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BIOTIC AND ABIOTIC EVENTS OF THE LATE CRETACEOUS ARCTIC BIOGEOGRAPHICAL REALM

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The marine biota of the Arctic paleobiogeographical realm differed from the biota of the Boreal realm in being taxonomically depauperated rather than in having endemics of a high rank (superrealm). The biota of the West Siberian province is typical of the Arctic. The Upper Cretaceous composite section in northern West Siberia contains traces of biotic and abiotic events restricted to the boundaries of stages or substages: Cenomanian-Turonian, Middle-Upper Turonian, Turonian-Coniacian, Lower-Upper Coniacian, Coniacian-Santonian, Santonian-Campanian, and Maastrichtian-Danian. There are two levels at which the maximum diversity of bottom mollusks, foraminifers, and dinocysts coincides and the taxonomic composition of the same groups becomes most uniform: at the Cenomanian-Turonian boundary and in the Late Santonian. They coincide with the warmest episodes in the Late Cretaceous of northern Siberia. In time, the two bioevents correspond to the period of accumulation of "black shales", associated with the eustatic rise of sea level in the late Cenomanian-early Turonian and vast Boreal transgression in the Santonian-Early Campanian. No considerable extinction has been recorded at the Cenomanian-Turonian boundary. The extinction of invertebrates in the Maastrichtian of the West Siberian province proceeded step by step. By the end of the Late Cretaceous the Siberian biota became less diverse as a result of general cooling in northern Eurasia.

Arctic biogeographical realm, marine biota, paleogeography, Late Cretaceous

INTRODUCTION

Over the area of distribution on the Earth's surface, the Upper Cretaceous deposits follow the Quaternary ones. This is one of the reasons why they are under intensive study. Among the Late Cretaceous biotic events whose vestiges are observed at a global or subglobal scale, the following phenomena are recorded: restructurings around the Cenomanian-Turonian and Maastrichtian-Danian boundaries, with mass extinction of biota at the end of the Maastrichtian; efflorescence of plankton, and restructuring in the composition of land vegetation (dispersal of angiosperms) [1].

Many regularities of the development of the Phanerozoic biota such as stage-by-stage character, dynamics of taxonomic diversity, relationship with abiotic events (greenhouse effect, tectono-eustatic changes in sea level, anoxic events, impact around the Maastrichtian-Danian boundary, and Pacific superplume) have been inferred from the results of study of the Late Cretaceous biota by the example of the Albian-Cenomanian, Cenomanian-Turonian, and Maastrichtian-Danian boundaries [2–4]. However, these regularities are scarcely exemplified by the Late Cretaceous Arctic biota, because this biota is explored much poorer as compared with biotas from the rest of the Earth.

Among the Late Cretaceous sedimentation events, the so-called "black-shale" episodes are widely known. They are associated with the distribution of anoxic conditions in the transition from Cenomanian to Turonian (OAE2) and from Turonian to Coniacian (OAE3), and with a thin clay interbed at the bottom of the Danian containing an abnormal concentration of siderophile elements, in particular, Ir [1, 2, 4–6]. Traces of these events

Fig. 1. Position of the Late Cretaceous Arctic biogeographical realm in the Panboreal biogeographical superrealm.

were most thoroughly studied in the sections of Tethyan, chiefly Mediterranean, type or in oceanic sediments. To a less extent, they are illustrated by materials from the Panboreal paleobiogeographical superrealm and, putting aside our papers, were only little discussed on the materials of the Arctic paleobiochoreme [7–11]. At the same time, the data on high-latitude regions are even more pereferable than low-latitude data for understanding the causes of a species' extinction, especially, in connection with changes in climate. Obviously, the neglect of the vast territory of the Arctic (more than 25 mln km^2) makes invalid the statements of global nature of any events. The purpose of this paper is to bridge the gap.

ARCTIC BIOGEOGRAPHICAL REALM

In the Late Cretaceous, the Arctic zoogeographical realm included the whole continental and shelf parts of the modern Arctic and some, adjacent in the south, areas covered by epicontinental seas open to the Arctic water space (Fig. 1). Its main feature is the taxonomic poverty of marine invertebrates as compared with the Boreal realm situated farther southward. For this reason and taking into account the specific character of the Late Cretaceous circum-Arctic flora, Saks [12] proposed to recognize a Boreal beogeographical zone in the Late Cretaceous Northern Hemisphere and to subdivide it into three realms: Boreal-Atlantic, Arctic, and Boreal-Pacific. The hierarchy and nomenclature of paleobiochoremes (this term is introduced instead of the preoccupied term "biochore" [13]) were in full agreement with the hierarchy and nomenclature adopted then for the Jurassic and Neocomian. To follow the modern concepts and international agreements on designation of the highest rank biochoreme, we discarded the term "zone" widely used in climatology [14–16]. To meet most strict criteria of recognition of biochoremes of regional and provincial ranks, the rank of Late Cretaceous biochoremes should, possibly, be lowered because throughout the Late Cretaceous there were neither taxa of supraspecies rank nor phylum lines pertinent exclusively to Late Cretaceous Arctic biota among the Arctic endemics. However, taking into account some conventionality in determination of the rank of paleobiochoremes and keeping the nomenclature stability, we adopt the division proposed by Saks [12].

