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Mediterranean and Paratethys palaeogeography during the Oligocene and Miocene

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Introduction

The Cenozoic configuration of continents and oceans is strongly influenced by plate tectonic movements. Opening and closing pathways for mammal migrations and marine exchanges are one of the triggering forces for faunal events and evolution. The impacts of a vanishing Tethys Ocean in the mid-Cenozoic are not only important for the marine and continental biotas of Eurasia and the Mediterranean, but also influenced the environmental conditions worldwide. The dispersal of continents in the Southern Hemisphere with the northward movement of the Indian and Australian continents, together with the counterclockwise rotation of Africa, closed down the Tethys Ocean. Parallel to these movements the Atlantic Ocean opened. The Mesozoic oceanic circulation patterns changed to varying conditions with decreasing temperatures in the Cenozoic. Based on oxygen isotopes (Kennett, 1995), bottom water temperatures were highest in the late Palaeocene–early Eocene (*c.* 55 Ma). Distinct steps to colder conditions followed around the Eocene/Oligocene boundary (33–35 Ma), in the middle Miocene (15 Ma), and in the Pliocene (3 Ma).

Different palaeogeographic reconstructions over the past two decades have attempted to solve the development of the Cenozoic Mediterranean and Paratethys areas. In many cases these reconstructions depend on the present sediment distribution and do not consider palinspastic reconstructions based on plate tectonic movements (e.g. Vinogradov, 1967–69; Senes & Marinescu, 1974; Steininger *et al.*, 1985a; Hamor & Halmai, 1988; Cahuzac *et al.*, 1992; Popov *et al.*, 1993). Other reconstructions include too long a time span within one time slice to present a distinct time level within a strongly changing environment (e.g. Biju-Duval *et al.*, 1977; Dercourt *et al.*, 1985, 1993). The best reconstructions, based on tectonic, sedimentological and stratigraphic investigations are currently available for the Western Mediterranean (Boccaletti *et al.*, 1986, 1990). The sketches for the Neogene, produced by Rögl & Steininger (1983) and Steininger & Rögl (1984), were based on plate tectonic hypotheses, sediment distribution, Eurasian mammal migrations, and marine faunal similarities between the Mediterranean and Paratethys. At that time the information on faunal development and stratigraphic correlation was poor for the Eastern Paratethys. Therefore a revision of those interpretations, including the early history of the Paratethys was discussed by Rögl (1998a,b). The sketches presented here are based on plate distributions at three levels from the Eocene to the late Miocene (Scotese *et al.*, 1988). The goal of the present palaeogeographic sketches is to explain mammal migration possibilities in and between Eurasia and Africa. Some marine connections are still being debated (Adams, 1998), and certain seaways proposed here are highly speculative. The open questions will require further tectonic and palaeontological studies.

A postulate for any time slice is the exact stratigraphic correlation of the different basins included in the reconstructions. The stratigraphic correlation chart (Table 2.1) is based on the most recent time tables of Berggren *et al.* (1995) and Steininger *et al.* (1996), correlated to the Paratethys (Popov *et al.*, 1993; Jones & Simmons, 1996; Rögl, 1998b).

