SEDIMENTOLOGICAL AND PALYNOLOGICAL ANALYSIS OF THE CENOMANIAN-TURONIAN EVENT IN NORTHERN SIBERIA

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The Oceanic Anoxic Event that occurred at the transition from Cenomanian to Turonian (OAE2) is a bright episode in the Cretaceous history. The section of the Cenomanian-Turonian terrigene deposits on the Nizhnyaya Agapa River (Ust'-Yenisei region) with vestiges of OAE2 has been analyzed in sedimentology and palynology. Textural features of deposits as well as their facies interactions in the section have been studied in detail. Stagnation and normal-marine settings alternate, which is typical of black-shale facies. This is well expressed in the replacement of shallow-marine sand rocks containing benthic fauna by black and brownish-gray leaf clays with signs of pyritization, without macrofauna, reflecting settings of stagnation. Qualitative and quantitative changes in the composition of organic-wall microphytoplankton have been established, and the facies-dependent dynamics of taxonomic variety of dinocysts has been traced. Comparative analysis of distribution of palynomorphs has been performed in deposits related to the Cenomanian-Turonian Oceanic Anoxic Event in different regions.

Sedimentology, palynology, paleogeography, Late Cretaceous, northern Siberia

INTRODUCTION

The Cretaceous deposits of the Earth bear traces of large geologic (tectonical, paleogeographical, etc.) and biological (changes in fauna and flora) events that transformed the face of our planet. Extremely wide occurrence of carbonaceous facies is a vestige of such global events. Drilling of the deep-water boreholes that penetrated the Barremian-Aptian and Cenomanian-Turonian "black shales" in the south of the Central and in the west of the Northern Pacific gave us a deeper insight into the structure and geographical range of deposits of this type [1]. They formed in different paleobathymetric settings, e.g. on oceanic plateaus, continental margins, and in epicontinental seas. The wide occurrence of this kind of sediments suggests that their formation was not governed by local conditions but resulted from global "oceanic anoxide events", which are treated as a consequence of the cumulative effect of several factors [1–5]. First of all, this is the Late Cretaceous transgression, having increased the area and volume of shallow epicontinental seas, combined with high biological productivity. Of importance are also global warming and climate levelling (decrease in temperature gradients), weakened oceanic circulation dwindling the range of cold, oxygen-saturated bottom waters in the world ocean. Finally, these are factors favoring the development of density stratification, e.g. freshening the surface waters of the shelf by rivers, supplying a great amount of organic matter of terrestrial plants, etc.

Deposits with a higher content of organic carbon exposed by deep-water boreholes are represented chiefly by black or dark-gray mudstones and siltstones, as well as by marls and limestones. Organic matter can be both of marine (sapropel type) and terrestrial (humic type) genesis. These deposits are laminated, with alternating C_{org}-rich and C_{org}-normal interbeds, are bioturbated, and have well-developed communities of benthic fauna [6]. Anaerobic conditions were supposed to appear at the water-sediment boundary; therefore, the burying organisms

could not live there. These facies contain only representatives of epibenthos (mainly, Inoceramidae) and remains of pelagic organisms [4, 5].

One of the most brilliant episodes of the Cretaceous history involved with the problem under consideration is the so-called Oceanic Anoxic Event at the Cenomanian-Turonian boundary (OAE2). It has received thorough study at Tethyan carbonate sections, sections of oceanic sediments, and has been described in many publications. Much less is known about the manifestation of this event in terrigenous deposits of the Boreal and, especially, Arctic basins.

As noted by Naidin et al. [5], the appearance of "black interbeds" in epicontinental sections should be considered against the background of the general structure of their hosting deposits. In this connection, of great interest is one of the best sections in northern Eurasia, the Cenomanian-Turonian section of terrigenous deposits on the Nizhnyaya Agapa River (near Ust'-Yeniseisk). Saks and Ronkina [7] inferred the existence of Cenomanian marine deposits in the Ust'-Yeniseisk depression from the interbeds with chamosite and glauconite found among the sands penetrated by boreholes on the Yakovlev arch and palynologically dated to the Cenomanian. But the actual disclosure of Upper Cenomanian marine sediments was made in 1988, when a group of paleontologists and lithologists of the UIGGM, Novosibirsk, including A.L. Beisel, K.V. Zverev, N.K. Lebedeva, and O.V. Khomentovsky, under the leadership of V.A. Zakharov, investigated the Upper Cretaceous in the Agapa basin. A 100 m thick section of terrigenous sand-clay deposits had been described on the Nizhnyaya Agapa River. It contained abundant fauna, including Inoceramidae, which indicated the presence of the Upper Cenomanian and permitted the Cenomanian-Turonian boundary to be located [8]. As a result of detailed sedimentological, paleontological, and palynological studies, a composite section of the Upper Cenomanian-Turonian has been constructed, parallel stratigraphic scales based on Inoceramidae and dinoflagellate cysts (dinocysts) have been developed, and main biotic and abiotic events that affected the sediment formation have been reconstructed [8–15].

Recent investigations have been focussed on distribution of various organisms, including organic-wall microphytoplankton, in the Cenomanian-Turonian deposits with traces of OAE2 on the European continent, in Great Britain, and in North America. This was an impetus to continue this line of work, as a detailed palynological analysis of the Nizhnyaya Agapa section has revealed diverse complexes of microphytofossils, including spores and pollen of terrestrial plants, dinocysts, prasinophytes, acritarchs, and other groups of unclear systematics.

The present paper is aimed at studying qualitative and quantitative changes in composition of microphyto-plankton, dynamics of taxonomic diversity of dinocysts as a function of facies in the Nizhnyaya Agapa section and at comparing the distribution of palynomorphs in the deposits related to the Cenomanian-Turonian OAE in separate regions.

MATERIALS AND METHODS

The sedimentology of deposits was studied at natural outcrops along the Nizhnyaya Agapa River and its tributaries. Since the rocks are fairly well exposed and are easy-to-investigate in exposures as well as in systems of artificial trenches (at less exposed sites), we had a possibility to study textural features of the deposits and their facies relationships in the section. The composite section has been built on the basis of correlation by lithological and paleontological methods of numerous outcrops of Cenomanian-Turonian deposits (see Fig. 1).

