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Paleogeography of the Southern Baltic Region in the Late Mesozoic: Implications of Foraminifers

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Abstract—Foraminifers from Middle–Upper Jurassic and Upper Cretaceous sediments of the Kaliningrad basin located in the southwestern part of the East European platform are studied. During the greater part of the Late Mesozoic, the study region represented a northern margin of a spacious epicontinental sea in the Boreal zoogeographic realm. The analyzed composition and quantitative distribution of foraminifers, ratio between planktonic and benthic species, ornamentation degree of tests, and their preservation are used to reconstruct paleogeography and history of eustatic sea-level changes. The upper Callovian through Upper Jurassic zonation based on distribution of *Epistomina* species is proposed. Defined foraminiferal assemblages are correlated with coeval assemblages from the East to West European platforms and North Atlantic

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Key words: Middle–Upper Jurassic, Upper Cretaceous, East European platform, Boreal realm, foraminifers.

INTRODUCTION

In order to reconstruct geological history of the Earth and reveal regularities in its development, regional studies that shed light on development of particular segments of the crust and provide factual material for generalization are needed. Upper Mesozoic sediments of the Boreal type occur from the Atlantic coast of North Europe on the west to the Aral Sea on the east. In northeastern Poland, the south Baltic region, and Belarus located in the southwestern margin of the East European platform (EEP), there are most complete sections of Upper Jurassic and Upper Cretaceous marine sediments separated by regional unconformities.

In the second half of the Middle Jurassic, oceanic crust was under formation between Central America and Africa after initiated opening of the North Atlantic. The incipient North Atlantic Ocean was bounded by a land bridge between the Iberian Peninsula and Newfoundland in the north and by the Guinea jut of Africa in the south (Kennett, 1987). The continental slope northeast of Newfoundland and between Greenland and Scandinavia was occupied by a freshened shallow sea basin, which joined via the North Sea the opening North Atlantic and Tethys oceans (Emel'yanov et al., 1989). Since the Middle Jurassic, the European coast of the North Atlantic ocean was bordered by vast epicontinental seas of the West European platform (WEP) and EEP.

Marine environments in West and East Europe existed from the Middle–Late Jurassic to the Volgian Age to give way to continental conditions in the greater part of this territory at the end of the Jurassic.

A new global sea-level rise commenced in the Middle Cretaceous (Albian), when all continents were subjected to transgression, the largest one in the Earth history. Vast territories of northern continents became flooded by epicontinental seas affected by many transgressions and regressions during the entire Late Cretaceous.

The largest and long-existing platform seas were located along the southern periphery of Laurasia. A wide band of interconnected epicontinental basins (the North, Danish–Polish, Central European, East European, North Caspian, and Turan seas) extended subparallel to the Tethys being separated from the latter by islands and deep troughs (Zharkov et al., 1995, 1998).

The Danish–Polish trough is located in the northwest of the EEP. Its northeastern margin is occupied by the Polish-Lithuanian depression, which comprises entire Latvia, western and southwestern Lithuania, and Kaliningrad region. Farther southwestward, it continues, subsiding, into Poland up to the Tornquist–Teiser lineament (*Mesozoic Sedimentation…*, 1985).

Marine sediments in the Polish–Lithuanian depression accumulated from the middle–late Callovian to the Volgian in the Jurassic and from the late Albian to late Maastrichtian in the Cretaceous. During these periods, the southern Baltic region represented a shallow-water margin in the vast Boreal basin of northwestern Europe with alternating marine and continental environments.

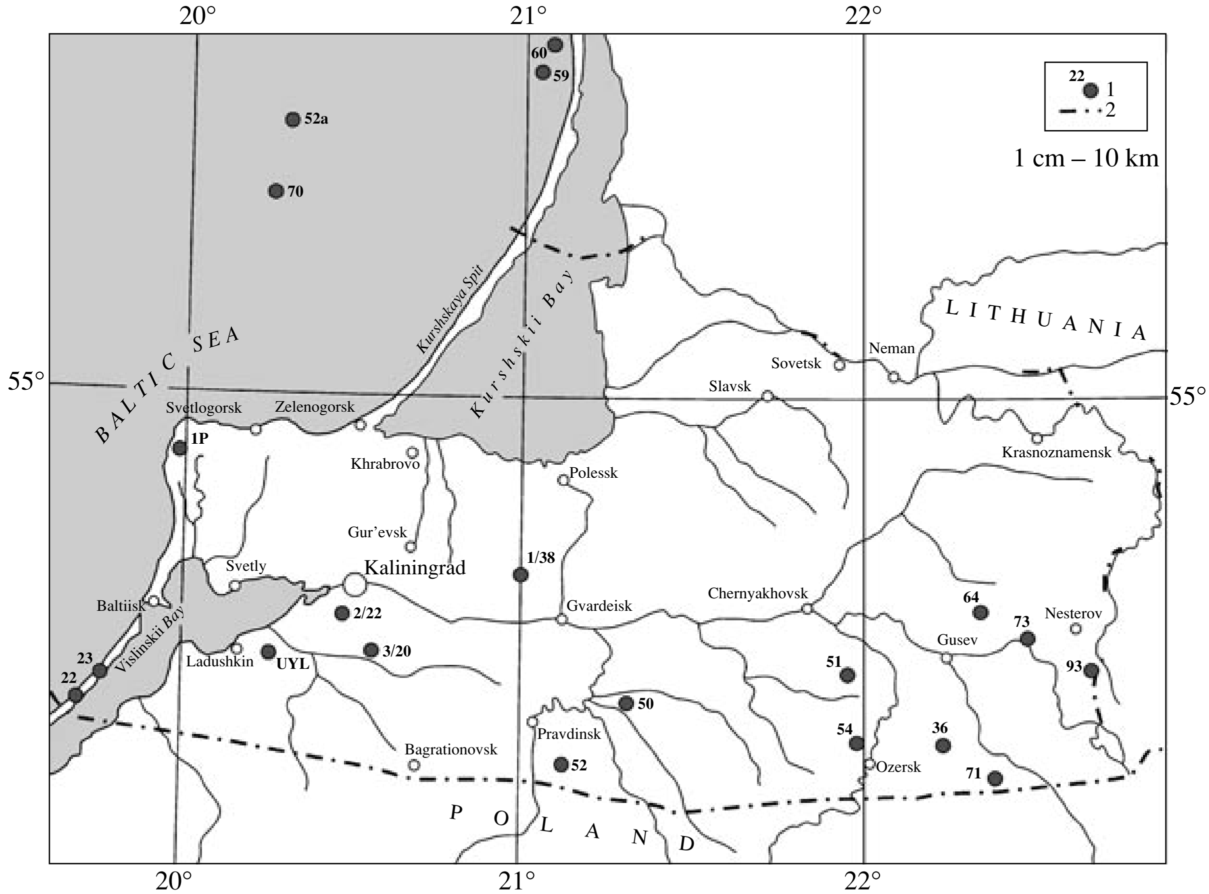


Fig. 1. Location of boreholes examined in the Kaliningrad region: (1) boreholes; (2) state boundary of the Russian Federation.

In the Late Mesozoic, the greater part of the EEP was an element of the Boreal zoogeographic region of the Boreal Atlantic subprovince, which was populated by ammonoids, foraminifers, brachiopods, bivalves, gastropods, echinoids, and other Boreal invertebrate organisms (*Mesozoic Sedimentation…*, 1985; Gordon, 1970).

MATERIAL AND METHODS

Drill cores obtained by the *LUKOIL-Kaliningrad-morneft* Ltd company, Kaliningard Hydrogeological Expedition, and Baltic Marine Engineering–Geological Expedition in the Kaliningrad region and adjacent Baltic Sea represented materials for this study. In total, 145 samples from 19 boreholes were studied (Fig. 1). Foraminifers were found in 126 samples.

Soft sediments were washed through the sieve with the mesh size of >0.1 mm and residue was examined under the microscope. Fraction >0.25 mm was examined in particular cases. By statistical analysis of paleocoenoses, abundance of benthic foraminifers, determination of dominant species, and percentages of planktonic and benthic species were used for paleoecological reconstructions. Lithology of sediments was also taken into consideration.

Quantitative proportions of agglutinated benthic and planktonic foraminifers and genera of secretory benthic foraminifers were used to discriminate different types of communities characteristic of various Late Mesozoic periods in the southern Baltic region. Average values of the foraminiferal diversity and abundance in sediments offer opportunity to trace evolution of paleogeographic settings in the region.

Based on dominant benthic species, regional stratigraphic schemes were compiled for the upper Callovian–Late Jurassic and Albian–Late Cretaceous intervals.

