

Organic-walled Phytoplankton from Paleogene Sections of Kamchatka

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Abstract—Organic-walled phytoplankton assemblages from Eocene and Oligocene reference sections of western Kamchatka are analyzed. They are close in taxonomic composition to coeval assemblages of northern Japan and Sakhalin that is a good opportunity to correlate regional units and verify their age. The euryhaline species *Trinovantedinium boreale* that is associated with *Paralecaniella indentata* and *Micrhystridium* preferring shallow low-salinity waters, on the one hand, and taxa dwelling in normal-salinity open sea environments, on the other, are dominant in most assemblages, which are examined. The suggested variant of bed succession with dinocyst assemblages may be valid for Japan, Sakhalin, Kamchatka, and the Bering Sea.

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Key words: Western Kamchatka, Sakhalin, Japan, Bering Sea, organic-walled phytoplankton, dinocysts, regional scale by dinocysts, Snatol, Kovachina, Rategin, Amanina, Galhin, and Utkholok, Poronai and Momijiyama formations, Paleogene, Paleocene, Eocene, Oligocene.

INTRODUCTION

The systematic study of Paleogene marine organic-walled phytoplankton from middle and high latitudes of the Northwest Pacific continental margin commenced only a decade ago. In contrast to microplankton from similar latitudes of North America and West Europe, where coeval regional assemblages are similar and zonal assemblages differ frequently only by index species, organic-walled microflora of Kamchatka, Sakhalin, and Japan is of a peculiar taxonomic composition. Endemism of the Northwest Pacific organic-walled biota is primarily a consequence of Pacific waters isolation from the Arctic and Antarctic influence in high latitudes and water exchange with other oceanic basins in low latitudes only. The biota composition was likely influenced by peculiar temperature, chemical, and hydrological regime of near-surface waters in the region and by distribution of nutrient resources. Composition of taphocoenoses essentially depended also on sedimentation regime that led to accumulation of thick sequences of dominant volcanogenic–siliceous, terrigenous–siliceous, and coarse-grained terrigenous sediments almost lacking carbonate material. Because of biogenic material dilution in areas of avalanche sedimentation, a low concentration of cysts and impoverished taxonomic composition are characteristic of organic-walled phytoplankton assemblages in a spacious region from the Bering Sea and Kamchatka to Japan. Macerates with low content of palynomorphs are frequently inappropriate for statistical processing and age interpretation. The high-resolution dinocyst zonations elaborated for inner and marginal seas of the

Atlantic and Peri-Tethys cannot be used in the Northwest Pacific with different sedimentation and hydrologic regimes in sea basins. Japanese researchers (Kurita et al., 2000) proposed recently an imperfect regional zonation for the upper middle Eocene–Miocene, which is unfortunately incomplete even for this interval. Data on Early Paleogene palynomorphs are insufficient for zonal interpretation. In addition, organic-walled phytoplankton is very irregularly studied in different stratigraphic intervals and regions of the Northwest Pacific.

First information on Eocene and Oligocene organic-walled phytoplankton of the North Pacific was obtained from deep-sea holes in the Norton Sound and Navarin basins of the Bering Sea (Bujak and Matsuoka, 1986; Matsuoka and Bujak, 1988). In several articles of the mid-1990s, Japanese researchers analyzed composition and distribution of dinocysts in Paleogene and Miocene sections of the Ishikari (Yubari area), Rumoi (Haboro area), Kushiro (Shiranuka area) and Dzeban sedimentary basins of northern Honshu and Hokkaido (Kurita and Obuse, 1994; Kurita and Matsuoka, 1995; Kurita and Miwa, 1997, 1998; and others). N.Ya. Brutman and I.V. Pozdnyakova, who examined the borehole section Borisovskaya-1 (Pogranichnyi area, eastern coastal zone of central Sakhalin) published in 1993 first data on Cenozoic dinocysts of the island (*Geological and Biotic...*, 1998). Later on, Japanese palynologists studied dinocysts from some intervals of sections in the Chekhov and Makarov areas of Sakhalin (Kurita et al., 1996), and then information on these fossils was supplemented by data from Paleogene and Miocene sec-

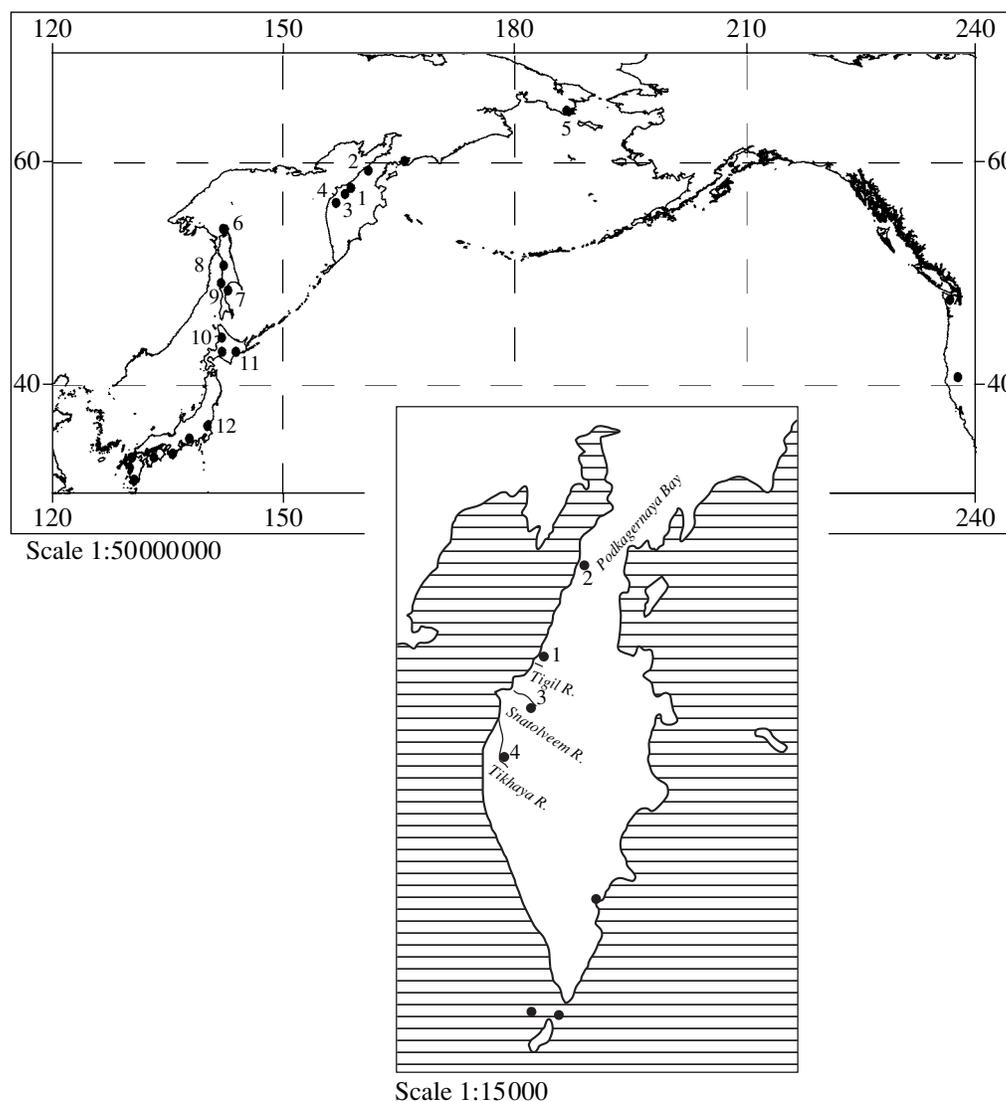


Fig. 1. Location of sections with microphytoplankton in Kamchatka and Asian part of the Northwest Pacific region: (1) Tochilo section; (2) Podkagernaya Bay, stratotype section of the Rategin Formation; (3) middle courses of the Snatolveem River; (4) Tikhaya River (right Khairyuzova River head); (5) Cape Navarin; (6) Shmidt Peninsula; (7) Makarov section; (8) Aleksandrovsk area; (9) Chekhov area; (10) Ishikari; (11) Kushiro; (12) Dzeban.

tions near the Makar'evka (Due) and Mgachi settlements in the Shmidt Peninsula and Aleksandrovsk area. In her report to the Third All-Russian Palynological Meeting held in Moscow, Shchenko (1996) presented first data on Paleogene dinocysts of Kamchatka representing six assemblages of organic-walled phytoplankton from the Napana, Kovachina, Amanina, and Gakkhin formations constituting the section along the Tikhaya River, a right source of the Khairyuzova River upstream of the Khairyuzovo Settlement. The oldest of these assemblages with *Apectodinium homomorphum*, *Paleoperidinium sibiricum*, *Vozzhennikovia apertura*, *Glaphyrocysta undulata*, and *Trinovantedinium boreale* (the *Apectodinium homomorphum*–*Vozzhennikovia apertura* assemblage after T.S. Shchenko) is prob-

ably from the Napana Formation of the Thanetian–Ypresian age.

G.M. Brattseva discovered a dinocyst assemblage in lower layers of the Tkapravayam Formation upper half (Member 20), the Paleogene section of the Chemurnaut Bay. The assemblage consists of *Wetzeliella articulata*, *Enneadocysta arcuata*, *Deflandrea* spp. (*D. heterophlycta* and others), *Hystriocholpoma cinctum*, *Cordosphaeridium funiculatum*, and others (*The Lower Paleogene...*, 1997). Because of impoverished composition of this dinocyst assemblage, the age interpretation of the Tkapravayam Formation upper part is ambiguous. In the cited work, its upper age limit is determined as corresponding to the Paleocene. Presence of *Wetzeliella* and *Enneadocysta* genera in this impoverished assemblage, which are known to occur

only since the Eocene, indicates that beds with dinocysts accumulated most likely in the first half of the Eocene. In the unified regional scale, the assemblage should be between the *Apectodinium homomorphum*–*Vozzhennikovia apertura* (Shchenko, 1996) and close assemblages from the Paleocene–Eocene boundary layers of the Haboro Formation in Hokkaido (Kurita and Obuse, 1994), on the one hand, and the middle Eocene assemblage with *Bellatodinium hokkaidoanum* from lower beds of the Poronai Formation (Kurita and Matsuoka, 1995), on the other. It is undoubtedly older than the assemblage from the middle part of the Kovachina Formation of the Tochilo section considered in this article.