A comment is needed here. Khomentovsky [14] has developed a zonal Inoceramidae scale for the Upper Cretaceous of the Ust'-Yeniseisk region. In the upper part of the section on the Nizhnyaya Agapa River in the Nasonov Formation, he has established the In. (In.) cf. cuvieri Subzone within the In. (In.) lamarcki Zone and has indicated a stratigraphic range, Upper Turonian, since the 1991 Stratigraphic Scheme adopts a bipartite division of the Turonian [16]. However, in the hypostratotype sections of the Northwestern Europe the In. (In.) lamarcki and In. (In.) cuvieri Zones date from the Middle Turonian. Therefore, to avoid confusion in the existing stratigraphic constructions, we will keep to this dating. Layer by layer, 57 samples were taken from all exposures and were processed by standard techniques for palynological analysis. As a result, not only spores and pollen of terrestrial plants were recognized but also spores of water ferns, one-cell organic-wall algae of Dinoflagellata, Chlorophyla (class Prasinophyceae), a group of unclear systematics (acrtitarchs), fresh-water microfossils of the formal genus *Schizosporis*.

Percentages of terrestrial and marine palynomorphs were counted in all spectra. Within the marine microphytoplankton, quantitative contents of different groups were determined for each spectrum and circograms were plotted. Then spectra of the same type were grouped into associations whose distribution was followed over the section.

DESCRIPTION OF THE SECTION OF CENOMANIAN-TURONIAN DEPOSITS ON THE NIZHNYAYA AGAPA RIVER

The most ancient rocks of the Upper Cretaceous of the western part of the Yenisei-Khatanga megatrough outcrop at the upper reaches of the Nizhnyaya Agapa River (Fig. 1). The explored section of the Upper Cenomanian-Turonian is represented by loose terrigenous deposits about 100 m thick and is characterized by a wide facies diversity. At the bottom of the composite Upper Cretaceous section, the Dolgan Formation occurs (Upper Cenomanian), represented chiefly by sandy, continental, and clay-silty, brackish-water transient deposits. Above, they are replaced by marine clays of the Dorozhkovo Formation (Upper Cenomanian–Lower Turonian). The Upper Cretaceous section is crowned by shallow-marine sands of the Nasonov Formation (Middle Turonian), which are quite drastically, with a minimal transient interval, overlap the sea siltstones and clays of the Dorozhkovo Formation. A general tendency toward an increase, from bottom to top, of the volume of fine-grained silty-clay deposits in the lower and central parts of the composite section, accompanied with the appearance of wave textures and remains of typical sea organisms in the rocks, reflects the sea transgression that began in the Upper Cenomanian from the west to the area of continental sedimentation.

A complicate multistage structure of channel sand deposits (Member I) and its fairly great thickness, with interchannel deposits rather scarce, suggest that this portion of the section had formed within a large river system of branching type, characterized by active lateral migration of channels, their multiple raisings and incisions within the paleovalley. The channel sands are overlain by sand-silt-clay rocks that formed in fresh-water, brackish-water (Member II, bottom), and marine (Member II, top) conditions. This unit can be considered as estuarine deposits, transient to marine deposits of a shelf system. The formation of a transient unit is connected with a gradual change of the general conditions of sedimentation from continental to estuarine settings partially pinched off the open sea and characterized by accumulation of predominantly fine-grained sediments. In this part of the section, rocks accumulated under perpetually decreasing influence of alluvial processes upon sedimentation and simultaneous increase in the influence of sea processes as transgression begins.

The member of leptochlorite sands with tubercular cross lamination (Members III and IV) overlying, with some erosion, fine-grained estuarine deposits is interpreted as transgressive shallow-sea cover sands. The source of sedimentary material that forms the cover of transgressive sand was, evidently, sand banks or small transgressive barrier islands developed at the estuarine mouth at the cost of wave processing of the underlying alluvium sediments. The absence of truly barrier deposits (beach sands of the frontal part of the barrier and/or sand eolian dunes), with the exception of fine layers of storm wash cones, among the clays and silts of the upper part of the estuarine deposits suggests deep erosion of underlying sediments while the shore line retreated landward. Such complete erosion of barrier deposits was promoted by a relatively small rate of transgression at which their complete wave reworking proceeded through a mechanism of the retreatment of the pre-frontal zone of the beach, with only a thin bed of transgressive sands formed *in situ*.

Paleontologically, the beginning of sea transgression is marked by a dinocyst-dominating microphytoplankton which appears in clays (Fig. 2). Macrofauna (Inoceramidae) appears only in Member IV.

The formation of shallow-sea transgressive sands of marine, predominantly, silty-clay deposits (Members V–XIII) reflects the formation of quiet conditions of sedimentation at the inner shelf which followed transgression. The shallow-sea sand and silt rocks (Members III, IV, VIII) with the benthic fauna, complicating the structure of the shelf complex, are often overlapped by black and brownish-gray leaf clays with signs of pyritization, without bioturbation and macrofauna (Members V, X, and XI). These clay-richest parts of the section usually contain horizons of dispersed phosphorite concretions in their primary occurrence. According to some authors [17], the presence of phosphorite concretions among clay siltstones and clays in these parts of the section suggests low rates of sedimentation. Given extremely low, if any, hydrodynamic activity of the medium, slow rates of accumulation are favorable for anaerobic infection. These conditions of sedimentation, most likely, existed during the accumulation of leaf clays, which can be inferred from pyrite nodules present in them as well as from the absence of any traces of life activity or remains of organisms.

