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From the Tethyan Ocean to the Paratethys Sea: Oligocene to Neogene Stratigraphy, Paleogeography and Paleobiogeography of the circum-Mediterranean region and the Oligocene to Neogene Basin evolution in Austria

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Abstract

The Oligocene and Neogene Molasse Basin and the Alpine/Carpathian intramountainous basins (e.g. Vienna and Styrian Basin) of Austria belong to the Paratethys realm. The most recent stratigraphic correlation of the Paratethys Chronostratigraphic Stage System with the world wide used Mediterranean Stage System is given. The three tectonic units of the Molasse Basin, the autochthonous, allochthonous and parautochthonous Molasse units and the sedimentary cycles of the Molasse Basin, and the tectonic history of the two larger intramountainous Vienna- and Styrian Basins, and their sedimentary sequences are described through time. The main part deals with the sedimentological and facial evolution, the paleogeography and the paleobiogeography of these Austrian basins, in six time slices (Late Eocene, Oligocene, Lower Miocene, Middle Miocene, Middle to Late Miocene and Pliocene) as seen within the general evolution of the circum-Mediterranean region.

Introduction

Within the last decades a wealth of new results have been compiled concerning the sedimentary sequences, their paleontological content, facies development and stratigraphy, paleogeography, paleobiogeography and palinspastic reconstructions of the Oligocene and Neogene evolution of the circum-Mediterranean area and the Paratethyan basins. Within this paper we will discuss these aspects with respect to the Austrian Oligocene and Neogene basins.

The contributions of DECKER and PERESSON (1996), FAUPL and WAGREICH (this volume), GENSER et al. (1998), KOVAC et al. (1993), NEUBAUER and al. (this volume), PERESSON and DECKER (1996, 1997), RÖGL (1996, 1998), STEININGER (1999), STEININGER et al. (1985, 1996), WAGNER (1996, 1998) and WAGREICH and FAUPL (1994) and literature cited herein set the scene of the Late Cretaceous and Cenozoic tectonic, stratigraphic, paleogeographic and paleobiogeographic evolution of these basins in the Eastern Alpine-Carpathian orogen.

The results of stratigraphic correlations between marine, reduced marine to endemic limnic realms and continental sequences within the vast realms of the Paratethys from the peri-Alpine foredeep in the west to Inner Asia in the Far East, form the basic requirement for the timing of the sedimentary cycles, their paleobiologic content and the paleobiogeographic reconstructions (RÖGL, 1996, 1998; STEININGER, 1999).

In the following we will first discuss the stratigraphic correlation and the paleogeographic setting between the Mediterranean Neogene Tethys and the Paratethys in relation to main regional sedimentary sequences and important biologic events. Afterwards we will characterize the main tectonic units during Oligocene and Neogene in Austria. The main part of the paper will focus on specific time slices to discuss the general sedimentary and biologic evolution within the circum Mediterranean and Paratethys areas in general and within the Austrian geologic units.

The Paratethys Bioprovince and Cenozoic Mediterranean/Paratethys Stratigraphic Correlations

Paratethys bioprovince

In 1924 LASKAREV proposed separating a Paratethys bioprovince from the Neogene marine Mediterranean bioprovince, referring to the well recognized Late Neogene evolution of endemic mollusc faunas in the Vienna, Pannonian, Styrian, Dacian and Euxinian basins. This definition was revised over the years and we now recognize the beginning of a biologically well defined Paratethys bioprovince from Oligocene time onward with a complicated bioprovincial evolution and extending in general north of the Alpine-Car-

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pathian orogen. In its modern definition the Paratethys province extends from the western Molasse Basin in Switzerland and Rhone Basin in France towards lake Aral in the Far East. It is subdivided into a western Paratethys, formed by the Rhone Basin and Molasse Basin of Switzerland and western Bavaria; a Central Paratethys extending from Bavaria to and partly including the eastern foredeep of the Carpathian mountain chain and the wellknown intra-Apine basins, e.g.: the Vienna, Styrian, Pannonian Basins, and an Eastern Paratethys. The latter extends over the vast areas of the Euxinian basin complex to Lake Aral in the east (Fig. 1; SENES, 1960). Besides this more static concept several evolutionary stages of this Paratethys bioprovince have been defined. These stages are caused by the geodynamic development of this tectonically highly mobile area and the rapid paleobiological changes. SENES and MARINESCU (1974) and RUSU (1988) recognised a "Protoparatethys" in the Early Oligocene (Kiscellian; respectively Pshekian, Solenovian and Early Kalmykian, see Tab. 1) and an "Eoparatethys" in the Late Oligocene and Early Miocene (Egerian, Eggenburgian and Ottnangian and Late Kalmykian, Karadzhalganian, Sakaraulian and Kotsakhurian, respectively, see Tab.1). These two evolutionary stages of the Paratethys bioprovince are characterised by west-east trending troughs throughout the Paratethys and are well recognizeable in Austria within the tectonic units of the Molasse Basin

Table 1
Cenozoic Mediterranean/Paratethys Stratigraphic Correlation chart (BERGGREN et al., 1995; POPOV et al., 1993; RÖGL, 1998, STEININGER et al., 1996; STEININGER, 1999).

M. A.	Epochs	Mediterranean Stages	Central Paratethys Stages	Eastern Paratethys Stages	BIOZONATIONS: Planktonic Foraminifera	BIOZONATIONS: Calcareous Nanno-plankton	BIOZONATIONS: EUROPEAN LAND MAMMAL ZONES	BIOZONATIONS: EUROPEAN LAND MAMMAL MEGA- ZONES
	Plio-cene	ZANCLEAN	DACIAN	KIMMERIAN	PL 1	NN 13	MN 14	RUSCINIAN
5								
	Late Miocene	MESSINIAN		PONTIAN	M 14	NN 12	MN 13	TUROLIAN
			PONTIAN			NN 11		
					M13 b		MN 12	
		TORTONIAN	PANNONIAN	MAEOTIAN				
							MN 11	
					M13 a			
						NN 10	MN 10	VALLESIAN
						NN 9b	MN 9	
10								
				SARMATIAN: Khersonian				
	Middle Miocene	SERRAVALLIAN			M 12	NN 9a / 8	MN 7+8	ASTERACIAN
				SARMATIAN: Bessarabian				
					M11 – 8	NN 7		
			SARMATIAN					
						NN 6		
				SARMATIAN: Volhynian				
			BADENIAN	Konkian Karaganian Tshokrakian	M 7			
						NN 5	MN 6	
		LANGHIAN		TARKHANIAN	M 6			
15								
							MN 5	ORLEANIAN
					M 5			
						NN 4		
	Early Miocene	BURDIGALIAN	KARPATIAN	KOTSAKHURIAN	M 4			
							MN 4	
			OTTNANGIAN		M 3			
						NN 3		
			EGGENBURGIAN	SAKARAULIAN	M 2		MN 3	
						NN 2		
20								
		AQUITANIAN	EGERIAN	KARADZHALGAN-IAN			MN 2	AGENIAN
					M1 b			
							MN1	
					M1 a	NN 1		
	Oligocene	CHATTIAN		KALMYKIAN	P 22	NP 25	MP 30 to MP 25	ARVERNIAN
25								
					P 21 b			
			KISCELLIAN					
					P 21 a	NP 24		
		RUPELIAN					MP 24 to MP 21	SUEVIAN
					P 20			
30						NP 23		
				SOLENOVIAN	P 19			
				PSHEKIAN	P 18	NP 22		
						NP 21		
	Late Eocene	PRIABONIAN	PRIABONIAN	BELOGLINIAN	P 17		MP 20 to MP 17	HEADONIAN
					P 16			
						NP 19 – 20		
35								
					P 15			
						NP 18		

(see below). The following two evolutionary stages of the Paratethys are marked by the creation of the large intra-Alpine basin systems and their subbasins, differentiated in their age of extension and downthrow from the west (e.g. Vienna Basin, in Middle Miocene) towards the east (e.g. Euxinian basin, in Late Miocene). The first of these two Paratethys bioprovincal stages is the "Mesoparatethys", which existed from the late Early Miocene to the middle Middle Miocene (Karpatian, Badenian and Tarkhanian, Tshokrakian, Karaganian and Konkian, repectively; see Tab. 1) the following stage is the "Neoparatethys", which existed from the upper Middle Miocene to the Pleistocene and Holocene (Sarmatian to Recent, see Tab. 1). Both stages are well expressed in Austria by the development of the Vienna Basin and its subbasins, the Austrian part of the western Danube Basin, the depressions on the eastern border and the basins within the Alps and the Styrian Basin (Figs. 1, 5).

Cenozoic Mediterranean/ Paratethys Stratigraphic Correlations

In contrast to the Neogene Mediterranean region, the geodynamic development and rapid paleobiological changes during the Oligocene and Neogene triggered a mainly endemic evolution of the flora and fauna, the sedimentary sequences and the overall facies development. This lead already in the 19th century to the development of separate chronostratigraphic stage concepts for the Paratethys realms. In general, the Mediterranean chronostratigraphic stage concept is widely accepted as the world chronostratigraphic standard and reference scale and biostratigraphic correlations are based on tropi-

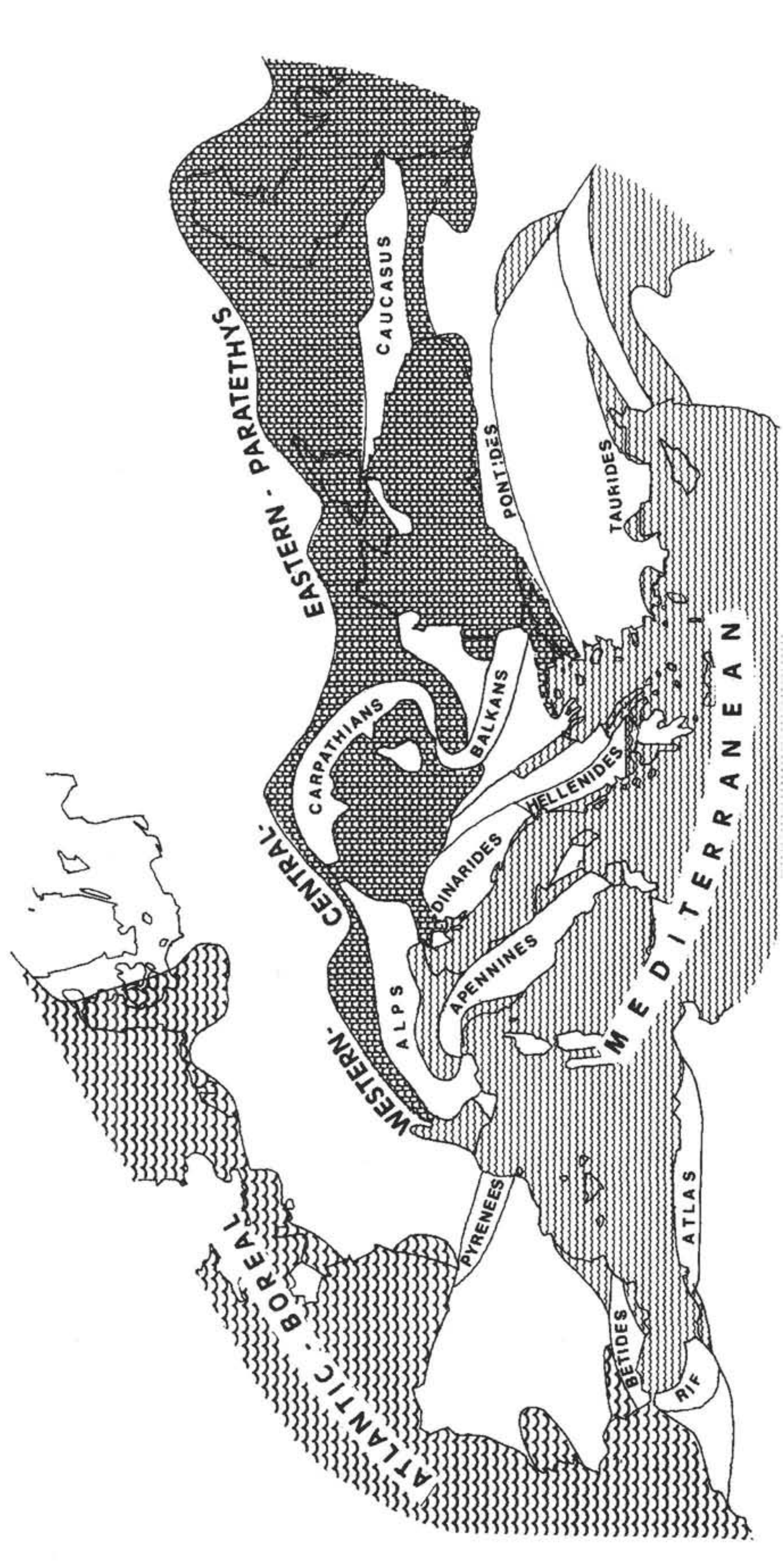


Fig. 1
Oligocene and Neogene Mediterranean and Paratethys realms (RÖGL & STEININGER, 1983).

cal to subtropical oceanic planktonic organisms. One can rarely identify these planktonic markers in the Paratethys realms. The biostratigraphic framework of the Paratethys stages is based in aquatic realms on endemic marine to reduced marine microfossils, marine to limnic mollusc faunas and ostracods and to micro- and macromammals respectively, intercalated either into these marine to limnic or into the continental sequences. Lately paleomagnetic and radiometric dating provided another excellent regional and interregional correlation tool. Even if the correlation of the different Paratethys stage concepts (e.g.: Central- to Eastern-Paratethys stages, see Tab. 1) with each other is more or less solved, we still have problems in correlating the Mediterranean regions. The correlation with the Mediterranean stage concept is based in the Early Miocene on mammal biostratigraphic/paleomagnetic and mammal biostratigraphic/marine correlations respectively, with several well calibrated marker horizons (European Land Mammal Zones MN 3, MN 4 and MN 5); the base of the Middle Miocene is marked world-wide and in the Paratethys by the first appearance of the plankton foraminifera genus *Praeorbulina*; several calcareous nannoplankton events are known within the upper Middle Miocene of the Paratethys and are used as marker horizons for Mediterranean correlations. European land mammal biostratigraphy provides us with important worldwide and European events (e.g.: the "Hipparion" event), which form the backbone of the stratigraphic correlations (Tab.1) for the Late Miocene and Pliocene of the Paratethys realms (RÖGL, 1996, 1998; STEININGER et al., 1985, 1996; STEININGER, 1999).

Oligocene and Neogene tectonic and sedimentary units of the Molasse Basin and the Alpine/Carpathian Intramontaneous Basins in Austria

Molasse Basin

From north to south the following tectonic units of the geology of Austria are relevant to the Molasse Basin: The Variscan and older crystalline basement of the Bohemian Massif, which is transgressively overlain in the subsurface to the south by a in many parts incomplete cover of Late Paleozoic and Mesozoic sediments in the characteristic "Outer Alpine – Germano-typic" facies (see WAGNER, 1996, Fig. 3a). In the Cenozoic, Late Eocene sediments interfinger with sediments of the autochthonous Helvetic unit to the south. Younger Oligocene to Neogene sediments follow transgressively on top of the crystalline and Mesozoic basement rocks to the north.

To the south the Molasse Basin is tectonically overthrusted by the Helvetic nappes and their eastern equivalents, which in turn are overthrusted by the Rhenodanubian Flysch nappes, the "Ybbsitz Klippen" belt representing the southern Penninic units and by the various Austroalpine nappes exposed in the Northern Calcareous Alpine Zone (Fig. 2).

The Molasse Basin, or in other terms the Alpine-Carpathian foredeep, north und underneath the Alpine-Carpathian tectonic front, with its tectonic setting and its sedimentary record provides the best possibility to unravel the Cenozoic history of the Alpine and Carpathian orogen.

Three main tectonic units characterize the Molasse Basin from north to south:

(1) The autochthonous Molasse: the term is used here for flat-laying Molasse sediments underneath and in front of the Alpine-Carpathian orogen. These sediments in front of the Alpine-Carpathian thrust sheets are tectonically disturbed only by normal faults or tilting (Fig. 3a; see also Fig. 6 in WAGNER, 1996). For the various terms used in the literature for this tectonic part, see STEININGER et al. (1986).

(2) The allochthonous Molasse: In contrast to the autochthonous Molasse, the allochthonous Molasse sediments are characterized by their tectonic position in folds and thrust sheets formed by the Alpine tectonics (e.g., the Waschberg unit, Figs. 3a, b). For the various terms used in the literature for this tectonic part, see STEININGER et al. (1986).

(3) The parautochthonous Molasse: the sediments here rest transgressively on top of various Alpine or Carpathian tectonic units and are moved during sedimentation and afterwards on the back of these tectonic units ("piggy-back basins"; Fig. 3a). For the various terms used in the literature for this tectonic part, see STEININGER et al. (1986).

Several sedimentary cycles characterize the Molasse sequence. On top of crystalline rocks of the Bohemian Massif, and the in parts incomplete Late Paleozoic to Mesozoic sedimentary sequence, we observe a first transgressive marine marly cycle (Late Eocene to Early Oligocene: Kiscellian) represented in Kiscellian time by a mainly fine-layered to laminated sequence characterized by a massive bloom of a few nannoplankton and planktonic foraminifera taxa and an endemic mollusc and ostracode fauna in Solenovian time, which thrived in an euxinic-sapropelic environment. The second transgressive marine clastic cycle (Late Oligocene to Early Miocene: Egerian), is characterised by an open marine flora and fauna, the terrigenous sedimentation and the translation of the basin axis in general to the north. This was caused by the beginning uplift and northward movement of the Alpine-Carpathian orogen. The third transgressive marine clastic cycle (Early Miocene: Eggenburgian, Ottnangian) is characterised by a farspread open marine fauna influenced biogeographically from the east in the Early Miocene (Eggenburgian), and by western faunal elements in the later Early Miocene (Ottnangian). Finally, the marine sedimentation ends in the Molasse Basin in the later Early Miocene (upper Ottnangian) and passes into a freshwater to lacustrine clastic cycle (uppermost Early Miocene: Karpatian, Middle Miocene: Badenian, Sarmatian to Late Miocene: Pannonian and younger sediments) with lake, coal swamp and river gravel deposits. This evolution is interrupted in the eastern part of the Molasse Basin by shortlived marine incursions in the late Early Miocene (Karpatian), Middle Miocene (base of the Badenian, base of the Sarmatian) and in the Late Miocene (base of the Pannonian).

Alpine/Carpathian Intra-mountainous basins

The emplacement and the sedimentation within the Alpine-Carpathian intra-mountainous basins (e.g. Vienna, Pannonian/Danube and Styrian-Basins) started in Middle Miocene (Badenian) times. In the early Miocene (Eggenburgian, Ottnangian, Karpatian) we recognize partly marine to non-marine clastic sediments with lake, coal swamp and

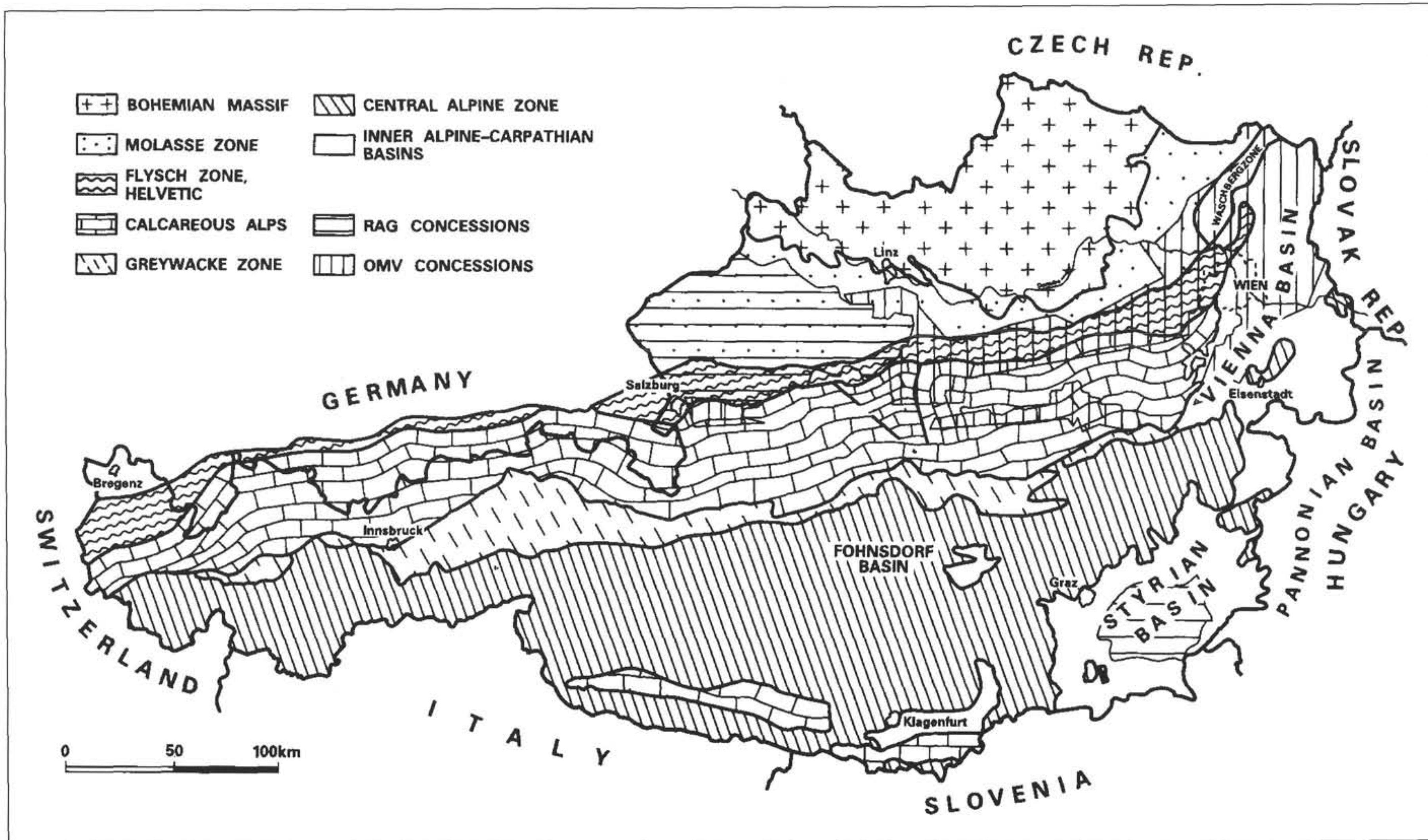


Fig. 2
Generalized tectonic units in Austria (after WAGNER, 1996).

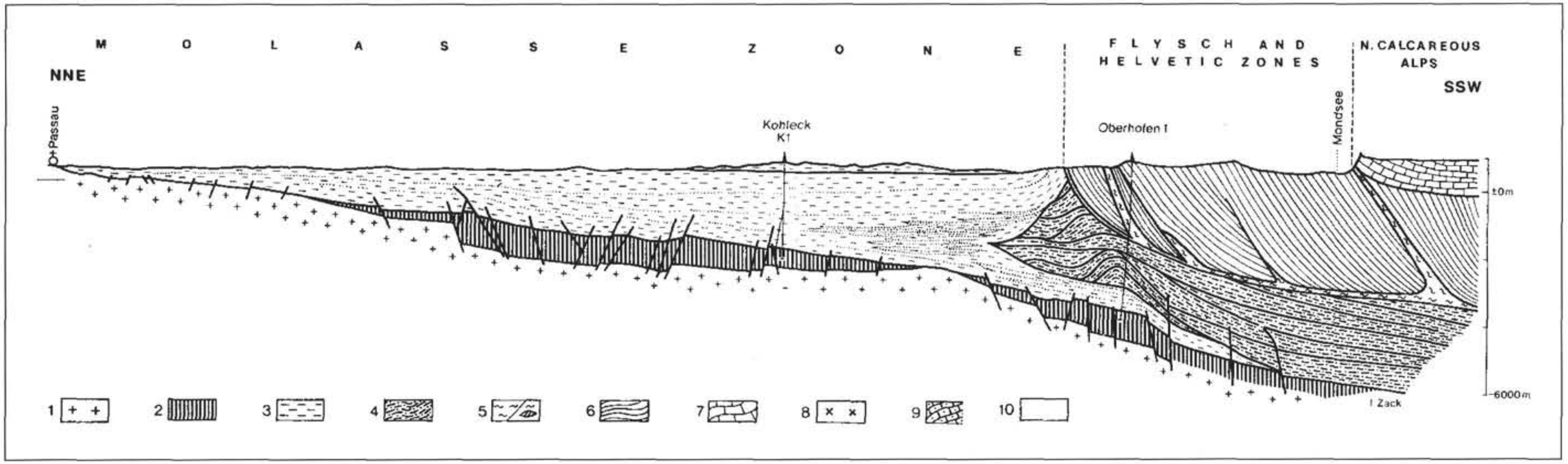


Fig. 3a
Cross section through the western part of the Upper Austrian Molasse basin (after STEININGER et al., 1986 and WAGNER, 1996, modified). (1) Crystalline of the Bohemian Massif; (2) Paleozoic and Mesozoic Sediments below the Molasse; (3) Autochthonous Molasse; (4) Allochthonous and Parautochthonous Molasse; (5) Helvetic and Klippen Zones; (6) Rhenodanubian Flysch Zone; (7) Northern Calcareous Alps and Greywacke Zone; (8) Tatric Crystalline; (9) Mesozoic Cover of the Tatric Crystalline; (10) Intramontane Basin (Neogene Sediments).

