Late Cretaceous palaeobiogeography and migrations of Foraminifera in western Eurasia

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Beniamovskii, V.N. & Kopaevich, L., 2002: Late Cretaceous palaeobiogeography and migrations of Foraminifera in western Eurasia. – In: Wagreich, M. (Ed.): Aspects of Cretaceous Stratigraphy and Palaeobiogeography. – Österr. Akad. Wiss., Schriftenr. Erdwiss. Komm. 15: 61–78, 10 Figs., Wien.

Abstract: In the Late Cretaceous the Northern Hemisphere comprised the Tethyan, Transitional and "Boreal" palaeobiogeographic Realms. The palaeobiogeographic European Province belonged to the Transitional Realm and largely to the Northern mid-Latitude climatic belt. It was the marginal zone of the Tethyan Realm called Peri-Tethys. The West Siberian Province was a part of the Northern High Latitude climatic belt and extended into the Northern mid-Latitude climatic belt. Each province was characterized by particular assemblages of benthic Foraminifera. Typical West Siberian assemblages of benthic Foraminifera were dominated by quartz-siliceous agglutinating forms. The palaeoassociations of the epicontinental seas of the European Province contained predominantly calcareous benthos.

There was an exchange between biotas of the European and West Siberian Provinces through straits. The Late Cretaceous history of the most significant Turgai Strait comprised four stages. Biotic evolution of the West Siberian Province was also affected by the Northern High Latitude climatic belt. The meridional current along the eastern slopes of the Urals existed during the entire Late Cretaceous period. Consequently, the foraminifers of the West Siberian Province developed under the combined influence of both "Boreal" and Tethyan water masses.

The eastern part of the European Province consisted of the Crimea-Caucasus and Dnieper-Peri-Caspian-Mangyshlak Subprovinces, which were recognized on the basis of the distribution of planktonic and benthic Foraminifera. The Crimean-Caucasian assemblages included many typical Tethyan planktonic Foraminifera, whereas the latter Subprovince was characterized by predominantly benthic Foraminifera with no Tethyan endemics.

Keywords: Tethyan, Transitional Realm, "Boreal" Realm, European Province, West Siberian Province, Foraminifera, Palaeobiogeography, Migrations

1. INTRODUCTION

Marine microfossils provide us with important information on sea surface conditions and, in some cases, on sea-floor temperatures. The first attempt to reconstruct Cretaceous planktonic foraminiferal provinces with regard to palaeoceanography was made by

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BANDY (1967), who was followed by many other investigators (FRERICHS, 1971; SLITER, 1977; HART & BAILEY, 1979; HART, 1980, 2000). Isotopic analysis was used to determine sea surface temperatures (CORFIELD et al., 1990; HUBER et al., 1995). All of the studies were based mainly on planktonic Foraminifera. The application of benthic foraminiferal data to the interpretation of Cretaceous palaeoclimates was limited (HAIG, 1979; OLSSON & NYONG, 1984; KUHNT, 1990; KOTSOUKAS & HART, 1990; PODOBINA, 1966, 1995, 2000a).

On the basis of the distribution of the Late Cretaceous planktonic foraminifers, Tethyan, Transitional and "Boreal" palaeobiogeographic Realms can be recognized in the Northern Hemisphere (HAY, 1995; HART, 2000) (Fig.1). The palaeobiogeographic European Province belonged to the Transitional Realm and largely to the Northern mid-Latitude climatic belt. The West Siberian Province was a part of the Northern High Latitude climatic belt and extended into the Northern mid-Latitude belt. Each province was characterized by a particular assemblage of benthic Foraminifera.

The European Province (EP) extended for about 7000 km from the Atlantic shores of northwestern Europe in the west to the Aral Sea and Kopet-Dag in the east (NAIDIN, 1969). It was the largest epicontinental sea in the Earth's history (about 7000 km long). The sea was relatively deep (nearly 200 m). White chalk and marls were the dominant lithofacies in the EP and similar foraminiferal assemblages occurred throughout, permitting long-range correlation. Only the northern and northeastern parts of this area were characterized by alternating clastic and carbonate lithofacies (central and eastern parts of the Russian Platform and Mangyshlak Peninsula).

The geographical distribution of the late Santonian – Maastrichtian benthic foraminifers in the EP enabled us to distinguish West European and East European parts (NAIDIN, 1969; CHRISTENSEN, 1997; BENIAMOVSKII & KOPAEVICH, 1998). The former part was connected with the North Sea, the northern Atlantic and the Tethys. The latter part had a restricted connection with the "Boreal" West Siberian Sea through the Turgai Strait, and was continuously linked with Tethys.