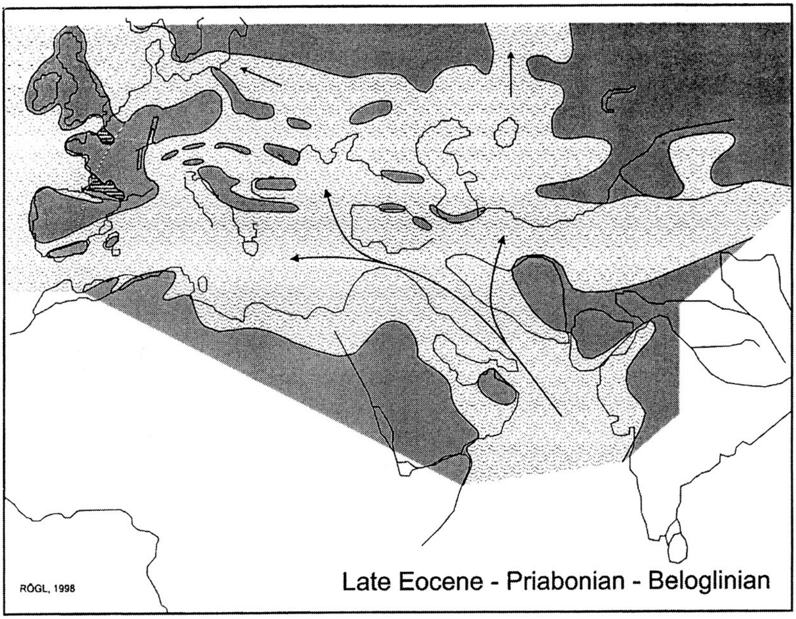
Birth of the Paratethys

In the late Eocene the Indian Plate collided with Eurasia. The Tethys Ocean vanished, leaving as relics the Mediterranean Sea at its western end, and to the north the intercontinental Paratethys Sea in Eurasia (Fig. 2.1). In the late Eocene, a pelagic *Globigerina* marl facies developed from the western Mediterranean to the Alpine–Carpathian belt and the inner-Asian Transcaspian Basin; north–south gradients in planktic faunal assemblages were evident. In the shallower parts of the basin tropical, larger foraminifera and mollusc faunas thrived. In the Eastern Paratethys the molluscs had a latitudinal distribution, with the most tropical assemblages in Transcaucasia (Akhaltsikhe depression), whereas in northern Ustyurt a northern fauna of low diversity was recorded (Krasheninnikov, 1974; Popov *et al.*, 1993; Popov, 1994). From the eastern part of the later Paratethys, the tropical Tethys Ocean communicated with the Polar Sea via the shallow Turgai Strait in western Siberia during the middle–late Eocene (Vinogradov, 1967–69; Popov *et al.*, 1993). This marine barrier prevented a continental faunal exchange between Asia and Europe. During the Eocene, western and middle Europe existed as an archipelago, with a distinct reduction of mammal diversity during the Priabonian. Northern Europe formed a landmass connected by the De Geer Route (over Svalbard) with North America (Königswald, 1981).

Around the Eocene/Oligocene boundary, continental collision and movements along the Alpine–Himalayan tectonic belt closed off the Paratethys. The Turgai Strait vanished, and the continentalisation of the European archipelago formed new configurations (Ziegler, 1990). The mammal immigration wave, coming from the east out of North America and Asia, reached western Europe during nannoplankton zone NP 22 (32–33 Ma) and resulted in the so-called 'Grande Coupure' (Stehlin, 1909; Tobien, 1987).

Table 2.1. *Stratigraphic correlation chart of the Central and Eastern Paratethys regional stage systems (Berggren* et al., *1995; Popov* et al., *1993; Rögl, 1996, 1998a,b; Steininger* et al., *1996).*

M. A.	EPOCH	AGE	CENTRAL PARATETHYS STAGES	EASTERN PARATETHYS STAGES	BIOZONES: Mammal Zones	BIOZONES: Planktic Foraminifera	BIOZONES: Calcareous Nanno-plankton
5	PLIO-CENE 5.3	ZANCLEAN	DACIAN	KIMMERIAN	MN 14	PL1	NN13 NN12
	Late MIOCENE	MESSINIAN 7.1	PONTIAN	PONTIAN	MN 13	M14 M13 b	NN11
10	Late MIOCENE 11.0	TORTONIAN	PANNONIAN (Vienna Basin: H, G, F, D-E, C, A/B) MALVENSIAN (Moldavian, Olteanian, Khersonian, up.Bessar)	MAEOTIAN (10.0) SARMATIAN: Khersonian	MN12 MN11 MN10 MN 9	M13 a	NN11 NN10 NN9b NN9a/8
	Middle MIOCENE	SERRAVALLIAN 14.8	11.5 SARMATIAN (13.0) BADENIAN	SARMATIAN: Bessarabian, Volhynian Konkian Karaganian Tshokrakian	MN 8-7 MN 6-5	M12 M11-M8 M7 M6	NN7 NN6 NN5
15	Middle MIOCENE 16.4	LANGHIAN	BADENIAN	TARKHANIAN	MN 6-5	M5	NN5
20	Early MIOCENE	BURDIGALIAN 20.5	KARPATIAN OTTNANGIAN EGGENBURGIAN	KOTSAKHURIAN SAKARAULIAN	MN 4 MN 3	M4 M3 M2	NN4 NN3 NN2
	Early MIOCENE 23.8	AQUITANIAN	EGERIAN	KARADZHALGAN	MN 2 MN 1	M1 b M1 a	NN2 NN1
25	OLIGOCENE	CHATTIAN 28,5	EGERIAN (27.5)	KALMYKIAN	MP 30-28 MP 27 - 24	P22 P21 b P21 a	NP25 NP24
30	OLIGOCENE 33.7	RUPELIAN	KISCELLIAN	SOLENOVIAN PSHEKIAN	MP 23 - MP 21 MP 20	P20 P19 P18 P17	NP23 NP22 NP21
35	Late EOCENE	PRIABONIAN	PRIABONIAN	BELOGLINIAN	MP 19 - MP 17	P16 P15	NP 19-20 NP18