MARINE BIOTA

The following types, classes, and orders have been established in the Late Cretaceous marine biota of the Arctic: vertebrates (Selachii, bony fishes, aquatic reptiles: Ichthyosauria, Mosasuridae), mollusks (ammonites, belemnites, bivalves, gastropods, Scaphopoda), echinoderms (sea urchins and lilies), Arthropoda (crustaceans: higher crayfishes and ostracodes), brachiopods, sponges (spicules), Proterozoa (foraminifers, radiolaria), microscopic algae (diatoms, dinoflagellate cysts, silicoflagellates, prasinophytes, acritarchs, coccolithophores). Diverse worms might be "creators" of some ichnofacies (Rhyzocorallium, Scolithos, and Cruziana).

At different times, certain groups of organisms were predominant in the Late Cretaceous Arctic biota. For example, during the Late Cenomanian—Early Campanian, the bottom communities were dominated by bivalves of the Inoceramidae family, in some periods of time the bottom communities were in places dominated by the genera *Semidicranodonta (=Lopatinia), Falcimytilus, Oxytoma* and invertebrates having left vestiges of the kind of *Arctichnus, Ophiomirpha, Rhyzocorallium* as well as small horizontal traces. Less frequent were gastropods, only sporadically did exist ammonites and belemnites, and Scaphopoda were extremely rare. Articulated brachiopods were established only in the Upper Cenomanian. Sea urchins were found only in the Upper Santonian, and remains of higher crayfishes, in the Upper Santonian and Maastrichtian, snark teeth, in the Upper Turonian and Coniacian, and teeth of marine reptiles, in the Coniacian, Upper Santonian, and Maastrichtian [17, 18]. The Upper Cretaceous microfauna is represented by numerous formainifers (more than 80 genera), at some levels, by abundant complexes of Radiolaria of the Spumellaria order [19] and solitary ostracodes [20]. Rather diverse are unicellular algae: diatoms, dinocysts, green (prasinophytes) [21–23]. Coccolites are found in the Campanian and Maastrichtian [24].

As might be judged from well-studied groups of organisms: mollusks (ammonites, belemnites, bivalves, gastropods), foraminifers, radiolarians, diatoms and dinoflagellates — there are no taxa of high rank among them, which would have an Arctic origin. Like most taxa of species rank, they are all immigrants from the European or North American regions. However, despite open sea ways providing free communication of the Arctic basin with the seas situated south of it, the associations os Arctic mollusks and foraminifers remained much poorer and scarce as compared with the coeval associations even from northeastern Europe. Low diversity of marine invertebrates contradicts the evidence of relative stability in time of the main factors of the environment: salinity, thermal regime, precipitation type, water mass, and communications with the World ocean. An indicator of medium stability may be characteristics of the largest water body of the Arctic basin, the West Siberian sea-gulf: throughout the Late Cretaceous, most of the basin was in the zone of moderately warm climate: siliceous and terrigene-oligomictic composition of sediments and relatively low rates of their accumulation were persistent [25]. The main groups of fauna and flora (at the level of families and genera) were also kept constant.

BIOTIC EVENTS

Traces of Late Cretaceous biotic events of various nature have been established on the basis of comparative analysis of the structure of heterochronous successive bottom paleocommunities and semipelagic and pelagic paleoassociations, as well as analysis of curves of taxonomic diversity of bottom mollusks, foraminifers, and dinocysts in the most complete section of the marine Upper Cretaceous in northern Asia — in the Ust'-Yenisei region of West Siberia (Fig. 2).

Succession of biotic events. I. The Late Cenomanian — advent of cosmopolite species of inoceramids *Inoceramus (Inoceramus) pictus* Sow. and representatives of the Pacific branch *I. (I.) ginterensis* Perg., "thorny" gastropods of the genus *Aporrhais*. Appearance of abundant large-shell ammonites of the genus *Placenticeras* and more rare small *Borissiakoceras*. This association of ammonites was widespread in both Boreal and peri-Tethyan seas of the Northern Hemisphere. In the Late Cenomanian the peridinioid dinoflagellates are predominant in associations. Just at that time, against the background of Cenomanian-Turonian transgression and levelling of climate, algofloras develop, which are similar in separate regions.