RESULTS

Jurassic System

The Jurassic sediments of variable origin, from continental to marine, are widespread in the western part of the EEP. Marine sediments represented by siliciclastic and siliciclastic–carbonate gray organogenic limestones and clays enriched in black organic matter accu-

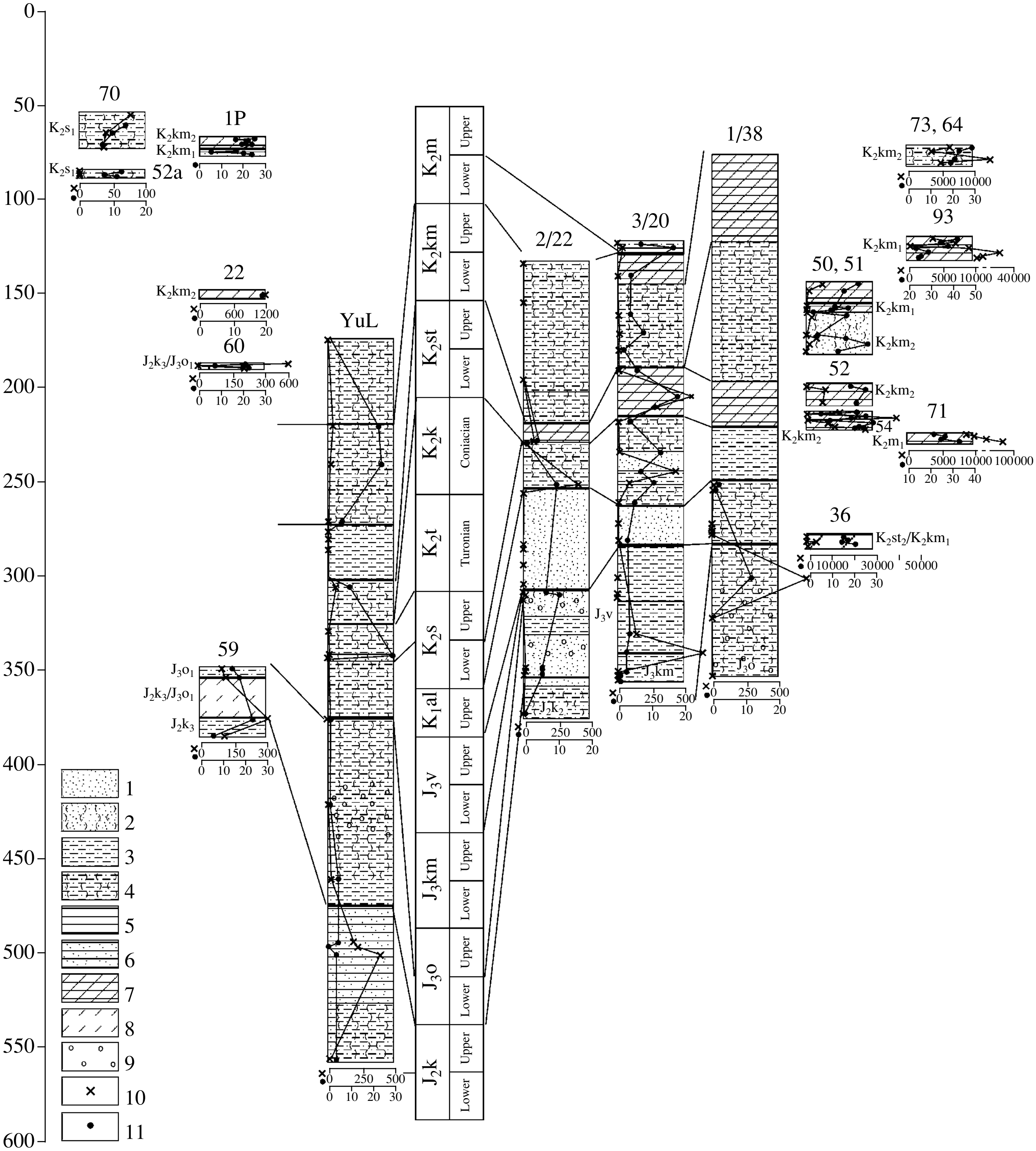


Fig. 2. Correlation of Upper Mesozoic sediments in the Kaliningrad region: (1) sand; (2) sandstone; (3) silt; (4) siltstone; (5) clay; (6) sandy clay; (7) marl; (8) organic detritus; (9) ooliths; (10) abundance of foraminifers, specimens/g of dry sediment; (11) diversity (number of species in sample). (YuL) Yuzno-Ladushkinskaya Borehole.

mulated there since the middle–late Callovian (*Geology of Soviet…*, 1982; Zagorodnykh et al., 2001).

In the Kaliningrad region, upper Callovian sediments are attributed to the Lesnovskaya Formation composed of dark gray to black micaceous–glauconitic clays and siltstones with pyrite and siderite nodules. Thickness of the formation increases from 2 to 54 m in the NE–SW direction. Lithology is described by G.S. Kharin. Correlation of Upper Jurassic and Upper Cretaceous sections in the Kaliningrad region is shown in Fig. 2.

The upper Callovian sediments penetrated by the Yuzhno-Ladushkinskaya Borehole are characterized by four samples from the depth interval of 556.6 to 493.5 m. The samples yielded rare (from 14 to 380 specimens/g of dry sediment) uniform (8 species) well-preserved large benthic foraminifers. The assemblage is dominated by upper Callovian species *Epistomina mosquensis* Uhlig and *E. planiconvexa* Bielecka et Styk. Other typical upper Callovian species are subdominant *Lenticulina polonica* (Wisniowski), *Cytharinella nikitini* (Uhlig), *Ichtiolaria franconica* Guembel, *Ophtalmidium areniforme* Bykova, and *Planularia dilatata* (Wisniowski). Sediments contain also gastropod and ostracod shells. The foraminiferal assemblage is characteristic of the upper Callovian *Lenticulina tumida* Zone (Grigelis, 1985).

The upper Callovian sediments with foraminifers are also established in Borehole 59 at the depth levels of 386 and 384 m. The foraminiferal assemblage from these levels is dominated by *Epistomina planiconvexa* Bielecka et Styk and *E. elshankoensis* Mjatluk and contains also *Lenticulina tumida* Mjatluk, a zonal species of the upper Callovian. Other typical upper Callovian species are *Ceratolamarckina parvula* Grigelis, *Pseudolamarckina rjasanensis* (Uhlig), *Lenticulina praepolonica* Kuznetsova, *L. cultratiformis* Mjatluk, *Trochammina baltica* Grigelis, *Saracenaria cornuspiae* (Schwager), and others. The assemblage includes 21 species occurring in abundance of 116 specimens per gram of sediment. The sample from depth of 372.0 m of Borehole 2/22 yielded the sole specimen of the upper Callovian species *Epistomina elshankoensis* Mjatluk.

The Yuzhno-Ladushkinskaya Borehole penetrated in the depth interval of 460 to 420 m the upper Callovian–lower Oxfordian sediments represented by calcareous siltstones with oolitic sandstone interbeds. The foraminiferal assemblage from these sediments consists of dominant upper Callovian–Oxfordian species *Epistomina uhligi Mjatluk* and subordinate lower Oxfordian *Paalzowella scalariformis* (Paalzow), *Epistomina paralimbata* Grigelis, *Lenticulina sigla* Grigelis, and others (6 species in total, abundance 30 specimens/g). Coeval sediments are also recovered by Borehole 59 in the depth interval of 375 to 353 m (4 samples). In the sample from depth of 375.0 m, dominant forms among foraminifers are *Epistomina elshankoensis* Mjatluk, *E. planiconvexa* Bielecka and Styk, upper Callovian *Globulina venusta* Grigelis, and *Reophax horridus* (Schwager). Most of other species are also characteristic of the upper Callovian: *Lenticulina cultratiformis* Mjatluk, *Cytharinella nikitini* (Uhlig), *Nodosaria mutabilis* Terquem, and *Vaginulina demida* Grivelis. In addition, two zonal species are found: lower Oxfordian *Lenticulina brueckmanni* Mjatluk and upper Callovian *Lenticulina tumida* Mjatluk. Abundant agglutinated foraminifers are represented by *Recurvoides* sp., *Textularia* sp., *Trochammina* sp., *Reophax* sp., *Cyclammina* sp., *Haplophragmoides* sp., *Ammobaculites irregularis* (Guembel), and *Paleogaudryina terra* (Bykova et Azbel). The assemblage includes 26 species in total; abundance is as high as 317 specimens/g.

The upper Callovian–lower Oxfordian sediments are also recovered by Borehole 60 from the depth interval of 189 to 178 m (3 samples). The foraminiferal assemblage includes dominant *Epistomina elshankoensis* Mjatluk, *Lenticulina brueckmanni* Mjatluk, *Pseudolamarckina suvalkensis* Grigelis, and subdominant *Lenticulina praepolonica* Kuznetsova, *Lenticulina subtilis* (Wisniowski), *Ichtiolaria inopinata* Grigelis, *Cytharinella nikitini* (Uhlig), *Miliospirella lithuanica* Grigelis, *Globulina venusta* Grigelis, *Nodosaria mutabilis* Terquem, and *Vaginulina demida* Grivelis. The assemblage diversity varies through the section from 9 to 18 species; their abundance, from 13 to 622 specimens/g.

The lower Oxordian Subststage is represented in the Kaliningrad region by the <u>Veselovskaya Formation</u> composed of micaceous siltstones, sandstones, and limestones saturated with ferruginate ooliths. The formation is penetrated by Borehole 2/22 in the depth interval of 351 to 305.7 m (3 samples). The assemblage of low diversity (5 species) and abundance (up to 19 specimens/g) is dominated by *Epistomina paralimbata* Grigelis accompanied by subordinate *E. rjasanensis* (Umanskaja et Kuznetsova), *E. uhligi* Mjatluk, *Paulina fursenkoi* Grigelis, and *Lenticulina hebetata* (Schwager).

In Borehole 2/22, oolitic sands in the depth interval of 309.0–307.8 m contain a peculiar uniform (7–12 species) assemblage of very small rare (2–14 specimens/g) foraminifers with prevalence of *Lenticulina* forms. The assemblage is dominated by *L.* aff. *brestica* (Mitjanina). *L. nostra* Grigellis, *L. sigla* Grigelis, *L. hebetata* (Schwager), *Planularia protracta* (Bornemann), and other *Lenticulina* species are subordinate. Similar assemblages are characteristic of limy (reefal) facies of West Europe (Grigelis, 1985). In opinion of Grigelis, the *Lenticulina* fauna is correlative with the middle Oxfordian *Ophtalmidium strumosum–Lenticulina brestica* Zone, but, judging from lithology of sediments and a high content of ooliths, they accumulated in the early Oxfordian.

The micaceous clayey–silty–carbonate sediments accumulated in the middle–late Oxfordian in the southern part of the region are attributed to the <u>Lermontovskaya Formation</u> 85 m thick.

