Lower Cretaceous palynostratigraphy and dinoflagellate cyst palaeoecology in the Siberian palaeobasin

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Palynological analysis of Lower Cretaceous (Berriasian-Barremian) sections from North Siberia allows definition of detailed dinocyst and spore-pollen zonations, which are calibrated against the established ammonite biostratigraphic schemes of Siberia. Most of the boundaries of the palynological zones are reliable correlative markers, which also can be recognized elsewhere in East and West Siberia (the spore-pollen zonation) and in NW Europe, Canada and Siberia (the dinocyst zonation). Changes in the microphytoplankton associations reflect both trends related to the dynamic evolution of the Siberian palaeobasin and trends of the dinocyst evolution. Results from the present study suggest that the diversity and the abundance of the Siberian microphytoplankton associations to a large extent were determined by sea water temperature and nutrients.

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Introduction

The investigation is based on palynological analysis of Berriasian, Valanginian, Hauterivain and Lower Barremian sections located in northern regions of West and East Siberia (Fig. 1). The samples are prepared using palynological techniques, including the treatment with nitric acid and natrium pyrophosphate (Wood et al. 1996). At least 200 specimens were counted per sample to establish taxon abundances. The following palynological features have been applied to define the dinocyst and spore-pollen zones: - appearance and extinction of stratigraphically important taxa; - increased and decreased diversity and abundance of selected subfamilies and genera. Stratigraphically important taxa are identified by analysis of their distribution based on the author's material and published data from North Siberia, Europe and America (dinocysts) and elsewhere in NW and NE Siberia (spores and pollen) (Pestchevitskaya 2007a,b). The stratigraphic position of the established palynological zones are validated by ammonites, bivalves, belemnites, foraminifers and ostracods in the Nordvik and Anabar sections; by ammonites, foraminifers and ostracods in the S.-Vologochanskaya and Romanovskaya wells; and by foraminifers and ostracods in the Urengojskaya, Yurkharovskaya and Medvezh'ya wells (Zakharov et al. 1983; Bogomolov 1989; Zakharov et al. 1999; Pestchevitskaya 2007a, b). For palaeoenvironmental analysis, the diversity and abundance of several palynological groups are studied (i.e. terrestrial palynomorphs, acritarchs, dinocysts,

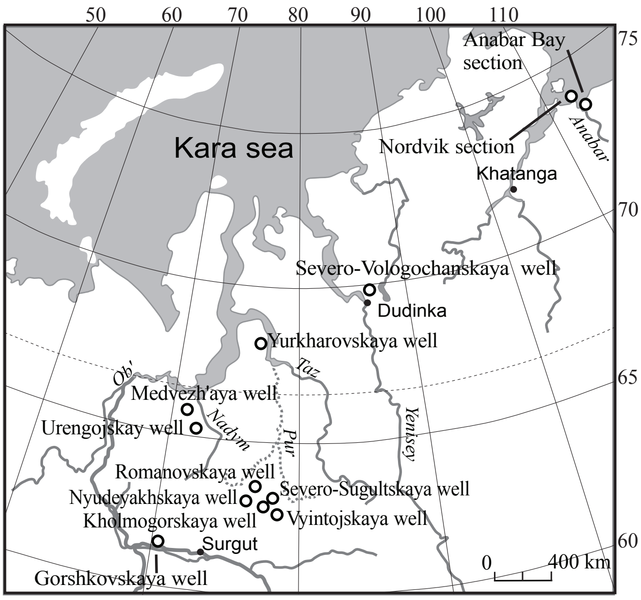

Fig. 1. The locations of studied sections.

Prasinophyceae and Zygnemataceae). The dinoflagellate cysts are further subdivided into proximate, proximochorate, chorate, "simple" morphology (*Escharisphaeridia, Kallosphaeridium, Batiacasphaera, Sentusidinium, Mendicodinium*), cavate, and holocavate cysts, and into families/subfamilies (i.e. families: Pareodiniaceae, Gonyaulacaceae, Areoligeraceae, Peridiniaceae; and subfamilies: Broomeoideae, Pareodinioideae, Leptodinioideae, Cribroperidinioideae, Gonyaulacoideae). The study is based on the Siberian materials listed above (Fig. 1) and data from the Yatrya River section in Subpolar Urals (Lebedeva & Nikitenko 1999). Published models and data on dinocyst palaeoecology (Kort 1969; Wall 1969; Davies et al. 1982; South & Whittick 1987; Wilpshaar & Leereveld 1994; Leereveld 1995; Konovalova, 1998; Lebedeva & Nikitenko 1999; Vinogradov & Lappo 2004; Pross & Brinkhuis 2005; Lebedeva 2008), as well as previous palaeoenvironmental reconstructions of Siberia (Golbert 1987), are also taken into consideration.

