

Palaeogeographic Considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene)

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(With 10 plates and 1 table)

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Abstract

Some considerations on the palaeogeography of the Mediterranean and Paratethys Oligocene to Miocene are presented in ten time-slices. The time-slices start with the vanishing Tethys Ocean in the late Eocene and the birth of two new marine realms at its western end: the Mediterranean Sea and the intercontinental Eurasian Paratethys basin. The time-slices were selected according to general palaeogeographic changes of seaways and arising land bridges for continental migrations. The palaeogeographic sketches were based on Cenozoic plate reconstructions, and the intermediate levels are interpolated accordingly. Strong changes occurred in the history of the Paratethys. From an open ocean in the Eocene with connections to the Polar Sea via the Turgai Strait, it changed to an enclosed basin in the early Oligocene with reduced salinity and endemic faunas. From the middle Oligocene on, the basin opened again, reaching a maximum connection with the Indian Ocean during late Oligocene and early Miocene (late Chattian – early Burdigalian). Intermittent seaways and regional close-off of basins with endemic development characterize the late Burdigalian and middle Miocene. By the mid-Serravallian the final disconnection of the Paratethys occurred, and since Sarmatian time reduced salinity conditions and endemisms prevailed. The Mediterranean was the connecting sea between Indo-Pacific and Atlantic Oceans until the late Burdigalian. With the collision of the Arabian and Anatolian plates in the late Burdigalian, an Eurasian – African landbridge opened for mammal migrations. A short interruption is proposed for the Langhian transgression, followed by a final closure in the Serravallian.

Zusammenfassung

In einer kurzen Übersicht werden neue Überlegungen zur Paläogeographie des Oligozän und Miozän von Mediterran und Paratethys gegeben. Die skizzenhafte Darstellung zeigt die Verteilung von Meer und Festland in einer Serie von zehn Zeitschnitten. Einerseits soll die regionale Entwicklung mit ihren wesentlichen paläogeographischen Veränderungen klar ersichtlich sein, andererseits wird versucht die interkontinentalen Migrationsmöglichkeiten der Säugetierfaunen zwischen Eurasien und Afrika zu dokumentieren. Als Grundlage wurden plattentektonische Darstellungen verwendet, die für mehrere magnetochronologische Zeitebenen vorlagen. Die dazwischenliegenden Zeitschnitte wurden intrapoliert.

Die Darstellungen beginnen mit dem Obereozän, dem Zeitraum, in dem der Tethys Ozean durch die Norddrift von Indien und die im Gegenuhrzeigersinn erfolgende Rotation von Afrika allmählich verschwand. Die Turgai-Straße in Westsibirien verband die Tethys mit dem Polarmeer und verhinderte einen kontinentalen Faunenaustausch zwischen Europa und Asien. Die Zeitebene basiert auf der Plattenverteilung im Chron 15, vor zirka 35 Millionen Jahren. Im untersten Oligozän (unterstes Kiscellien – Pshekien) bildete sich durch tektonische Vorgänge eine Ost–West gerichtete Schwellenzone, die am Westende der Tethys im Süden das Mediterran und im Norden das intrakontinentale Meer der Paratethys entstehen ließ.

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Die Turgai-Straße verlandete und ermöglichte den Faunenaustausch zwischen Europa und Asien ("Grande Coupure"). Im Norden bestand über die polnisch-dänische Meeresstraße ein mariner Faunenaustausch bis in das Kaspische Becken. In der Paratethys kam es durch die Abschnürung und das Absinken tiefer Becken zu anoxischen Ablagerungsbedingungen. Im tieferen Oligozän (mittleres Kiscellien – Solenovien) erreichte die Abschnürung der Paratethys ihren Höhepunkt. Nur am Westende, über die Prealps in Savoyen und über den Rheingraben bestanden noch schmale Verbindungen zu offenen Meeren. Weit verbreitet lagerten sich monospezifische Nannoplanktonmergel und Diatomite ab; der Salzgehalt sank stark ab. Über die ganze Paratethys vom Kaspischen Becken bis in die oberösterreichische Molasse breitete sich eine kleinwüchsige, endemische Bivalvenfauna aus ("*Cardium*" *lipoldi* - *Janschinella*-Fauna). Das Mittelmeer blieb weiterhin in offener Verbindung zum Indopazifik und Atlantik. Der nächste Zeitschnitt im Untermiozän (Aquitaniens – oberes Egerien – Karadzhalgan) beruht auf der Plattenverteilung in Chron 6B (23 Mill. Jahre). Dieses Niveau zeigt die weite Öffnung der Paratethys zum Indopazifik über den Iran, die im ganzen Becken vollmarine Verhältnisse und Warmwasserfaunen brachte. Von eher lokaler Bedeutung ist das Schließen des Rheingrabens und der alpinen Vortiefe zwischen dem Rhonebecken und Bayern. Im Mittelmeer begann die Öffnung des Balearen-Beckens und die Auffaltung und ostwärts gerichtete Überschiebung des Apenninenbogens. Durch die Rotation der Arabischen Platte öffnete sich der Graben des Roten Meeres. Ein kontinentaler Faunenaustausch zwischen Eurasien und Afrika war weiterhin nicht möglich.

Erst im höheren Untermiozän (oberes Burdigalien – Otnangien – unteres Kotsakhurien) schloß sich eine Landbrücke zwischen der Arabischen und der Anatolischen Platte. Die Verbindung zum Indischen Ozean wurde unterbrochen. Die Östliche Paratethys wurde zu einem abgeschnürten Becken mit endemischen Brackwasserbedingungen. In der Westlichen und Zentralen Paratethys bestanden vollmarine Verhältnisse mit einer offenen Verbindung zum Mittelmeer. Die westliche, alpine Vortiefe wurde in der Oberen Meeresmolasse neuerlich überflutet. Der Apennin setzte seine Bewegung mit einer Rotation im Gegenurzeigersinn fort. Durch tektonische Bewegungen kam es am Ende des Untermiozän zu großräumigen Umgestaltungen im Westen der Paratethys. Die West-Ost gerichteten Tröge wurden weitgehend durch intramontane Becken abgelöst (oberstes Untermiozän – oberstes Burdigalien – Karpatien – oberes Kotsakhurien). Das Meer zog sich aus der Alpenvortiefe, aus dem Transsylvanischen Becken und dem Balkan zurück. Über Slovenien bestand eine Meeresverbindung ins Pannonische Becken und von dort aus in die westliche Karpatenvortiefe. Die Östliche Paratethys blieb weiterhin isoliert. Die Landbrücke zwischen Eurasien und Afrika bestand wahrscheinlich noch, war aber schon stärker eingeschnürt.

Im unteren Mittelmiozän (Langhien – unteres Badenien – Tarkhanien) nahmen die tektonischen Aktivitäten weiter zu. Die Meeresstraße zwischen Mittelmeer und Indischem Ozean öffnete sich neuerlich an der Naht zwischen Arabischer und Anatolischer Platte. Aber auch über Ostanatolien wurde die Verbindung zur Östlichen Paratethys wieder aktiv. Eine Transgression ließ in der Paratethys vom Kaspischen Becken bis in die Karpaten-Vortiefe und das Wiener Becken, aber auch in den intramontanen Becken in Transsylvanien und in Ungarn, marine Ablagerungsräume entstehen. Eine westliche Verbindung zum Mittelmeer bestand über Slovenien. Da aber zwischen der Biofazies der Östlichen und Zentralen Paratethys tiefgreifende Unterschiede bestehen, wird eine hypothetische Meeresverbindung zwischen dem Südrand der Schwarzmeer-Platte und dem Nordrand der Anatolischen-Platte angenommen. Durch eine derartige Meeresstraße läßt sich die vollmarine, tropisch-subtropische, einheitliche Fauna in der Karpatenvortiefe und in Transsylvanien beziehen. Eine neuerliche Umgestaltung erfolgt zu Beginn des Serravallien (mittleres Badenien – Karaganien). Die Meeresverbindung vom Indischen Ozean zum Mittelmeer wurde im Nahen Osten endgültig und zur Paratethys vorübergehend geschlossen. Die Levante Störung wurde ebenso wie die Ost- und Nordanatolische Störungszone aktiv. Dies wurde durch die endgültige Kollision der Arabischen und Anatolischen Platte in der Bitlis Zone verursacht. Die Abschnürung der Paratethys war gleichzeitig mit einem neuerlichen Zerfall in zwei getrennte Bioprovinzen verbunden. Die Östliche Paratethys wurde im Karaganien wiederum zu einem endemischen Brackwasserbecken mit einer Fauna, die von der Bivalve *Spaniodontella* dominiert war. In der Zentralen Paratethys blieb die Verbindung über den "Trans-Tethyan-Trench-Corridor" in Slovenien zum Mittelmeer bestehen. Regressionen setzten auch hier ein und brachten im höheren Mittelbadien die Abschnürung der Karpatenvortiefe und des Transsylvanischen Beckens mit mächtigen Evaporitbildungen. Der nächste Schritt der paläogeographischen Entwicklung erfolgt sehr rasch, noch immer im unteren Serravallien (oberes Badenien/Kosovien – Konkian). Durch eine neuerliche Transgression wurde fast das gleiche Gebiet der Paratethys wie im unteren Badenien/Tarkhanien überflutet. Entlang der Störungszone in Ostanatolien öffnete sich die alte Meeresstraße zum Indischen Ozean. Die Verbindung zum Mittelmeer im Westen hatte sich geschlossen. Die Fazies zwischen Östlicher und Zentraler Paratethys war zwar

sehr ähnlich, im unteren Kosovien des Transsylvanischen Beckens und der Karpatenvortiefe bestanden aber die besten marinen Bedingungen mit der Ablagerung von Radiolarien-Schichten. Darüber folgten in der gesamten Zentralen Paratethys Pteropodenmergel, die im oberen Kosovien von einer regressiven Phase mit Faunenverarmung abgelöst wurden. Der Mikrofossilinhalt und die Fischfauna des oberen Badenien belegen eine indopazifische Verbindung, die sich deutlich vom Serravallien des Mediterran unterscheidet.

Als letzter Zeitschnitt wird das untere Sarmatien (Volhynien) präsentiert. Die Paratethys wurde im oberen Kosovien/Konkien vom Indopazifik getrennt. Eine neue Meeresstraße öffnete sich entlang der Ostanatolische Störungszone zwischen Mediterran und Östlicher Paratethys. Sie folgte dem oberen Euphrat-Tal in das Araks-Becken und das Kaspische Becken. In der gesamten Paratethys entstand im Untersarmat eine einheitliche Fauna mit vielen Endemismen bei reduzierter Salinität und starker Zunahme des Karbonatgehaltes und der Alkalinität. Das Ende der Paratethys mit zunehmender Kontinentalisierung und Verlagerung der aquatischen Bereiche in den Osten wurde in diesen Skizzen nicht mehr dargestellt.

Introduction

Palaeoceanographic changes, the opening and closing of seaways between oceans, as well as deep-water and surface currents influence climatic conditions and faunal exchanges. These factors are driving forces in evolution. An example for such changes is the vanishing Tethys and the birth of the Mediterranean and Paratethys Seas. Plate tectonic motions, with the northward drift of India and Australia and a simultaneous counterclockwise rotation of Africa, closed the Tethys Ocean. In the late Eocene, India collided with Asia, and the compression between Africa and Europe formed an active Alpine mountain belt along the southern border of the Eurasian continent. Finally, at the Eocene/Oligocene boundary, a southern Mediterranean Sea was created at the western end of the Tethys and an intercontinental Paratethys Sea arose north of this tectonic belt.

Different palaeogeographic reconstructions have been presented for the entire area or parts of it. One problem with the general reconstructions was the duration of the time-slices, where too much of geological time was shown in one map (e.g. BIJU-DUVAL et al. 1977, DERCOURT et al. 1985). In other cases the paleogeography is presented in the form of facies distribution maps (e.g. HAMOR & HALMAI 1988, CAHUZAC et al. 1992, POPOV et al. 1993). Sometimes the distances between different time slices failed to provide the necessary resolution (e.g. DERCOURT et al. 1993). For the Mediterranean, certain regional maps (e.g. BOCCALETTI et al. 1986, 1990) show the necessary resolution and details of facies distribution based on palinspastic reconstructions.

Some of the results of IGCP Project No. 25 "Tethys-Paratethys Neogene" were presented as a series of time slices for the circum-Mediterranean Neogene (RÖGL & STEININGER 1983, STEININGER & RÖGL 1984, STEININGER et al. 1985). The knowledge of regional palaeoecological development and correlation was still scanty at that time, and tectonically based palinspastic reconstructions were missing in critical areas. The postulated land and sea distributions were therefore presented as sketches only. The main purpose was to demonstrate marine faunal relations and potential continental migrations. This model is still fragmentary and problematic, and may be incorrect in many details. A revised and stratigraphically extended series of time slices is presented here, although many questions in tectonically active regions remain unresolved. The new sketches are based on the plate distribution of SCOTESE et al. (1988), and missing time levels are interpolated between two successive horizons. The most critical areas are the bend of the South Carpathians, the Balkanides, and the North Anatolian fault zone, where no

Neogene reconstructions exist. In these areas any reconstruction is hypothetical or, in the words of J. KOKAY (1984: 47), "sheer nonsense". Otherwise different paleomagnetic measurements exist in the northeastern Mediterranean, demonstrating a northward drift of about 10° latitude since the early Miocene. Such distances provide enough space for connecting seaways in any direction. The sketches are based on existing palinspastic reconstructions of distinct areas, facies distribution, palaeobioprovincial similarities, and necessities for mammal migration: ADAMS (1973), ADAMS et al. (1983), BALDI (1986), BALLA (1987), BOCCALETTI et al. (1986, 1990), DERCOURT et al. (1993), GOFF et al. (1995), DE GIULI et al. (1987), HAMOR & HALMAI (1988), JONES & RACEY (1994), KOVAC et al. (1989), MARTINI (1990), NEVESSKAYA et al. (1984, 1987), NEY et al. (1974), POMEROL (1973), POPOV et al. (1993), VINKEN (1988), VINOGRADOV (1967–69), ZIEGLER (1990).