II. Beginning of the Early Turonian — mass appearance of the cosmopolite species of mytiloid inoceramids *I. (Mytiloides) labiatus* Sow. Immigration of the planktonic genus of foraminifers *Hedbergella* in the Arctic zone (Kara Sea) of West Siberia [26].

III. The Late Turonian — successive mass appearance in shallow waters of: (1) cosmopolitan species of inoceramids *I. (I.) lamarcki* Sow. and seven species of inoceramid neoendemics; (2) two genera of bivalves *Semidicranodonta* and *Falcimytilus*; (3) genus of ammonites *Scaphites*; (4) first expansion of planktonic foraminifers (four genera: *Whiteinella, Blefuscuiana, Hedbergella,* and *Heterohelix*); (5) outburst of species diversity and mass distribution of the Boreal genus of dinocysts *Chatangiella*; (6) disappearance of elements of Early Cretaceous algofloras and development of taxa reaching their efflorescence in the Cenomanian.

IV. Short-term episode around the Turonian-Coniacian boundary — a drastic enrichment of a thin interbed within a 5 m clay member by dinocysts.

V. Early Coniacian — mass occurrence (craggy accumulations of shells) of bivalves of the genus *Volviceramus*. First appearance of marine reptiles.

VI. Early Santonian — nearly simultaneous appearance of first representatives of bivalves of the genus *Sphenoceramus* and species *Oxytoma tenuicostata* (Roemer) spread in the eastern part of the European