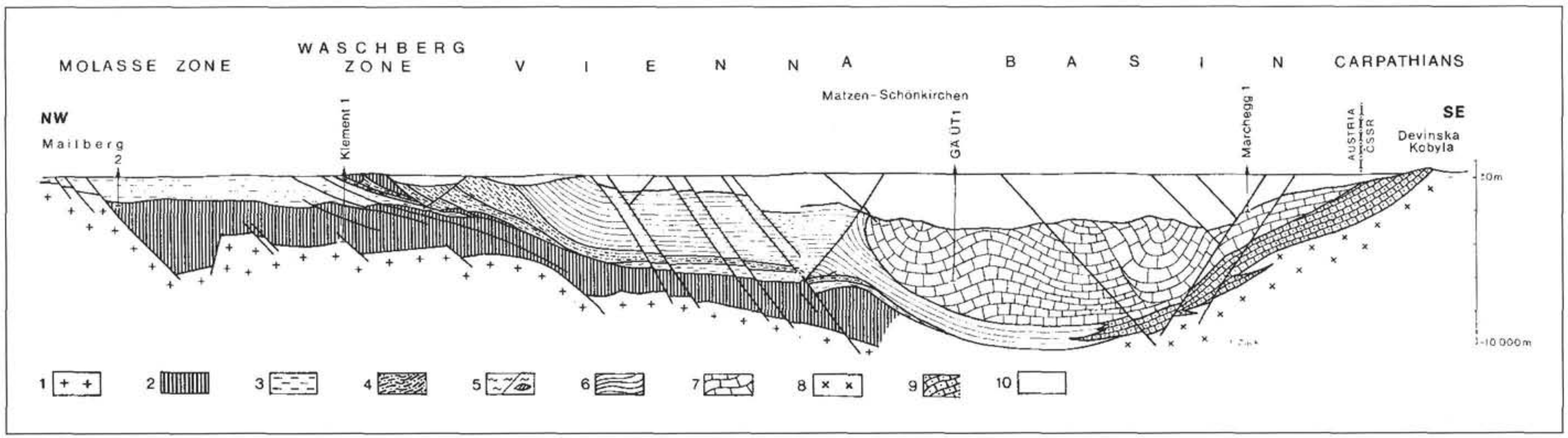


Fig. 3b
Cross section through the eastern part of the Lower Austrian Molasse basin, the Waschberg unit (allochthonous Molasse Zone) and the northern part of the Vienna basin (after STEININGER et al., 1986 and WAGNER, 1996, modified). For legend see Fig. 3a.

river gravel deposits, representing the "piggy back" basin sedimentation of the Molasse Basin on top of the basement of these basins built by various Alpine- and Carpathian tectonic units. At the beginning of this intra-mountainous basin configuration these "piggy-back" basin sediments are transgressively overlain by an open marine clastic cycle grading into reduced marine conditions (mainly Middle Miocene: Badenian) followed by a sequence of reduced marine to lacustrine and fluvatile sediments (Middle Miocene: Sarmatian, Late Miocene and Pliocene: Pannonian, Pontian). In Middle Miocene time (Badenian to Early Sarmatian) these basins belonged to a huge, interconnected and intracontinental sea, which progressively decayed from Late Miocene onwards to a system of isolated lakes, each with a characteristic evolution of an endemic aquatic fauna and flora.

In the region of the **Vienna Basin** the Alpine-Carpathian nappe system itself was thrusted over the European continental margin (Bohemian Massif with its Late Paleozoic and Mesozoic cover and the autochthonous Molasse Basin sediments) from the Middle Eocene onwards to later Early Miocene (Fig. 3b). These nappes of the Alpine-Carpathian system form the basement of the Vienna Basin. The morphotectonic behavior of the Bohemian Massif caused a delay of movements W of Vienna, while towards the NE thrusting advanced and ended later. The difference created the pull apart conditions which led to the extension of the Vienna Basin (ROYDEN, 1985).

The development of the Vienna Basin area in its early stage (Eggenburgian to Karpatian) coincides with the piggy back phase mentioned above. A beginning pull apart effect at that time is shown by the NE striking synsedimentary faults with displacements of about 1,800 m in the Mistelbach area and E Zistersdorf (LADWEIN et al., 1991; KREUTZER 1993). In Eggenburgian to Karpatian time a so called "Proto-Vienna Basin" was formed by similar geodynamics as the Vienna Basin sensu strictu later in the Badenian time. This "Proto-Vienna Basin" was filled by "Parautochthonous Molasse" in the sense of STEININGER et al. (1986) and the isopachs of that fill show a generally ESE-WNW orientation (JIRICEK and SEIFERT, 1990). The basin was restricted to the northern part of the today's Vienna Basin, but extended toward the south, already forming the nucleus of a later remarkable depocenter the Schwechat depression in the course of the Upper Karpatian sedimentation. The sediment input in Karpatian time came from the south (SAUER et al., 1992). After the Karpatian sedimenation phase and before the Badenian ingression, an important inversion took place and large amounts of the Early Miocene sediments were eroded, in some areas even down to the basement of the basin (e.g. in Matzen ridge down to the Rhenodanubian Flysch). A new transgressive sequence started with the Badenian ingression and subsequently the basin was enlarged to its present shape. This "Neo-Vienna Basin" subsided on an already stabilised Alpine nappe system from the Middle Miocene onwards.

The considerable amount of subsidence and fault offsets are connected with the largest extension of the Vienna Basin caused by movements to the northeast in the Carpathian region (ROYDEN, 1985; WESSELY, 1988, 1993; DECKER and PERESSON, 1996; SEIFERT 1996). Faults with huge synsedimentary displacements originated by the resulting pull-apart effect beside deep depocenters. The largest are the Steinberg and the Leopoldsdorf faults (6,000 m and 4,000 m displacement). Many of these faults show right stepping en echelon arrangements pointing to a distinct sinistral component of motion besides the predominating dip-slip component. Near the SE flank of the basin a series of graben-like subsidiary pull-apart basins along a NE striking sinistral strike slip fault opened. They contain very young sediments including Pliocene to Quaternary coarse clastics. The formation of negative flower structures caused some steepening of these layers. The strike-slip fault extends into the Mur-Mürz fault system within the Central Alps, and is accompanied by a high recent seismicity.

The more than 4 km deep **Styrian Basin** is located at the eastern border of the Alpine orogen and is part of the Pannonian Basin system. It represents an extensional structure on top of a crustal wedge, which moved eastward during the final stages of the Neogene Alpine orogeny. The basin evolution can be subdivided in an Early Miocene (Ottnangian, Karpatian, Early Badenian) synrift phase of subsidence over an extremly weak lithospheric crust with thick clastic limnic/fluviatile and marine sediments and a first andesitic volcanic phase (Fig. 4a, b). The Middle and Late Miocene post-rift phase is controlled by the transgressive Middle Miocene (Badenian) marine sequences. These grade into reduced marine conditions (Sarmatian) and finally into limnic/fluviatile (Pannonian) sequences depicting the endemic evolution of the aquatic biotas characteristic of the Paratethys realms (Fig. 4c, d, e). In Pliocene times a basin inversion and uplift resulted in an erosional phase with a second volcanic phase producing basalts in the Late Pliocene to Pleistocene (Fig. 4f) (EBNER and SACHSENHOFER, 1995; FRITZ, 1996; KOLLMANN, 1965; SACHSENHOFER and al., 1996, and literature cited herein).

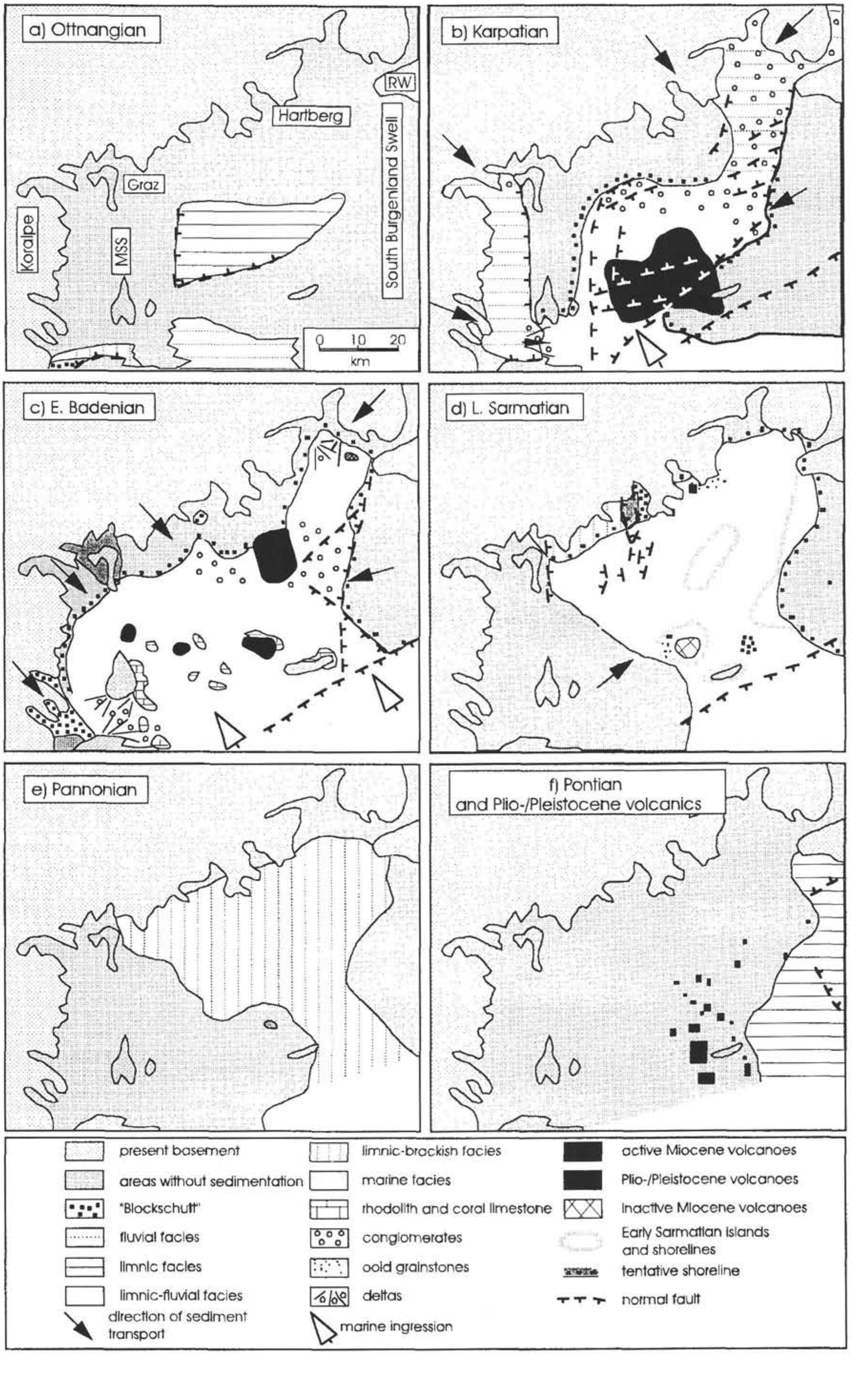
Intra-Alpine Neogene basins: Smaller Neogene basins within the Alpine system were created in the Miocene time by the Neogene fault and shear systems of the Eastern Alps (e.g. the Salzach-Enns, Mur-Mürz, Lavantal- and Periadriatic-fault/shear systems (Fig. 5) (DECKER and PERESSON, 1996, NEUBAUER et al., 1999). Most of these basins were filled with limnic to fluviatile sediments and intercalated larger to smaller browncoal seams; some of these were reached by the Badenian marine and the Sarmatian reduced marine ingression (e.g. in the Lavantal-basin) (WEBER and WEISS, 1983; STEININGER et al., 1988/89).

Paleogeography and Paleobiogeography of the circum-Mediterranean region and the Austrian basins

In general, Cenozoic plate tectonic motions created the oceans of today and shaped the bordering continents with their young collisional mountain chains. The final closure of the Tethyan Ocean and the creation of the Mediterranean Sea as well as the Paratethys Sea close to the Eocene/Oligocene boundary were caused by a reorganization of the lithospheric plates. This includes the northward movement

Fig. 4 see next page →
Paleogeographic maps of the Styrian Basin. MSS: Middle Styrian swell; RW: Rechnitz window of the Penninic unit (after EBNER and SACHSENHOFER, 1995 and SACHSENHOFER, 1996, modified).

Fig. 4


a) Ottnangian
Hartberg
RW
Graz
Koralpe
MSS
South Burgenland Swell
0 10 20
km
b) Karpatian
c) E. Badenian
d) L. Sarmatian
e) Pannonian
f) Pontian
and Plio-/Pleistocene volcanics
present basement
areas without sedimentation
"Blockschutt"
fluvial facies
limnic facies
limnic-fluvial facies
direction of sediment transport
limnic-brackish facies
marine facies
rhodolith and coral limestone
conglomerates
ooid grainstones
deltas
marine ingression
active Miocene volcanoes
Plio-/Pleistocene volcanoes
inactive Miocene volcanoes
Early Sarmatian islands and shorelines
tentative shoreline
normal fault

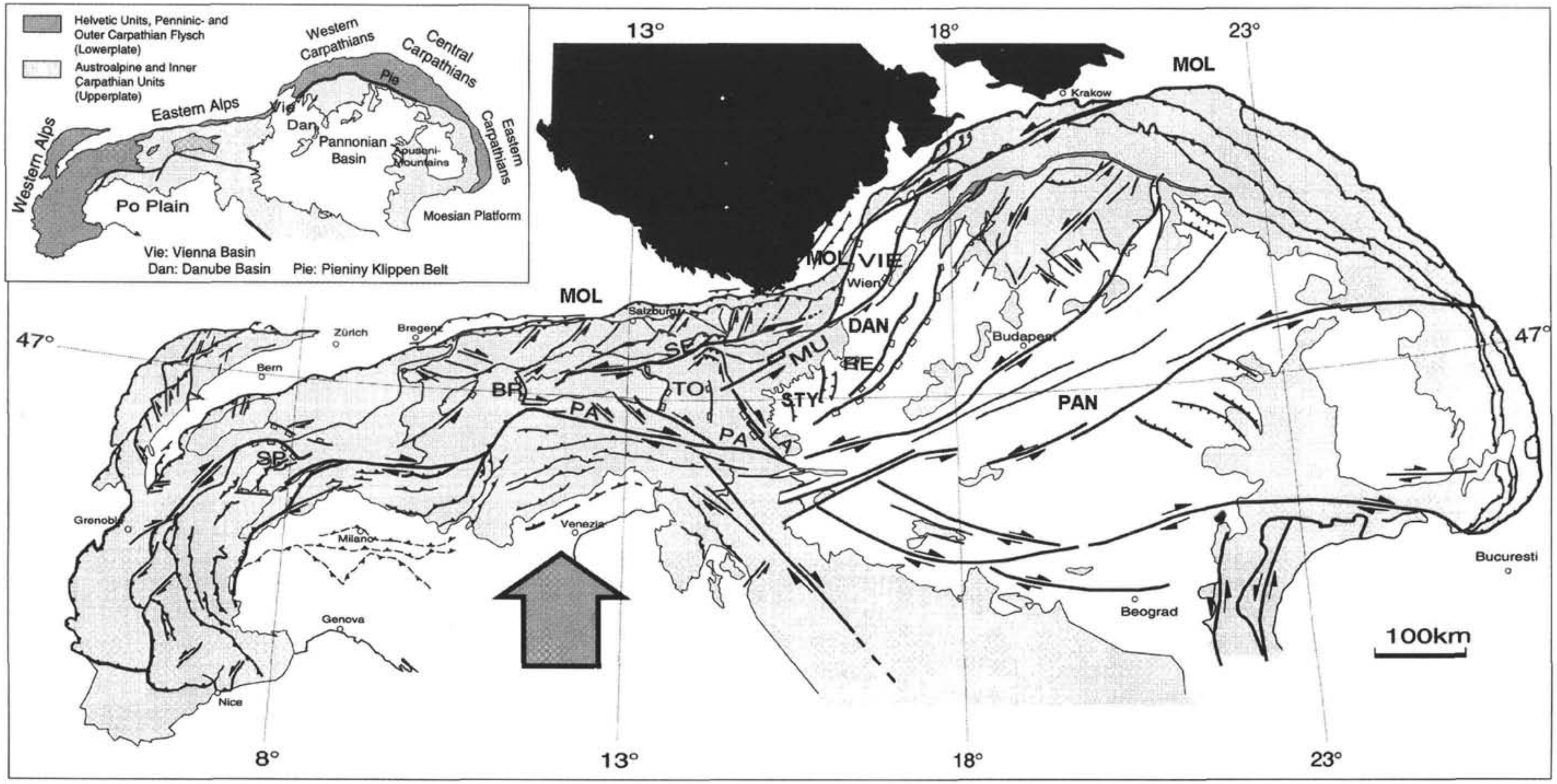


Fig. 5
Neogene tectonic/kinematic map of the Alpine-Carpathian-Pannonian area. BR: Brenner fault; DAN: Danube Basin; LA: Lavanttal fault; MOL: Molasse Basin; MU: Mur-Mürz fault; PA: Periadriatic fault; PAN: Pannonian Basin; RE: Rechnitz Penninic window; SE: Salzachtal-Ennstal fault; SP: Simplon fault; STY: Styrian Basin; TO: Tauernostrand fault; VIE: Vienna Basin. Inset: Overview and geographical terms (after DECKER and PERESSON, 1996, modified).

of India and Australia, the beginning collision of India and Asia in the Late Eocene, as well as the northward movement and counterclockwise rotation of Africa from the Late Eocene onwards and the collision of Africa and its subplates (e.g. the Adriatic and Arabian subplate) with the Eurasian plate and subplates.

Within the last decade several paleogeographic/palinspastic reconstructions have been presented. One of the major problems of such reconstructions is the insufficient and incorrect stratigraphic correlation, the long duration of the time slices shown on these maps (e.g. BIJU-DUVAL et al., 1977; DERCOURT et al., 1985) and the long time intervals between the time slices presented, respectively (e.g. DERCOURT et al., 1993). Other reconstructions present static sediment/facies distribution maps without plate tectonic elements (e.g.: CAHUZAC et al., 1992; HAMOR and HALMAI, 1988; POPOV et al., 1993; STEININGER et al., 1985; STUDENKA et al., 1998). First attempts with a more accurate correlation, the necessary time resolution and combining sedimentary and facies developments as well as tectonic/palinspastic details have been published in relation to various aspects for the circum-Mediterranean region including the Paratethys by RÖGL and STEININGER (1983), STEININGER and RÖGL (1984), STEININGER et al. (1985), KOVAC et al. (1993) and for the Mediterranean region by BOCCALETTI et al. (1986, 1990). The latest results in stratigraphic correlation, marine faunal relations and continental faunal migrations have been taken into account by the palinspastic maps published lately by RÖGL (1998) showing the paleogeographic evolution of the circum-Mediterranean area.

We have choosen for this paper some time slices relevant to the evolution of the Austrian Oligocene and Neogene basins from RÖGL (1998). We will first briefly describe the circum-Mediterranean setting for each time slice and than focus on the Austrian basins.

The Late Eocene Archipelago

(Fig. 6: Priabonian – Beloglinian: 37 to 33.7 Ma)

This time slice is centered on Chron 15 around 35 Ma (Fig. 6) and corresponds approximately to the time span of the Priabonian and the Beloglinian – stage, – respectively or to calcareous Nannoplankton Zones upper NP 18 to lower NP 21 and to the Planktonic Foraminifera zones upper P 15 to P 17 (Tab. 1).

The circum-Mediterranean paleogeographic setting is characterised by an open marine connection with the Indopacific and the Atlantic. In central Europe we find the emerging Alpidic mountain chains (e.g. Alps, Carpathians, Dinarids, Pontids and the Caucasian mountains), the Helvetic Sea extensively flooded the central European platform, and a seaway – the Danish-Polish trough – connected this sea with the North Sea Basin. The Turgai Strait, a shallow water seaway, allowed for an exchange of marine warmer water faunas of this Tethyan Sea towards the polar waters in the north and hindered the terrestrial faunal exchange be-

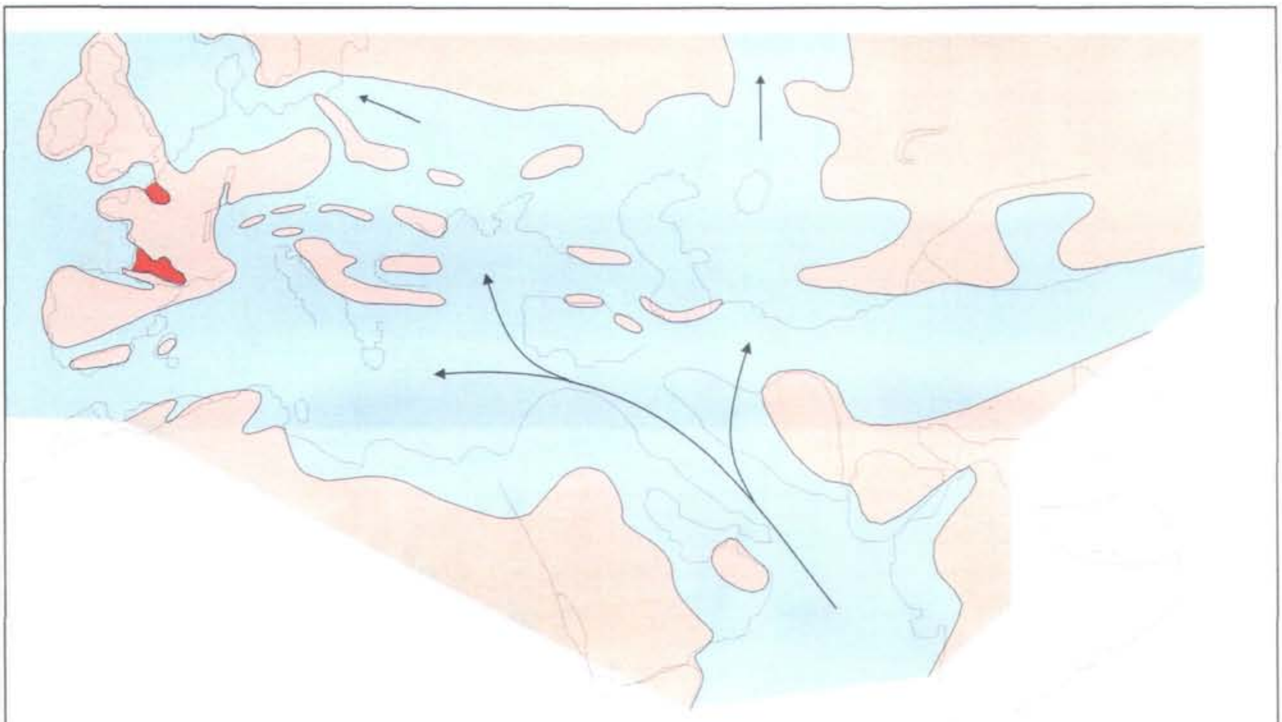


Fig. 6
Palinspastic reconstruction of the Late Eocene Tethys archipelago (37 to 33.7 Ma) of the circum-Mediterranean area (from RÖGL, 1998).

tween Asia and Europe. In the east the marine sedimentation extended to Inner Asia (RÖGL, 1998; POPOV et al., 1993).

A Late Eocene palinspastic cross section of the evolution of the western Molasse Basin and a new model for the paleogeographic reconstruction of tectonic units of the central European region have been recently published by WAGNER (1996) and OBERHAUSER (1995).

In the Austrian Molasse Basin sediments of Late Eocene age are found on the Upper Austrian Molasse shelf with a paralic facies and nearshore sands (Voitsdorf Formation and Cerithian Beds; WAGNER, 1998). The clastic input of these sediments was derived from the Bohemian Massif in the north. These sands interfinger and continue to the south with corallinaceen limestones (Lithothamnium Limestone, WAGNER, 1998) passing into slope sediments of the Perwang-Formation (WAGNER, 1998) containing *Globigerina* and *Discocyclina* marls. Similar sediments are known, squeezed inbetween the imbricated allochthonous Molasse, within the nappes of the Rhenodanubian Flysch-Zone and Northern Calcareous Alps. Sediments of the southern coast of this sea transgressively overlie the Northern Calcareous Alps nappe complex (e.g. from west to east: Inn Valley, Oberaudorf, Reichenhall, Liezen and Radstadt; for a reconstruction see the palinspastic cross section, Fig. 9c in: WAGNER, 1996). In Lower Austria massive conglomerates have been recovered in deep wells (Moosbierbaum Conglomerate; WAGNER, 1998), contemporaneous littoral sediments are further known from a deep well (Zistersdorf ÜT 2A) below the Vienna Basin, the Alpine-Carpathian nappes in the autochthonous Molasse. Within the allochthonous Molasse Zone – the "Waschberg unit" in Lower Austria – a variety of Eocene sediments are known in the imbricated scales (Fig. 3b).

The rich nannoflora, the planktonic and benthic foraminifera including larger foraminifera and the tropical mollusc fauna, show strong Tethyan-Mediterranean affinities.

The creation of the Paratethys and its Oligocene development

(Fig. 7: Middle Kiscellian-Solenovian: 32 to 30.2 Ma)

To illustrate the origin of the Paratethys bioprovince we have choosen this Middle Kiscellian-Solenovian time slice (Fig. 7) because it most impressively marks the isolation of parts of the vanishing Tethyan Sea in the north of the Mediterranean region and the birth of the Paratethys Sea, beginning around the Eocene/Oligocene boundary. This isolation was caused by the progressive rise of the collisional orogen and, within this time slice, the restriced, endemic realms were most widespread. This time slice corresponds approximately to the time span of the Middle Rupelian, the Middle Kiscellian – Solenovian in Early Oligocene, respectively and

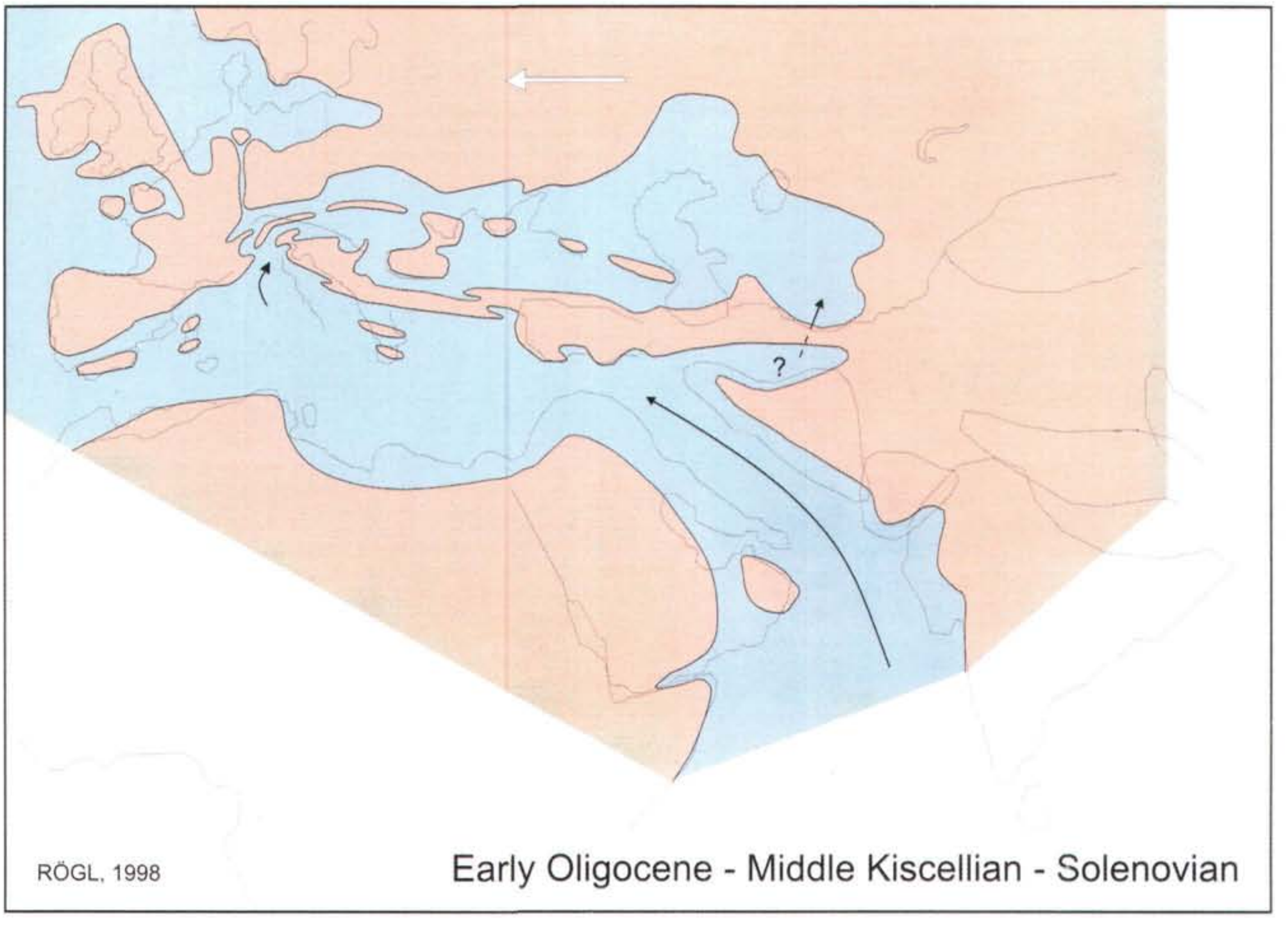


Fig. 7
Palinspastic reconstruction of an early stage of the beginning of the Paratethys in the Early Oligocene (Middle Kiscellian, Solenovian), 32 to 30 Ma (from RÖGL, 1998).

