

Palynofacies in Upper Cretaceous Sediments of Northern Siberia

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Abstract—Different palynomorph groups (spores and pollen of terrestrial plants, dinoflagellate cysts, prasinophytes, acritarchs, *Zygnemataceae* algae, and others) have been thoroughly studied to define major patterns in their distribution depending on the impact of different environmental factors and to establish their paleoecological characteristics. The comparative analysis of palynomorph assemblages from coeval Cenomanian–Coniacian sediments of the Ust'-Yenisei area, Berezovskaya 23k, Yuzhno-Russkaya 113, Leningradskaya-1 boreholes and Santonian–Campanian sequences of the Ust'-Yenisei, Khatanga and Polar Urals regions reveals transgressive–regressive cycles, which are best evident in coastal sections and smoothed in their marine counterparts. The biofacies and compositions of palynomorphs form the regular succession from the periphery toward central parts of the West Siberian basin. The facies successions in Santonian–Campanian sections of the eastern and western parts of the basin are inconsistent with each other, which may be explained by influence of both the West Siberian and Russian seas on sedimentation in its western areas.

Key words: palynomorphs, Upper Cretaceous, biofacies, northern Siberia.

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INTRODUCTION

The significance of microphytofossils for paleogeographic and paleoecological reconstructions is one of the most complex and debatable questions. The distribution of different palynomorph groups, including dinoflagellate cysts, acritarchs, and unicellular green algae, through bionomic zones of sea, depends on many interrelated factors, the influence of which on the biota structure frequently cannot be discriminated when reconstructing different parameters of paleobasins (depth, salinity, hydrodynamics, isolation degree of the basin, water chemistry, and others).

This work continues the series of papers dedicated to paleoecological properties of marine microphyto-fossils and their significance for reconstructing habitat conditions (Lebedeva and Zverev, 2003; Lebedeva, 2008a, 2008b). They present the results of the biofacies analysis of palynomorphs from natural outcrops of Upper Cretaceous sediments in the Ust'-Yenisei area. This section was selected to serve as a standard for development of methodical approaches, since it is composed of different-facies sediments with abundant and diverse assemblages of plant microfossils and is well studied both in the paleontological and sedimentological aspects (Zakharov et al., 1986, 1989, 1991, 1998, 2002, 2003; Sakharov and Khomentovsky, 1989; Sahagian et al., 1996; Zverev, 1999; Lebedeva and Zverev, 2003; Lebedeva, 2006a). The analysis of quan-

titative characteristics of individual palynomorph groups, morphotypes and taxa of dinocysts, as well as changes in their taxonomical structures revealed seven palynomorph assemblages that characterize terrestrial, coastal-marine, shallow-, and deep-water settings (Lebedeva, 2008a). It should be noted that the terms “shallow-water” and “deepwater” are conditional, since microphytoplankton is linked more to distance from the shore than to depth of the basin.

The purpose of this work is to define patterns in the distribution of palynomorphs through Upper Cretaceous sections of the Khatanga area, West Siberia, Kara Sea shelf, and Polar Cis-Urals using methods described elsewhere (see above).

MATERIAL AND METHODS

Upper Cretaceous rocks sampled from natural outcrops along the Kheta (Khatanga area) and Seida (Polar Cis-Urals) rivers and core samples from wells drilled in West Siberia (Bovanenkovskaya 2, Yuzhno-Russkaya 113, Berezovskaya 23k) and on the Kara Sea shelf (Leningradskaya-1) provided material for this study (Fig. 1). The palynological analysis of examined sediments and comparison with sections of the Ust'-Yenisei area characterized by the inoceram fauna made it possible to substantiate their age and subdivide them based on dinocysts (Khomentovsky et al., 1999; Lebedeva et al., 2004; Lebedeva, 2005, 2006a, 2006b).

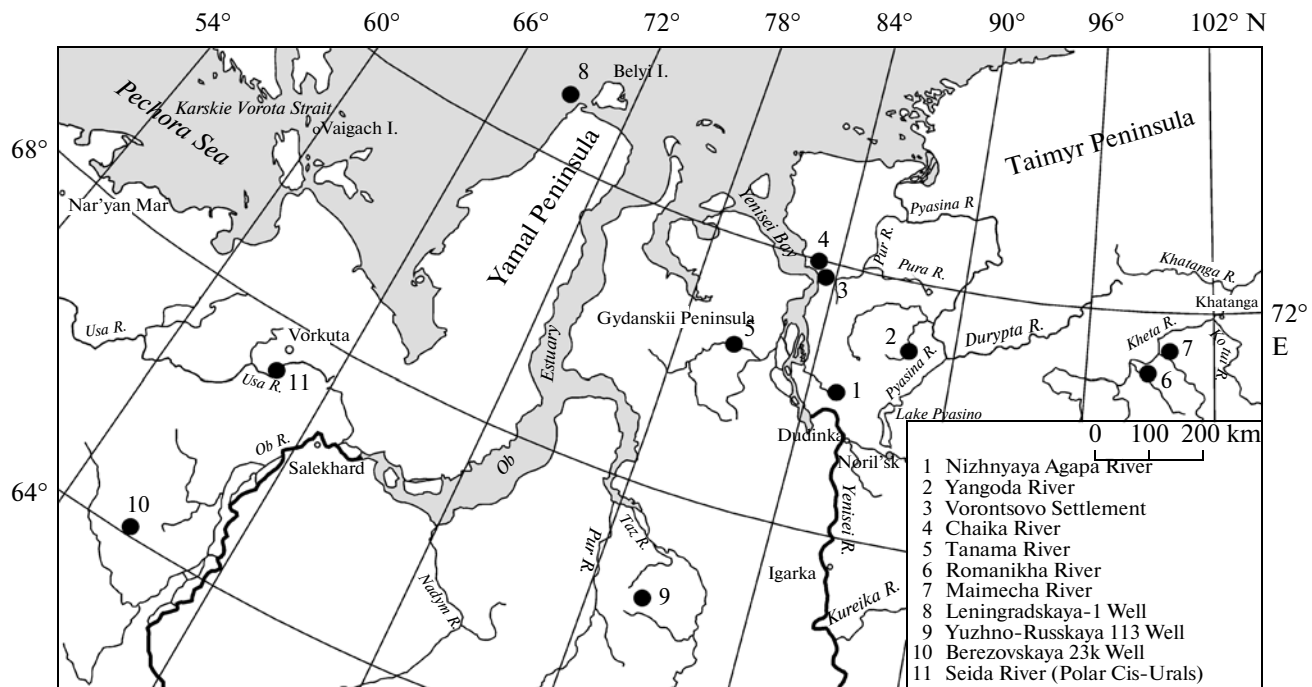


Fig. 1. Schematic location of examined sections.

The diagrams illustrating proportions of prasinophytes (*Leiosphaeridia*, *Pterospermella*, *Cymatiosphaera*), acritarchs, microforaminifers, and *Zygnemataceae* algae, species diversity, and ratios between morphotypes of dinocysts for each examined section were used as initial material for defining the relationships between various palynomorph groups and facies. In calculations of ratios between the terrestrial (spores and pollen, freshwater algae *Schizoporis*, *Schizocysta*, *Tetraporina*) and marine (microphytoplankton) components, the integral content of all the palynomorphs was taken as being equal to 100%. The total quantity of dinocysts, acritarchs, and prasinophytes was accepted as equal to 100% in calculating the percentage of different groups in the microphytoplankton assemblage. The available sedimentological data were also taken into consideration.

The characteristics of morphological types of dinoflagellate cysts and microfossil assemblages defined in the Ust'-Yenisei section were described elsewhere (Lebedeva, 2008a, 2008b). Below, a brief description is provided for every type of assemblages.

Terrestrial

Assemblage 1 is dominated by spores and pollen (90–100%) accompanied by common aqueous ferns and microphytofossils represented by freshwater *Schizoporis*, *Schizocysta*, and *Tetraporina* forms.

Coastal-marine (Sublittoral Settings with High-energy Hydrodynamics and a Varying Degree of Desalination)

Assemblage 2a is dominated by spores and pollen (40–90%). Phytoplankton includes freshwater algae (0–10%), acritarchs (8%: *Michrhystridium*, *Veryhachium*, *Leiofusa*), and prasinophytes (0–12%: *Pterospermella*, *Cymatiosphaera*; 5–45%: *Paralecaniella*). Dinocysts are largely represented by the gonyaulacoid group accompanied by chorate (0–40%), diverse cavate (*Chatangiella*, *Trithyrodinium*, *Alterbidinium*, *Palaeohystrichophora*), and rare (up to 6%) holocavate (*Chlamydochorella*, *Chlonoviella*) forms. The remarkable feature of the assemblage is the occurrence of proximochorate cysts of the *Cyclonephelium*–*Circulodinium* group, *Fromea*, and *Microdinium* species (locally >5%).

Assemblage 2b is also dominated by spores and pollen (40–90%). The composition of microphytofossils is highly impoverished. All the groups occur in insignificant quantities except for freshwater algae, which constitute 5–20%, and *Paralecaniella* (up to 50%). Dinocysts are of extremely low diversity with *Fromea* playing the most notable role.

Assemblage 3 is characterized by the dominant role of the genus *Paralecaniella* (80–100%) and a highly impoverished dinocyst composition, which are either missing or uniformly lacking chorate forms such as *Pterospermella* and *Schizoporis* representatives.