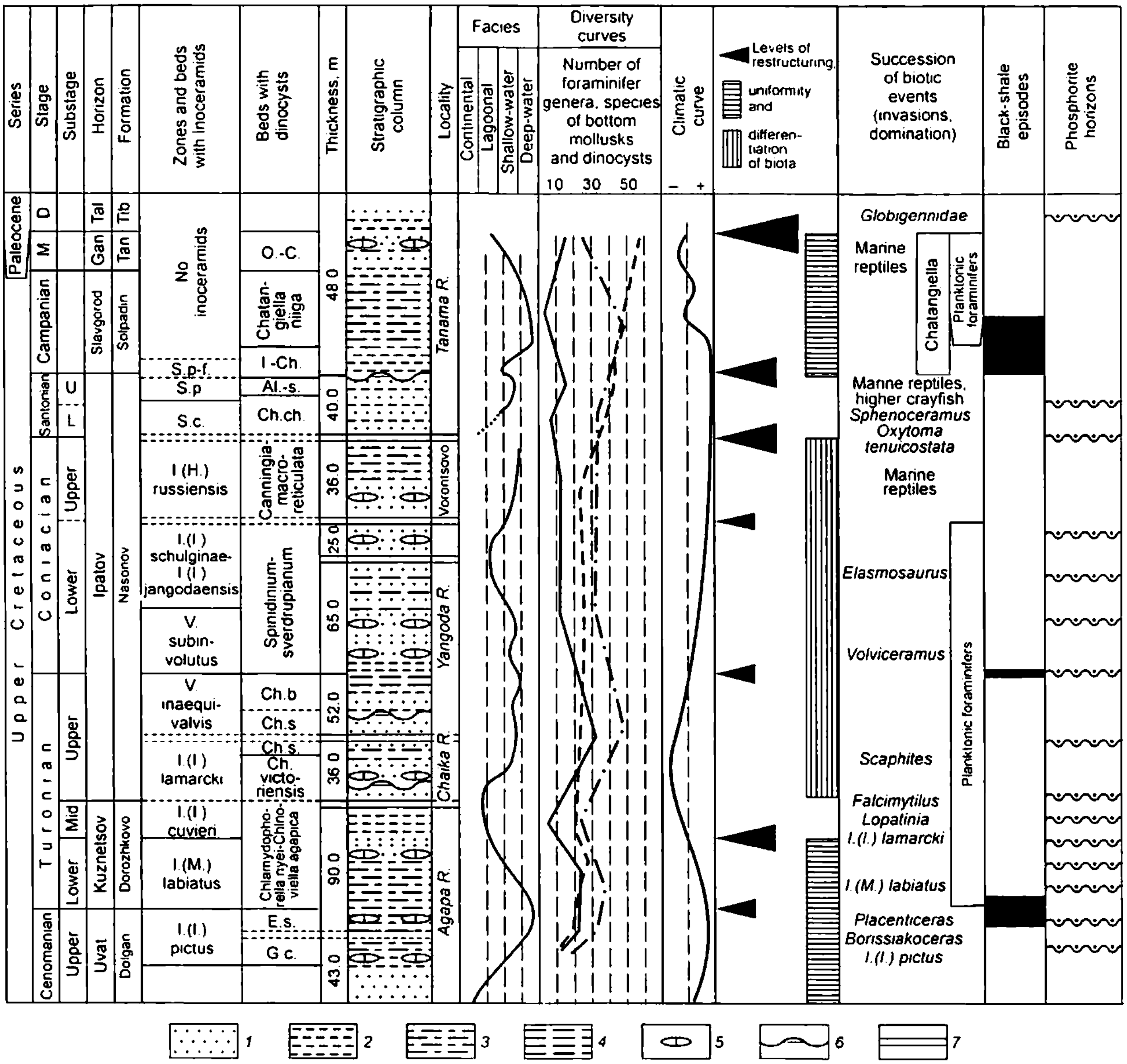

Fig. 2. Composite section of the Upper Jurassic northeastern West Siberia and main events of biotic nature (curves of taxonomic diversity of benthonic mollusks, foraminifers and dinocysts; levels of restructuring in the biota, intervals of taxonomic levelling and differentiation, succession of the appearance of the most important organisms) and of abiotic nature (facies types, heat curve, episodes of black clays and diastems = horizons of phosphorite nodules). Stages and substages: M — Maastrichtian, D — Danian, L — Lower, Mid — Middle, U — Upper. Horizons and formations: Gan — Gan'kino, Tal — Talitsa, Tan — Tanama, Tib — Tibes. Zones and beds with inoceramids: I. (I.) — Inoceramus, M — Mytiloides, V — Volviceramus, H — Haenleinia, S — Sphenoceramus, c — cardissoides, p — patootensis, p-f — patootensiformis. Beds with dinocysts: G. c. — Geiselodinium cenomanicum, E. s. — Eurydinium saxoniense, Ch.s. — Chatangiella spectabilis—Oligosphaeridium pulcherrimum, Ch. b. — Chatangiella bondarenkoi—Pierceites pentagonum, Ch. ch. — Chatangiella chetiensis, Al.-s. — Alterbidimium spp.—Spinidium echinoidium, I.-Ch. — Isabelidinium spp.—Chatangiella verrucosa, O.-C. — Operculodinium centrocarpum—Cerodinium diebelii. *1* — sands, *2* — siltstones, *3* — silty clays, *4* — clays, *5* — calcareous concretions, *6* — gaps in sedimentation, *7* — interruptions in observations. Curves of diversity. Lines: solid — species of bottom mollusks, dash — genera of foraminifers, dash-and-dot — dinocyst species.

paleobiogeographical realm in the Late Santonian and Early Campanian, and in the western part, only in the Early Campanian. Dinocysts such as *Chatangiella, Trithyrodinium, Spinidinium, Alterbidinium, Isabelidinium* etc. come to the climax in the Santonian–Campanian. At that time the latitudinal differentiation of dinoflagellate associations is expressed most distinctly.

VII. The Late Santonian — occupation of shallow waters by sea urchins, higher crayfishes, and Selachii.

VIII. Beginning of the Early Campanian — disappearance of inoceramids (finding of *Inoceramus* cf. *nagaio* Matsumoto et Yeda in the Lower Campanian of the Yurkhar area [27] needs checking). This level is well traceable in West Siberia. Below this stratigraphic level, the rocks are usually saturated in clastics of the prismatic bed of inoceramid shells. The Early(?) Campanian — outburst of species diversity, and then throughout the Campanian and Maastrichtian – the mass distribution of *Chatangiella*, the Boreal genus of dinocysts.

IX. Late(?) Campanian — the second expansion of planktonic foraminifers (four genera: *Hedbergella, Heterohelix, Globigerinelloides*, and *Rugoglobigerina*) and their existence during the Maastrichtian. A bright episode in the Late Campanian (beginning of the Cibicidoides eriksdalensis primus Zone time) is the levelling of taxonomic composition of associations of benthonic foraminifers over the whole Arctic and a drastic increase in their generic diversity (46 genera). This zone time is characterized by the mass appearance of the species "*Eponides*" *sibiricus* Neckaja. This event is well documented both in west Siberia and on the Barents Sea shelf [26].

X. Maastrichtian — advent of marine reptiles. Bones of marine reptiles (*Elasmosaurus*?) were found in northern Siberia in the Coniacian as well [17, p. 38], but especially frequently they occur in the Maastrichtian [18, p. 58, 64]. Findings of "Ichthyosauria" in the sandstones of the Kolchedan section in West Siberia were mentioned earlier [28]. On the basis of foraminifers, Amon [19] referred them to the Lower Maastrichtian. Probably, the population of the West Siberian Sea in the Maastrichtian and wide occurrence in it of marine reptiles should be explained by the opening of the Turgai strait that communicated the peri-Tethys basins with the Arctic ones. In the late Maastrichtian, ammonites disappeared from the West Siberian basin. Findings of baculites are quite usual in the Maastrichtian (Gan'kino Formation) [28] but are not known above the lower boundary of the Brotzenella praecuta Zone of West Siberia. The Lower Maastrichtian sections contain the greatest number of genera of benthonic foraminifers — 57 (see Fig. 2). During the Maastrichtian some Cretaceous genera of dinocysts disappeared, giving way to original taxa found in the Paleogene as well: *Cerodinium, Palaeocystodinium, Operculodinium*, etc.

