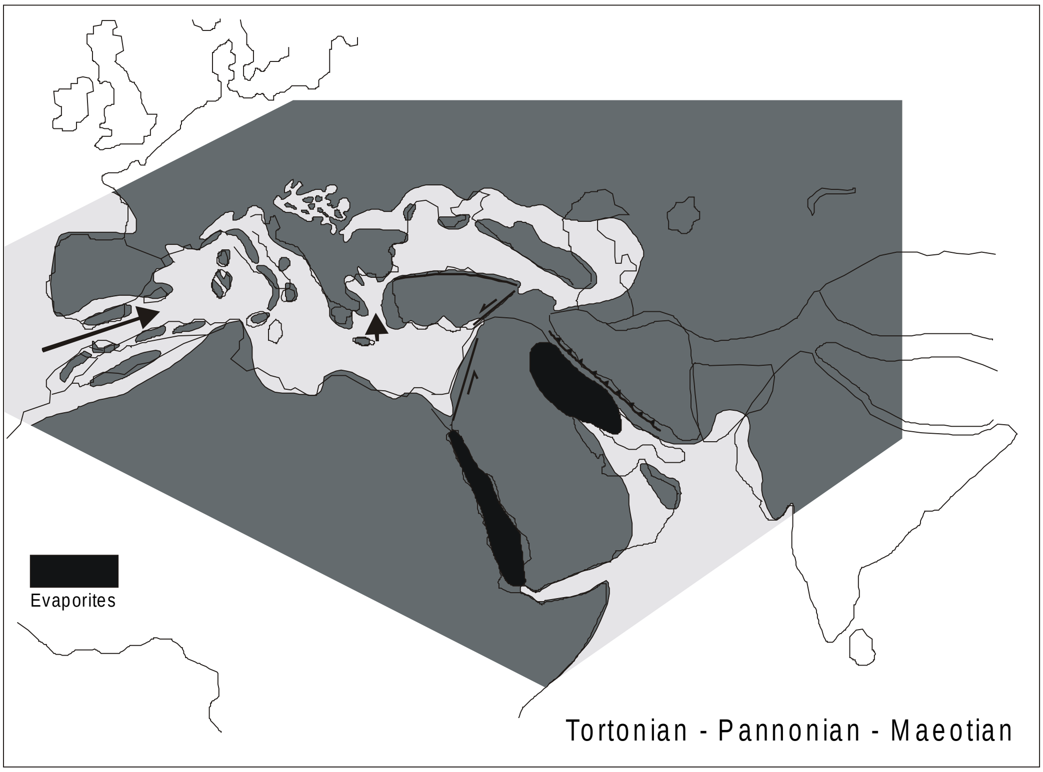

Fig. 12. The Pannonian Lake and the final isolation of the Paratethys. The increasing continentalization and tectonic uplift in the Carpathians isolated the Pannonian Basin from the reduced salinity realm of the Eastern Paratethys. Nearly freshwater conditions with a radiation of the molluscs *Congeria, Melanopsis* and *Limnocardium* dominated the lake. From the Dacian Basin eastward, facies was reduced marine with a Sarmatian fauna. After strong regressions the Maeotian transgression entered the Eastern Paratethys on the way from the newly formed Aegean Sea during the Tortonian transgressive highstand.

eas. Radiolaria shales were sedimented on top of evaporites in the Transylvanian Basin, followed by pteropod marls. By the end of the Late Badenian/Konkian, regressive tendencies increased.

The endemic Paratethys

The connections of the Paratethys to the open oceans were strongly restricted by the end of the Badenian. A general reorganization of the circum-Mediterranean area closed the Indo-Pacific connection (Fig. 11). A new small seaway supplied the Eastern Paratethys from the Mediterranean along the Anatolian Fault zones in the upper Euphrates valley (Chepalyga 1995). At the beginning of the Sarmatian, salinity dropped and, probably more importantly, alkalinity increased (Pisera 1996). All stenohaline organisms became extinct. A mass production of a few groups with increasing endemisms developed. The fauna and facies were similar throughout the Paratethys.

The aquatic realm of the Central Paratethys was strongly reduced in the Pannonian. The Carpathian Foredeep became dry land. In the Carpathian arc, the Pannonian Lake remained; it showed strongly reduced salinity conditions (Fig. 12). Almost all Sarmatian faunal elements vanished. The limnocardiids evolved as relics of the Sarmatian. Congerias and melanopsids of freshwater origin showed a remarkable radiation. Sarmatian facies conditions continued in the Dacian and Euxinian Basins. During the Bessarabian and Khersonian, a bloom of mactras took place. In the Late Khersonian a strong regression isolated the Black Sea Basin, which was flooded again in the Lower Maeotian. This Maeotian transgression followed the new graben structures of the Aegean Sea at the Middle Tortonian high stand (for discussion of correlations see Jones & Simmons 1996; Rögl & Daxner-Höck 1996).

A further regression in the Late Maeotian led to the nearly freshwater conditions of the Pontian. The Pontian Lake extended from the Pannonian to the Euxinian Basin, and southward into the Aegean Basin. This corresponds to the time of the Messinian regression and salinity crisis in the Mediterranean Basin. Modern conditions were established by the Pliocene Mediterranean transgression.

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