The nonuniform character of the structure of the central part of the composite Upper Cretaceous section, caused by the appearance of members of leptochloritic sands and silts among silty clays at some stratigraphic level of the Dorozhkovo Formation (Members VIII, X, and XII), imply multiple periodical changes of sedimentation conditions in connection with short-period sea level fluctuations and/or variations in the amount of sediments brought to the basin. The specific structure of members of leptochloritic sands and siltstones (distinct sole and roof, inner surfaces of erosion, numerous horizons of redeposited phosphorite nodules, increased content of heavy minerals, including authigenic ones, connected with their concentration at the cost of sediment rewashing) implies
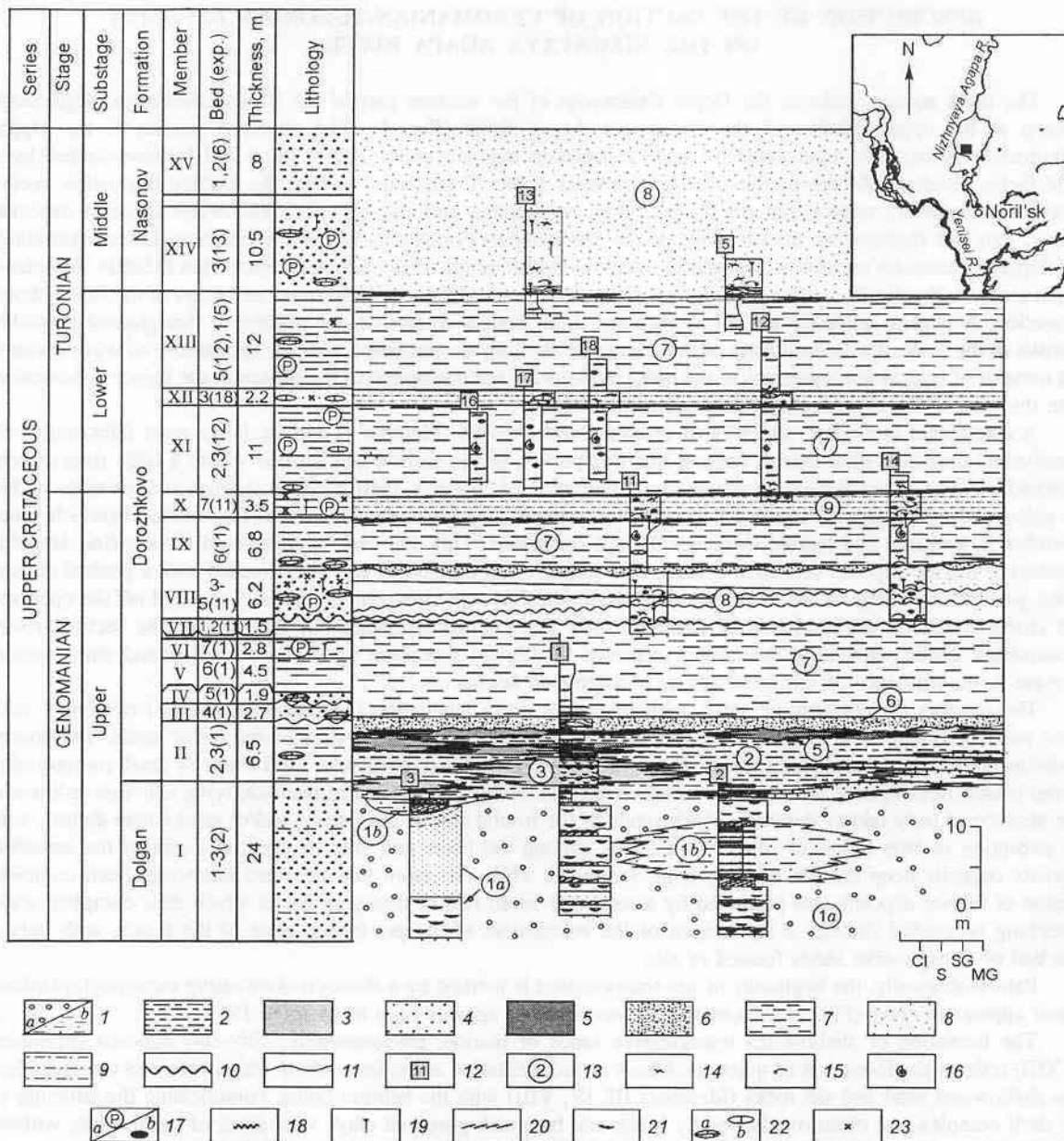
Fig. 1. Schematic lithofacies dismembering and interpretation of the Cenomanian-Turonian deposits of the Nizhnyaya Agapa basin. Deposits: *1a* — alluvial, largely sandy, of active channels, *1b* — sandy-clayey-silty fillings of inactive channels and interchannel areas, *2* — silty-clayey estuarine, *3* — tidal deltas of the rear part of the barrier-island system; *4* — fan-rill system; *5* — storm fans; *6* — shallow-sea transgressive sands; *7* — clayey silts and clays of inner shelf; *8* — shallow-sea beach sands; *9* — rather shallow-water siltstones of distal beach; *10* — marine erosion surfaces; *11* — transgressive erosion surfaces; *12* — numbers of exposures; *13* — sedimentary settings; *14* — remains of charred wood; *15* — bioclastics; *16* — macrofauna; *17* — phosphate concretions (*a*) and nodules (*b*); *18* — mud-eaters; *19* — lugworms; *20* — fine cross lamination of ascending current ripple; *21* — coarse cross lamination of trough kind; *22* — concretions: *a* — calcareous, *b* — sideritic; *23* — leptochlorite. Horizontal scale is arbitrary. Symbols on granulometric rule: Cl — clay; S — silt; SG — small-grained, MG — medium-grained sand.
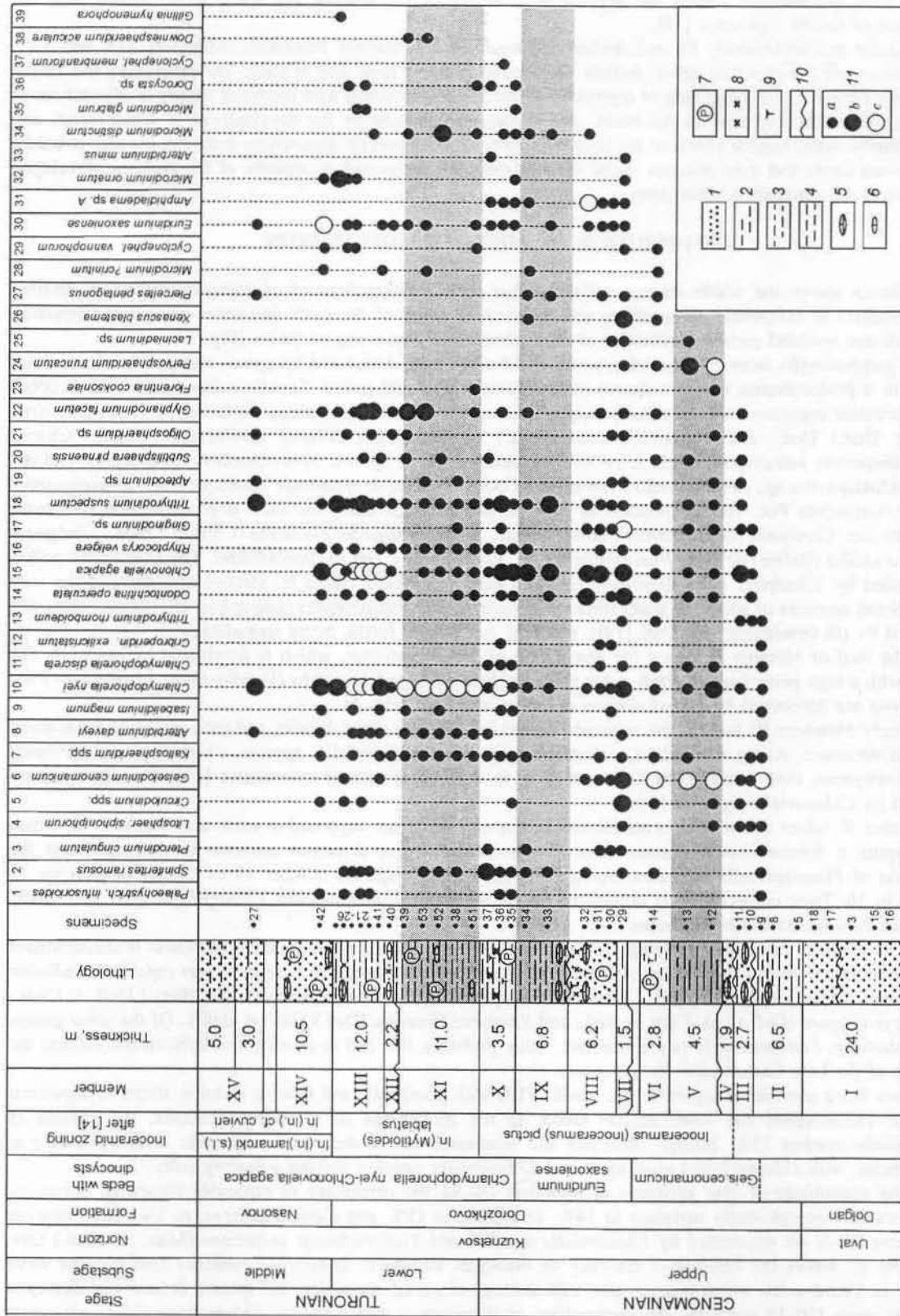
Fig. 2. Distribution of dinocysts in the Nizhnyaya Agapa section. Background – supposed stagnation settings. 1 — sand; 2 — silt; 3 — clayey silt; 4 — clay; 5–7 — concretions: 5 — calcareous, 6 — sideritic, 7 — phosphatic; 8 — leptochlorite; 9 — bioturbation; 10 — erosion boundary; 11 — content of dinocysts: a — rare (0–5%), b — persistent (5–10%), c — abundant (>10%).