Recently, Zaporozhets has studied organic-walled phytoplankton from three sections of western Kamchatka. Her data on dinocysts from basal layers of the Rategin Formation stratotype in the Podkagernaya Bay (samples 82/1, 82/2, 82/4) were partly discussed earlier (Zaporozhets, 1999). For some stratigraphic intervals, representative results were obtained from the Kovachina (Sample 15), Amanina (samples 24, 25, 30, 31), lower (Sample 28) and upper (samples 48, 51) Gakkhin, and upper Utkholok (Sample 41) formations in the southwestern limb of the Tochilo anticline, the Tigil area north of the Tigil River mouth. Several examined samples are from Eocene sediments exposed in the middle courses of the Snatolveem River, upstream (Sample 14) and downstream (samples 14h, 14g/2, 14g/3) of the Mt. Sosopkhan. Geographic location of examined sections is shown in Fig. 1. Below, we consider results of organic-walled phytoplankton analysis in all the mentioned localities. Samples are from collections of V.N. Sinel'nikova and D.I. Vitukhin, who also informed us about sampling levels in lithostratigraphic units of the Tochilo and Snatol sections.

THE EXAMINED SECTIONS

Podkagernaya Bay. In this area, samples have been collected from the lower 30-m-thick basal part of the Rategin Formation overlying the Irgirni coal-bearing formation in the right bank of the Podkagernaya River mouth. Sample 82/1 is from the transitional member with *Lingula hians* at the base of the formation; samples 82/2 and 82/4 are taken 10 and 30 m above the latter, respectively (Fig. 2). In terms of facies affinity, the sampled member is composed of shallow-water sandy sediments corresponding to the initial stage of transgression that followed accumulation of the Irgirni coal-bearing formation. This is evident from found shallow-water inarticulate brachiopods *Lingula*, which dwelt in liquid mud at the depth of 30 m and shallower, and from occurrence of an oyster bank. The gradual advance of

transgression during the early Rategin time is consistent with successively increasing proportion of organic-walled phytoplankton relative to higher plant palynomorphs (the offshore distance coefficient increases from 15 to 32%). This inference is also supported by the composition of plant detritus: larger fragments of higher plants prevail in lower samples 82/1 and 82/2. Terrestrial detritus with distinct cellular structure is also abundant in Sample 82/4 though being associated with fragments of Phaeophyceae algae thalluses and embryonic foraminiferal chambers.

Tigil area. Samples are collected in the southwestern limb of the Tochilo anticline (Figs. 3, 41 Plates I, II) from members and beds, which are described and successively enumerated in monograph dedicated to this section (*Atlas...*, 1984) and in book on other Eocene sections of western Kamchatka (*The Eocene...*, 1991). Sample 15 characterizing siltstones in the middle part of the Kovachina Formation that is 225–280 m thick in sampling area is taken in the left bank of the Tochilo Creek mouth from concretions with *Lima twinensis* in clays of Member 7 approximately 110–120 m below the formation top. The overlying tuffaceous clayey-silty Amanina Formation (201.6 m) is sampled in the basal part: Sample 30 is taken from the base of *Yoldia ovata*–*Nemocardium yokoyami* Beds (I); Sample 31, 30 m above it. Sample 25 is from Bed 11 of the Amanina Formation top, Sample 24 has been collected 20 m below from Bed 9 corresponding to the middle part of *Monia schmidti* Beds (II), and Sample 26, from the *Solen amaninensis* Beds (III). Higher in the section, there is the Gakkhin Formation 945 m thick, composed of volcanogenic–terrigenous sediments. The formation thickness is likely overestimated, because some of its intervals are doubled of the section. Sample 28 from Bed 9 in the formation lower part corresponds to the *Nuculana (Saccella) praefurlongi* Beds (IV), while samples 51 and 48 are collected from beds 58 and 64, respectively, in the upper molluscan *Multidentata multidentata* Beds (V) of the formation. Sample 41 is from Bed 21 located several meters below the top of the Utkholok Formation that is 457.5 m thick in the Tochilo section. Its position corresponds to the molluscan *Yoldia utcholokensis*–*Deltopecten utcholokensis* Beds. Thus, the samples representatively characterize four formations of the Tochilo section, which are over 1200 m thick in total.

Distribution of organic-walled phytoplankton in sections of the Podkagernaya Bay and southwestern limb of the Tochilo anticline is presented in Table 1.

Snatolveem River middle reaches. In this area, we sampled the Napana (Sample 14), Snatol, and Kovachina (samples 14h, 14g/2, 14g/3) formations, and

Fig. 2. Distribution of organic-walled phytoplankton in the stratotype section of the Rategin Formation: (1) conglomerate; (2) sandstone and small-pebbled conglomerate; (3) mudstone and clay; (4) siltstone and sandy clay; (5) opoka; (6) cross bedding; (7) tuff; (8) concretions; (9) gennoishi (glendonite); (10) coal; (11) over 100 specimens; (12) over 20 specimens.

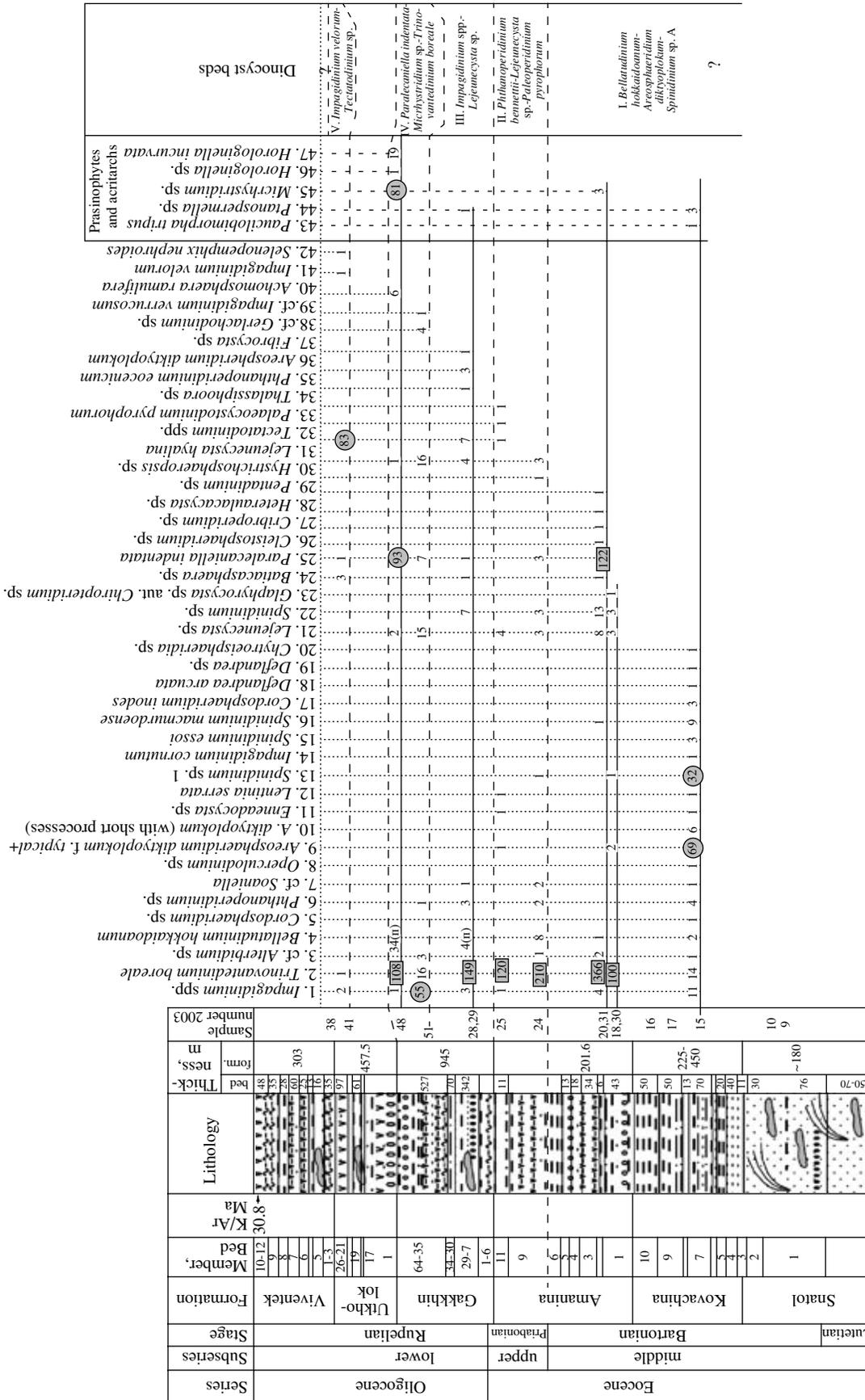


Fig. 3. Distribution of organic-walled phytoplankton in the section of the Tochiino anticline southwestern limb (symbols as in Fig. 2).