The series of sketches begin with the late Eocene in order to include the birth of the Paratethys and to demonstrate the "Grand Coupure" event in European mammal evolution. The different horizons have been selected according to distinct palaeogeographic changes. One of those important events is the closure of the Eastern Mediterranean seaway and the rise of the "*Gomphotherium* Landbridge" in the early Miocene. The history of the Paratethys is more complicated than that of the Mediterranean. Therefore the definition of a Paratethys bioprovince by LASKAREV (1924) for the later Neogene was revised and re-defined over the years. A regional subdivision into Western, Central, and Eastern Paratethys was proposed by SENES (1960). Based on the geodynamic and palaeobiological development, different evolutionary stages were distinguished by SENES & MARINESCU (1974) and RUSU (1988): Protoparatethys (early to middle Oligocene, Kiscellian), Eoparatethys (late Oligocene to early Miocene, Egerian–Ottományian), Mesoparatethys (late early Miocene to early middle Miocene, Karpatian–middle Badenian) and Neoparatethys (middle Miocene to Pleistocene, late Badenian–Neoeuxinian). The relations between palaeogeographic patterns and mammal migrations were discussed recently by RÖGL (1996a, 1998). The discussion is influenced by the situation of the Paratethys, and therefore more details are presented for this area.

Stratigraphic correlation (tab. 1)

A stratigraphic correlation between the Mediterranean standard scale and the regional stage systems of the Central and Eastern Paratethys is presented in table 1. The stratigraphic correlation follows BERGGREN et al. (1995) and for the Central Paratethys RÖGL (1996b). An updated stratigraphic system was proposed for the Oligocene of the Eastern Paratethys by VORONINA & POPOV (1985) and POPOV et al. (1993). The Neogene marine and continental correlation was discussed by STEININGER et al. (1996). The Mediterranean stratigraphy is connected with a continuous marine development and is therefore comparable to the stratigraphic standard scale. The Paratethys basins were isolated for different times and different regional stage systems are in use for the Central and Eastern Paratethys. The definition of the Paratethys bioprovince, with first isolations from open oceans around the Eocene/Oligocene boundary, follows BALDI (1969, 1979), VORONINA & POPOV (1985), and POPOV et al. (1993). During the early Oligocene the isolation increased throughout the area (Protoparatethys), followed by more open marine connections in the late Oligocene and early Miocene (Eoparatethys). During the early–middle Miocene the history of the central and eastern part developed in different directions

M. A.	EPOCH	AGE	CENTRAL PARATETHYS STAGES	EASTERN PARATETHYS STAGES	BIOZONES Berggren & al. 1995		
					Planktonic Foraminifera	Calcareous Nannoplankton	
5	PLIOCENE 5.3	ZANCLEAN	DACIAN	KIMMERIAN	PL1	NN13	
		MESSINIAN	PONTIAN	PONTIAN	M14	NN12	
10	Late MIOCENE 11.0	TORTONIAN	PANNONIAN	MAEOTIAN	M13	b	
		SERRAVALLIAN				SARMATIAN	SAR-MATIAN
		LANGHIAN	BADENIAN	Khersonian	M11-M8	NN11	
			BURDIGALIAN	EGGENBURGIAN		Bess-arabian	NN10
15	Middle MIOCENE 16.4	AQUITANIAN	EGGERIAN	KARADZHALGAN	M7	NN9b	
		CHATTIAN				KALMYKIAN	M6
		RUPELIAN	KISCELLIAN	SOLENOVIAN	M5	NN7	
			PRIABONIAN	PRIABONIAN		BELOGLINIAN	M4
20	Early MIOCENE 23.8	BURDIGALIAN	KARPATIAN	KOTSAKHURIAN	M3	NN5	
		AQUITANIAN	OTTNANGIAN	SAKARAU LIAN	M2	NN4	
		CHATTIAN	EGGENBURGIAN	SAKARAU LIAN	M1	NN3	
		RUPELIAN	KISCELLIAN	SOLENOVIAN	M1	b	
PRIABONIAN	PRIABONIAN	BELOGLINIAN	a	NN2			
25	OLIGOCENE	CHATTIAN	EGGERIAN	KARADZHALGAN	P22	NN1	
		RUPELIAN	KISCELLIAN	SOLENOVIAN		P21	b
		PRIABONIAN	PRIABONIAN	BELOGLINIAN	P20		a
		PRIABONIAN	PRIABONIAN	BELOGLINIAN		P19	NP24
30	OLIGOCENE	RUPELIAN	KISCELLIAN	SOLENOVIAN	P18	NP23	
		RUPELIAN	KISCELLIAN	SOLENOVIAN	P17	NP22	
		PRIABONIAN	PRIABONIAN	BELOGLINIAN	P16	NP21	
		PRIABONIAN	PRIABONIAN	BELOGLINIAN	P15	NP	
35	Late EOCENE	PRIABONIAN	PRIABONIAN	BELOGLINIAN	P15	19-20	
		PRIABONIAN	PRIABONIAN	BELOGLINIAN		NP18	

Tab. 1. Stratigraphic correlation chart of the standard scale with Central Paratethys and Eastern Paratethys regional stage systems, and the planktic foraminifera and calcareous nannoplankton biozonation (acc. BERGGREN et al. 1995, POPOV et al. 1993, RÖGL 1996b).

(Mesoparatethys), continuing in the middle–late Miocene with strong endemisms (Neoparatethys). The Western Paratethys (Haute Savoie, Switzerland, Bavaria) had strong affinities to the Mediterranean during marine phases.

A key point in Cenozoic stratigraphy was the definition of a GSSP (global boundary stratotype section and point) for the Eocene/Oligocene boundary (PREMOLI-SILVA et al. 1988). The boundary is based on the extinction of planktonic foraminifera due to a sequence of events, ending at the boundary with the last appearance of Hantkeninidae. This event falls within nannoplankton zone NP 21, and is not very applicable in temperate areas. In the Paratethys the indicative microfossils are generally missing in the late Eocene; therefore the boundary is tentatively positioned by different authors at the first appearance of "*Globigerina tapuriensis*" within NP 21. Another GSSP has been defined for the Paleogene/Neogene boundary (STEININGER et al. 1997). This palaeomagnetically defined boundary is near the first appearance of *Paragloborotalia kugleri*, and correlates to the base of nannoplankton zone NN 1. These events are also problematic in Paratethys stratigraphy as *P. kugleri* is a tropical marker, and the definition of NN 1 is difficult there. A better stratigraphic marker horizon defines the base of middle Miocene based on the worldwide first appearance of the genus *Praeorbulina*, which is recorded in the Mediterranean and the Central Paratethys. Beginning with the final closure of open marine connections and the rise of endemisms in the upper middle Miocene (Sarmatian) of the Paratethys, correlation with the stratigraphic standard scale becomes more difficult. It is based mostly on single nannoplankton horizons of brief marine incursions and on second order correlations with the mammal zonations.

Selected palaeogeographic horizons

Late Eocene – Priabonian – Beloglinian (37 – 33.7 Ma), plate 1

The presented time-slice includes nannoplankton zones NP 18 to lower NP 21, corresponding to planktonic foraminifera zones upper P 15 to P 17. It is based on the plate distribution of Chron 15, around 35 Ma (SOCTESE et al. 1988). The collision of the Indian plate with the Asian craton closed the Tethys Ocean north of India. In the whole area of the later Mediterranean, strong compressions occurred during the Pyrenean tectonic phase with crustal shortenings and emplacement of nappes. In connection with the Eocene subduction, a back arc thrust belt formed along the Paratethys basins north of a magmatic arc running from the Rhodopes to northern Iran (BOCCALETTI 1979). The distribution of the sea between Asia and India, in the Ponto-Caspian region, and along the southwestern margin of the Tethys is compiled from VINOGRADOV (1967–69), DERCOURT et al. (1993), POPOV et al. (1993), GOFF et al. (1995), and from ADAMS et al. (1990). According to ADAMS, upper Eocene larger foraminifera are reported from the relic sea between India and Asia, in the Himalayan collision zone. The western part of the Tethys Ocean covered the Mediterranean and the area of the later Paratethys. In the Apennine basins of the Western Mediterranean, pelagic sedimentation crossed the Eocene/Oligocene boundary. Tectonic activities gave rise to island chains in the Alpine-Carpathian arch (OBERHAUSER 1995) and further to the east in the Pontides and in the Caucasus. Along this chain, sedimentation continued in the western Prealps, in the Alpine Gosau basins, and in the Carpathian flysch troughs as well as in the Helvetikum basin, from where the Eocene sea transgressed on the European platform. The facies development on this platform

is described in detail by WAGNER (1980). In the shallow algal limestone facies of the Molasse Basin the Eocene/Oligocene boundary is taken at the extinction of *Discocyclina*.

The Hungarian Paleogene basin is now interpreted as a retroarc flexural basin with a shift of depocenters in a northeastern direction (TARI et al. 1993). In the Priabonian, biogenic limestones with rich megafauna, nummulites and discocyclinids were deposited, followed after a short erosional interval by Bryozoa Marls. Due to gradual deepening of the basin, the deep-water Buda Marl followed with a change of the mollusc assemblages to *Propeamussium* and *Palliolium*. In turbiditic intercalations, shallow faunas with *Nummulites fabiani* occur. The basin was in direct communication with the North Italian basins (BALDI 1984, 1986). The upper Eocene mollusc fauna of the Transylvanian Basin also had Mediterranean affinities. In the Brebi Marls, *Turborotalia cerroazulensis cerroazulensis* and *T. cerroazulensis cocoaensis* are recorded (IVA & RUSU 1982).

In the Eastern Paratethys Beloglinian Basin, the richest tropical mollusc faunas were recorded from Transcaucasia, and the lowest diversity with cold water influences were in the Transcaspiian Ustyurt Basin. Marine sedimentation existed as far east as Tadshikistan. The Turgai Strait, as a shallow seaway, connected the warm waters of the Tethys with the Polar Sea. West–east elongated deep-water basins with pelagic sedimentation extended from the Black Sea to Ciscaucasia and the Caspian Basin, but also in the south in Transcaucasia and Kopet Dag. The stratotype of Beloglinian is situated in the famous Kuban River section near Cherkessk, with white *Globigerina*-marls (Belaya Glina) of the *Globigerapsis tropicalis*-, *Globigerina corpulenta*-, and the Oligocene *Globigerina tapuriensis* Zones, and is transitional in the upper part to the Khadum Beds with the *Bolivina antegressa* Zone. In Armenia, *Cribohantkenina* and *Turborotalia cunialensis* are reported from the uppermost Eocene, and correlate to the Eocene/Oligocene boundary in the Apennine Basin (KRASHENINNIKOV et al. 1986, KRASHENINNIKOV & AKHMETIEV 1996, POPOV et al. 1993). In the western part of the Beloglinian Sea, rich tropical mollusc faunas occurred in the locality Mandrikovka in the Ukraine (NP 18 to 20, acc. MARTINI & RITZKOWSKI 1970), and in southern Bulgaria. Wide-spread upper Eocene sediments were deposited from the region of Varna to Thrace and the eastern Rhodope Massif, and were connected over the Erdine Basin (Turkish and Greek part of Thrace) with the Mediterranean Tethys. Volcanites are intercalated in the sequence with molluscs (e.g. *Propeamussium fallax*, *Limopsis scalaris*, *Thyasira ignota*), nummulites and discocyclinas. In the southwest, coral limestones are common. (KOPP 1965, KOJUMDIEVA & SAPUNDGIEVA 1981, GORANOV et al. 1986, SAPUNDGIEVA 1986).

A shallow water connection existed between the Paratethys and the North Sea Basin via the Danish–Polish trough (KRUTSCH & LOTSCH 1958, VAN COUVERING et al. 1981, VINKEN 1988, ZIEGLER 1990). According to the results of IGCP Project no. 124, the Latdorfian during NP 21 nannoplankton zone (upper Eocene – lower Oligocene) was transgressive in the Baltic region. The palaeogeography of western and northwestern Europe follows POMEROL (1973, 1982), ZIEGLER (1990), and the IGCP results (VINKEN 1988). The southern Rhine Graben opened in the late Eocene but was filled by brackish sediments and probably secondarily deposited potash salts. A connection with the Pre-alpine Basin is questionable (MARTINI 1990, HUBER 1994).

For western Eurasia and the Mediterranean a zoogeographic zonation based on Eocene bivalves has been proposed by POPOV (1994). He has found the strongest differences

between the southern (Indo-African province) and northern (Mediterranean province) coasts of the Tethys. In the north, the North European and in Asia the Turan provinces follow. This zonation is in agreement with the distribution of larger and planktic foraminifera.

Early Oligocene – lower Rupelian – lower Kiscellian – Pshelian (33.7 – 32 Ma), plate 2

The earliest Oligocene time slice corresponds to nannoplankton zones upper NP 21 and NP 22, and the foraminifera zone P 18. The plate distribution is still based on the time slice of Chron 15 (SCOTSE et al. 1988). The palaeogeographical configuration is compiled from KRUTSCH & LOTSCH (1958), VINOGRADOV (1967–69), POMEROL (1973, 1982), VAN COUVERING et al. (1981), ADAMS et al. (1983), VINKEN (1988), ZIEGLER (1990) and POPOV et al. (1993).

A tectonic turnover changed the palaeogeographic pattern of Eurasia. The new bioprovince of the Paratethys was born. Along the Alpinotype tectonic belts, the open seaways were narrowed between the Mediterranean Tethys and the Western/Central Paratethys. The Eastern Paratethys was closed off from the Indian Ocean. In the north, the important Turgai Strait became dry land and opened the migration pathway for Asian and American mammals to the west. These events coincided with the strong sea level change TA 4.3/TA 4.4 of HAQ et al. (1988) within NP 21. Continentalisation also increased in central and western Europe. The Danish–Polish Trough connected the North Sea Basin with the Eastern Paratethys only during Latdorfian time (NP 21). The Rhine Graben opened a narrow connection between the Prealpine Basin and the North Sea, reaching a maximum flooding in the middle Pechlbronn Beds in nannozone NP 22 (TOBIEN 1987, MARTINI 1990), where the important "Grande Coupure" mammal event is dated. This also dates the closure of the Danish–Polish seaway in NP 22, and the opening of intercontinental migrations.