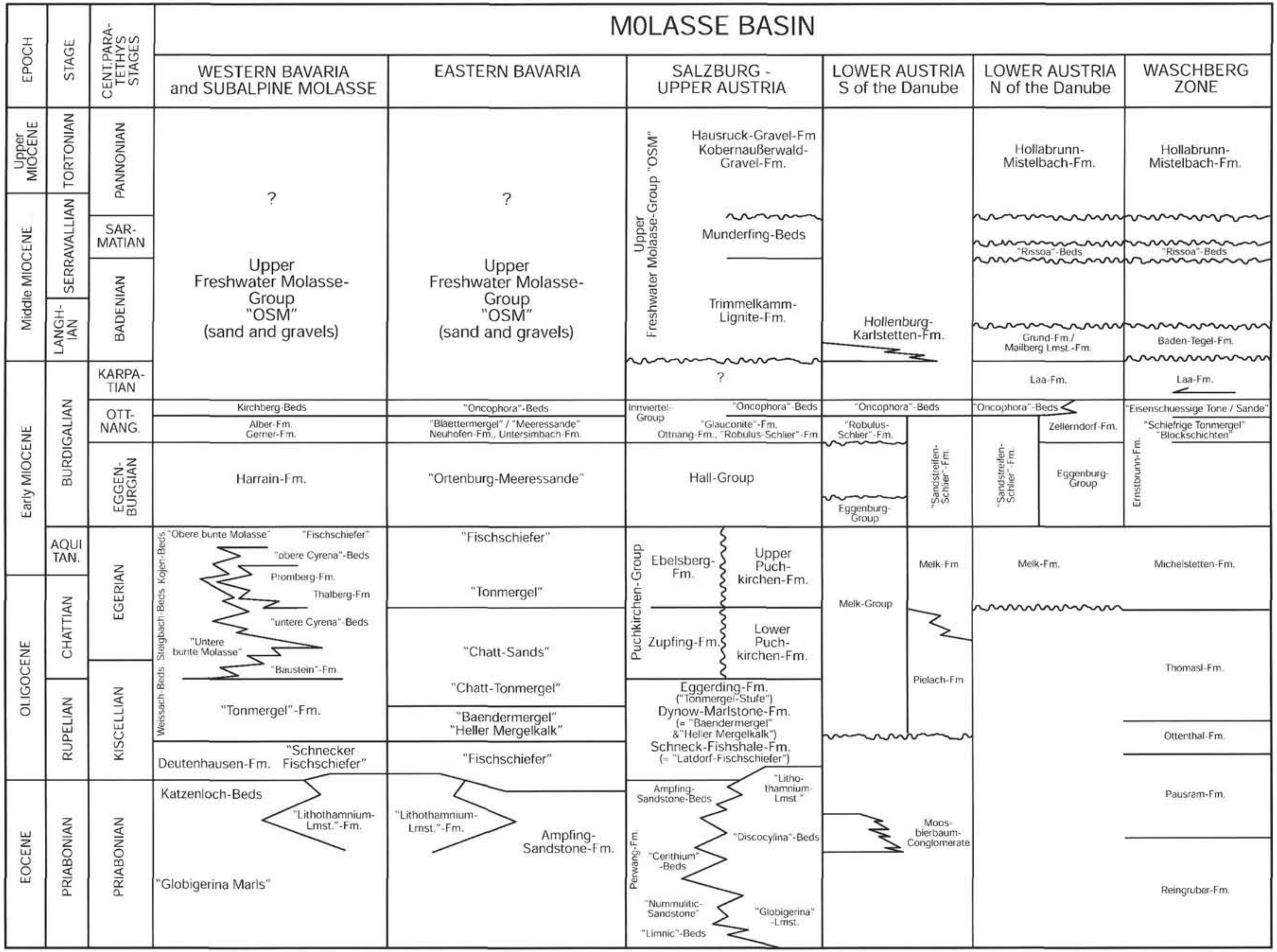


Fig. 8
Molasse Basin sedimentary cycles and lithostratigraphic units from western Austria (Vorarlberg) across Bavaria to Upper and Lower Austria (after STEININGER and al., 1986, WAGNER, 1998, modified).

to the calcareous nannoplankton zone NP 23 and approximately to the planktonic foraminifera zone P 19 (Tab. 1).

The Mediterranean area is still connected with the Indopacific and the Atlantic ocean by a wide open seaway. The strongly restricted connection with the Paratethys realms is reconstructed here through the Dinaride corridor and via the western Molasse Basin. A link to the Eastern Paratethys was still in existence in lowermost Early Oligocene (Early Kiscellian, Peshekian). The opening of the Rhine graben provided an active seaway from the Molasse Basin to the North Sea realms. Most important for the European/Asian mammal exchange was the closure of the Turgai strait at ca. the Eocene to Oligocene boundary. This is one of the most prominent events in the European and the Asian mammal faunas, known also as the "Grand Coupure".

The Paratethys is characterised by long west-east trending basins with a restricted marine flora and fauna and mostly thin-layered to laminated sediments. This facies points in most parts of the Paratethys to low salinity and oxygen-depleted conditions prevailing in the deeper parts of the basins (RÖGL, 1998).

In Austria the beginning of the Paratethys realm biofacies is marked in the Molasse Basin by a remarkable facies change on top of the Late Eocene sediments. The Early Oligocene – the Kiscellian Stage contains in general marly to often dark coloured pelitic, thin layered to laminated sediments with nannochalks and diatomites with monospecific, low diverse microfossils assemblages and a macrofauna dominated by endemic taxa (e.g. Schöneck-Formation, Dynow Marlstone, Eggerding Formation; WAGNER, 1998) deposited in restricted environments (Fig. 8). In the later Kiscellian gradually open marine conditions were restored ("Tonmergelstufe" = Zupfing-Formation, WAGNER, 1998) (Fig. 8). This entire sedimentary cycle is confined to the deeper parts of the basin, overlain by younger sediments and known only by deep wells (Fig. 8 and WAGNER, 1996, Fig. 2a).

The Tertiary sediments of the lower Inn valley (Häring and Reith im Winkel) near Innsbruck (Tyrol) were deposited in a typical Molasse Basin "piggy back" situation with the fluviatile/limnic/paralic to marine Kiscellian sediments (Häring Formation) grading into the Egerian limnic/fluviatile sediments of the Angerberg Formation.

The transgressive base of the following Egerian turbiditic lower and upper Puchkirchen-Formation in the western Molasse Basin deeply erodes and incises the older sediments under submarine conditions (WAGNER, 1996, Fig. 2a) and

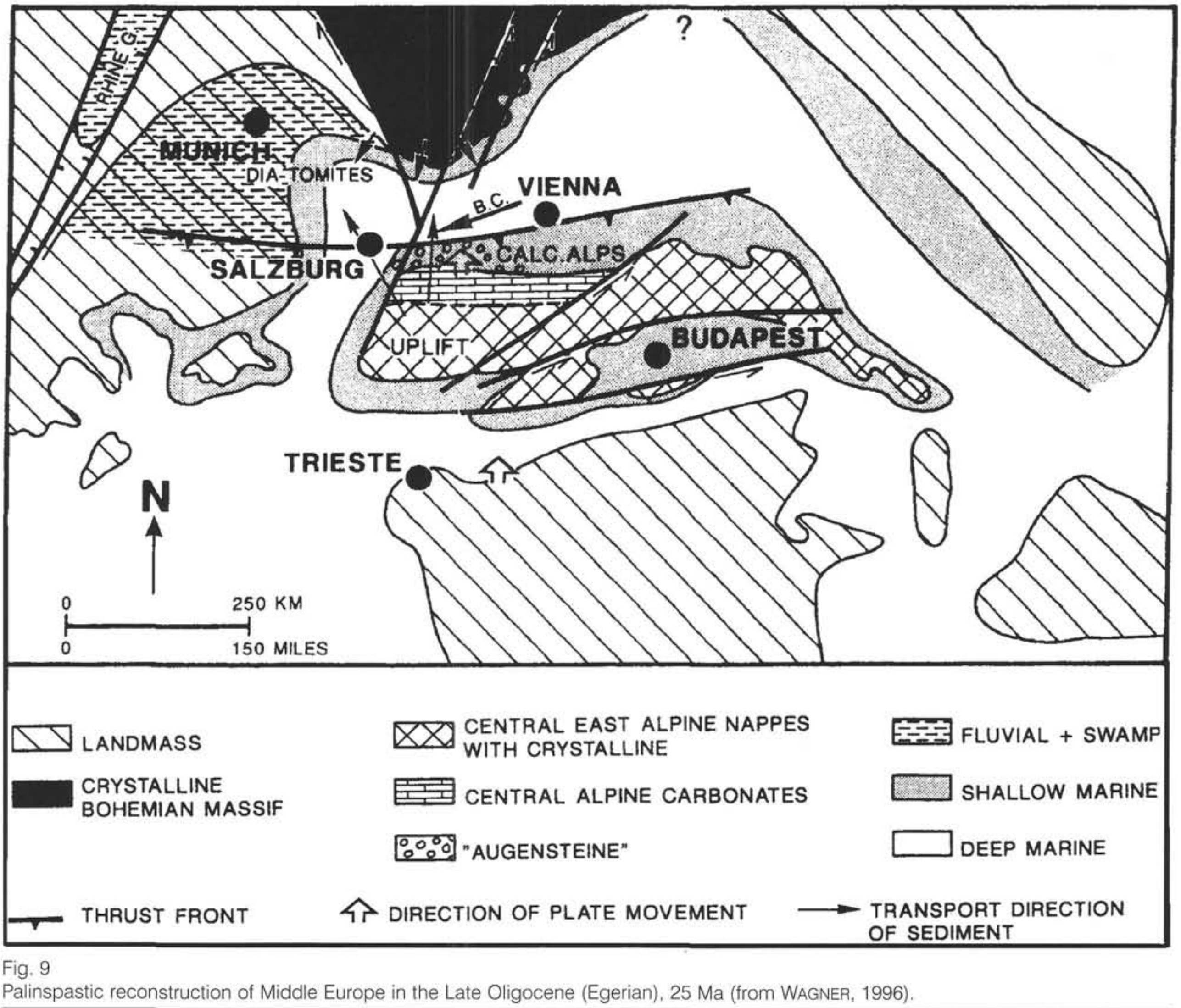


Fig. 9
Palinspastic reconstruction of Middle Europe in the Late Oligocene (Egerian), 25 Ma (from WAGNER, 1996).

the basin axis is further shifted to the north (Figs. 3a, 9). This transgression also spreads across the Molasse Basin shelf far to the north into the Bohemian Massif (see also the palinspastic section in WAGNER, 1996, Fig. 9b). The open marine conditions are fully restored with a rich marine microfauna where again larger foraminifera invade this area and with a diverse macrofauna. These thriving conditions are obviously caused in these parts of the Molasse Basin by the paleogeographic situation with a marine connection with the south from the Salzburg area across the still submerged Alpine system to the Mediterranean basin (Fig. 9; see also RÖGL, 1998, plate 4). The Puchkirchen-Formation in the Salzburg and Upper Austrian Molasse Basin and its equivalents, the Melk-Formation in Lower Austria are made up by a siliciclastic facies of shales, sandy shales, nearshore sands and paralic to limnic to fluviatile deposits. Intercalated conglomerates in the western Molasse Basin have been deposited in channels and in the form of submarine fandelta deposits originating from different Alpine tectonic units (WAGNER, 1996). From Salzburg to the west the Molasse Basin is filled with paralic, limnic to fluviatile sediments the so called USM = "Lower Freshwater Molasse" = Lower Freshwater Molasse-Group (WAGNER, 1998). Typical lithologic units are: "Cyrena"- and Promberg Formations in Bavaria, and "Baustein"-, Weissach-, Steigbach-, Kojen Formations and the "Granitische Molasse", in ascending order, in Vorarlberg (see also Fig. 8).

Lower Miocene tidal dominated seaways and the creation of the Alpine lowlands

(Fig. 10: Late Burdigalian – Ottnangian – Early Kotskhurian: 18 to 17 Ma)

In the Early Miocene (Aquitanian to Early Burdigalian, Late Egerian to Eggenburgian, Karadzhalganian to Sakaraulian; Tab. 1) the Mediterranean area was still connected with the Indopacific and the Atlantic ocean. However, the Arabian subplate now moved counterclockwise and faster towards the northeast than the African plate. This caused the opening of the Red Sea and the beginning of evaporitic environments on the northeastern edge of the subplate and narrowed the Indopacific seaway. The northward movement of the African plate system created the emerging Atlas and Betic mountain chains, which narrowed the Atlantic portal of the Mediterranean. Elongated mountain chains emerged in the central Mediterranean by the counterclockwise motion and overthrusting of the Apennine basin. The Paratethys still has a wide open connection with the Indopacific seaway and by the "Transtethyan Trench Corridor" from Slovenia via the Venetian Basin to the Mediterranean. These openings obviously caused the tidal dominated sediments in the Eggenburgian deposits of Hungary. The connection of the Paratethys with the west and from here to the north via the Rhine Graben was not active anymore (Fig. 9) and the northern faunal elements vanished. The marine flora and fauna on the contrary was now enriched by warmer water elements (larger foraminifera and specific mollusc taxa) which point to prominent Indopacific influences (RÖGL, 1998: plate 4). In the Early Eggenburgian time a characteristic warm water mollusc fauna (with large pectinids: *"Chlamys gigas"* horizon) spread from the east throughout the entire Paratethys to Bavaria (STEININGER and SENES, 1971; BALDI, 1979; RUSU, 1996).

In the Salzburg and Upper Austrian part of the Molasse Basin we recognize a distinct gap between the Late Egerian Upper Puchkirchen Formation and the transgressively following Eggenburgian Lindach- and Hall Formations (see WAGNER, 1996, Fig. 2a, and WAGNER, 1998). This Early Miocene transgression reworked parts of the Late Egerian nearshore sediments (Linz Sand and "Älterer Schlier" = Ebelsberg Formation and Zupfing Formation, WAGNER, 1998) and spread farther across the Molasse shelf and the Bohemian Massif to the north. In the south the Hall Formation transgressively overlies the overthrusted Alpine nappe system (Fig. 3a, and WAGNER, 1996, Fig. 9a). In Lower Austria the Eggenburgian parts of the Sandstreifen Schlier (WAGNER, 1998) transgressively covers large parts of the Molasse Basin shelf directly overlying the basement. These sediments are also found beneath the overthrusted Eastern Alpine nappes and below the Vienna Basin (Fig. 3b and STEININGER et al. 1986, Figs. 3, 4, 5, 6, 7). The transgressive marine sediments of the Eggenburg Group (WAGNER, 1998) are spread farther across the southern and eastern edge of the Bohemian Massif in Lower Austria.

To illustrate the closure of the Indopacific/Mediterranean/Paratethys seaway we have chosen the Late Burdigalian – Ottnangian – Early Kotsakhurian time slice around 18 to 17 Ma (Tab. 1, Fig. 10) because it most impressively marks this important marine and continental event (the "*Gomphotherium* event" see RÖGL, 1998), as well as the biologic separation and evolution of the Neogene Mediterranean bioprovince, respectively. This event was caused by the progressive counterclockwise rotation of the Arabian subplate and its collision with the Eurasian plate system and a global sea-level drop (cycle TB 2.1 of HAQ et al. 1987; Bur 3 of HARDENBOL et al., 1998). The Arabian- Eurasian landbridge for the first time allowed a (mammal-) faunal exchange beginning in European Mammal Zone MN 4 (STEININGER, 1999) between these bioprovinces approximately around 18 Ma (THENIUS, 1979; STEININGER et al., 1985; BARRY and FLYNN, 1988).

During the same time slice we observe the isolation of the Eastern Paratethys from the oceanic realms and the Central Paratethys sea. This causes the evolution of the peculiar endemic semi-marine Kotsakhurian fauna (POPOV et al., 1993). From the Central Paratethys an active seaway developed across the western Alpine foredeep and the Rhone valley area towards the western Mediterranean and across the Rhine Graben into the north Sea realm (Fig. 11). This western Mediterranean connection allowed for the immigration of western Mediterranean faunal elements (bryozoa, molluscs) into the western Central Paratethys and triggered the tidal dominated sediments (Innviertel-Group: Atzbach Sands, WAGNER, 1998) known from the Swiss, Bavarian and Upper-Austrian Molasse Basin (FAUPL and ROETZEL, 1987; KRENMAYER et al. 1996; MARTEL et al., 1994; ZWEIGEL, 1998). In the uppermost Late Burdigalian-Karpatian this western marine connection again ceased and the entire western Paratethys and the western Molasse Basin dried up (see RÖGL, 1998, plate 6).

In the Molasse Basin of Austria marine sedimentation continues into Ottnangian time with a pelitic marly basinal facies, intercalated towards the southern coasts with coastal sands and fan delta conglomerates of Alpine origin and a sandy facies at the northern coasts of Bohemian Massif origin, summarized within the Innviertel Group (WAGNER,

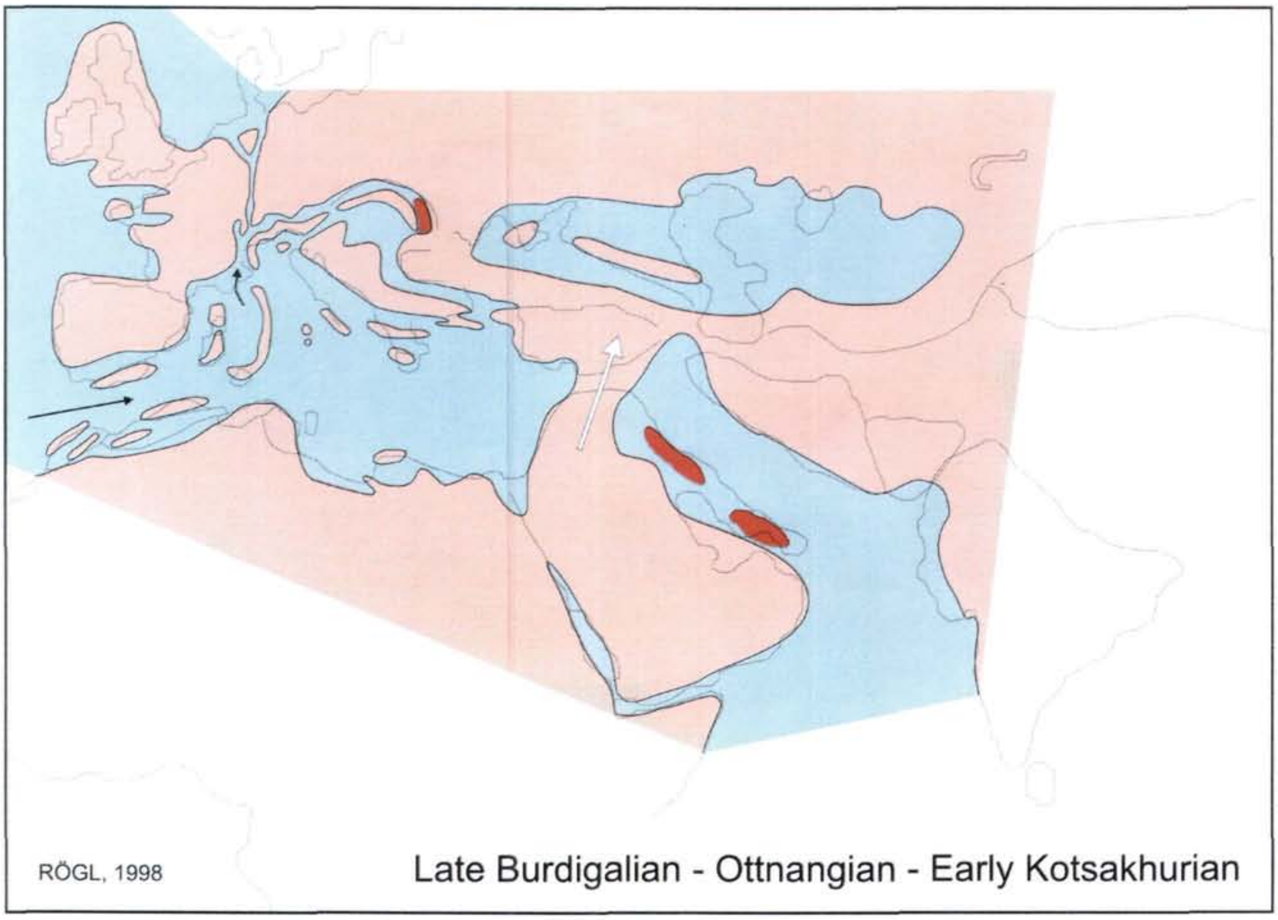


Fig. 10
Palinspastic reconstruction of the Paratethys in the Late Burdigalian (Ottnangian, Early Kotsakhurian), 18 to 17 Ma (from RÖGL, 1998).

1998) in the Salzburg and Upper Austrian part of the Molasse Basin (WAGNER, 1996, Fig. 2a) and the Ottangian "Robulus Schlier" "Sandstreifen Schlier" and Zellerndorf Formation in the east (Fig. 3b and WAGNER, 1998). As mentioned above, this marine event can be followed across Bavaria (Harrain Formation) to Vorarlberg (western Austria). These marine sediments are incorporated within the OMM = Upper Marine Molasse. In the Late Ottnangian regressive conditions prevailed and triggered a widespread endemic nearshore estuarine to fluviatile facies (Oncophora-Formation, WAGNER, 1998) dominated by a mollusc fauna similar to the Kotsakhurian fauna (Fig. 3b).

From the uppermost Late Burdigalian to Karpatian the western Molasse Basin to the southern spur of the Bohemian Massif dried up and paralic, limnic to fluviatile sediments ("Kohleführende Süßwasserschichten", STEININGER et al., 1986) prevailed in the Middle and Late Miocene (Fig. 3b). The continental Molasse Basin east of the spur of the Bohemian Massif was reached episodically by short living marine transgressions coming out of the Vienna Basin in Karpatian and Early Badenian time and by the Early Sarmatian and Early Pannonian transgressions (Fig. 3b). These transgressions seemed to follow from Badenian time onwards depressions and incised vallies from an eastward directed drainage system beginning east of the spur of the Boehmian Massif. This drainage system can be followed in Badenian time from Spitz in the Danube valley in Lower Austria across the Molasse Basin entering the Vienna Basin around Mistelbach in northern Lower Austria. Also the Sarmatian and Pannonian drainage systems follow this direction (STEININGER and ROETZEL, 1996).