that they were accumulated during the periods of lowering of the relative sea level, accompanied with the development of forced regression [18].

Obliquely and horizontally layered shallow-sea sands of the Nasonov Formation (Members XIV and XV), crowning the studied Upper Cretaceous section, correspond to a new large step of shore-line prograding that began in the Upper Turonian. The beginning of regression seemed to be connected with increased supply of allochthonous sedimentary material from land to the basin, which was accompanied by the development of trend (sand) and chenier (chiefly, silty) seaside plains in the interdelta parts of the shoreline. Proceeding from the specific structure of shallow-sea sands and their position in the section, they are interpreted as deposits of bar beaches, developed at the front of the prograding wave delta.

DISTRIBUTION OF MICROPHYTOPLANKTON

As shown above, the whole section contains rather diverse associations of microphytoplankton. A detailed lit-by-lit analysis of taxonomic composition and quantitative ratios of dinocysts and other groups of vegetation microfossils has revealed certain regularities of their distribution depending on facies (Fig. 3).

The palynomorphs from continental deposits of Member I are dominated by spores and pollen of terrestrial plants, with a predominance of moss spores (*Stereisporites* spp.) and pollen *Taxodiaceaepollenites hiatus* (Pot.) Kremp; persistent organisms are: *Cyathidites* spp., *Ruminatisporites delicatus* Strep., *Foraminisporis asymmetricus* (Cooks et Dett.) Dett., *Baculatisporites comaumensis* (Cooks.) Pot., *Lobatia involucrata* (Chlon.) Chlon., *Lycopodiumsporites marginatus* Singh, *L. cerniidites* (Ross) Delc. et Sprum., *Foveosporites cenomanicus* (Chlon.) Schvetz., *Klukisporites* sp., *Aequitriradites verrucosus* Cooks. et Dett., *A. spinulosis* Cooks. et Dett., *Rouseisporites* sp., and *R. reticulatus* Poc. The composition of gymnosperm pollen is nearly the same over the section. The main components are: *Cerdipites parvisaccatus* (Sauer) Chlon., *Sequoiapollenites cretaceus* (Chlon.) Chlon., *Ginkgocycadophytus nitidus* (Balme) de Jars., *Pinuspollenites* sp., *Vitreisporites*, and *Phyllocladidites*. The angiosperm pollen is represented by *Tricolpites* spp., *Retitricolpites* spp., with *Polyporites clarus* N. Mtched appearing at the very top [13]. Small amounts of spores of water ferns, *Schizosporis*, and prasinophytes (*Leiosphaeridia*) occur; dinocysts categorized Px (in terminology by Evitt [19]), possibly, fresh-water forms, occur sporadically.

At the roof of Member II occurs the association of sea microfossils, which is dominated by dinocysts (14 species), with a high percentage of fresh-water phytoplankton (6%) and acritarchs (*Veryhachium*, *Leiofusa* — 7%); the dinocysts are dominated by *Geiselodinium cenomanicum* Leb. (Fig. 4).

In sandy Members III and IV, the microphytoplankton becomes more diverse, and the amount of fresh-water component decreases. Along with others, an interesting group, *Paralecaniella*, appears, which first was attributed to Volvocophyceae, then to dinocysts [20], and now, to a group of unclear systematics [21]. The dinocysts are dominated by *Chlonoviella agapica* Leb.