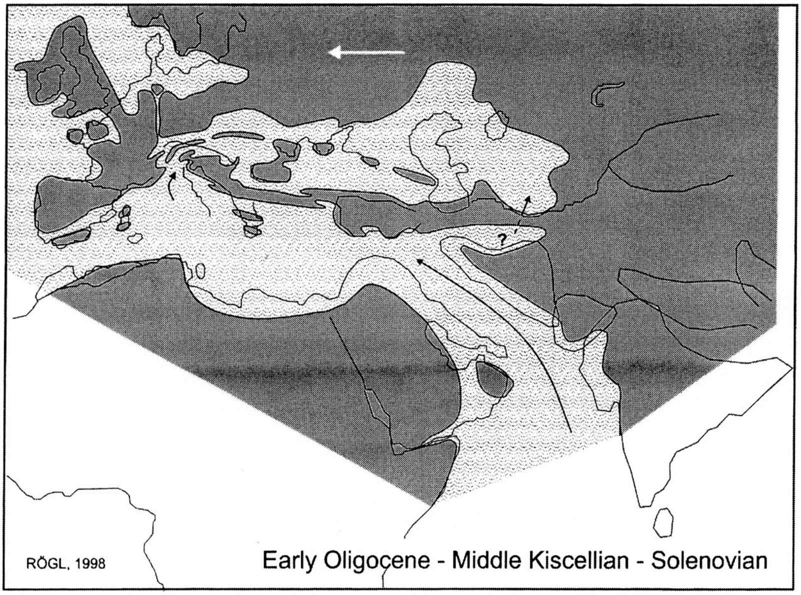


[Figure 2.1]
Palaeogeographic sketch of the western end of the Tethys Ocean in the late Eocene. The western Tethys communicated with the Polar Sea via the Turgai Strait and prevented mammal migrations between Asia and Europe (Rögl, 1998a,b).

Sixteen new mammal families are mentioned by Savage (1990). New important immigrants in mammal zone MP 21 include: *Anthracotherium, Eusmilus,* Rhinocerothidae, Lagomorpha, Eomyidae, and Cricetidae. This faunal migration was made possible by the closure of the Turgai Strait and the continuing northwestward movement of North America, closing in for a first Bering landbridge. The Paratethys extended as an orogenic foredeep and intercontinental sea from the Western Alps to Central Asia (early Kiscellian/Pshekian). Marine connections existed in the far west with the Mediterranean, and to the northwest along the Danish–Polish Strait with the North Sea Basin (only in Latdorfian, NP 21).