The middle Oxfordian Substage is represented by micaceous siltstone penetrated by Borehole 1/38 at depth of 300 m. The rock yields foraminiferal assemblage with the middle Oxfordian species *Epistomina perfidosa* Grigelis (dominant), *E. nemunensis* Grigelis, *E. multialveolata* Grigelis, *Pseudolamarckina suvalkensis* Grigelis, *Astacolus dubius* Paazlow, *Trocholina teifeli* Paalzow, and *T. belorussica* Mjatluk. Some species are characteristic of the lower Oxfordian: *Epistomina rjasanensis* (Umanskaja et Kuznetsova), *Paulina fursenkoi* Grigelis, *Ceratolamarckina speciosa* (Dain et

Mjatluk), *Paalzowella scalariformis* (Paalzow). Foraminiferal tests are dwarfish and poorly preserved. Low diversity of foraminifers (13 species) is compensated by their high abundance (up to 2304 specimens/g).

The depth interval of 355.0 to 350.3 m in Borehole 3/20 is composed of micaceous siltstones attributed to the Kolosovskaya Formation of the Kimmeridgian. The impoverished foraminiferal assemblage (1–3 species and 1–6 specimens/g) from these sediments consists mainly of dwarfish *Epistomina praetatariensis* (Umanskaja). The assemblage includes also planktonic species *Globuligerina stellapolaris* Grigelis and fragments of *Lenticulina* ssp. This assemblage is untypical of the lower Kimmeridgian *Lenticulina prussica* and *Lenticulina kuznetsovae* zones, where it is diverse (42 species) and represented by lenticulinids and vaginulinids.

The lower Volgian Strel'nenskaya Formation is composed of calcareous–siliciclastic sediments. They are known in southwestern Lithuania and western part of the Kaliningrad region being represented by limestones and gray to dark gray, sometimes, micaceous siltstones with rare interbeds of dark gray fine-grained sandstone. Foraminifers are studied in two samples from depth levels of 330 and 340 m in Borehole 3/20. The assemblage of 3 to 6 abundant species (178 to 708 specimens/g) includes dominant *Epistomina interfusa* Grigelis, a typical lower Volgian species, and subdominant *E. oriunda* Grigelis, *Astacolus opinatus* Grigelis, *Lenticulina sublenticularis* Grigelis, and *Marginulinopsis* sp.

Cretaceous System

The Cretaceous System is represented by Lower Cretaceous siliciclastic–siliceous–carbonate sequences. They rest transgressively on Upper Jurassic strata. In the largest part of the Kaliningrad region, Lower Cretaceous rocks are overlain by Quaternary sediments except for southern and western areas, where they are covered unconformably by Paleogene layers. In these areas, Cretaceous deposits are most thick (320 m); they occur at depths ranging from 10 to 277 m and wedge out completely seaward (*Geology of Soviet…,* 1982; Zagorodnykh et al., 2001).

The oldest Cretaceous (Albian) sediments of the Kaliningrad region belong to the Osinovskaya Formation composed of micaceous–glauconitic siltstones and loosely cemented siltstones and sands. Based on lithological features, the formation is recognized in depth intervals of 300 to 260 m, 280 to 250 m, and 320 to 260 m in boreholes 2/22, 1/38, and 3/20, respectively. In Borehole 2/22, foraminifers are missing; in two others, single *Anomalina belorussica* Akimez together with rare *Lenticulina* and *Nodosaria* forms are found at depth levels of 250.5 and 280 m.

In the region under consideration, Cenomanian sediments divisible based on foraminifers in two substages occur almost everywhere.

The lower substage corresponds to the Chkalovskaya Formation composed of glauconitic–quartzose–micaceous siltstones and sandstones. These sediments are penetrated by Borehole 2/22 at depth of 250.2 m. The corresponding foraminiferal assemblage consists of 10 abundant species (417 specimens/g). The assemblage is mostly composed of *Lenticulina secans* Reuss accompanied by various nodosariids of genera *Dentalina*, Astacolus, and *Marginulina* (*M. jonesi Reuss included)* and by agglutinated *Gaudryinella frankei* Brady, *Ataxophragmium compactum* Brady, and *Hagenowella chapmani* Cushman. The secretory species *Anomalina senomanica* (Brady), a zonal taxon of the lower Cenomanian, is also present.

The lower Cenomanian sediments are also recognized in the depth interval of 260 to 233.5 m in Borehole 3/20, where they are characterized by four samples with ecinoderms, fragments of bivalve shells, ostracodes, pellets, wood and plant remains, roots included. The foraminiferal assemblage is dominated by typical (zonal) Cenomanian species *Lenticulina secans* Reuss, *Anomalina senomanica* Brady, and *Gavelinella baltica* (Brady) accompanied by various nodosariids of genera *Dentalina, Nodosaria, Lenticulina, Marginulina*, and *Saracenaria*, and by planktonic species *Hedbergella* ex gr. *infracretacea* (Glaessner). The diversity ranges from 5 to 13 species occurring in abundance from 2 to 430 specimens/g. Coeval sediments are also recovered by boreholes 52a and 70 from depth intervals of 88–83.5 m and 70–54 m, respectively. In each case, Cenomanian sediments are characterized by 3 samples.

The upper Cenomanian sediments occur mainly in the central and southern parts of the region, where they constitute the Pobedinskaya Formation of dark gray glauconitic–quartzose siltstones with carbonate admixture. They are recovered by the Yuzhno-Ladushkinskaya Borehole from the depth of 341 m. The diverse (29 species), although not abundant (22 specimens/g) foraminifers belong to planktonic species *Hedbergella planispira* (Tappan), *H. infracretacea* (Glaessner), *Globigerina caspia* Vasilenko, *G.* sp., *Ticinella gaultina* Morozova, *Praeglobotruncana stephani* (Gandolf), and *Rotalipora cushmani* (Morozova). Associated benthic foraminifers are represented by *Eouvigerina formis* Keller, *Textularia indistincta* Akimez, *Gavelinella schloenbachi* (Reuss), *Lingulogavelinella spinosa* (Plotn.), *Globorotalites* spp., *Valvulina* spp., *Bulimina* spp., and other Middle Cretaceous forms. Sediments of the Turonian and Coniacian stages are not established in the examined boreholes.

The Santonian Stage corresponds to sediments of the Demidovskaya Formation, which are mostly characteristic of western areas in the region. Sediments of the upper substage (upper part of the Demidovskaya Formation) are defined in the Yuzhno-Laduskinskaya Borehole at the depth of 305 m, in Borehole 2/22 at the levels of 228.6 and 227 m, and in Borehole 3/20 at depth levels of 217.3 to 203.8 m.

The first two boreholes yielded impoverished assemblages (2–8 species, 2–87 specimens/g) of planktonic (*Globotruncana verrucosa* (Vasilenko) and *Guembelina striata* Ehrenberg) and benthic (*Cibicides eriksdalensis* Brotzen, *Planomalina roweri* Barr, and others) foraminifers. In Borehole 3/20, they are more diverse and abundant (6–18 species, 6–578 specimens/g). This assemblage is lacking planktonic species. Dominant among benthic forms are *Eponides whitei* Brotzen, *Gyroidina obliquaseptatus* Mjatluk, *Robulus leptus* Reuss, which occur together with subordinate *Globorotalites mishelianus* (d'Orbigny), *Plectina convergens* (Keller), *Lenticulina* spp., *Astacolus* spp., *Frondicularia* spp. and others. The zonal species *Gavelinella stelligera* has not been found.

Four samples taken from the depth interval of 282 to 279 m characterize upper Santonian–lower Campanian layers in Borehole 36. The foraminiferal assemblage from this interval includes many planktonic species, which are poorly preserved being either fragmented or enveloped by marl. Dominant among them are *Globigerinella aspera* (Ehrenberg), *Rotundina ordinata* Subbotina, *Globotruncana linneana* (d'Orbigny), and *Gumbellina striata* Ehrenberg. The benthic assemblage consists of dominant *Anomalina lorneiana* d'Orbigny and subordinate *Eponides concinnus* Brady, *E. monterelensis* Marie, *E. biconvexus* Marie, *Valvulineria lenticula* Reuss, *Gyroidina obliquaseptatus* (Mjatluk), *Globorotalites miltisepta* (Brady), and others.

The lower Campanian Substage corresponding to the <u>Loznyakovskaya Formation</u> is composed of silty quartzose–glauconitic sediments with pellets. It is recognized based on four examined samples from the depth interval of 75 to 73.5 m in Borehole 1P.

Dominant benthic species *Bulimina ventricosa* Brotzen, *Globorotalites mishelianus* (d'Orbigny), and *Cibicides temirensis* Vasilenko occur in these sediments together with *Gyroidina obliquaseptatus* (Mjatluk), *Anomalina umbilicatula* Mjatluk), and others. The zonal species *Brorzenella insignis* has not been found in lower Campanian sediments so far. The assemblage diversity varies from 5 to 20 species.

The upper Campanian Substage is represented by the <u>Kalinovskaya Formation</u> composed of siltstones and glauconitic–quartzose and micaceous marls, frequently containing sponge spicules, fish teeth, fragments and detritus of ostracodes, brachiopods, bivalves, and abundant foraminifers.

The upper Campanian sediments are recovered at eight sites by boreholes Yuzno-Ladushkinskaya (depth interval of 270 to 220 m, three samples), 3/20 (depth interval of 190 to 160 m, four samples), 1/38 (depth interval of 180 to 120 m, six samples), 1P (depth interval of 70 to 67 m, six samples), 22 (depth level of 150 m), 50 (depth interval of 180 to 148 m, 11 samples), 51 (depth interval of 156.8 to 150.5 m, five samples), 52 (depth interval of 207 to 198 m, three samples), and 54 (depth interval of 221 to 212 m, (nine samples).