Member V, where macrobiota is absent and anoxic conditions are supposed to exist, and Member VI, which contains quite a diverse benthic fauna, share an assemblage where dinocysts continue to dominate, and the contribution of Pterospermella increases (up to 9%). The dinocyst species number 19 to 22 and only in sp. 13 decreases to 16. Their composition is dominated by *Geiselodinium cenomanicum*, *Chlamydophorella nyei* Cook. et Eis., and *Pervosphaeridium truncatum* (Dav.) Below.

The assemblage from the overlying clay member (VII, sp. 29) 1.5 m in apparent thickness is distinguished by the maximum taxonomical diversity of dinocysts (32 species). It abounds in *Circulodinium* spp., *Geiselodinium cenomanicum*, *Chlamydophorella nyei*, *Chlonoviella agapica*, *Odontachitina operculata* (O. Wetz.) Defl. et Cook., *Phyptocorys veligera* (Defl.) Lej.-Carp. et Sarj., and *Xenascus blastema* (Dav.) Stov. et Halby. Of the other groups of microplankton, *Pterospermella* is predominant. Quite probably, this bed is a condensed horizon and reflects the maximum of the Late Cenomanian transgression.

Above lies a member of leptochloritic sands (VIII) with phosphatic and siderite nodules, traces of lugworms (Skolithos, Phiomorpha) and Inoceramidae fauna. In the assemblage of microphytoplankton, the amount of *Paralecaniella* reaches 25%. Though dinocysts still dominate, their content and taxonomic diversity reduce to 13–19 species, with *Odontochitina operculata* and *Chlonoviella agapica* playing a leading role.

In the assemblage of clay siltstones of Members IX–XI, the percentage of dinocysts somewhat decreases. The amount of *Pterospermella* increases to 14%, acritarchs, to 15%, and *Cymetiosphaera*, to 5%. The dinocysts of Members IX–X are dominated by *Chlonoviella agapica* and *Trithyrodinium suspectum* (Man. et Cook.) Dav. In Member X, where the taxonomic diversity of dinocysts increases, *Spiniferites ramosus* also become more abundant. In Member XI, which is associated with settings of partial stagnation, the species diversity of dinocysts diminishes again (10–16 species). The composition of dinocysts is dominated by *Chlamydophorella nyei*, while
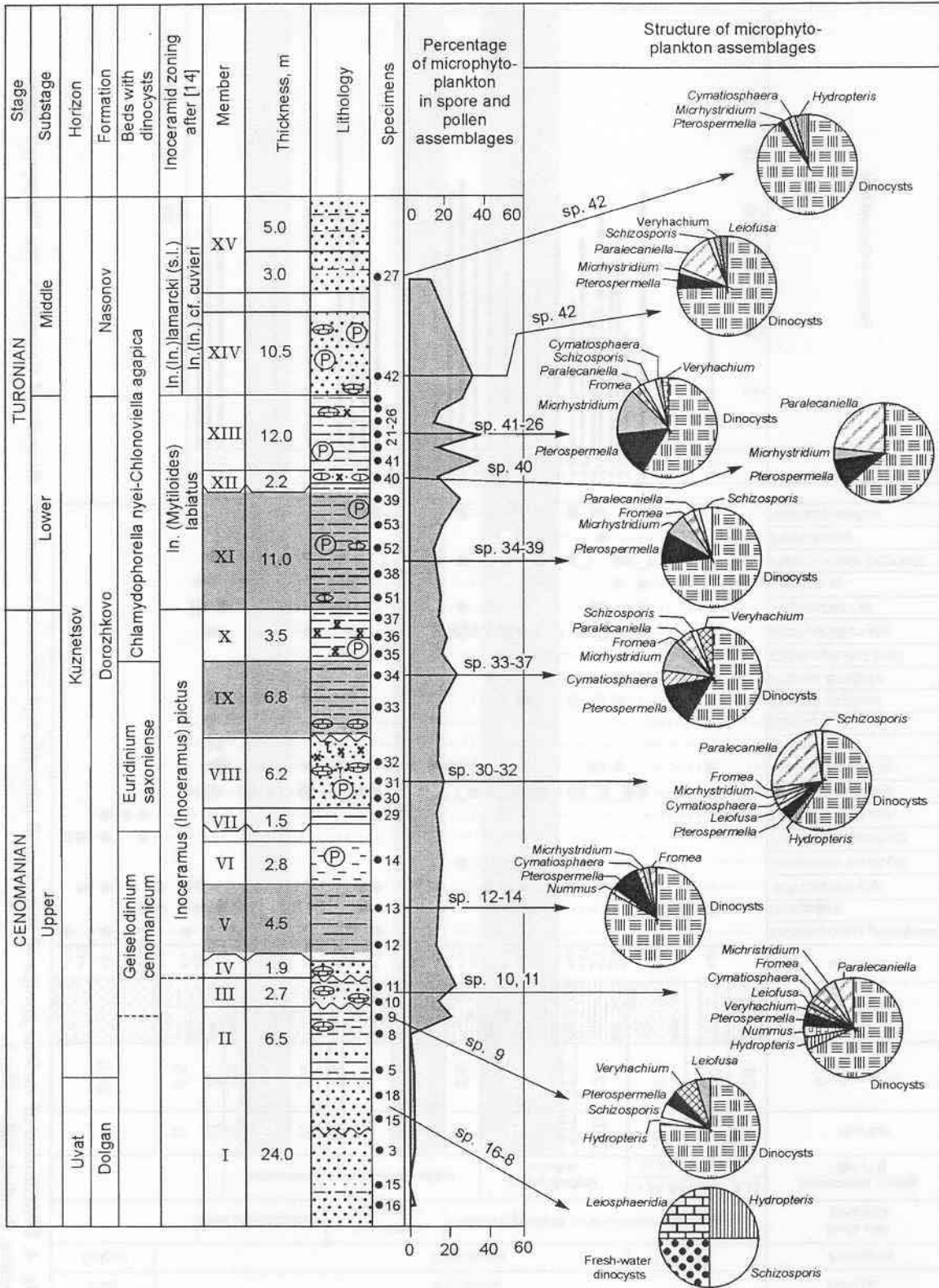
**Fig. 3. Structure of microphytoplankton assemblages in the
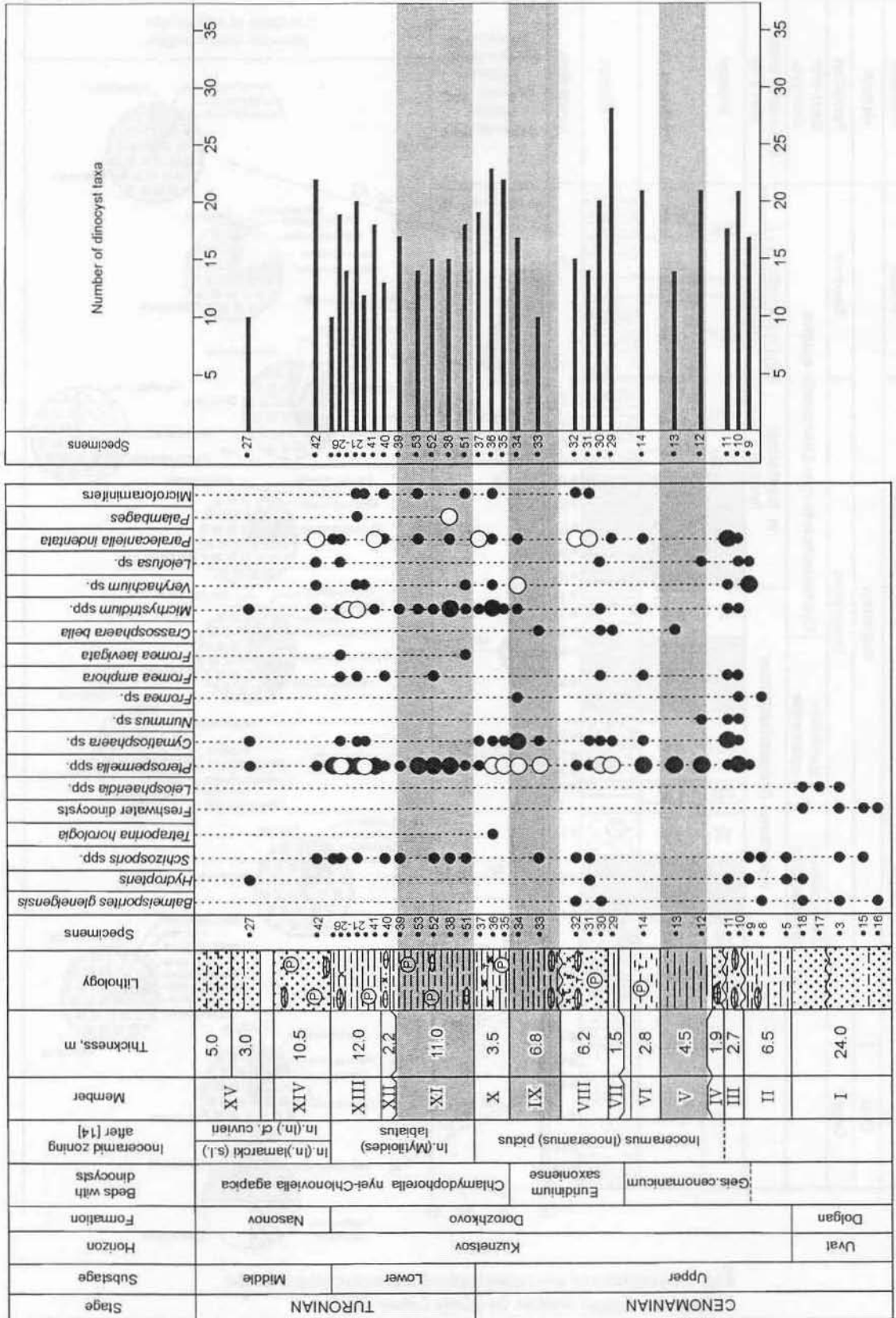Nizhnyaya Agapa section. Symbols follow Fig. 2.**