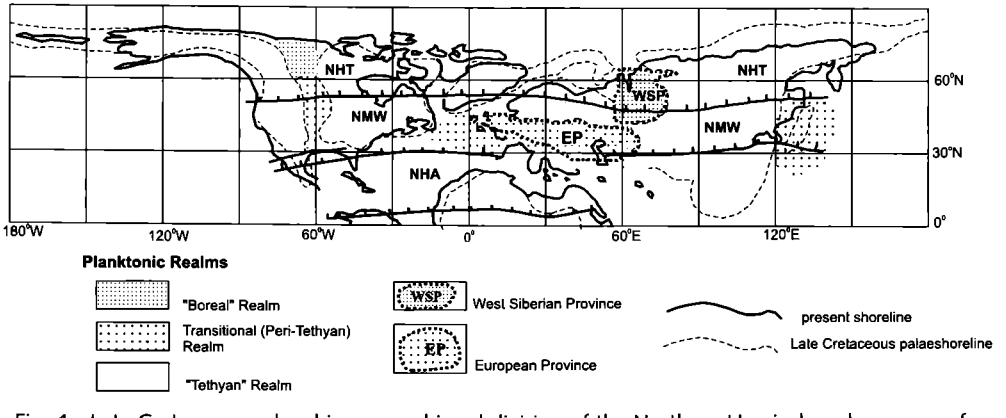

Fig. 1: Late Cretaceous palaeobiogeographic subdivision of the Northern Hemisphere by means of foraminifers (HART, 2000; with small additions). NHT – Northern High Latitude Temperate climatic belt; NMW – Northern mid-Latitude Wet climatic belt, NHA – Northern Hot Arid belt. Provinces: EP – European Province, WSP- West Siberian Province.

2. STUDIED AREA, MATERIAL AND METHODS

The present work is based on studies of many outcrops and boreholes of the Russian Platform and its framework (NAIDIN & KOPAEVICH, 1977; NAIDIN et al., 1984 ; AKIMEZ et al., 1992; NIKISHIN et al., 1993), as well as on a detailed analysis of published data on the West Siberian Province (SUBBOTINA (ed.), 1964; PODOBINA, 1966, 1989, 1995, 1997, 2000a, 2000b; AMON, 1990, 2001); the Volga region, Peri-Caspian depression, Mangyshlak Peninsula and Crimea were studied in detail (AKIMEZ et al., 1979, 1983; BENIAMOVSKII et al., 1988; NAIDIN et al., 1994; KOPAEVICH, 1996; KOPAEVICH & WOLASZCZYK, 1990; ALEKSEEV, 1989; ALEKSEEV & KOPAEVICH, 1997; ALEKSEEV et al., 1997, 1999; KOPAEVICH & BENIAMOVSKII, 1999; GORBACHIK et al., 2000).

Palaeogeographical investigations should be carried out in accordance with precise and reliable zonal stratigraphical schemes allowing wide correlations. We used the planktonic foraminiferal Cretaceous zonation for the low and middle latitudes (ROBASZYNSKI & CARON, 1995). This zonation is partly (at least from uppermost Albian to lower Coniacian) applicable to the "Boreal" belt. We used the benthic foraminiferal zonal scheme for the upper Santonian – Maastrichtian interval (BENIAMOVSKII & KOPAEVICH, 1998, Fig.3, left column), which is based on the distribution of zonal assemblages in different regions of Eastern and Western Europe, particularly the Mangyshlak-Caspian Basin and the NW German Basin (NAIDIN et al., 1984; KOCH , 1977; SCHÖNFELD, 1990; SCHÖNFELD & BURNETT, 1991). This benthic zonal scheme was correlated with the planktonic and nannofossils schemes (HERMAN et al., 1988; ALEKSEEV & KOPAEVICH, 1997; ALEKSEEV et al., 1999). We used the benthic foraminiferal zonal schemes of AMON (1999) and PODOBINA

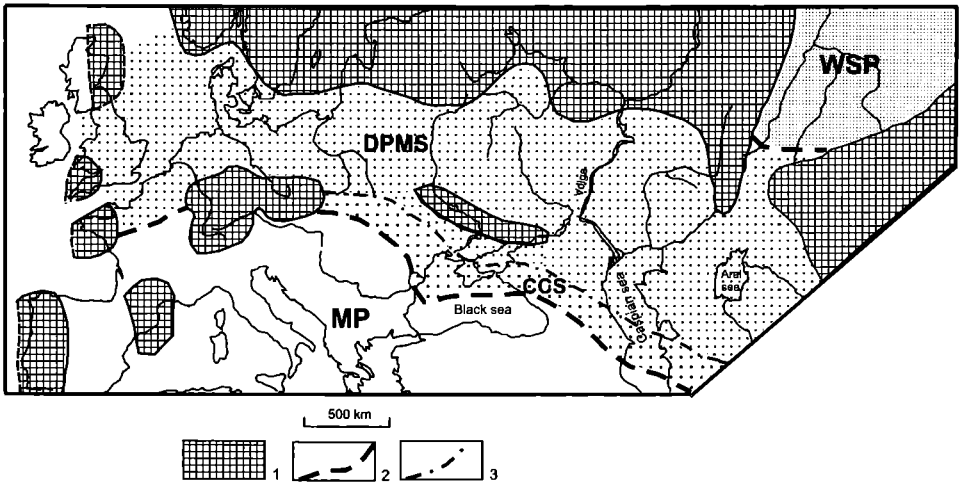

Fig. 2: Late Cretaceous palaeobiogeographic subdivision of the European Province by means of foraminifers. 1 – land, 2 – boundaries between provinces, 3 – boundaries between subprovinces, MP – Mediterranean Province, WSP – West Siberian Province, CCS – Crimea-Caucasus Subprovince, DPMS – Dnieper-Peri-Caspian-Mangyshlak Subprovince.