The tectonic movements caused a distinct isolation of the entire Paratethys. Deep, starving basins with reduced circulation and dysaerobic bottom conditions developed from the Western Alps to the Transcaspien Basin. In the Prealps at the top of the Eocene a progressive change from "Marnes à Foraminifères" to the "Schistes à *Meletta*" occurred, with dark dysaerobic shales and pyritized microfossil preservation (CHAROLLAIS et al. 1980, Ujetz 1996). In the North Helvetikum, flysch and black fish shales of Glarus (Switzerland) were deposited. These dark fish shales (NP 21–22) continued to the east in the Molasse Basin of Bavaria and Austria, and are the source rock of Molasse oil. Few well-oxygenated layers contain rich benthic and planktic microfossils. To the south the fish shales were replaced by flysch sedimentation (Deutenhausen Beds). The continuation in the Carpathian flysch basins shows the same changes from *Globigerina* marls to dark, laminated dysaerobic marls and shales, and widespread turbidites. From W to E, in Moravia, follow the upper Pouzdrany Marls, upper Sheshory Marls and Subchert Member of the Menilitic Formation; in Poland the Menilite Fm. with Jamna Shales, Boryslaw Sandstone, and Kotow Cherts (KRHOVSKY et al. 1991, KOTLARCZYK 1988, KOTLARCZYK et al. 1991). In the Rumanian flysch, in an inner belt of the Pucioasa - Fusaru facies in the early Oligocene, the Lower Dysodilic Shales were deposited, and in the outer bituminous Kliwa facies the Lower Menilitic Formation developed (SANDULESCU

& MICU 1989, RUSU et al. 1996). From the Prealps in the west to the Carpathian flysch basins in the east, full marine intercalations in the dysaerobic sediments decreased. An interesting bioevent in these sediments of nannozone NP 22 is the mass occurrence of small planktic foraminifera with a bipolar distribution showing North Sea Basin and New Zealand similarities: *Chiloguembelina gracillima* (*Ch. ototara*), *Ch. cubensis*, *Tenuitella? danvillensis* (*T.? aculeata*), *T. munda*, *Globigerina officinalis*, *G. ouachitaensis*.

In the North Hungarian Paleogene Basin the transition from light-coloured Buda Marls to the Oligocene (lower Kiscellian) Tard Clay was gradual, with intercalations of dark laminites and a continuous increase of clay contents. The sedimentation rate in the lower Tard Clay was very low under dysaerobic conditions. In the lowermost Tard Clay, planktic foraminifera and the bivalve *Propeamusium fallax* still occurred. In laminitic beds of the lower Tard Clay, two pteropod horizons with *Limacina* contain fish scales and an increased pyrite content (NP 22). These horizons are also found in the Western Carpathians (BALDI et al. 1984, BALDI & BALDI-BEKE 1985, KRHOVSKY et al. 1991, KRHOVSKY 1995, SEIFERT et al. 1991, RÖGL et al. 1997). In the Transylvanian Basin the Eocene/Oligocene boundary lies within the Brebi Marls, which merge from the Hoia Beds into the early Oligocene Mera Beds (Merian regional stage). In the shallower facies the sequence is represented by the Cozla Limestone and the Cuciulat Formation, and is followed by the bituminous Bizusa Formation. A rich mollusc fauna is described, with a *Pycnodonte gigantea* level marking the boundary. The marine character of the lowermost Oligocene sediments is documented by different molluscs (e.g. *Chlamys bellucostata*, *Pitar incrassata*, *Turritella biarritzensis*), echinoids (*Scutella subtrigona*), and small nummulites (*Nummulites retiatius*), comp. IVA & RUSU (1982), MESZAROS et al. (1989), RUSU et al. (1996). The development in Bulgaria is more similar to the Transylvanian Basin than to the Psheikian Basin. Continuing from the late Eocene, marine sediments with faunas of Mediterranean Tethys affinities were deposited in the area of the eastern Rhodope Massif and in Thrace. Strong volcanic activity continued. The sediments contain small nummulites (*Nummulites incrassatus*, *N. intermedius*, *N. vascus*), molluscs (*Pycnodonte gigantea*, *Spondylus cisalpinus*, *Laevicardium comatulum*, *Ampulina crassatina*, *Globularia angustata*), and echinoids with *Echinolampas*, *Eupatangus* (e.g. KOPP 1965, SAPUNDGIEVA 1986, STRASHIMIROV & MOEV 1988).

In the Eastern Paratethys the Psheikian Basin had nearly the same dimensions as in the upper Eocene. An increase in basin depth, and dividing islands and shallows in a W–E direction are observed. Hydrogen sulfide contaminations in the bottom waters and metallic exhalations prevented all benthic life, but promoted the precipitation of giant manganese ore deposits at the shelves. In the Kuban River section a transition from the Belaya Gлина marls to the dark, carbonate-free and laminated marls with fish remains of the Khadum Formation occurred. The planktic foraminiferal assemblage yields *Globigerina ampliapertura*, *G. officinalis*, *Subbotina prasaepis*, *Tenuitella gemma*, *Pseudohastigerina micra* (KRASHENINNIKOV 1986). A strong northern influence is observed in the mollusc faunas of the shallow areas, which were very rich in the Ustyurt Basin in Transcaspia but also in the SE in the Kopet Dag. The bivalve fauna is characterised by *Palliolium simile*, *Yoldiella chadumica*, *Pterolucina batalpaschinica*, *Thyasira nysti*, *Flabellipecten stettensis*. In contrast, the Transcaucasian faunas were still tropical (*Atrina*, *Isognomum*, *Cubitoostrea*, *Ctena*). In the upper part of the Psheikian the sea regressed, and some endemic molluscs developed in the Transcaspian Basin (POPOV et al. 1993). The closure between

Plate 1: The vanishing Tethys Ocean.

The northward drift of the Indian continent and the rotation of Africa left an elongated sea at the western end of the Tethys and south of the Asian continent. The Turgai Strait, communicating with the Polar Sea, hindered mammal migrations between Asia and the European archipelago in the Eocene.

Plate 2: The birth of the Mediterranean and Paratethys Seas.

At the Eocene-Oligocene boundary, tectonic activity created the Eurasian intercontinental Paratethys Basin, and the Mediterranean Sea in the south. The seaway from the Indo-Pacific to the Atlantic stayed open. The Turgai Strait closed and enabled continental migrations. An open connection through the Danish-Polish Trough brought cool waters from the North Sea into the Eastern Paratethys. The deep basins had a strongly reduced oxygen content, and the Eastern Paratethys was poisoned by exhalations of hydrogen sulfide and metals. In the Western Paratethys the Rhinegraben opened a new strait to the north.

Plate 3: The dysaerobic Paratethys Sea.

The disconnection of the Paratethys Basin increased during early Oligocene. Dysaerobic conditions continued in the deep basins. The very narrow marine seaways stayed open in the west. Salinity decreased, monospecific nannoplankton blooms and diatomites were widespread. An endemic bivalve fauna spread over the entire basin. No changes occurred in the Mediterranean Basin.

Plate 4: Tropical incursions.

Around the Paleogene - Neogene boundary a warm water transgression spread from the Middle East to the Mediterranean and the entire Paratethys. A horizon of larger foraminifera (*Lepidocyclina* horizon) marks this event throughout the area, and Indo-Pacific corals grew along the Lut Block from Makran to Qum Basin and Lake Urmia. Along the eastern shelf of the Arabian Plate, evaporite basins developed. 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 and initiated the eastward movement of Sardinia, Corsica, and the Apennine belt.

the Eastern Paratethys and Mediterranean is documented in Thrace by the deposition of dark, laminated clays with fish remains ("paper shales"), and also by the occurrence of the two "*Spiratella*" marker horizons near Bjala at the Black Sea coast of Bulgaria (KOPP 1965, SAPUNDGIEVA 1986).

Early Oligocene – lower Rupelian – lower Kiscellian – Solenovian (32 – 30 Ma), plate 3

The Solenovian horizon spans about the time of nannoplankton zone NP 23, approximately P 19 of the foraminiferal zonation. The plate distribution of Chron 15 is corrected towards the next horizon in the lowermost Miocene of SCOTSE et al. (1988). This was the time of the most intensive restriction of the Paratethys, with the most far-reaching uniform facies distribution in the entire history of the Paratethys. During this time the connection between the Mediterranean Basin and the Indo-Pacific remained unchanged. Tectonic activities along the northern border of the Mediterranean are documented by overthrusts and by the subsidence of the molasse basin of the Mesohellenic Trough in the Pelagonian and Pindos zones.

A peculiar facies development characterized the Solenovian Basin. Carbonate-free dark sediments of the "Maikop" facies were wide-spread. In the Volga–Don region, and also in the Kuban River section, the lower part of the Solenovian consisted of light-coloured marls and clays with carbonate-free intercalations. In the upper part, dark, carbonate-free clays prevailed. The marls contain layers of ostracods specific to reduced salinity (*Disponocypris oligocaenica*) and monospecific nannoplankton blooms (*Dictyococcites ornatus*). The mollusc fauna was restricted to very small endemic bivalves (*Ergenica*, *Urbnisia*, *Korobkoviella*, in the upper part *Janschinella*, *Cyrtodaria*, *Nucula*). The correlation of the upper boundary of the Solenovian is difficult, as the upper part – the lower member of the Morozkina Balka Formation – is not well dated, and the lower part of the upper member (already Kalmykian) is still in nannozone NP 23 (KRHOVSKY et al. 1995). In Transcaucasia the endemic fauna was distinctly richer, with about 20 species including cardiids (*Cerastoderma*, *Merklinocardium*). The same Solenovian fauna is reported from southern Bulgaria from the Thrace Basin near Plovdiv (Srednogorje Unit of Balkanides) with "*Cardium*" *lipoldi*, *Nucula comta*, *Janschinella garetzkii*, *Lenticorbula sokolovi*, *Cerastoderma merklini*. In the upper part of this sequence (Ezerovo Fm.) the fauna was dominated by *Lenticorbula sokolovi*, associated with *Cerastoderma* spp., followed by a horizon with *Lenticorbula helmersenii* (KOJUMDGIEVA & SAPUNDGIEVA 1981).

For the Paratethys the only open marine connections existed in the far west. The Prealps in Savoy were connected to the Mediterranean, but had a marine development with partly dysaerobic *Meletta* Shale facies. A transgression from the northern Hessian Depression linked the marine sands in the Maynce Basin and Foraminifera Marls of the Rhine Graben with the Alpine Foredeep (MARTINI 1990, HUBER 1994, UJETZ 1996). A fine clastic marine sedimentation of "Tonmergelschichten", partly distal turbidites, is found in the western Molasse of Switzerland and Upper Bavaria. In the still starving deep basin of the Upper Austrian Molasse the coccolith marlstone of the "Heller Mergelkalk" with *Dictyococcites ornatus* blooms was deposited within NP 23. It is continuous with the underlying fish shales. This sediment corresponds to the Dynow Marlstone of the Carpathians (KOTLARCZYK & LESNIAK 1990, KRHOVSKY et al. 1991, RÖGL et al. 1997). This nanno-chalk contains some endemic bivalves of the Eastern Paratethys (*Janschinella*,

Ergenica). The following dark, laminated clays of the "Bändermergel" with thin white nannoplankton surfaces (blooms of *Dictyococcites ornatus*), are carbonate-free in the lower part of different drilled sections, and in the lower part probably belong to NP 23. This part may be correlated to the upper Solenovian carbonate-free Lower Morozkina Balka Formation in the Belaya River section (KRHOVSKY et al. 1995, and pers. comm.). In the Carpathian basins the Menilitic Formation consists of dark turbidites, diatomaceous mudstones, diatomites and cherts (Chert-, Hornstone-Member and Futoma Diatomite), followed by the Dynow Marlstone, and the Rudawka Member with shales and thin-bedded sandstones. The diatomites contain freshwater and brackish water diatoms. This is explained by strong stratification of the water column and occasional freshwater overflow. An interesting phenomenon is some thin layers of laminated coccolith limestone (6–10 laminae per millimetre), where a few-centimetre-thick layers can be traced over hundreds of kilometers (from Poland to Rumania). These layers are sometimes subdivided by turbidites into a few thin beds. In NP 23 the Tylawa Limestones were deposited and consist of blooms of *Dictyococcites ornatus* and *Transversopontis fibula* (HACZEWSKI 1989, RUSU et al. 1996).

The connection from the Venetian Basin to Slovenia was probably strongly reduced, and in the Hungarian Paleogene Basin the sedimentation of Tard Clay continued. Under reduced salinity conditions the endemic "*Cardium lipoldi*" fauna immigrated from the east. This endemic bivalve assemblage is also recorded from the western end of the Carpathians (Waschberg Unit, Austria), corresponding to the "*Janschinella-Ergenica*" fauna (BALDI 1979, 1984; SEIFERT et al. 1991). In the Transylvanian Basin, the upper Bizusa Formation consists of whitish marlstones and bituminous shales, and contains a rich fauna of "*Cardium*" *lipoldi*, *Janschinella*, *Ergenica*, and also the pteropod *Limacina* (RUSU et al. 1996). Rich ostracod assemblages are reported as well. It was followed by the Ileanda Formation, dark bituminous claystones to siltstones, with intercalations of sideritic limestone layers. A few thin layers of Tylawa Limestone are intercalated (HACZEWSKI 1989, RUSU et al. 1996). The marine seaway to the Mediterranean in southern Bulgaria also was closed as shown by the occurrence of a "*Cardium*" *lipoldi* fauna in the Balkanides (KOJUMDGIEVA & SAPOUNDGIEVA 1981). The biotas point to reduced salinities and cooler waters in most of the Paratethys Basin from Bavaria to Transcaspia.

Middle to late Oligocene – upper Rupelian to Chattian – upper Kiscellian to lower Egerian – Kalmykian (30–23.8 Ma)

This period has a rather long time range because it is more uniformly developed and poorly subdivided in the Paratethys. It comprises nannoplankton zones NP 24–25. No reconstruction is provided here, as the differences with the early Miocene configurations are insignificant. The Mediterranean Oligocene basin remained unchanged for a long time. The Apennine trough had a western position till the late Oligocene, then the Balearic Basin opened, causing the overthrust of Apennine nappes (BOCCALETTI et al. 1990). Beginning with NP 24 a distinct change of sedimentation occurred throughout the Paratethys due to tectonic activities and uplift in the mountain chains. The deep troughs were filled with thick clastic sediments. New seaways from the Indian Ocean and Mediterranean to the Paratethys opened. Normal marine conditions were re-established throughout the basin.