The first Alpine lowlands must have come into existence from the Eocene/Oligocene times onwards by the northward movement of the Alpine promontory, since we recover their earliest erosional products – the "Augenstein" gravel – within the submarine fan deposits in the Egerian Puchkirchen-Formation. (Figs. 3b, 10, 11). The general drainage system west of the spur of the Bohemian Massif and the Regensburg high in Late Oligocene-Early Egerian time (during the deposition of the USM, Fig. 3b and see above) was directed from west to east, but turned around during the Early Miocene. In Late Ottnangian it was then directed until Pannonian times towards the west, towards a pre-Rhone river system. Only since the Late Miocene – since Pannonian time the drainage of the Bavarian and the Austrian Molasse Basin followed an eastern direction and a pre-Danube river system came into existence. Another prominent drainage system originating in the Alpine lowlands in Badenian time is known near Krems. Here a pre-Traisen river entered the Molasse Basin from the south and built a huge submarine fan reaching far to the north into the Bohemian Massif (Hollenburg-Karlsstetten Formation; STEININGER and ROETZEL, 1996). The lowland character of the Alps can also be deduced from the sedimentary fill of small Neogene basins within the Alpine system itself (e.g. Salzach-Enns, Mur-Mürz, Lavantal and Periadriatic-basins; Fig. 5). These ba-

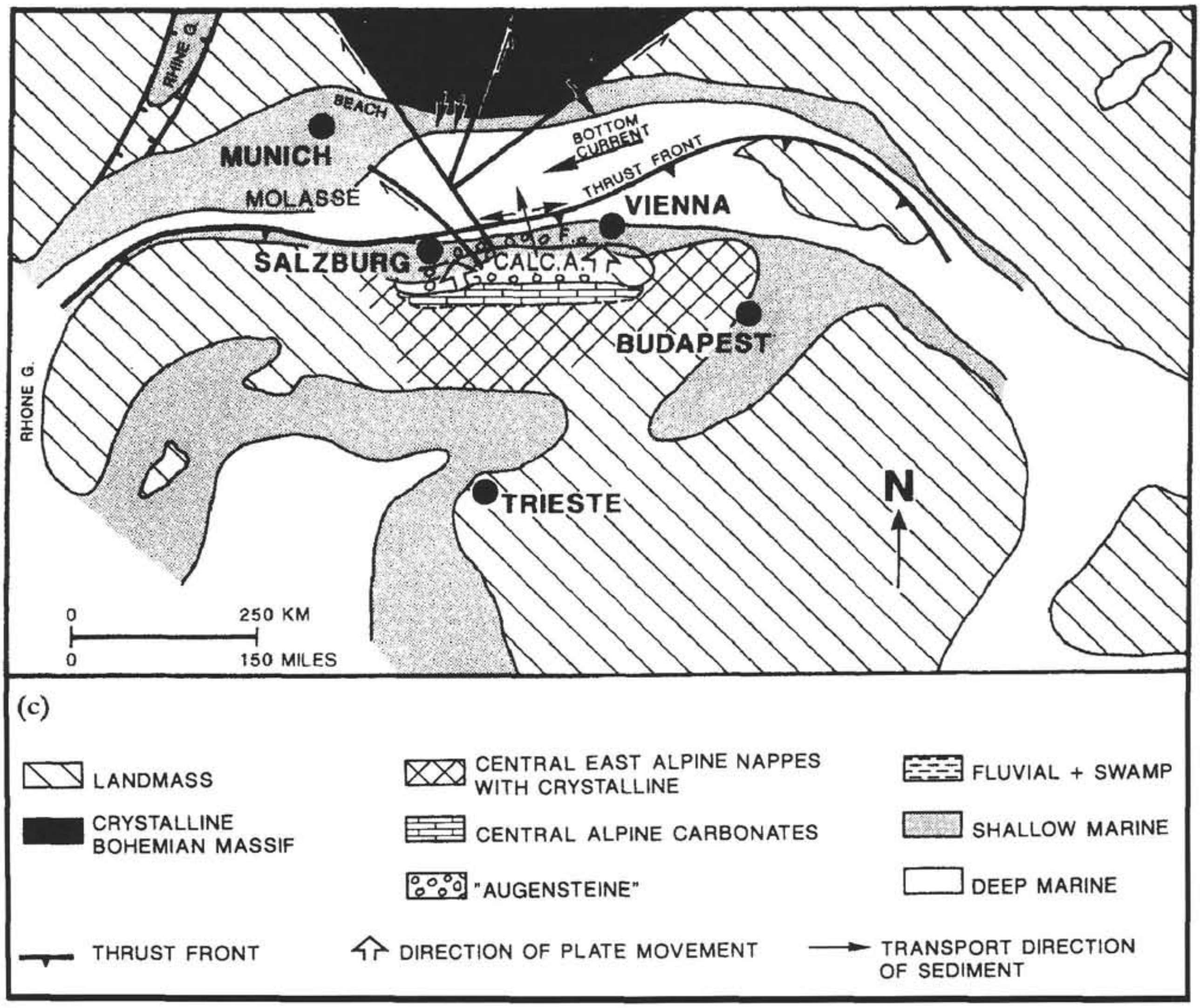


Fig. 11
Palinspastic reconstruction of Middle Europe in the Early Miocene (Eggenburgian/Ottnangian), 20 to 18 Ma (from WAGNER, 1996).

sins are mostly filled from Ottnangian and Karpatian time onward, respectively, with paralic, limnic and fluviatile sediments, which point to prevailing lowland conditions in the Austrian Alps up to the Late Miocene by virtue of their floral and faunal content (STEININGER et al., 1986).

Middle Miocene basin development and river systems

(Fig. 12: Early Badenian, Tarkhanian: 16.4 to 15 Ma)

The beginning of the Middle Miocene is marked worldwide by a sea-level high (TB 2.3 of HAQ et al., 1987; between Bur5/Lan1 and Lan2/Ser1of HARDENBOL et al., 1998). This global sea-level rise reconnected the Mediterranean with the Indopacific realms, flooded transgressively the Eastern Paratethys and the Central Paratethys, which was still linked by the "Trans-Tethyan Trench Corridor" with the Mediterranean via the Venetian Basin to Slovenia, and the Drava-Sava Basin, respectively (Fig. 12). Because of paleobiogeographic considerations, the highly diverse marine fauna, known from the Carpathian foredeep and the more restricted marine fauna from the eastern Paratethys, a speculative seaway is proposed south of the Black Sea plate and the Pontides in northern Anatolia, which provides this open marine connection with the Carpathian foredeep of the Central Paratethys (RÖGL, 1998). Beginning with the Middle Miocene the sedimentary depocenters of the Paratethys were tectonically rearranged from the former west-east trending Molasse Basin trenches to the intra-mountainous basin systems (e.g. Vienna, Styrian, Drava-Sava, Danube, Pannonian, Dacian and Euxinian-basin systems) The subsidence of these basins by various tectonic mechanisms started from Karpatian/Badenian time onwards.

This Middle Miocene sea-level rise event corresponded to a global warming phase and warm water elements are wide spread (e.g.: warm water planktonic foraminifera, mass occurrences of large foraminifera of Indopacific origin, tropical to subtropical corallinacea/coral reefs growing as far north as Krakow (Poland) and tropical mollusc faunas and fishes). On the other hand, the mammal faunal exchange between Africa via Arabia to Eurasia was interrupted, which can be seen in the hominoid record.

In Austria, the Vienna Basin began to subside from north to south into the east Alpine-Carpathian nappe system by

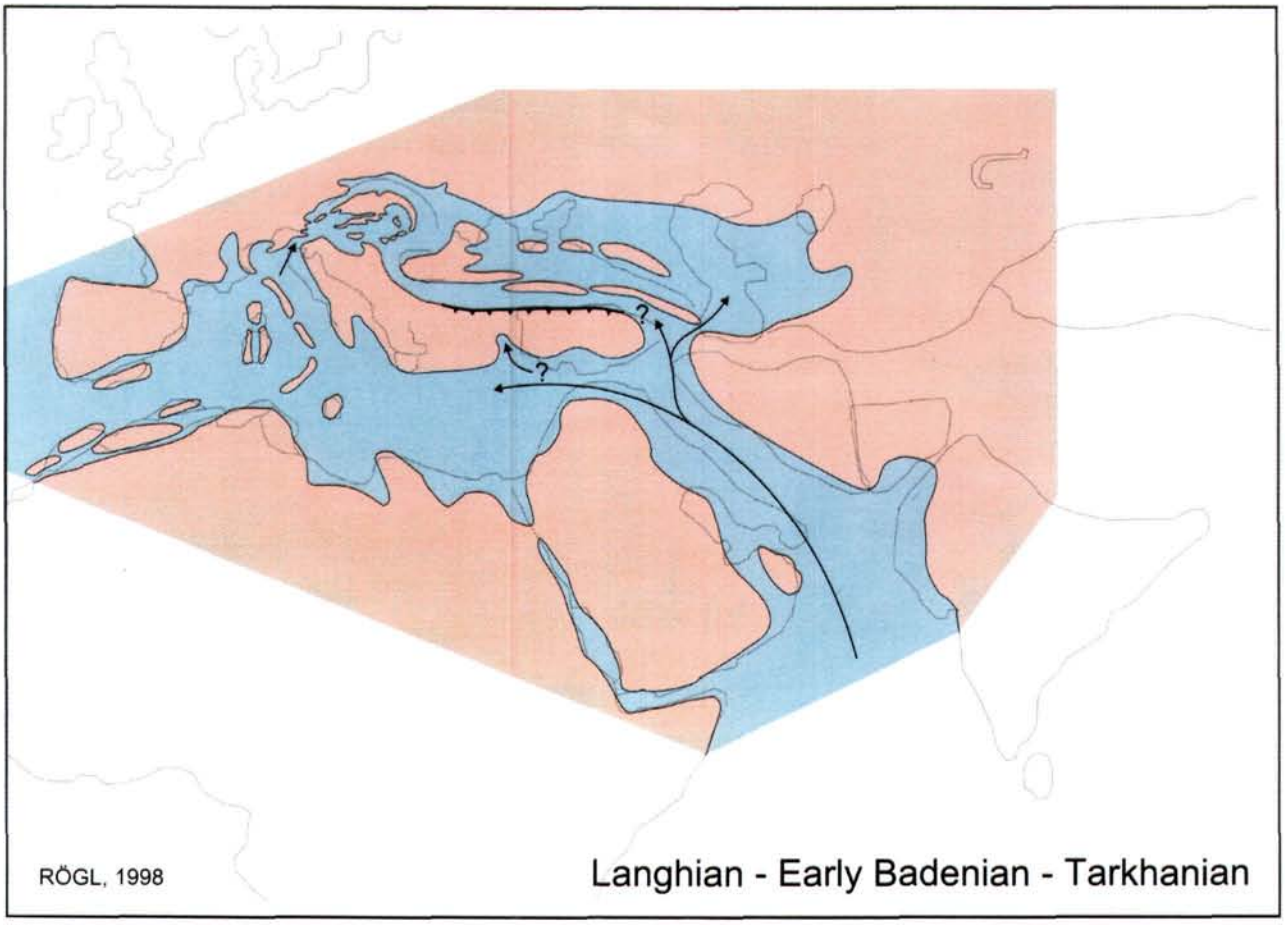


Fig. 12
Palinspastic reconstruction of the Paratethys in the Langhian (Early Badenian, Tarkhanian), 16.4 to 15 Ma (from RÖGL, 1998).

synsedimentary faulting in Eggenburgian to Karpatian time (Proto-Vienna Basin) and in Badenian to Pannonian time (Neo-Vienna Basin). This caused a strong relief of the basin-basement with buried mountains important to hydrocarbon production (HAMILTON et al., this volume). The synsedimentary subsidence was largest during Late Badenien (up to 2,000 meters), the greatest depth of the basin is 6,000 meters in the Zistersdorf depression and 5,200 meters in the area close to the Schwechat airport east of Vienna (SAUER et al., 1992; SEIFERT, 1996; WESSELY, 1993). During Karpatian time the basin was divided by the Matzen-Spannberg swell into a marine sediment regime in the north (Laa Formation) and a reduced marine (Bockflies Beds) to a limnic and fluviatile sediment regime towards the south (Gänserndorf Member, Aderklaa Formation; Fig. 13, WAGNER, 1998). In Badenian time the entire basin was filled throughout with open marine sediments arranged in differentiated facies belts from deeper water to nearshore sediments, transgressively overlying the older sediments and the basement (Fig. 13). At the rim of the basin and on the elevations within it, coastal terraces are preserved and corallinacea/coral reefs grew. A similar marine facies development is found in the Styrian Basin, besides the intercalation of the Karpatian to Early Badenian submarine andesitic volcanics (Figs. 3b, 4, 13; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996).

The base of the Badenian sediments upon the Karpatian/Badenian sequence boundary was formed south of the Matzen ridge by the fluviatile Aderklaa conglomerate representing a lowstand (WEISSENBÄCK, 1995, 1996). The erosional truncation at its base was low or non-existent in depressions (non-deposition) and remarkable along elevation areas (up to 300 m along the Matzen ridge). The thickness of the conglomerate itself reflects the later subsidence conditions within the "Neo-Vienna Basin": for example a thickness of 350 m in the Schwechat depression contrasts with 50 m on the neighbouring Oberlaa high. According to the conglomerate as the basal member of a sequence it is included in the formations of the Badenian stage (WEISSENBÄCK, 1996). Marine sediments were deposited on top of the conglomerate and north of the Matzen ridge. Sedimentation reached the crest of the Matzen ridge in the Middle Badenian at the *Spiroplectammina*-biozone during a transgressive systems tract (KREUTZER 1993). According to WEISSENBÄCK (1996) the Badenian sediments contain two sequences with several highstand, transgressive and lowstand systems tracts. Subsidence and sediment thickness in depressions (e.g. in Zistersdorf or Schwechat lows) differ enormously from those on elevations (e.g. Steinberg and Oberlaa highs). The trend of subsidence continued throughout the Sarmatian and Pannonian times all over the Vienna Basin.

The Aderklaa and the Rothneusiedl Conglomerate with gravel derived from an Alpine source point to the first known drainage systems of the Alps coming from the southwest and discharging into the Vienna Basin. From the Middle

Epochs	Mediterranean Stages	Central Paratethys Stages	Central Paratethys Biozones	Lithostratigraphy of Vienna basin	Lithostratigraphy of Styrian basin
Pliocene	Gelasian	Romanian		Gravel-beds	postbasaltic gravel, basalts, basaltic-tuffs, prebasaltic gravel
	Piacenzian				
5.3 Ma.	Zanclian	Dacian			
Late Miocene	Messinian	Pontian	Zone G/H		Tabor-gravel-Fm.
			Zone F		"Lignitic sequence of Rechnitz"
	Tortonian	Pannonian	Zone E to Zone A / B	"Yellow-marl-sequence"/ Rohrbach Congl. "Blue-marl-sequence" "Lignitic-sequence" "Congeria-beds"	Loipersbach-/ Stegersbach-Fm. Schemerl-gravel Karnerberg-gravel Kirchberg-gravel Kapfenstein-gravel
11.1 Ma.					
Middle Miocene	Serravallian	Sarmatian	Elphidium granosum-Zone	"Verarmungs-Zone" "Mactra-beds" "upper Ervilia-beds" / Atzgersdorf-Limestone	Gleisdorf-Fm. / Hartberg-Fm. Carinthian-gravel
			Elphidium hauerinum-Zone	"lower Ervilia-beds"	sands
			Elphidium reginum-Zone	"Rissoa-beds" = Hernals-marl-Fm.	lignites and marls of the Graz-,Weiz- and Pinkafeld-basin
		Badenian	Rotalia and Bulimina-Zone Spiroplectammina-Zone	gravel sands marls / Leitha-limestone-Fm.	marls / sands / Leitha-limestone-Fm.
16.4 Ma.	Langhian		Lagenid-Zone	Baden-Tegel-Fm.	Gleichenberg-vulkanite-Fm.
Early Miocene	Burdigalian	Karpatian		Laa-Fm./Aderklaa-/ Rothneusiedl-Congl.-Fm. Gaenserndorf-Fm. "Oncophora"-Beds Bockfließ-Fm. Luzice-Fm. Orth-Conglomerat	Sinnersdorf-Congl./ "Styrian-Schlier"; Lignites of western Styrian-basin
		Ottnangian			
		Eggenburgian			
23.8 Ma.	Aquitanian	Egerian			

Fig. 13
Vienna and Styrian Basins sedimentary cycles and lithostratigraphic units.

Badenian time onwards there was a remarkable input of fluviatile transported terrigenous material into the northern Vienna Basin. It entered the basin in the area of Mistelbach and created an enormous submarine fandelta with prominent lobes (SAUER et al., 1992); it was responsible for an important hydrocarbon reservoir (HAMILTON et al., this volume). As we discussed above this points again, to a sort of "pre-Danube" drainage system originating in Badenian time east of the spur of the Bohemian Massif and connected only since Pannonian time (Hollabrunn-Mistelbach-Formation) with the west (Hausruck-Kobernaußer Wald-Formation: WAGNER, 1998) (Fig. 8; BERNOR et al., 1993). During Sarmatian, Pannonian and Pontian times this deltafront spread farther to the southern parts of the basin. Another river discharge entered the basin in the Middle Badenian at the northernmost tip coming from the Carpathian mountain ranges. At the same time two subordinate deltas are recognised in the southern part of the basin, one entering from the west and the other from the southern tip of the basin. All deltas had their maximum spread in Sarmatian time and can be followed into the Pannonian (SAUER et al., 1992).

By the regressive phase during the Serravallian and in Middle Badenian – Karaganian, respectively (TB 2.3/TB 2.4 sea level drop of HAQ et al., 1988; between Lan2/Ser2 and Ser2/Ser3 of HARDENBOL et al., 1998), the Indopacific marine link with the Mediterranean and the Eastern Paratethys ceased and disconnected the Mediterranean and the Paratethys from the Indopacific realm (see RÖGL, 1998, plate 8). The Eastern Paratethys was also disconnected from the Central Paratethys and developed the endemic (*Spaniodontella*-) fauna, characteristic of the Karaganian time span. The narrow marine connections from the Pannonian Basin to the Transsylvanian subbasin and the Carpathian foredeep created evaporitic conditions in these areas (see RÖGL, 1998, plate 8). The brief reopening and restoration of marine conditions through the Mesopotamian trough flooded the Eastern and the Central Paratethys but did not reach the Mediterranean Sea. This event and the closure of the "Trans-Tethyan Corridor" gave rise to the Indopacific faunal influence in the entire Paratethys in Late Badenian/Konkian time (see RÖGL, 1998, plate 9). However, regressive events caused by tectonic rearrangements between the Arabian subplate and along the Anatolian fault zone, shrunk this huge intercontinental sea at the end of the Badenian and Konkian, respectively.

Middle to Late Miocene intracontinental sea and lake systems

(Fig. 14: Middle Serravallian – Early Sarmartian – Volhynian, Early Bessarabian: 13 to 11.7 Ma)

The movements along the Anatolian fault system, caused by the northward motion of the Arabian plate activating the Dead Sea fault system, opened a narrow marine connection from the Eastern Mediterranean towards the Eastern Paratethys and created a transgressive sequence, which marked the base of the Sarmatian and Volhynian, respectively (Fig. 14). This narrow marine connection and the river drainage into the vast Paratethys realm triggered waters with a decreasing salinity, oversaturated in carbonate. In this intracontinental sea an environment with a uniformly low diversity but individually rich flora and fauna developed covering in a most astonishing uniform biofacies, the entire Paratethys from the Vienna Basin to Lake Aral. All euhaline groups (e.g. radiolaria, planktonic foraminifera, corals and echinoderms) were lacking and few benthic foraminifera, ostracodes and molluscs dominate these peculiar aquatic realms. The characteristic morphologic mollusc evolution (e.g.: *Ervilia, Irus, Mactra, Calliostoma* and *Dorsanum*) through time is used for high resolution biostratigraphy (POPOV and STOLYANOV, 1996; STEININGER, 1977).

In Austria, this Sarmatian biofacies covers the entire Vienna Basin and the Early Sarmatian transgression reaches across the Molasse Basin to Krems in Lower Austria (Figs. 8, 13). A similar reduced marine facies development is found in the Styrian Basin (Figs. 4, 13; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996).

In Pannonian time the continued thrusting and the elevation of the Carpathian mountain chain finally restricted the connections of the Central Paratethys, the Pannonian Basin and its satellite basins (e.g. Vienna, Styrian and Transsylvanian Basins), to the Eastern Paratethys into a narrow connection in the area of today's "Iron Gate" (STEVANOVIC in PAPP et al., 1985). This caused a further drop in salinity close to sweet water conditions and only few ostracode and mollusc taxa populated this Pannonian lake system. In contrast, the „Sarmatian" biofacies prevailed in the Eastern Paratethys from Volhynian to Khersonian. The debate about the Sarmatian stage sensu strictu defined by SUESS (1866) and a Sarmatian stage sensu latu as used in the Eastern Paratethys and the correlation of the base of the Pannonian

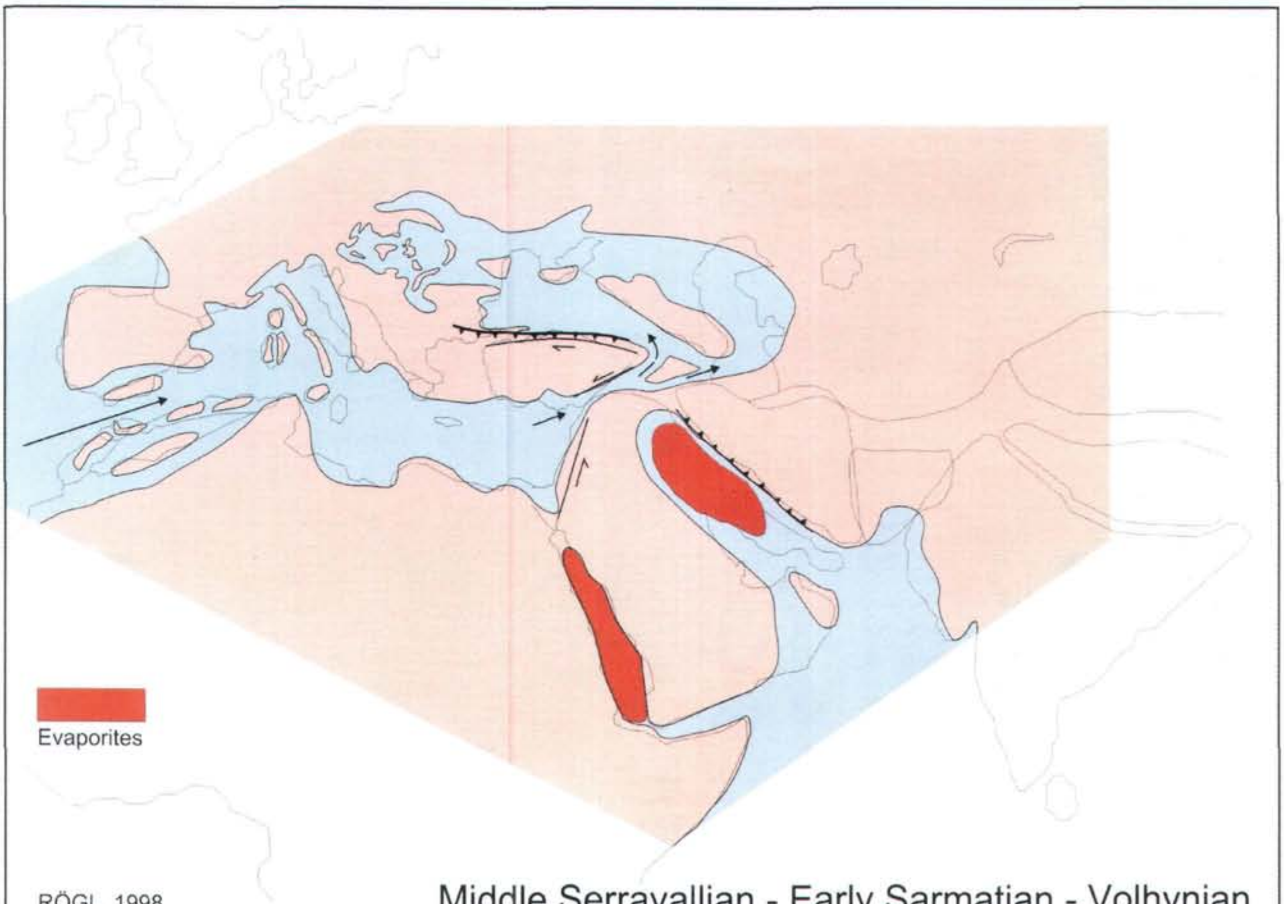


Fig. 14
Palinspastic reconstruction of the Paratethys in the Middle Serravallian (Early Sarmartian), 13 to 11.7 Ma (from RÖGL, 1998).

stage respectively could be solved through the „*Hipparion*" event known from both realms and is now better understood (Tab. 1; BERNOR et al. 1988).

In Austria, this pelitic to clastic facies of the Pannonian Basin covers the entire Vienna Basin and in the Early Pannonian a transgressive event reaches across the Molasse Basin to Krems in Lower Austria (Figs. 8, 13). A similar facies development is found in the Styrian Basin. However, the subsidence in the Styrian Basin ceased and the thin cover of Pannonian sediments was restricted to the eastern Styrian Basin (Figs. 4, 13; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996). The characteristic morphologic evolution of the gastropod genus *Melanopsis* and bivalve genus *Congeria* through time is used for high resolution biostratigraphy (STEININGER, 1977).

In the Tortonian, which is correlative to the Pannonian and to the Late Bessarabian, Khersonian and Maeotian, respectively (Tab. 1), the Aegean Sea opened, and by this time another connection via the Dardanelles towards the Eastern Paratethys came into existence. Short living marine excursions are known to have occurred several times in the Late Miocene from the Aegean into the Eastern Paratethys (RÖGL and STEININGER, 1983) and the Maeotian Paratethys fauna migrated into the Aegean Sea (PAPP et al. 1978).

The Messinian Mediterranean salinity crises ended the continuous marine sedimentation in the Neogene Mediterranean Basin. The interconnected Paratethyan water bodies became disconnected and evolved into fresh water lake systems, which were successively drained and began to dry up completely. In the uppermost Messinian this endemic Paratethys biofacies even invaded the Mediterranean region through the Aegean.

Biostratigraphically dated Pontian sediments, which would be correlative to the Messinian time interval, are unknown from the Molasse Zone and the Vienna and Styrian Basins. However, conglomerates in the Molasse Zone, a sequence of multicoloured marls, brown coals and conglomerates in the Vienna Basin and similar sediments restricted to the eastern part of the Styrian Basin close to the Burgenland swell, which separates the Styrian Basin from the Pannonian Basin system, are assigned to Late Miocene and Pliocene times, respectively (Fig. 4; EBNER and SACHSENHOFER, 1995; SACHSENHOFER et al., 1996).

The Pliocene dessication phase and the birth of the modern river drainage systems

In Early Pliocene (Zanclean) the modern Mediterranean Sea came into existence by a transgressive phase, flooding the desiccated basin with marine waters from the Atlantic. At the peak of this transgression in the Middle Pliocene (Piacenzian) even the Eastern Paratethys was flooded again via the Aegean and the Dardanelles strait (RÖGL and STEININGER, 1983).

In Austria, the dessication of the Vienna Basin is marked by red bed and fluviatile deposits. The few biostratigraphic dates derived from scarce mammal finds point to a Pliocene age of some of the gravel beds. South of Vienna the Mitterndorf-Wiener Neustadt graben system is actively subsiding up to the present and is filled with Pliocene and Pleistocene gravel deposits.

During Pliocene/Pleistocene the Styrian Basin was uplifted and a strong erosion of several 100 meters took place. A second young nephelinitic/basanitic volcanic phase with basaltic lava flows as well as a variety of pyroclastic rocks with radiometric ages between 3.8 and 1.7 Ma is spread far in the southeastern part of the basin (Fig. 8; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996).

In the Molasse Basin and the intra-mountainous basins loess sedimentation began about 3 Ma. In the Molasse Basin of Lower Austria a loess sequence with an age of 3 Ma was deposited on top of the gravel deposits of the pre-Danube river system (Hollabrunn-Mistelbach Formation). This might have been the time when the Danube river began to follow its present river bed, entering the Vienna Basin through the Bisamberg/Kahlenberg furrow and leaving the Vienna Basin through the Bruck and Hainburg straits, creating the modern river drainage system.