*Shallow-Water (Sublittoral Settings
with Normal Marine Salinity, Subjected
to Substantial Influence of Land: Dominant Role
of Terrestrial Plants and Others)*

Assemblage 4 is largely composed of spores and pollen (40–60%) accompanied by freshwater algae (0–10%), acritarchs (0–20%), prasinophytes (0–12%) and *Paralecaniella* (0–20%). Dinocysts are dominated by the peridinioid group mainly represented by cavate, proximate (*Microdinium*, *Rhyptocorys*, *Glyphanodinium*), and chorate forms; the last group is relatively abundant (0–24%), although of uniform composition.

Assemblage 5 is dominated by spores and pollen (40–60%) also includes freshwater algae (0–5%), acritarchs (0–15%), prasinophytes (1–25%), and *Paralecaniella* (0–40%) forms. Dinocysts are dominated by the peridinioid group with diverse cavate and proximate forms being represented in approximately equal proportions; chorate and holocavate forms are rare.

*Deepwater (Sublittoral Zone with Normal Marine
Salinity, Most Remote From the Shoreline)*

Assemblage 6 is dominated by marine microphytoplankton (up to 70%) with freshwater algae, acritarchs, prasinophytes, and *Paralecaniella* present in small quantities. Dinocysts are alternatively dominated by either gonyaulacoid and peridinioid forms; diverse cavate and proximate forms occur in approximately equal proportions and abundance of chorate cysts amounts to 40%.

Assemblage 7 is dominated by marine microphytoplankton (up to 100%) accompanied by rare freshwater algae, acritarchs, prasinophytes, and *Paralecaniella* species, which constitute a few percents. Diverse dinocysts represented by all morphotypes are dominated by the peridinioid group (mostly cavate forms).

CHARACTERISTIC OF PALYNOMORPH
ASSEMBLAGES FROM UPPER
CRETACEOUS SECTIONS

Natural outcrops of Upper Cretaceous rocks are observable in many areas of West Siberia: Ust'-Yenisei, Khatanga, eastern slope of the Urals, and Polar Cis-Urals. Their sections are saturated with fossils and are considered as standards for development of parallel biostratigraphic scales using different faunal and floral groups of organisms. At the same time, these sections frequently differ substantially from their counterparts in inner areas of the West Siberian basin. The sections from both marginal and central parts of the basin were analyzed with regard to the above-described facies types of assemblages and patterns in the distribution of different microfossil groups.

Kheta River Section (Khatanga Area)

In the Kheta River section, the palynomorph assemblage is distinct in showing stable abundances of all the constituent groups, a dominant role of cavate forms (*Chatangiella*, *Trithyrodinium*, *Alterbidinium*), and a very low proportion of proximate, holocavate, and chorate dinocysts. Spores, pollen and microphytoplankton are present in approximately equal proportions with *Fromea* characterized by high abundance. Four palynomorph assemblages are defined in this section (Fig. 2).

Assemblage 1 (Member 1, samples 53–55) is dominated by spores and pollen accompanied by rare freshwater alga *Schizoporis*.

Assemblage 4 (Member 2, lower part of Member 3, samples 56–59) is characterized by prevalence of peridinioid over gonyaulacoid cysts mainly on account of cavate forms (Fig. 2). Proximate (*Canningia*, *Rhyptocorys*, *Microdinium*) and chorate (*Fibrocysta*) cysts are very rare.

Assemblage 5 (upper part of Member 3, Member 4, samples, 61, 62, 64, 106) is dominated by peridinioid cysts. The abundance and diversity of chorate forms represented by *Cleistosphaeridium*, *Pterodinium*, *Oligosphaeridium*, and subordinate *Pterospermella*, *Cymatiosphaera*, and *Paralecaniella* slightly increase. The assemblage also contains acritarchs and freshwater microphytofossils, including spores of aqueous ferns.

Assemblage 4 (members 5–9, samples 110, 102, 103, 92–94, 97–100) is largely composed of peridinioid cysts represented by dominant cavate (*Trithyrodinium*, *Chatangiella*, *Isabelidinium*, *Alterbidinium*) and subordinate proximate and chorate morphotypes. The proportion of *Paralecaniella* increases to 25%.

The analysis of the palynomorph distribution through the section revealed that facies more remote from the shoreline constitute the upper part of Member 3 and Member 4. The structure of palynomorph assemblages remains practically uniform through the entire section, which indicates relatively stable sedimentation environments except for transition from terrestrial to marine settings.

Seida River Section (Polar Cis-Urals)

The Coniacian–Campanian section along the Seida River represented by silicified sandstones, siltstones, and mudstones with abundant faunal remains and ichnofossils was formed in sublittoral settings (Papulov, 1974; Sitnikova, 1977). Its palynomorph assemblages differ substantially from their counterparts in coeval sediments of the West Siberian basin. All the palynospectra from the Seida section are dominated by marine phytoplankton with highly diverse dinocysts (35 to 70 taxa), including holocavate forms which are always present, representatives of *Spiniferites* and *Tetraporina* genera, acritarchs, which are

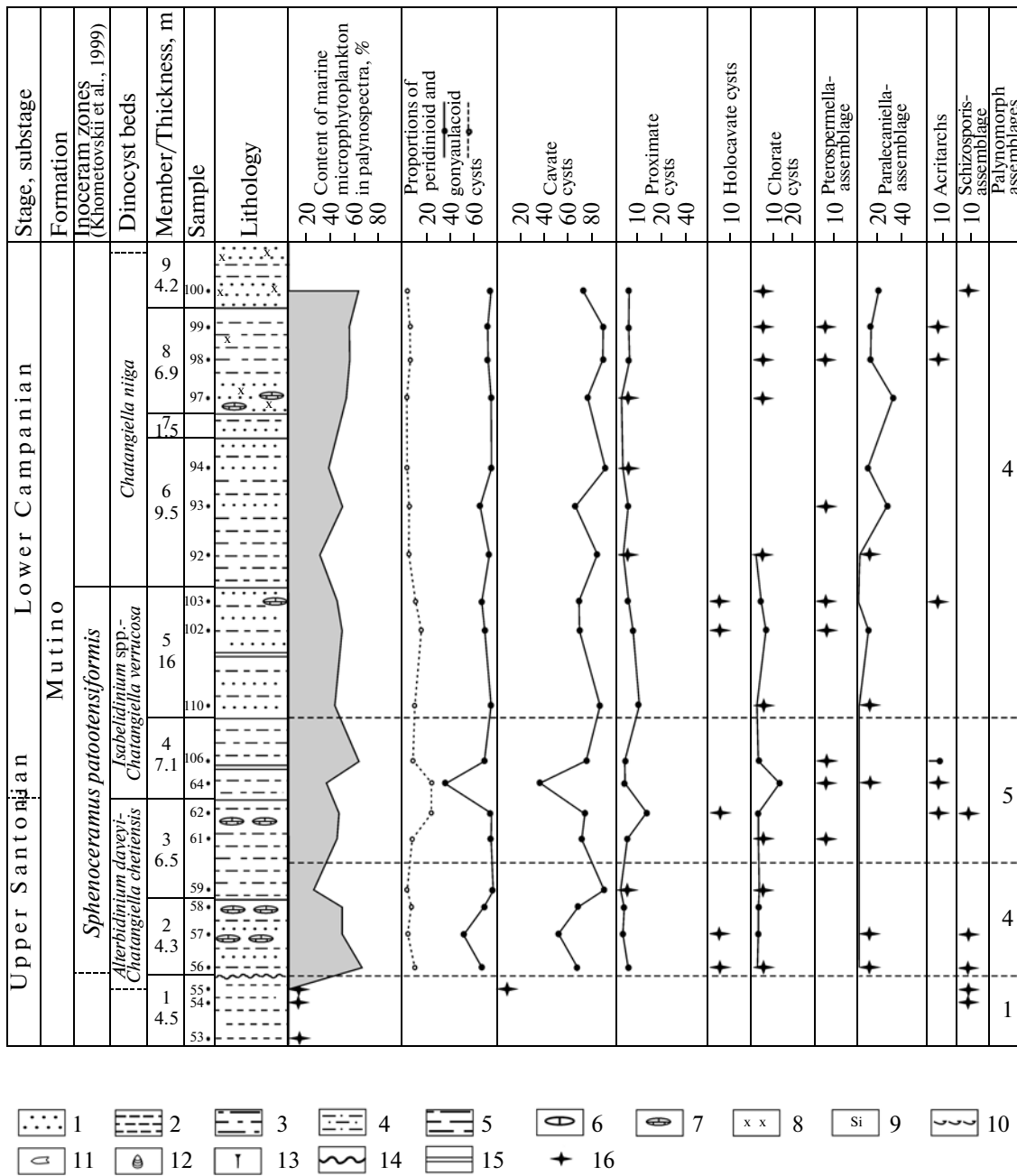


Fig. 2. Percentages of different microphytofossil groups in the Kheta River section. (1) sand; (2) silt; (3) silty clay; (4) clayey siltstone; (5) clay; (6) siderite concretions; (7) calcareous concretions; (8) leptochlorite; (9) SiO₂ content; (10) accumulations of *Oxytoma tenuicostata* (Roemer); (11) belemnites; (12) bivalves; (13) bioturbation; (14) sedimentation breaks; (15) gaps in observations; (16) content of palynomorphs <2%.