XI. In the late Maastrichtian (beginning of the Brotzenella praeacuta Zone time) the composition and structure of the foramineral communities experience the most drastical changes ever to have been in the Late Cretaceous. The benthonic communities acquire the "Paleogenic" habit. The most typical elements of the Late Cretaceous associations disappear. Later on, such considerable changes in the communities of Siberian foraminifers were not recorded until the advent of elfidiids in the Oligocene (or late Eocene). "Specialized" forms, representatives of the genus *Rugoglobigerina*, as well as "nospecialized" *Heterohelix* and *Globigerinelloides*, disappear from the associations of planktonic foraminifers. Though in a weaker form, these changes took place in the European paleobiogeographical realm, where specialized planktonic foraminifers of the genera *Globotruncana* and *Rugoglobigerina* disappeared in the Late Maastrichtian [29]. Worthy of note is that the sole of the Brotzenella praeacuta Zone may be at different chronostratigraphic levels in Siberia and Eastern Europe. It is a possible explanation of the abundance of *Globotruncana* and *Pseudotextularia* documented in the terminal Maastrichtian of the Saratov Region [30]. No considerable restructurings are documented in the Maastrichtian associations of planktonic foraminifers in the Tethys-Panthalassa superrealm [31]. There are no reliable planktonic foraminifers in the West Siberian Danian. The species "*Globigerina*" *triloculinoides* Plummer (=*Subbotina triloculinoides* (Plummer)) frequently listed for northern Siberia, is the most widespread in Zealand [32].

Dynamics of diversity. Comparison of curves of changes in the diversity of foraminifer genera (microzoobenthos), species of benthonic mollusks (macrozoobenthos), and dinocysts (microphytoplankton) shows that simultaneous high diversity of these groups falls on the latest Cenomanian-early Turonian and late Santonian (Table 1). Of the entire Late Cretaceous, the Late Turonian most abounds in bivalves (31 species) and dinocysts (47 species) and contains a relatively small number of foraminifer genera (25). In the Campanian, foraminifer genera and dinocyst species are numerous (49 and 50, respectively), but species diversity of benthonic mollusks is quite low (4) (see Fig. 2).

Restructurings. Nearly all biotic restructurings but Middle Turonian one correspond to age boundaries. They are reflected in the composition and structure of reconstructed paleocommunities and associations. Traces of biotic restructurings are most distinctly expressed around the boundaries of Early and Middle Turonian, Coniacian-Santonian, Santonian-Campanian, and in the late Maastrichtian. The composite section reflects the sequence of bioevents of varying nature, local restructurings are localized by numerous horizons with accumulations of phosphorite concretions and abundant remains of ammonites (scaphites), bivalves, gastropods, sea urchins, shark teeth, and dinocysts.

Table 1

Data on Taxonomic Diversity of Bottom Mollusks, Foraminifers, and Dinocysts

Substage	Bottom mollusks (number of species)	Foraminifers (number of genera)	Dinocysts (number of species)
Upper Cenomanian	21	18	32
Lower Turonian	22	28	38
Middle Turonian	6		25
Upper Turonian	31	23	47
Lower Coniacian	12	25	31
Upper Coniacian	12	22	33
Lower Santonian	8	37	33
Upper Santonian	16	42	38
Campanian	4	46	47
Maastrichtian	15	57	25

Note. Data on bottom mollusks and dinocysts are given only for northern West Siberia, and data on foraminifers, for the whole territory of West Siberia.

Invasions, speciation, and migration. Other important biotic events are two invasions of planktonic foraminifers: at the Turonian—Early Coniacian and Late Campanian(?)—Early Maastrichtian (see Fig. 2) as well as time intervals with a high percentage of endemic species of inoceramids (in the Late Turonian and Coniacian) and intervals with a predominance of cosmopolite taxa: Late Cenomanian—Early Turonian, Santonian.

ABIOTIC EVENTS

Events of abiotic nature have been revealed by interdisciplinary analysis of time succession of facies [10].

Transgressive-regressive events. Combined analysis of the succession of facies in the composite section shows a repeated change of conditions of sedimentation during the Late Cretaceous in northern Siberia. Thus, on the territory of the Ust'-Yenisei region shallow-sea conditions were predominant in the Late Turonian, Coniacian, Santonian, and Maastrichtian; relatively deep-water, in the Late Cenomanian and Early Turonian; continental, before the Late Cenomanian transgression, and, probably, lagoon settings, in the transition from Middle to Late Turonian [10] (see Fig. 2).