Fig. 4. Distribution of various groups of organic-wall microphytoplankton and taxonomic diversity of dinocysts in the Nizhnyaya Agapa section. Symbols follow Fig. 2.

the amounts of *Trithyrodinium suspectum* and *Chlonovella agapica* become less. *Cymatiosphaera* and *Veryhachium* are missing.

In sp. 40 from leptochloritic sands (Member XII) the content of *Pterospermella* is kept the same, *Paralecaniella* increases to 22%, the species diversity of dinocysts is considerably reduced (to 11 species).

In the overlying member of clay siltstones (XIII) the structure of the microphytoplankton assemblage is similar to that in Member X. In sand Member XIV the amount of *Paralecaniella* increases again (up to 13%). The diversity of dinocysts is rather great (22 species), with *Chlamydophorella nyei, Chlonoviella agapica,* and *Euridinium saxoniense* Marsch. et Batt. being predominant.

In the assemblage from sp. 27 (Member XV), a decrease is recorded in the percentage of marine microphytoplankton in the spore-pollen spectrum and in the species diversity of dinocysts (11 species). Only *Chlamydophorella nyei* and *Trichyrodinium suspectum* are fairly abundant. Again, spores of water ferns appear.

In recent time, a great deal of data have been published on the distribution of dinocysts and other microphytoplankton in section with traces of OAE2.

In the Cenomanian-Turonian carbonate deposits of Dover, England, isotope analysis records an oceanic anoxic event [22]. A possible cause for it is increased upwelling, leading to a wide occurrence of the zone of oxygen minimum. Prasinophytes have not been recorded in these deposits. As to dinocysts, they are absent from the interval corresponding to the anoxic event and then reappear nearly in the same composition as they were before the zone of oxygen minimum. Great abundance of *Kallosphaeridium* is also typical of this range. At the explored section on the Nizhnyaya Agapa River this genus of dinocysts is not abundant and is spread evenly.

The complexes of Cenomanian-Turonian dinocysts separated from bituminous marls of Northern Europe (Lower Saxony basin, Germany, and Eastern England) differ in composition according to lithofacies [23]. The authors have recognized two main assemblages of dinocysts. The first one, *Spiniferites* assemblage, is confined to chalk and marls that formed in open sea settings. It has also been found in organic-enriched marls, where an oxygen zone is supposed to rest upon an oxygen-depleted zone in the stratified water column. The *Cyclonephelium-Euridinium* assemblage is usually found in specimens rich in amorphous organic matter. In the authors' opinion, this indicates the conditions with a low content of oxygen, which is supposedly the case of the formation of a stagnation basin within which no water circulation occurred [23]. A similar regularity in distribution of dinocysts has been recognized in the Lower Turonian bituminous clay marls and marl limestones on the island of Helgoland (southern North Sea) [24].