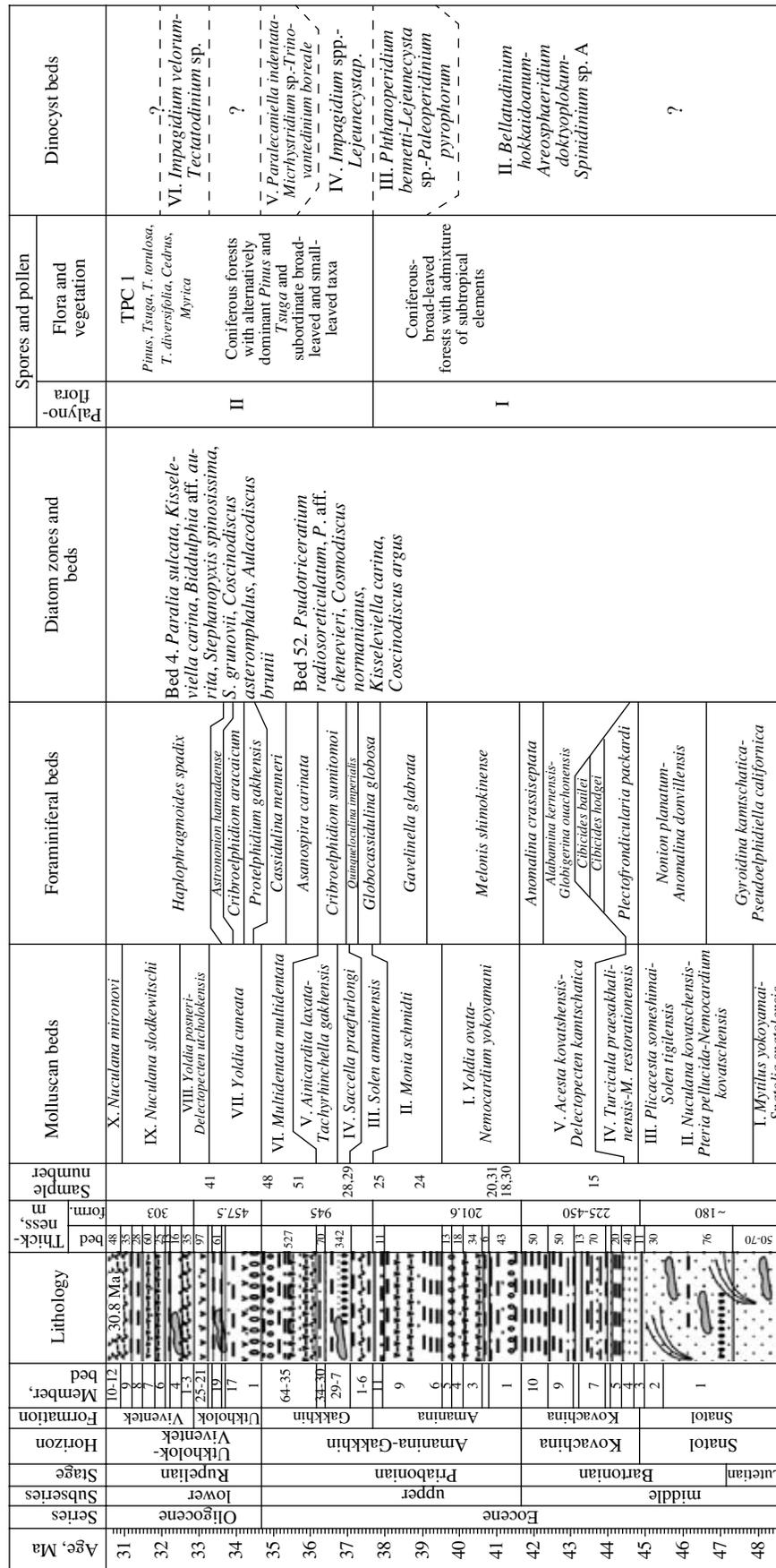
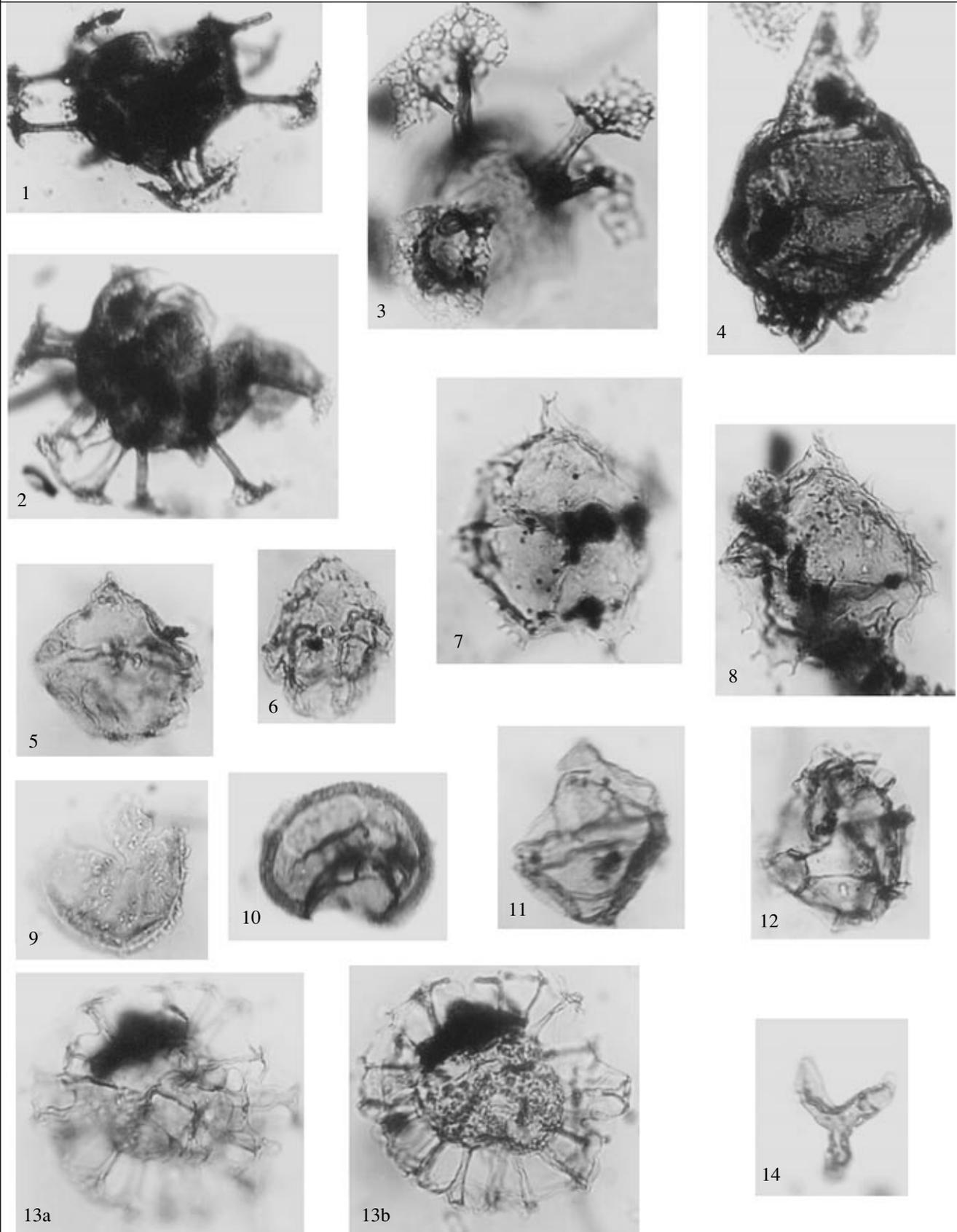


Fig. 4. Correlation of defined biostratigraphic units in the Tochilo section (Atlas., 1984, with additions) (symbols as in Fig. 2).

Plate I



most representative phytoplankton is detected in two samples from the Snatol Formation (Plate III).

COMPOSITION OF ORGANIC-WALLED PHYTOPLANKTON ASSEMBLAGES

As evident from Table 1, dinocyst assemblages from Kamchatka sections are of relatively low diversity being usually represented by less than 60 species in the interval from the Kovachina Formation middle part up to the Utkholok Formation. The same is typical of phytoplankton from the Rategin Formation close in age to the Amanina Formation in the Podkagernaya Bay. It was assumed previously that these formations are the late Eocene–Oligocene in age (*Atlas...*, 1984; *The Eocene...*, 1991; *The Lower Paleogene...*, 1999; Serova, 2001). As compared with dinocyst assemblages from concurrent sediments of West to Central Europe and southern Russia, dinocysts from Kamchatka sections are 2.5 to 3.0 times less diverse. The maximal diversity is characteristic of the Kovachina (18 species), Amanina (14 species), and Rategin (30 species) formations, except for basal layers of the last two units, where 6 and 4 species respectively are detected. In terms of dinocyst diversity, the sampled deposits are comparable with coeval sediments of different lithology in the Ishikari and Rumoi basins of Hokkaido. The assemblages so impoverished are termed restricted (Kurita and Matsuoka, 1995), since they consist of 5 to 7 species. Japanese paleontologists believe that they reflect the initial regressive phase of the basin development.

Assemblages of the Tochilo sections change notably in composition near boundaries between the formations, although group of dominant species is transit. The Kovachina assemblage is dominated by *Areosphaeridium diktyoplokum* and *Spinidinium* sp.1 (up to 2/3 of the spectrum in Sample 15), which occur in association with *Trinovantedinium boreale* (approximately 10%), *Impagidinium* sp., *Enneadocysta* sp., *Spinidinium macmurdoense*, and *S. essoi*, the last forms representing together over 20% of the assemblage. It is remarkable that only the Kovachina Formation yields occasional specimens of *Impagidinium cornutum*, *Deflandrea arcuata*, *Chytroeisphaeridia* sp., and variable cysts of *Areosphaeridium diktyoplokum* with short processes besides the other typical of the species morphotype. Only two specimens of *Bellatudinium hokkaidoanum* usual in Eocene sections of Japan are found in Sample 15. Dominant dinocysts in the Amanina and Rategin formations are the same: *Impagidinium* spp., *Lejeunecysta* spp., *Phthanoperidinium* spp., *Spinidin-*

ium spp., *Paraleceniella indentata*, and *Trinovantedinium boreale*. The last two taxa prevail, although in different proportions. While in the Amanina Formation *Trinovantedinium boreale* represents 75 to 95% of the assemblage, in the Rategin Formation its share decreases to 20–35%. Content of *Paraleceniella indentata* corresponds to 25% of the assemblage only in some samples. It is noteworthy that low-diversity assemblages from basal parts of both formations include *Trinovantedinium*, *Lejeunecysta*, and *Spinidinium*. *Bellatudinium hokkaidoanum* and *Areosphaeridium diktyoplokum* occurring in the Amanina Formation are inherited from the underlying Kovachina Formation. The dinocyst assemblage of the Gakkhin Formation in the Tochilo section inherited most species from the Amanina Formation: *Trinovantedinium boreale*, *Impagidinium* sp., and *Paraleceniella indentata* are similarly dominant at this level and species diversity of genera *Lejeunecysta* and *Phthanoperidinium* remains high. The uppermost part of the Gakkhin Formation yields abundant *Micrhystridium* forms. Composition of dinocysts from the Utkholok Formation is substantially different: *Trinovantedinium boreale* is practically missing to give way to *Tectatodinium* (over 85% of the spectrum in Sample 41).