characterized by increased abundance, prasinophytes, *Palaeohystrichophora*, and *Cyclonephelium* group (Fig. 3). It is conceivable that differences in the taxonomic compositions of dinocysts in the eastern and western flanks of the West Siberian basin are determined by their provincialism, since the larger portion of the Seida assemblage is represented by “European” species (Lebedeva, 2005). The physicochemical conditions in the West Siberian basin and sea that covered

the Polar Cis-Urals region during the Late Cretaceous were also different, which is reflected in the composition of sediments and different structure of palynomorph assemblages. Nevertheless, the palynological analysis revealed four assemblages (from the base upward the section: 5, 6, 5, 2a) (Fig. 3), which were correlated based on their principal characteristics with type assemblages from West Siberian sections. All the palynomorph groups from the Seida River section

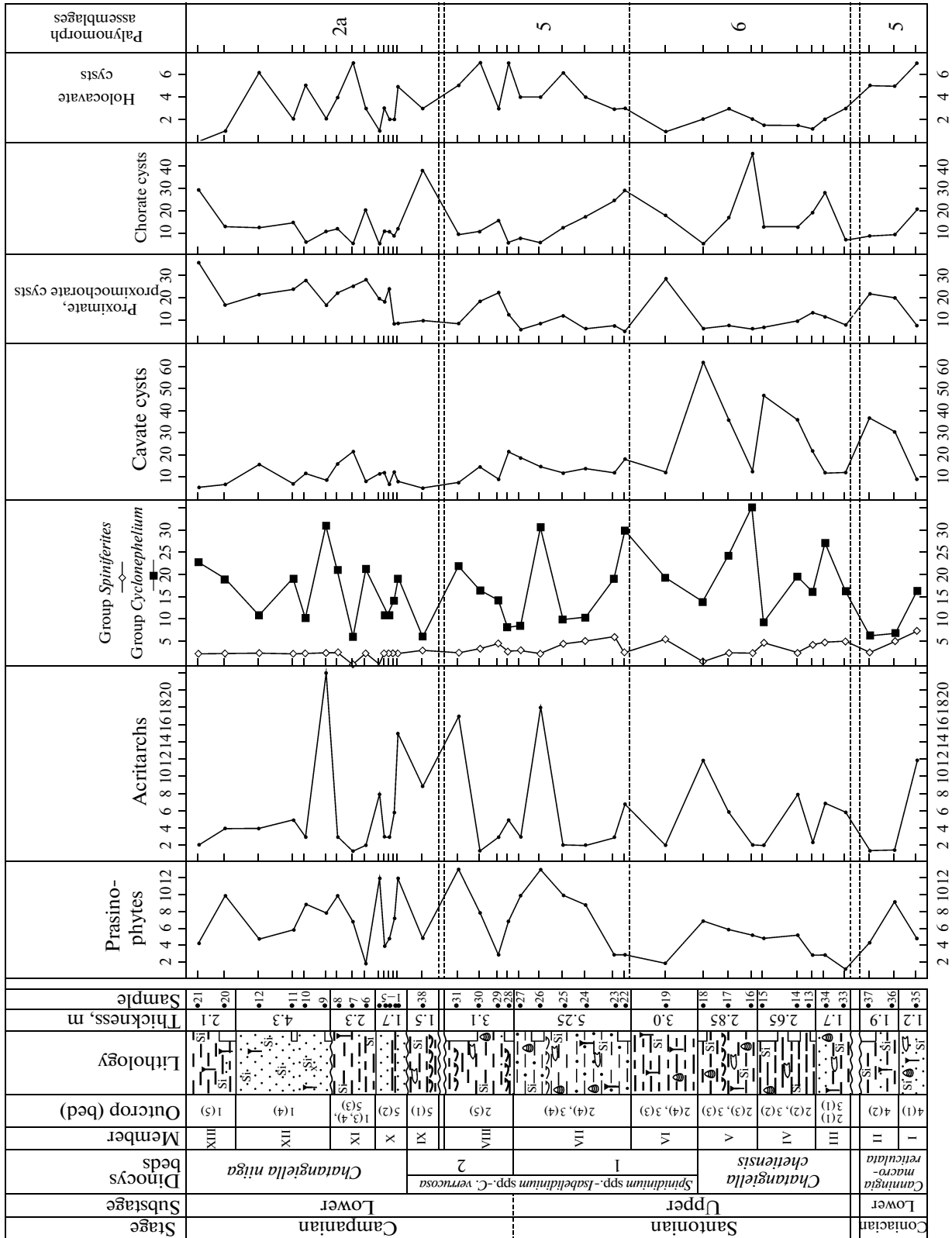


Fig. 3. Percentages of different microphytofossil groups in the Seida River section (Polar Cis-Urals). See Fig. 2 for the legend.

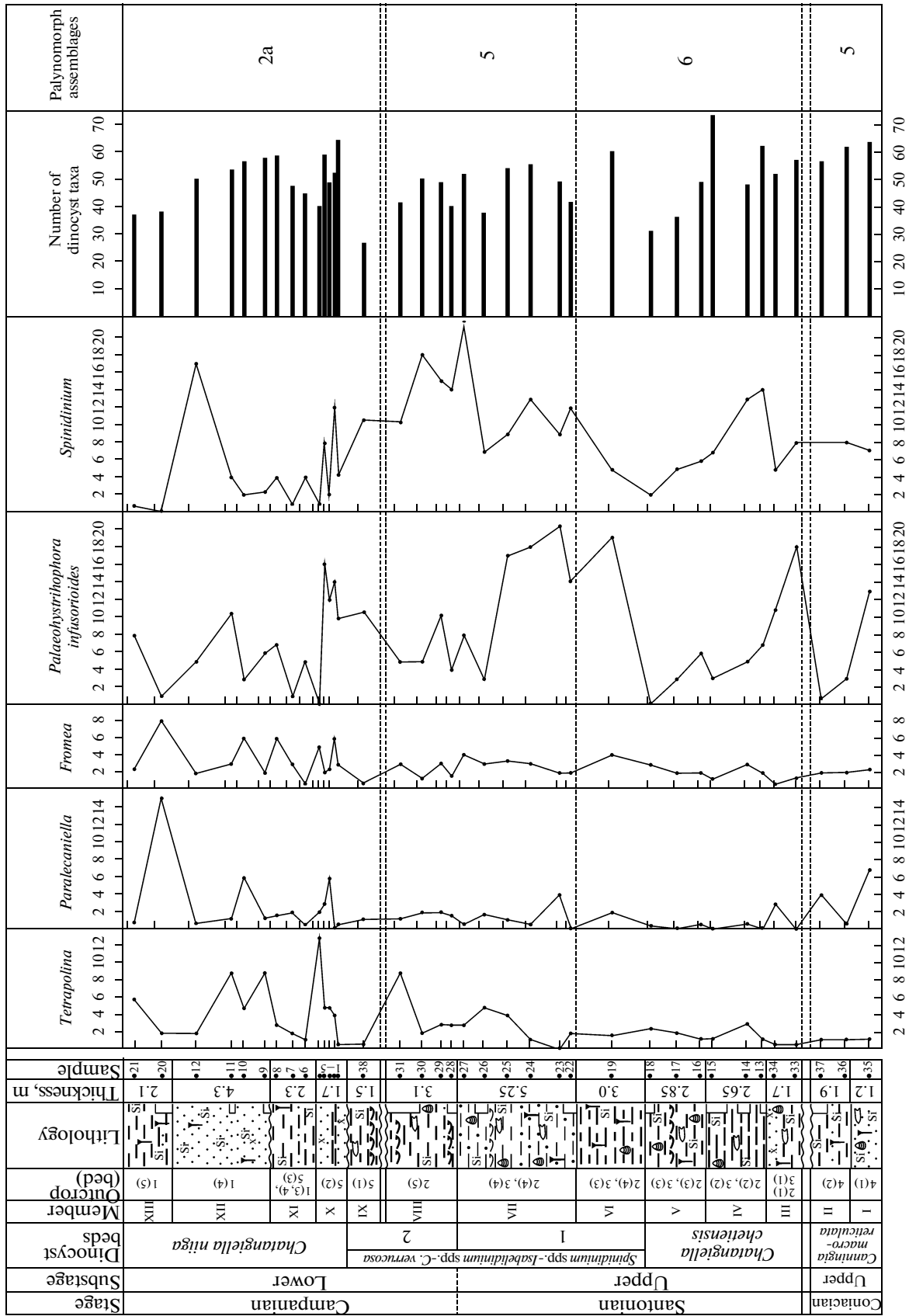


Fig. 3. (Contd.)

exhibit frequent significant quantitative variations. The section is composed of more or less consolidated lithological varieties. Most abundant acritarchs are confined to more loose varieties.

Assemblage 5 (members I and II, samples 35–37) is characterized by the dominant role of peridinioid forms among dinocysts. Acritarchs, prasinophytes, and *Paralecaneia* constitute 1–12, 4–10, and 1–7%, respectively. Cysts are dominated by cavate (*Palaeohystrichophora*, *Chatangiella*, *Spinidinium*) palynomorphs accompanied by relatively abundant holocavate (*Chlonoviella*, *Chlamydophorella*) and subordinate chorate (5–20%) morphotypes represented by the genera *Downiesphaeridium*, *Spiniferites*, *Hystrichosphaeridium*, *Florentinia*, *Oligosphaeridium*, *Coronifera*, and others.