Palynostratigraphy

Established spore-pollen and dinocyst zones have been studied in several Siberian sections dated by faunas. The sections stratigraphically overlap each other and make it possible to define certain isochronous levels (Fig 2) characterized by the same bioevents (Fig. 3, 4). Most of the bioevents are identified, not only in studied sections, but also in northern areas of Europe and America (dinocyst zones) and in different regions of West and East Siberia (spore-pollen zones) (Pestchevitskaya 2007a,b).

In Subarctic Urals and northern regions of East Siberia typical Berriasian spore-pollen assemblages are observed from the Middle Berriasian Kochi ammonite zone (Pestchevitskaya 2007b). The present investigated sections begin with the Late Berriasian Analogus ammonite zone, so the lower boundary of the zone SPA1 is not well constrained and possibly should be

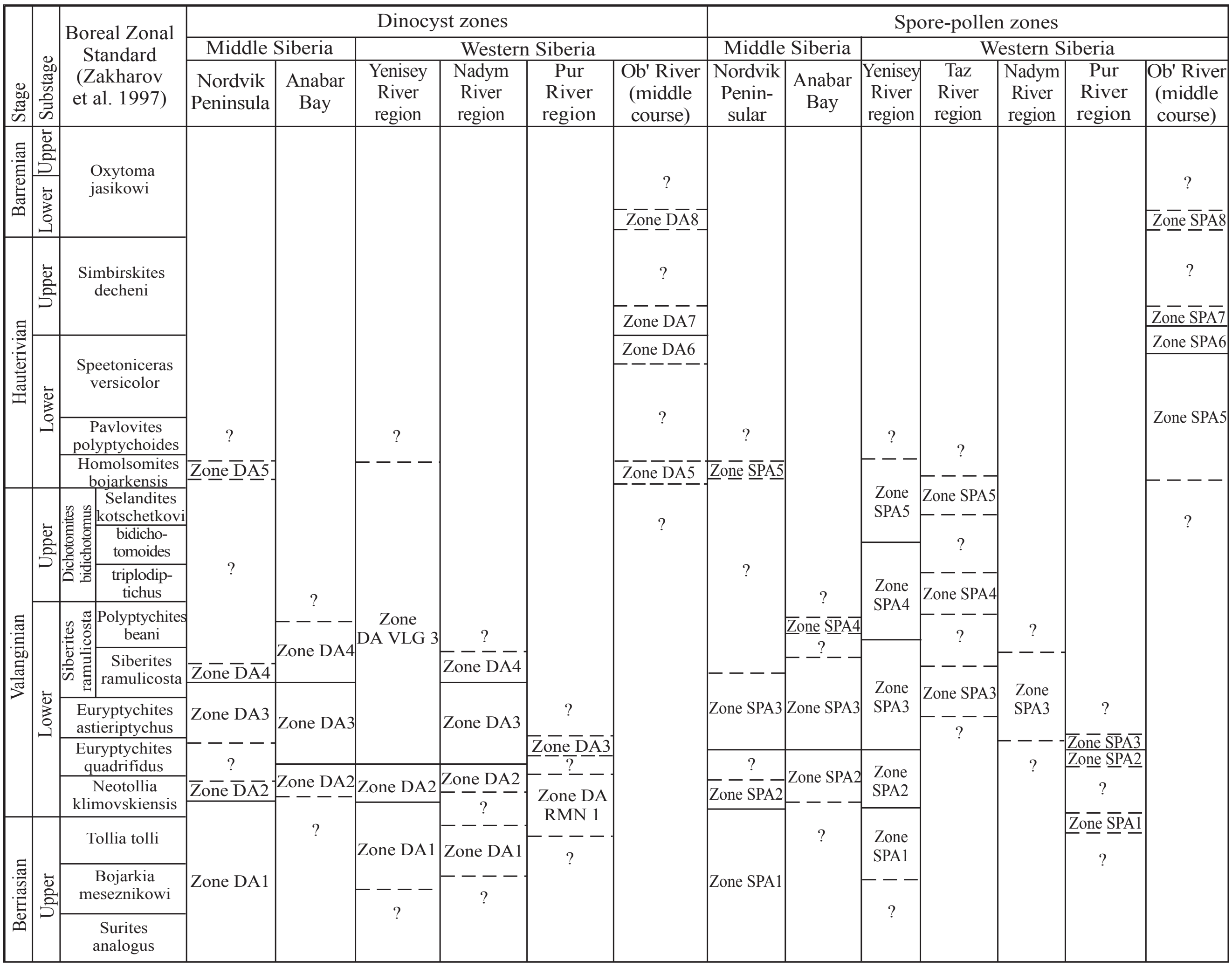

Fig. 2. Spore-pollen and dinocyst zones and their correlation in different Siberian regions.