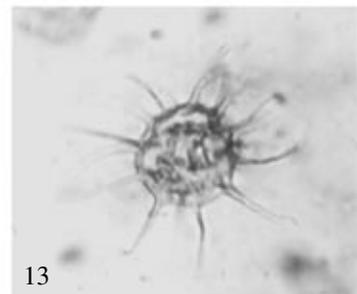
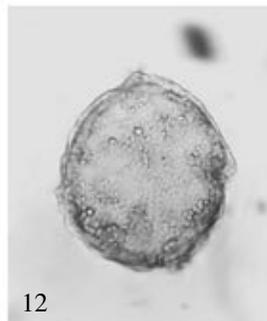
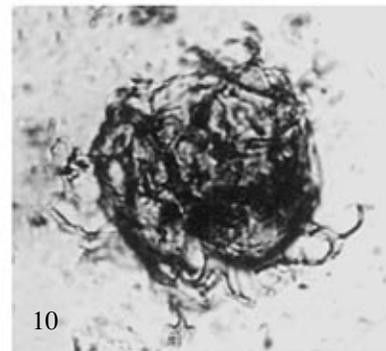
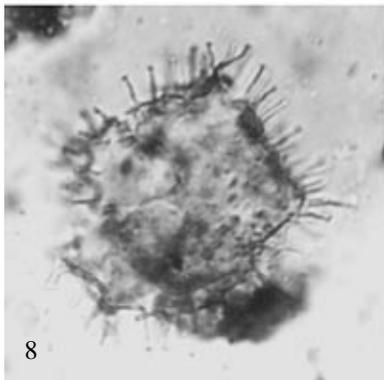
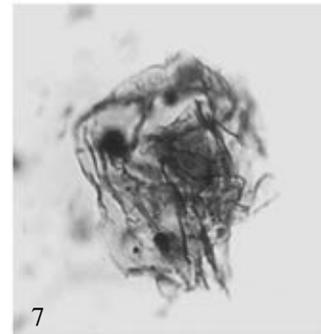
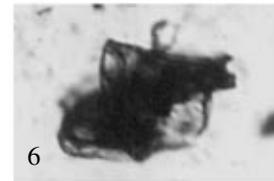
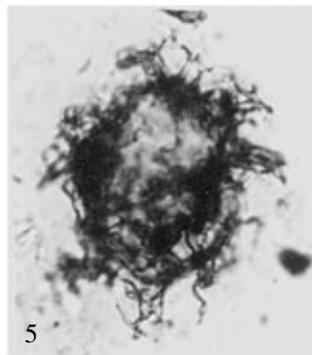
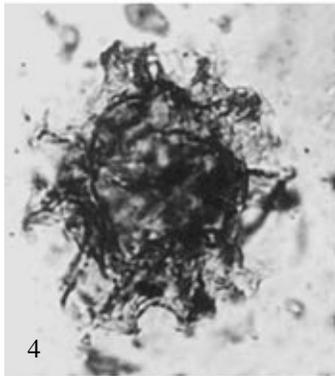
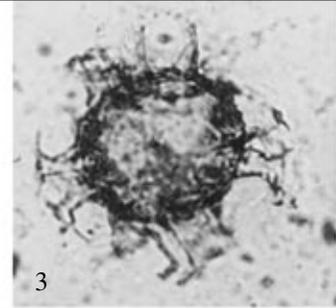
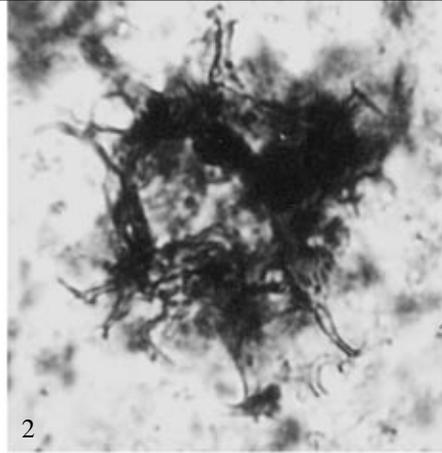
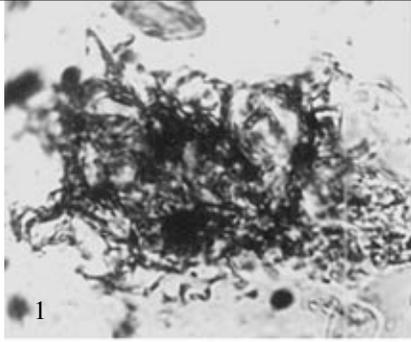
In the Snatolveem River area, samples have been collected from the Napana, Snatol, and Kovachina formations. The most diverse dinocyst assemblages are observed in samples 14g/2 and 14g/3 from the Snatol Formation. They are dominated by *Trinovantedinium boreale*, and phytoplankton spectrum in Sample 14g/3 is in fact monotaxonic (over 90% of this taxon). In all samples, the dominant species is accompanied by representatives of genera *Spinidinium* and *Lejeunecysta* (*L. hyalina* included). In addition to dominant *Trinovantedinium boreale*, the most diverse assemblage from Sample 14g/2 includes *Thalassiphora reticulata* (10 specimens), *Bellatudinium hokkaidoanum*, *Lentinia serrata*, *Hystrichosphaeropsis* sp., *Paraleceniella indentata*, *Cribroperidinium* sp., and *Impagidinium* sp.

Trinovantedinium boreale is the most important taxon in all the examined sections. It prevails in dinocyst assemblages of the Snatol, Kovachina, Amanina, Rategin (close in age to the latter), and Gakkhin formations. The species disappears from assemblages at the boundary between the Gakkhin and Utkholok formations or in lower layers of the latter. Appearing in the Northwest Pacific region in the late Paleocene, it becomes abundant only in monotaxonic assemblages of the late Eocene and Oligocene; in the middle Eocene and middle–upper Eocene boundary layers, the domi-

Plate I. Dinocysts from Eocene sediments of the Tochilo Section of western Kamchatka (southwestern limb of the Tochilo anticline, Kovachina Formation, Sample 15).

(1–3) *Areosphaeridium diktyoplokum* (Klump, 1953) Eaton, 1971: (1, 2) ×500, (3) ×750; (4) *Deflandrea* sp., ×750; (5, 6) *Bellatudinium hokkaidoanum* Kurita et Matsuoka, 1966: (5) ×750, (6) ×500; (7, 8) *Spinidinium* sp., ×500; (9) *Kallosphaeridium* sp., ×500; (10) *Selenopemphix crenata* Matsuoka et Bujak, 1988, ×750; (11) *Impagidinium* sp., ×750; (12) *Impagidinium* cf. *I. cornutum* Matsuoka et Bujak, 1988, ×750; (13, 13b) *Nematosphaeropsis lamniscata* Bujak, 1984, ×500; (14) *Paucilobimorpha tripus* de Coninck, ×750.

Plate II



nant taxa are *Bellatudinium hokkaidoanum* and *Areosphaeridium diktyoplokum*.

Nevertheless, the interval with abundant *T. boreale* can hardly be considered as the species epibole, because in Kamchatka and Japan beds with its mass abundance alternate with layers containing notably lesser amount of this form. As shown below, the geographic distribution of *Trinovantedinium boreale* in the North and Northwest Pacific outlines areas, where the regional dinocyst zonation of the upper Paleogene can be used for reliable interregional correlation (Fig. 4). On the other hand, morphological variability of this species (the genus exists nowadays) depends on habitat environments and is a reliable indicator of ecological changes recorded at particular levels.

The high or notable content of *Paralecianiella indentata*, *Micrhystridium*, *Tectatodinium*, *Impagidinium*, *Spinidinium*, and *Lejeunecysta* in some samples is also determined by ecological factors. For example, abundant *Paralecianiella indentata* in Sample 25 and, in particular, its combination with *Micrhystridium* forms in Sample 48 suggest the lowered salinity and shoaling of sea basin. Appearance of these taxa in the uppermost parts of the Amanina and Gakkhin formations is concurrent to changes in lithology, being probably not incidental. *Spinidinium* is characteristic of the Kovachina Formation and lower members of the Amanina and Rategin formations, while representatives of genera *Phthanoperidinium*, *Impagidinium*, and *Lejeunecysta* are peculiar of the Amanina, Rategin, and Gakkhin formations, where they occur, however, as single specimens. Slightly unusual is prevalence of *Impagidinium* and *Lejeunecysta* forms in upper layers of the Gakkhin Formation. Noteworthy is a significant similarity between the Amanina (Rategin) and Gakkhin assemblages with dominant *Trinovantedinium boreale*; the Kovachina assemblage with abundant *Areosphaeridium* and *Spinidinium* and the Utkholok assemblage dominated by *Tectatodinium* look more isolated.

CORRELATION

Based on analyzed distribution of dinocyst assemblages, a correlation scheme can be proposed for the Northwest Pacific region (Fig. 5). Many taxa characteristic of Kamchatka sections are known from Eocene–Oligocene sediments of Japan, Sakhalin, and the Bering Sea.