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From the Tethyan Ocean to the Paratethys Sea: Oligocene to Neogene Stratigraphy, Paleogeography and Paleobiogeography of the circum-Mediterranean region and the Oligocene to Neogene Basin evolution in Austria

FRITZ F. STEININGER[1] & GODFRID WESSELY[2]

14 Figures and 1 Table

Abstract

The Oligocene and Neogene Molasse Basin and the Alpine/Carpathian intramountainous basins (e.g. Vienna and Styrian Basin) of Austria belong to the Paratethys realm. The most recent stratigraphic correlation of the Paratethys Chronostratigraphic Stage System with the world wide used Mediterranean Stage System is given. The three tectonic units of the Molasse Basin, the autochthonous, allochthonous and parautochthonous Molasse units and the sedimentary cycles of the Molasse Basin, and the tectonic history of the two larger intramountainous Vienna- and Styrian Basins, and their sedimentary sequences are described through time. The main part deals with the sedimentological and facial evolution, the paleogeography and the paleobiogeography of these Austrian basins, in six time slices (Late Eocene, Oligocene, Lower Miocene, Middle Miocene, Middle to Late Miocene and Pliocene) as seen within the general evolution of the circum-Mediterranean region.

Introduction

Within the last decades a wealth of new results have been compiled concerning the sedimentary sequences, their paleontological content, facies development and stratigraphy, paleogeography, paleobiogeography and palinspastic reconstructions of the Oligocene and Neogene evolution of the circum-Mediterranean area and the Paratethyan basins. Within this paper we will discuss these aspects with respect to the Austrian Oligocene and Neogene basins.

The contributions of DECKER and PERESSON (1996), FAUPL and WAGREICH (this volume), GENSER et al. (1998), KOVAC et al. (1993), NEUBAUER and al. (this volume), PERESSON and DECKER (1996, 1997), RÖGL (1996, 1998), STEININGER (1999), STEININGER et al. (1985, 1996), WAGNER (1996, 1998) and WAGREICH and FAUPL (1994) and literature cited herein set the scene of the Late Cretaceous and Cenozoic tectonic, stratigraphic, paleogeographic and paleobiogeographic evolution of these basins in the Eastern Alpine-Carpathian orogen.

The results of stratigraphic correlations between marine, reduced marine to endemic limnic realms and continental sequences within the vast realms of the Paratethys from the peri-Alpine foredeep in the west to Inner Asia in the Far East, form the basic requirement for the timing of the sedimentary cycles, their paleobiologic content and the paleobiogeographic reconstructions (RÖGL, 1996, 1998; STEININGER, 1999).

In the following we will first discuss the stratigraphic correlation and the paleogeographic setting between the Mediterranean Neogene Tethys and the Paratethys in relation to main regional sedimentary sequences and important biologic events. Afterwards we will characterize the main tectonic units during Oligocene and Neogene in Austria. The main part of the paper will focus on specific time slices to discuss the general sedimentary and biologic evolution within the circum Mediterranean and Paratethys areas in general and within the Austrian geologic units.

The Paratethys Bioprovince and Cenozoic Mediterranean/Paratethys Stratigraphic Correlations

Paratethys bioprovince

In 1924 LASKAREV proposed separating a Paratethys bioprovince from the Neogene marine Mediterranean bioprovince, referring to the well recognized Late Neogene evolution of endemic mollusc faunas in the Vienna, Pannonian, Styrian, Dacian and Euxinian basins. This definition was revised over the years and we now recognize the beginning of a biologically well defined Paratethys bioprovince from Oligocene time onward with a complicated bioprovincial evolution and extending in general north of the Alpine-Car-

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pathian orogen. In its modern definition the Paratethys province extends from the western Molasse Basin in Switzerland and Rhone Basin in France towards lake Aral in the Far East. It is subdivided into a western Paratethys, formed by the Rhone Basin and Molasse Basin of Switzerland and western Bavaria; a Central Paratethys extending from Bavaria to and partly including the eastern foredeep of the Carpathian mountain chain and the wellknown intra-Apine basins, e.g.: the Vienna, Styrian, Pannonian Basins, and an Eastern Paratethys. The latter extends over the vast areas of the Euxinian basin complex to Lake Aral in the east (Fig. 1; SENES, 1960). Besides this more static concept several evolutionary stages of this Paratethys bioprovince have been defined. These stages are caused by the geodynamic development of this tectonically highly mobile area and the rapid paleobiological changes. SENES and MARINESCU (1974) and RUSU (1988) recognised a "Protoparatethys" in the Early Oligocene (Kiscellian; respectively Pshekian, Solenovian and Early Kalmykian, see Tab. 1) and an "Eoparatethys" in the Late Oligocene and Early Miocene (Egerian, Eggenburgian and Ottnangian and Late Kalmykian, Karadzhalganian, Sakaraulian and Kotsakhurian, respectively, see Tab.1). These two evolutionary stages of the Paratethys bioprovince are characterised by west-east trending troughs throughout the Paratethys and are well recognizeable in Austria within the tectonic units of the Molasse Basin

Table 1

Cenozoic Mediterranean/Paratethys Stratigraphic Correlation chart (BERGGREN et al., 1995; POPOV et al., 1993; RÖGL, 1998, STEININGER et al., 1996; STEININGER, 1999).

M. A.	Epochs	Mediterranean Stages	Central Paratethys Stages	Eastern Paratethys Stages	BIOZONATIONS: Planktonic Foraminifera	Calcareous Nanno-plankton	EUROPEAN LAND MAMMAL ZONES	MEGA– ZONES
5	Plio-cene	ZANCLEAN	DACIAN	KIMMERIAN	PL 1	NN 13	MN 14	RUSCINIAN
	Late Miocene	MESSINIAN	PONTIAN	PONTIAN	M 14	NN 12	MN 13	TUROLIAN
					M13 b	NN 11	MN 12	
		TORTONIAN	PANNONIAN	MAEOTIAN	M13		MN 11	
10					M13 a	NN 10	MN 10	VALLESIAN
				SARMATIAN: Khersonian		NN 9b	MN 9	
	Middle Miocene	SERRAVALLIAN	SARMATIAN	SARMATIAN: Bess-arabian	M 12	NN 9a / 8	MN 7+8	ASTERACIAN
				SARMATIAN: Volhynian	M11 – 8	NN 7		
						NN 6		
			BADENIAN	Konkian Karaganian Tshokrakian	M 7	NN 5	MN 6	
15		LANGHIAN		TARKHANIAN	M 6			
					M 5		MN 5	ORLEANIAN
	Early Miocene	BURDIGALIAN	KARPATIAN	KOTSAKHURIAN	M 4	NN 4		
			OTTNANGIAN		M 3		MN 4	
						NN 3		
20			EGGENBURGIAN	SAKARAULIAN	M 2	NN 2	MN 3	
		AQUITANIAN	EGERIAN	KARADZHALGAN-IAN	M1 b		MN 2	AGENIAN
					M1 a	NN 1	MN1	
25	Oligocene	CHATTIAN		KALMYKIAN	P 22	NP 25	MP 30 to MP 25	ARVERNIAN
					P 21 b			
		RUPELIAN	KISCELLIAN		P 21 a	NP 24	MP 24 to MP 21	SUEVIAN
30					P 20			
				SOLENOVIAN	P 19	NP 23		
				PSHEKIAN	P 18	NP 22		
					P 17	NP 21		
35	Late Eocene	PRIABONIAN	PRIABONIAN	BELOGLINIAN	P 16	NP 19 – 20	MP 20 to MP 17	HEADONIAN
					P 15	NP 18		

(see below). The following two evolutionary stages of the Paratethys are marked by the creation of the large intra-Alpine basin systems and their subbasins, differentiated in their age of extension and downthrow from the west (e.g. Vienna Basin, in Middle Miocene) towards the east (e.g. Euxinian basin, in Late Miocene). The first of these two Paratethys bioprovincal stages is the "Mesoparatethys", which existed from the late Early Miocene to the middle Middle Miocene (Karpatian, Badenian and Tarkhanian, Tshokrakian, Karaganian and Konkian, repectively; see Tab. 1) the following stage is the "Neoparatethys", which existed from the upper Middle Miocene to the Pleistocene and Holocene (Sarmatian to Recent, see Tab. 1). Both stages are well expressed in Austria by the development of the Vienna Basin and its subbasins, the Austrian part of the western Danube Basin, the depressions on the eastern border and the basins within the Alps and the Styrian Basin (Figs. 1, 5).

Cenozoic Mediterranean/ Paratethys Stratigraphic Correlations

In contrast to the Neogene Mediterranean region, the geodynamic development and rapid paleobiological changes during the Oligocene and Neogene triggered a mainly endemic evolution of the flora and fauna, the sedimentary sequences and the overall facies development. This lead already in the 19th century to the development of separate chronostratigraphic stage concepts for the Paratethys realms. In general, the Mediterranean chronostratigraphic stage concept is widely accepted as the world chronostratigraphic standard and reference scale and biostratigraphic correlations are based on tropi-

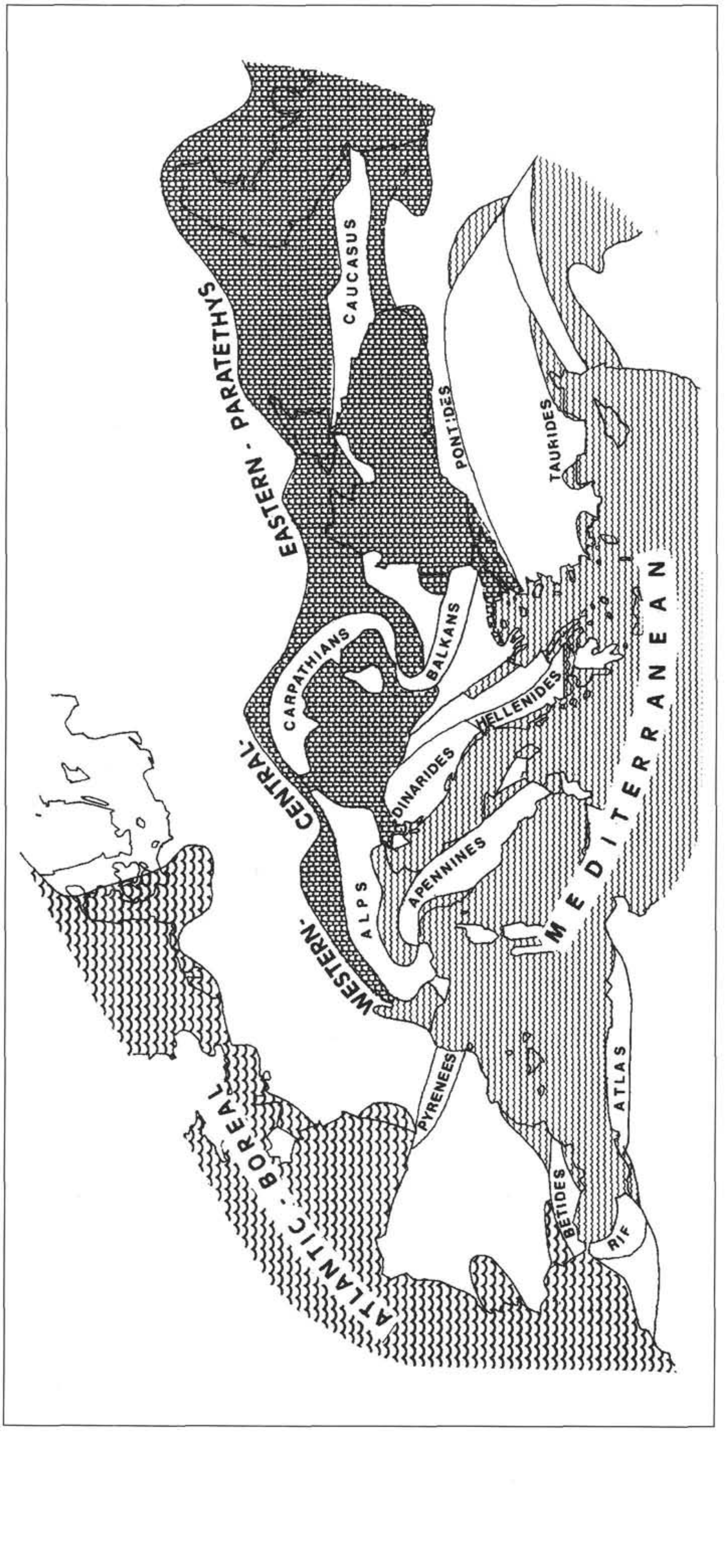


Fig. 1
Oligocene and Neogene Mediterranean and Paratethys realms (RÖGL & STEININGER, 1983).

cal to subtropical oceanic planktonic organisms. One can rarely identify these planktonic markers in the Paratethys realms. The biostratigraphic framework of the Paratethys stages is based in aquatic realms on endemic marine to reduced marine microfossils, marine to limnic mollusc faunas and ostracods and to micro- and macromammals respectively, intercalated either into these marine to limnic or into the continental sequences. Lately paleomagnetic and radiometric dating provided another excellent regional and interregional correlation tool. Even if the correlation of the different Paratethys stage concepts (e.g.: Central- to Eastern-Paratethys stages, see Tab. 1) with each other is more or less solved, we still have problems in correlating the Mediterranean regions. The correlation with the Mediterranean stage concept is based in the Early Miocene on mammal biostratigraphic/paleomagnetic and mammal biostratigraphic/marine correlations respectively, with several well calibrated marker horizons (European Land Mammal Zones MN 3, MN 4 and MN 5); the base of the Middle Miocene is marked world-wide and in the Paratethys by the first appearance of the plankton foraminifera genus *Praeorbulina*; several calcareous nannoplankton events are known within the upper Middle Miocene of the Paratethys and are used as marker horizons for Mediterranean correlations. European land mammal biostratigraphy provides us with important worldwide and European events (e.g.: the "Hipparion" event), which form the backbone of the stratigraphic correlations (Tab.1) for the Late Miocene and Pliocene of the Paratethys realms (RÖGL, 1996, 1998; STEININGER et al., 1985, 1996; STEININGER, 1999).

Oligocene and Neogene tectonic and sedimentary units of the Molasse Basin and the Alpine/Carpathian Intramontaneous Basins in Austria

Molasse Basin

From north to south the following tectonic units of the geology of Austria are relevant to the Molasse Basin: The Variscan and older crystalline basement of the Bohemian Massif, which is transgressively overlain in the subsurface to the south by a in many parts incomplete cover of Late Paleozoic and Mesozoic sediments in the characteristic "Outer Alpine – Germano-typic" facies (see WAGNER, 1996, Fig. 3a). In the Cenozoic, Late Eocene sediments interfinger with sediments of the autochthonous Helvetic unit to the south. Younger Oligocene to Neogene sediments follow transgressively on top of the crystalline and Mesozoic basement rocks to the north.

To the south the Molasse Basin is tectonically overthrusted by the Helvetic nappes and their eastern equivalents, which in turn are overthrusted by the Rhenodanubian Flysch nappes, the "Ybbsitz Klippen" belt representing the southern Penninic units and by the various Austroalpine nappes exposed in the Northern Calcareous Alpine Zone (Fig. 2).

The Molasse Basin, or in other terms the Alpine-Carpathian foredeep, north und underneath the Alpine-Carpathian tectonic front, with its tectonic setting and its sedimentary record provides the best possibility to unravel the Cenozoic history of the Alpine and Carpathian orogen.

Three main tectonic units characterize the Molasse Basin from north to south:

(1) The autochthonous Molasse: the term is used here for flat-laying Molasse sediments underneath and in front of the Alpine-Carpathian orogen. These sediments in front of the Alpine-Carpathian thrust sheets are tectonically disturbed only by normal faults or tilting (Fig. 3a; see also Fig. 6 in WAGNER, 1996). For the various terms used in the literature for this tectonic part, see STEININGER et al. (1986).

(2) The allochthonous Molasse: In contrast to the autochthonous Molasse, the allochthonous Molasse sediments are characterized by their tectonic position in folds and thrust sheets formed by the Alpine tectonics (e.g., the Waschberg unit, Figs. 3a, b). For the various terms used in the literature for this tectonic part, see STEININGER et al. (1986).

(3) The parautochthonous Molasse: the sediments here rest transgressively on top of various Alpine or Carpathian tectonic units and are moved during sedimentation and afterwards on the back of these tectonic units ("piggy-back basins"; Fig. 3a). For the various terms used in the literature for this tectonic part, see STEININGER et al. (1986).

Several sedimentary cycles characterize the Molasse sequence. On top of crystalline rocks of the Bohemian Massif, and the in parts incomplete Late Paleozoic to Mesozoic sedimentary sequence, we observe a first transgressive marine marly cycle (Late Eocene to Early Oligocene: Kiscellian) represented in Kiscellian time by a mainly fine-layered to laminated sequence characterized by a massive bloom of a few nannoplankton and planktonic foraminifera taxa and an endemic mollusc and ostracode fauna in Solenovian time, which thrived in an euxinic-sapropelic environment. The second transgressive marine clastic cycle (Late Oligocene to Early Miocene: Egerian), is characterised by an open marine flora and fauna, the terrigenous sedimentation and the translation of the basin axis in general to the north. This was caused by the beginning uplift and northward movement of the Alpine-Carpathian orogen. The third transgressive marine clastic cycle (Early Miocene: Eggenburgian, Ottnangian) is characterised by a farspread open marine fauna influenced biogeographically from the east in the Early Miocene (Eggenburgian), and by western faunal elements in the later Early Miocene (Ottnangian). Finally, the marine sedimentation ends in the Molasse Basin in the later Early Miocene (upper Ottnangian) and passes into a freshwater to lacustrine clastic cycle (uppermost Early Miocene: Karpatian, Middle Miocene: Badenian, Sarmatian to Late Miocene: Pannonian and younger sediments) with lake, coal swamp and river gravel deposits. This evolution is interrupted in the eastern part of the Molasse Basin by shortlived marine incursions in the late Early Miocene (Karpatian), Middle Miocene (base of the Badenian, base of the Sarmatian) and in the Late Miocene (base of the Pannonian).

Alpine/Carpathian Intra-mountainous basins

The emplacement and the sedimentation within the Alpine-Carpathian intra-mountainous basins (e.g. Vienna, Pannonian/Danube and Styrian-Basins) started in Middle Miocene (Badenian) times. In the early Miocene (Eggenburgian, Ottnangian, Karpatian) we recognize partly marine to non-marine clastic sediments with lake, coal swamp and

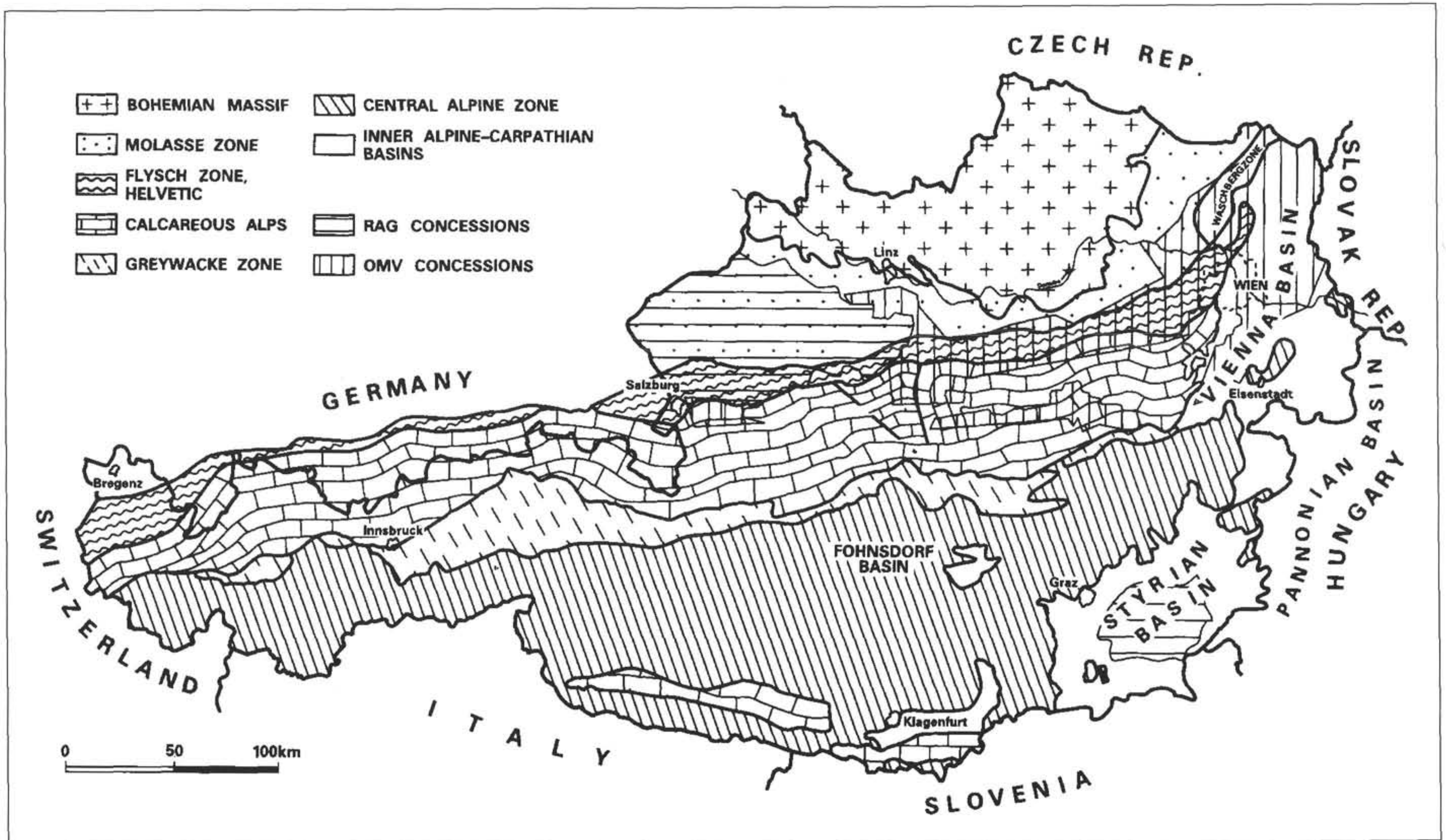


Fig. 2
Generalized tectonic units in Austria (after WAGNER, 1996).

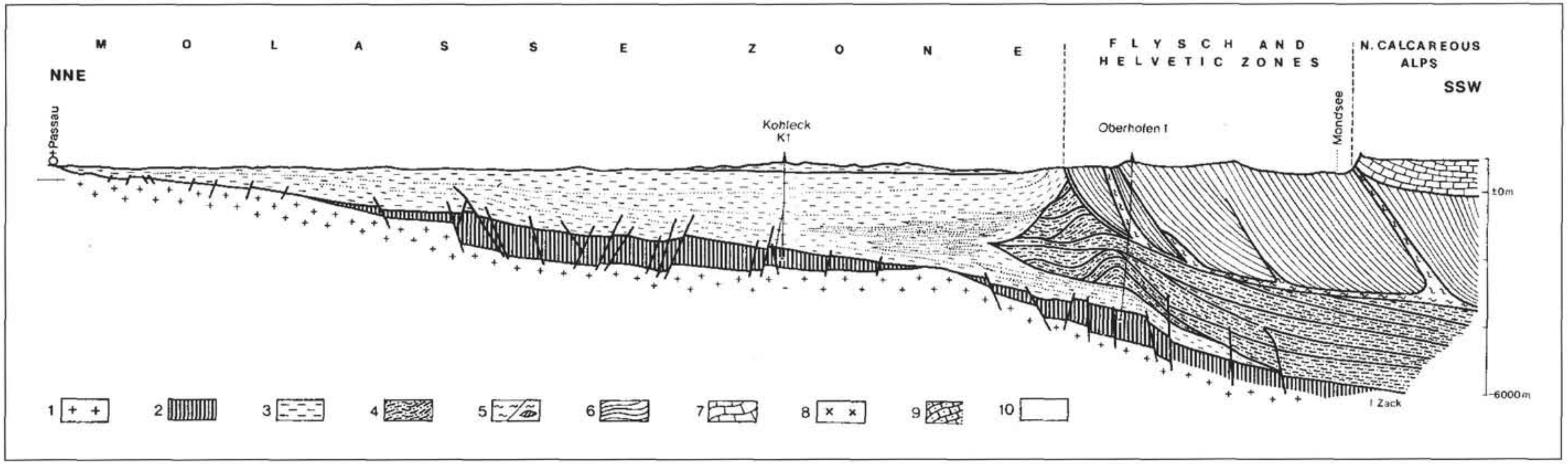


Fig. 3a
Cross section through the western part of the Upper Austrian Molasse basin (after STEININGER et al., 1986 and WAGNER, 1996, modified). (1) Crystalline of the Bohemian Massif; (2) Paleozoic and Mesozoic Sediments below the Molasse; (3) Autochthonous Molasse; (4) Allochthonous and Parautochthonous Molasse; (5) Helvetic and Klippen Zones; (6) Rhenodanubian Flysch Zone; (7) Northern Calcareous Alps and Greywacke Zone; (8) Tatric Crystalline; (9) Mesozoic Cover of the Tatric Crystalline; (10) Intramontane Basin (Neogene Sediments).

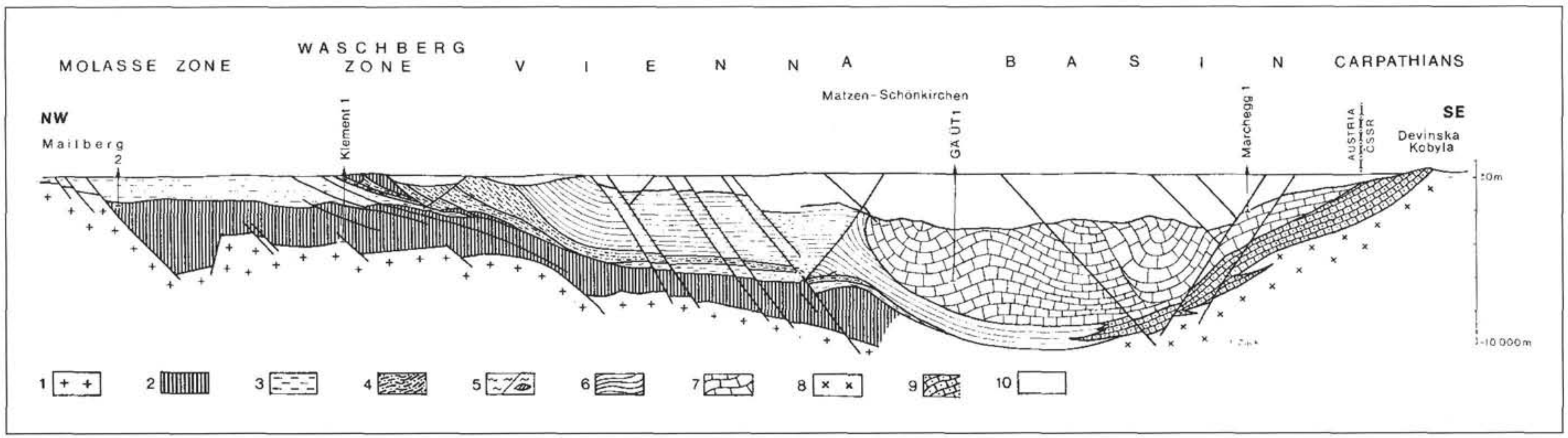


Fig. 3b
Cross section through the eastern part of the Lower Austrian Molasse basin, the Waschberg unit (allochthonous Molasse Zone) and the northern part of the Vienna basin (after STEININGER et al., 1986 and WAGNER, 1996, modified). For legend see Fig. 3a.

river gravel deposits, representing the "piggy back" basin sedimentation of the Molasse Basin on top of the basement of these basins built by various Alpine- and Carpathian tectonic units. At the beginning of this intra-mountainous basin configuration these "piggy-back" basin sediments are transgressively overlain by an open marine clastic cycle grading into reduced marine conditions (mainly Middle Miocene: Badenian) followed by a sequence of reduced marine to lacustrine and fluvatile sediments (Middle Miocene: Sarmatian, Late Miocene and Pliocene: Pannonian, Pontian). In Middle Miocene time (Badenian to Early Sarmatian) these basins belonged to a huge, interconnected and intracontinental sea, which progressively decayed from Late Miocene onwards to a system of isolated lakes, each with a characteristic evolution of an endemic aquatic fauna and flora.