Notes: *dotted lines mark supposed levels of zone boundaries; Zones DA (dinocyst assemblage): DA1- Pareodinioidea, Batioladinium varigranosum, Cassiculosphaeridia reticulata; DA RMN1- Paragonyaulacysta sp., Batiacasphaera sp.; DA2- Escharisphaeridia spp., Oligosphaeridium spp., Circulodinium spp.; DA3- Oligosphaeridium complex, Dingodinium cerviculum; DA VLG3- Sentusidinium spp., Apteodinium spp.; DA4- Aldorfia sibirica, Aprobolocysta galeata; DA5- Hystrichodinium solare, Muderongia spp.; DA6- Aptea anaphrissa, Oligosphaeridium aff. totum, Batioladinium longicornutum; DA7- Aprobolocysta eilema, A. neista, Odontochitina spp.; DA8- Canningia spp., Nelchinopsis kostromiensis; Zones SPA (spore-pollen assemblage): SPA1- Foraminisporis wonthaggiensis, Trilobosoprites valanjinensis, Cicatricosisporites ludbrookiae, C. subrotundus; SPA2- Rouisesporites spp., Cicatricosisporites minutaestriatus, Pilosisporites spp., Ornamentifera granulata; SPA3- Cicatricosisporites australiensis, C. dorogensis, Foraminisporis dailyi; SPA4- Appendicisporites spp., Trilobosporites purverulentus, T. uralensis; SPA5- Ruffordia goepperti, Aequitriradites spp., Ornamentifera spp., O. echinata; SPA6- Cicatricosisporites tersus, Foraminisporis spp., Taxodiaceaepollenites spp.; SPA7- Pilosisporites notensis, Pilosisporites echinaceus; SPA8- Pilosisporites hirsutus, Lygodium longipilosum, Rouseisporites laevigatus, R. radiatus.*

Fig. 3. Siberian spore-pollen zones and main bioevents.

Spore-pollen zones	Main bioevents
?	
SPA8	*Pilosisporites hirsutus*, *Lygodium longipilosum*, *L. calvum*, permanent occurrences of *Pilosisporites* spp., *Rouseisporites* spp.
?	
SPA7	*Pilosisporites echinaceus*, *P. notensis*, *Gleicheniidites toriconcavus*, permanent occurrences of *Cicatricosisporites dorogensis*
SPA6	increased percentage of *Taxodiaceaepollenites* spp. (up to 17%) and diversity of *Cicatricosisporites*
SPA5	*Ruffordiaspora goepperti*, ***Ornamentifera echinata,*** permanent occurrences of *Aequitriradites* spp., *A. spinulosus*, *A. verrucosus*
SPA4	*Appendicisporites* spp., *A. parviangulatus*, *A. problematicus*, *Trilobosporites purverulentus*, *T. uralensis*
SPA3	*Cicatricosisporites dorogensis*, *C. australiensis*, *C. mediostriatus*, *C. pseudotripartitus*, *C. mohrioides*, *C. imbricatus*, *C. stoveri*, *C. verbitskaja*
SPA2	*Rouseisporites* spp., *Pilosisporites* spp., *Ornamentifera granulata*, *Clavifera* sp., *Cicatricosisporites minutaestriatus*, *C. pseudoauriferus*, *C. brevilaesuratus*
SPA1	*Foraminisporis wonthaggiensis, Aequitriradites spinulosus*, *A. verrucosus*, *Trilobosporites valanjinensis*, *T. bernissartensis*, *T. grossetuberculatus*, *Concavissimisporites multituberculatus*, *Cicatricosisporites ludbrookiae*, *C. perforatus*, *C. subrotundus, Plicatella tricostata*, *Taxodiaceaepollenites* spp.

Fig. 4. Siberian dinocyst zones and main bioevents.

Dinocyst zones	Main bioevents	
?		
DA8	Occurrences of *Nelchinopsis kostromiensis*, *Aprobolocysta galeata*, *A. eilema*, *A. cornuta*	*Muderongia*, *Hystrichodinium*, *Oligosphaeridium*, *Vesperopsis*, *Cassiculosphaeridia*, *Odontochitina*, *Pseudoceratium*
?		
DA7	*Aprobolocysta eilema*, *A. neista*, *A. cornuta*, *Odontochitina* spp., *Odontochitina operculata*, *Psedoceratium expolitum*, *Vesperopsis fragilis*, *V. mayi*	*Hystrichodinium solare*, *Tenua americana*, *Oligosphaeridium ?asterigium*
DA6	*Aptea anaphrissa*, *Batioladinium longicornutum*, *Oligosphaeridium* aff. *totum*	
?		
DA5	*Hystrichodinium solare*, *Muderongia tetracantha*, *M. staurota*, increased percentage and diversity of *Muderongia*	
?		
DA4	*Aprobolocysta galeata*, *Aldorfia sibirica*, increased percentage of *Dingodinium cerviculum* (up to 6%)	
DA3	*Oligosphaeridium complex*, *Dingodinium cerviculum*, *Muderongia crucis*, *M. australis*, *M.* "*tomaszovensis*", *Batioladinium reticulatum*	
DA2		*Pargonyaulacysta ?borealis*, *Tubotuberella rhombiformis*, *Ocissucysta wierzbowskii*, *Dingodinium ?spinosum*, reduced diversity of Pareodinioideae
DA1	*Tanyosphaeridium magneticum*, *Cassiculosphaeridia reticulata*, *Batioladinium varigranosum*	