"Black" clay events. Two intervals of the Upper Cretaceous section comprise black or dark-gray clays: around the Cenomanian-Turonian boundary (about 20 m of section, corresponding to two inoceramid zones) and around the Turonian-Coniacian (a 5 m thick layer, see Fig. 2). Dark-gray and gray opoka-like clays are also present at the base of the Campanian. Two first episodes may be interpreted in the context of eustatics as they are documented (especially, the Late Cenomanian episode) throughout the Northern Hemisphere [7]. In Germany (sections in the vicinity of Hanover), a succession of episodes of biotic and abiotic events around the Turonian-Coniacian boundary is like the northern succession [4]. The Early Campanian event reflects the Boreal transgression, whose traces are also documented at the Alpha Ridge [23].

Horizons of phosphorite concretions. The Upper Cretaceous composite section in northeastern West Siberia comprises about 15 horizons with phosphorite concretions [10] (see Fig. 2). According to Zverev [33], the phosphate-bearing concretion formations can be genetically subdivided into six types, among which nodules are drastically predominant. Most of the concretion horizons (twelve) are confined to a comparatively narrow stratigraphic interval from the top Cenomanian through Lower Coniacian (see Fig. 2). Nearly all of them are within a sand-siltstone unit, enriched in authigenic minerals: leptochlorite, (?)glauconite, and phosphate-bearing minerals [33, 34]. The nodules are dissipated within relatively thin layers and form accumulations immediately above the sinuous (in section) surfaces of sedimentary erosion. It is generally believed that phosphorite nodules are accumulated at sites of sea bottom with low rates of accumulation and in oxidation environment, in the range of depths of 30–200 m [35, 36]. However, in our opinion, the nodules were accumulated immediately above the eroded surfaces as a result of secondary rewashing of the deposited but still unconsolidated sediment under extremely shallow conditions. The evidence is given by well-rounded nodules and vertical trails of soft-body organisms (Scolithos facies) permeating the nodule-saturated sand-siltstone beds. The sinuous lower contacts of these beds are indicative of diastems, short interruptions in sedimentation. Relatively close accumulation of surfaces of interruptions in sedimentation within the Turonian—Lower Coniacian suggests frequent alternation of episodes of stable sedimentation and periods of sediment erosion. This could be linked to rather frequent changes in sea level as a result of pulse "activity" of the sourceland at vertical oscillations of the northwestern margin of the East Siberian Platform.

Heat fluctuations. The "heat" curve plotted on the basis of analysis of paleobiogeographical and paleoecological structure of communities of invertebrates and phytoplankton (see Fig. 2) shows fluctuations at two time intervals: (1) in the Cenomanian—Turonian (with a peak of heat around the Cenomanian—Turonian boundary and cooling in the Middle Turonian and at the beginning of the Late Turonian); (2) in the Late Campanian—Maastrichtian (with cooling in the late Campanian, short-term warming in the Early Maastrichtian and then cooling in the late Maastrichtian). A moderately warm regime was kept on the territory of northern West Siberia since the late Turonian to the end of the Santonian.

RESULTS AND DISCUSSION

Comparison of the above data shows that a positive correlation between biotic and abiotic data is observed only around the Cenomanian-Turonian boundary. Within this time interval, the taxonomic diversity of all explored groups of invertebrates grows (bivalves, gastropods, ammonites, benthonic and planktonic foraminifers, microphytoplankton (dinoflagellates)). The black-shale episode at the Cenomanian-Turonian boundary is usually related to a eustatic event, which led to a wide occurrence of anoxic settings in seas and biogeographical levelling. A specific structure of the section and the taxonomic composition of marine biota in northern West Siberia bear traces of global events [7]. Thus, the Cenomanian-Turonian boundary layers are made up of black clays more than 20 m in total thickness (see Fig. 2). The mollusks are dominated by the cosmopolitan species of inoceramids: *Inoceramus (Inoceramus) pictus* Sow. and *I. (Mytiloides) labiatus* Sow., including the varieties defined in Western Europe as different subspecies [37]. Immigration of the species *I. (I.) ginterensis* Perg. and *I. (I.) tenius* Mant. is the only case throughout the Late Cretaceous, when the North Pacific low-rank taxa penetrated to the north of Siberia [38]. Ammonites of the genera *Borissiakoceras* and *Placenticeras* are known virtually over the whole Northern Hemisphere [39]. Throughout the Late Cretaceous, the planktonic foraminifers penetrated to the Eurasian shores of the Arctic. These both episodes are linked to eustatic rises of sea level in the Turonian and Campanian. Similar algofloras develop in separate regions of the world, first of all in Boreal basin, in the transition from Cenomanian to Turonian [21, 40]. Assemblages of dinocysts of Early Cenomanian—Late Turonian age demonstrate a similarity with coeval assemblages of northern West Europe.