According to Naidin et al. [5], in basins of the European paleogeographical region, stagnation encompassed local sites of the bottom and was "sliding" from place to place. The dinocyst complexes from open-sea settings are fairly diverse, with the chorate morphotype of Gonyaulax forms (*Achomosphaera, Exochosphaeridium, Florentinia, Spiniferites, Pterodinium,* etc.). Such complexes have been described from the Cenomanian-Turonian deposits of Southern England, France, and Germany [24, 25].

A detailed palynological analysis of Cenomanian-Turonian carbonaceous slates and marls of the western interior of the USA has demonstrated that the reduced diversity of dinocysts is bearing on the prograding shoreline, that dinocysts are most abundant in the lower part of the transgressive cycle rather than at the maximum transgression, and that the *Spiniferites/Cyclonephelium* ratio increases off the shore and during transgression [26].

Comparison shows that the data on the distribution of organic-wall microphytoplankton are rather diverse, which is possibly due to the type of the sections under study and to different conditions under which they formed. Worthy of note is that ecologically the dinoflagellates are quite diverse. They comprise autotrophs and heterotrophs, benthic and planktonic forms, with the latter essentially dominating. This possibly accounts for the variations in taxonomic composition of dinocysts and abundances of some species. The oxygen deficiency in the bottom waters seems to affect most of all autotrophic and benthic forms of dinoflagellates. Nevertheless, the change in physicochemical conditions during stagnation should affect the whole structure of algal flora.

DISCUSSION

Typical of carbonaceous facies, the alternation of anoxic and normal-sea settings is also well-expressed in the Upper Cenomanian deposits of the Nizhnyaya Agapa basin. In particular, the shallow-sea sand rocks (Members IV and VIII) with benthic fauna grade upsection into black and brownish-gray leaf clays with signs of pyritization, without macrofauna, reflecting stagnation settings (Members V, IX, and XI). The fairly homogeneous composition of leaf clays, with no silt-sandy sediments with wavy textures in them, suggests their accumulation in relatively deep-water (below the storm wave basis) parts of sea basin under conditions of background sedimentation. The presence of phosphorite nodules among clay sitstones and clays in the part of the section is indicative of low rates of sedimentation [17], which also favored the development of anoxic conditions. An increase in hydrodynamic

activity, related to gradual shallowness as a result of regression, and/or change in wave climate (an increase in quantitative parameters of waves, frequency and intensity of storms) which caused an improvement in aeration of bottom waters (at the cost of wave mixing of the water column) led then to the accumulation of typically marine sand-silty sediments with traces of bioturbation, with the nektonic and benthic faunas (Members VI and VIII). Repeated development of anoxic conditions in the basin could be connected with its relative deepening, in connection with the beginning of a new phase of transgression, and was caused by climatic changes, in particular, with a general weakening of the hydrodynamic activity of the medium, caused by a change in the wave regime.

Despite the absence of geochemical data, one can suppose that humic matter dominated over sapropel in accumulated organics. The evidence comes from abundant terrestrial vegetation that covered the land subsequently overflooded with sea, whose traces remained in the alluvial deposits (dispersed plant detritus, wood, amber). The subsequent removal of terrestrial vegetation matter was also considerable, which is inferred from the predominance of spores and pollen over marine microphytofossils, the presence of fresh-water algae, spores of water ferns (see Fig. 3), and inclusions of coalified detritus in sediments and concretions.

The data on macrofauna and algal flora from the Upper Cenomanian–Lower Turonian deposits on the Nizhnyaya Agapa River are indicative of a fairly warm climate. First, comparison of dinocyst complexes from these sediments shows the greatest similarity with coeval complexes of West Europe. Second, the composition of dinocysts is dramatically dominated by Gonyaulax forms, though they are less abundant there than in Tethian sections. Third, there is a great diversity of species and genera. All morphotypes of dinocysts are present there in equal proportions [13]. This is all in agreement with paleontological data indicating a fairly warm climate in northern Siberia: This is one of the levels of invasion of warm-loving forms of macrofossils (ammonites, bivalves) [10, 11].

An important biological event of the Late Cretaceous epoch was a drastic increase in taxonomic diversity and biological productivity of phyto- and zooplankton, the plankton "boom" [4, 5], which also played an important role in the formation of carbonaceous facies. In the Tethian basins it was expressed in the widest development of calcareous nannoplankton (coccolithophorides) and, to a less extent, of zooplankton (foraminifers), which induced the accumulation of thick planktonic carbonate sediments. In the Boreal basins, where terrigenous and siliceous sedimentation was predominant, the core of phytoplankton communities was made up of diatomaceous and organic-wall algae — dinoflagellates, with their fossils represented by their cysts — dinocysts.

The facies change in the section of Cenomanian-Turonian deposits on the Nizhnyaya Agapa River is accompanied by a change in the structure and composition of microphytoplankton assemblages, though it is not always clear which factors are crucial in one case or another. Thus, quantitative relationships of various groups of plant microfossils from clay Members V, IX–XI, and XIII are very close, and the taxonomic composition and percentage of dinocysts differ very much. Of great interest is the recurrent increase in *Paralecaniella* and reduced species diversity in leptochlorite sands. The clay deposits are characterized by an increased content in *Pterospermella*, accompanied with an increased content of *Michrystridium* in the Turonian part. The taxonomic diversity of dinocysts varies within narrow limits. Smaller numbers of species were recorded in clay Members V and IX, where anoxic conditions are supposed to exist, and in members of leptochloritic sands (III, IV, VIII, and XII). The regression stage also comes to an end with the dinocysts less diverse.

The recorded microphytoplankton relations to anoxic events suggest various conditions under which "black shales" formed. It is likely that anoxic conditions themselves had no direct effect on the planktonic organisms. Rather, the plankton was affected by the factors that led to these conditions (e.g., water stratification by salinity, density, temperature, etc., upwelling, and other causes) or by the resulting factors (e.g., enrichment of bottom waters in organic matter). It is evident that the degree and duration of anoxic events were different in separate districts, and this also had an effect on the composition of phytoplankton assemblages.