located at the base of Kochi ammonite zone. In the central regions of West Siberia the earliest apperances of *Cicatricosisporites minutaestriatus* (Bolchovitina) Pocock in the Early Valanginian allows us to recognize the base of the zone SPA2 (Pestchevitskaya 2007b). Increased diversity of *Cicatricosisporites* and the inception of several species of this genus are observed in different regions in Western Siberia and the north Enysey River area (Pestchevitskaya 2007b). Bioevents of the upper part of the Lower Valanginian (Fig. 3) are recognised only in the Nordvik and Anabar sections, while common occurrences of *Aequitriradites* species in the Upper Valanginian and Hauterivian are also recovered in different regions in Subarctic Urals, West Siberia and Yakutiya (Pestchevitskaya 2007b).

Berriasian dinocyst assemblages of Siberia comprise several species which have their earliest appearance in this stage elsewhere in NW Europe and Canada (Pestchevitskaya 2007a). *Cyclonephelium cuculliforme* (Davies) Aarhus and *Paragonyaulacysta ?borealis* (Brideaux & Fisher) Stover et Evitt allows the correlation of the DA1 zone and the Cyclonephelium cuculliforme – Paragonyaulacysta ?borealis zone of Arctic Canada (Davies 1983). The inception of *Batioladinium varigranosum* (Duxbury) Davey is reported from the Upper Berriasian of Newfoundland (Van Helden 1986) and NW Europe (Davey 1982). Its inception provides a direct calibration of the bases of the DA1 zone and the Scriniodinium campanula zone of Newfoundland (Van Helden 1986). The first occurrences of *Cassiculosphaeridia reticulata* Davey in the Upper Berriasian is also recovered in the Subarctic Urals (Lebedeva & Nikitenko 1999). The important events at the base of DA2 zone are the extinctions of *Pagaronyaulacysta ?borealis* and *Dingodinium ?spinosum* (Duxbury) Davey, that are also defined in NW Europe, Greenland, Norway, Arctic Canada and Siberia (Fisher & Riley 1980; McIntyre & Brideaux 1980; Häkansson et al. 1981; Aarhus et al. 1986; Lebedeva & Nikitenko 1999; Smelror & Dypvik 2005). The inception of *Oligosphaeridium complex* (White) Davey & Williams (DA3 base) is observed in NW Europe and Canada almost at the same level, providing reliable correlations (Duxbury 2001; McIntyre & Brideaux 1980; Davies 1983; Aarhus et al., 1986; Costa & Davey 1992). The earliest apperance of *Aptea anaphrissa* (Sarjeant) Sarjeant & Stover in the Lower Hauterivian are reported from Subarctic Urals and Barents Sea shelf (Aarhus et al. 1990; Smelror et al. 1998; Lebedeva & Nikitenko 1999). The inception of *Aprobolocysta eilema* Duxbury and *Vesperopsis fragilis* (Harding) Harding and the extinction of *Tenua americana* (Pothe de Baldis & Ramos) Prössl are defined at the base of the Upper Hauterivian in NW Europe (Costa & Davey 1992; Duxbury 2001). The occurrences of *Aprobolocysta eilema* and *Nelchinopsis kostromiensis* (Vozzhennikova) Wiggins are not recovered in Siberia and NW Europe above the Lower Barremian (Aarhus et al. 1990; Costa & Davey 1992; Smelror et al. 1998).

Evolution of Early Cretaceous dinocyst associations and palaeoenvironments

The established dinocyst zonation is based on taxonomic changes in the dinocyst assemblages which reflect the evolutionary stages of the dinocyst associations. They show a gradual extinction of the Jurassic marine microflora and the inception of Early Cretaceous dinocyst communities (Fig. 5). The Berriasian and earliest Valanginian associations are characterized by a wide distribution of genera and species of Gonyaulacaceae and Pareodinioideae arisen from the Jurassic (Pestchevitskaya 2007a). Upwards in the section, there is a considerable decrease in their diversity (Fig. 5). Taxonomic changes in the family Gonyaulacaceae observed in the Valanginian (stage II) are marked by extinction of Jurassic species and inception of Cretaceous species (Pestchevitskaya 2007a). In the middle part of the Early Valanginian, an increase