The Cenomanian-Turonian situation is repeated only in the Late Santonian. An outburst of taxonomic diversity of bivalves, foraminifers, and dinocysts is recorded at that time (see Fig. 2). A considerable increase in biota diversity occurs at the expense of the immigrants from the eastern part of the European paleobiogeographical realm and western interior basin of North America. The brightest event is immigration of the cosmopolitan genus of inoceramids *Sphenoceramus* and sea urchins of the genera *Holaster*, *Cordiaster*, and *Hemiaster* close to the North American Boreal forms [18].

The dynamics of taxonomic diversity of mollusks (ammonites, bivalves, gastropods), foraminifers, and dinocysts around the Cenomanian-Turonian boundary gives no ground to suggest a rather considerable biotic restructuring at the boundary of ages (see Fig. 2, curves of taxonomic diversity). The most remarkable event at the boundary of ages is the change of dominants in the benthos: The group of the Late Cenomanian *Inoceramus pictus* is inferior to the Early Turonian group *Mytiloides labiatus*. Thus, the Arctic marine biota gives no evidence in the favor of "mass extinction" around the Cenomanian-Turonian boundary, which is recorded in this interval in the western interior of the USA by several episodes over about 1 mln years in the latest Cenomanian and earliest Turonian [4]. In a "global scale" the restructuring in the taxonomic composition of marine and land biota occurs throughout the Cenomanian age [41].

Evidence of a drastic restructuring of the Arctic marine biota is found in the Middle Turonian. The taxa of bottom mollusks and foraminifers as well as dinocysts became less diverse, and the degree of their endemism increased (see Fig. 2). Thus, only two cosmopolites are known among inoceramids: *I. (I.)* cf. *cuvieri* Sow. and *Mytiloides labiatus* (Sow.) inherited from the Early Turonian. This situation is possibly related to a short regression (genesis of Gaz-Sale sand member in the central part of the Turonian is treated as lagoonic). In any case the overlying marine deposits of the Upper Turonian abound in remains of eight species of inoceramids [38] and other diverse mollusks [18]. In general, however, the Middle Turonian-Early Coniacian time interval, except of the mentioned phase Volviceramus inaequivalvis, is characterized by a low diversity of mollusks, moderate diversity of foraminifers and dinocysts (see Fig. 2). The amount of endemic species grows in all groups of organisms in the Late Turonian and Coniacian. This event seems to be out of coordination with the state of abiotic environment — rather frequent difference in depth and, therefore, variable hydrodynamics (see indicators of the presence of diastems, Fig. 2), differences in temperature caused by variations in depth, and water salinity caused by fluctuations in runoff because of periodical change in the position of shoreline. The increase in the number of endemics contradicts one of the postulates of general ecology, according to which the taxonomic diversity (and, therefore, endemism) grows on stabilization of environmental factors [42]. A possible explanation of this discrepancy could be small sizes of populations because of restricted life space in the northeastern part of the Late Cretaceous West Siberian Sea. The size of populations is inversely proportional to the rate of speciation [43]. In the Late Turonian elements of Early Cretaceous algofloras disappear and taxa began to develop, reaching their climax in the Cenonian. A remarkable event is the appearance of the stratigraphically important genus *Chatangiella* [44].

Around the Turonian-Coniacian boundary, the taxonomic diversity decreases once more, and endemism increases. The structure of dinocyst associations changes considerably, and the pollen of angiosperms becomes more diverse. The Coniacian age is the time of active local speciation among inoceramids (five endemic species). Of special interest is the boundary layer of black clays. It is nearly devoid of remains of macrofossils. Its central part contains a horizon with a high concentration of dinocysts. Their diversity is poor but abundance is high. The Late Turonian-Early Coniacian associations of dinocysts from northern West Siberia are similar to coeval associations of Eastern Canada. The similarity is not, however, complete because of endemism of North Siberian dinoflagellates of that time.

Around the Santonian-Campanian boundary, the bottom communities experience a considerable destruction: In the early Campanian, inoceramids, which made up the core of bottom communities, are completely absent from their composition; the taxonomic diversity of foraminifer associations decreases.

In the Northern Hemisphere, the Campanian boreal transgression is associated with the Late Cretaceous outburst in biota diversity. In the northern West Siberian paleobiogeographical province, this event was linked first of all to microbiota. Over the Arctic basin (data on northwestern West Siberia and vicinities of the Alpha Ridge) the phytoplankton is characterized by the efflorescence of diatoms [22, 23] and dinoflagellates, whose associations are enriched in new genera and species [21]. The Santonian—Campanian is the time of the greatest species diversity of the boreal genus *Chatangiella* [44, 45]. The North Siberian assemblages of dinocysts have much in common with assemblages from the Santonian—Maastrichtian deposits of Arctic Canada, the Mackenzie River delta [46, 47]. The complexes of the Atlantic shore of the USA (New Jersey) and northern West Siberia share no common species, but among scarce peridinioid dinocysts of the genera *Chatangiella*, *Spinidium*, and *Diconidium* some are similar to the species of the Ust'-Yenisei region [48, 49].