Assemblage 6 (members III–VI, samples 33, 34, 13–19) demonstrates alternative prevalence of peridinioid and gonyaulacoid cysts. Acritarchs and prasinophytes are of low abundance (up to 6% on average); *Paralecaneia* occurs as single grains. The content of chorate forms amounts to 40%, while that of holocavate morphotypes decreases to 1–2%. Cavate cysts are dominated by *Chatangiella*, *Spinidinium*, *Palaeohystrichophora*, and *Trithyrodinium*.

Assemblage 5 (members VII and VIII, samples 22–31) is characterized by the decreased proportion of cavate forms, among which *Palaeohystrichophora* and *Spinidinium* representatives prevail, although their diversity remains high. The role of holocavate cysts and prasinophytes increases to 12%, while that of proximate and chorate forms usually decreases.

Assemblage 2a (members IX–XIII, samples 38, 1–12, 20, 21) exhibits the dominant role of gonialacoid forms among dinocysts with the content of cavate cysts being low (up to 20%) and that of holocavate and chorate morphotypes remaining at the same level. The percentage of proximate and proximochorate cysts, acritarchs, and prasinophytes slightly increases. Among cavate forms, the proportion of *Palaeohystrichophora* and *Spinidinium* decreases and that of *Paralecaneia* increases.

Thus, the composition and quantitative proportions of microphytofossils reflect the deepest (most distant from the shore) deposition settings for members III–VI and gradual regression for overlying sediments up to Member XIII.

Yuzhno-Russkaya 113 Well

The analysis of lithological–geophysical and palynological data from Turonian–Coniacian marine sediments recovered by the Yuzhno-Russkaya 113 Well revealed a regular coordinated change in facies and composition of palynomorphs (Lebedeva et al., 2004), which form three assemblages (Fig. 4).

Assemblage 6 (samples 28–18) is characterized by the prevalence of microphytoplankton over spores and

pollen of terrestrial plants, maximal taxonomic diversity of dinocysts, and permanent occurrence of microforaminifers. The lower part of the section is marked by the largest proportion of representatives of the *Spiniferites* group, proximate (*Rhiptocorys*, *Microdinium*, *Criproperidinium*, *Dorocysta*), chorate (*Spiniferites*, *Pervosphaeridium*, *Oligosphaeridium*, *Pterodinium*), and holocavate (*Chlonoviella*, *Chlamydophorella*) cysts. Sample 26 has a reduced proportion of microforaminifers, reduced dinocyst diversity, and an increased role of prasinophytes, acritarchs, and cavate dinocysts (*Trithyrodinium*, *Alterbidinium*, *Odontochitina*, *Eurydinium*). In samples 25–20, abundance and diversity of microphytoplankton are high and stable with cavate dinocysts playing a dominant role. The upper part of this interval (samples 20–18) is marked by reduced diversity of dinocysts and an increased role of prasinophytes and freshwater algae (*Ovoidites*).

Assemblage 5 (samples 17–7) has the content of marine algae, diversity of dinocysts, and proportion of holocavate, proximate, and chorate forms substantially reduced, with cavate cysts (*Trithyrodinium*, *Odontochitina*) and species from the *Cyclonephelium* group in dominant roles. Acritarchs demonstrate high abundance being accompanied by prasinophytes and freshwater algae, which are rare but always present, and sporadic microforaminifers.

The palynospectrum of Sample 16 (from a bed of carbonate concretions) shows a sharp increase in the content of marine phytoplankton (acritarchs, chorate and holocavate cysts) with a dominant role of the *Cyclonephelium* group.

Assemblage 6 (Samples 6–2) is again dominated by microphytoplankton with increased diversity of dinocysts and abundance of all groups, especially cavate, chorate, and holocavate morphotypes. The assemblage again includes representatives of the *Spiniferites* group, while the role of the *Cyclonephelium* group and acritarchs is reduced.

Berezovskaya 23k Well

The basal part of the Berezovskaya 23k Well section is composed of terrestrial sediments of the Uvat Formation overlain at a depth of 219.5 m by marine facies of the Kuznetsovo Formation. The section encloses two microfossil assemblages reflecting the regressive trend (Fig. 5).

Assemblage 1 (samples 61–66) includes only spores and pollen of terrestrial plants.

Assemblage 6 (samples 66–83) is dominated by microphytoplankton with the high diversity of dinocysts. The samples demonstrate variations in the content of different palynomorph groups. As a whole, the assemblage is characterized by high abundance of holocavate cysts (up to 20%). Cavate, proximate, and chorate forms are present in approximately equal proportions. Acritarchs and prasinophytes are rare except

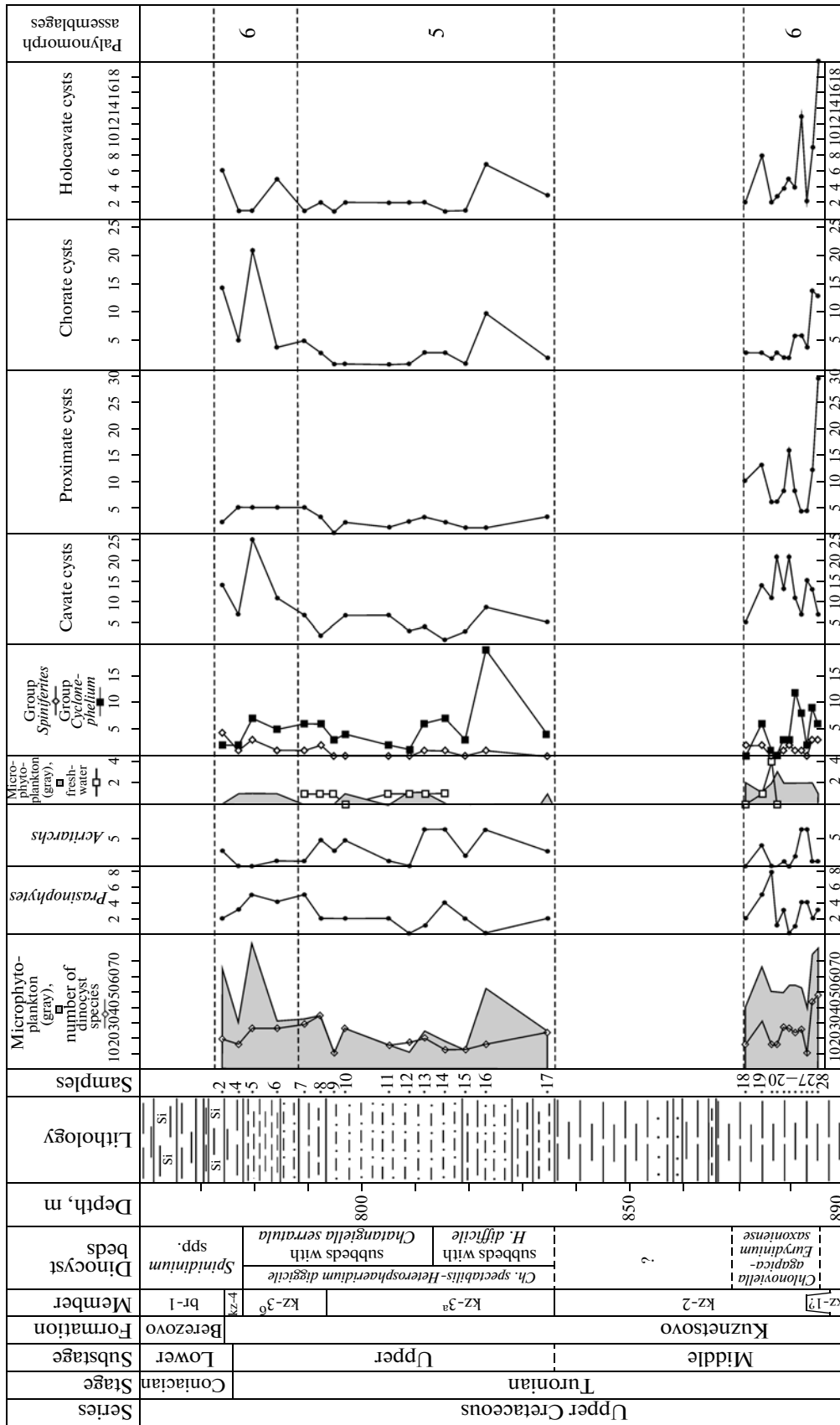


Fig. 4. Percentages of different microphyto-fossil groups in the Yuzhno-Russkaya 113 Well section. See Fig. 2 for the legend. Beds with dimocysts: (*H. difficile*) *Heterosphaeridium difficile*; (MF) microfossils.