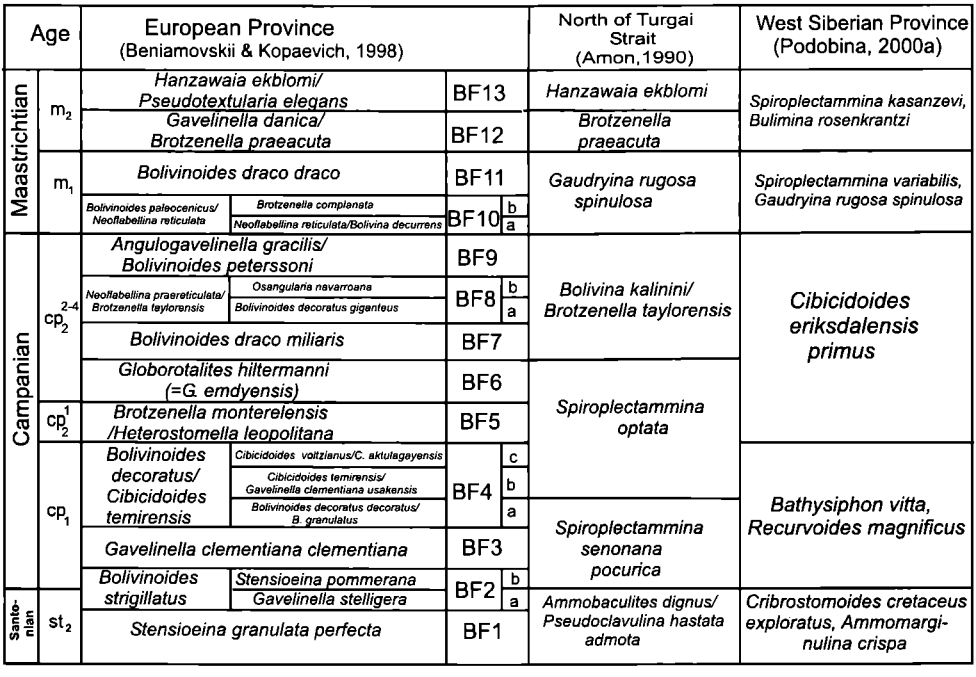

Fig. 3: Santonian – Maastrichtian zonations based on benthic foraminifers for the European and the West Siberian provinces.

(2000a) for the Upper Santonian – Maastrichtian interval of the Turgai Strait-Sea and West Siberian Basin (Fig. 3).

2.1. Benthic Foraminifera

Comparative analysis showed that the assemblage of benthic foraminifers of the northern and central parts of the West Siberian Province were strongly dominated by quartz-siliceous agglutinating forms of the genera *Rhabdammina, Rhizammina* and *Bathysiphon*, as well as *Psammosphaera, Saccammina, Ammodiscus, Glomospira, Hyperammina, Reophax, Haplophragmoides*, and *Ammobaculites*. Scarce calcareous foraminifers were represented mainly by the genera *Neobulimina, Globulina, Pyrulina, Nodosaria, Lagena* and rare *Discorbis* (Figs. 4, 5, 6). The agglutinating foraminiferal assemblages frequently show a low specific diversity, being dominated by few taxa. They consist mostly of stratigraphically long-ranged forms. They were usually confined to the deep- and cool-water conditions of the bathyal zone (KOUTSOUKOS & HART, 1990; KUHNT et al., 1989). The presence of quartz-siliceous agglutinated astrorhizids, ammodiscids, lituolids and trochamminids in the West Siberian Basin can be explained by the open connection with the Arctic Basin and the lower temperature regime than in the European Basin

Agglutinated Foraminifera

Type of the wall	Orders	Genera	"Boreal" Realm	Tethyan Realm
			West Siberian Province	European Province
quartz-siliceous	Astrorhizida	Rhabdammina	+	
		Bathysiphon	+	
		Psammosphaera	+	
		Stegnammina	+	
		Saccammina	+	
		Thurammina	+	
	Ammodiscida	Hippocrepinella	+	
		Hyperammina	+	
		Ammodiscus	+	
		Glomospirella	+	
		Reophax	+	
		Haplophragmoides	+	
	Lituolida	Trochamminoides	+	
		Ammobaculites	+	
		Ammobaculoides	+	
	Trochamminida	Trochammina	+	
carbonate-cemented	Textulariida	Textularia	+	+
		Spiroplectammina	+	+
	Ataxophragmiida	Pseudoclavulina	+	
		Arenobulimina	+	+
		Gaudryina	+	+
		Dorothia		+
		Marssonella		+
		Plectina*		+
		Eggerellina*		+
		Ataxophragmium*		+
		Orbignyna*		+
		Voloshinovella		+
		Verneuilina		+
		Tritaxia		+
		Heterostomella		+
		Clavulina		+

*European genera, migrated to West Siberian Province in the Late Campanian-Maastrichtian

Fig. 4: Comparison of some agglutinated orders and genera typical of the West Siberian and European provinces.

(Podobina, 1989), as well as by oxygen depletion of bottom water (Marinov, 1997). According to Gradstein & Berggren (1981) and Miller et al. (1982), depth was not a decisive factor in the development of agglutinated "primitive" foraminifers (Astrorhizidae, Ammodiscidae, Lituolidae). They inferred that certain hydrographic properties (low oxygen, high CO_2, low pH and thus corrosive waters) favoured the development of these assemblages. Another controlling factor was the relatively rapid deposition of fine-grained, organic-rich, carbonate-poor clastics under somewhat restricted bottom water circulation in compartmented basins. These authors noted a wide bathymetrical zonation

of these factors – from neritic to abyssal. In the middle and high latitudes, the environments favourable for the formation of agglutinating foraminiferal assemblages occurred frequently in the shelf depths. We suggest that such environments appeared in the West Siberian Basin in the Late Cretaceous and resulted in the wide distribution of agglutinated assemblages.