First Paratethys isolation

Cold water influx, dysaerobic bottom conditions, aberrant microfloras and microfaunas, and northern molluscs characterised the early to middle Oligocene (Baldi, 1979, 1984; Krhovsky *et al.*, 1991; Popov *et al.*, 1993; Rusu *et*

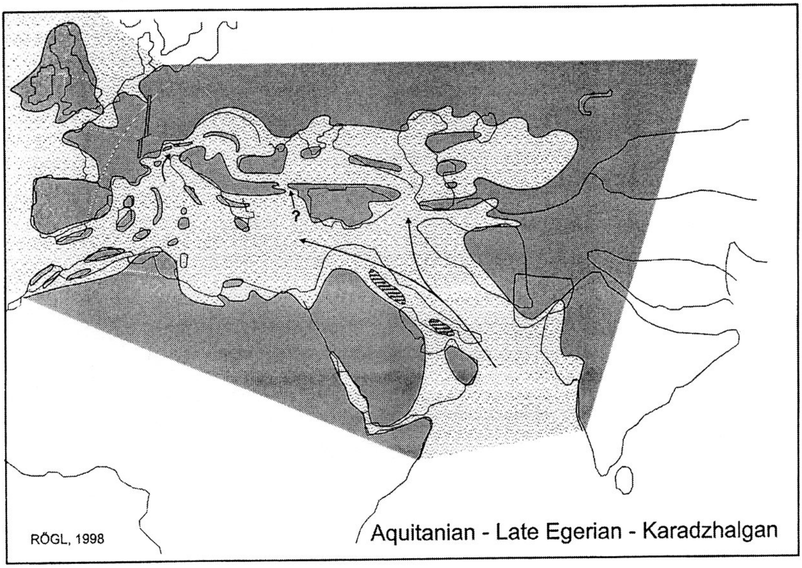


[Figure 2.2]
The isolated Paratethys Basin in the early Oligocene. Only narrow seaways remained open in the west. Salinity decreased and endemic conditions developed in the entire basin. The closure of the Turgai Strait established the conditions for the Eurasian faunal exchange known as the 'Grande Coupure' (Rögl, 1998a,b).

al., 1996). The isolation of the Paratethys culminated (Fig. 2.2) during nannoplankton zone NP 23 (Solenovian stage) with reduced salinity conditions and endemic bivalves (*'Cardium lipoldi'* – *Janschinella* fauna). In contrast, the Mediterranean Tethys remained open between the Indo-Pacific and Atlantic Ocean, and prevented a continental faunal exchange between Eurasia and Africa. Most of the Oligocene was characterised by a continuous faunal exchange within Eurasia, rather than a distinct migration wave, e.g. the appearance of *Melissiodon* and *Paracricetodon* in MP 24, and of Zapodidae in MP 26.

Tropical marine excursion

A worldwide excursion of the tropical belt in the marine realm occurred in the late Oligocene–early Miocene. Horizons of tropical, larger foraminifera and molluscs are reported from the Mediterranean, the Paratethys, and the Middle East (Adams, 1973, 1976, 1983; Baldi & Senes, 1975; McGowran,



[Figure 2.3]
In the late Oligocene–early Miocene a transgression spread from the Middle East to the Mediterranean and Paratethys. Larger foraminifera, molluscs, and corals fringed the eastern shelf along the Lut Block from Makran to Qum Basin, Lake Urmia, and Transcaucasia. In the Western Paratethys the Rhinegraben connection and the seaway along the Alpine Foredeep closed. In the Western Mediterranean the Balearic Basin started to spread, with an eastward move of the Apennines (Rögl, 1998a,b).