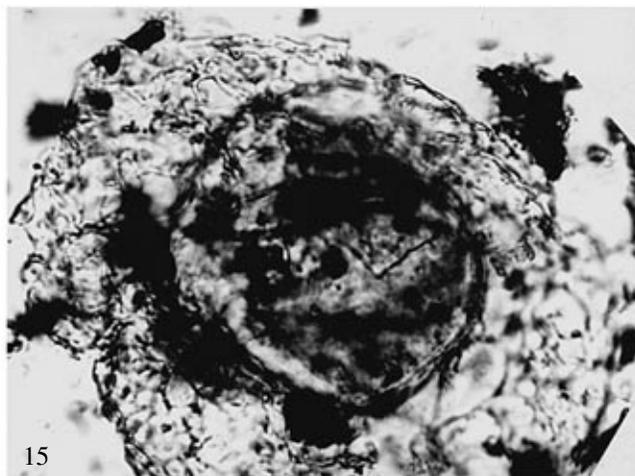
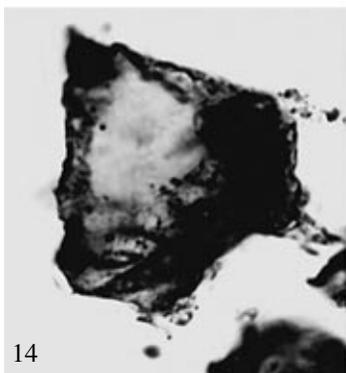
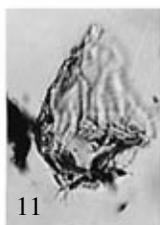
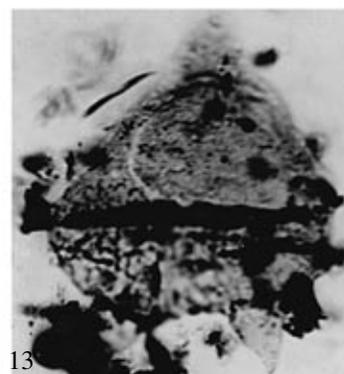
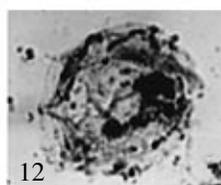
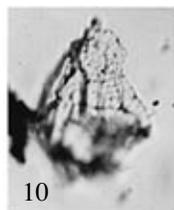
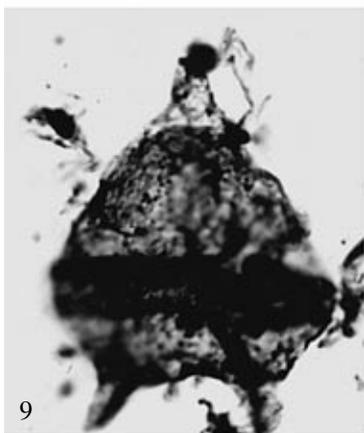
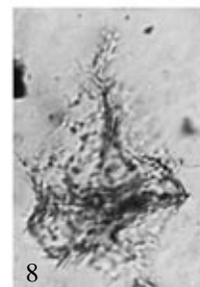
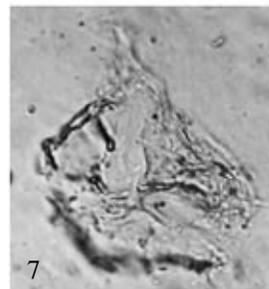
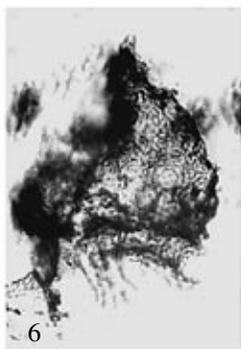
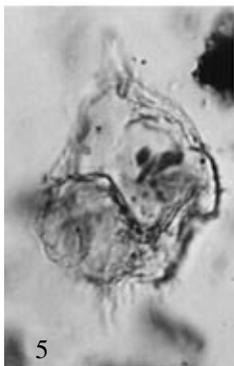
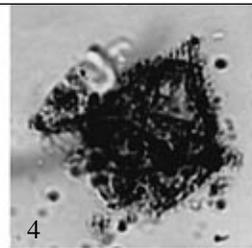
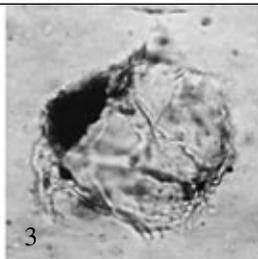
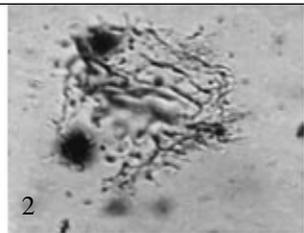
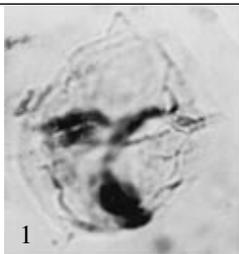
Characteristic dinocyst taxa of Kamchatka sections. *Bellatudinium hokkaidoanum* is abundant in the lower layers of the Poronai Formation (Yubari, Shiriruumappu section). It is also common in lower members of the Sankebetsu Formation (Haboro) and in sediments of the Shitakara marine “tongue” in the coal-bearing Urahoro Formation of the Kushiuro Depression, eastern Hokkaido. In Kamchatka section, this species occurs only in the upper part of the Snatol Formation stratotype exposed along the Snatolveem River and in the Kovachina and basal Amanina formations. In Sakhalin, it is known from the Takaradai Formation (Kurita and Matsuoka, 1995; Kurita et al., 1996).

Trinovantedinium boreale widespread in Kamchatka sections is also abundant in sections of Japan and Sakhalin, particularly in the restricted assemblages containing up to 95% and more of this taxon. In Hokkaido, the species is present in all the examined beds of the Poronai and Momijiyama formations (Yubari), in the Sunkebetsu Formation lower part (Rumoi), and in the Haro and Nuibetsu (Kushiuro), Asagai and Shirasaka (Dzeban) formations. The first occurrence level of this taxon is confined in the island to the upper Paleocene Haboro Formation (Kurita and Obuse, 1994; Kurita and Matsuoka, 1995; Kurita and Miwa, 1998). In Sakhalin, it is dominant in Lower Paleogene reference sections of the southwestern area (Takaradai Formation), Shmidt Peninsula (Machigari and lower Tum formations) (Kurita et al., 1996), and Makarov area (Gastello Formation and lower sequences of the Kholmsk–Nevel’skoi Horizon) (Kurita et al., 1996; 2000). N.Ya. Brutman and I. V. Pozdnyakova detected *Trinovantedinium boreale* in the Eocene–Oligocene boundary beds of coastal sections in eastern Sakhalin (*Geological Events...*, 1998), and Shchenko detected this species in the Snatol, Kovachina, and Amanina formations of the Tikhaya River basin in Kamchatka. The species is dominant also in the Eocene and Oligocene sections of the Navarin and Norton Sound basins of the Bering Sea shelf (Bujak and Matsuoka, 1986; Matsuoka and Bujak, 1988). According to our data, over 80% of the dinocyst generic spectrum in Kamchatka and at least 50% of species represent taxa in common for assemblages from coeval sediments in Japan and Sakhalin. Dinocyst assemblages of Kamchatka, except for those from basal beds of the Amanina and Rategin formations, are more diverse in taxonomic composition than assemblages from coeval sediments in Hokkaido and the Shmidt Peninsula (Sakhalin), being comparable with assemblages from eastern coasts of Japan and Sakhalin or from the Bering Sea region.

Plate II. Dinocysts from lower Oligocene sediments of the Tochilo Section of western Kamchatka (southwestern limb of the Tochilo anticline, Utkholok Formation, Sample 48).

(1) *Glaphyrocysta* sp., ×500; (2, 3) *Achomosphaera ramulifera* (Deflandre, 1937) Evitt, 1963: (2) ×750, (3) ×500; (4) *Spiniferites* cf. *S. membranaceus* (Rossignol, 1964) Sarjeant, 1970, ×750; (5) *Spiniferites* sp., ×500; (6) *Lejeunecysta* sp., ×500; (7) *Lejeunecysta fallax* (Morgenroth, 1966) Artzner et Dörhöfer, 1978, ×500; (8) *Trinovantedinium boreale* Bujak, 1984, ×500; (9) *Kallosphaeridium* sp., ×500; (10) cf. *Glaphyrocysta* sp., ×500; (11) *Paralecianiella indentata* (Deflandre et Cookson, 1955) (Cookson et Eisenack, 1970), ×500; (12) *Paralecianiella* sp., ×500; (13) *Micrhystridium*, sp., ×750.

Plate III



Batiacasphaera occurs in upper part of the Machigari and lower half of the Tum formations of the Machigari section in the Shmidt Peninsula and in the upper layers of the Momijiyama Formation (Yubari, Ishikari).

Single *Hystriosphæropsis* species are occasional in the Amanina and Utkholok formations and occur also in the Poronai Formation (Yubari), in upper layers of the Tum Formation, and in the Pil Formation of synonymous section in the Shmidt Peninsula. In Sakhalin, it is registered in the Miocene of the Aleksandrovska area (Kurita and Matsuoka, 1995; Kurita et al., 2000).

Impagidinium velorum found in the Utkholok Formation of the Tochilo section is an index species of the middle lower Oligocene zone in the Bering Sea segment of the Pacific immediately above the *Trinovantedinium boreale* Zone. Cysts *Impagidinium* spp. are reported from Paleogene and Miocene sediments of northern Japan and Sakhalin, the interval of *Trinovantedinium boreale* Zone included, although, in contrast to Kamchatka, they are insignificant components in taphocoenoses. *Nematosphaeropsis lemniscata* is found in the Eocene Kovachina Formation of Kamchatka and Poronai Formation of Hokkaido.