The assemblages of the European epicontinental seas were dominated by calcareous foraminifers of the genera *Neoflabellina, Stensioeina, Angulogavelinella, Gyroidinoides, Gyroidina, Globorotalites, Osangularia, Cibicidoides, Gavelinella, Brotzenella, Praebulimina, Bolivinoides* and *Bolivina.* The most abundant agglutinating foraminifers

Calcareous Foraminifera

Genera	"Boreal" Realm	Tethyan Realm
	West Siberian Province	European Province
Nonionella	+	
Neobulimina	+	
Nodosaria	+	+
Dentalina	+	+
Globulina	+	+
Guttulina	+	+
Lenticulina	+	+
Valvulineria	+	+
Discorbis	+	+
Globorotalites	+	+
Eponides	+	+
Epistomina	+	+
Gavelinella	+	+
Cibicides	+	+
Praebulimina	+	+
Bulimina	+	+
Bolivina*	+	+
Bolivinoides*	+	+
Cibicidoides*	+	+
Neoflabellina		+
Stensioeina		+
Osangularia		+
Angulogavelinella		+
Oridorsalis		+
Brotzenella*		+
Coleites		+
Aragonia		+

* European genera, migrated to West Siberian Province in the Late Campanian-Maastrichtian

Fig. 5: Comparison of some calcareous orders and genera typical of the West Siberian and European Provinces.

were carbonate-cemented forms of the genera *Heterostomella, Voloshinovella, Spiroplectammina, Marssonella, Gaudryina, Ataxophragmium* and *Orbignyna* (see Figs. 5,6). This is the typical shelf fauna of the chalk facies (KOUTSOUKOS & HART, 1990).

2.2. Planktonic Foraminifera

The Cretaceous assemblages of the West Siberian Province are characterized by the predominance of heterohelicids, hedbergellids, and planomalinids (PODOBINA, 1995, 1999, 2000a,b). All of these taxa have non-ornamented chamber surfaces and are of very small size – maximum 250 μm in diameter (ALEKSEEV et al., 1999).

The Russian Platform and Mangyshlak Peninsula successions are characterized by numerous planktonic foraminifers with pustulose, rarely rugose, chamber surfaces (*Hedbergella, Whiteinella, Archaeoglobigerina, Rugoglobigerina*) and other weakly ornamented hedbergellids, planomalinids, heterohelicids and guembelitrids. Rare species of *Rotalipora* were recorded in the Lower Cenomanian. The Coniacian–Maastrichtian assemblages contain very few keeled morphotypes of *Marginotruncana, Globotruncana* and *Globotruncanita* and also multicamerate heterohelicids (ALEKSEEV et al., 1999, KOPAEVICH & BENIAMOVSKII, 1999).

The Late Cretaceous successions of the Crimea and North Caucasus is characterized by different planktonic and benthic foraminiferal assemblages with a high planktonic/benthic ratio: from 40 to 90% in some intervals (BOTVINNIK, 1978; 1983, ALEKSEEV, 1989;

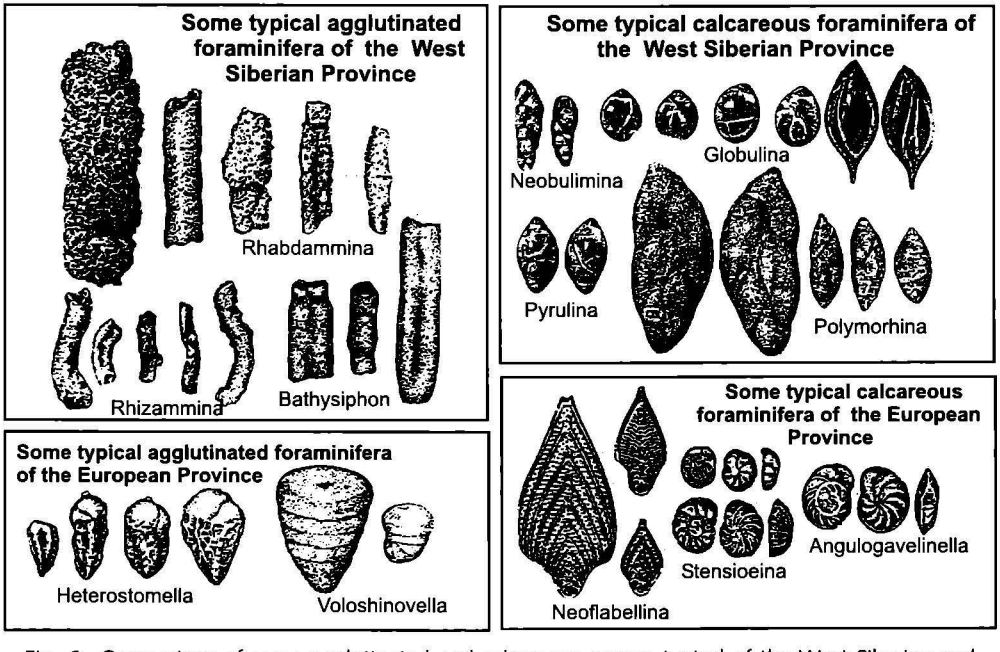

Fig. 6: Comparison of some agglutinated and calcareous genera typical of the West Siberian and European Provinces.