In the region of the **Vienna Basin** the Alpine-Carpathian nappe system itself was thrusted over the European continental margin (Bohemian Massif with its Late Paleozoic and Mesozoic cover and the autochthonous Molasse Basin sediments) from the Middle Eocene onwards to later Early Miocene (Fig. 3b). These nappes of the Alpine-Carpathian system form the basement of the Vienna Basin. The morphotectonic behavior of the Bohemian Massif caused a delay of movements W of Vienna, while towards the NE thrusting advanced and ended later. The difference created the pull apart conditions which led to the extension of the Vienna Basin (ROYDEN, 1985).

The development of the Vienna Basin area in its early stage (Eggenburgian to Karpatian) coincides with the piggy back phase mentioned above. A beginning pull apart effect at that time is shown by the NE striking synsedimentary faults with displacements of about 1,800 m in the Mistelbach area and E Zistersdorf (LADWEIN et al., 1991; KREUTZER 1993). In Eggenburgian to Karpatian time a so called "Proto-Vienna Basin" was formed by similar geodynamics as the Vienna Basin sensu strictu later in the Badenian time. This "Proto-Vienna Basin" was filled by "Parautochthonous Molasse" in the sense of STEININGER et al. (1986) and the isopachs of that fill show a generally ESE-WNW orientation (JIRICEK and SEIFERT, 1990). The basin was restricted to the northern part of the today's Vienna Basin, but extended toward the south, already forming the nucleus of a later remarkable depocenter the Schwechat depression in the course of the Upper Karpatian sedimentation. The sediment input in Karpatian time came from the south (SAUER et al., 1992). After the Karpatian sedimenation phase and before the Badenian ingression, an important inversion took place and large amounts of the Early Miocene sediments were eroded, in some areas even down to the basement of the basin (e.g. in Matzen ridge down to the Rhenodanubian Flysch). A new transgressive sequence started with the Badenian ingression and subsequently the basin was enlarged to its present shape. This "Neo-Vienna Basin" subsided on an already stabilised Alpine nappe system from the Middle Miocene onwards.

The considerable amount of subsidence and fault offsets are connected with the largest extension of the Vienna Basin caused by movements to the northeast in the Carpathian region (ROYDEN, 1985; WESSELY, 1988, 1993; DECKER and PERESSON, 1996; SEIFERT 1996). Faults with huge synsedimentary displacements originated by the resulting pull-apart effect beside deep depocenters. The largest are the Steinberg and the Leopoldsdorf faults (6,000 m and 4,000 m displacement). Many of these faults show right stepping en echelon arrangements pointing to a distinct sinistral component of motion besides the predominating dip-slip component. Near the SE flank of the basin a series of graben-like subsidiary pull-apart basins along a NE striking sinistral strike slip fault opened. They contain very young sediments including Pliocene to Quaternary coarse clastics. The formation of negative flower structures caused some steepening of these layers. The strike-slip fault extends into the Mur-Mürz fault system within the Central Alps, and is accompanied by a high recent seismicity.

The more than 4 km deep **Styrian Basin** is located at the eastern border of the Alpine orogen and is part of the Pannonian Basin system. It represents an extensional structure on top of a crustal wedge, which moved eastward during the final stages of the Neogene Alpine orogeny. The basin evolution can be subdivided in an Early Miocene (Ottnangian, Karpatian, Early Badenian) synrift phase of subsidence over an extremly weak lithospheric crust with thick clastic limnic/fluviatile and marine sediments and a first andesitic volcanic phase (Fig. 4a, b). The Middle and Late Miocene post-rift phase is controlled by the transgressive Middle Miocene (Badenian) marine sequences. These grade into reduced marine conditions (Sarmatian) and finally into limnic/fluviatile (Pannonian) sequences depicting the endemic evolution of the aquatic biotas characteristic of the Paratethys realms (Fig. 4c, d, e). In Pliocene times a basin inversion and uplift resulted in an erosional phase with a second volcanic phase producing basalts in the Late Pliocene to Pleistocene (Fig. 4f) (EBNER and SACHSENHOFER, 1995; FRITZ, 1996; KOLLMANN, 1965; SACHSENHOFER and al., 1996, and literature cited herein).

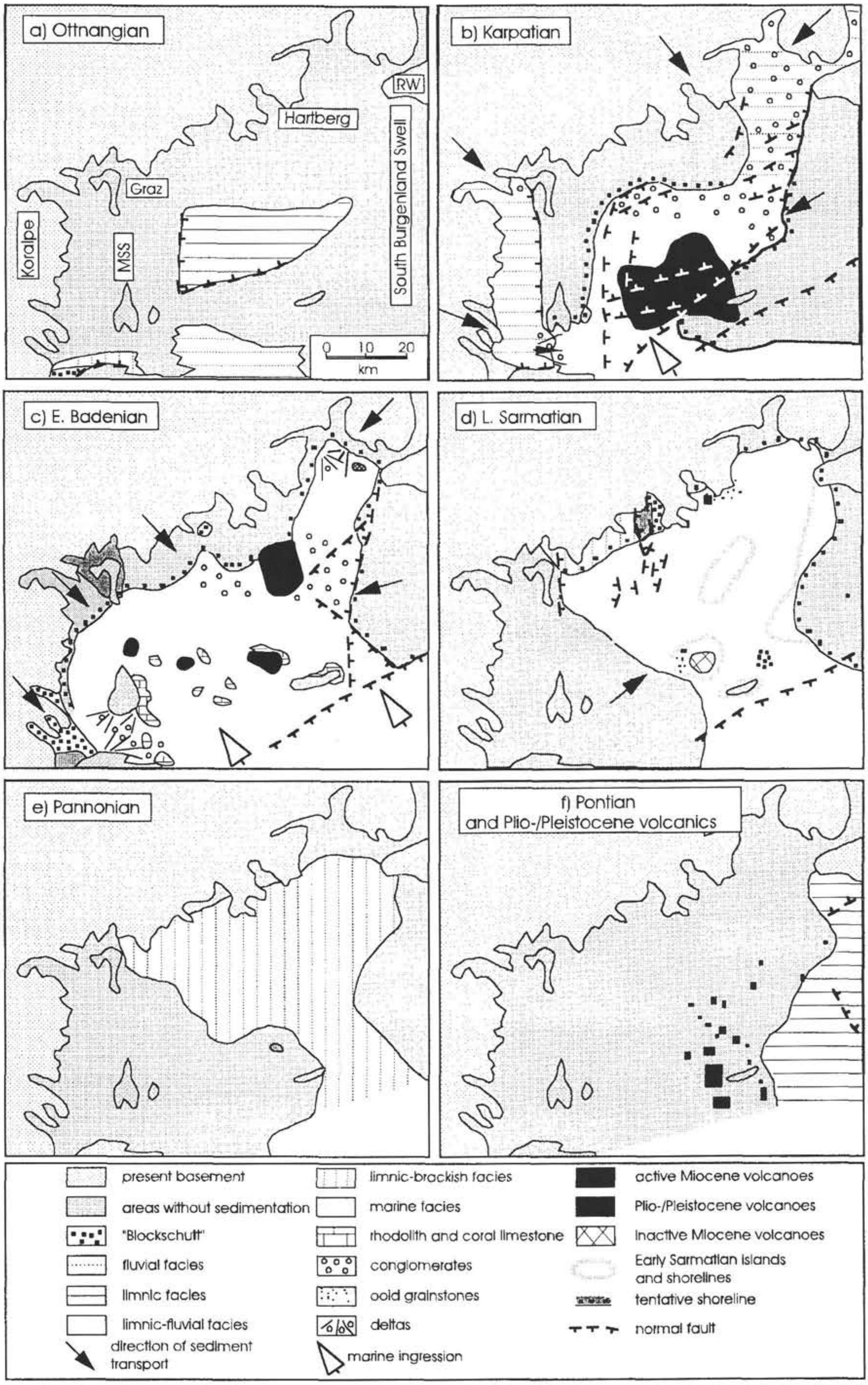
Intra-Alpine Neogene basins: Smaller Neogene basins within the Alpine system were created in the Miocene time by the Neogene fault and shear systems of the Eastern Alps (e.g. the Salzach-Enns, Mur-Mürz, Lavantal- and Periadriatic-fault/shear systems (Fig. 5) (DECKER and PERESSON, 1996, NEUBAUER et al., 1999). Most of these basins were filled with limnic to fluviatile sediments and intercalated larger to smaller browncoal seams; some of these were reached by the Badenian marine and the Sarmatian reduced marine ingression (e.g. in the Lavantal-basin) (WEBER and WEISS, 1983; STEININGER et al., 1988/89).

Paleogeography and Paleobiogeography of the circum-Mediterranean region and the Austrian basins

In general, Cenozoic plate tectonic motions created the oceans of today and shaped the bordering continents with their young collisional mountain chains. The final closure of the Tethyan Ocean and the creation of the Mediterranean Sea as well as the Paratethys Sea close to the Eocene/Oligocene boundary were caused by a reorganization of the lithospheric plates. This includes the northward movement

Fig. 4 see next page →
Paleogeographic maps of the Styrian Basin. MSS: Middle Styrian swell; RW: Rechnitz window of the Penninic unit (after EBNER and SACHSENHOFER, 1995 and SACHSENHOFER, 1996, modified).

Fig. 4


a) Ottnangian
RW
Hartberg
Graz
Koralpe
MSS
South Burgenland Swell
0 10 20
km
b) Karpatian
c) E. Badenian
d) L. Sarmatian
e) Pannonian
f) Pontian
and Plio-/Pleistocene volcanics
present basement
areas without sedimentation
"Blockschutt"
fluvial facies
limnic facies
limnic-fluvial facies
direction of sediment transport
limnic-brackish facies
marine facies
rhodolith and coral limestone
conglomerates
oold grainstones
deltas
marine ingression
active Miocene volcanoes
Plio-/Pleistocene volcanoes
Inactive Miocene volcanoes
Early Sarmatian islands and shorelines
tentative shoreline
normal fault

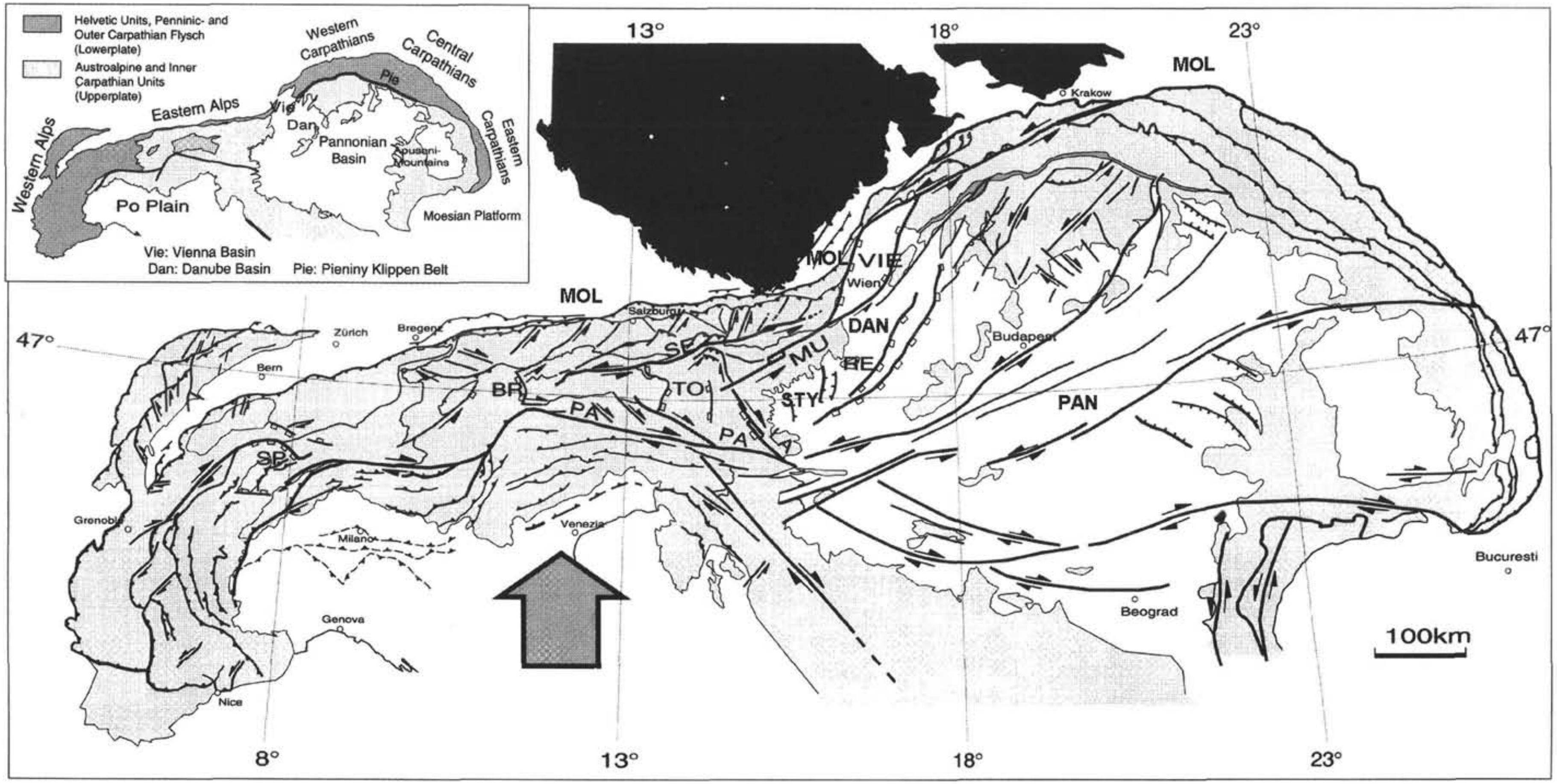


Fig. 5

Neogene tectonic/kinematic map of the Alpine-Carpathian-Pannonian area. BR: Brenner fault; DAN: Danube Basin; LA: Lavanttal fault; MOL: Molasse Basin; MU: Mur-Mürz fault; PA: Periadriatic fault; PAN: Pannonian Basin; RE: Rechnitz Penninic window; SE: Salzachtal-Ennstal fault; SP: Simplon fault; STY: Styrian Basin; TO: Tauernostrand fault; VIE: Vienna Basin. Inset: Overview and geographical terms (after DECKER and PERESSON, 1996, modified).

of India and Australia, the beginning collision of India and Asia in the Late Eocene, as well as the northward movement and counterclockwise rotation of Africa from the Late Eocene onwards and the collision of Africa and its subplates (e.g. the Adriatic and Arabian subplate) with the Eurasian plate and subplates.

Within the last decade several paleogeographic/palinspastic reconstructions have been presented. One of the major problems of such reconstructions is the insufficient and incorrect stratigraphic correlation, the long duration of the time slices shown on these maps (e.g. BIJU-DUVAL et al., 1977; DERCOURT et al., 1985) and the long time intervals between the time slices presented, respectively (e.g. DERCOURT et al., 1993). Other reconstructions present static sediment/facies distribution maps without plate tectonic elements (e.g.: CAHUZAC et al., 1992; HAMOR and HALMAI, 1988; POPOV et al., 1993; STEININGER et al., 1985; STUDENKA et al., 1998). First attempts with a more accurate correlation, the necessary time resolution and combining sedimentary and facies developments as well as tectonic/palinspastic details have been published in relation to various aspects for the circum-Mediterranean region including the Paratethys by RÖGL and STEININGER (1983), STEININGER and RÖGL (1984), STEININGER et al. (1985), KOVAC et al. (1993) and for the Mediterranean region by BOCCALETTI et al. (1986, 1990). The latest results in stratigraphic correlation, marine faunal relations and continental faunal migrations have been taken into account by the palinspastic maps published lately by RÖGL (1998) showing the paleogeographic evolution of the circum-Mediterranean area.

We have choosen for this paper some time slices relevant to the evolution of the Austrian Oligocene and Neogene basins from RÖGL (1998). We will first briefly describe the circum-Mediterranean setting for each time slice and than focus on the Austrian basins.

The Late Eocene Archipelago

(Fig. 6: Priabonian – Beloglinian: 37 to 33.7 Ma)

This time slice is centered on Chron 15 around 35 Ma (Fig. 6) and corresponds approximately to the time span of the Priabonian and the Beloglinian – stage, – respectively or to calcareous Nannoplankton Zones upper NP 18 to lower NP 21 and to the Planktonic Foraminifera zones upper P 15 to P 17 (Tab. 1).

The circum-Mediterranean paleogeographic setting is characterised by an open marine connection with the Indopacific and the Atlantic. In central Europe we find the emerging Alpidic mountain chains (e.g. Alps, Carpathians, Dinarids, Pontids and the Caucasian mountains), the Helvetic Sea extensively flooded the central European platform, and a seaway – the Danish-Polish trough – connected this sea with the North Sea Basin. The Turgai Strait, a shallow water seaway, allowed for an exchange of marine warmer water faunas of this Tethyan Sea towards the polar waters in the north and hindered the terrestrial faunal exchange be-

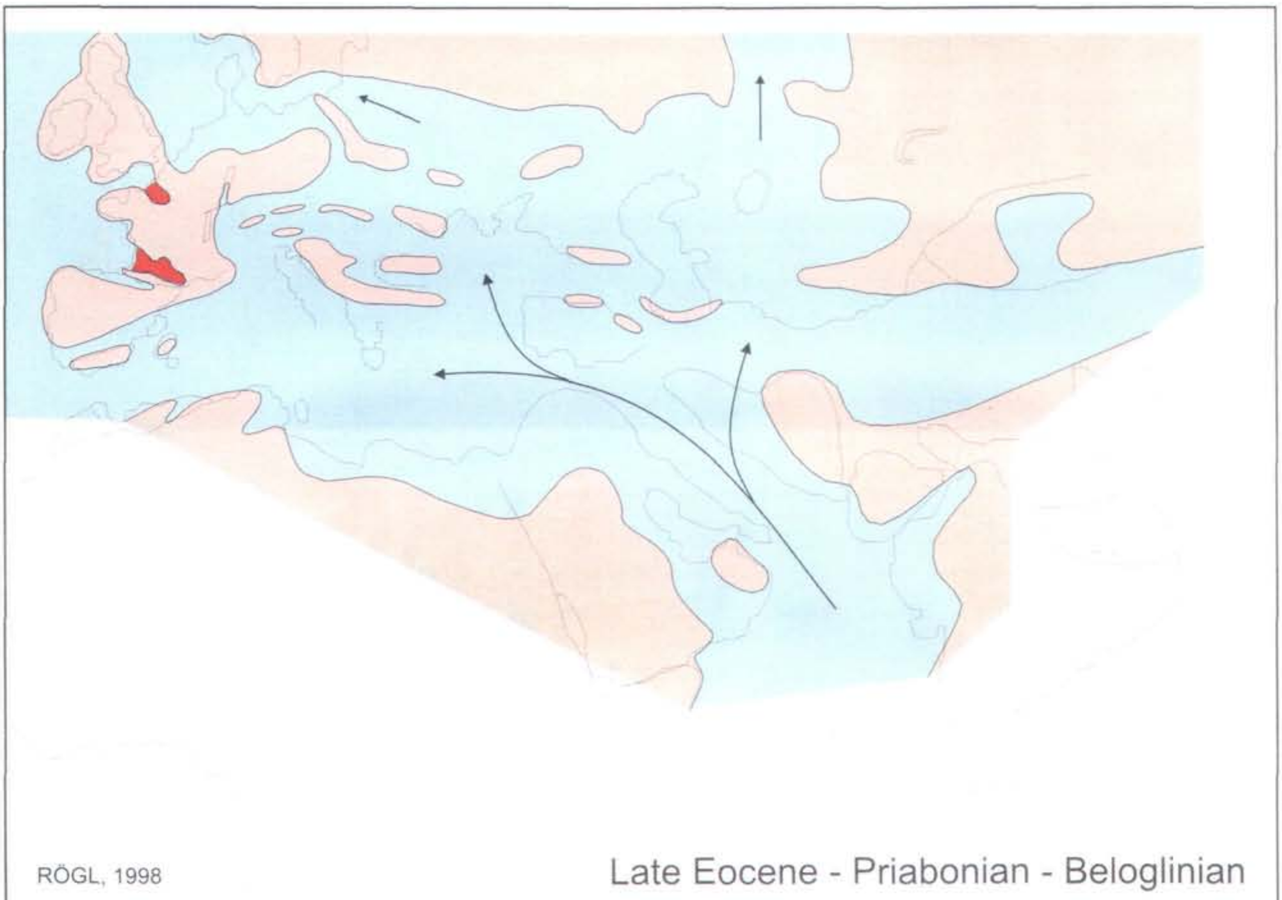


Fig. 6
Palinspastic reconstruction of the Late Eocene Tethys archipelago (37 to 33.7 Ma) of the circum-Mediterranean area (from RÖGL, 1998).

tween Asia and Europe. In the east the marine sedimentation extended to Inner Asia (RÖGL, 1998; POPOV et al., 1993).

A Late Eocene palinspastic cross section of the evolution of the western Molasse Basin and a new model for the paleogeographic reconstruction of tectonic units of the central European region have been recently published by WAGNER (1996) and OBERHAUSER (1995).

In the Austrian Molasse Basin sediments of Late Eocene age are found on the Upper Austrian Molasse shelf with a paralic facies and nearshore sands (Voitsdorf Formation and Cerithian Beds; WAGNER, 1998). The clastic input of these sediments was derived from the Bohemian Massif in the north. These sands interfinger and continue to the south with corallinaceen limestones (Lithothamnium Limestone, WAGNER, 1998) passing into slope sediments of the Perwang-Formation (WAGNER, 1998) containing *Globigerina* and *Discocyclina* marls. Similar sediments are known, squeezed inbetween the imbricated allochthonous Molasse, within the nappes of the Rhenodanubian Flysch-Zone and Northern Calcareous Alps. Sediments of the southern coast of this sea transgressively overlie the Northern Calcareous Alps nappe complex (e.g. from west to east: Inn Valley, Oberaudorf, Reichenhall, Liezen and Radstadt; for a reconstruction see the palinspastic cross section, Fig. 9c in: WAGNER, 1996). In Lower Austria massive conglomerates have been recovered in deep wells (Moosbierbaum Conglomerate; WAGNER, 1998), contemporaneous littoral sediments are further known from a deep well (Zistersdorf ÜT 2A) below the Vienna Basin, the Alpine-Carpathian nappes in the autochthonous Molasse. Within the allochthonous Molasse Zone – the "Waschberg unit" in Lower Austria – a variety of Eocene sediments are known in the imbricated scales (Fig. 3b).

The rich nannoflora, the planktonic and benthic foraminifera including larger foraminifera and the tropical mollusc fauna, show strong Tethyan-Mediterranean affinities.

The creation of the Paratethys and its Oligocene development

(Fig. 7: Middle Kiscellian-Solenovian: 32 to 30.2 Ma)

To illustrate the origin of the Paratethys bioprovince we have choosen this Middle Kiscellian-Solenovian time slice (Fig. 7) because it most impressively marks the isolation of parts of the vanishing Tethyan Sea in the north of the Mediterranean region and the birth of the Paratethys Sea, beginning around the Eocene/Oligocene boundary. This isolation was caused by the progressive rise of the collisional orogen and, within this time slice, the restriced, endemic realms were most widespread. This time slice corresponds approximately to the time span of the Middle Rupelian, the Middle Kiscellian – Solenovian in Early Oligocene, respectively and

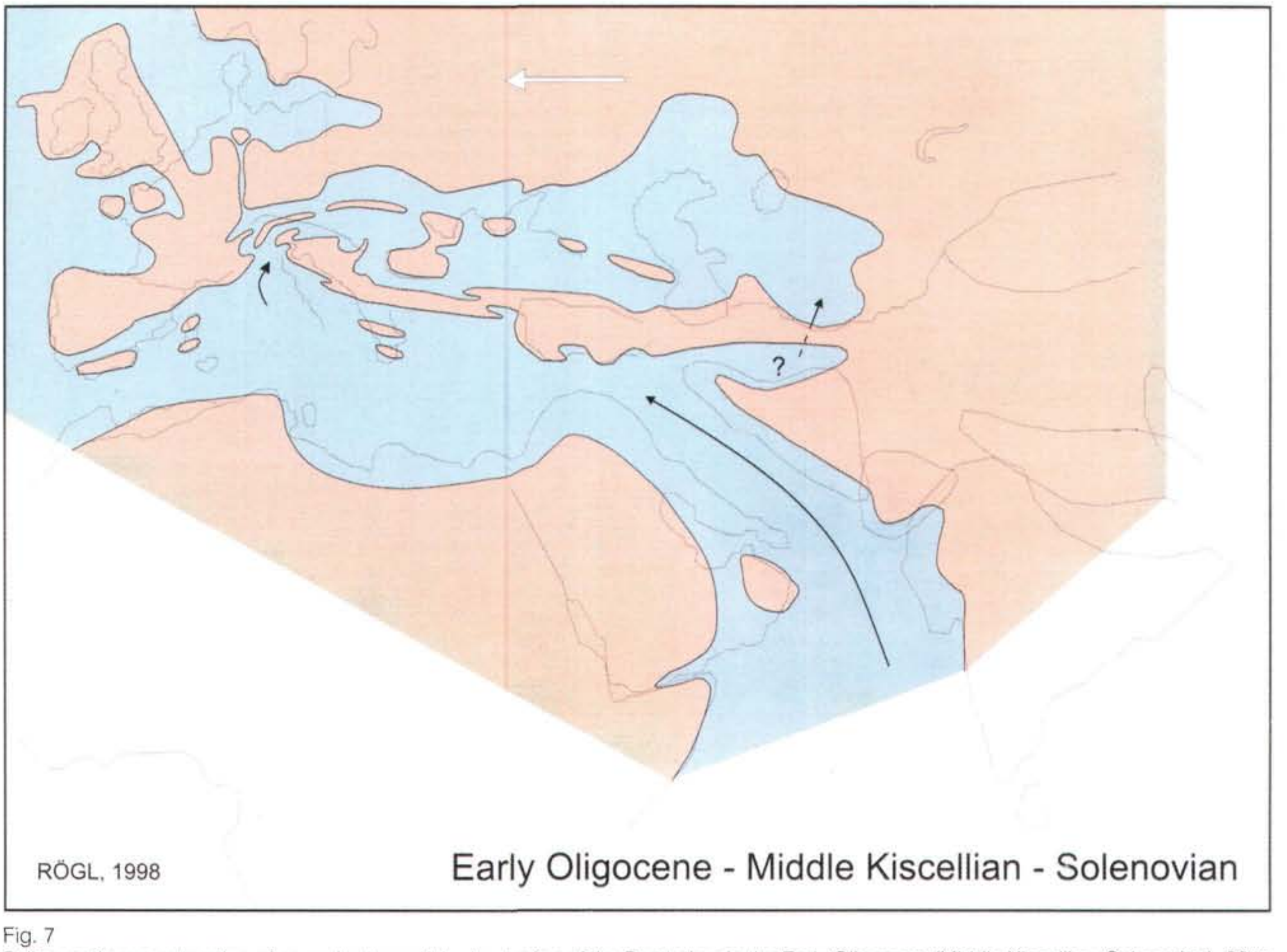


Fig. 7
Palinspastic reconstruction of an early stage of the beginning of the Paratethys in the Early Oligocene (Middle Kiscellian, Solenovian), 32 to 30 Ma (from RÖGL, 1998).