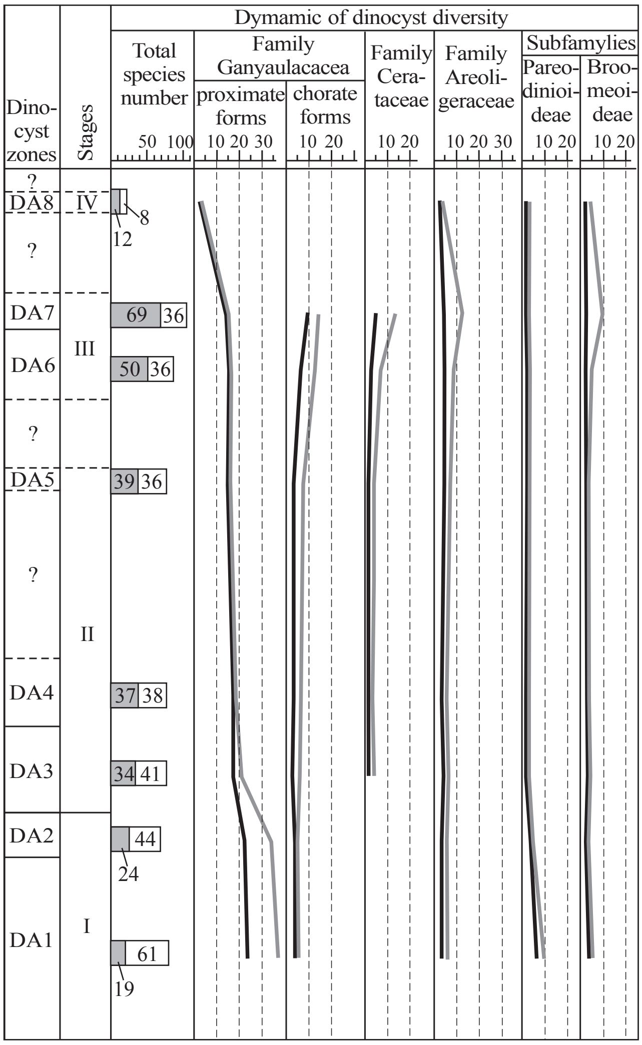

Fig. 5. Evolution stages of Siberian dinocyst associations.
Notes: *Stage I- The origin of Early Cretaceous microflora; Stage II- The development of Early Cretaceous microflora; Stage III- The bloom of Early Cretaceous microflora; Stage IV- Reduced diversity of Early Cretaceous microflora; white filling – taxa derived from the Jurassic, grey filling – Cretaceous taxa; black lines – number of genera; grey lines – number of species.*