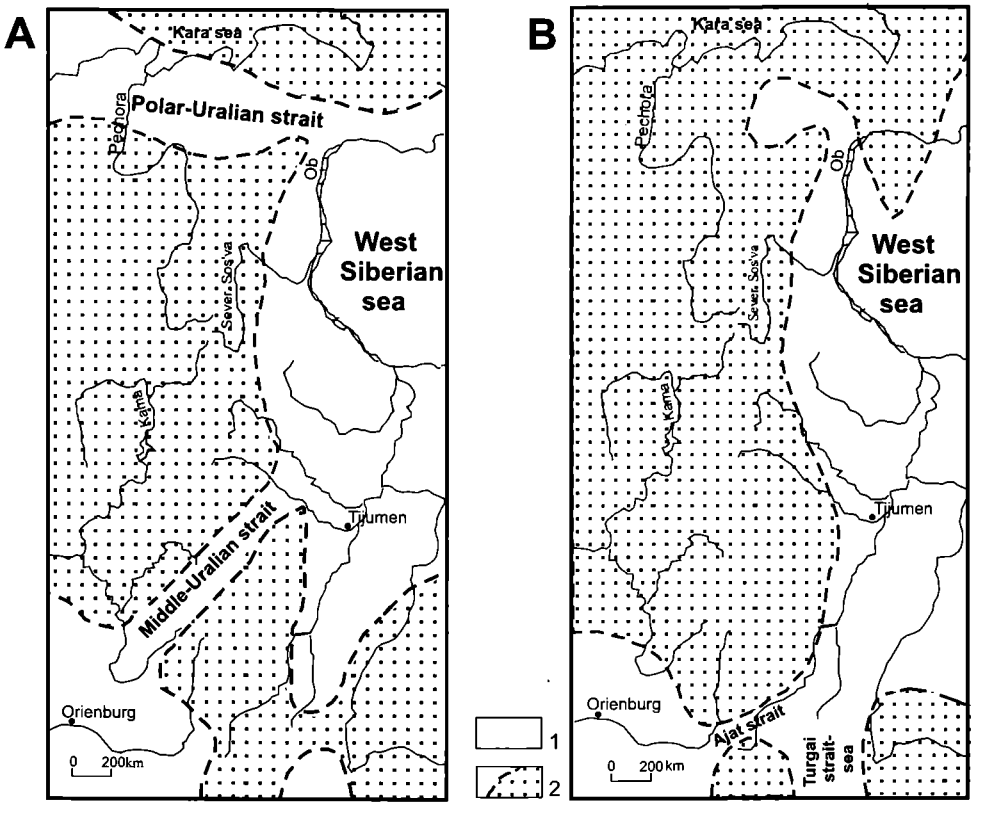

Fig. 7: Straits connecting the European and West Siberian Provinces in the Coniacian – Early Campanian (A) and in the Maastrichtian (B) (according to AMON, 1997, 2001). 1 – sea, 2 – land.

TUR, 1994; ALEKSEEV et al., 1997). The specialized keeled taxa (*Rotalipora*, *Marginotruncana*, *Globotruncana*, *Globotruncanita* and *Contusotruncana*), rugoglobigerinellids and large-sized multicamerate heterohelicids occur commonly.

3. DISCUSSION

The eastern part of the European Basin was connected to the Western Siberian basin by a system of straits (Fig. 7) including those crossing the Ural Mountains in the north, centre, and south (the Polar Ural, Middle Ural and Ajat straits) and the meridional Turgai Strait-Sea (AMON, 1990, 2001; AMON et al., 1997; OLFERIEV et al., 2000). The Turgai Strait-Sea is considered to have bordered the Peri-Tethyan basins in the northeast during the Late Cretaceous. This area contained elements of each regional fauna, i.e., both the relatively warm-water Peri-Tethyan or European fauna and the cool-water West Siberian one.

The Polar and Middle Ural straits connected the basins of the Western Siberian Province and the Dniepr-Caspian-Mangyshlak Subprovince during the Turonian – Campanian time interval. The Turonian – Upper Coniacian deposits of the Moscow depression contain the foraminiferal assemblage of the Western Siberian *Gaudryinopsis filiformis angustus* Zone (PODOBINA, 1966, 1997, OLFERIEV et al., 2000). The penetration of Siberian species was very intense.

In the Late Coniacian, the European species *Cibicides sandidgei* and *Gavelinella thalmanni* migrated through the Middle Ural Strait into the West Siberian Sea (the river Sos'va area). The distribution of the former species extended up to the river Kenga to the west from Tomsk (PODOBINA, 1997). Abundant radiolarian assemblages represented mainly by the West Siberian species were found in Santonian – Campanian dark-coloured non-carbonate siliceous clays and silts in the Ulyanovsk and Volgograd areas. The agglutinated benthic genera *Ammobaculites, Rhabdammina, Bathysiphon, Rhizammina, Saccammina* and *Haplophragmoides* were widely distributed in the boreal West Siberian Basin (BENIAMOVSKII *et al.*, 1988; PODOBINA, 1966, 1989; BRAGINA et al., 1999). The Turgai Strait connected the West Siberian Basin and the marginal East European basins during the Turonian to Maastrichtian. Four stages can be distinguished in the Late Cretaceous history of the strait.

The first (Turonian) stage was marked by a strong northern influence. The Turonian deposits of the entire Turgai Strait contain the foraminiferal assemblage of the West Siberian *Gaudryinopsis filiformis angustus* Zone. In addition to the index-species, the assemblage includes the characteristic agglutinated species *Haplophragmoides semiinvolutus* (LIPMAN & KHOKHLOVA, 1964). The zonal species had a very wide distribution throughout the EP as far as the United Kingdom (ALEKSEEV et al., 1997; HART, in JARVIS et al., 1988; OLFERIEV et al., 2000) and northern Central Asia (ZHUKOVA, 1963).