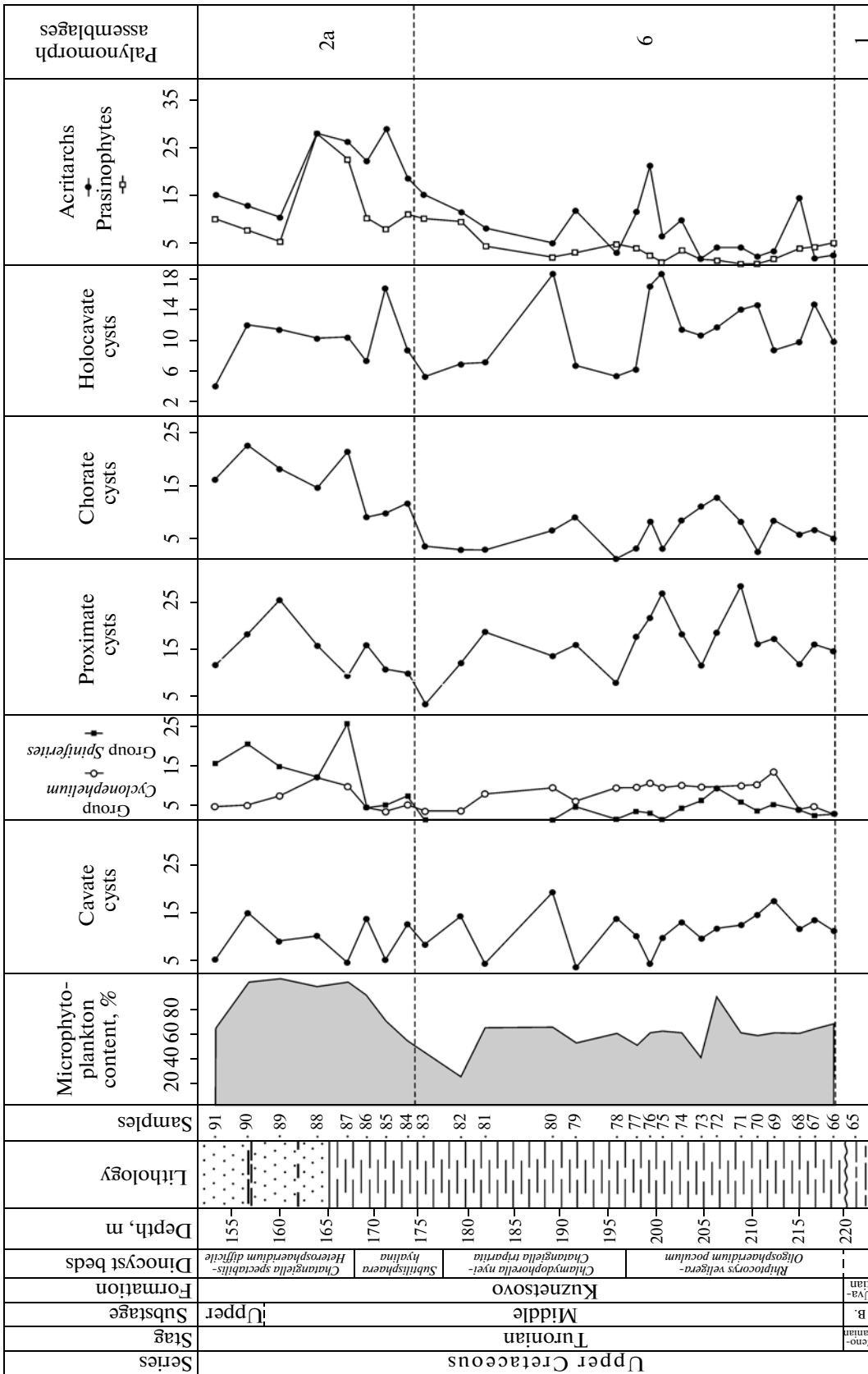


Fig. 5. Percentages of different microfossil groups in the Berzovskaya 23k Well section. See Fig. 2 for the legend. Substage: (U) upper.

in samples 68 and 76, which show high acritarch content. Abundance of acritarchs and prasinophytes increases in the upper part of this interval, with simultaneous reduction of the species diversity of dinoflagellate cysts.

Assemblage 2a (samples 84–91) is characterized by high abundance of microphytoplankton due to increased content of acritarchs and prasinophytes up to 30%. Dinocysts are dominated by gonyaulacoid group. The proportion of cavate forms decreases, although they remain relatively diverse with the dominant role of *Palaeohystrichophora* and *Chatangiella* representatives. The content of the *Spiniferites* group substantially increases up to maximal values. The role of the *Cyclonephelium* group is highest in the lower part of this interval. The average content of proximate (*Kallosphaeridium*, *Rhytocorys*, *Microdinium*, *Dorocysta*) and chorate (*Cleistosphaeridium*, *Spiniferites*, *Downiesphaeridium*) cysts also increases, while that of holocavate forms remains unchanged. In Sample 91, abundance of all the palynomorphs becomes sharply reduced except for the *Cyclonephelium* group, acritarchs, and prasinophytes. This assemblage differs from its analog in the Ust'-Yenisei section in the dominant role of microphytoplankton and lack of *Paralecaniella* representatives.

According to some researchers, the assemblages dominated by *Spiniferites*, the chorate forms with long processes, are characteristic of open marine settings (Downie et al., 1971; Davey Rogers, 1975; Brinkhuis and Zachariasse, 1988; Marshall and Batten, 1988; Eshet et al., 1994). There are also data indicating that the *Spiniferites/Cyclonephelium* ratio increases seaward and in periods of transgressions (Li and Habib, 1996). The last viewpoint is inconsistent with the data on Berezovskaya 23k Well, where Assemblage 6 demonstrates prevalence of the *Cyclonephelium* group over the *Spiniferites* group, which is characterized by minimal or zero abundance. The sharp increase of the proportion of *Spiniferites* in Assemblage 2a is at variance with the above-mentioned concept, since the increase in sand admixture upward the section and appearance of sandstones in its upper part indicate a regressive trend in basin development. At the same time, many works demonstrated maximal abundance of the *Spiniferites/Areoligera* group in recent sediments of estuaries and the inner shelf zone (Wall et al., 1977), which is consistent with the increased role of the *Spiniferites* group in the upper substantially sandy part of the Berezovskaya 23k Well section.

Leningradskaya-1 Well (Kara Sea Shelf)

In the Leningradskaya-1 Well section, only some intervals, which were sampled in sufficient detail, are suitable for the microphytological studies. They yielded five palynomorph assemblages (Fig. 6).

Assemblage 1 (samples 1–5) is represented only by spores and pollen of terrestrial plants, including rare *Schisporis*.

Assemblage 2a (Samples 6–12) is dominated by spores and pollen of terrestrial plants. Either gonyaulacoid or peridinioid forms prevail among dinocysts. The peridinioid diversity is low with *Subtilisphaera* representatives being most abundant. Chorate cysts constitute up to 20%. They include representatives of the *Pterodinium*, *Litosphaeridium*, *Downiesphaeridium*, *Oligosphaeridium*, and *Kiokansium* genera accompanied by rare holocavate cysts, *Pterospermella* forms, and acritarchs.

Assemblage 6 is defined only in Sample 13, which characterizes the Kuznetsovo Formation, and is dominated by marine microphytoplankton with gonyaulacoid forms being prevalent among dinocysts. The maximal abundance is characteristic of proximate cysts: *Microdinium*, *Glyphanodinium*, *Dorocysts*, *Kallosphaeridium*. They are accompanied by subordinate cavate (*Trithyrodinium*, *Subtilisphaera*) and chorate (*Spiniferites*) morphotypes. Acritarchs occur as single grains.

Assemblage 7 (samples 14–17) is largely composed of marine phytoplankton with peridinioid cysts slightly prevailing over gonyaulacoid forms. Cavate cysts are dominated by *Trithyrodinium*, *Alterbidinium*, and *Chatangiella*. Proximate and chorate forms occur in approximately equal proportions. Chorate cysts are diverse being represented by genera *Exochosphaeridium*, *Oligosphaeridium*, *Spiniferites*, *Florentinia*, *Achomosphaera*, *Hystrichosphaeridium*, *Dapsilidium*, and others. Holocavate cysts are present as single specimens.

Assemblage 6 (samples 18–20) is characterized by a decreased role of marine phytoplankton, and is alternatively dominated by either peridinioid or gonyaulacoid forms. The proportion of cavate and proximate cysts is slightly reduced, while chorate forms remain abundant and diverse. The assemblage also includes rare acritarchs and *Paralecaniella*.

Thus, the Leningradskaya-1 Well demonstrates a transgressive succession from the terrestrial Marresale Formation to typical marine Kuznetsovo Formation and lower Berezovo Subformation. Due to discontinuous core recovery, some palynomorph assemblages are missing, which prevented the documentation of small-scale variations. The upper part of the lower Berezovo Subformation corresponds to the onset of the regressive trend.