Connections of the Paratethys to the North Sea Basin still existed via the Rhine Graben. In the upper Rupelian *Meletta* Beds the current system was northward directed in NP 24, and the connection to the North Sea continued to the lower Chattian *Cyrena* Beds. After some disruption by freshwater sedimentation, the seaway was re-opened from the north in the upper Chattian *Cerithium* Beds. In the late Oligocene the connection was closed and freshwater beds were deposited in the southern Rhine Graben (MARTINI 1990, HUBER 1994). In the western Alpine foredeep, marine clastic sedimentation of silts, clays, and sandstones occurred under well oxygenated conditions. In the deeper part of the basin this sedimentation was strongly influenced by turbidites. In the upper Oligocene the basin was closed in the west by coarse fluvial sediments of the Lower Freshwater Molasse. A paralic coal basin and brackish *Cyrena* Beds developed in the Bavarian embayment. The deep Austrian Molasse Basin communicated to the SW with the Mediterranean Sea (WAGNER 1996). In the Carpathian flysch basins the Menilitic Formation continued with variegated clays, dark shales and thick turbiditic sandstones (Kliwa Sandstone). Laterally the Menilitic Formation interfingered with gray clays, siltstones and sandstones of the Lower Krosno Formation (KOTLARCZYK 1988). In the Rumanian Carpathians the sedimentation was similar (SANDULESCU & MICU 1989), and in both regions thin layers of laminated coccolith limestone (Jaslo Limestone, NP 24) occurred again.

The conditions also changed in the Hungarian and Transylvanian Basins; a broad seaway had opened to the Venetian Basin in the SW. The more clastic Kiscell Clay (NP 24) was transgressive on the Tard Clay. A very rich benthic microfauna (*Clavulina szaboii* Beds of HANTKEN 1875) and well dated planktic assemblages are reported. The Schlier facies and sandstones of the Eger Group (upper NP 24 to NP 25) continued without interruption. From the Egerian sections rich mollusc faunas with e.g. *Palliolium incomparabilis*, *P. decussata*, *Flabellipecten burdigalensis*, *Mytilus aquitanicus*, *Pitar beyrichi*, *Glycimeris latiradiatus* are described. And in the upper part of the Oligocene the widespread Mediterranean horizon of larger foraminifera appeared with e.g. *Miogypsinoides formosensis*, *Miogypsina septentrionalis*, *Lepidocyclina dilatata*, and *L. morgani* (BALDI et al. 1961, BALDI & SENES 1975, BALDI 1969, 1980). In Transylvania the upper Ileanda Formation continued without break in the Buzas Formation (prevailing sandstones) and Vima Formation (NP 24 to NN 2). The Vima Fm. was the pelitic deep-water equivalent and also contained thin coccolith layers of the Jaslo Limestone. The microfauna of the lower part compares well with the Kiscell Clay, and in the upper part Chechis type assemblages are developed (BOMBITA 1989, RUSU et al. 1996). In the Buzas Fm. some characteristic mollusc horizons appear. Boreal influences are observed in the *Pycnodonte callifera* level in NP 24, with *Thracia speyeri*, *Angulus nysti*, *Arctica rotundata*, *Pholadomya puschi*, and *Turritella venus*. In NP 25, two slightly impoverished horizons follow, the *Turritella* and the *Thracia* level. In upper NP 25 the *Amusiopecten burdigalensis* level occurred, indicating warmer climates. The assemblage includes *Cardium egerense*, *Nuculana psammobiaeformis*, *Solecurtus basteroti*, *Ficus conditus*, and *Aporrhais cf. callosus* (RUSU 1996).

According to NEVESSKAYA et al. (1984), marine species returned in the uppermost Solenovian, and full marine conditions were re-established in the Roshnean (lower part of Kalmykian). The longer part of the Kalmykian and the Karadzhalgan was formerly referred to as the Caucasian stage. The deep-sea sedimentation was dominated by turbidites and dark carbonate-free clays with fish remains (Maikopian facies). An important

event was the new contamination of the deep basins by hydrogen sulfide, combined with uranium and rare-metal ore formation. These unique ores are bound to layers and lenses of fish bones, and extend for 20–30 km and are several metres thick. The bones were cemented by clay and sulfides. At the end of Kalmykian the salinity decreased again. In the shallower parts a benthic microfauna with *Uvigerinella californica* and abundant molluscs with affinities to the North Sea faunas occurred. Some important species are: *Chlamys bifida*, *Plagiocardium abundans*, and *Nuculana gracilis*. In the upper part of the Kalmykian the salinity decreased with dominance of *Corbula helmersenii* and *Cerastoderma prigorovskii* (POPOV et al. 1993, VORONINA et al. 1993). A communication to the North Sea Basin at this time was rather difficult, as the Masurian High in Poland closed the Danish–Polish Trough at the end of the Latdorfian. There is no possibility to connect the faunas via the Hungarian Basin, which had a pronounced Mediterranean influx. The connection may have been by way of the Carpathian Basin and the Rhine Graben. There is a rather abundant occurrence of *Uvigerinella californica* in the Waschberg Unit (Austria), and *Miogypsina septentrionalis* occurs in Eger, described also from the Chattian of the Doberg (Germany). In Transcaucasia, southern influences are reported with mollusc assemblages of e.g. *Glycymeris*, *Callista*, and *Parvicardium*. In the southwest of the Eastern Paratethys near Plovdiv (Bulgaria) the sedimentation ceased in the late Oligocene with brackish and freshwater beds. An alternation of horizons with *Polymesoda convexa* and *Lenticorbula helmersenii* is observed in the terminal Ezerovo Fm. and basal Marica Fm., and ended with *Congerina kochi*, *Melanopsis*, and *Theodoxus crenulatus* (KOJUMDIEVA & SAPUNDGIEVA 1981).

Early Miocene – Aquitanian – upper Egerian – Karadzhalgan (23.8 – 20.5 Ma), plate 4

This time-slice covers the range of nannoplankton zones NN 1 to lower NN 2. The exact position of the Paleogene/Neogene boundary in the Paratethys is uncertain as discussed above. The plate distribution is based on the reconstruction for Chron 6B at 23 Ma (SCOTESI et al. 1988). This time corresponds to a broad connection between the Indian Ocean and both the Mediterranean and Paratethys Seas. Wide-spread warm water faunas occurred, but a thermal latitudinal gradient is observed. The counter-clockwise rotation and overthrust in the Apennine Basin increased, forming an elongated island chain in the Western Mediterranean (BOCCALETTI et al. 1990). Along the Red Sea Fault, graben systems opened in the south since the late Oligocene (GOFF et al. 1995), and started in the north with shallow water sediments (*Miogypsina*, *Amphistegina lessonii*, *Planostegina heterostegina*), presumably in Aquitanian (ABDELGAHNY 1996).

The general configuration of the Paratethys did not change compared with the upper Oligocene. As in former stages, the Eastern Paratethys configuration is important for the development of seaways. In the deep basins hydrogen sulfide contamination continued, and some parts in the northern Caucasus syncline again had uncompensated sedimentation. Fish remains continued to accumulate. The sea was transgressive to the northwest, to the Dnieper–Donets Basin, and to the east in the Kyzylkum and Turkmenia. Along the coastlines sandy deposits with rich but poorly preserved mollusc faunas accumulated. Numerous warm water immigrants are similar to the Egerian fauna of the Central Paratethys or have Indo-Pacific relations. The northern influences were lost. Typical forms are: *Callista lilacinoides*, *Palliolulum incomparabile*, *Lentipecten corneus*, *Venus*

multilamella; and in Transcaucasia, *Barbatia*, *Isognomum*, *Cardita*. In the Tadzhik part of the basin the fauna was replaced by polyhaline communities of *Cerastoderma* and *Mesohalina* ("*Tympanotonus*") (POPOV et al., 1993, VORONINA et al. 1993).

In the Central Paratethys the upper part of the Egerian stage is correlated to the Aquitanian, although some difficulties remain. In the deeper basins the clastic sedimentation continued without break, and nannoplankton zone NN 1 is recorded in few places only. An important marker bed is the biogenic limestone with larger foraminifera of the Bretka Formation, southern Slovakia (VANOVA 1975). The reported species *Miogypsina gunteri* and *Lepidocyclina morgani* indicate an Aquitanian age (WIELANDT 1997). The mollusc faunas from the Molasse Basin to Transylvania are similar. In the upper Buzas Fm., Transylvania, the *Callista lilacinoides* level is situated on top of the Paleogene/Neogene boundary, accompanied by *Isocardia subtransversa*, *Glycymeris* ex gr. *latiradiatus*, and *Turritella venus* (RUSU 1996). NN 1 is documented in a continuous clayey sedimentation of the Vima Formation. From the southern Carpathians to the western Balkanides no Aquitanian sediments are recorded; the only marine basin in the southeast is the Mariza Basin in SE Bulgaria (HAMOR & HALMAI 1988, map 1). From there a connection may have existed to the Mediterranean along the western margin of the Anatolian plate, which today is subducted in the collision zone with the Aegean plate.

Early Miocene – early Burdigalian – Eggenburgian – Sakaraulian (20.5 – 18.8 Ma)

The timespan of the upper NN 2 nannoplankton zone is characterized by extensive Indo-Pacific connections. The paleogeographic situation is similar to the Aquitanian. Warm water faunas which already appeared in the late Oligocene continued to migrate from tropical–subtropical areas. Mollusc faunas from the Iranian Qum Basin, the Mediterranean and Paratethys have strong relations. According to the observations of KÜHN (1933) on the early Miocene coral faunas of Iran, there was a strong Indo-Pacific similarity in the Isfahan Basin (locality Saidabad). The corals from the upper Asmari Limestone in the Asmari Mountains, and from the Urmia series in NW Iran, had Mediterranean connections. Studying the Makran faunas in southern Iran from the Aquitanian to Burdigalian, MCCALL et al. (1994) found that all the Iranian faunas are very similar to the Makran assemblages and have distinct Indo-Pacific affinities. The connection of these areas during early Burdigalian is generally accepted. The problem of the various seaways is still under debate. In contrast to a proto-Persian Gulf from the Makran to Saidabad (Sirjan) in SE Iran (MCCALL et al. 1994), we keep open the seaway from the Indian Ocean to the Qum Basin and further to the NE from Lake Urmia to Transcaucasia. These Makran mollusc and coral faunas may mark the northeastern fringe of the deep-water trough to the Mediterranean and Paratethys. Pelagic sedimentation in the Pabdeh Formation is recorded up to the Oligocene (Baba Heidar section, Iran, collected by A. HAMEDANI, University of Isfahan), and probably continued into younger stratigraphic levels. According to the plate distribution, large space existed between the Arabian plate and the Lut block. Perhaps this is the site of the younger deep-water basin in the Zagros crush zone along the ophiolite belt. The Arabian plate rotated counterclockwise, and the Red Sea opened further as documented by *Globigerinoides alitaperturus* at the coast of Sudan (material of R. TOLEIKIS, Berlin), and by shallow water sediments in the Eastern Dessert in the north (ABDELGHANY 1996).

In spite of the more open connections to the Indian Ocean, the sea was regressive in the Eastern Paratethys. Sedimentary ore deposits in Ciscaucasia and in the Northern Caucasus show that the geochemical conditions did not change in the deep basins. Distinct faunal elements which are absent in the Mediterranean document the Indo-Pacific origin of some parts of the fauna. Such forms are e.g. the bivalves *Plagiocardium*, *Discors*, and *Fragum*, and the fish *Alepes* (POPOV et al. 1993). According to NEVESSKAYA et al. (1975, 1984) many mollusc species are comparable with the Central Paratethys Eggenburgian faunas.

Throughout the Paratethys from Georgia to the Transylvanian Basin, and further to the Bavarian Molasse Basin, a marker horizon with *Chlamys gigas* or "horizon with giant pectinids" is developed (STEININGER & SENES 1971, BALDI 1979, RUSU 1996). This horizon of giant pectinids is also known from the Pacific (ADDICOTT 1974). Along the Alpine foredeep a seaway opened again between the Central and the Western Paratethys, from Bavaria to the Rhone Basin, on top of the Lower Freshwater Molasse. A strong Atlantic influence occurred in the upper Eggenburgian (lower NN 3) and in the Ottnangian. This is supported by a change in bryozoan faunas with distinctly new western immigrants (VAVRA 1981, 1987). In the Carpathian basins flysch sedimentation continued (e.g. Krosno Formation).

Early Miocene – middle Burdigalian – Ottnangian – lower Kotsakhurian (18.8 – 17.3 Ma), plate 5

This horizon corresponds to nannoplankton zones upper NN 3 to lower NN 4, and randomly to the planktonic foraminifera zone M 3 (BERGGREN et al. 1995). This middle part of the Burdigalian is difficult to define and is determined in the Paratethys by mollusc assemblages (*Flabellipecten hermannsenni*). The plate distribution is adjusted from the distribution in Chron C6B (SCOTESE et al. 1988). During this time important tectonic events occurred. Due to the northeastern movement of the Arabian Plate a continental collision with the Anatolian Plate followed.

The seaway between the Mediterranean and Indian Ocean closed, and a continental migration bridge between Eurasia and Africa came into existence during a sea level drop (cycle TB 2.1 of HAQ et al. 1988). Extensive mammal migrations in mammal zone MN 4 introduced the proboscideans *Gomphotherium* and *Deinotherium* to Eurasia (THENIUS 1979, BARRY & FLYNN 1989) and the Eurasian rhino *Dicerorhinus* to the Rotem fauna of the Negev (GOLDSMITH et al. 1988). In the region of the Persian Gulf (northern Iraq) the sedimentation of the Euphrates Limestone and pelagic carbonates of the Serikagni Formation continued. In the east along the Zagros front, platform carbonates of the Asmari Formation were deposited (JONES & RACEY 1994).