During the second (Santonian – Early Campanian) stage, warm waters of the marginal East European seas sometimes reached the northern Turgai Strait and the southern West Siberian Basin, as evidenced by the occurrence of warm-water molluscs (*Trigonia*) in the Lower Santonian deposits of these areas. According to POYARKOVA (1990), this fauna migrated northward from the Central Asia Subprovince. The Santonian – Early Campanian foraminiferal assemblages of the northern Turgai Depression and adjacent areas of the southern Transuralian region are entirely composed of West Siberian boreal benthic agglutinating species (AMON, 1990): predominant Lituolida, Astrorhizida, Ammodiscida (Fig. 8), frequent Trochamminida and scarce Ataxophragmiida. Deposits of this stage are missing in the key sections of the Turgai Depression because of the pre-middle Campanian erosion. This time was a sea-level low in the Turgai Depression, but in most places it was a sea-level high (HART & BAILEY, 1979; HANCOCK, 1992).

The third stage of development of the Turgai Strait-sea connecting the marginal seas of the eastern part of the European Province and the West Siberian Basin embraced the Late Campanian interval. The stage began with the eustatic rise of the initial late Campanian (*Brotzenella monterelensis/Heterostomella leopolitana* Zone), which provided an extensive expansion of European species into the northern Turgai Strait-sea and the southern West Siberian Province. Two Late Campanian eustatic sea level rises were marked by changes in abundance of benthic foraminifer orders. The agglutinated Ammodiscida, Lituolida and Trochamminida disappeared, the Astrorhizida were strongly reduced, whereas the Ataxophragmiida increased in abundance. Calcareous foraminifers

A

Orders	st	cp_1	cp_2	cp_3	m_1	m_2^1	m_2^2
Astrorhizida	26	26	10	5	2		
Ammodiscida	3	12	10				
Lituolida	55	45	22				
Textulariida		6	15	13	10	2	5
Trochamminida	8	6	2				
Ataxophragmiida	8	5	21	20	8	8	20
Miliolida					1		
Lagenida				18	18	16	10
Polymorphinida					3	3	
Rotaliida			18	37	51	49	47
Globigerinida				5	4	18	18
Incerta sedis			2	2	3	4	
	100%	100%	100%	100%	100%	100%	100%

B

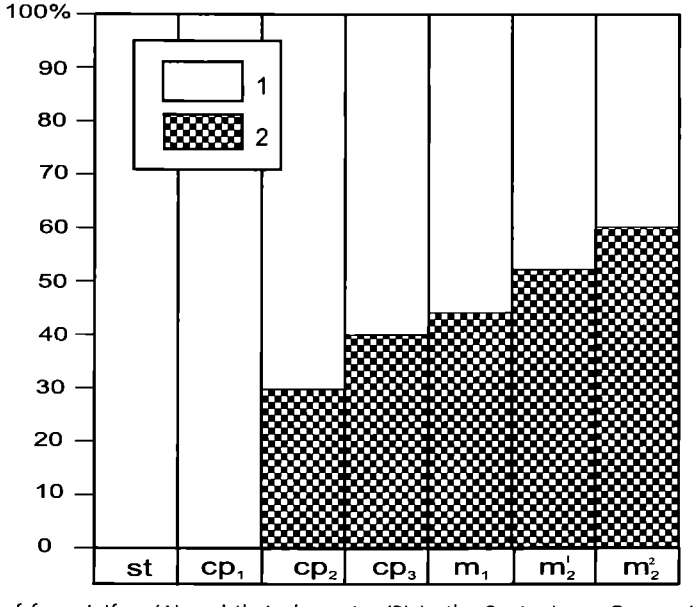

Fig. 8: Orders of foraminifers (A) and their dynamics (B) in the Santonian – Campanian deposits of the northern Turgai Strait-Sea. 1 – West Siberian species, 2 – European species.

appeared and became predominant by the end of the Campanian. The content of European species in the northern Turgai assemblage increased from the mid-Campanian (cp_2^1) and reached 37% in the latest Campanian (Fig.8). According to Barron (1985), the CESAR 6 core obtained in the flank of the Alpha Ridge in the Arctic Ocean contains a diverse, well-preserved diatom assemblage of probably Late Campanian age, which closely resembles the Late Campanian diatom assemblages from the Northern Urals (STREL'NIKOVA, 1974).

During the fourth (Maastrichtian) stage of the Turgai Strait history, the Ajat Strait opened between the Mugodzhary area and the Urals (AMMON, 2001; AMON et al., 1997). The increasing water area experienced a strong European influence. The Maastrichtian was marked by the maximal abundance of European species in the assemblages. At the end of the Maastrichtian, they amounted to 60% of the assemblage (Fig. 8). Benthic foraminifers were dominated by calcareous forms, represented up to 47–49% by the order Rotaliida.