BIOFACIES ANALYSIS OF EXAMINED SECTIONS BASED ON PALYNO MORPH ASSEMBLAGES

The palynomorph assemblages from Cenomanian–Coniacian sediments of the Ust'-Yenisei area, Berezovskaya 23k, Yuzhno-Russkaya 113, and Leningradskaya-1 wells and from Santonian–Campanian

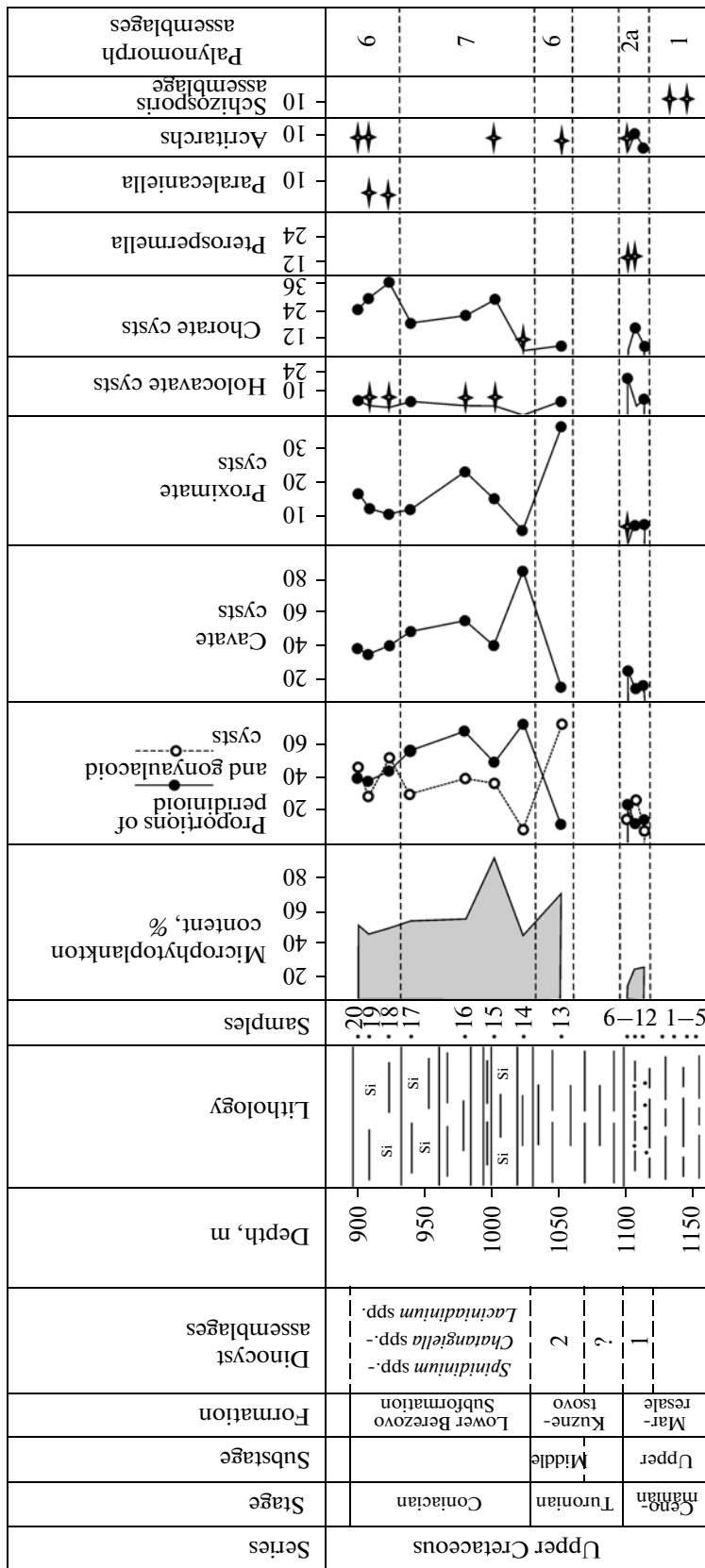


Fig. 6. Percentages of different microphytofossil groups in the Leningradskaya-1 Well section. See Fig. 2 for the legend. Substage: (Mid.) middle.

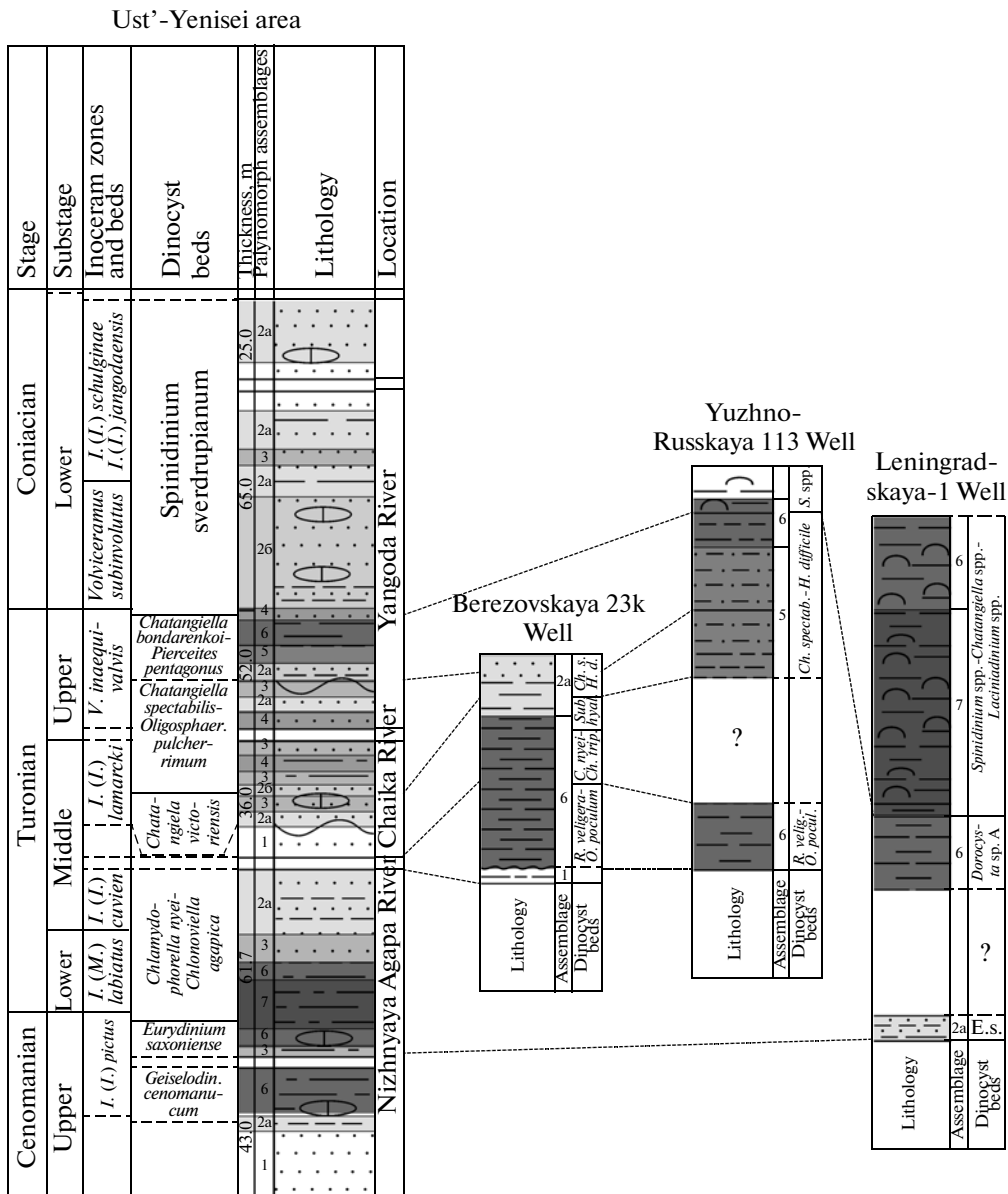


Fig. 7. Palytomorph assemblages in Cenomanian-Coniacian sections of the Ust'-Yenisei area and wells drilled in West Siberia and on the Kara Sea shelf. See Fig. 2 for the legend. Dashed lines between columns show stratigraphic correlation.

Inoceram zones and beds: (*I.*) *Inoceramus*, (*M.*) *Mytiloides*, (*V.*) *Volviceramus*.

Dinocyst beds: (*E. s.*) *Eurydinium saxoniense*, (*R. veligera*, *R. velig.*) *Rhytocorys veligera*, (*C. nyei-Ch. tripartita*) *Chlamydophorella nyei-Chatangiella tripartita*, (*Sub. hyal.*) *Subtilisphaera hyalina*, (*Ch. s.*, *Ch. spectab.*) *Chatangiella spectabilis*, (*H. d.*, *H. difficile*) *Heterosphaeridium difficile*, (*O. pocul.*) *Oligosphaeridium poculum*, (*Ch. serratula*) *Chatangiella serratula*, (*S. spp.*) *Spindinium spp.*

sections of the Ust'-Yenisei, Khatanga, and Polar Cis-Urals regions were compared. Transgressive-regressive cycles reflected in the structure of assemblages are most distinct in coastal sections (particularly, at the transition from terrestrial to marine facies) and smoothed within the marine section (Li and Habib, 1996). The results of this work confirm the last observation.

The *Eurydinium saxoniense* Beds in the Leningradskaya-1 Well section are represented by coastal-marine

facies (Assemblage 2a), while in the section of the Ust'-Yenisei area, similar facies are established only at the base of this biostratigraphic unit; its remainder is characterized by deepwater sediments (assemblages 6 and 7) (Fig. 7).

The *Chlamydophorella nyei-Chatangiella* Beds are traceable only in the Ust'-Yenisei area, where they are represented by a regressive systems tract from deepwater facies (assemblages 6 and 7) to coastal-marine sediments (assemblages 2a and 3). The mid-Turonian

coincides with a strong regressive phase, which is reflected through the entire peripheral part of the West Siberian basin (Amon and Papulov, 1989). The sea probably retreated beyond the limits of the Ust'-Yenisei Depression at that time and this area was covered by prograding terrestrial facies (Zakharov et al., 1991).

The onset of the next, middle Turonian transgression in the Ust'-Yenisei area is documented in the Chaika River section in the central part of the depression, where gradual transition from continental to marine facies is observable. The *Rhiptocorys veligera*–*Oligosphaeridium poculum* Beds recovered by Berezovskaya 23k and Yuzhno-Russkaya 113 wells are represented by deepwater facies (Assemblage 6). The *Chatangiella victoriensis* Beds of the Ust'-Yenisei section were largely deposited in unstable coastal-marine environments, which is reflected in frequently alternating assemblages 2a and 3, with high-energy hydrodynamics and, probably, insignificant desalination. The coeval section penetrated by Berezovskaya 23k Well is composed of deepwater facies (Assemblage 6).