Interesting microfaunas deviating from the "normal" Mediterranean assemblages, but with strong Central Paratethys affinities, were recorded in Anatolia. In northeastern Anatolia fine clastic sediments (Schlier) with microfaunas similar to the late Eggenburgian–Ottnangian of the Central Paratethys were deposited (material of S. ÖZGÜR, Trabzon). Also, a similar late Burdigalian fauna was described by BIZON et al. (1974) in the South Anatolian Mut Basin. The authors discussed the similarities with the Paratethys, and the figured specimens fall in the variability of *Globigerina dubia* EGGER (figured as *G. cf. fariasi*), and *G. ottnangiensis* RÖGL (*G. cf. ciperensis*). The connection of those microfaunas remains unresolved, but may be along the proposed Carpathian-Balkanides seaway. An early Miocene marine sedimentation is mentioned from the Aegean island Cos

(LÜTTIG & STEFFENS 1976: 32). The occurrence in northeastern Anatolia is more problematic. The connection from the Adana Basin to the Sivas Basin and Erzurum in the Aquitanian–Burdigalian is only patchy and not correlated to modern stratigraphy (ERENTÖZ 1956), and a seaway did not continue to the Eastern Paratethys. The figured extensive transgression for the early Miocene (LÜTTIG & STEFFENS 1976: map 3) did not consider late Burdigalian changes.

The Eastern Paratethys Basin was closed off from the Central Paratethys and Mediterranean, and probably also from the Indian Ocean. The size of the basin shrank strongly, especially in the Black Sea depression. No marine sediments are recorded in the south-west, in Bulgaria. Hydrogen sulfide contamination and sedimentation of Maikop facies continued in the deeper basins. Euryhaline and endemic mollusc faunas developed; *Rzehakia dubiosa* was very common. *Eoprosodacna*, *Cerastoderma*, *Lenticorbula*, and *Siliqua* indicate salinities similar to the modern Caspian Sea (NEVESSKAYA et al. 1975, POPOV et al. 1993). The Kotsakhurian facies lasted until the end of the early Miocene.

In the Central Paratethys the connection between the western Mediterranean and the Alpine Foredeep existed throughout most of the Ottnangian. A communication with the North Sea via the Rhine Graben developed again during the time of Lower *Hydrobia* Beds (upper NN 3–lower NN 4), indicated also by fish faunas (MARTINI 1990). Characteristic molluscs include *Flabellipecten hermannsenni*, *Pecten dunkeri*, and *Chlamys albina*. Tectonic movements and uplift in the Carpathians caused sedimentation of conglomerates and olistostromes (KOVAC et al. 1989). The eastern Carpathian basin in Rumania was cut off from open marine connections and evaporites were deposited. In the late Ottnangian, from Bavaria to northern Hungary, widespread estuarine sandy facies ("*Oncophora*" Beds) developed with a mollusc fauna very similar to the Eastern Paratethys Kotsakhurian, dominated by *Rzehakia socialis* together with *Congerina andrussovi*, *Limnopageticia moravica*, and *Melanopsis impressa*. The sea regressed from the Alpine-Carpathian Foredeep by the end of the Ottnangian.

Early Miocene – upper Burdigalian – Karpatian – upper Kotsakhurian (17.3 – 16.4 Ma), plate 6

The proposed palaeogeographic reconstruction is based on the plate configuration of SCOTSE et al. (1988) for Chron C6B with an interpolation to the next level in C3A. The late Burdigalian–Karpatian time span corresponds approximately to M 4 zone of BERGGREN et al. (1995), with the appearance of *Globigerinoides bisphericus* in its upper part. The entire Karpatian falls within nannozone NN 4. The long range of NN 4 complicates correlations with the Eastern Paratethys, where the Tarkhanian is often correlated with the Karpatian, and planktic foraminiferal markers are absent. According to our correlation the sedimentation under reduced salinity conditions in the upper Kotsakhurian correlates with the shrunken marine realm in the Central Paratethys Karpatian. The middle Miocene Tarkhanian sedimentation was transgressive with a remarkable unconformity all over the Paratethys.

A distinct tectonic turnover, the Savian Phase, changed the configuration in the Central Paratethys from elongated W–E stretching basins to the development of intra-mountain basins (RÖGL & STEININGER 1983, CSASZAR et al. 1987). The Karpatian itself was restricted to the most Central Paratethys, characterized by the immigration of a new mollusc fauna, different from the Ottnangian. Marine sedimentation occurred only in the area from the

Slovenian "Trans-Tethyan Trench Corridor" to the Styrian and Pannonian Basins, spreading into the Carpathian foredeep, from Austria north of the Danube to Poland and the Ukraine in the Balychskaya Fm. (NEY et al. 1974, KOVAC et al. 1989). Further to the east, in the Rumanian Carpathian foredeep, evaporite sedimentation continued. In the inner Carpathian basins evaporites were deposited in East Slovakia, and in the Transylvanian Basin erosional surfaces developed (the marine transgression already contains *Praeorbulina*). In the Alpine foredeep, fluviatile sedimentation of Upper Freshwater Molasse started.

The tectonic Styrian phase was active at the end of the Karpatian time. The "Steirischer Schlier" was strongly folded. Intensive uplift occurred and Carpathian nappes were overthrust. The same event caused some new configurations in the collision zone of Apulia with the European platform. Strong compressions and opposite rotations in the Ionian – Lycian arc, together with overthrusts in the Hellenides, ended the marine sedimentation in the Mesohellenic Trough. A strong northward movement of the area, of about 10° latitude took place between 20 and 15 Ma (JACOBSHAGEN et al. 1978, KISSEL et al. 1989, FERMELI & JOAKIM 1993). A re-opening of the seaway along the Bitlis Zone, between the Anatolian and Arabian plates, may have already started in the latest Burdigalian (*Globigerinoides bisphericus* Zone) as indicated by widespread microfaunas of the *Globigerinoides bisphericus* horizon in the Antalya, Mut and Adana Basins (BIZON et al. 1974). If the reconstruction of VRIELYNCK et al. (1997) is interpreted as the latest Burdigalian, then the opening already happened.

Middle Miocene – Langhian – lower Badenian – Tarkhanian (16.4 – approx. 15 Ma), plate 7

A far reaching transgression involved the entire circum-Mediterranean area at the beginning of the middle Miocene, Langhian. It is correlated to the sea level high stand of TB 2.3 (HAQ et al. 1988). Stratigraphically, the base of the Langhian and Badenian is marked by the worldwide appearance of the planktic foraminifer *Praeorbulina* within nannoplankton zone NN 4. This event coincided with a global warming which is indicated by a bipolar spreading of warm water elements into higher latitudes as exemplified by larger foraminifera (MCGOWRAN 1979a+b), and by calcareous nannoplankton around 17–16 Ma (HAQ 1980). In the Central Paratethys, this warming led to mass occurrences of larger foraminifera (*Amphistegina*, *Planostegina*) of Indo-Pacific origin as far north as Poland, accompanied by algal-coral patch reefs, tropical mollusc faunas, and fishes (STEININGER et al. 1978, DULLO 1983, BELLWOOD & SCHULTZ 1991, RÖGL & BRANDSTÄTTER 1993, PISERA 1996).

The Tarkhanian, with *Lentipecten denudatus*, was dated by N. MUZYLEV and C. MÜLLER (1987–88, unpublished) as nannozone NN 5 in the section Jurkino near the stratotype at Kerch Peninsula. Frequent species are *Coccolithus pelagicus*, *Helicosphaera carteri*, *Rhabdosphaera* spp., and the stratigraphically important *Sphenolithus heteromorphus*. The grey silty and sandy clays have an aberrant microfauna with abundant debris of ophiurids (Echinodermata), thin-shelled bivalves, pteropods, few shallow water benthic foraminifera (miliolids, ammonias), and common small globigerinas (*Globigerina tarchanensis*). The section continued without break and change in microfossils in the overlying *Spirialis* clays. With a nanno-datum of NN 5, a correlation of the Tarkhanian with the Karpatian stage of Central Paratethys is incorrect. Planktic foraminifera do not give a correlation, as *Globigerinoides bisphericus* or *Praeorbulina* are not recorded in the Eastern Paratethys.

The general considerations on the paleogeography of the circum-Mediterranean, proposed by RÖGL & STEININGER (1983) and STEININGER & RÖGL (1984) must be revised. A marine seaway from the Central Paratethys through the Black Sea Basin to the Indo-Pacific has to be abandoned because of palaeoecological differences in faunal development. The Mediterranean communicated with the Central Paratethys by the well-known seaway from the Venetian Basin along the "Trans-Tethyan-Trench-Corridor" in Slovenia. A uniform tropical–subtropical mollusc and foraminifera fauna developed in all intra-mountain basin areas (Styrian, Vienna, Pannonian and Transylvanian Basins) and in the Carpathian Foredeep. If we consider the diversified faunas and their distribution in the Carpathian foredeep and in the intra-Carpathian basins, especially in Transylvania, then sole flooding through the narrow channel of the "Transtethyan-Trench-Corridor" appears rather unlikely. No connections existed from the Albanian Korca Graben and the Mesohellenic Basin to the Central Paratethys as proposed by STUDENCKA et al. (1995). In the Mesohellenic Basin the marine sedimentation had ended in the *Globigerinoides bisphericus* Zone, as mentioned above. The Morava Graben SE of Beograd was filled by continental sediments, and most of the area of Serbia was covered by the "Serbian Lake" extending to SE to the surroundings of the town Skopje (KRSTIC et al. 1996, CICALIC & DOLIC 1996). A potential second Mediterranean connection may have existed along western Anatolia, in the tectonically unstable zone (probably subduction zone) with the Aegean plate. In the northern Aegean itself, offshore drillings in the Prinos-Kavalla Basin revealed more than 2000 m of middle?–lower Miocene clastic sediments (POLLAK 1979). A very poor fossil content makes such an Aegean seaway during the Langhian unlikely. The lower part of this sequence was correlated to the continental clastics in the northern Aegean area, whereby the part with lignite layers is lagoonal equivalent to the coal measures of the Strimon Basin (TAUPITZ 1984).

Another highly speculative possibility is therefore discussed between the southern border of the Black Sea plate and the Pontides in northern Anatolia. According to GÖRÜR (1989) the northern trough of the Neotethys disappeared along the Rhodopes-Pontides between Cretaceous and Miocene time. A re-activation of such a trough would open the required connection and would explain the immigration of marine tropical–subtropical faunas along the Carpathian foredeep. Considering the strong shortening and northward movements in the Ionian–Lycian arc during the Miocene (KISSEL et al. 1989), there must have been considerable space between the Vadar Zone and the Balkanides. Transgressive lower Badenian of Central Paratethys facies is known in NW Bulgaria on the Balkanides and the Moesian Platform, and also on the flysch of the Kula Zone of the South Carpathians. Eastern Paratethys facies occurred at the Bulgarian Black Sea coast near Varna and Burgas (KOJUMDIEVA et al. 1978). A sill of the Black Sea plate could have hindered an extensive marine exchange in the north of this seaway. Today the southern rim of the Black Sea plate is preserved north of the North Anatolian transform fault (ERKAL 1987), and deposits of Eastern Paratethys facies are recorded along the Turkish Black Sea coast (ÖZSAYAR 1977).

The question of a restored connection between the Mediterranean Sea and the Indian Ocean is still being argued (ADAMS 1998, RÖGL 1996a, 1998, WHYBROW 1984). The Langhian was transgressive in the Mut and Adana Basins in southern Anatolia (BIZON et al. 1974). The Bitlis suture zone was activated only in the Serravallian. In eastern Anatolia, in the Lake Van area, deep marine deposition occurred until the Serravallian,

and during the Langhian–Serravallian, shallow marine environments changed to molasse basins with red beds and marine intervals (GELATI 1975, SENGÖR et al. 1985). A connection of the Eastern Paratethys in the south-southeast, from the Araks Depression along the Euphrates valley to the Tethys (Indian Ocean), was proposed by different authors (NEVESSKAYA et al. 1984, 1987, CHEPALYGA 1995, ILJINA 1995). It was widest in early Tarkhanian and early Konkian time. The faunal development in the Eastern Paratethys basins was still influenced by dysaerobic bottom conditions. The microfauna and molluscs were rather poor compared with the Central Paratethys. In the upper Tarkhanian, reduced salinity conditions changed the faunal assemblages (NEVESSKAYA et al. 1984). Additional problems arise if the correlation of early Langhian/Badenian is incorrect and early Badenian is compared with the Tshokrakian (STUDENCKA et al. 1995).

Middle Miocene – lower Serravallian – middle Badenian – Tshokrakian to Karaganian (approx. 15 – 14 Ma), plate 8

The Serravallian is a time of regressions in the circum-Mediterranean, coinciding with the sea level drop of TB2.3/TB2.4 (HAQ et al. 1988). The short-lived marine connection between the Mediterranean and Indian Ocean in the Bitlis zone, but also the seaway to the Transcaucasian Basin, closed again. The final closure of the Mediterranean gateway was cited by FLOWER & KENNETT (1993) as one of the reasons for the final expansion of the East Antarctic ice sheet around 14.8 Ma. The global change in the ocean deep water current systems was coincident with changes in stable isotopes, as indicated by an increase of benthic $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. In Serravallian time the tectonic movements along the Levant Fault, East and North Anatolian Faults began (SENGÖR et al. 1985, LE PICHON & GAULIER 1988). A westward escape of the Anatolian plate was initiated.

In the Central Paratethys, the western connection to the Mediterranean and marine sedimentation continued in the middle Badenian, Wielician substage, with some changes in facies. Regressions occurred in the shallower parts, with erosions and sandy sedimentation. In the upper part a strongly reduced open circulation closed off the Carpathian fore-deep and satellite basins of the intra-Carpathian arc. Thick evaporite deposits of gypsum and halite covered the foredeep from Poland to Rumania. The famous salt mine of Wieliczka provided the name for this substage. A similar development is found in the Transylvanian, East Slovakian and Ukrainian Transcarpathian Basins.