During the late Campanian through early Late Maastrichtian eustatic transgressions, warm-water masses penetrated into the southern West Siberian Basin, as indicated by the occurrence of some characteristic Peri-Tethyan species of benthic foraminifers: *Bolivinoides decoratus, B. laevigatus, B. miliaris, Bolivina decurrens, B. incrassata, B. plaita* (KISSEL'MAN, 1969). Their stratigraphic ranges in the boreal successions are much shorter than in the intermediate zone (Fig. 9). The absence of European species suggests that the northwestern and northern parts of the Siberian Basin remained under the influence of northern boreal waters at that time (Fig. 10). Comparison of Santonian – Maastrichtian zonations of the eastern EP, northern Turgai depression and Western Siberia shows that the Turgai zonation correlates well with the EP zonation, from the mid-Campanian. On the other hand, the West Siberian and EP zonal schemes are different (Fig.3).

The occurrence of some West Siberian species, such as *Cibicides kurganicus, Anomalinoides subcarinatus, A. pinguis, A. gankinoensis* in the Maastrichtian deposits of the Dnieper-Caspian-Mangyshlak Subprovince, proves the southward movement of water masses through the Turgai Strait-sea. *Anomalinoides pinguis* and *A. gankinoensis* reached the Polish basin, where they are the zonal and lower subzonal index-species of the Upper Maastrichtian *Anomalinoides pinguis* Zone respectively (GAWOR-BIEDOVA, 1992). The stratigraphic range of these species in the "boreal" sequences is greater than in the intermediate zone (see Fig. 9). At the same time, foraminiferal faunas of the Volga River, the Peri-Caspian Depression and even the Crimea demonstrate immigrations of some characteristic "boreal" species in the Late Maastrichtian. This provides evidence for extensive faunal migrations through the basins at that time.

The short-term transgression in the latest Maastrichtian coincided with a warming episode, which was reflected in sections of the Russian Platform (ALEKSEEV et al., 1999), Crimea (ALEKSEEV & KOPAEVICH, 1997) and Mangyshlak (KOPAEVICH & BENIAMOVSKII, 1999). The sharp increase in the abundance of planktonic species of globotruncanids and especially of *Pseudotextularia* in the uppermost Maastrichtian sediments was recorded not only in Northern Europe, where it is known as the "*elegans* transgression" (WICHER, 1953), but also in the North Atlantic (NEDERBRAGT, 1989).

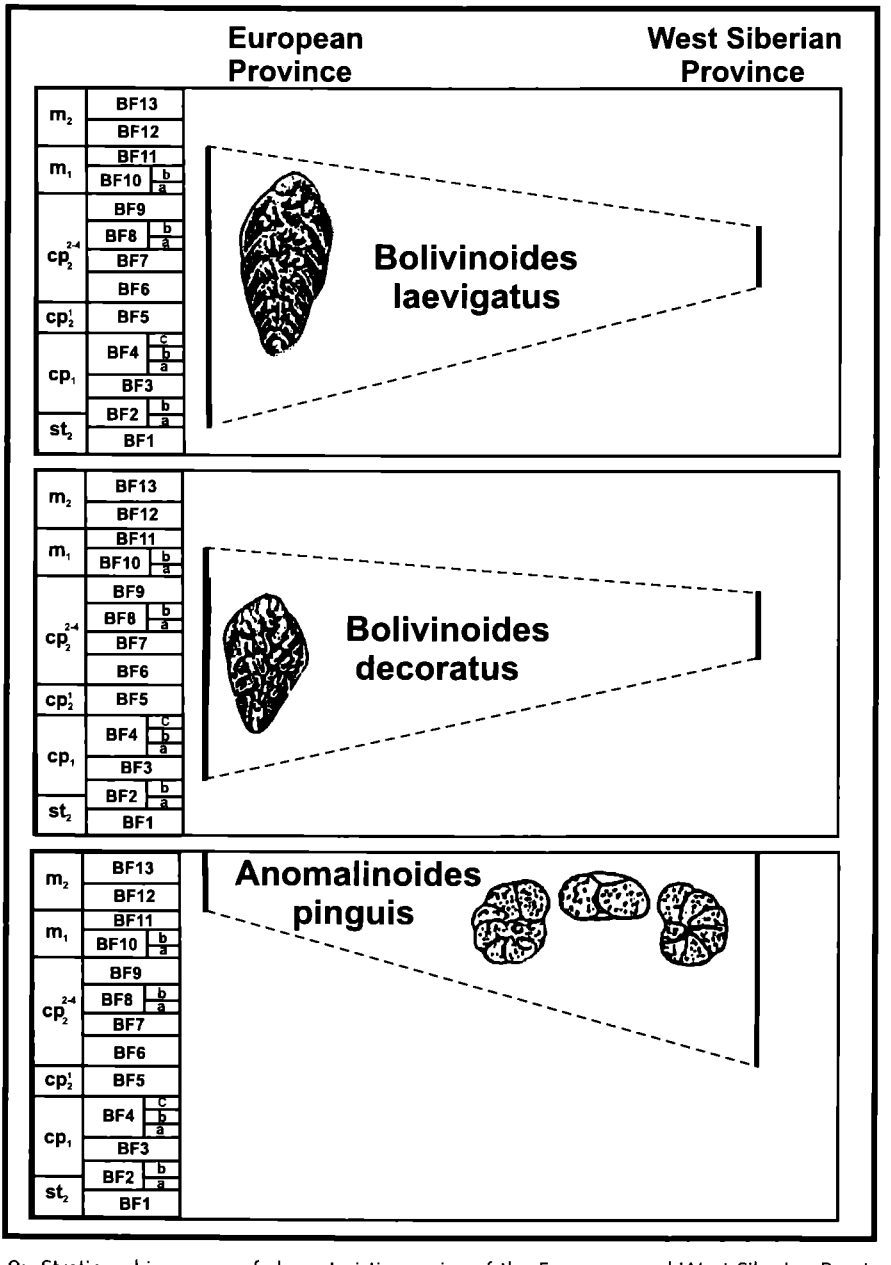

Fig. 9: Stratigraphic ranges of characteristic species of the European and West Siberian Provinces.