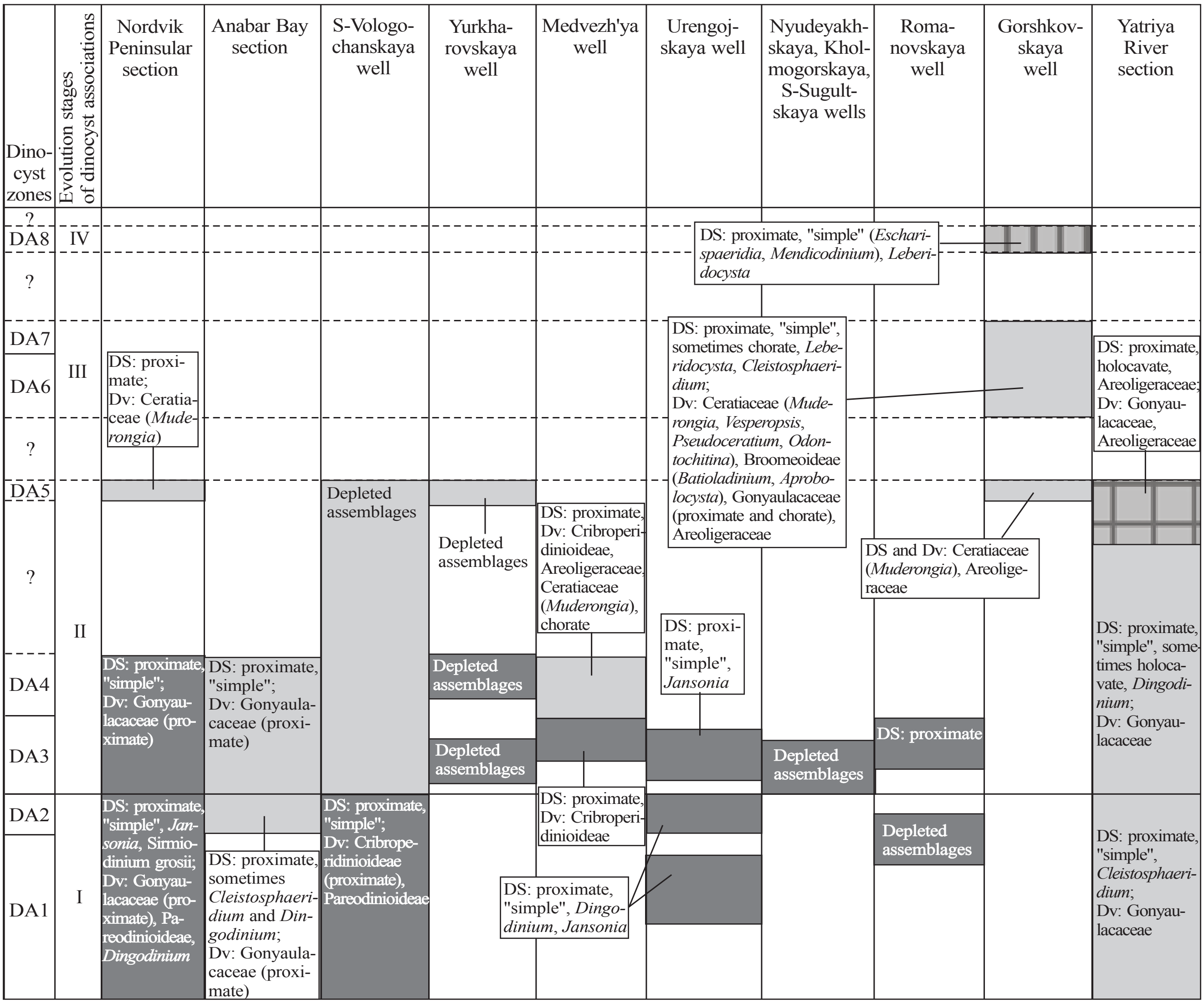

Fig. 6. Dominant/subdominant (DS) and most diverse (Dv) dinocyst taxa and groups in Siberian sections characterized by different facies. Note: *filled areas illustrate facies in studied intervals of the sections, for legend see Fig. 8.*

in quantity and diversity of Areoligeraceae and Ceratiaceae began, and in the Hauterivian (stage III) these forms became most characteristic and prolific. In the Early Barremian (stage IV), there was a sharp depletion of dinocyst associations which may have been caused by the regression of the Siberian palaeobasin (Pestchevitskaya 2007a).

In addition to having some evolution regularities, the microphytoplankton associations are characterized by specific features related to the palaeoenvironments. The quantitative changes of the main palynological groups and dinocyst taxa related to different environments are shown on Figs. 6-11. In general, the Siberian dinocyst associations are dominated by proximate and "simple" forms (Fig. 6). Chorate dinocysts, like those which are typical for Tethyan regions, are rather rare. This is possibly related to the relatively low temperatures (11-20°C, as determined from isotopic studies of belemnites) of the Siberian basin in the Early Cretaceous (Golbert 1987). In should be pointed out that the highest diversity of these forms, as well as most diverse and abundant microphytoplankton associations, is observed in the western part of the studied region in all stages (Figs. 6-11). This may be related to warmer and more favorable conditions for microphytoplankton development influenced by the invasion of warm water masses through the Ural straits (Baraboshkin et al. 2007). The tendency of an increase in diversity and abundance of dinocysts and chorate forms in offshore associations compared to more shallow waters (Wall et al. 1977; Davies et al. 1982; Pross & Brinkhuis 2005) is not recognized in the Siberian material (Figs. 6-11). In the Yatriya section the most abundant and diverse associations are found in near-shore sublittoral and lagoon environments (Lebedeva & Nikitenko 1999). In the Medvazh'ya well, dinocyst diversity also increases in the upper sublittoral zone (Fig. 6). In the Nordvik section and the S-Vologochanskaya well, more diverse and abundant associations are found in the middle sublittoral zone (Figs. 6-9). The studies of recent microphytoplankton also demonstrate an uneven distribution in the marine basins (Kort 1969; Wall 1969; South & Whittick 1987;

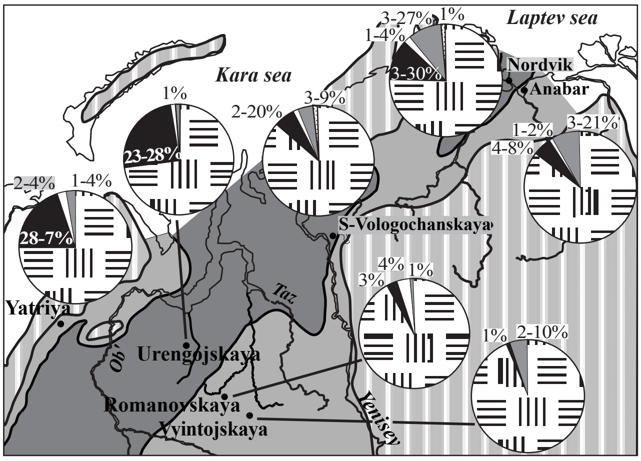

Fig. 7. Palaeoenvironments of North Siberia in the Late Berriasian – Earliest Valanginian (stage I) (Zakharov & Yudovny 1974; Golbert 1987) and quantitative relations of main palynological groups. Notes: for legend see Fig. 8.

Konovalova 1998). The cyst content in the sediments is related to the total productivity in the watermasses, which together with other parameters is strongly determined by available nutrients. Abundant accumulations of microphytoplankton are observed in areas with intensive vertical and horizontal water mixing that cause high concentration of biogenetic components in the near-surface water layers (Kort 1969; Konovalova, 1998; Vinogradov & Lappo 2004). Apparently, the microphytoplankton distribution in the Siberian palaeobasin may have been influenced by similar regularities.