Paralecaniella indentata is abundant in Paleogene sections of Japan and Kamchatka, being confined there to sandy facies at several levels of the basin freshening or substantial shoaling. In other cases, abundance of this species varies from single to few specimens per preparation in some samples. It has been never found in the Paleocene and Eocene strata (Haboro Formation, Hokkaido) (Kurita and Matsuoka, 1995). The first mass occurrence of this species is registered in the upper part of the Poronai Formation (Yubari), although its single specimens are present in its basal layers as well. Abundant *Paralecaniella indentata* cysts are frequently accompanied by even more abundant *Trinovantedinium boreale*, single *Achomospaera ramulifera*, and *Micrhystridium*. In Sakhalin, the maximal content of *Paralecaniella indentata* is characteristic of the Takaradai Formation, the Chekhov area, that is usually correlated with the Poronai Formation of Hokkaido. In the Oligocene, the mass abundance of this taxon and *Trinovantedinium boreale* is noted in the upper part of the Momijiyama Formation

(Yubari) and in the uppermost portion of the Shirasaka Formation of the Dzeban basin in Honshu, where these taxa occur together with single specimens of *Micrhystridium* and *Spiniferites* (Kurita and Matsuoka, 1995). In Kamchatka sections, abundant *P. indentata* are recorded in lower parts of the Amanina and Rategin formations and in the uppermost portion of the Gakkhin Formation, being accompanied by maximal concentrations of *T. boreale* and *Micrhystridium* in the last formation. In Oligocene sediments of the Makarov area and Shmidt Peninsula of Sakhalin, genus *Paralecaniella* is represented by single cysts. Japanese paleontologists noted that macerates with abundant *Paralecaniella* forms are enriched in amorphous organic matter of cyanobacterial origin, probably, and characterize sediments accumulated in highly stratified oxygen-deficient waters. In Kamchatka, the same situation can be suggested for terminal beds of the Gakkhin Formation.

Spiniferites cysts determined usually in open nomenclature are established as single specimens in many sections, but their stratigraphic position is very uncertain. In the Early Paleogene, this genus was usually distributed, similar to *Impagidinium*, in open normal-salinity seas basins. In the Oligocene, the genus became euryhaline.

The distribution of *Bellatudinium hokkaidoanum* in Paleogene sections was preliminarily discussed above. This taxon is missing from Paleocene and Eocene sediments of the Haboro Formation, although it is known from the basal part of the Poronai Formation (Yubari), correlative beds of the Sankebetsu (Haboro) Formation, and from the Shitakara Formation sandwiched in the continental coal-bearing Harutori Sequence in the Kushiro basin of southeastern Hokkaido (Kurita and Matsuoka, 1995). Thus, the stratigraphic range of this species in Japanese sections spans the upper middle–lower upper Eocene. In Kamchatka, this interval corresponds to upper members of the Snatol Formation, Kovachina Formation, and lower part of the Amanina Formation. Only redeposited specimens occur higher in the sections.

Lejeunecysta hyalina and other species of this genus appear as single specimens in the upper part of the Poronai Formation (Yubari). In other basins of Hokkaido and Honshu, they occur mostly in sediments

Plate III. Dinocysts from Eocene sediments of the Snatolveem River basin, western Kamchatka.

(1) *Bellatudinium hokkaidoanum* Kurita et Matsuoka. Sample 14, $\times 750$. Western Kamchatka, middle courses of the Snatolveem River, Sosopkhan (Napana) Formation, Eocene; (2–4) *Trinovantedinium boreale* Bujak, 1984: (2, 3) Sample 14h, $\times 750$. Western Kamchatka, middle courses of the Snatolveem River, Snatol Formation, middle Eocene, (4) Sample 17, $\times 750$. Western Kamchatka, Tochilo section, southwestern limb, Amanina Formation, uppermost Eocene; (5–8) *Spinidinium* sp.: (5) Sample 14a, $\times 750$. Western Kamchatka, middle courses of the Snatolveem River, Sosopkhan (Napana) Formation, Eocene, (6–8) Sample 14h, $\times 750$. Western Kamchatka, middle courses of the Snatolveem River, Snatol Formation, middle Eocene; (9, 13) *Lejeunecysta* sp., Sample 14d, $\times 750$. Western Kamchatka, middle courses of the Snatolveem River, Sosopkhan (Napana) Formation, Eocene; (10, 11) *Spinidinium* sp. A Matsuoka, 1995. Sample 14h, $\times 500$. Western Kamchatka, middle courses of the Snatolveem River, Snatol Formation, middle Eocene; (12) *Heteraulacysta* sp. Sample 14d, $\times 500$. Western Kamchatka, middle courses of the Snatolveem River, Sosopkhan (Napana) Formation, Eocene; (14) *Lejeunecysta hyalina* (Gerlach) Artzner et Dörhöfer. Sample 14d, $\times 750$. Western Kamchatka, middle courses of the Snatolveem River, Sosopkhan (Napana) Formation, Eocene; (15) *Thalassiphora reticulata* Morgenroth. Sample 14, $\times 500$. Western Kamchatka, middle courses of the Snatolveem River, Sosopkhan (Napana) Formation, Eocene.

Distribution of organic-walled phytoplankton in the stratotype section of the Rategin Formation (Podkagernaya Bay) and in Paleogene sediments of the Tochilo anticline southwestern limb

Taxa	Kv		Am			Rt			Gkh			Ut
	Sample											
	15	30	31	24	25	82/1	82/2	82/4	28	51	48	41
1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Batiacasphaera</i> sp.			1				1	2	1			3
<i>Hystrichosphaeropsis</i> sp.				1			3	1				1
<i>Impagidinium velorum</i> Bujak, 1984												1
<i>Impagidinium</i> spp.	11		4		1		4	3	3	55	1	2
<i>Selenopemphix nephroides</i> Benedek, 1972												1
<i>Spiniferites</i> spp.							5				2	2
<i>Tectatodinium</i> spp.					1				7			83
<i>Trinovantedinium boreale</i> Bujak, 1984	14	100	366	210	120	3	17	7	149	16	108	1
<i>Nematosphaeropsis limniscata</i> Bujak, 1984	3											
<i>Selenopemphix crenata</i> Matsuoka et Budjak, 1988	1											
<i>Achomosphaera ramulifera</i> (Deflandre, 1937) Evitt, 1963											6	
cf. <i>Alterbidinium</i> sp.	1		2	1						3	3	
<i>Bellatudinium hokkaidoanum</i> Kurita et Matsuoka, 1995	2		1	8					4 (r)		4 (r)	
<i>Cordosphaeridium</i> sp.	1						1					
<i>Kallosphaeridium</i> sp.							1				1	
<i>Lejeunecysta hyalina</i> (Gerlach, 1961) Artzner et Dörhöfer, 1978				3			3	1	4	16	1	
<i>Lejeunecysta</i> sp.		3	8	3	4	1	6	7		15	2	
<i>Glaphyrocysta</i> sp.											1	
cf. <i>Gerlachodinium</i> sp.										4		
cf. <i>Impagidinium verrucosum</i> (Brideaux et Mc Intyre, 1975) Stover et Evitt, 1978										1		
<i>Lejeunecysta</i> cf. <i>fallax</i> (Morgenroth, 1966) Artzner et Dörhöfer, 1978							1				1	
<i>Phthanoperidinium</i> sp.	4			2		2	7	2	3	1		
<i>Spinidinium</i> sp.		3	13	3			3	2	7			
<i>Phthanoperidinium eocenicum</i> (Cookson et Eisenack, 1965) Lentin et Williams, 1973									1			
cf. <i>Soaniella</i>	1			2					1			
<i>Areosphaeridium diktyoplokum</i> (Klumpp, 1953) Eaton, 1976 (reworked)									3			
<i>Fibrocysta</i> sp.									1			
<i>Trinovantedinium</i> spp.						5	5	5				
<i>Phthanoperidinium bennettii</i> Matsuoka et Bujak, 1988							10	1				
<i>Lejeunecysta convexa</i> Matsuoka et Bujak, 1988							1					
<i>L. granosa</i> Biffi et Grignani, 1983							1	2				
<i>Operculodinium</i> sp.	1						3					
<i>Spiniferites</i> cf. <i>nortonensis</i> Matsuoka et Bujak, 1988							1					
<i>S. pseudofurcatus</i> (Klumpp, 1953) Sarjeant, 1981									1			
<i>Spiniferites</i> cf. <i>membranaceus</i> (Rossignol, 1964) Sarjeant, 1970									1			
<i>Spiniferites</i> sp.									1			
<i>Cleistosphaeridium</i> sp.			1				2					

1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Phelodinium</i> sp.							3					
<i>Systematophora</i> cf. <i>curta</i> Matsuoka et Bujak							1					
<i>Heteraulacacysta campanula</i> Drugg et Loeblich, 1967							1					
<i>Diphyes</i> cf. <i>colligerum</i> (Deflandre et Cookson, 1955) Cookson, 1965							1					
<i>Palaeocystodinium golzowense</i> Alberti, 1961							3					
<i>Rhombodinium</i> sp.							1					
? <i>Leptodinium</i> sp.							2					
<i>Achomosphaera</i> sp.							1					
<i>Hafnisphaera septata</i> (Cookson et Eisenack, 1967) Hansen, 1977							1					
<i>Glaphyrocysta</i> sp. aut <i>Chiropteridium</i> sp.		1						2				
<i>Lingulodinium</i> sp.								1				
<i>Palaeoperidinium pyrophorum</i> (Ehrenberg, 1938) Sarjeant, 1967					1							
<i>Areosphaeridium diktyoplokum</i> f. typical + A. d. (short processes) (Klumpp, 1953) Eaton, 1976	69 6	2			1							
<i>Enneadocysta</i> sp.	1				1							
<i>Lentinia serrata</i> Bujak, 1980	1				1							
<i>Thalassiphora</i> sp.					1							
<i>Spinidinium</i> sp. 1	32	1		1								
<i>Cribroperidinium</i> sp.			1									
<i>Heteraulacacysta</i> sp.			1									
<i>Pentadinium</i> sp.			1									
<i>Impagidinium cornutum</i> Matsuoka et Bujak, 1988	1											
<i>Spinidinium essoii</i> Cookson et Eisenack, 1967	3											
<i>S. macmurdoense</i> (Wilson, 1967) Lentin et Williams, 1976	9		1									
<i>Cordosphaeridium inodes</i> (Klumpp, 1953) Morgenroth, 1968	3											
<i>Deflandrea arcuata</i> Vozzhennikova, 1967	1											
<i>Deflandrea</i> sp.	1											
<i>Chytroeisphaeridia</i> sp.	1											
Unidentified dinocysts						3	11	1				
Total dinocyst abundance	167	110	520	237	131	14	125	55	125	183	223	95
Total taxa	19	6	14	11	9	4	30	15	13	9	12	9
Prasinophytes and acritarchs	5		3				1		1		107	
<i>Micrhystridium</i> sp.			3								81	
<i>Horologinella incurvata</i> Cookson et Eisenack, 1962											19	
<i>Horologinella</i> sp.											1	
<i>Paucilobimorpha tripus</i> de Coninck, 1986	1											
<i>Paucilobimorpha triradiata</i> de Coninck, 1986	1											
<i>Ptanospermella</i> sp.	3								1			
<i>Paralecaniella indentata</i> (Deflandre et Cookson, 1955) Cookson et Eisenack, 1970			122	2			24	15	1	7	93	1
<i>Cyclopsiella elliptica</i> Drugg et Loeblich, 1967												
<i>Tasmanites</i> sp.							1					
Embryonal chambers of foraminifers	3			5					3	1	3	

Note: Formations (Kv) Kovachina, (Am) Amanina, (Rt) Rategin, (GkH) Gakkhin, (Ut) Utkholok.

that are attributed by Japanese researchers to the lower half of the lower Oligocene. As was mentioned, in Kamchatka they occur mostly in the Amanina and Rategin formations. Judging from the composition of the dinocyst assemblage, their maximal content in the Gakkhin Formation is confined to sediments in its upper part (Sample 51) corresponding to a freshening phase in the basin development.