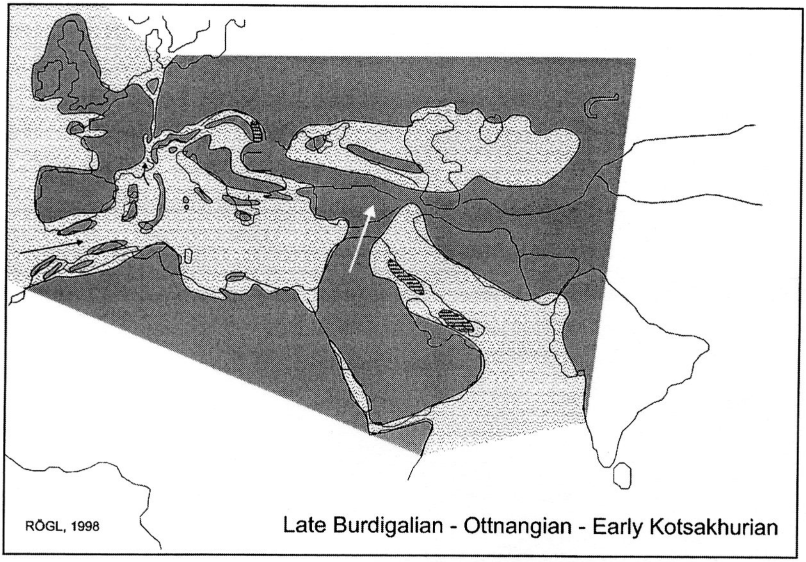
1979a,b; Popov *et al.*, 1993; McCall *et al.*, 1994). The Mediterranean–Indian Ocean gateway was open between the Anatolian and Arabian Plates (Fig. 2.3). A tropical-subtropical southeastern connection for the Paratethys newly opened across the Iranian plate (Transcaucasia–Qom Basin–Makran). In the south, the rotation of Arabia opened the graben of the Red Sea in the late Oligocene (Jones & Racey, 1994). The Central Paratethys was connected to the Mediterranean along fault structures in the Alps and between the Alps and Dinarides. The marine straits in the western Alpine foredeep and the Rhinegraben were closed intermittently. The Alpine foredeep re-opened for a seaway to the Rhône Basin in the early Burdigalian (Eggenburgian).

In the late Oligocene (mammal zone MP 28–30) new forms appeared in Europe successively: *Heterocricetodon, Rhizospalax,* and the second invasion of Lagomorpha. In the early Miocene (Aquitanian), important new forms include the suoids *Palaeochoerus* and *Hyotherium* in the European mammal zone MN 1 and *Bunolistriodon* in Dera Bughti (Pakistan). In the lower Burdigalian (MN 3) the North American immigrant *Anchitherium* reached Europe (Thenius, 1972; Steininger *et al.*, 1985b; Made, 1990). A

Eurasian–African faunal exchange was still impossible, and no relation existed to the first East African mammal fauna of Meswa Bridge (23.5 Ma).

The *Gomphotherium* Landbridge

During the middle Burdigalian (upper Eggenburgian–Ottnangian), strong movements of the Savic tectonic phase changed the palaeogeographic patterns in the circum-Mediterranean (Fig. 2.4). The rotation of Africa finally closed the gap to Eurasia. The Arabian peninsula collided with the Anatolian Plate. The '*Gomphotherium* Landbridge' was established. Continental faunal exchanges in both directions started in MN 4, around 19 Ma. Successive arrivals of gomphotheres, deinotheres, and primates are observed in Eurasia, while rhinos, tayassuids, or *Amphicyon* arrived in Africa. The first *Gomphotherium* are recorded in the Siwaliks (Kamlial Formation) at > 18 Ma,



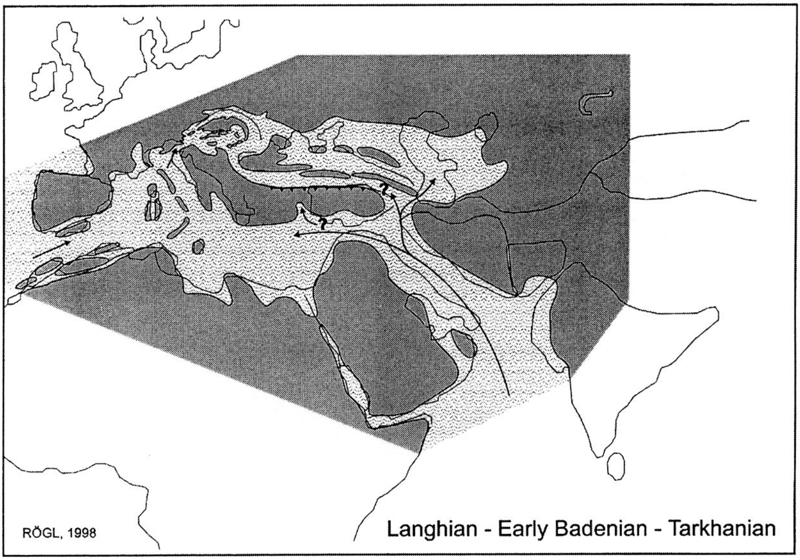
[Figure 2.4]
The *Gomphotherium* Landbridge. The Eastern Mediterranean seaway closed, and a landbridge opened between the Anatolian and Arabian/African Plates, enabling a remarkable faunal exchange. The Eastern Paratethys became entirely isolated, with reduced salinity and endemic faunas. The Mediterranean communicated with the Atlantic Ocean and fed the Western and Central Paratethys. The renewed seaway in the Alpine Foredeep was again connected to the North Sea by the Rhinegraben (Rögl, 1998a,b).