REFERENCES

1. Schlanger, S.C., and H.C. Jenkyns, Cretaceous oceanic anoxic events: causes and consequences, *Geologie en Mijnbouw*, 3–4, 179–185, 1976.

2. Jenkyns, H.C., Cretaceous anoxic events: From continents to oceans, *J. Geol. Soc.*, **137**, 2, 171–188, 1980.

3. Schlanger, S.C., and M.B. Cita, *Nature and origin of Cretaceous carbon-rich facies*, 230 pp., Acad. Press, N.Y., 1982.

4. Krasilov, V.A., *The Cretaceous. Evolution of the Earth's crust and biosphere* [in Russian], 240 pp., Nauka, Moscow, 1985.

5. Naidin, D.P., V.P. Pokhialainen, Yu.I. Kats, and V.A. Krasilov, *The Cretaceous. Paleogeography and paleoceanology* [in Russian], 262 pp., Nauka, Moscow, 1986.

6. Murdmaa, I.O., *Geological formations of the northwestern Atlantic* [in Russian], 943–946, Nauka, Moscow, 1979.

7. Saks, V.N., and Z.Z. Ronkina, *Jurassic and Cretaceous deposits of the Ust'-Yenisei depression* [in Russian], 232 pp., Gosgeoltekhizdat, Moscow, 1957.

8. Zakharov, V.A., A.L. Beizel, and V.P. Pokhialainen, Discovery of the marine Cenomanian in northern Siberia, *Geologiya i Geofizika (Soviet Geology and Geophysics)*, **30**, 6, 10–13(7–10), 1989.

9. Zakharov, V.A., A.L. Beisel, N.K. Lebedeva, and O.V. Khomentovskii, Evidence of Upper Cretaceous world ocean eustacy in the north of Siberia, *Geologiya i Geofizika (Soviet Geology and Geophysics)*, **32**, 8, 8–14(1–6), 1991.

10. Zakharov, V.A., A.L. Beisel, O.A. Betekhtina, et al., The main biotic events in the Phanerozoic of Siberia, in *Problems of pre-anthropogenic evolution of the biosphere* [in Russian], 25–54, Nauka, Moscow, 1993.

11. Zakharov, V.A., A.L. Beisel, Yu.I. Bogomolov, et al., Stages and periodicity in the evolution of marine ecosystems of the Boreal Mesozoic, in *Ecosystem restructurings and evolution of biosphere* [in Russian], issue 1, Eds. A.Yu. Rozanov and M.A. Semikhatov, 139–151, Nedra, Moscow, 1994.

12. Zakharov, V.A., A.L. Beisel, N.K. Lebedeva, and O.V. Khomentovsky, The novelty in the Upper Cretaceous of Northern Siberia, in *Proceedings of the conference "Urgent Problems of Geology and Geography of Siberia"* [in Russian], 210–215, Tomsk, 1998.

13. Il'ina, V.I., I.A. Kul'kova, and N.K. Lebedeva, *Microphytofossils and detailed stratigraphy of the marine Mesozoic and Cenozoic of Siberia* [in Russian], 190 pp., OIGGM SO RAN, Novosibirsk, 1994.

14. O.V. Khomentovsky, *Inoceramidae (Bivalvia) and biostratigraphy of the Upper Cretaceous of northern Siberia. PhD Thesis* [in Russian], 20 pp., OIGGM SO RAN, Novosibirsk, 1998.

15. Sahagian, D., O.V., Pinous, A.G. Olferiev, and V.A. Zakharov, Eustatic curve for the Middle Jurassic—Cretaceous based on Russian Platform and Siberian stratigraphy: zonal resolution, *AAPG Bull.*, **80**, 9, 1433–1458, 1996.

16. *Resolutions of the Fifth Interdepartmental Regional Stratigraphic Meeting on Mesozoic Deposits of the West Siberian Plain* [in Russian], 54 pp., ZapSibNIGNI, Tyumen', 1991.

17. Heckel, P.H., Recognition of ancient shallow marine environments, in *Recognition of ancient sedimentary environments. Tulsa, Soc. Econ. Paleont. Miner., Spec. Publ.*, 16, 226–286, 1972.

18. Posamentier, H.W., J.P. Allen, D.P. James, and M. Tesson, Forced regression in a sequence stratigraphic framework: Concepts, example and exploration significance, *Bull. Amer. Assoc. Petrol. Geol.*, **76**, 1687–1709, 1992.

19. Evitt, W.R., *Sporopollenin dinoflagellate cysts. Their morphology and interpretation*, 333 pp., Austin, American Association of Stratigraphic Palynologists Foundation, 1985.

20. Elsik, W.C., Paralecaniella indentata (Defl. and Cook., 1955) Cookson and Eisenack 1970 and allied dinocysts, *Palynology*, **1**, 95–102, 1977.

21. Fensome, R.A., G.L. Williams, M.S. Bars, J.M. Freeman, and J.M. Hill, *Acritarchs and fossil prasinophytes: an index to genera, species and infraspecific taxa*, 771 pp. Contribution series, 25, Austin, AASP, 1990.

22. Jarvis, I., G.A. Carson, M.K.E. Cooper, et al., Microfossil assemblages and the Cenomanian—Turonian (Late Cretaceous) oceanic anoxic event, *Cretaceous Research*, **9**, 3–103, 1988.

23. Marshall, K.L., and D.J. Batten, Dinoflagellate cyst association in Cenomanian—Turonian — "Black shale" sequences of Northern Europe, *Rev. Palaeobot. and Palynol.*, **54**, 85–103, 1988.

24. Batten, D.J., and K.L. Marshall, Palynology of Upper Cretaceous "Black Shales" from Helgoland, southern North Sea, *Geol. Jb.*, **A120**, 105–115, 1991.

25. Tocher, B.A., and I. Jarvis, Dinocyst distribution and stratigraphy of two Cenomanian—Turonian boundary (Upper Cretaceous) sections from the western Anglo-Paris basin, *J. Micropaleont.*, **14**, 97–105, 1995.

26. Li, H., and D. Habib, Dinoflagellate stratigraphy and its response to sea level change in Cenomanian—Turonian sections of the Western Interior of the United States, *Palaios*, **11**, 15–30, 1996.