In Japanese sections, *Spinidinium* appears in the Haboro Formation (late Paleocene–early Eocene) and occurs also in younger sediments (up to the terminal Eocene). Its stratigraphic range in other regions spans the upper Paleocene–lower upper Eocene. In Sakhalin, this taxon (probably redeposited) is distributed in Eocene and Oligocene sediments. *Spinidinium* morphotypes established in Kamchatka sections (Kovachina, Amanina, and Rategin formation) occur usually in sediments older than the Oligocene. There is a significant similarity in the structure of peridinoid cysts between representatives of the genera *Spinidinium*, *Trinovantedinium*, and *Vozzhennikovia* presumably originating from the same ancestral forms (Kurita and Matsuoka, 1995; Williams et al., 1998). Their diagnosis and discrimination in macerates is difficult therefore. The stratigraphic distribution of *Areosphaeridium diktyoplokum* in Japan is limited by basal lower Oligocene sediments, where this taxon is extremely rare and occurs only in the Dzeban area (northeastern Honshu). At the same time, it is common in Paleogene sediments of the Bering Sea region of the Pacific, where it is confined to the synonymous zone of the Eocene upper half immediately underlying the *Trinovantedinium boreale* Zone. Species *Phthanoperidinium benettii*, *Impagidinuim velorum*, and some other species are found only in sections of the Bering Sea region (Kamchatka included).

The presented materials lead to the following inferences.

Dinocyst assemblages from Upper Paleogene sediments of Kamchatka demonstrate significant taxonomic similarity with coeval assemblages in other regions of the North Pacific, which are of low diversity as well.¹ In Kamchatka, assemblages of low diversity are particularly characteristic of basal layer of the Amanina and Rategin formations, as these layers were deposited during the initial phase of transgressive cycles, and of the Gakkhin Formation. The taxonomic diversity of dinocyst associations in Kamchatka is close to that in the Bering Sea and Sakhalin. They are also more similar to associations in outer basins (Dzeban) of Japan rather than in inner basins of Hokkaido (Ishikari, Runoi).

Similarity of all the regional associations from the Northwest Pacific region is emphasized by the mass development of euryhaline species *Trinovantedinium*

boreale especially typical of the “anomalous” assemblages.

In the Northwest Pacific, latitudinal differentiation of upper Eocene and lower Oligocene associations is relatively weak: *Areosphaeridium* and *Phthanoperidinium* are slightly more developed in the Bering Sea and Kamchatka sections, while *Hexagonifera* is widespread in northern Japan.

One of the possible factors responsible for origin of restricted dinocyst assemblages in the Northwest Pacific. Diversity of late Eocene and early Oligocene dinocyst assemblages from shelf sediments of the World Ocean corresponds to hundreds species (Fig. 6). They are similarly diverse in open epicontinental sea basins, for example, in the West Siberian sea. The correlation potential of this group is significant. Zonal assemblages contain taxa in common, index species included, in coeval sections of remote regions, e.g., of the North Atlantic, Caucasus, West Siberia, Australia, and New Zealand. In this connection, prevalence of *Trinovantedinium boreale* Bujak in phytoplankton assemblages of the upper middle Eocene–lower Oligocene (Kamchatka and Japan) and Miocene (Sakhalin), which are in general of notably reduced diversity in the Northwest Pacific, is enigmatic. Japanese paleontologists tend to explain this phenomenon by stratification of water column, low water temperature, and high phytoplankton productivity with prevalence of peridinoid forms. The basin freshening could not be responsible for the diversity decrease of dinocysts, since they occur together with mollusks that dwell in normal-salinity environments. In the terminal middle Eocene, *T. boreale* replaced *Bellatudinium hokkaidoanum*, the taxon dominated previously in organic-walled phytoplankton assemblages of the Northwest Pacific. Beginning from the late Eocene, *T. boreale* got the dominant position, representing 50 and even 90–95% of dinocyst assemblages sometimes.

The restricted dinocyst assemblages are unknown beyond the area of the *Trinovantedinium boreale* mass development being confined to the present-day Okhotsk and Bering seas. In areas, where abundance of this taxon is substantially decreased, for example, in northeastern Honshu and northern Kyushu (Kurita and Matsuoka, 1995), or it is unknown like in the East China Sea (He and Wang, 1990), Mackenzie River mouth area, and Beaufort Sea of Arctic Canada (Norris, 1986), the taxonomic diversity of dinocyst assemblages turns out to be rapidly restored. In the lower Oligocene Shirasaka Formation of the Dzeban basin in northeastern Honshu that is in the eastern periphery of the *Trinovantedinium* distribution area, the dominant role of this taxon is still retained. At the same time, the taxonomic diversity of dinocyst assemblages becomes 3–5 times higher there as compared with their counterparts in coeval sediments of Hokkaido.

¹ In this work, species groupings are termed as assemblages in stratigraphy and as associations characterizing stages in the biota development in biogeography.

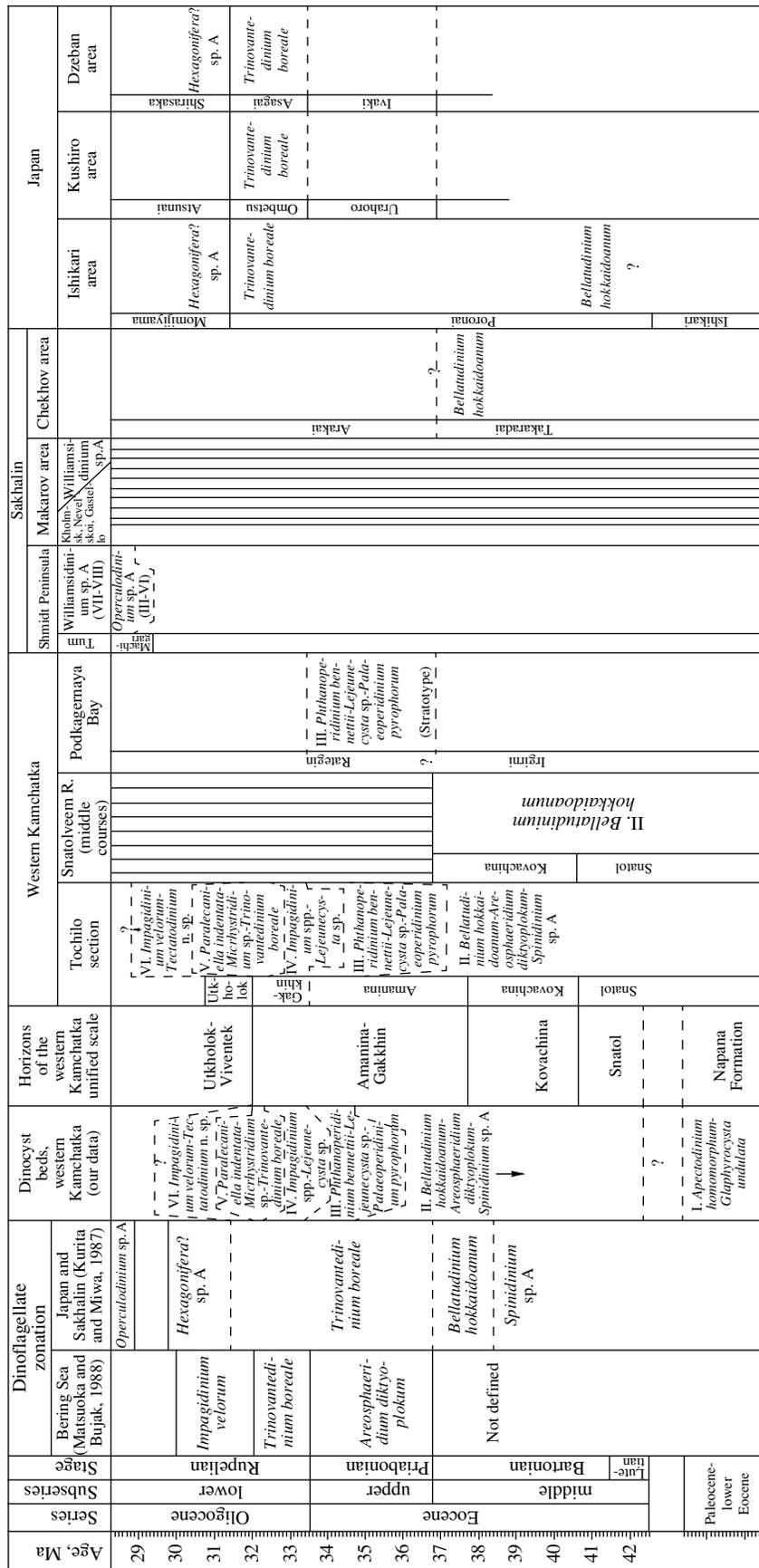


Fig. 5. Correlation of Eocene-Oligocene sediments of Kamchatka, Sakhalin, and Japan based on dinocysts.