Dominant among foraminifers are *Eponides concinna* Brotzen, *E. grodnoensis* Akimez, *E. monterelensis* Marie, *Globorotalites mishelianus* (d'Orbigny), *Anomalina umbilicatula* Mjatluk, *Buliminella ventricosa* Brady, which are accompanied by the upper Campanian zonal species *Gavelinella monterelensis* Marie. The associated other forms characteristic of the Campanian–lower Maastrichtian sediments are *Bolivina incrassata* Reuss, *Gyroidinoides nitida* Reuss, *Valvulineria camerata* Brotzen, *Valvulineria camerata* Brotzen, *V. lenticula* Reuss, *Eponides grodnoensis* Akimez, *E. whitei* Brotzen, *E.* spp., *Cibicides pingius* Jennings, *C. actualagayensis* Vasilenko, *C. eriksdalensis* Brotzen, *C.* spp., *Bolivina plaita* Carsey, *B.* spp., *Bulimina ventricosa* Brady, *B.* sp., *Dentalina* spp., *Gyroidina* spp., *Pullenia* spp., *Parella*, spp., *Nodosaria* spp., and others. The upper Campanian assemblage consists of 31 species as abundant as 47000 specimens/g.

At many depth levels, planktonic species *Globigerinella aspera* (Ehrenberg) is dominant. Locally, other Upper Cretaceous planktonic foraminifers occur. The late Campanian age is inferred based on the found zonal species *Eponides monterelensis* Marie and on associated *E. moskvini* (Keller) and *E. grodnoensis* Akimez, which do not occur in the lower Campanian sediments. Upper Campanian foraminifers are diverse (31 species) and abundant (47000 specimens/g).

The Maastrichtian sediments are characteristic of southern and eastern parts of the region, where they contain very rich and diverse, although usually poorly preserved foraminifers.

The lower Maastrichtian sediment corresponding to the <u>Vorontsovskaya Formation</u> are composed of micaceous marl with greenish tint because of glauconite admixture. They are established in the depth interval of 130 to 120 cm in Borehole 93 (seven samples), where relevant sediments contain corals, bryozoan, echinoid, gastropod, and bivalve remains. The diverse (26–43) and abundant (1935 to 37734 specimens/g) foraminiferal assemblages are dominated by planktonic species *Guembelina striata* Ehrenberg and *Globigerinella aspera* (Ehrenberg) ranging throughout the Upper Cretaceous. Characteristic of the Maastrichtian are benthic species *Bolivina incrassata* Reuss, *B. decurrens* (Ehrenberg), *Pseudouvigerina plummerae* Cushman, *Anomalina complanata* Reus, *Stensioina stellaria* Vasilenko, *Cibicides bemix* Neckaja, *C. pinguis* (Jennings), and others. Many species are typical of the lower Maastrichtian and upper Campanian: *Bulimina ventricosa* Brotzen, *Bolivinoides peterssoni* Brotzen, *Eponides moskvini* (Keller), *Anomalina clementiana* (d'Orbigny), *Cibicides voltcianus* (d'Orbigny), *Globorotalites mishelianus* (d'Orbigny), *G. emdyensis* Vasilenko, and others. The assemblage contains also diverse species of the *Reussella, Bolivinoides, Eponides, Parella, Anomalina, Stensioina, Valvulineria, Cibicides, Globorotalites, Pullenia, Nonionella, Discorbis, Nodosaria*, and other genera. Fraction >0.25 mm contains various agglutinated and secretory forms: *Ataxophragmium compactum* Brady, *Neoflabellina reticulata* (Reuss), *Frondicularia inversa* Reuss, *Flabellina elliptica* (Nilsen), *Flabelammina compressa* Bessel, *Orbignyna ovata* Hagenow, *Plectina convergens* (Keller), and others.

The lower Maastrichtian sediments are also recovered by Borehole 71 from the depth interval of 229 to 223 m (four samples), Borehole 50 from the depth of 144 m, and by Borehole 51 from the depth interval of 156.8 to 147.8 m (eight samples).

Foraminiferal assemblages from boreholes 71 and 50 are dominated by planktonic species *Guembelina straita* Ehrenberg and *Globigerinella aspera* (Ehrenberg). Species characteristic of the lower Maastrichtian are *Anomalina monterelensis* (Marie), *Eponides grodnoensis* Akimez, *E. moskvini* (Keller), *Bulimina ventricosa* Brotzen, *Bolivinoides peterssoni* Brotzen, *Bolivina decoratus* (Jones), and others unknown from the upper Maastrichtian. The diversity of foraminifers varies from 23 to 34 species and their abundance ranges from 5662 to 61090 specimens/g.

The lower Maastrichtian sediments penetrated by Borehole 51 yielded abundant benthic foraminifers. Prevalent agglutinated species are *Arenobulimina d'orbignyi* Reuss, *Haplophragmoides* sp., *Spiroplectammina suturalis* (Kalinin), *Plectina convergens* (Keller), and other species characteristic of the Upper Cretaceous. In the depth interval of 151.5 to 150.5 m, diversity and abundance of foraminifers increases to 27–29 species and 2560–23167 specimens/g, respectively. Among them there are rare, although relatively diverse Upper Cretaceous planktonic species. *Cibicides eriksdalensis* Brotzen, *C. voltcianus* d'Orbigny, *Globorotalites emdyensis* Vasilenko, *G. mishelianus* d'Orbigny, and others prevail among benthic species, which occur in both the upper Campanian and lower Maastrichtian sediments. In the depth interval of 156.8 to 152.5, the foraminiferal abundance and diversity are reduced to 6–3036 specimens/g and 13–20 species, respectively. Dominant forms are *Globorotalites mishelianus* d'Orbigny and *Eponides grodnoensis* Akimez.

Borehole 3/20 recovered undivided Maastrichtian sediments from the depth levels of 124.8 and 123 m, where agglutinated foraminifers are dominant in micaceous siltstones. The precise age determination is impossible, because relevant sediments are lacking index species. The assemblage diversity and abundance range from 7 to 17 species and 6–23 specimens/g, respectively. The upper Maastrichtian sediments of the Spasskaya Formation are represented by quartzose–glauconitic and, frequently, micaceous silts and siltstones. They are recognized in three sections.

In boreholes of 64 and 73 at the depth of 79 and 80 to 72 m, respectively, four upper Maastrichtian horizons contain rare echinoid needles and rare ostracodes occurring together with diverse (20–33 species) and abundant (268–10267 specimens/g) foraminifers. At depth of 72 m in Borehole 73, foraminifers are poorly preserved. Benthic foraminifers are dominated by the upper Maastrichtian *Eponides moskvini* (Keller) and Lower Paleocene *Bulimina quadrata* (Plummer). The other Lower Paleocene species are *Anomalina affinis* (Hantken), *Cibicides incognitus* Vasilenko, *Globulina amigdaloides* Reuss, and planktonic form *Globigerinella micra* (Cole). At the same time, there are many Upper Cretaceous (Maastrichtian) species: *Bolivina decurrens* (Ehrenberg), *B. incrassata* Reuss, *Reussella minuta* (Marsson), large agglutinated *Ataxophragmium compactum* Brady, *A. crassum* (d'Orbigny), *Beisselina aequisgranensis* Beisel)., *Plectina convergens* (Keller), *P. ruthenica* Marie, *Neoflabellina reticulata* (Reuss), and others. Benthic foraminifers are represented by *Nonion* cf. *ovatum* Cushman and by representatives of genera *Eponides, Gyroidina, Bulimina, Bolivina, Valvulineria, Cibicides, Anomalinoides*, and others. In addition to benthic forms, the assemblage includes also Upper Cretaceous planktonic *Globigerinellla aspera* (Ehrenberg) and *Rotundina ordinaria* Subbotina.

Circle diagrams (Fig. 3) illustrate proportions of various taxa in defined foraminiferal assemblages. Dominant groups of foraminifers can be used to discriminate different communities, which were characteristic of the Late Mesozoic in the southern Baltic region. Lagenid communities including other groups of subdominant foraminifers were widespread in the Late Jurassic–middle Late Cretaceous (early Cenomanian). Lagenids were characteristic of the late Callovian, and lagenids associated with agglutinated species or rotaliids existed respectively in the early and late Oxfordian. The Kimmeridgian community consisted of lagenids and rotaliids occurring in equal proportions and associated with a single planktonic form. Like the late Oxfordian, the Volgian community was represented by the lagenids and rotaliids. The late Albian community was similar to the early Oxfordian one. The Aptian–Albian period corresponded to drastic changes in paleooceanography, which affected development of biota, planktonic foraminifers included. Since the early Cenomanian, foraminiferal communities became more diverse, because new secretory benthic orders appeared in their composition. In the early Cenomanian and Santonian, lagenids represented up to 50% of the foraminiferal community, the other half of which consisted of rotaliids, buliminids, agglutinated and planktonic species. The late Cenom-