In the Eastern Paratethys, changes from marine environments to brackish conditions were gradual. During the marine Tshokrakian a connection existed in the southeast, where the most diverse faunas are known. ILJINA (1995) reported the Indo-Pacific gastropod *Obtortio* from the lower Tshokrakian. In the later Tshokrakian, marine conditions changed to aberrant salinity. The Karaganian Basin was entirely isolated and developed an endemic mollusc fauna dominated by *Spaniodontella* accompanied by *Solen* and *Pholas*. Near the end of Karaganian the southeastern seaway to the Middle East opened again with richer assemblages and evaporites in the Araks Depression (NEVESSKAYA et al. 1994, JONES & SIMMONS 1996). The palaeogeographic and lithologic conditions in the Mesopotamian Basin have been discussed more recently by JONES & RACEY (1994) and GOFF et al. (1995). If the stratigraphic correlation with nannozone NN5 is correct, then this level compares to the Jeribe Formation in Northern Iraq. More to the south of today's SW Iran in the upper Asmari and Gachsaran Formation, platform carbonates and evaporites were deposited.

Middle Miocene – lower Serravallian – upper Badenian – Konkian (14 – approx. 13 Ma), plate 9

This short time-slice is of great importance in the Paratethys. It is the last event of marine flooding, covering the entire region in late Badenian (Kosovian)/Konkian, about lower nannoplankton zone NN 6. In the "Trans-Tethyan-Trench-Corridor" the Mediterranean connection was closed. Therefore a broad re-opening of the Indo-Pacific seaway was proposed. During the early Konkian, Sartaganian substage, the connection was open in eastern Georgia and the Transcaspien Basin, and full marine conditions returned with stenohaline molluscs, echinoids, and foraminifera (NEVESSKAYA et al. 1984, 1987). Some communication also existed with the Central Paratethys, which was interpreted by KOKAY (1984) as the water and faunal supply for the Eastern Paratethys.

In the Rumanian Carpathian Foredeep and the Transylvanian Basin a sedimentation of Radiolaria shales and *Spiralis* marls (pteropod marls) on top of the evaporites is unique in all the basins. The *Spiralis* marls are also recorded in the other Central Paratethys basins in the lower Kosovian. The sediments are commonly thin bedded and laminated, with a benthic foraminiferal fauna of buliminids and uvigerinids indicating water stratification and bottom conditions with reduced oxygen content. The planktic microfossil composition of these deposits is interesting. Nannoplankton, diatoms and radiolaria have a distinct Indo-Pacific relation, and such radiolarian and pteropod sediments are missing in the Mediterranean (DUMITRICA et al. 1975, RÖGL & MÜLLER 1976, POPESCU 1979). The occurrence of a planktic foraminiferal genus, *Velapertina*, somewhat similar to *Praeorbulina* but of different stratigraphic range from NN 6 upwards is also remarkable. The genus is now known from the middle-late Miocene of California and Ecuador (comp. discussion in RÖGL, 1998). An Indo-Pacific connection is also documented by the parrotfish *Calotomus* and the wrasse *Asima* from the Vienna Basin (BELLWOOD & SCHULTZ 1991). These highly marine faunas differ from the Eastern Paratethys. Therefore the same seaway as in the early Badenian must have been re-opened along the Pontides to eastern Anatolia.

In the upper Kosovian/Konkian, salinity was lowered, and the fauna is reduced to polyhaline and endemic elements. This is the time span which was considered by KOKAY (1984) as the late Badenian. An interesting event is a short recurrence of euhaline environments in the Eastern Paratethys, with *Chlamys*, *Turritella*, and *Murex* (NEVESSKAYA et al. 1984). The same event was observed in the western part of the Central Paratethys (Styrian Basin) at the top of the Badenian with layers of algal limestones and euhaline mollusc and echinoid faunas (KOLLMANN 1965: "marine Rekurrenz").

Middle Miocene – upper Serravallian – lower Sarmatian – Volhynian (13 – approx. 12.2 Ma), plate 10

The plate configuration corresponds to Chron C3A of SCOTESE et al. (1988). At this time the Paratethys had the most uniform conditions since the early Oligocene. The area between the Vienna Basin and the Caspian Basin was covered by a sea with the same biofacies. Salinity decreased and water chemistry changed to oversaturated carbonate content and high alkalinity (PISERA 1996). Such conditions explain the growth of red algal-vermetid or "*Nubecularia*" (foraminifera) bioherms. Such reefs formed a series of complexes along the edge of the Podolian platform, but also occurred from the Vienna Basin to

Bulgaria and Crimea (PISERA 1996). This explains the far-ranging Sarmatian oolitic limestones with *Borelis* and *Spirolina* (GAGIC 1983, 1988). A very rich biocoenosis with increasing endemism developed. The lowermost beds in the Ukraine (Buglov Beds) have a considerable marine relic fauna, and in the Central Paratethys a basal horizon with the foraminifer *Anomalinoides* was developed; this was followed by the *Elphidium reginum* Zone. Euhaline organisms such as planktic foraminifera or radiolaria and echinoids disappeared. The mollusc faunas throughout the Paratethys were dominated by the bivalves *Ervilia*, *Irus*, *Mactra*, *Cerastoderma*, and the gastropods *Mohrensternia*, *Calliostoma*, and *Pirenella*. This type of fauna gave rise to the definition of a Sarmatian Stage in the Vienna Basin (E. SUESS 1866). The same faunal type was developed in the Eastern Paratethys in the Volhynian as well; it survived in the Bessarabian and Khersonian substages. Therefore the Sarmatian stage is used a much longer time interval in the Eastern Paratethys than in the Vienna Basin, raising stratigraphical correlation problems.

A reduced connection of the Mediterranean to the Sarmatian Sea followed the fault zones in southern and eastern Anatolia, along the upper Euphrates Valley to the Araks Depression and to the Caspian Basin (CHEPALYGA 1995). As demonstrated by KEMPLER & GARFUNKEL (1994), extensional basins developed in the northeastern Mediterranean collision zone due to the westward escape of Anatolia. A similar situation may have existed in the late Miocene–Pliocene more to the NE, and also at the junction of East Anatolian and North Anatolian Faults. The deep basin along the Zagros front disappeared; around the Persian Gulf, shallow water limestones and evaporites are widespread in the Lower Fars and Gachsaran Formations (JONES & RACEY 1994).

Late Miocene – Tortonian – Pannonian – upper Bessarabian to Maeotian (11.5 – 7.1 Ma)

The European continentalisation continued, and the aquatic realm of the Central Paratethys shrank to the inner-Carpathian basins. This area corresponds to the Pannonian Basin and its satellite basins, and was covered by a sea of lowered salinity similar to today's Caspian Sea. The diversity of the fauna was strongly reduced to a few genera of molluscs and ostracods. The main groups were distinctly oligohaline ostracods (e.g. *Candona*, *Caspiolla*, *Cyprideis*, *Hemicytheria*, *Loxoconcha*), endemic bivalves (*Congeria*, *Lymnocardium*, *Dreissenomya*) and gastropods characteristic of low salinity environments (*Melanopsis*, *Valenciennius*, *Viviparus*, *Theodoxus*). A correlation with the Eastern Paratethys is difficult because of higher salinity values and Sarmatian-type faunas outside the Carpathians. According to the current correlation the Pannonian corresponds to the upper Bessarabian, Khersonian, and Maeotian. An important marker in this correlation is given by the first appearance of the three-toed horse "*Hipparion*" at the boundary of Vienna Basin zones B/C, and in the Dacian Basin in the upper Bessarabian (BERNOR et al. 1988).

As discussed above, the Sarmatian facies continued in the Eastern Paratethys, which had extended to the west and covered the Dacian Basin. Some changes in salinity and fauna are observed. Tectonic movements in the late Khersonian isolated the different basin parts. The Black Sea regressed and evaporitic carbonate and dolomite precipitation occurred in the deepest part. In the northeast, freshwater sediments were deposited in the Azov Basin and Northern Caspian Basin, supplied by the drainage of the continent. A stronger marine incursion took place in the Maeotian. This ingression was connected

to the opening of the Aegean Sea along graben structures during the Tortonian, following such structures into Bulgaria and along the Dardanelles into the Balck Sea Basin (KOJUMDIEVA 1983, 1987, SCHRÖDER 1986, JONES & SIMMONS 1996). Since that time the main seaway of the Eastern Paratethys to the Mediterranean followed the Aegean Sea, and connected over Thrace or the Bosphorus. The Euphrates passage was also repeatedly open to the Araks Depression or the Caspian Basin (ERENTÖZ 1956, CHEPALYGA 1995). The palaeogeographic reconstruction of VRIELYNCK et al. (1997) for the Tortonian is incorrect for the Paratethys. There was no shallow sea around the Alpine-Carpathian foredeep, and the Aegean Sea had already opened.