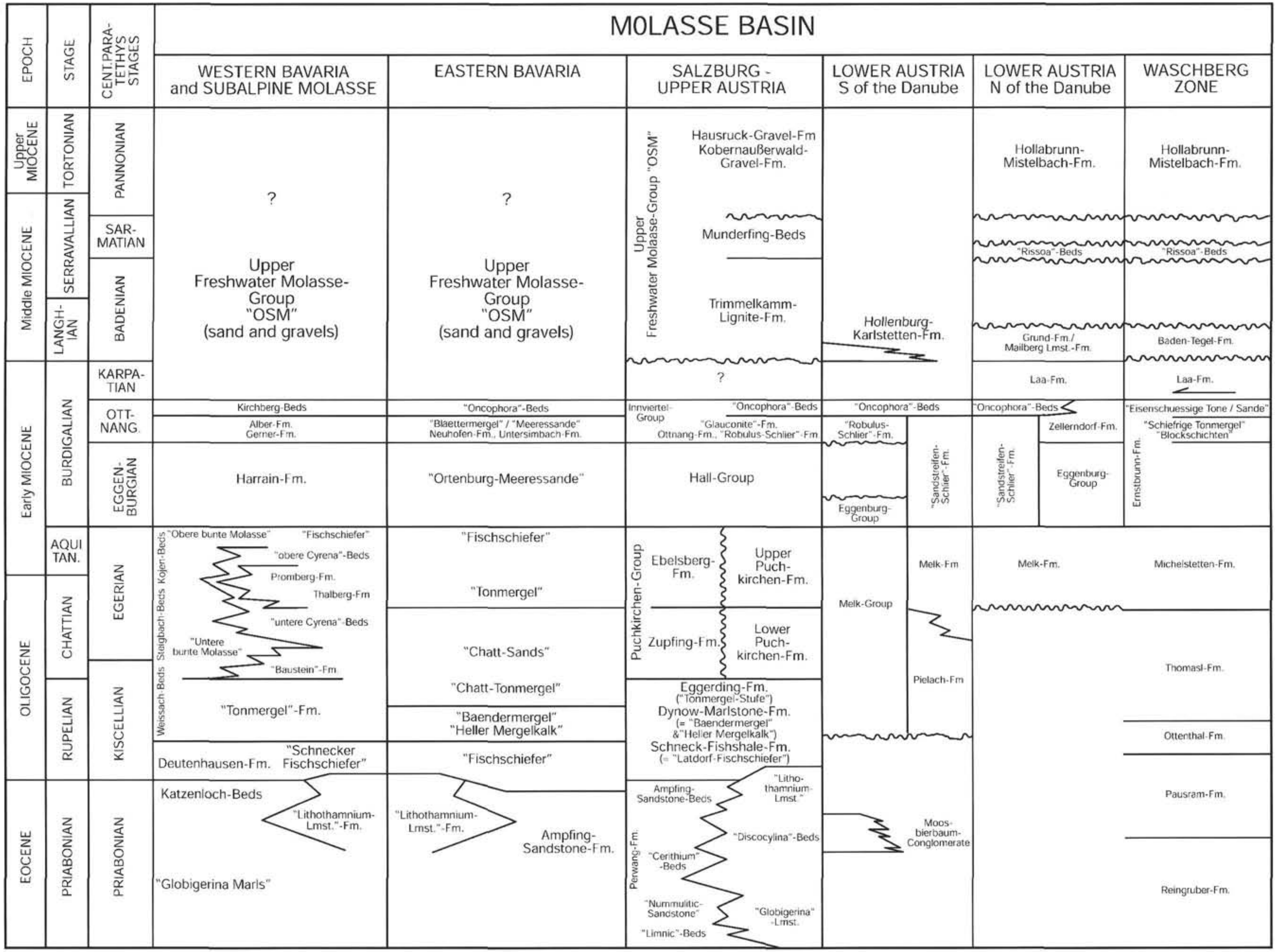


Fig. 8
Molasse Basin sedimentary cycles and lithostratigraphic units from western Austria (Vorarlberg) across Bavaria to Upper and Lower Austria (after STEININGER and al., 1986, WAGNER, 1998, modified).

to the calcareous nannoplankton zone NP 23 and approximately to the planktonic foraminifera zone P 19 (Tab. 1).

The Mediterranean area is still connected with the Indopacific and the Atlantic ocean by a wide open seaway. The strongly restricted connection with the Paratethys realms is reconstructed here through the Dinaride corridor and via the western Molasse Basin. A link to the Eastern Paratethys was still in existence in lowermost Early Oligocene (Early Kiscellian, Peshekian). The opening of the Rhine graben provided an active seaway from the Molasse Basin to the North Sea realms. Most important for the European/Asian mammal exchange was the closure of the Turgai strait at ca. the Eocene to Oligocene boundary. This is one of the most prominent events in the European and the Asian mammal faunas, known also as the "Grand Coupure".

The Paratethys is characterised by long west-east trending basins with a restricted marine flora and fauna and mostly thin-layered to laminated sediments. This facies points in most parts of the Paratethys to low salinity and oxygen-depleted conditions prevailing in the deeper parts of the basins (RÖGL, 1998).

In Austria the beginning of the Paratethys realm biofacies is marked in the Molasse Basin by a remarkable facies change on top of the Late Eocene sediments. The Early Oligocene – the Kiscellian Stage contains in general marly to often dark coloured pelitic, thin layered to laminated sediments with nannochalks and diatomites with monospecific, low diverse microfossils assemblages and a macrofauna dominated by endemic taxa (e.g. Schöneck-Formation, Dynow Marlstone, Eggerding Formation; WAGNER, 1998) deposited in restricted environments (Fig. 8). In the later Kiscellian gradually open marine conditions were restored ("Tonmergelstufe" = Zupfing-Formation, WAGNER, 1998) (Fig. 8). This entire sedimentary cycle is confined to the deeper parts of the basin, overlain by younger sediments and known only by deep wells (Fig. 8 and WAGNER, 1996, Fig. 2a).

The Tertiary sediments of the lower Inn valley (Häring and Reith im Winkel) near Innsbruck (Tyrol) were deposited in a typical Molasse Basin "piggy back" situation with the fluviatile/limnic/paralic to marine Kiscellian sediments (Häring Formation) grading into the Egerian limnic/fluviatile sediments of the Angerberg Formation.

The transgressive base of the following Egerian turbiditic lower and upper Puchkirchen-Formation in the western Molasse Basin deeply erodes and incises the older sediments under submarine conditions (WAGNER, 1996, Fig. 2a) and

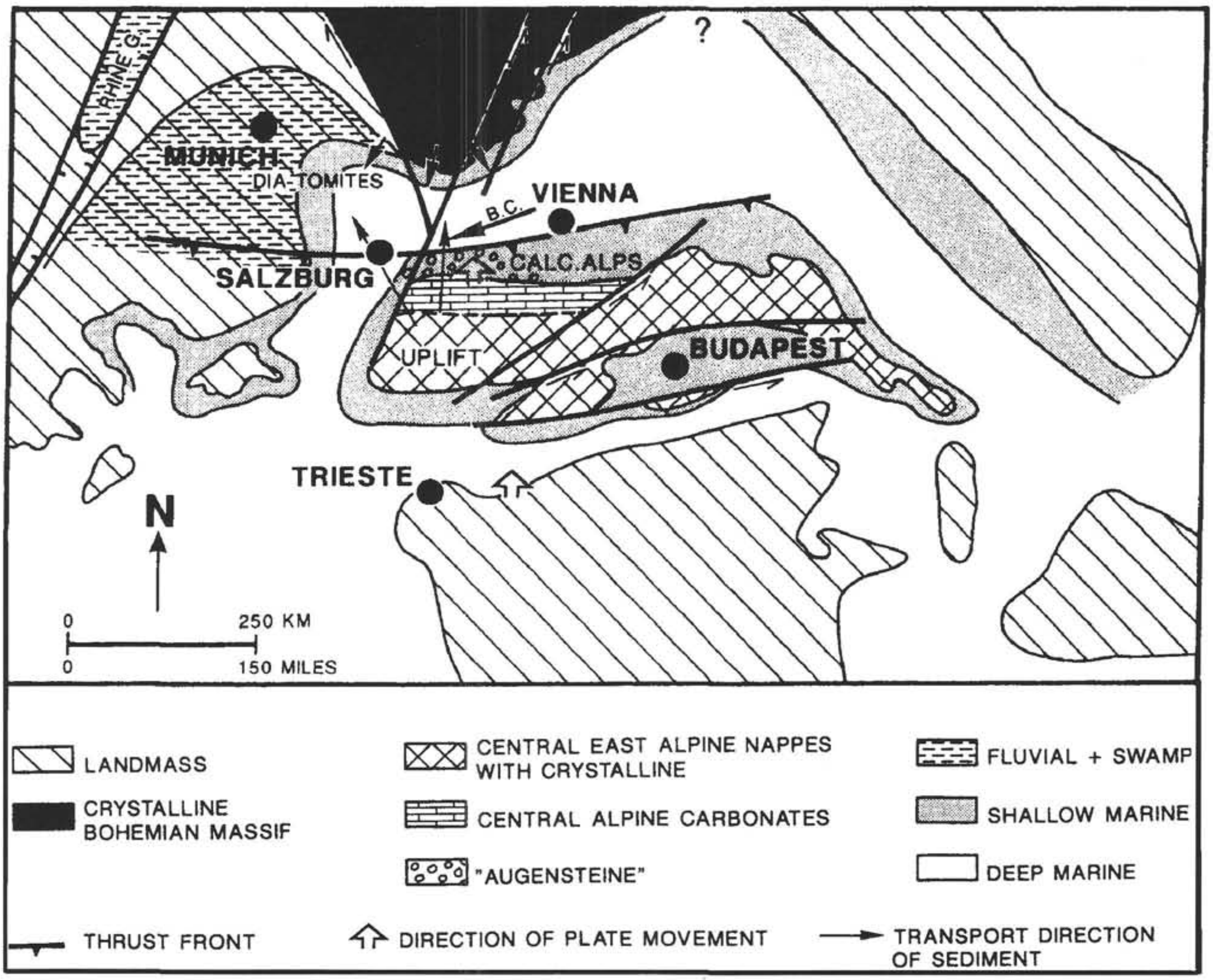


Fig. 9
Palinspastic reconstruction of Middle Europe in the Late Oligocene (Egerian), 25 Ma (from WAGNER, 1996).

the basin axis is further shifted to the north (Figs. 3a, 9). This transgression also spreads across the Molasse Basin shelf far to the north into the Bohemian Massif (see also the palinspastic section in WAGNER, 1996, Fig. 9b). The open marine conditions are fully restored with a rich marine microfauna where again larger foraminifera invade this area and with a diverse macrofauna. These thriving conditions are obviously caused in these parts of the Molasse Basin by the paleogeographic situation with a marine connection with the south from the Salzburg area across the still submerged Alpine system to the Mediterranean basin (Fig. 9; see also RÖGL, 1998, plate 4). The Puchkirchen-Formation in the Salzburg and Upper Austrian Molasse Basin and its equivalents, the Melk-Formation in Lower Austria are made up by a siliciclastic facies of shales, sandy shales, nearshore sands and paralic to limnic to fluviatile deposits. Intercalated conglomerates in the western Molasse Basin have been deposited in channels and in the form of submarine fandelta deposits originating from different Alpine tectonic units (WAGNER, 1996). From Salzburg to the west the Molasse Basin is filled with paralic, limnic to fluviatile sediments the so called USM = "Lower Freshwater Molasse" = Lower Freshwater Molasse-Group (WAGNER, 1998). Typical lithologic units are: "Cyrena"- and Promberg Formations in Bavaria, and "Baustein"-, Weissach-, Steigbach-, Kojen Formations and the "Granitische Molasse", in ascending order, in Vorarlberg (see also Fig. 8).

Lower Miocene tidal dominated seaways and the creation of the Alpine lowlands

(Fig. 10: Late Burdigalian – Ottnangian – Early Kotskhurian: 18 to 17 Ma)

In the Early Miocene (Aquitanian to Early Burdigalian, Late Egerian to Eggenburgian, Karadzhalganian to Sakaraulian; Tab. 1) the Mediterranean area was still connected with the Indopacific and the Atlantic ocean. However, the Arabian subplate now moved counterclockwise and faster towards the northeast than the African plate. This caused the opening of the Red Sea and the beginning of evaporitic environments on the northeastern edge of the subplate and narrowed the Indopacific seaway. The northward movement of the African plate system created the emerging Atlas and Betic mountain chains, which narrowed the Atlantic portal of the Mediterranean. Elongated mountain chains emerged in the central Mediterranean by the counterclockwise motion and overthrusting of the Apennine basin. The Paratethys still has a wide open connection with the Indopacific seaway and by the "Transtethyan Trench Corridor" from Slovenia via the Venetian Basin to the Mediterranean. These openings obviously caused the tidal dominated sediments in the Eggenburgian deposits of Hungary. The connection of the Paratethys with the west and from here to the north via the Rhine Graben was not active anymore (Fig. 9) and the northern faunal elements vanished. The marine flora and fauna on the contrary was now enriched by warmer water elements (larger foraminifera and specific mollusc taxa) which point to prominent Indopacific influences (RÖGL, 1998: plate 4). In the Early Eggenburgian time a characteristic warm water mollusc fauna (with large pectinids: *"Chlamys gigas"* horizon) spread from the east throughout the entire Paratethys to Bavaria (STEININGER and SENES, 1971; BALDI, 1979; RUSU, 1996).

In the Salzburg and Upper Austrian part of the Molasse Basin we recognize a distinct gap between the Late Egerian Upper Puchkirchen Formation and the transgressively following Eggenburgian Lindach- and Hall Formations (see WAGNER, 1996, Fig. 2a, and WAGNER, 1998). This Early Miocene transgression reworked parts of the Late Egerian nearshore sediments (Linz Sand and "Älterer Schlier" = Ebelsberg Formation and Zupfing Formation, WAGNER, 1998) and spread farther across the Molasse shelf and the Bohemian Massif to the north. In the south the Hall Formation transgressively overlies the overthrusted Alpine nappe system (Fig. 3a, and WAGNER, 1996, Fig. 9a). In Lower Austria the Eggenburgian parts of the Sandstreifen Schlier (WAGNER, 1998) transgressively covers large parts of the Molasse Basin shelf directly overlying the basement. These sediments are also found beneath the overthrusted Eastern Alpine nappes and below the Vienna Basin (Fig. 3b and STEININGER et al. 1986, Figs. 3, 4, 5, 6, 7). The transgressive marine sediments of the Eggenburg Group (WAGNER, 1998) are spread farther across the southern and eastern edge of the Bohemian Massif in Lower Austria.

To illustrate the closure of the Indopacific/Mediterranean/ Paratethys seaway we have chosen the Late Burdigalian – Ottnangian – Early Kotsakhurian time slice around 18 to 17 Ma (Tab. 1, Fig. 10) because it most impressively marks this important marine and continental event (the "*Gomphotherium* event" see RÖGL, 1998), as well as the biologic separation and evolution of the Neogene Mediterranean bioprovince, respectively. This event was caused by the progressive counterclockwise rotation of the Arabian subplate and its collision with the Eurasian plate system and a global sea-level drop (cycle TB 2.1 of HAQ et al. 1987; Bur 3 of HARDENBOL et al., 1998). The Arabian- Eurasian landbridge for the first time allowed a (mammal-) faunal exchange beginning in European Mammal Zone MN 4 (STEININGER, 1999) between these bioprovinces approximately around 18 Ma (THENIUS, 1979; STEININGER et al., 1985; BARRY and FLYNN, 1988).

During the same time slice we observe the isolation of the Eastern Paratethys from the oceanic realms and the Central Paratethys sea. This causes the evolution of the peculiar endemic semi-marine Kotsakhurian fauna (POPOV et al., 1993). From the Central Paratethys an active seaway developed across the western Alpine foredeep and the Rhone valley area towards the western Mediterranean and across the Rhine Graben into the north Sea realm (Fig. 11). This western Mediterranean connection allowed for the immigration of western Mediterranean faunal elements (bryozoa, molluscs) into the western Central Paratethys and triggered the tidal dominated sediments (Innviertel-Group: Atzbach Sands, WAGNER, 1998) known from the Swiss, Bavarian and Upper-Austrian Molasse Basin (FAUPL and ROETZEL, 1987; KRENMAYER et al. 1996; MARTEL et al., 1994; ZWEIGEL, 1998). In the uppermost Late Burdigalian-Karpatian this western marine connection again ceased and the entire western Paratethys and the western Molasse Basin dried up (see RÖGL, 1998, plate 6).

In the Molasse Basin of Austria marine sedimentation continues into Ottnangian time with a pelitic marly basinal facies, intercalated towards the southern coasts with coastal sands and fan delta conglomerates of Alpine origin and a sandy facies at the northern coasts of Bohemian Massif origin, summarized within the Innviertel Group (WAGNER,

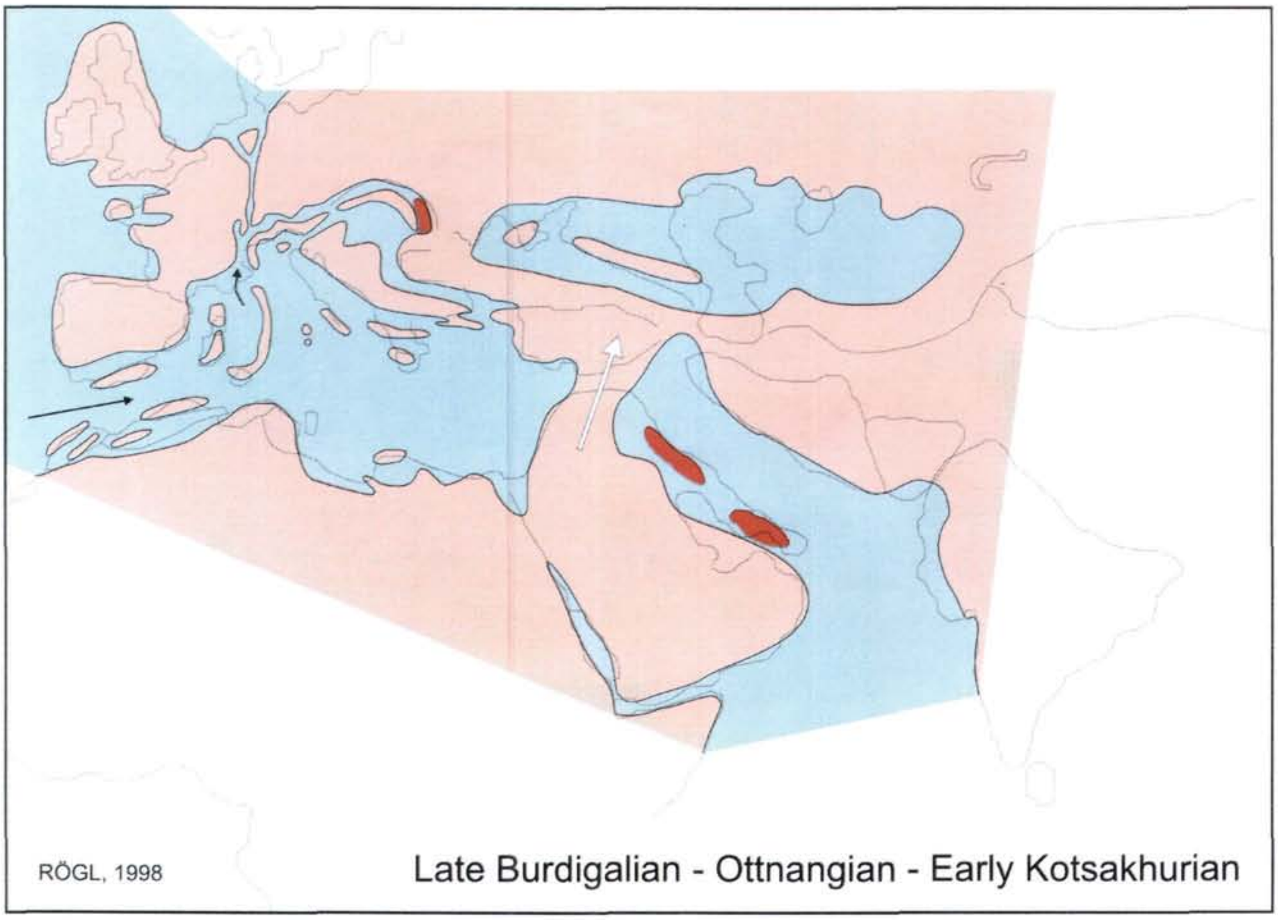


Fig. 10
Palinspastic reconstruction of the Paratethys in the Late Burdigalian (Ottnangian, Early Kotsakhurian), 18 to 17 Ma (from RÖGL, 1998).

1998) in the Salzburg and Upper Austrian part of the Molasse Basin (WAGNER, 1996, Fig. 2a) and the Ottangian "Robulus Schlier" "Sandstreifen Schlier" and Zellerndorf Formation in the east (Fig. 3b and WAGNER, 1998). As mentioned above, this marine event can be followed across Bavaria (Harrain Formation) to Vorarlberg (western Austria). These marine sediments are incorporated within the OMM = Upper Marine Molasse. In the Late Ottnangian regressive conditions prevailed and triggered a widespread endemic nearshore estuarine to fluviatile facies (Oncophora-Formation, WAGNER, 1998) dominated by a mollusc fauna similar to the Kotsakhurian fauna (Fig. 3b).

From the uppermost Late Burdigalian to Karpatian the western Molasse Basin to the southern spur of the Bohemian Massif dried up and paralic, limnic to fluviatile sediments ("Kohleführende Süßwasserschichten", STEININGER et al., 1986) prevailed in the Middle and Late Miocene (Fig. 3b). The continental Molasse Basin east of the spur of the Bohemian Massif was reached episodically by short living marine transgressions coming out of the Vienna Basin in Karpatian and Early Badenian time and by the Early Sarmatian and Early Pannonian transgressions (Fig. 3b). These transgressions seemed to follow from Badenian time onwards depressions and incised vallies from an eastward directed drainage system beginning east of the spur of the Boehmian Massif. This drainage system can be followed in Badenian time from Spitz in the Danube valley in Lower Austria across the Molasse Basin entering the Vienna Basin around Mistelbach in northern Lower Austria. Also the Sarmatian and Pannonian drainage systems follow this direction (STEININGER and ROETZEL, 1996).