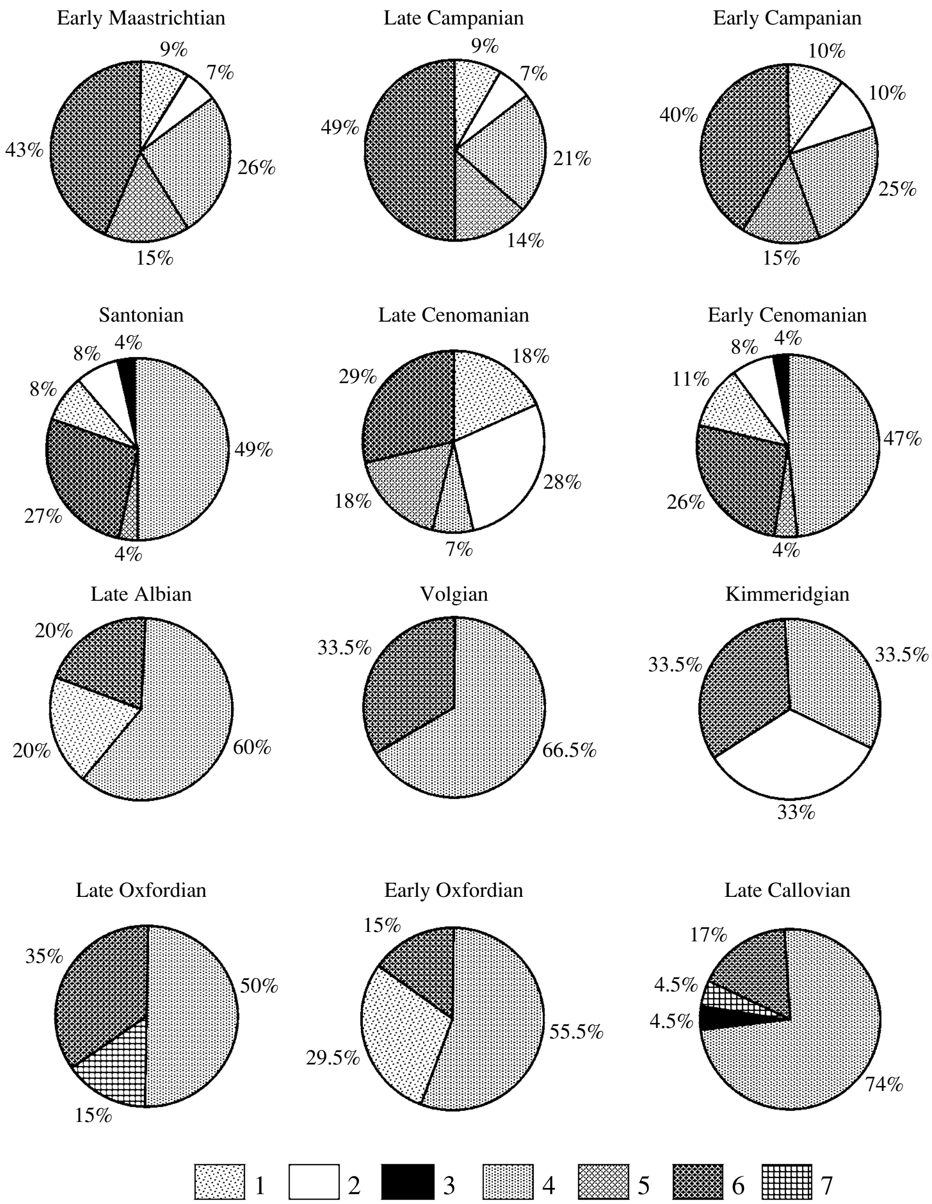
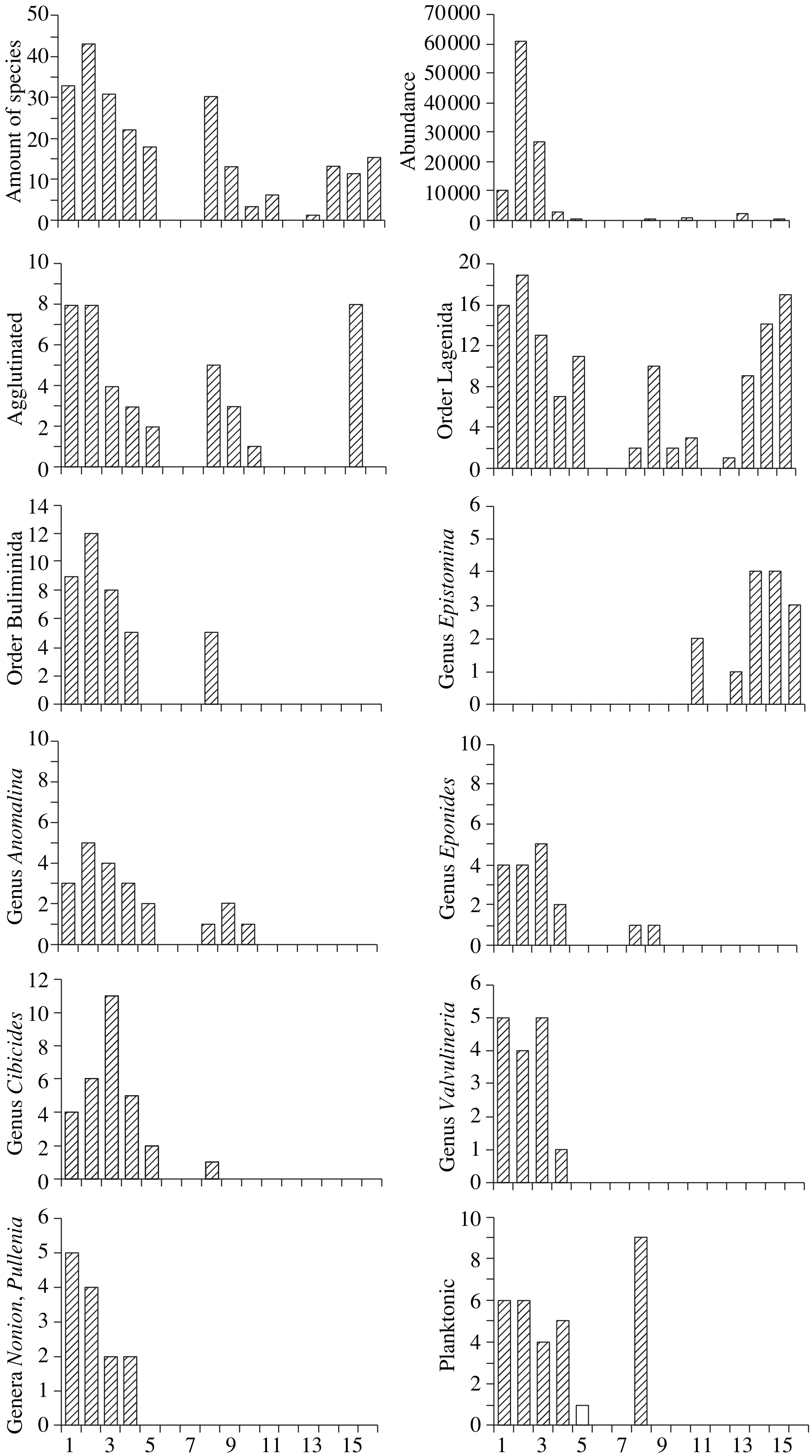


Fig. 3. Circle diagrams illustrating percentages of foraminiferal taxa in Late Jurassic to Late Cretaceous assemblages: (1) agglutinated species; (2) planktonic species; (3) order Miliolida; (4) order Lagenida; (5) order Buliminida; (6) order Rotaliida; (7) order Heterohelicida.

anian community remarkable among the others was of the rotaliid–planktonic type. In the Late Cretaceous, lagenids lost their dominant position. The rather uniform foraminiferal communities of the late Campanian–late Maastrichtian can be attributed to the rotaliid–buliminid type.

Histograms in Fig. 4 illustrate secular changes in occurrence frequency of benthic foraminifers, their abundance (specimens/g), and in species diversity of main foraminiferal groups distinguished in Upper Mesozoic sediments of the southern Baltic region.

Fig. 4. Occurrence frequency (specimens/g) of Late Jurassic and Late Cretaceous foraminiferal species in total and in particular taxonomic groups (vertical axis); numbers under horizontal axis denote the following chronostratigraphic divisions: (1) late Maastrichtian, (2) early Maastrichtian, (3) late Campanian, (4) early Campanian, (5) Santonian; (6) Coniacian, (7) Turonian, (8) late Cenomanian, (9) early Cenomanian, (10) late Albian, (11) Volgian, (12) late Kimmeridgian, (13) early Kimmeridgian, (14) late Oxfordian, (15) early Oxfordian, (16) late Callovian.


Amount of species
Abundance
Agglutinated
Order Lagenida
Order Buliminida
Genus *Epistomina*
Genus *Anomalina*
Genus *Eponides*
Genus *Cibicides*
Genus *Valvulineria*
Genera *Nonion*, *Pullenia*
Planktonic

CORRELATION

The irreversible evolutionary trend of foraminifers enables dating of particular sedimentary layers, and the defined zones can be correlated with foraminiferal zonations established in adjacent regions.

The study of species composition in the Middle–Upper Jurassic and Upper Cretaceous assemblages and interregional correlation show that development of foraminiferal communities was surprisingly similar in the Boreal paleozoogeographic regions, i.e., in west-northwestern (Lithuania, Belarus, Ukraine, Poland) and southwestern (Mangyshlak, Aral region) parts of the East European platform and in West European areas (Germany, Denmark, Holland, Sweden, northwestern France).

Jurassic System

In southeastern periphery of the East European platform, the Middle–Upper Jurassic sediments are studied along the Teisser–Tornquist lineament in northeastern Poland, in the eastern Baltic Sea and on land in Latvia, Lithuania, and Kaliningrad oblast (*Mesozoic Sedimentation…*, 1985).

Jurassic foraminifers of the southern Baltic region are studied in detail by Grigelis (1985) who proposed the Upper Jurassic regional stratigraphic scale and defined zones with characteristic foraminiferal species. Because of local peculiarities of foraminiferal assemblages from different areas, the regional stratigraphic schemes should be consistent with local foraminiferal zonations. As the assemblages studied are frequently dominated by species different from index taxa of former zonal units a parallel Upper Jurassic zonation is substantiated in this work for the Kaliningrad oblast. In contrast to zonation by Grigelis established on succession of lenticulinids, the new one is based on different species of the dominant genus *Epistomina* (Table 1).

In the Kaliningrad region, the **upper Callovian** sediments of the Lesnovskaya Formation are established in four sections located south of Kaliningrad and in adjacent part of the Baltic Sea. The upper Callovian foraminiferal assemblage is dominated by three *Epistomina* species: *E. planiconvexa, E. elshankoensis*, and *E. mosquensis.* The Lesnovskaya Formation is correlative with an upper part of the Papartine Formation and Skinija Formation of southwestern Lithuania, which are attributed by Grigelis to the *Lenticulina paracultrata* Zone. In the Baltic Sea (Grigelis, 1986) and western Belarus (Mityanina, 1957), the upper Callovian sediments correspond to the *Lenticulina tumida* Zone.

Epistomina mosquensis is known from the middle–upper Callovian sediments of the East European platform (Khabarova, 1959; Grigelis, 1985) being characteristic also of the Callovian in the Atlantic shelf of Canada (Ascoli and Grigelis, 1993). *E. planiconvexa* is confined to upper Callovian sediments of Germany (Lutze, 1960) and Poland (Bielecka and Pozaryski, 1954).