In the Early Barremian, shallow water, brackish environments in Siberia were characterized by wide distribution of prasinophytes (*Leiosphaeridia*) and specific dinocyst associations, which included abundant *Mendicodinium*. It is interesting to note that morphologically similar forms have been recovered from Quaternary lacustrine sediments (Norris & McAndrews 1970). Siberian Early Barremian assemblages also contain rare *Batioladinium, Aprobolocysta, Apteodinium,*

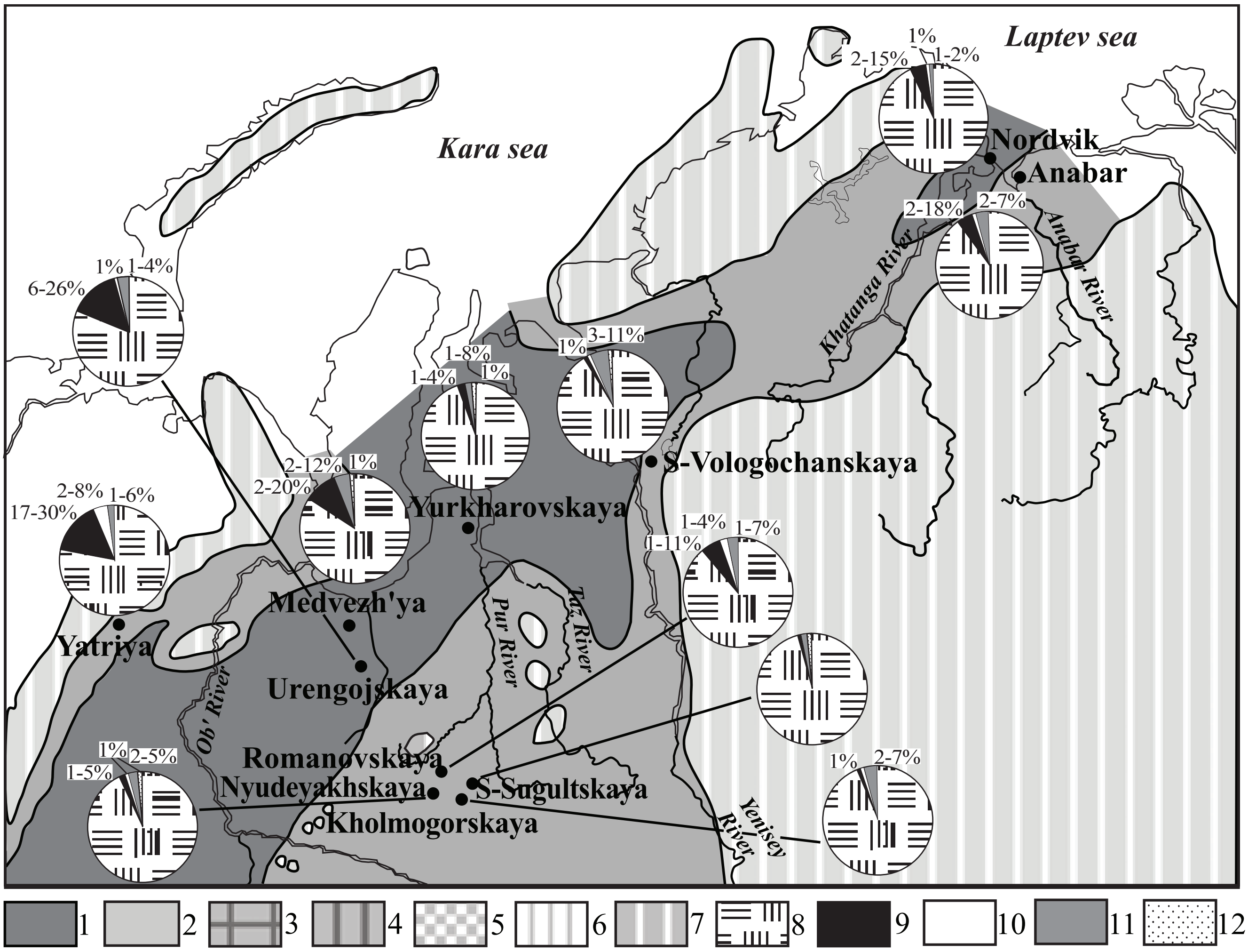

Fig. 8. Palaeoenvironments of North Siberia in the Valanginian (stage II, DA3-4) (Zakharov & Yudovny 1974; Golbert 1987) and quantitative relations of main palynological groups.

Notes: 1-7 – *palaeoenvironments: 1 – middle sublittoral zone, 2 – upper sublittoral zone, 3 – lagoons, 4 – shallow water desalinated basin, 5 – coastal plain sometimes flooded by sea, 6 – alluvial plain, 7 – denudation areas; 8-12 – main palynological groups: 8 – terrestrial palynomorphs, 9 – dinocysts, 10 – acritarchs, 11 – Prasinophyceae, 12 – Zygnemataceae.*

Nelchinopsis, Cyclonephelium and *Sentusidinium*, but lacks ceratioid dinocysts which often are regarded as indicators of restricted and low salinity environments (Wilpshaar & Leerveld 1994; Leerveld 1995). In Siberia, diverse and abundant Ceratiaceae are found in off-shore environments of the upper sublittoral zone.