The Late Campanian and Early Maastrichtian comprise the greatest number of the genera of benthonic foraminifers (46 and 57, respectively, see Fig. 2). An inverse picture is observed among mollusks: The number of their taxa in the Early Campanian has drastically been reduced among the benthos (only few small-shell genera of paleotaxodonts and heterodonts have been found) as well as among semipelagic taxa (ammonites are represented by one small-shell species of the *Baculites* genus). A drastic depauperation of benthos in the Campanian as compared with the Santonian is, most likely, connected with the change in ground types: from sand-siltstones in the Late Santonian to mostly silt-mudstones in the Early Campanian.

The Campanian-Maastrichtian boundary in the north of West Siberia runs in a uniform sand-siltstone rocks. No bright vestiges of events at the Campanian-Maastrichtian transition have been found. Signs of carbonate sedimentation are absent from the only Maastrichtian section at the Tanama River (the boundary with the Danian is not observed there). The northernmost sections containing carbonate rocks of this age are penetrated by boreholes in the Mid-Ob' region. The carbonate sedimentation in West Siberia is supposed to be involved with the invasion of warm waters of the peri-Tethys through the Turgai strait opened in the Maastrichtian [25]. The cold waters of the Arctic basin seemed to prevent the warm waters from ingress into the Arctic seas. This supposition is feasible as the North American Interior Western Sea-Strait was closed in the north in the Late Maastrichtian and its warm waters ceased to come to the Arctic [50].

The Maastrichtian-Danian boundary of the global restructuring of biota in the Arctic remains to be studied. The boundary interval of the marine Maastrichtian-Danian layers is exposed only by boreholes. Their core is mostly lost. The observed changes in assemblages of mollusks, benthonic foraminifers, and dinocysts indicate, as in other regions of the world, the stepwise character of the Cretaceous-Paleogene biotic crisis [51]. Data on the Arctic suggest climatic causes of biotic restructuring rather than a stepwise impact bearing on a comet shower [3, 52, 53]. Other bioevents are also well linked to climatic fluctuations. Thus, peaks of taxonomic diversity of marine biota in the transition from Cenomanian to Turonian and from Santonian to Campanian coincide with periods of warming, and taxa depauperation in the middle Turonian, middle Campanian, and late Maastrichtian, with coolings. A relatively warm climate in the late Santonian and early Campanian in the western part of the West Siberian basin is inferred from findings of oysters *Pycnodonte*, *Curvostrea*, and *Lopha* on the Synya River in Arctic Cisuralia and on the Seida River in Arctic Transuralia [54]. The Late Cretaceous heat fluctuations established in northern Siberia on the basis of marine biota virtually coincide with reconstructions of warmings and coolings from terrestrial flora of northeasternmost Asia [55].

CONCLUSIONS

As repeatedly emphasized, the Late Cretaceous bottom communities were dominated by inoceramids, which disappeared from Arctic seas in the early Campanian. The latest stages in the development of this group (genus *Tenuipteria*) are documented in seas of northwestern Europe, in the Mediterranean Province and in the south of the Interior Western sea of the USA, where they inhabit warm waters in the late Maastrichtian [56, 57]. In the Campanian, all convolute ammonites and belemnites disappear from northern West Siberia, though in southern seas they continue to exist until the late Maastrichtian. The greatest changes in composition and structure of foraminifer communities were established by Marinov [58] at the lower boundary of the Brotzenella praeacuta Zone in the Late Maastrichtian. Even the dinocyst genus *Chatangiella*, typical of the Arctic, disappears from the sections in the lower Maastrichtian. The last representatives of this genus are known from southern territories: Northern Italy, Israel, New Jersey, Texas [45]. Thus, the Cretaceous-Paleogene biotic crisis in the Arctic realm was displayed earlier than in the paleobiogeographical Tethys-Panthalassa superrealm and even in the south of the Panboreal superrealm. At the same time, it is not distinctly delimited by a certain stratigraphic interval. The dynamics of the taxonomic diversity of the Arctic marine biota suggests that the Late Cretaceous biota was gradually depleted, with dwindling of the geographical range of dominating taxa at the expense of high-latitude water areas and complete extinction of typical Late Cretaceous representatives in the Tethyan seas around the Cretaceous-Paleogene boundary. As shown by many authors and corroborated by us, the cause of extinction is climatic. Simultaneously, the gradual cooling in northern Siberia makes the climate less stable [11]. It is possible that frequent and wide-amplitude fluctuations rather than general cooling were the main cause of destabilization of the habitat of marine organisms and qualitative depauperation of communities.

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