The **lower Oxfordian** sediments of the Veselovskaya Formation occur above the upper Callovian layers in the same sections. They correspond to the lower part of the Azoulija Formation in southwestern Lithuania, where it is attributed by Grigelis to the *Ophtalmidium saggitulum–Lenticulina brueckmanni* Zone. In the Kaliningrad region, these specimens are established based on dominant *Epistomina paralimbata* and *E. uhligi.* These species were previously found in the lower–middle Oxfordian of the southwestern Baltic region (Grigelis, 1985) and in the Dniester–Donets depression (Kaptarenko-Chernousova, 1959).

The **middle–upper Oxfordian** sediments that constitute the Lermontovskaya Formation of the Kaliningrad region are correlative with upper two thirds of the Azoulija Formation that is defined as the *Ophtalmidium strumosum–Lenticulina brestica* and *Leniculina quenstedti* zones. Based on dominant *Epistomina perfidosa*, only the lower part of the Lermontovskaya Formation is recognized in one section eastward of Kaliningrad. *E. perfidosa* has been found previously in the southwestern part of the Baltic region (Grigelis, 1985). The lower–middle Oxfordian sediments are attributed to the *Lenticulina brestica* Zone in western Belarus and to the *Lenticulina brueckmanni* and *Lenticulina brestica* zones offshore in the Baltic Sea.

The **lower Kimmeridgian** sediments of the Kolosovskaya Formation are correlative with the lower part of the Tarava Formation defined in Lithuania as corresponding in range to the *Lenticulina prussica–Lenticulina kuznetsovae* Zone. In a section located southeastward of Kaliningrad, concurrent sediments are established based on dominant *Epistomina praetatarensis.* The last species is typical of the lower Kimmeridgian in the southwestern Baltic region (Grigelis, 1985), Russian platform (Kuznetsova, 1979), and Poland (Bielecka and Pozaryski, 1954). Toward the Baltic Sea and western Belarus, the lower Kimmerdgian strata pinch out.

The upper Kimmerdgian sediments have not been established in examined boreholes.

The **lower Volgian Substage** corresponding to the Strel'nikovskaya Formation is correlative with the Girdava Formation in Lithuania, where it spans the range of the *Marginulina striatocostata* Zone. In the study region, coeval sediments containing dominant *Epistomina interfusa* occur above the lower Kimmeridgian sediments in the same section. In the Baltic Sea and western Belarus, the lower Volgian deposits are unknown.

Table 1. Regional Upper Jurassic stratigraphy, the southwestern part of the East European platform

Group	System	Series	Stage	Northeastern Poland (*Resolutions…*, 1978)	Baltic Sea (Grigelis, 1986)	Southwestern Baltic region, foraminiferal zonation (Grigelis, 1985)		Kaliningrad region: Formations (Zagorodnykh et al., 2001)	Kaliningrad region: Foraminiferal zonation (this work)	Western Belarus (Mityanina, 1976)
Mesozoic	Jurassic	Upper	Volgian	*Z. ccythicus*		Girdava Formation	*Marginulina striatocostata*	Strel'nikovskaya	*Epistomina interfusa*	
			Kimmeridgian	*A. pseudomutabilis*		Tarava Formation	*Lenticulina illustris* *L. daiva*	Tishinskaya		
				A. lothari			*Lenticulina prussica* *L. kuznetsovae*	Kolosnikovskaya	*Epistomina praetatariensis*	
			Oxfordian	*R. stephanoides* *A. alternans*	*Epistomina uhligi*		*Lenticulina quenstedti*	Lermontovskaya		
				C. tenuistriatum	*Lenticulina brestica*	Azuolija Formation	*Ophnalmidium strumosum* *Lenticulina brestica*		*Epistomina perfidiosa*	*L. brestica*
					Lenticulina brueckmanni		*Ophnalmidium sagittulum* *Lenticulina brueckmanni*	Veselovskaya	*Epistomina paralimbata*	
		Middle	Callovian	Mixed fauna	*Lenticulia tumida*	Skinija Formation	*Lenticulia tumida*	Lesnovskaya	*Epistomina planiconvexa* *Epistomina mosquensis*	*L. tumida*
						Papartine Formation	*L. paracultrata*			
				K. jason			*Lenticulina cultratiformis*	Priozerskaya		

Note: Hatched intervals designate breaks in sedimentation.

Cretaceous System

Stratigraphic subdivision of Upper Cretaceous sediments is substantiated in works by Grigelis (1963) and Akimets (1961) who proposed detailed foraminiferal zonations for the southern Baltic region and Belarus, respectively. The correlation scheme for Upper Cretaceous sediments of the west-northwestern East European and Russian platforms is in this work (Table 2).

The **upper Albian** deposits are rare in the northwestern margin of the East European platform. The Osinovskaya Formation of the Kaliningrad region corresponds to the Esyaskaya Formation of western Lithuania, which contains shark teeth (*Resolution of the Interdepartmental…*, 1976).

The **lower Cenomanian** Chkalovskaya Formation is established in four sections located in the southwestern part of the Kaliningrad region and adjacent Baltic Sea. It is correlative with the *Gavelinella senomanica* Zone. All the sections contain agglutinated benthic form *Hagenowella chapmani* Cushman, in addition to the zonal index species.

Sediments of the lower Cenomanian *Gavelinella senomanica* Zone are widespread in both platforms. Foraminiferal assemblages of this zone are known in Poland (Gawor-Biedowa, 1972; Peryt, 2004), Lithuania (Grigelis, 1963), Belarus (Akimets, 1961), and in other areas of the East European platform (Grigelis et al., 1980; Naidin et al., 1984). Its most characteristic species *Anomalina senomanica* (Brady), *Gavelinella baltica* (Brady), and *Hagenowella chapmani* Cushman have been found in coeval layers of the West European sedimentary basin (Magniez-Jannin,1995) and southeast England (Carter and Hart, 1977).

In addition, typical lower Cenomanian species are discovered at the paleodepth of 1200 m in the North Atlantic near Spain (Vasilenko, 1980; Basov and Vasilenko, 1986) and on the Newfoundland shelf (Hart, 1976).

The **upper Cenomanian** Pobedinskaya Formation is established in the southwestern part of the Kaliningrad region. Characteristic of this formation is appearance of diverse and relatively abundant planktonic foraminifers, bicarinate forms of genera *Rotundina* and *Globotruncana* included. Abundant planktonic foraminifers are typical of the *Linguligavelinella globosa* Zone (Akimets, 1974). The upper Cenomanian foraminiferal assemblage in the peripheral part of the EEP (Poland) contains from 10 to 30% of planktonic species (Peryt, 2004). In the North Atlantic, species of these and other planktonic genera occur in undivided Cenomanian sediments (Leckie, 1989). The zonal species *Linguligavelinella globosa* is missing in examined samples from the Kaliningrad region.

The **Turonian–Coniacian** sediments have local distribution through the region under consideration and were not established in the examined boreholes.

Rare *Globotruncana* forms and dominant benthic species *Epistomina whitei* Brotzen occurring in three sections south of Kaliningrad define the undivided **Santonian** Stage. Dominance of the last species is characteristic of the upper Santonian sediments of the European paleobiogeographic region (Naidin et al., 1984).

Only one section recovered in the western part of the region in question is established to contain the **lower Campanian** layers with dominant *Bulimina ventricosa* Brotzen and *Cibicides temiensis* Vasilenko. The last species is index taxon of the synonymous zone in Belarus (Akimets, 1974), Ul'yanovsk region near the Volga River, and western Kazakhstan (Beniamovski et al., 1988). In Lithuania and other East European areas, the lower Campanian Substage is defined as corresponding to the *Brotzenella insignis* Zone.

The **upper Campanian** sediments occur throughout the Kaliningrad region. They are established in eight sections based on rich assemblages of secretory benthic foraminifers dominated by *Globorotalites mishelianus* (d'Orbigny), *Eponides grodnoensis* Akimez, *E. monterelensis* Marie, *Anomalina umbilicata* Mjatluk, and *Cibicides actulagayensis* Vasilenko. Many agglutinated species characteristic of the upper Campanian in the East European platform are also present in examined sediments. The upper Campanian Substage corresponds to the *Eponides monterelensis* Zone in Lithuania and to the *Cibicides actulagayensis* Zone in Belarus.

Diversity and abundance of agglutinated benthic foraminifers representing *Ataxophragmium, Arenobulimina, Neoflabellina, Orbignyna, Plectina*, and other genera sharply increase in the **lower Maastrichtian** sediments of the Kaliningrad region, where they are established in four sections drilled in southeastern areas. In Lithuania and Belarus, the lower Maastrichtian sediments correspond to the *Brotzenella complanata* Zone. This index species is scarce however in the examined core samples. Characteristic species of this zone occur in the West European platform, for example in upper Campanian and lower Maastrichtian sediments of the Mons basin in Belgium (Robaszynski and Christiansen, 1989).

The **upper Maastrichtian** Substage is established in three sections of southern and southeastern areas of the region. Indicative of the substage are *Eponides moskvini* (Keller) and large agglutinated forms. Species typical of the *Hanzawaia ekblomi* Zone in Lithuania and Belarus have not been identified in the examined material. Characteristic species of this zone occur in upper Maastrichtian sediments of the East and West European platforms (Grigelis et al., 1980).