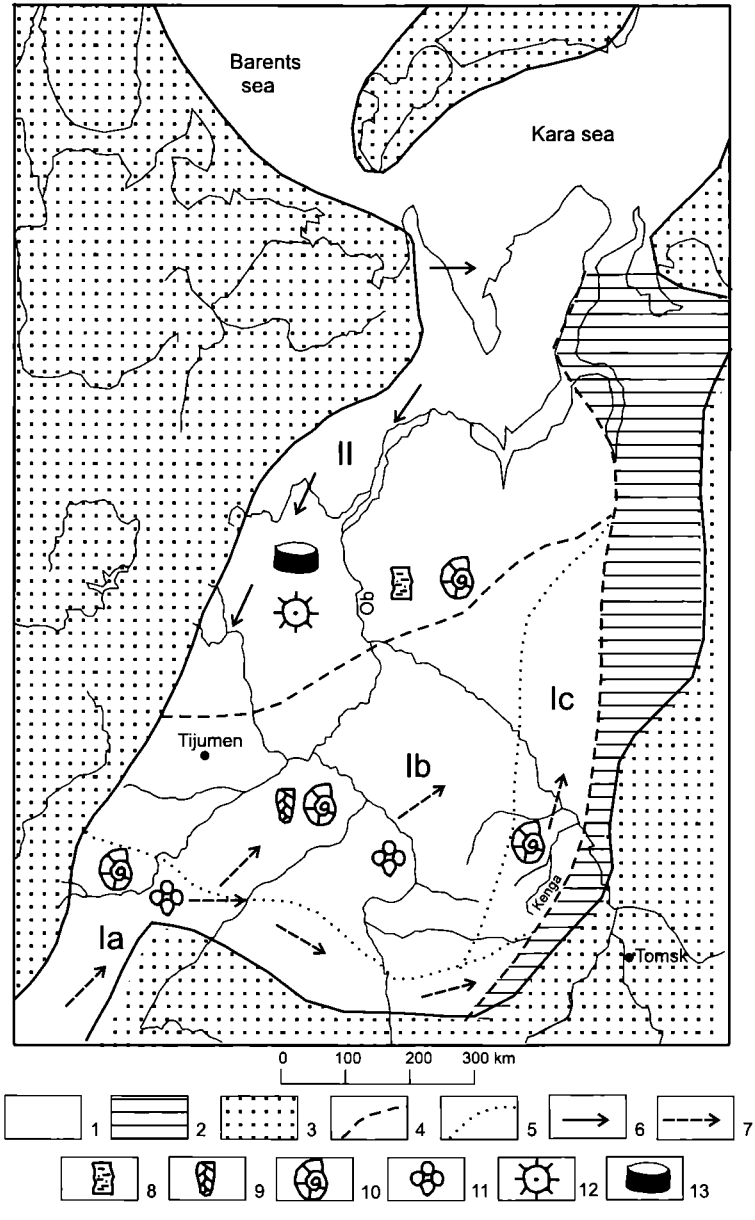

Fig. 10: The Late Maastrichtian West Siberian Sea. 1 – sea, 2 – very shallow sea, 3 – land, 4 – boundary between zones influenced by the southern (I) and northern (II) water masses, 5 – boundaries between subzones (a,b,c) characterized by different foraminiferal associations, 6 – north cold current, 7 – south warm current, 8–11 benthic foraminifers: 8 – "primitive" agglutinated (Astrorhizida, Ammodiscida), 9 – agglutinated (Textulariida and Ataxophragmiida), 10 – calcareous (Rotaliida), 11 – planktonic (Planomalinida and Heterohelicida), 12 – radiolaria, 13 – diatoms.

4. CONCLUSIONS

1. During the Late Cretaceous in West Eurasia there existed Tethyan and "Boreal" water basins characterized by contrasting assemblages of benthic and planktonic foraminifers.
2. The northern margin of the Tethyan Realm (the Peri-Tethys) was referred to the palaeobiogeographic European Province. The west part of the European Province comprises the Dnieper-Caspian-Mangyshlak and Crimea-Caucasus Subprovinces.
3. The "boreal" West Siberia Basin was connected with the marginal seas of the east part of the European Province by the Turgai and Transuralian straits. The first phase of influence of the East European waters on the West Siberian Basin can be established in the Coniacian. This influence increased during the late Campanian to Maastrichtian. The foraminiferal biota of the central, eastern and southern parts of the West Siberian Basin formed under the influence of the marginal East European water masses penetrating into the basin through the straits.
4. The West Siberian Basin was also affected by the northern water masses. The submeridional current along the eastern slope of the Urals existed during the entire Late Cretaceous period (Gol'bert et al., 1968; see Fig.10). Thus, the foraminifers of the "boreal" West Siberian Province developed under the control of both the "boreal" and Tethyan water masses.

Acknowledgements: We are grateful to our reviewers M.B. Hart, M. Wagreich, Ch. Wood and H.A. Kollmann for their remarks on our paper. The work was supported by Russian Federal Program "Integration" and the Russian Foundation for Basic Research, projects nos. 00-05-64917 and 00-05-64738.

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