and in Poland in the coal mine Belchatow C also at this time (Thenius, 1979; Steininger *et al.*, 1985b; Goldsmith *et al.*, 1988; Barry & Flynn, 1989; Pickford, 1989; Kowalski & Kubiak, 1993; Fortelius *et al.*, 1996; Bernor *et al.*, 1996).

The Paratethys Sea was divided in two separate realms. The Eastern Paratethys formed an enclosed basin with endemisms under reduced salinity (Kotsakhurian stage). The Western and Central Paratethys remained connected to the Mediterranean and via the Rhinegraben, to the North Sea. Cooler conditions were observed in the marine faunas. By the end of Ottnangian the Alpine foredeep became dry land. The Mediterranean itself was open to the Atlantic Ocean.

Re-opening of the Indo-Pacific gateway

The exact process by which the seaway between the Indian Ocean and the Mediterranean reopened is still being discussed and remains controversial,

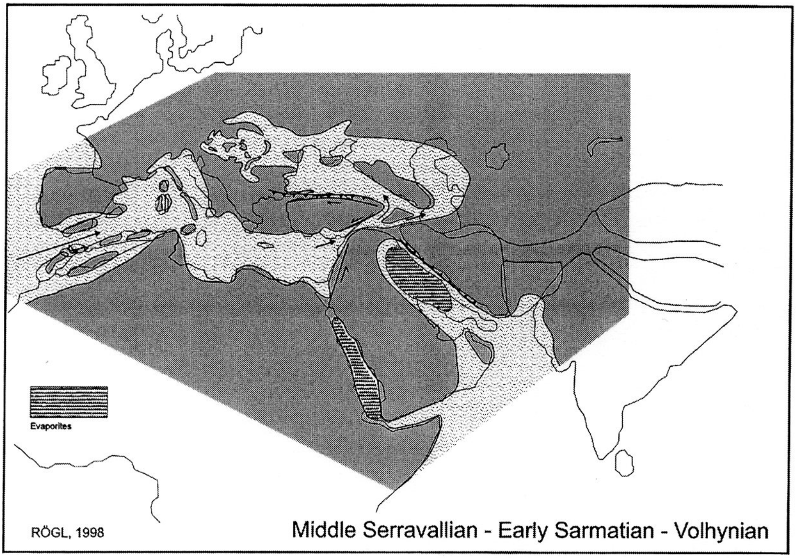


[Figure 2.5]
Indo-Pacific recurrence. For a short time the Mediterranean–Indo-Pacific seaway reopened around the early–middle Miocene boundary. From Eastern Anatolia a new transgression flooded the Paratethys. The intramountain basins and the Carpathian foredeep in the Central Paratethys were covered by tropical–subtropical waters. A connection is proposed along the Rhodopes and Pontides, south of the Black Sea Plate. The Eastern Paratethys stayed in reduced communication (Rögl, 1998a,b).

based on the interpretation of the distribution of larger foraminifera (Adams *et al.*, 1983; Adams, 1998). At least for the lower Langhian, such a short connection along the Bitlis Zone between the Anatolian and Arabian Plates is required (Fig. 2.5). Another connection must have existed in eastern Anatolia linking the Paratethys with the Indian Ocean for an early Badenian transgression. During the time of open seaways the Eurasian/African mammal migrations were interrupted, which seems to be demonstrated by migration waves, e.g. arrivals of primates: *Pliopithecus* in MN 5, *Griphopithecus* and *Plesiopliopithecus* in MN 6, and *Dryopithecus* in MN 8 (Andrews *et al.*, 1996; Begun, 1996).