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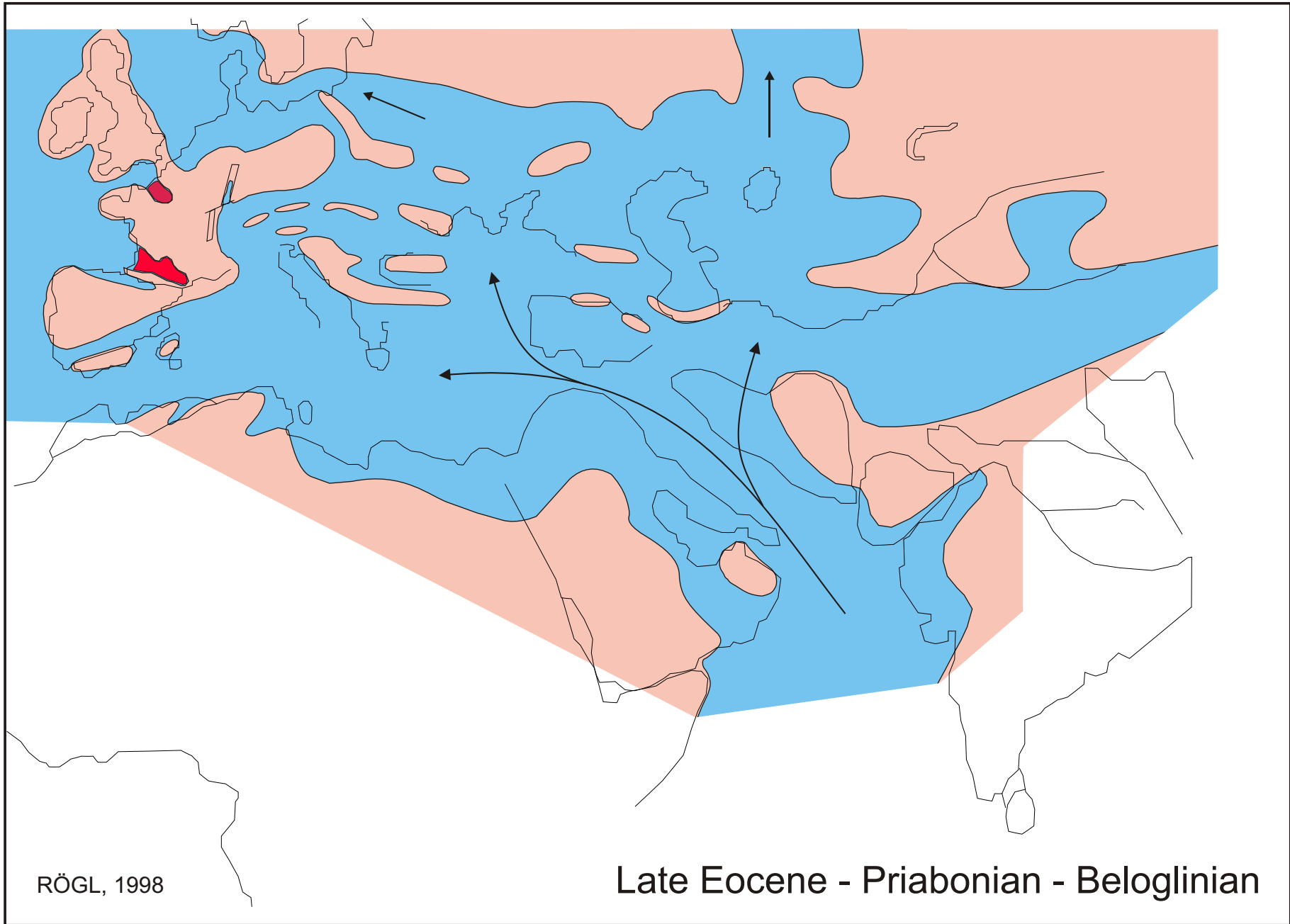
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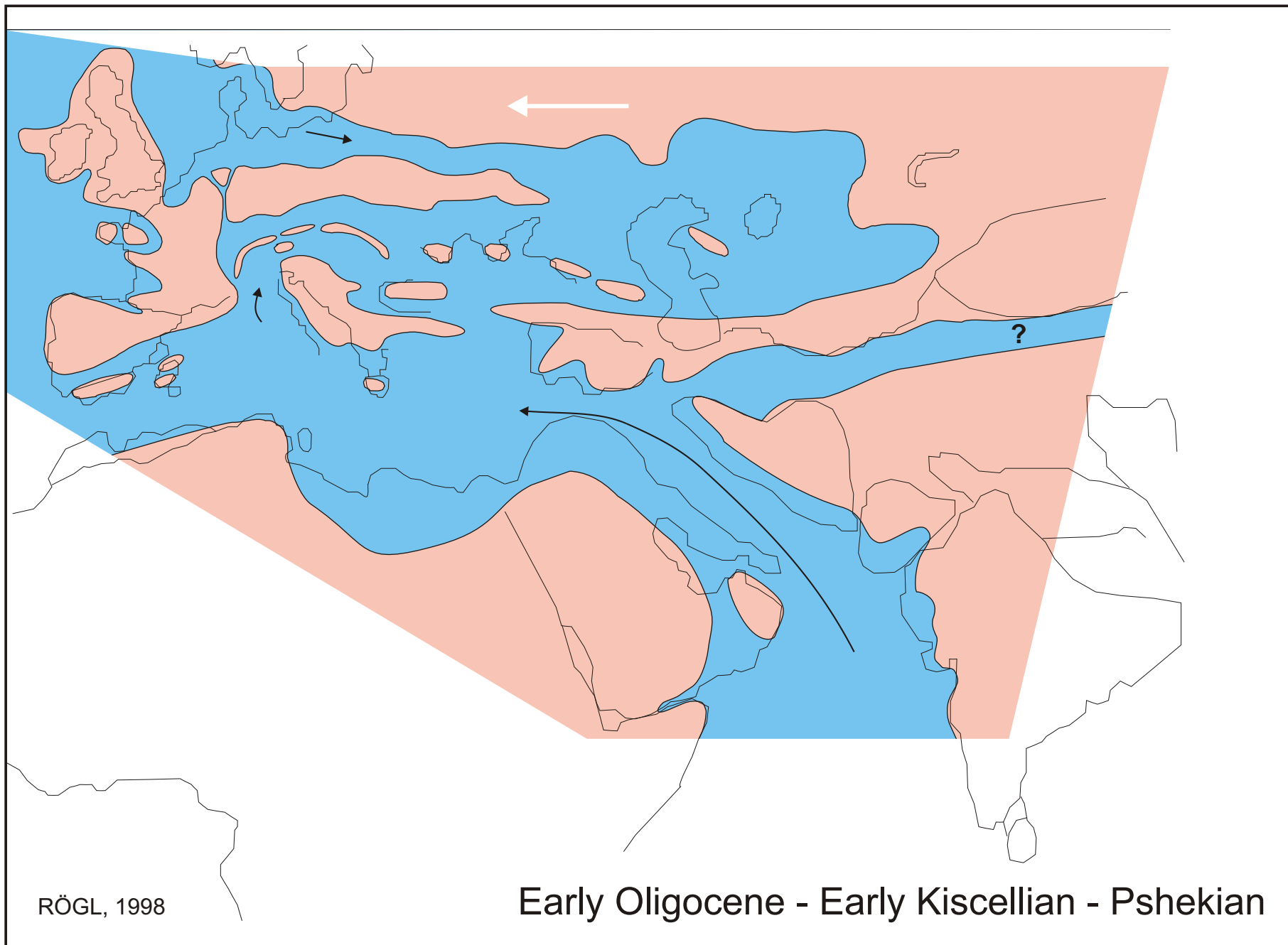
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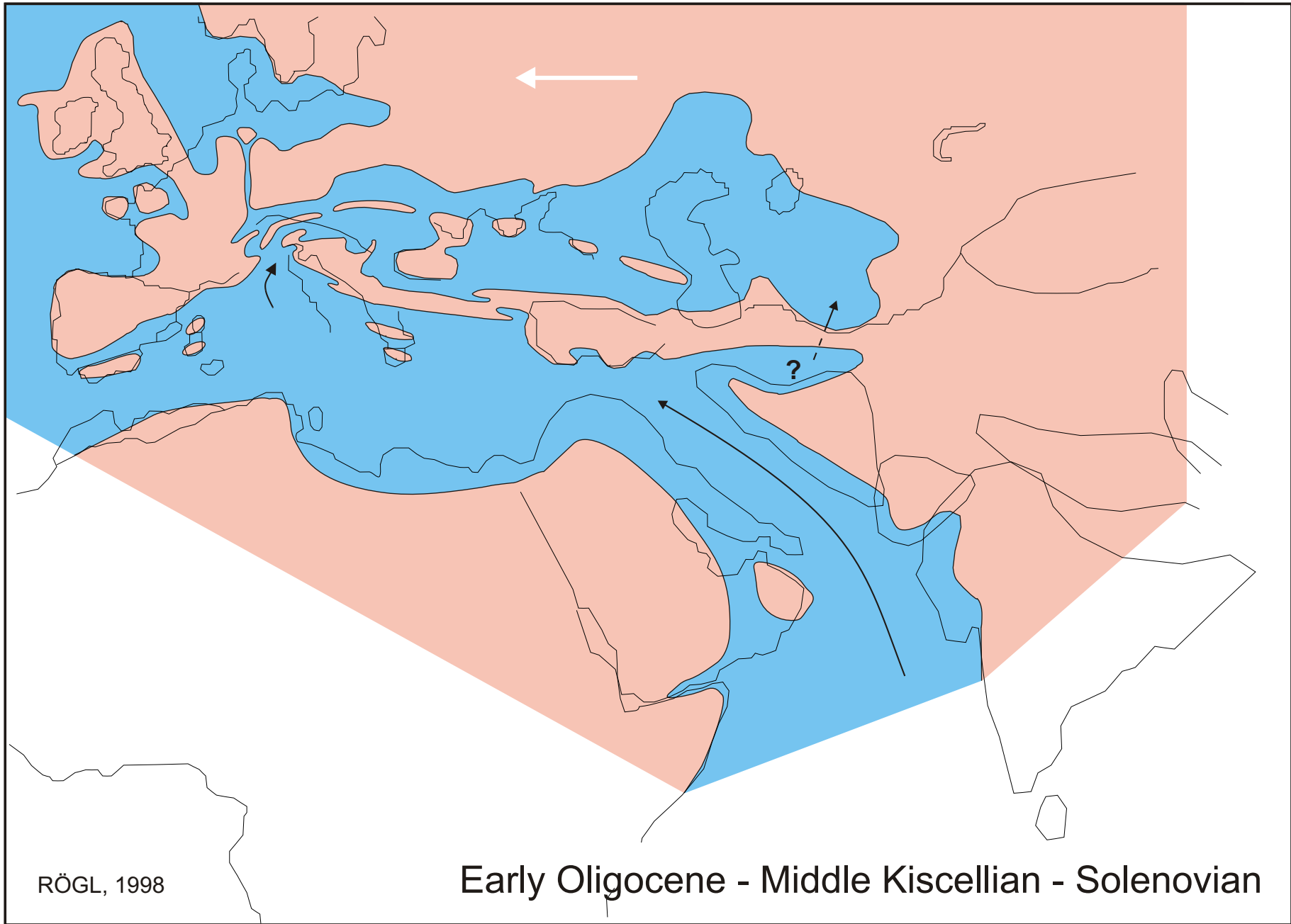
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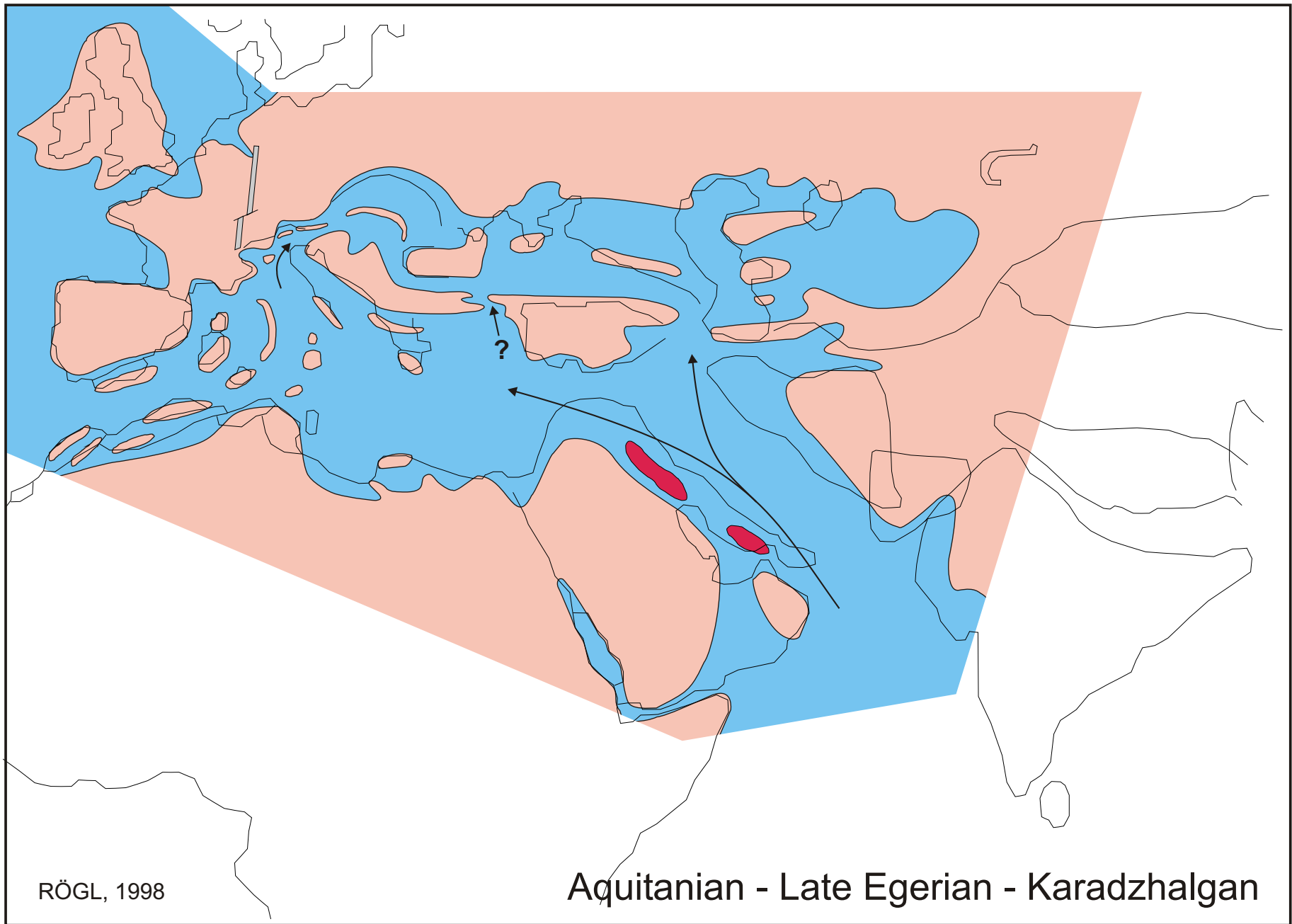
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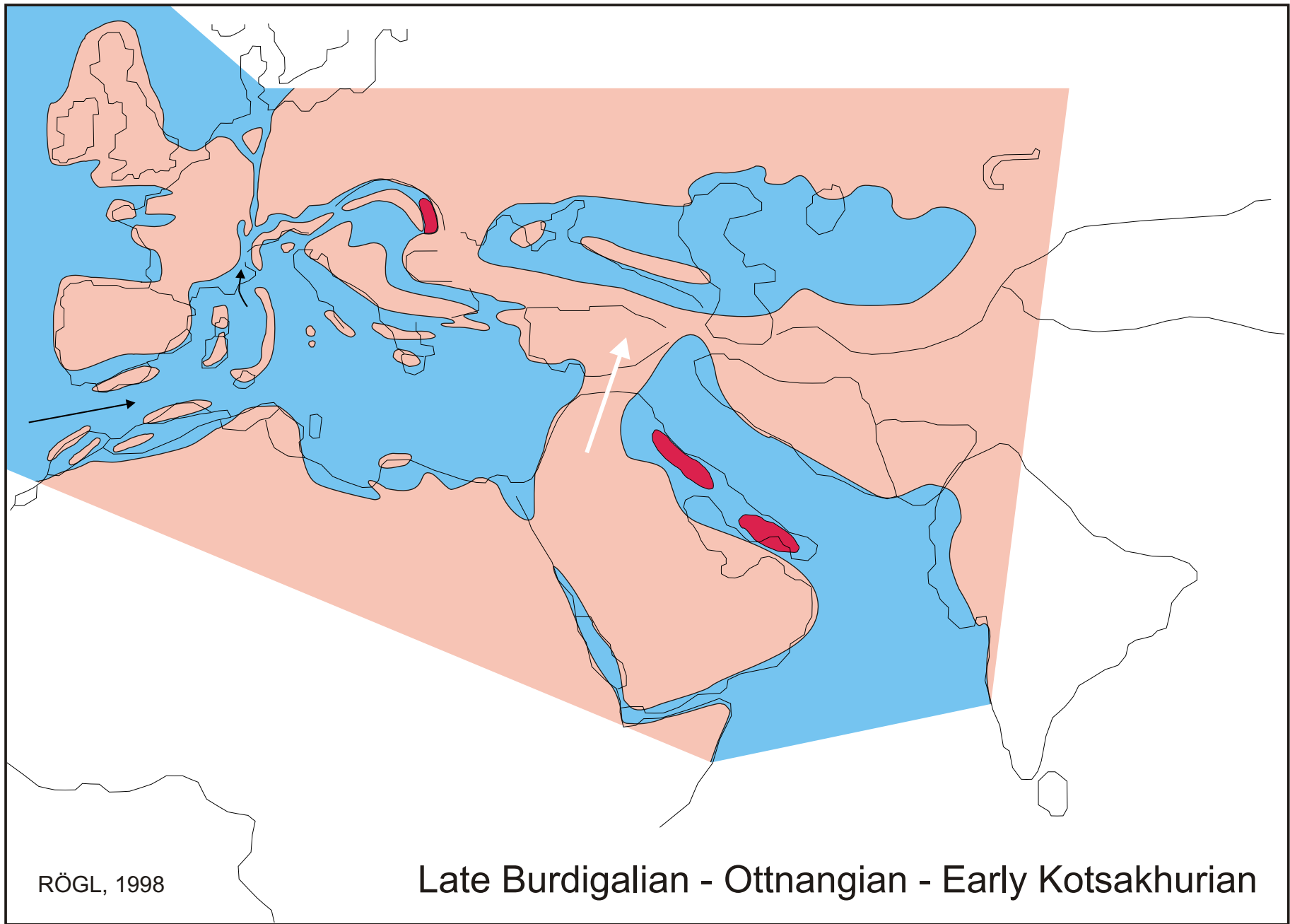
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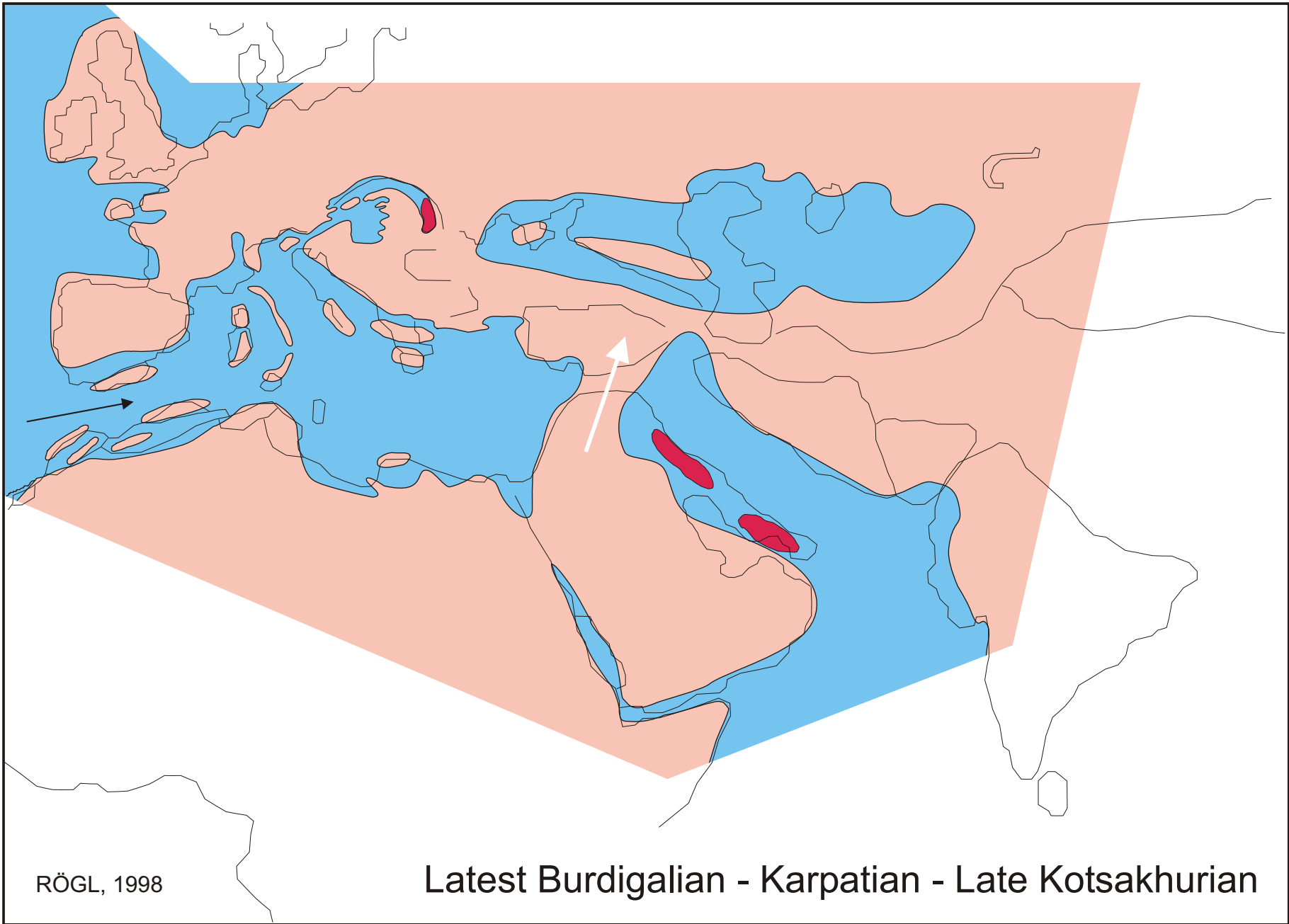