The *Chatangiella spectabilis*–*Oligosphaeridium pulcherrimum* Beds are characterized by alternating coastal-marine and shallow-water facies. Coeval layers (lower part of the *Chatangiella spectabilis*–*Heterosphaeridium difficile* Beds) are represented by shallow-water facies (Assemblage 5) in the Yuzhno-Russkaya 113 Well section (central part of the West Siberian basin) and by coastal-marine sediments (Assemblage 2a) in Berezovskaya 23k Well (its western margin).

The *Chatangiella bondarenkoi*–*Pierceites pentagonus* Beds of the Ust'-Yenisei section demonstrate a distinct transgressive systems tract from coastal-marine to deepwater facies (assemblages 2a, 5, and 6). This stratigraphic interval in the Berezovskaya 23k Well section (upper part of the *Chatangiella spectabilis*–*Heterosphaeridium difficile* Beds) corresponds to coastal-marine facies. The Yuzhno-Russkaya 113 Well section is characterized by the transgressive systems tract similar to that in the Ust'-Yenisei section (assemblages 5 and 6). In the Leningradskaya-1 Well section, the uppermost layers of the upper Turonian interval contain Assemblage 6.

The lower Coniacian sediments of the Ust'-Yenisei section are represented by coastal-marine regressive facies with indications of probable desalination of the basin in the lower part (Assemblage 2b). The mid-Coniacian was marked by further reduction of the Ust'-Yenisei sea basin. The central areas of the West Siberian sea (Yuzhno-Russkaya 113, Medvezh'ya 50 wells) and Kara Sea shelf (Leningradskaya-1 Well) accumulated opoka-like clays in relatively deep settings (assemblages 6 and 7).

The late Coniacian transgression is reflected in the Ust'-Yenisei section (Fig. 8), which exhibits a succession of coastal-marine (assemblages 2a and 3), shallow-water (Assemblage 4), and deepwater (Assem-

blage 6) facies. Coeval sediments of the Polar Cis-Urals enclose shallow-water marine Assemblage 5.

The section at the Tanama River of the Ust'-Yenisei area begins with Santonian regressive terrestrial sediments. Higher in the section, lower and upper Santonian sediments are largely represented by shallow-water facies (Assemblage 4) (Fig. 8). The deepest facies are established for the Campanian (Assemblage 7). The Campanian–Maastrichtian interval of the section is characterized by the successive regressive systems tract reflected in assemblages 7, 6, 5, and 3. In the Kheta River section (Khatanga area), the upper Santonian is partly represented by shallow-water facies (Assemblage 4). The deepest facies are documented in the Santonian–Campanian boundary layers (Assemblage 5). The overlying sediments again accumulated in shallow-water settings (Assemblage 4). Thus, the Ust'-Yenisei and Khatanga sections demonstrate similar trends in facies changes, although the latter was formed closer to the shoreline.

A different situation is observed in the Seida River section of the Polar Cis-Urals. The deepest sediments constitute members III–VI of the Santonian section (Assemblage 6). Higher in the section, the regressive facies succession is observed. The Santonian–Campanian boundary layers contain shallow-water Assemblage 5, which is replaced upward by coastal-marine Assemblage 2a.

Such a difference in facies succession allows the assumption that the Polar Urals strait (where the Seida section was forming) was influenced by both the West Siberian basin and Northeastern strait, which connected the Pechora and Russian seas during the Santonian–Campanian (Amon, 2001).

DISTRIBUTION PATTERNS OF SOME PALYNOMORPH TAXA AND THEIR GROUPS

The analysis of proportions between different taxa and morphotypes of dinocysts, acritarchs, and prasinophytes in defined assemblages revealed certain patterns in their distribution. Abundances of some taxa (*Fromea*, *Tetraporina*) sharply increased in some intervals of the section, although no correlation between this phenomenon and facies or lithological variety is found. Proportions between peridinioid and gonyaulacoid dinocysts represent one of the important characteristics of assemblages. The prevalence of gonyaulacoid cysts in the West Siberian basin is characteristic of Assemblage 2a (coastal-marine facies). This is consistent with the data on palynomorphs from Turonian–Coniacian sediments of the North Sea, England, and France (Pearce et al., 2003). These authors believe that the *Circulodinium*–*Heterosphaeridium* assemblage, characterized by low diversity and a dominant role of gonyaulacoid cysts, indicates coastal water masses. Assemblage 6, indicating a setting relatively remote from the shore, demonstrates the alternative prevalence of gonyaulacoid and

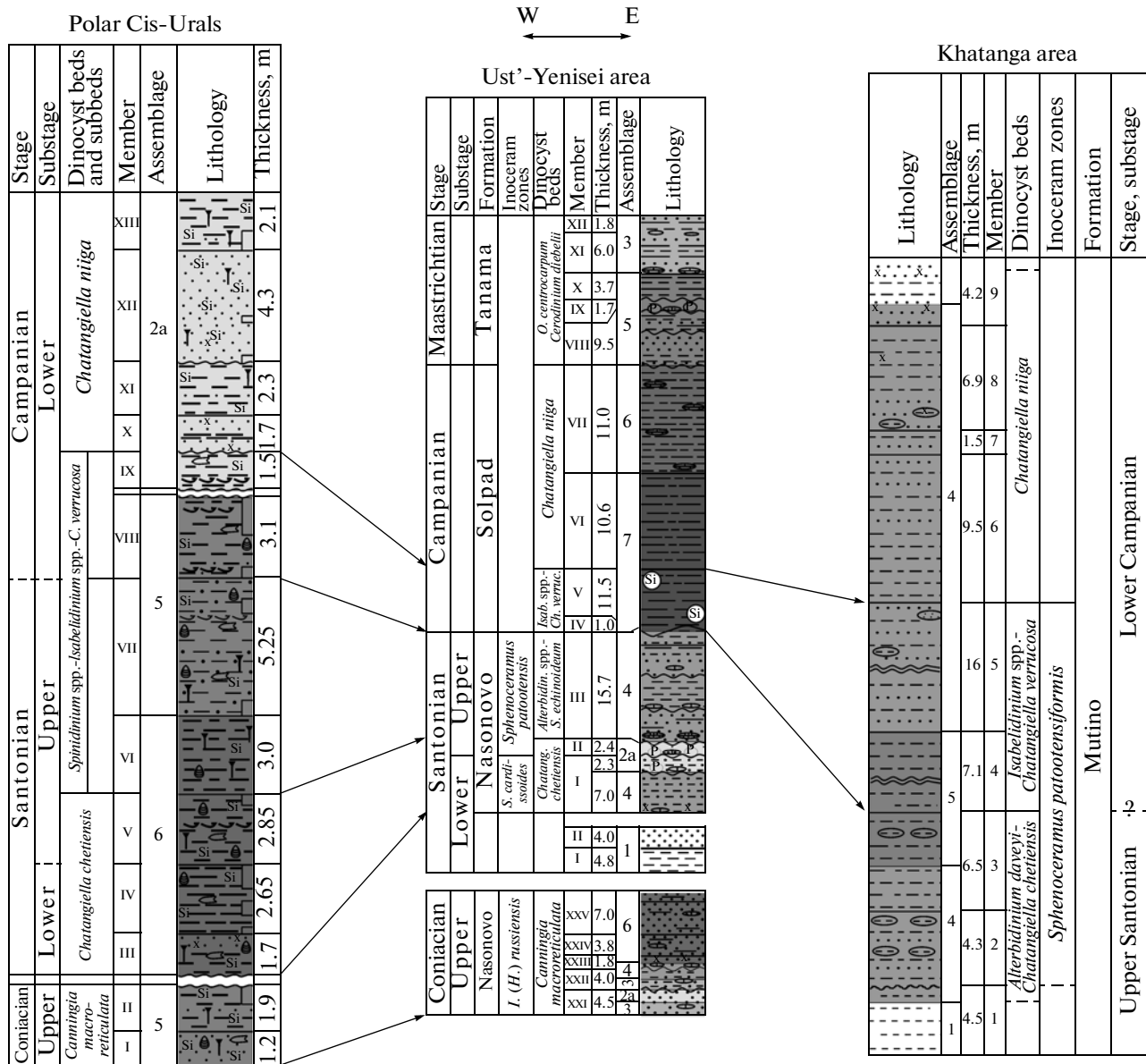


Fig. 8. Palynomorph assemblages in Coniacian-Campanian sections of the Polar Cis-Urals, Ust'-Yenisei, and Khatanga areas. Fig. 2 for the legend. Arrows show stratigraphic correlation.

Inoceram zones and beds: (H.) *Haenleinia*, (S.) *Sphenosceramus*.

Dinocyst beds: (*Chatang. chetiensis*) *Chatangiella chetiensis*, (*Alterbidin. spp. - S. echinoideum*) *Alterbidinium spp. - Spinidinium echinoideum*, (*Isab. spp. - Ch. verruc.*) *Isabelidinium spp. - Chatangiella verrucosa*, (*O. centrocarpum*) *Operculodinium centrocarpum*.

peridinioid cysts. In other assemblages, the proportion of peridinioid forms is substantially higher. Thus, the gonyaulacoid/peridinioid index proposed by Harland (1973) for determining the relative distance from the shore, in which the higher value of this index should indicate a greater distance from the shore, cannot be used immediately for this purpose.