Final closure between Eurasia and Africa

The Serravallian regression coincided with the re-establishment of the '*Gomphotherium* Landbridge'. Evaporitic sedimentation and continentalisation took place in the area around the Persian Gulf (Jones & Racey,



[Figure 2.6]
The Paratethys closure. The end of open marine connections transformed the Paratethys environment into an endemic bioprovince under reduced salinity conditions. Since early Oligocene times, the most uniform biofacies was observed from the Vienna to the Caspian Basin in the Sarmatian. Intermittent narrow marine straits opened from the Mediterranean to the Eastern Paratethys along the East Anatolian fault zone. The Persian Gulf was characterised by evaporitic and continental sedimentation of the Fars and Gachsaran Formations (Rölg, 1998a,b).

1994). The final closure of the circum-equatorial oceanic current system caused worldwide cooling and an increased accumulation of the East Antarctic ice sheet around 15 Ma (Kennett, 1995). Short-lived connections between the Indo-Pacific, the Mediterranean and the Eastern Paratethys (Fig. 2.6) existed in eastern Anatolia in the upper middle Miocene in the Konkian/late Badenian and Sarmatian, but also in the Pliocene (Nevesskaya *et al.*, 1984; Chepalyga, 1995; Iljina, 1995). These channels may have briefly acted as barriers for mammal exchanges. The regression of the sea from the Greek mainland and the Aegean landmass at the end of the Burdigalian prevented marine connections with the Paratethys in the area of the Dardanelles. The earliest rodent faunas are reported from the Aegean in Orleanian times (Sen, 1982). Beginning with the Tortonian transgression, an Aegean seaway opened to the Black Sea Basin (Rögl & Steininger, 1983; Marunteanu & Papaianopol, 1995).

Since the Sarmatian the open ocean connections of the Paratethys were interrupted. The gigantic inland sea of the Paratethys turned into continuously shrinking basins. A reduced salinity and the alkaline chemistry of the aquatic realm led to strong endemisms and caused the stenohaline organisms in the Sarmatian sea to disappear (Pisera, 1996). The environments of the Eastern Paratethys Sea had higher salinities from the Sarmatian up to the Maeotian (late Miocene) and extended to the west to the Dacian Basin, whereas the enclosed Pannonian Basin turned to nearly freshwater conditions (Pannonian stage). The connecting facies between the Pannonian and Euxinian basins is expressed by the local Malvensian stage in the Eastern Carpathians and Dacian realm (Motas & Marinescu, 1969; Marinescu, 1985; Papaianopol *et al.*, 1995). During MN 6 an increasing faunal exchange occurred between Eurasia and Africa (Bernor *et al.*, 1996; Fortelius *et al.*, 1996).

The appearance of '*Hipparion*' is one of the last Miocene immigration events from North America. A strong sea level drop around 11 Ma (Haq *et al.*, 1988) once again opened the Bering landbridge. In a rapid wave the three-toed horse spread from China to the Eastern Paratethys and western Europe (Bernor *et al.*, 1989). During the Turolian (late Miocene, MN 11–13) in southeastern Europe and southwestern Asia, the 'Pikermian' faunal province extended with a radiation in hipparionine horses and ruminants. Additionally, Asian 'steppe elements' such as *Cricetus* and *Pliospalax* appeared in Europe (Steininger *et al.*, 1985b; Bernor, 1984; Bernor *et al.*, 1996; Gentry & Heizmann, 1996). Finally, new but limited faunal routes with Africa were opened by the Messinian salinity crisis in the late Turolian (MN 13). Important representatives include *Protatera, Hippopotamus,* and *Macaca* (Agustí, 1996). Modern conditions were established in the circum-Mediterranean by the Pliocene marine transgression coming from the Atlantic Ocean.

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