Table 2. Regional Upper Cretaceous stratigraphy, the southwestern part of the East European platform

Group	System	Series	Stage	Northeastern Poland (*Resolutions*…, 1978)	Polish-Lithuanian gulf (*Mesozoic Sedimentation*…, 1985): NW part	Polish-Lithuanian gulf (*Mesozoic Sedimentation*…, 1985): SE part	Kaliningrad region, southwestern Lithuania: Formations (Zagorodnykh et al., 2001)	Kaliningrad region, southwestern Lithuania: Foraminiferal zonation (Geology of Soviet…, 1982)	Kaliningrad region, foraminiferal zonation (this work)	Belarus, foraminiferal zonation (Akimets, 1991)	Russian platform, foraminiferal zonation (Grigelis et al., 1980)
Mesozoic	Jurassic	Upper	Maastrichtian	*B. kazimirovensis* *B. junior*			Spasskaya	*Hanzawaia ekblomi*		*Hanzawaia ekblomi*	*Hanzawaia ekbloi*
			Maastrichtian	*B. occidentalis* *B. lanceolata*			Vorontsovskaya	*Brotzenella complanata*	Agglutinated	*Brotzenella complanata*	*Brotzenella complanata*
			Campanian	*N. vistulae* *C. donecianus* *N. phaleratum* *G. guarrata*			Kalinovskaya	*Brotzenella monterelensis*	*E. grodnoensis* *E. monterelensis*	*G-s emdyensis*	*G. emdyensis*
										C. actulagayensis	*B. monterelensis*
							Loznyakovskaya	*Brotzenella insignis*	*B. ventricosa* *C. temirensis*	*Cibicides temirensis*	*Brotzenella insignis*
			Santonian	*G. granulata*			Demidovskaya	*Gavelinella stelligera*	*E. whitei* *Robulus leptus*	*Gavelinella stelligera*	*Gavelinella stelligera*
				I. patotensis *I. cardissoides*				*Gavelinella infrasantonica*		*Gavelinella infrasantonica*	*Gavelinella infrasantonica*
			Coniacian	*I. involutus* *I. schloenbachi*			Dubrovskaya	*G. costulata* *G. kelleri*		*B. eleyi* *E. cretacea*	*G. costulata*
											G. kelleri
			Turonian	*I. incostatus* *I. labiatus*			Vysokovskaya	*G. moniliformis* *G. ammonoides*		*G. variabilis* *G. turonicus*	*G. moniliformis* *G. ammonoides*
			Cenomanian	*H. subangulosus* *A. rhotomagense* *M. mantelli*			Pobedinskaya	*Lingulogavelinella globosa*	Planktonic	*Lingulogavelinella globosa*	*Lingulogavelinella globosa*
							Chkalovskaya	*Gavelinella senomanica*	*A. senomanica*	*Gavelinella senomanica*	*Gavelinella senomanica*
									H. chapmani		
			Albian	*M. inflatum*			Osinovskaya		*A. belorussica*		

Note: Hatched intervals designate breaks in sedimentation.

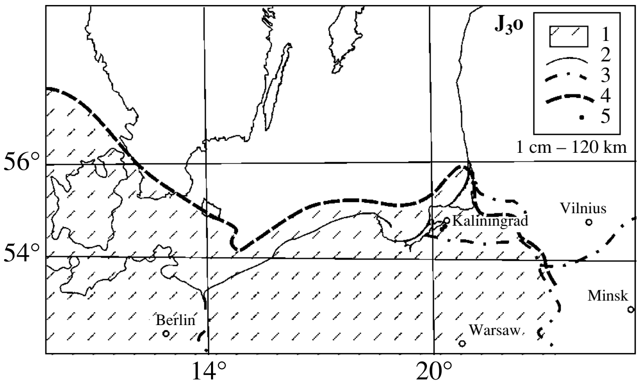


Fig. 5. The Late Jurassic (Oxfordian) paleogeography of the southwestern East European platform: (1) Oxfordian sea; (2) present-day shoreline; (3) state boundary; (4) boundary of the Oxfordian sea; (5) examined boreholes (after Grigelis, 1991; Surlyk and Hakansson, 1998; *Atlas of Paleogeographic…*, 1993, maps 11.2a and 11.2c; Zagorodnykh et al., 2001).

PALEORECONSTRUCTIONS

In the Jurassic, a large epicontinental basin extending from the Atlantic coast of North America to Mangyshlak was populated by boreal benthic foraminifers of uniform generic and species composition. Similarity between faunas from the Atlantic shelf and epicontinental seas of West and East Europe indicates that these regions, located now thousands of kilometers away from each other, belonged to indivisible paleobiogeographic region at that time.

Foraminiferal communities that populated Jurassic Boreal seas of the East European platform are of the nodosariid–epistominid type. In southern areas of the former USSR, faunas of this type have been characteristic of the Callovian and Oxfordian sediments only. The Kimmeridgian and Tithonian foraminifers represent the northern subtype of the thermophilic Tethyan fauna classed with the cyclamminid–pavonitid communities (Basov, 1980; Basov and Kuznetsova, 2000). In their composition and diversity, the Callovian–Upper Jurassic foraminiferal assemblages of the southern Baltic region, Belarus, Dnieper–Donets depression, Middle Volga region, and Mangyshlak are almost identical (Myatlyuk, 1939; Mityanina, 1957; Kaptarenko-Chernousova, 1959; Kuznetsova, 1979; and others).

Simultaneously, coeval assemblages of the Upper Jurassic foraminifers are similar in the East and West European sections (Lutze, 1960; Bielecka and Pozaryski, 1954; Gordon, 1962; Barnard, 1951) and in the Canadian Atlantic shelf (Ascoli and Grigelis, 1993).

In the second half of the Middle Jurassic, a narrow North Atlantic sea appeared between North America and Europe. Interchange of waters between this sea and the World Ocean was insignificant at first. The sea was approximately 1 km deep and shallower (upper bathyal) in the Callovian–Kimmeridgian and accumulated greenish gray to red limy sediments with spirillinid–lenticulinid foraminiferal assemblages. Judging from rare benthic foraminifers preserved in white pelitomorphic limestones, depth of the basin increased up to 2–3 km in the terminal Jurassic–initial Cretaceous (Basov et al., 1980).

Depending on transgressions and regressions, depth and configuration of epicontinental seas of West and East Europe changed slightly. The basin located in the present-day Kaliningrad region represented a northeastern marginal part of the Polish basin that developed on both sides of the Polish–Danish trough.

A shallow strongly freshened basin emerged in the Early Jurassic in northwestern margin of the East European platform. With short-term interruptions in the Aalenian and Bathonian, the basin existed up to the middle Callovian, when a large transgression commenced. Its reflections are recorded throughout the vast territory of the East European platform. Northern and southern basins became connected via the Norwegian–Greenland passage and Arctic waters flooded the North Sea, while the Tethys advanced to the Dnieper–Donets basin (*Atlas of Paleogeographic…*, 1991; *Geology and Geomorphology…,* 1991). The middle Callovian sea that replaced the shallow freshened basin in the southern Baltic region was first populated by rare though diverse *Lenticulina* species (Grigelis, 1985). Bielecka and Pozaryski (1954) believe that this foraminiferal group is characteristic of sublittoral zone. Now, nodosariids prevail in upper–middle bathyal communities dwelling at the depth of 130 to 1000 m (Boltovskoy and Wright, 1976).

In the late Callovian, when the basin widening was in progress, it became populated by more diverse and abundant benthic foraminifers. *Lenticulina* and other nodosariid genera (*Citharinina, Ichtiolaria, Planularia, Saracenaria, Dentalina, Nodosaria*) coexisted at that time with various *Epistomina* species having large ornamented tests. Shape and size of tests suggest normal salinity of the late Callovian sea, high saturation of seawater with $CaCO_3$, and, probably, a relatively low temperature of bottom waters: individuals living in cold water are usually larger than those of warm-water habitats. This is also consistent with data on oxygen isotope composition in belemnite rostra, which indicate low water temperatures in the Callovian–Oxfordian sea basins (Louis et al., 2004). In the present-day ocean, epistominids are characteristic likely of the outer shelf depth range. Gordon (1970) who divided all the Jurassic foraminifers into five groups argued for the shelf origin of communities dominated by epistominids and nodosariids.

The Callovian–Oxfordian transition was the existence time of even more diverse and abundant foraminiferal communities in seas of the southern Baltic region, where they included also abundant primitive agglutinated species. On the New Scotia shelf of North America, agglutinated species *Haplophragmoides* and

Ammobaculites, which present also in the examined samples, are widespread in shallow-water Callovian sediments (Basov and Vasilenko, 1986).

In the early Oxfordian, a shallow sea that covered almost entirely the Kaliningrad region, northeastern Poland, and southern part of the modern Baltic Sea extended farther westward (Fig. 5). It was populated by diverse brachiopods, ostracodes, gastropods, bivalves, and fishes, whose remains are abundant in relevant sediments. Organogenic–detrital oolitic sediments and sandy facies are indicative of the basin shoaling at that time. In the early Oxfordian, the sea basin that covered the southern Baltic region became populated by stenobiontic *Lenticulina* fauna of smaller foraminifers (Grigelis, 1985). An impoverished composition and dwarfish appearance of foraminifers was probably controlled by lagoonal environments with elevated salinity and oxygen deficiency probably.

In the middle Oxfordian, the South Baltic sea was colonized by abundant dwarfish *Epistomina, Trocholina*, and *Lenticulina* species. This was a period of maximal population density of benthic foraminifers for the entire Late Jurassic. The dwarfish suppressed fauna develops usually under unfavorable conditions, e.g., under deficiency of food or oxygen, by the basin freshening or, in contrast, in response to increasing salinity.

In the Kimmeridgian, the sea retreated from the southern Baltic region although covered still the Kaliningrad region. Foraminiferal community of that time consisted of dwarfish rare and uniform *Epistomina* forms. Its low diversity and small sizes of tests imply persistence of unfavorable environments. On the other hand, planktonic species *Globuligerina stellaporalis* and ammonite fragments found in the lower Kimmeridgian sediments suggest penetration of warm waters from the Tethys, the center of planktonic foraminifer dispersal in the Jurassic (Gordon, 1970) to western marginal basins of the East European platform.

During the Volgian powerful transgression into the East European platform, sea covered almost 90% of its territory (Mesezhnikov et al., 1985). In the early Volgian time, benthic foraminifers of the South Baltic sea were more abundant than in the Kimmeridgian, although remained not diverse. The low diversity and relatively high population density are characteristic of coastal sedimentation settings. In the late Volgian time, an uplift eastward of the Polish trough caused the sea retreat from the southern Baltic region (Zagorodnykh, 2001).