Conclusions

Detailed dinocyst and spore-pollen zonations have been defined for the Berriasian – Lower Barremian succession of North Siberia. The boundaries of the dinocyst and spore-pollen zones are calibrated againts one another, and are also calibrated to the established Boreal ammonite zonation (Zakharov et al. 1997). Most of the boundaries serve as good stratigraphic markers and are useful for regional correlations. The boundaries of the dinocyst zones are of special interest since they are recognized not only in Siberia, but also in NW Europe and Canada. The taxonomic changes in the microphytoplankton associations reflect trends related both to the dynamic changes of the Siberian palaeobasin and to the dinocyst evolution. From palaeoenvironmental analysis an irregular distribution of microphytoplankton associations in the different bionomical zones is evident. The present investigation suggests that the diversity of Siberian microphytoplankton associations was determined mainly by water temperature and nutrients.

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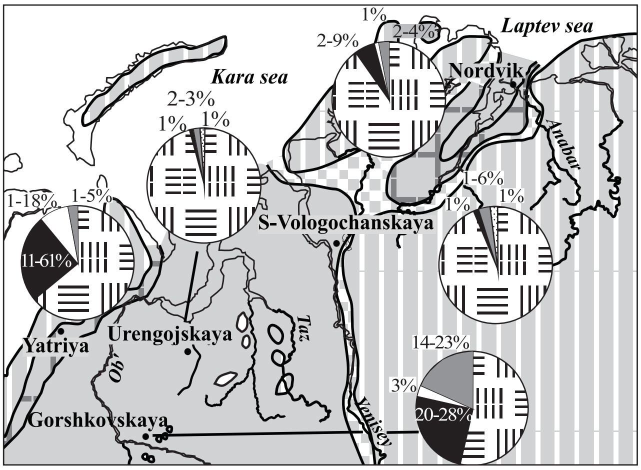

Fig. 9. Palaeoenvironments of North Siberia in the Latest Valanginian – Earliest Hauterivian (stage II, DA5) (Zakharov & Yudovny 1974; Golbert 1987) and quantitative relations of the main palynological groups. Notes: for legend see Fig. 8.

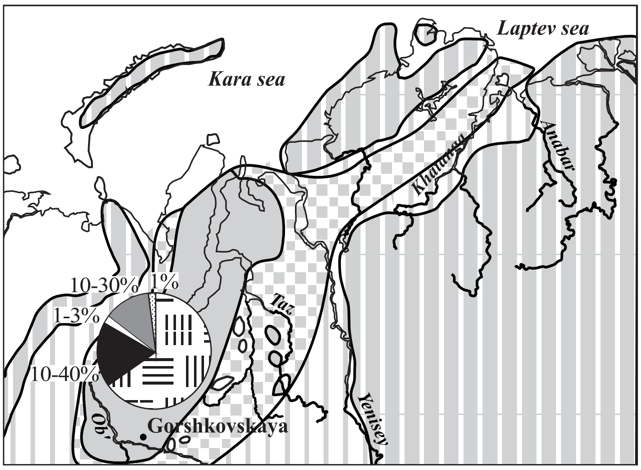

Fig. 10. Palaeoenvironments of North Siberia in the Hauterivian (stage III) (Zakharov & Yudovny 1974; Golbert 1987) and quantitative relations of the main palynological groups. Notes: for legend see Fig. 8.

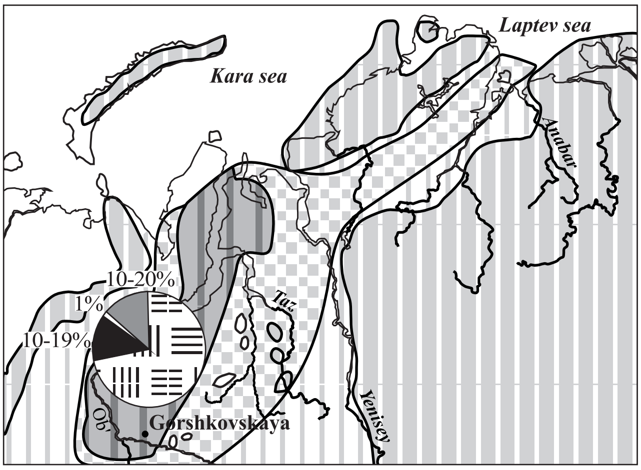

Fig. 11. Palaeoenvironments of North Siberia in the Early Barremian (stage IV) (Zakharov & Yudovny 1974; Golbert 1987) and quantitative relations of the main palynological groups. Notes: for legend see Fig. 8.

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