Cavate cysts (*Eurydinium*, *Trithyrodinium*, *Palaeohystrichophora*, *Alterbidinium*, *Odontochitina*, *Subtilisphaera*, *Spinidinium*, *Isabelidinium*, *Chatangiella*). This tolerant cosmopolitan group occurs in practically

all the facies types of assemblages, except for assemblages 1 and 3, although is most abundant and diverse in assemblages 4–7 (shallow-water and deepwater facies).

The genera *Chatangiella* and *Trithyrodinium* are registered in all assemblages, being most abundant in assemblages 4–6 and prevailing in sandy sediments (Khlonova and Lebedeva, 1988; Lebedeva, 2001). The genus *Palaeohystrichophora* occurs as single specimens in most sections, but is abundant only in the Seida and Leningradskaya-1 Well sections. It is conceivable that

representatives of this genus may tolerate desalination, which is evident from its mass occurrence in assemblages 2a and 3. May (1980) noted the confinement of *Palaeohystrichophora* forms to estuarine or coastal bay settings. The genus *Odontochitina* is probably eurybiontic, since it occurs in all the defined assemblages, except for assemblages dominated by *Paralecaniella*. Many authors (e.g., Brideaux and McIntyre, 1975; Tocher and Jarvis, 1987) also emphasized the tolerance of this genus to changeable environments. The genera *Spinidinium* and *Isabelidinium* prefer shallow-water and deepwater facies (assemblages 4 and 7). The maximal *Spinidinium* content is recorded in the Seida River section.

Proximate, proximochorate cysts (*Rhyptocorys*, *Microdinium*, *Glyphanodinium*, *Cribroperidinium*, *Apteodinium*, *Kallosphaeridium*, *Canningia*, *Cyclonephelium*, *Circulodinium*, *Laciniadinium*, *Senoniasphaera*, *Dorocysta*, and others) include taxa with a wide habitat range, being most abundant in assemblages 2a and 6.

The genera *Cyclonephelium* and *Circulodinium* occur universally. They tolerate brackish-water settings, as is evident from their abundance in Assemblage 2a. The genera *Cribroperidinium*, *Apteodinium*, *Kallosphaeridium*, and *Canningia* are similarly tolerant to different environments, which is also confirmed by published data (Harris and Tocher, 2003). Development of the genera *Apteodinium*, *Kallosphaeridium*, and *Batiacasphaera* is closely connected with prograding transgression: their content increases seaward. The genus *Microdinium* is most abundant in coastal-marine and shallow-water settings (assemblages 2a, 4, and 5). The genus *Rhyptocorys* is usually confined to shallow- and deepwater sediments (assemblages 4 and 6).

Holocavate cysts (*Chlonoviella*, *Chlamydothorella*, *Membranisphaera*) occur in all the defined assemblages. They represent one of a few groups, which occur in Assemblage 3. In the Ust'-Yenisei section, the genera *Chlonoviella* and *Chlamydothorella* are abundant in Assemblage 6. In sections of West Siberia, Kara Sea shelf, and Polar Cis-Urals, the content of holocavate cysts is substantially higher and they are abundant in shallow- and deepwater assemblages 5–7 as well as in coastal-marine Assemblage 2a. This group probably occupied remote biotopes regardless of their depths. This assumption is confirmed by data on other regions and stratigraphic intervals (Sharafutdinova, 1988; Lebedeva and Nikitenko, 1998, 1999; Harris and Tocher, 2003; Peshchevitskaya, 2003; Nikitenko et al., 2008).

Chorate cysts (*Spiniferites*, *Achomosphaera*, *Coronifera*, *Oligosphaeridium*, *Hystrichosphaeridium*, *Raetiadinium*, *Surculosphaeridium*, *Heterosphaeridium*, *Exochosphaeridium*, *Pterodinium*, *Florentinia*, *Cleistosphaeridium*, *Pervosphaeridium*, *Membranilarnacia*, and others) occur in all the assemblages (except for assemblages 1 and 3), although they prefer environ-

ments with low-energy hydrodynamics (assemblages 2a, 4, 6, 7). The genera and their species constituting this group exhibit different ecological preferences. As previously mentioned, the data on facies confinement of the genus *Spiniferites* are ambiguous. Our materials contribute little to the solution of this problem. The substantial increase in abundance and diversity of this genus is observable both in deepwater assemblages 6 and 7 and in coastal-marine Assemblage 2a. At the same time, there are no grounds to speak about wide-range tolerance of the genus *Spiniferites*, since in all other settings it is either absent or occurs as single specimens. The genus *Oligosphaeridium* occurs in all the settings, although the species *Oligosphaeridium complex* (White) Davey et Williams is usually confined to deepwater facies (Assemblage 7). *Oligosphaeridium pulcherrimum* (Deflandre et Cookson) Davey et Williams is considered to be a euryhaline species (probably, preferring lowered salinity) (Harris and Tocher, 2003). The genera *Pterodinium* and *Dapsilidinium* are confined to deepwater remote settings. In contrast, the genera *Exochosphaeridium* and *Cleistosphaeridium* are abundant in coastal-marine and shallow-water facies.

Prasinophytes (*Pterospermella*, *Cymatiosphaera*, *Leiosphaeridia*) occur in facies of two types. They are usually confined to shallow-water and deepwater sediments (assemblages 5 and 6) in the Ust'-Yenisei section and coastal-marine facies (Assemblage 2a) in sections of West Siberia and Polar Cis-Urals region. The dual distribution patterns were also noted elsewhere (Lebedeva, 2008a). It should, however, be noted that no representatives of the genus *Pterospermella* are found in brackish-water environments. The genus *Leiosphaeridia* occurs universally in small quantities being usually confined to sediments reflecting the onset of transgression or regressive phase.

Acritarchs (*Micrhystridium*, *Veryhachium*, *Leiofusa*) occur in small abundance in Assemblage 2a, where they are represented by the genera *Micrhystridium* and *Leiofusa*. Such a distribution of acritarchs is consistent with the data indicating their confinement to sediments reflecting either the initial stage of a transgression or regression. Moreover, they are more abundant in clayey and silty sediments as compared with coarse-grained varieties. Acritarchs (largely *Veryhachium* representatives) are also abundant in deepwater environments with slightly stagnant waters.

Paralecaniella representatives occur in all the assemblages in variable proportions. The largest proportion of this genus is recorded in assemblages 2a and 3 with its dominant role in the last one. The genus is generally characteristic of rapidly changeable settings (Chaika River section). The coastal-marine settings with normal salinity, high-energy hydrodynamics, and sufficient aeration were probably most favorable for the genus *Paralecaniella*. The data obtained are consistent with the results of other studies (Brinkhuis and Schiöler, 1996; Schiöler et al., 1997; Hergreen et al., 1998).

The *Schizoporis* Assemblage (*Schizoporis*, *Schizocysta*, *Tetraporina*, spores of aqueous ferns) unites microfossils different with respect of their taxonomic position and similar in their facies confinement. Abundance of *Schizoporis* and *Schizocysta* is maximal in terrestrial sediments and high in coastal-marine facies (Assemblage 2b). In other assemblages, they occur as single grains. Spores of aqueous ferns are also registered in Assemblage 2b. The ecological confinement of *Tetraporina* representatives remains unclear. This genus is abundant through the entire Seida River section, while in other sections, it is rare.

CONCLUSIONS

The detailed study of various palynomorph groups (spores and pollen of terrestrial plants, dinoflagellate cysts, prasinophytes, acritarchs, *Zygnemataceae* algae, and others) in different-facies of the Upper Cretaceous sections of Siberia made it possible to reveal principal patterns in their distribution depending on the influence of various environmental factors, and establish their paleoecological characteristics. The Upper Cretaceous section of the Ust'-Yenisei area, which represents a perfect object for exploring facies confinement of dinoflagellate and other microphytoplanktonic genera and species, was selected as a standard one. Based on quantitative proportions of morphological groups and taxonomic composition, seven palynomorph assemblages were defined in this section, which reflect terrestrial, coastal-marine, shallow-water, and deepwater facies (Lebedeva, 2008a).

The comparative analysis of palynomorph assemblages from the Cenomanian–Coniacian sections of the Ust'-Yenisei area, Berezovskaya 23k, Yuzhno-Russkaya 113, and Leningradskaya-1 wells and from Santonian–Campanian sediments of the Ust'-Yenisei, Khatanga, and Polar Cis-Urals regions demonstrates that transgressive–regressive cycles reflected in the taxonomic structure of assemblages are most distinct in coastal sections (particularly at the transition between terrestrial and marine sediments) and less distinct in the marine section. The biofacies and palynomorph compositions exhibit regular succession from the periphery toward central parts of the West Siberian basin. It is established that facies successions in sections of the eastern and western areas of West Siberia during the Santonian–Campanian differ from each other, which is probably explained by the influence of both the West Siberian and Russian seas on sedimentation in the last domain at that time.

Some defined patterns in the facies affinity of individual palynomorph groups, morphotypes and taxa of dinocysts may be used for paleogeographic interpretations. The established distribution patterns of dinocyst and other microphytofossil morphotypes determined by transgressive–regressive cycles make them a useful tool for reconstruction of sedimentation paleosettings.

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