Continental environments lasted during the Early Cretaceous. The North Atlantic opening throughout the Cretaceous resulted in formation of the submeridional Atlantic Ocean, which was as wide in the Northern Hemisphere as 5000 km by the end of the Cenomanian (Zharkov et al., 1998). The epicontinental basin that was located in the Jurassic between North America and West Europe became divided by a deep oceanographic barrier.

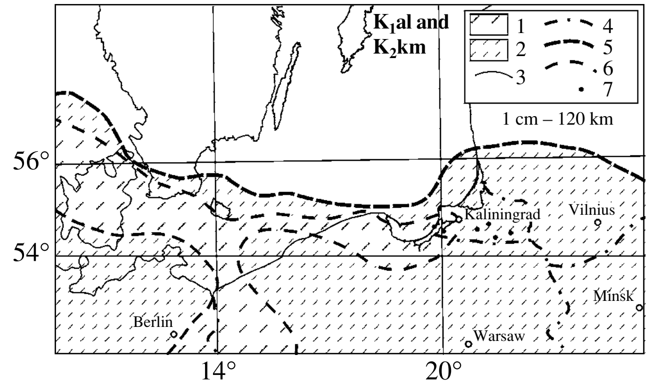


Fig. 6. The Middle (late Albian) to Late (Campanian) Cretaceous paleogeography of the southwestern East European platform: (1) Albian sea; (2) Campanian sea; (3) present-day shoreline; (4) state boundary; (5) boundary of the Campanian sea; (6) boundary of the late Albian sea; (7) examined boreholes.

The next phase of the global sea-level rise was in the terminal Early Cretaceous. The Baltic syneclise was flooded by sea only in the late Albian, when a shallow gulf open southwestward originated in the western part of the Kaliningrad region (Fig. 6). It was colonized by first rare benthic foraminifers at the end of the Albian Age.

In the early Cenomanian, the gulf widened to occupy the southwestern part of the Kaliningrad region, adjacent Baltic Sea areas, and neighboring areas of Poland. It was a warm basin with normal salinity populated by diverse echinoderms, mollusks, ostracodes, and benthic foraminifers. Algae were abundant in intertidal and subtidal zones located southward of Kaliningrad. Diversity and abundance of foraminifers increased as compared with the late Albian, and their community included many agglutinated species of the family Ataxophragmiidae, which dominate now on shelf and in abyssal zone of the Bay of Biscay (Boltovskoy and Wright, 1976)`

The area occupied by the South Baltic sea was increasing in the late Cenomanian parallel to growing diversity and population density of foraminifers. They were represented by buliminids, genera *Eponides* and *Cibicides*, nonionids, and various planktonic species, bicarinate forms of genera *Rotalipora* and *Praeglobotruncana* included. Bicarinate foraminifers are mainly characteristic of the narrow equatorial belt (Frerichs, 1971). Their occurrence in sediments of the southern Baltic region suggests existence of a very warm and relatively deep (approximately 200 m) basin with normal salinity, which has been open southward. Abundant and diverse planktonic foraminifers colonized the late Cenomanian epicontinental seas of the entire East European platform (Grigelis et al., 1980; Peryt, 2004).

In the Turonian and Coniacian, sedimentation in the Kaliningrad region and neighboring areas of Poland

Table 3. Paleogeography of the southern Baltic region in the Late Mesozoic

Age		Fauna	Paleogeography	Sea level position relative the present-day one (Harland et al., 1985)
K_2m	Late	Highly diverse and abundant planktonic and benthic foraminifers, rare ostracodes and echinoids	Gradual regression	By 300 above the present-day one
	Early	Richest foraminiferal assemblages for the Late Mesozoic, large agglutinated species, sponges, corals, bryozoans, echinoids	Wide gulf with moderate water temperature, normal salinity, and depths up to 200 m	330 higher
K_2km	Late	Very diverse and abundant planktonic and benthic foraminifers, fish remains, ostracodes, sponges, bivalves, brachiopods		
	Early	Abundant and diverse planktonic and benthic foraminifers, large agglutinated species, belemnites, bivalves, gastropods		
K_2st	Late	Rare relatively uniform benthic foraminifers, rare planktonic species	Advancing low-salinity sea basin	300 m higher
	Early		Continental setting in the most of the region	
K_2k, t				
K_2s	Late	Diverse benthic foraminifers (buliminids, Nonionina, Pullenia, Cibicides, Eponides, and others) represented by rare specimens, dominant thermophilic planktonic species	Very warn sea basin with normal salinity and depths of approximately 200 m	150 m higher
	Early	Relatively diverse and abundant foraminifers, many agglutinated species, algae remains, echinoids, mollusks, ostracodes	Gulf with moderate water temperature and normal salinity	200–300 m higher
K_1al	Late	Very rare and uniform foraminifers, wood fragments		
	Early		Continental settings	Similar
J_3v	Late		Regression	50 m higher
	Early	Uniform, although abundant *Lenticulina* and *Epistomina*	Tidal zone	
J_3km	Late		Continental settings	100 m higher
	Early	Single small *Epistomina* spp.	Lagoon with elevated salinity and, probably, oxygen deficiency	
J_3o	Late	Relatively diverse and abundant small foraminifers		
	Early	Very rare and small foraminifers, abundant brachiopods, ostracodes, gastropods, bivalves, fish remains		
J_2k	Late	Rare and relatively diverse *Lenticulina* species, large *Epistomina* spp.	Gulf with normal salinity and, probably, low water temperature	50 m higher
	Middle	Rare small *Lenticulina* sp.	Transgression onset	

ceased because of crustal upwarping (*Sedimentation…*, 1985).

Transgression that commenced in the terminal Coniacian resulted in the formation of a sea basin, which was again gradually colonized by different organisms in the Santonian. The diversity and abundance of foraminifers was, however, much lower than in the late Cenomanian, although presence of single planktonic species in their community indicates normal salinity and depth exceeding 100 m.

After a short break, the western part of the region under consideration was again flooded by sea in the early Campanian, and the relevant basin became populated by belemnites, bivalves, brachiopods, and secretory foraminifers.

In the late Campanian, a vast sea covered entire Northwestern Europe, the southern Baltic region, and greater part of East Europe (Fig. 6). It was populated by sponges, bivalves, ostracodes, brachiopods, and fishes. The foraminiferal community of the sea was more diverse and abundant than ever and included Boreal planktonic species indicating temperate temperatures and a great depth of the basin. Numerous bivalve fragments found in the southern part of the region suggest flat coastal settings with low-energy hydrodynamics.

Similar conditions existed also in the early Maastrichtian basin inhabited by abundant sponges, corals, bryozoans, echinoids, bivalves, and ostracodes. Foraminifers became even more diverse and abundant than in the late Campanian, and their community included planktonic, diverse secretory taxa (lagenids, buliminids, and rotaliids, genera *Eponides, Anomalina*, and *Cibicides* included), and new agglutinated forms (Ataxophragmiidae).

In the late Maastrichtian, diversity and abundance of benthic foraminifers was reducing because of the basin contracting and shoaling, although proportions between different taxa remained unchanged. Poor preservation of foraminifers in two of three sections suggests the high-energy wave activity in the intertidal zone. Only rare ostracodes and echinoids represented the late Maastrichtian descendants of diverse marine organisms, which populated the early Maastrichtian basin.

The Late Mesozoic regressions and transgressions in the southern Baltic region were of eustatic type. The formation of a large deep and moderately warm sea gulf with normal salinity resulted from the maximal (up to 300 m or higher) sea-level rise at the end of the Late Cretaceous (Harland et al., 1985). Continental settings in the region during the Turonian and Campanian appeared probably in response to regional tectonic events, which caused the sea retreat. The Kimmeridgian regression at the time of the global 100-m-high sea-level rise was likely caused by the same factor (Table 3).

A relatively low sea-level stand (150 m above the present-day one) was characteristic of the late Cenomanian. The examined foraminiferal assemblages imply that the southern Baltic region was influenced by warm and saline Tethyan waters probably via strengthened surface circulation in the World Ocean.

Glauconite occurring in all Upper Cretaceous deposits suggests that there was upwelling near coastal zone of the southern Baltic region. Consequently, there was vertical circulation as well in the Late Cretaceous epicontinental seas of the West and East European platforms.

CONCLUSIONS

Benthic and planktonic foraminiferal assemblages have been studied in Late Mesozoic sediments of the Kaliningrad region located in northeastern periphery of the spacious epicontinental Danish–Polish sea of that time.

Based on dominant species of the benthic genus *Epistomina*, the new zonation is established for Callovian (Upper Jurassic sediments of the region. The Upper Cretaceous sediments are stratified according to succession of dominant benthic genera and species occurring in association with abundant planktonic forms. The proposed zonations are correlated with other zonal scales characterizing western areas of the East European platform.

Proportions between planktonic and benthic foraminiferal species, their diversity, abundance and preservation are used, along with distribution of other marine fossils, to reconstruct the development history of the South Baltic sea.

During the Late Mesozoic, the Kaliningrad region was twice flooded by sea: since the late Callovian until early Volgian and since late Albian until late Maastrichtian.

Judging from the appearance of equatorial planktonic foraminifers, water exchange between the South Baltic sea and Tethys commenced already in the late Cenomanian, but the sea was largest and deepest in the late Campanian–early Maastrichtian. The outer shelf and upper bathyal zone of the sea with slightly changing environments were populated by communities of diverse and abundant foraminifers and by other organisms.

In other periods of the Late Mesozoic, the Kaliningrad region corresponded to the inner shelf and intertidal zone of the Boreal epicontinental sea, where settings were unfavorable for foraminifers whose impoverished assemblages are of uniform composition. During the Kimmeridgian regression, sea retreated from the region in the Turonian and Coniacian, when sedimentation ceased.

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