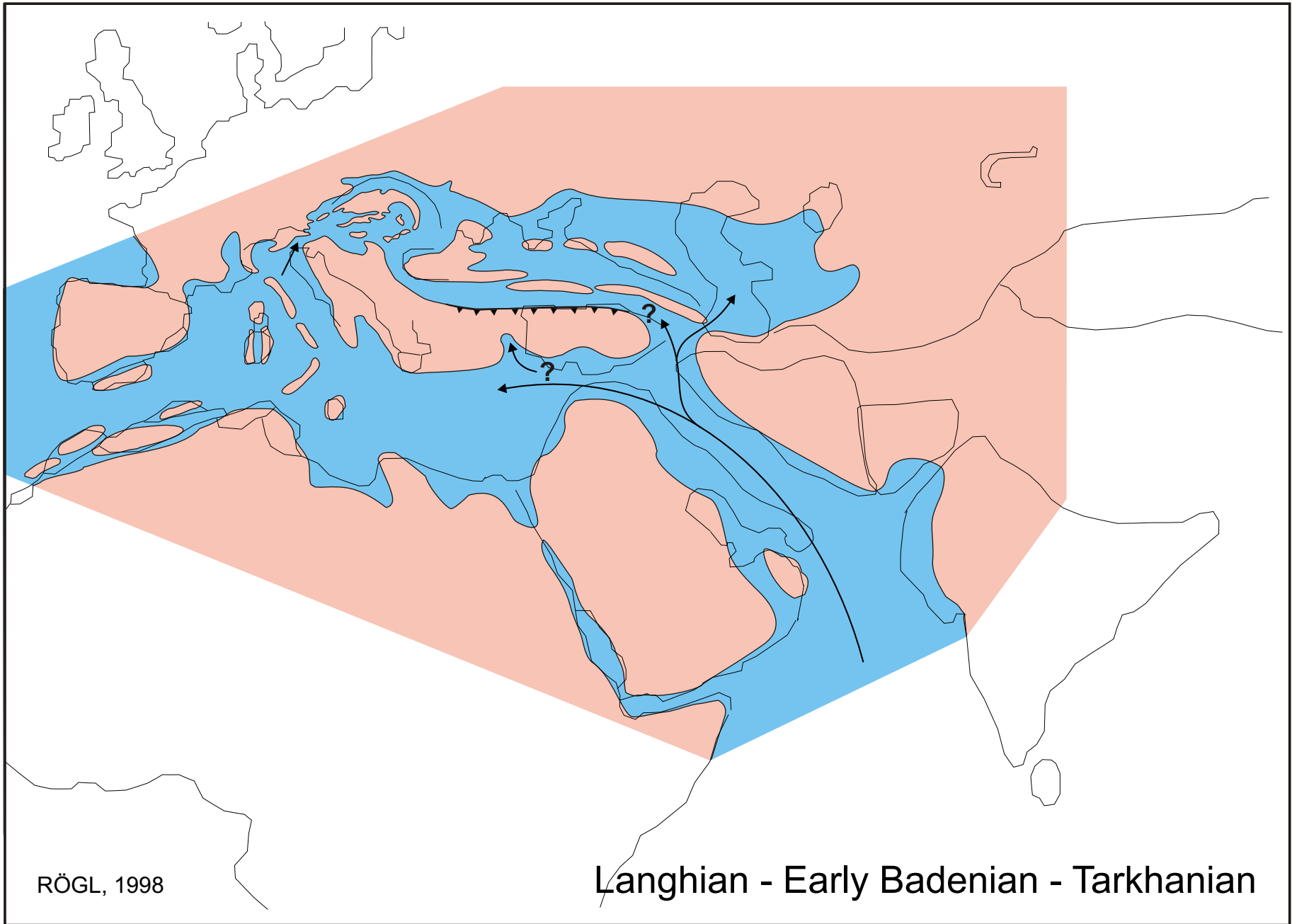






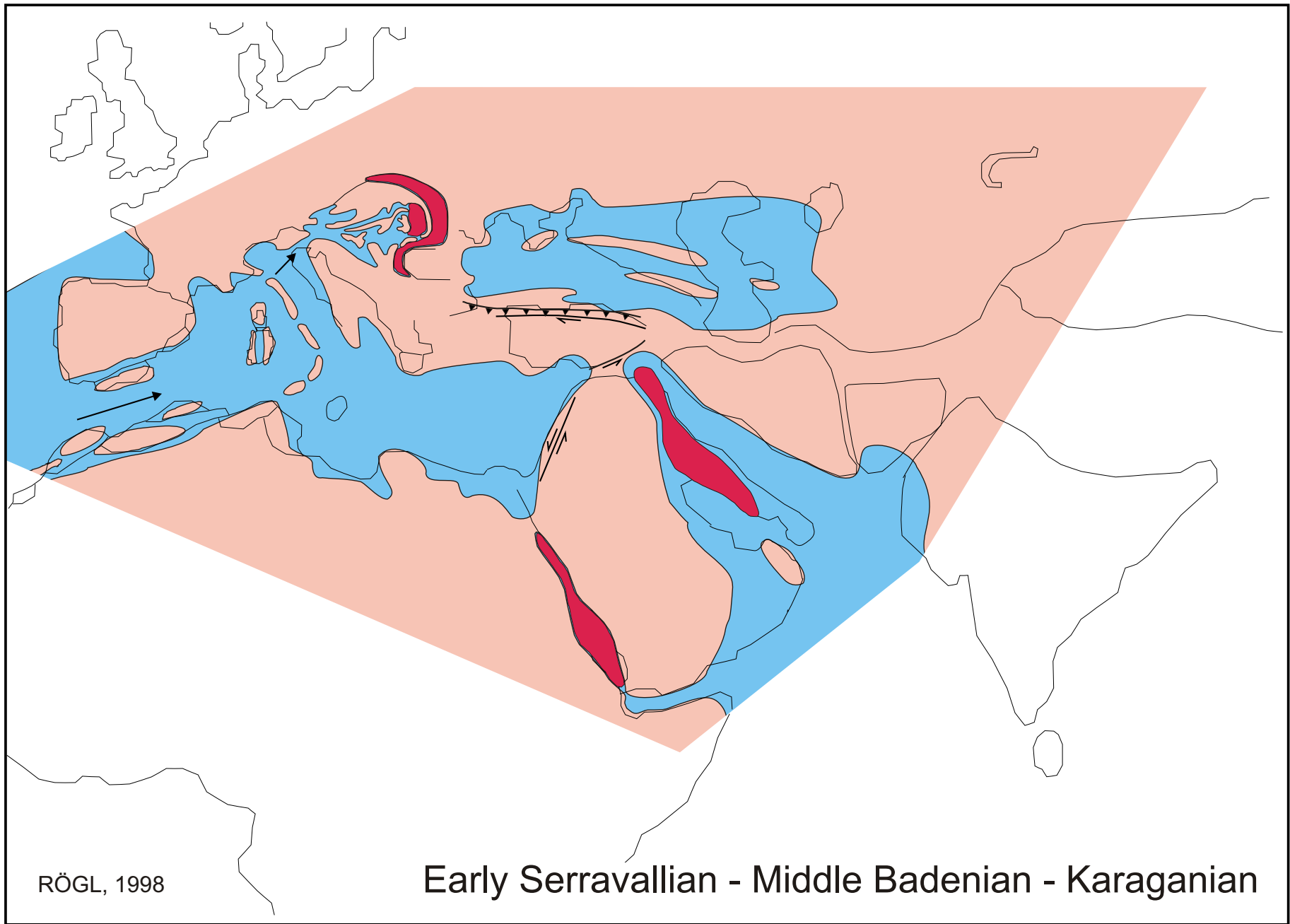
RÖGL, 1998

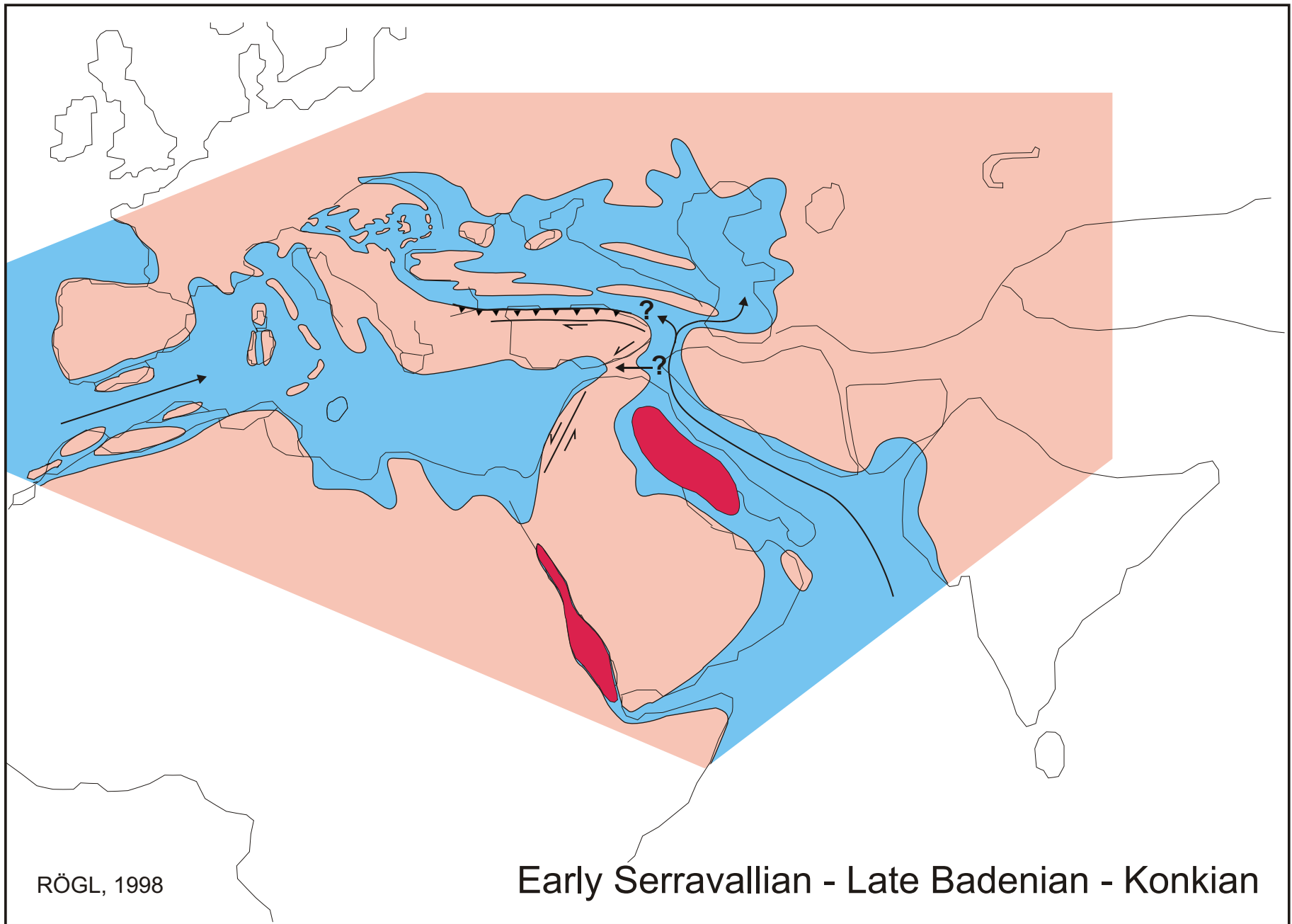
Latest Burdigalian - Karpatian - Late Kotsakhurian



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Langhian - Early Badenian - Tarkhanian





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Early Serravallian - Late Badenian - Konkian