The first Alpine lowlands must have come into existence from the Eocene/Oligocene times onwards by the northward movement of the Alpine promontory, since we recover their earliest erosional products – the "Augenstein" gravel – within the submarine fan deposits in the Egerian Puchkirchen-Formation. (Figs. 3b, 10, 11). The general drainage system west of the spur of the Bohemian Massif and the Regensburg high in Late Oligocene-Early Egerian time (during the deposition of the USM, Fig. 3b and see above) was directed from west to east, but turned around during the Early Miocene. In Late Ottnangian it was then directed until Pannonian times towards the west, towards a pre-Rhone river system. Only since the Late Miocene – since Pannonian time the drainage of the Bavarian and the Austrian Molasse Basin followed an eastern direction and a pre-Danube river system came into existence. Another prominent drainage system originating in the Alpine lowlands in Badenian time is known near Krems. Here a pre-Traisen river entered the Molasse Basin from the south and built a huge submarine fan reaching far to the north into the Bohemian Massif (Hollenburg-Karlsstetten Formation; STEININGER and ROETZEL, 1996). The lowland character of the Alps can also be deduced from the sedimentary fill of small Neogene basins within the Alpine system itself (e.g. Salzach-Enns, Mur-Mürz, Lavantal and Periadriatic-basins; Fig. 5). These ba-

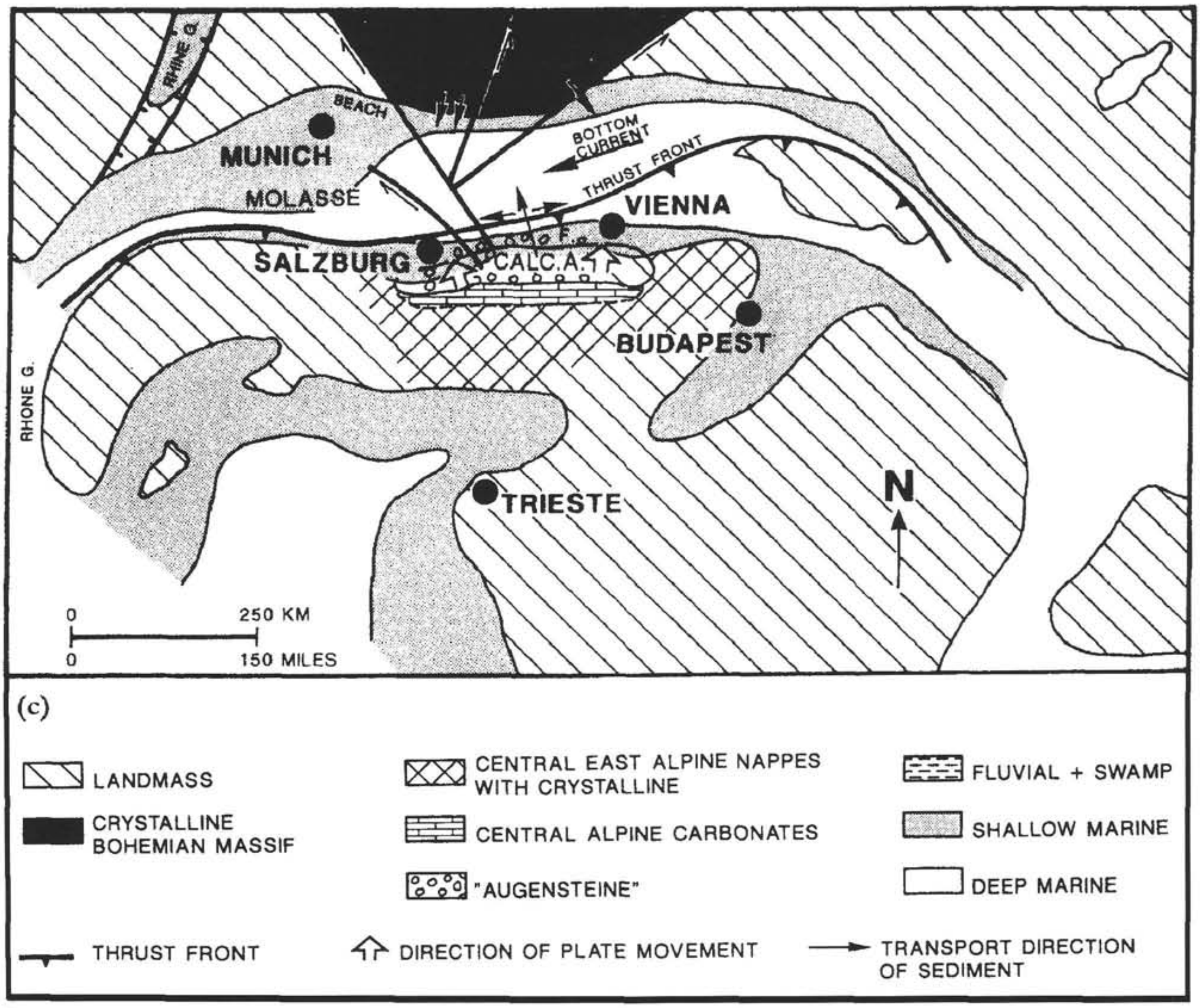


Fig. 11
Palinspastic reconstruction of Middle Europe in the Early Miocene (Eggenburgian/Ottnangian), 20 to 18 Ma (from WAGNER, 1996).

sins are mostly filled from Ottnangian and Karpatian time onward, respectively, with paralic, limnic and fluviatile sediments, which point to prevailing lowland conditions in the Austrian Alps up to the Late Miocene by virtue of their floral and faunal content (STEININGER et al., 1986).

Middle Miocene basin development and river systems

(Fig. 12: Early Badenian, Tarkhanian: 16.4 to 15 Ma)

The beginning of the Middle Miocene is marked worldwide by a sea-level high (TB 2.3 of HAQ et al., 1987; between Bur5/Lan1 and Lan2/Ser1of HARDENBOL et al., 1998). This global sea-level rise reconnected the Mediterranean with the Indopacific realms, flooded transgressively the Eastern Paratethys and the Central Paratethys, which was still linked by the "Trans-Tethyan Trench Corridor" with the Mediterranean via the Venetian Basin to Slovenia, and the Drava-Sava Basin, respectively (Fig. 12). Because of paleobiogeographic considerations, the highly diverse marine fauna, known from the Carpathian foredeep and the more restricted marine fauna from the eastern Paratethys, a speculative seaway is proposed south of the Black Sea plate and the Pontides in northern Anatolia, which provides this open marine connection with the Carpathian foredeep of the Central Paratethys (RÖGL, 1998). Beginning with the Middle Miocene the sedimentary depocenters of the Paratethys were tectonically rearranged from the former west-east trending Molasse Basin trenches to the intra-mountainous basin systems (e.g. Vienna, Styrian, Drava-Sava, Danube, Pannonian, Dacian and Euxinian-basin systems) The subsidence of these basins by various tectonic mechanisms started from Karpatian/Badenian time onwards.

This Middle Miocene sea-level rise event corresponded to a global warming phase and warm water elements are wide spread (e.g.: warm water planktonic foraminifera, mass occurrences of large foraminifera of Indopacific origin, tropical to subtropical corallinacea/coral reefs growing as far north as Krakow (Poland) and tropical mollusc faunas and fishes). On the other hand, the mammal faunal exchange between Africa via Arabia to Eurasia was interrupted, which can be seen in the hominoid record.

In Austria, the Vienna Basin began to subside from north to south into the east Alpine-Carpathian nappe system by

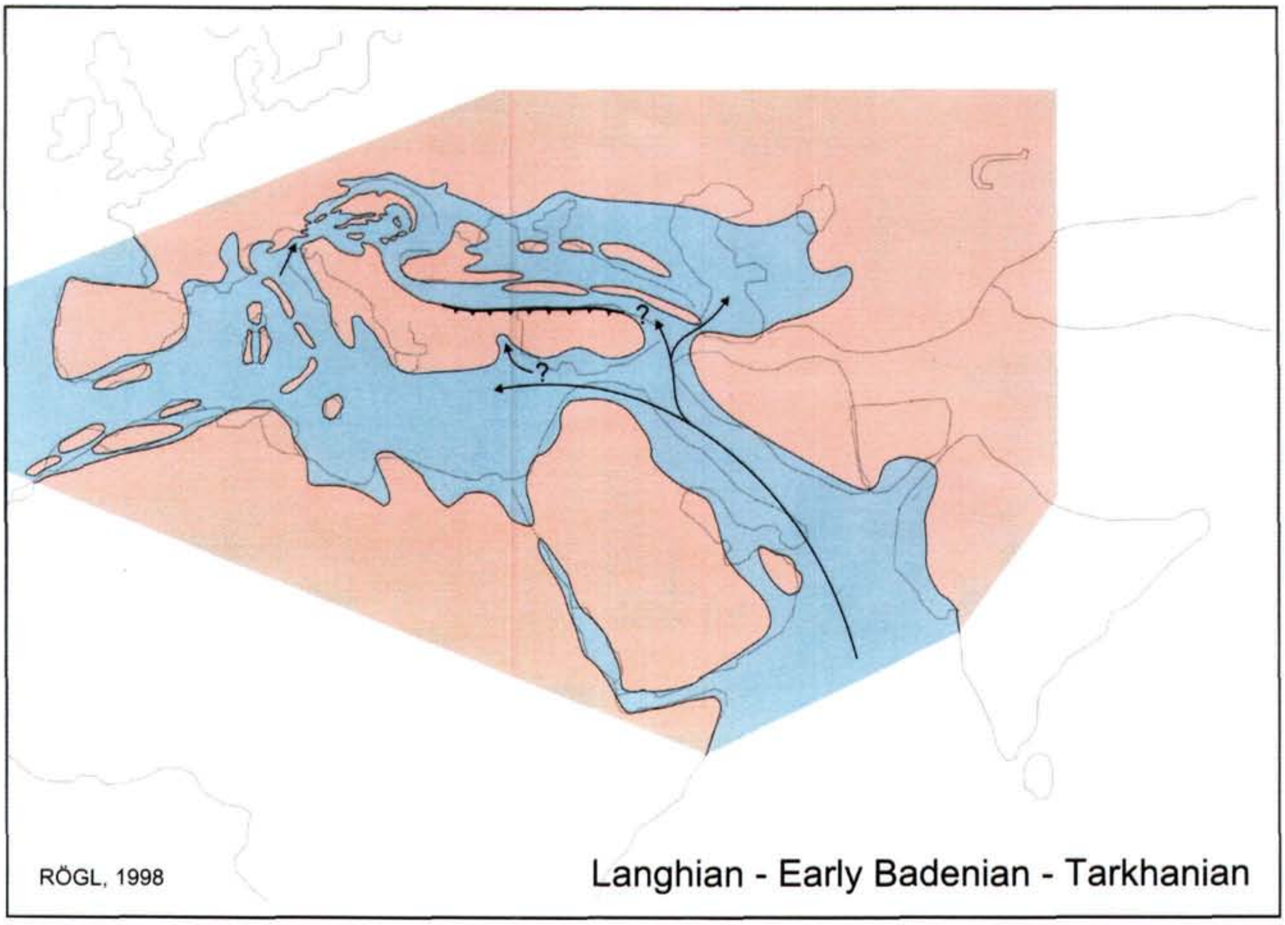


Fig. 12
Palinspastic reconstruction of the Paratethys in the Langhian (Early Badenian, Tarkhanian), 16.4 to 15 Ma (from RÖGL, 1998).

synsedimentary faulting in Eggenburgian to Karpatian time (Proto-Vienna Basin) and in Badenian to Pannonian time (Neo-Vienna Basin). This caused a strong relief of the basin-basement with buried mountains important to hydrocarbon production (HAMILTON et al., this volume). The synsedimentary subsidence was largest during Late Badenien (up to 2,000 meters), the greatest depth of the basin is 6,000 meters in the Zistersdorf depression and 5,200 meters in the area close to the Schwechat airport east of Vienna (SAUER et al., 1992; SEIFERT, 1996; WESSELY, 1993). During Karpatian time the basin was divided by the Matzen-Spannberg swell into a marine sediment regime in the north (Laa Formation) and a reduced marine (Bockflies Beds) to a limnic and fluviatile sediment regime towards the south (Gänserndorf Member, Aderklaa Formation; Fig. 13, WAGNER, 1998). In Badenian time the entire basin was filled throughout with open marine sediments arranged in differentiated facies belts from deeper water to nearshore sediments, transgressively overlying the older sediments and the basement (Fig. 13). At the rim of the basin and on the elevations within it, coastal terraces are preserved and corallinacea/coral reefs grew. A similar marine facies development is found in the Styrian Basin, besides the intercalation of the Karpatian to Early Badenian submarine andesitic volcanics (Figs. 3b, 4, 13; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996).

The base of the Badenian sediments upon the Karpatian/Badenian sequence boundary was formed south of the Matzen ridge by the fluviatile Aderklaa conglomerate representing a lowstand (WEISSENBÄCK, 1995, 1996). The erosional truncation at its base was low or non-existent in depressions (non-deposition) and remarkable along elevation areas (up to 300 m along the Matzen ridge). The thickness of the conglomerate itself reflects the later subsidence conditions within the "Neo-Vienna Basin": for example a thickness of 350 m in the Schwechat depression contrasts with 50 m on the neighbouring Oberlaa high. According to the conglomerate as the basal member of a sequence it is included in the formations of the Badenian stage (WEISSENBÄCK, 1996). Marine sediments were deposited on top of the conglomerate and north of the Matzen ridge. Sedimentation reached the crest of the Matzen ridge in the Middle Badenian at the *Spiroplectammina*-biozone during a transgressive systems tract (KREUTZER 1993). According to WEISSENBÄCK (1996) the Badenian sediments contain two sequences with several highstand, transgressive and lowstand systems tracts. Subsidence and sediment thickness in depressions (e.g. in Zistersdorf or Schwechat lows) differ enormously from those on elevations (e.g. Steinberg and Oberlaa highs). The trend of subsidence continued throughout the Sarmatian and Pannonian times all over the Vienna Basin.

The Aderklaa and the Rothneusiedl Conglomerate with gravel derived from an Alpine source point to the first known drainage systems of the Alps coming from the southwest and discharging into the Vienna Basin. From the Middle

Epochs	Mediterranean Stages	Central Paratethys Stages	Central Paratethys Biozones	Lithostratigraphy of Vienna basin	Lithostratigraphy of Styrian basin
Pliocene	Gelasian	Romanian		Gravel-beds	postbasaltic gravel, basalts, basaltic-tuffs, prebasaltic gravel
	Piacenzian				
5.3 Ma.	Zanclian	Dacian			
Late Miocene	Messinian	Pontian	Zone G/H		Tabor-gravel-Fm.
			Zone F		"Lignitic sequence of Rechnitz"
11.1 Ma.	Tortonian	Pannonian	Zone E to Zone A / B	"Yellow-marl-sequence"/ Rohrbach Congl. "Blue-marl-sequence" "Lignitic-sequence" "Congeria-beds"	Loipersbach-/ Stegersbach-Fm. Schemerl-gravel Karnerberg-gravel Kirchberg-gravel Kapfenstein-gravel
Middle Miocene	Serravallian	Sarmatian	Elphidium granosum-Zone	"Verarmungs-Zone" "Mactra-beds" "upper Ervilia-beds" / Atzgersdorf-Limestone	Gleisdorf-Fm. / Hartberg-Fm. Carinthian-gravel
			Elphidium hauerinum-Zone	"lower Ervilia-beds"	sands
			Elphidium reginum-Zone	"Rissoa-beds" = Hernals-marl-Fm.	lignites and marls of the Graz-, Weiz- and Pinkafeld-basin
		Badenian	Rotalia and Bulimina-Zone Spiro-plectammina-Zone	gravel sands marls Leitha-limestone-Fm.	marls / sands / Leitha-lime-stone-Fm.
16.4 Ma.	Langhian		Lagenid-Zone	Baden-Tegel-Fm.	Gleichenberg-vulkanite-Fm.
Early Miocene	Burdigalian	Karpatian		Laa-Fm./Aderklaa-/ Rothneusiedl-Congl.-Fm. Gaenserndorf-Fm. "Oncophora"-Beds Bockfließ-Fm. Luzice-Fm. Orth-Conglomerat	Sinnersdorf-Congl./ "Styrian-Schlier" / Lignites of western Styrian-basin
		Ottnangian			
		Eggenburgian			
23.8 Ma.	Aquitanian	Egerian			

Fig. 13
Vienna and Styrian Basins sedimentary cycles and lithostratigraphic units.

Badenian time onwards there was a remarkable input of fluviatile transported terrigenous material into the northern Vienna Basin. It entered the basin in the area of Mistelbach and created an enormous submarine fandelta with prominent lobes (SAUER et al., 1992); it was responsible for an important hydrocarbon reservoir (HAMILTON et al., this volume). As we discussed above this points again, to a sort of "pre-Danube" drainage system originating in Badenian time east of the spur of the Bohemian Massif and connected only since Pannonian time (Hollabrunn-Mistelbach-Formation) with the west (Hausruck-Kobernaußer Wald-Formation: WAGNER, 1998) (Fig. 8; BERNOR et al., 1993). During Sarmatian, Pannonian and Pontian times this deltafront spread farther to the southern parts of the basin. Another river discharge entered the basin in the Middle Badenian at the northernmost tip coming from the Carpathian mountain ranges. At the same time two subordinate deltas are recognised in the southern part of the basin, one entering from the west and the other from the southern tip of the basin. All deltas had their maximum spread in Sarmatian time and can be followed into the Pannonian (SAUER et al., 1992).

By the regressive phase during the Serravallian and in Middle Badenian – Karaganian, respectively (TB 2.3/TB 2.4 sea level drop of HAQ et al., 1988; between Lan2/Ser2 and Ser2/Ser3 of HARDENBOL et al., 1998), the Indopacific marine link with the Mediterranean and the Eastern Paratethys ceased and disconnected the Mediterranean and the Paratethys from the Indopacific realm (see RÖGL, 1998, plate 8). The Eastern Paratethys was also disconnected from the Central Paratethys and developed the endemic (*Spaniodontella*-) fauna, characteristic of the Karaganian time span. The narrow marine connections from the Pannonian Basin to the Transsylvanian subbasin and the Carpathian foredeep created evaporitic conditions in these areas (see RÖGL, 1998, plate 8). The brief reopening and restoration of marine conditions through the Mesopotamian trough flooded the Eastern and the Central Paratethys but did not reach the Mediterranean Sea. This event and the closure of the "Trans-Tethyan Corridor" gave rise to the Indopacific faunal influence in the entire Paratethys in Late Badenian/Konkian time (see RÖGL, 1998, plate 9). However, regressive events caused by tectonic rearrangements between the Arabian subplate and along the Anatolian fault zone, shrunk this huge intercontinental sea at the end of the Badenian and Konkian, respectively.

Middle to Late Miocene intracontinental sea and lake systems

(Fig. 14: Middle Serravallian – Early Sarmartian – Volhynian, Early Bessarabian: 13 to 11.7 Ma)

The movements along the Anatolian fault system, caused by the northward motion of the Arabian plate activating the Dead Sea fault system, opened a narrow marine connection from the Eastern Mediterranean towards the Eastern Paratethys and created a transgressive sequence, which marked the base of the Sarmatian and Volhynian, respectively (Fig. 14). This narrow marine connection and the river drainage into the vast Paratethys realm triggered waters with a decreasing salinity, oversaturated in carbonate. In this intracontinental sea an environment with a uniformly low diversity but individually rich flora and fauna developed covering in a most astonishing uniform biofacies, the entire Paratethys from the Vienna Basin to Lake Aral. All euhaline groups (e.g. radiolaria, planktonic foraminifera, corals and echinoderms) were lacking and few benthic foraminifera, ostracodes and molluscs dominate these peculiar aquatic realms. The characteristic morphologic mollusc evolution (e.g.: *Ervilia, Irus, Mactra, Calliostoma* and *Dorsanum*) through time is used for high resolution biostratigraphy (POPOV and STOLYANOV, 1996; STEININGER, 1977).

In Austria, this Sarmatian biofacies covers the entire Vienna Basin and the Early Sarmatian transgression reaches across the Molasse Basin to Krems in Lower Austria (Figs. 8, 13). A similar reduced marine facies development is found in the Styrian Basin (Figs. 4, 13; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996).

In Pannonian time the continued thrusting and the elevation of the Carpathian mountain chain finally restricted the connections of the Central Paratethys, the Pannonian Basin and its satellite basins (e.g. Vienna, Styrian and Transsylvanian Basins), to the Eastern Paratethys into a narrow connection in the area of today's "Iron Gate" (STEVANOVIC in PAPP et al., 1985). This caused a further drop in salinity close to sweet water conditions and only few ostracode and mollusc taxa populated this Pannonian lake system. In contrast, the „Sarmatian" biofacies prevailed in the Eastern Paratethys from Volhynian to Khersonian. The debate about the Sarmatian stage sensu strictu defined by SUESS (1866) and a Sarmatian stage sensu latu as used in the Eastern Paratethys and the correlation of the base of the Pannonian

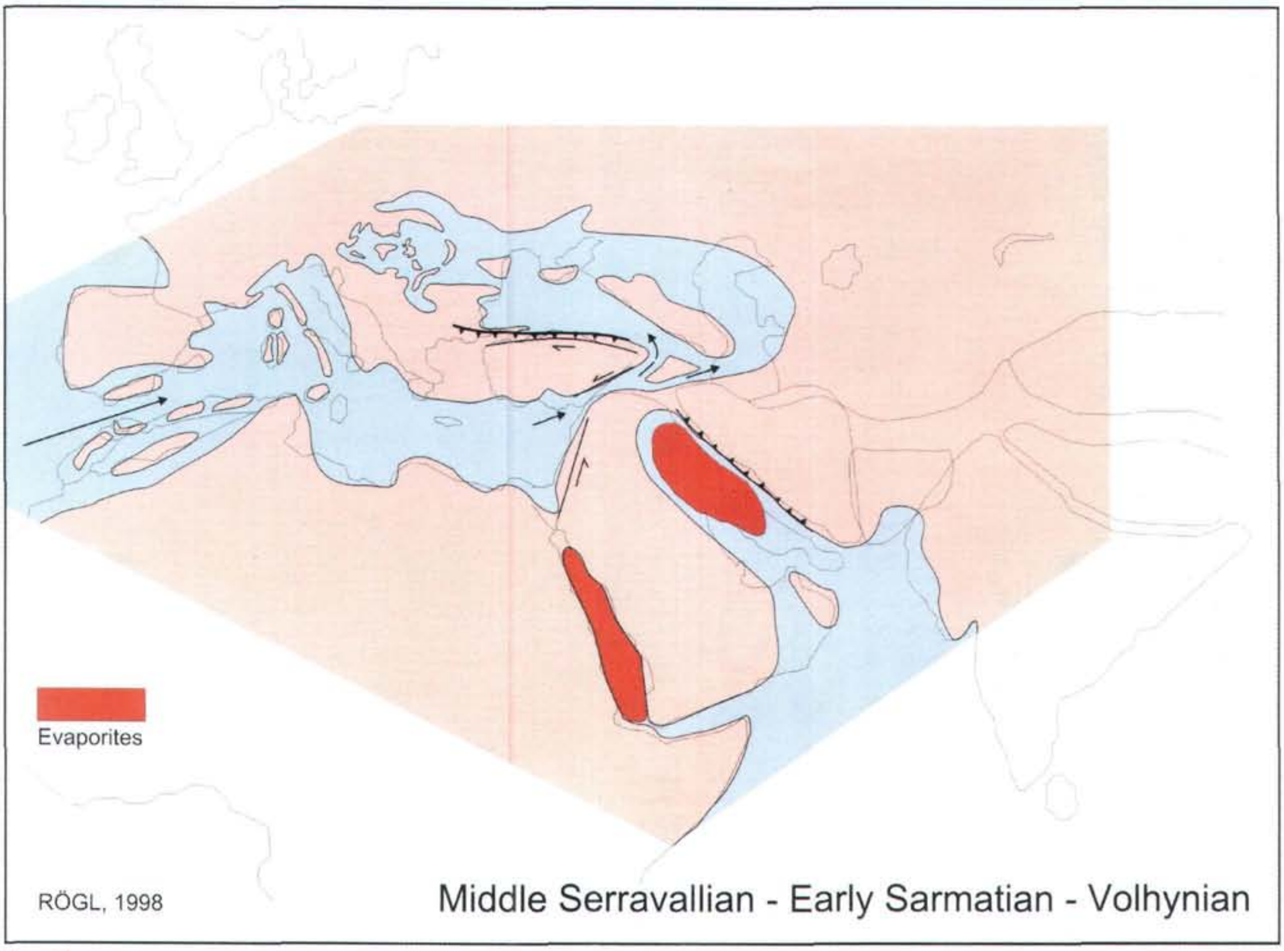


Fig. 14
Palinspastic reconstruction of the Paratethys in the Middle Serravallian (Early Sarmartian), 13 to 11.7 Ma (from RÖGL, 1998).

stage respectively could be solved through the „*Hipparion*" event known from both realms and is now better understood (Tab. 1; BERNOR et al. 1988).

In Austria, this pelitic to clastic facies of the Pannonian Basin covers the entire Vienna Basin and in the Early Pannonian a transgressive event reaches across the Molasse Basin to Krems in Lower Austria (Figs. 8, 13). A similar facies development is found in the Styrian Basin. However, the subsidence in the Styrian Basin ceased and the thin cover of Pannonian sediments was restricted to the eastern Styrian Basin (Figs. 4, 13; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996). The characteristic morphologic evolution of the gastropod genus *Melanopsis* and bivalve genus *Congeria* through time is used for high resolution biostratigraphy (STEININGER, 1977).

In the Tortonian, which is correlative to the Pannonian and to the Late Bessarabian, Khersonian and Maeotian, respectively (Tab. 1), the Aegean Sea opened, and by this time another connection via the Dardanelles towards the Eastern Paratethys came into existence. Short living marine excursions are known to have occurred several times in the Late Miocene from the Aegean into the Eastern Paratethys (RÖGL and STEININGER, 1983) and the Maeotian Paratethys fauna migrated into the Aegean Sea (PAPP et al. 1978).

The Messinian Mediterranean salinity crises ended the continuous marine sedimentation in the Neogene Mediterranean Basin. The interconnected Paratethyan water bodies became disconnected and evolved into fresh water lake systems, which were successively drained and began to dry up completely. In the uppermost Messinian this endemic Paratethys biofacies even invaded the Mediterranean region through the Aegean.

Biostratigraphically dated Pontian sediments, which would be correlative to the Messinian time interval, are unknown from the Molasse Zone and the Vienna and Styrian Basins. However, conglomerates in the Molasse Zone, a sequence of multicoloured marls, brown coals and conglomerates in the Vienna Basin and similar sediments restricted to the eastern part of the Styrian Basin close to the Burgenland swell, which separates the Styrian Basin from the Pannonian Basin system, are assigned to Late Miocene and Pliocene times, respectively (Fig. 4; EBNER and SACHSENHOFER, 1995; SACHSENHOFER et al., 1996).

The Pliocene dessication phase and the birth of the modern river drainage systems

In Early Pliocene (Zanclean) the modern Mediterranean Sea came into existence by a transgressive phase, flooding the desiccated basin with marine waters from the Atlantic. At the peak of this transgression in the Middle Pliocene (Piacenzian) even the Eastern Paratethys was flooded again via the Aegean and the Dardanelles strait (RÖGL and STEININGER, 1983).

In Austria, the dessication of the Vienna Basin is marked by red bed and fluviatile deposits. The few biostratigraphic dates derived from scarce mammal finds point to a Pliocene age of some of the gravel beds. South of Vienna the Mitterndorf-Wiener Neustadt graben system is actively subsiding up to the present and is filled with Pliocene and Pleistocene gravel deposits.

During Pliocene/Pleistocene the Styrian Basin was uplifted and a strong erosion of several 100 meters took place. A second young nephelinitic/basanitic volcanic phase with basaltic lava flows as well as a variety of pyroclastic rocks with radiometric ages between 3.8 and 1.7 Ma is spread far in the southeastern part of the basin (Fig. 8; EBNER and SACHSENHOFER, 1995; SACHSENHOFER, 1996).

In the Molasse Basin and the intra-mountainous basins loess sedimentation began about 3 Ma. In the Molasse Basin of Lower Austria a loess sequence with an age of 3 Ma was deposited on top of the gravel deposits of the pre-Danube river system (Hollabrunn-Mistelbach Formation). This might have been the time when the Danube river began to follow its present river bed, entering the Vienna Basin through the Bisamberg/Kahlenberg furrow and leaving the Vienna Basin through the Bruck and Hainburg straits, creating the modern river drainage system.

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