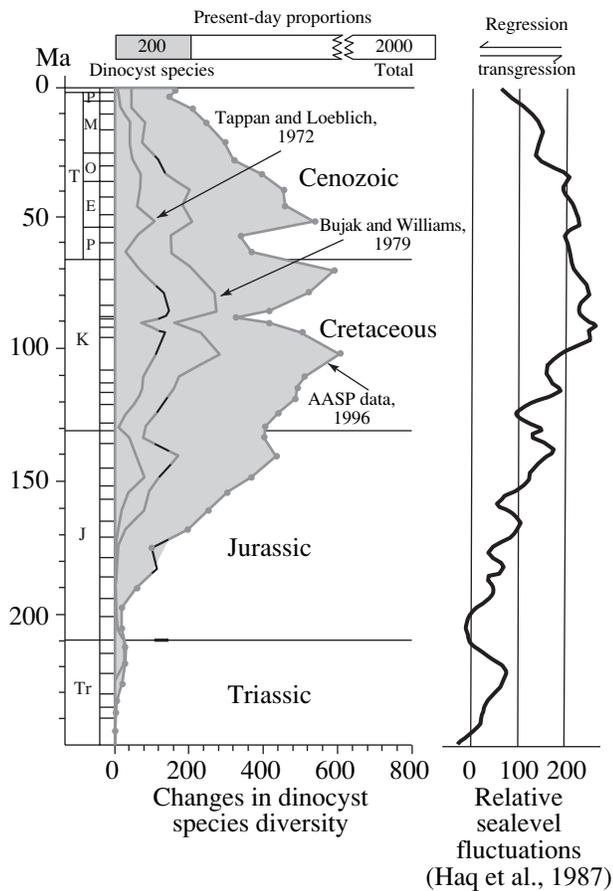


Fig. 6. Dynamics of dinoflagellate species diversity since the Triassic.

As is seen, the number of dinoflagellate species in the upper Eocene and Eocene–Oligocene boundary sediments known by 1996 was about 400, according to AASP data. The plot illustrates also variations in species diversity of recent dinoflagellates (2000 species), approximately 200 cyst-producing species included. Dinocyst diversity curves are after Tappan and Loeblich (1972), Bujak and Williams (1979), and AASP (1996). Comparison between dinocyst diversity and eustatic (Haq et al., 1987) curves indicates direct relationships of diversity with transgressive cycles.

In our opinion, a high toxicity of this taxon and its mass development, which created an effect of “red tides,” could be a factor responsible for sharply disproportional distribution of dinocysts in open sea basins. It is known, that during the last 20–25 years of progressive warming, toxic dinoflagellate species substantially advanced into the Northern Hemisphere from temperate to high latitudes to cross the Polar Circle in the Norwegian segment of the Atlantic and in the Pacific. In the Bering Sea, toxic dinoflagellates acquired mass development by the 1990s and since that time “red tides” became permanent (Okolodkov, 2000). They advanced along the eastern Koryak coast to reach the Anadyr Bay. In eastern Kamchatka, there are registered fatal cases of people, who ate fish and mollusks poisoned by toxins produced by “red tides.” Present-day agents, which pro-

voke these tides, include also other taxa attributed to the category of harmful algae. Developing in mass, the later produce anoxic environments and cause death of fishes, invertebrates, and aqueous vegetation in shoals. Representatives of *Ceratium*, *Protocentrum*, *Lingulodinium*, and other genera are among nontoxic dinoflagellate taxa provoking “red tides.” It should be noted that *Lingulodinium* species are known also in Paleogene sections of western Kamchatka. The analysis of the geographic organic-walled phytoplankton distribution shows that more than half of recent species exciting “red tides” belong to the “Boreal–Tropical” taxa localized in the Pacific near the “Orthman line” and northward (north of 30–35° N). The taxonomic diversity of dinocysts during “red tides” is insignificant.

In the Paleogene, distribution area of *Trinovantedinium boreale* comprised peripheral parts of present-day marginal seas of the Northwest Pacific (Bering, Okhotsk, and Japan seas) thus being the Boreal–Tropical in terms of biogeography. The upper Eocene and lower Oligocene sections of Sakhalin and Japan enclose clayey members that accumulated in oxygen-deficient environments (Kurita and Matsuoka, 1995). *Trinovantedinium boreale* that survived the taxonomic diversity reduction of organic-walled phytoplankton observed in these sequences, was probably responsible, being toxic, for oxygen deficiency and mass death of fishes, whose remains are abundant in the boundary layers between the Amanina and Kovachina formation in western Kamchatka. It is noteworthy that *T. boreale* is the only dominant species in dinocyst assemblages with diversity reduced to 6–7 species in beds with accumulations of fish remains.

It is noted also that wide development of *Trinovantedinium boreale* is characteristic of regions, where diatom algae are either missing (western Kamchatka, Navarin and Norton Sound basins) or have limited distribution (for example, in the Kurile Islands). Beyond the distribution area of this species, diatoms are known from many areas of the North Pacific. It is conceivable therefore that diatom algae were in the Paleogene, as they are now, main “victims” of toxic dinoflagellates.

Because of *Trinovantedinium boreale* prevalence in phytoplankton assemblages of the North Pacific, they are of endemic character, poorly comparable with coeval dinocyst assemblages of the Peri-Tethys that communicated with the Atlantic and the Tethys. It is much easier to correlate the Paleocene–Eocene boundary sections (Haboro Formation of Hokkaido, where *Trinovantedinium* only appears above coaliferous beds, and Napana Formation of western Kamchatka) in the North Pacific region owing to zonal and key taxa in common: *Apectodinium hyperocanthum*, *Areoligera coronata*, *Cerodinium diebelii*, *Spiniferites ramosus*, *Glaphyrocysta* spp., *Isabelidinium* spp., and others. The Pacific and Tethys more easily communicated most likely via low latitudes of the Northern Hemisphere.

Age. Taking into consideration inadequate sampling density, stratigraphic units of Kamchatka can be dated based on dinocysts with a great caution. More reliable age estimates can be obtained for the Kovachina and Amanina formation by comparing Kamchatka organic-walled phytoplankton assemblages with their counterparts from Hokkaido and Honshu sections, where they associate with calcareous microfossils. Based on nannoplankton, the Poronai Formation (Yubari) is attributed to the late middle–late Eocene (Zones CP 14a?–CP 15b; Okada and Kaiho, 1992), although planktonic foraminifers from its terminal layers are of the Oligocene age (Kaiho et al., 1986). The lower part of the formation with *Bellatudinium hokkaidoanum* is attributed to the middle Eocene. The middle–upper Eocene boundary in Yubari sections is at the disappearance level of this taxon shown in the recent Japanese schemes of dinocyst distribution (Kurita et al., 2000, p. 198). At the same time, in two other Hokkaido sections (Haboro and Shiranuka areas), sediments that host *Bellatudinium hokkaidoanum* are referred to the upper Eocene (Kurita and Matsuoka, 1995). Taking into consideration the aforementioned later publication of Japanese palynologists, this should be confirmed however, particularly for basal layers of the Sankebetsu Formation. The genus *Spinidinium* is most widespread in Paleocene–middle Eocene dinocyst assemblages of the Northern Hemisphere being extremely rare in upper Eocene sediments. Its dominant role in Sample 15 from the Kovachina Formation indicates that the lower part of the latter is of the middle Eocene age.

Areosphaeridium diktyoplokum is another taxon important for dating the Kovachina Formation. It is practically missing from Japanese sections, but in the Bering Sea region this species represents an index taxon of the local zone immediately underlying the *Trinovantedinium boreale* Zone (Matsuoka and Bujak, 1988). In the geological record, *A. diktyoplokum* is known since the late Ypresian and disappears from sections at the Eocene–Oligocene boundary. This species with maximal abundance in the late middle Eocene is also an index taxon of the late Lutetian–Bartonian zone in the Crimea–Caucasus region (Andreeva-Grigorovich, 1991) and West Siberia (Akhmet'ev et al., 2001, 2004). In dinocyst assemblages of the North Pacific, *Areosphaeridium diktyoplokum* and *Bellatudinium hokkaidoanum* can partly replace each other. The former is characteristic of the Bering Sea–Kamchatka segment, while the latter, of the Sakhalin–Japan one. Based on distribution of these taxa in Kamchatka sections, it can be inferred that the Snatol and Kovachina formation are the middle Eocene in age. This inference is indirectly supported by presence of other taxa: *Soaniella* sp. (the genus is usually confined to the middle–upper Eocene boundary layers), *Lentinia serrata*, *Spinidinium essoii*, *S. macmurdoense*, and *Deflandrea arcuata*. The interval of *Trinovantedinium boreale* mass development in section of Japan, Sakhalin, and

Bering Sea shelf corresponds to the middle early Oligocene; single specimens of this taxon occur also in upper Oligocene sediments of Sakhalin. As is shown, it is unknown in Kamchatka from sediments overlying the Gakkhin Formation. Taking these data into consideration, the Amanina and basal Rategin formations are most likely of the late Eocene age. Moreover, basal layers of the Amanina Formation correspond, probably, to the middle–late Eocene boundary interval, as they contain *Bellatudinium hokkaidoanum*. Upper parts of the Gakkhin and Utkholok formations accumulated in the early Oligocene, as it is evidenced by *Impagidinium velorum* found in Sample 41 from the last formation: this species is an index taxon of the middle zone in the lower Oligocene section of Hole 183 (DSDP Leg 19) in the Bering Sea (Bujak, 1984).

The inferred ages of lithostratigraphic units and dinocyst assemblages can independently be tested by data on plant megafossils from the type section of the Irgirni Formation in the Podkagernaya Bay. Their collection studied by Akhmet'ev was sampled by geologists from the former *Aerogeologiya* Enterprise in the Irgirnivayam River mouth area of the Podkagernaya Bay. There are also several works dedicated to description of plant remains from the Irgirni assemblage of this area (Fot'yanova, 1984; Chelebaeva, 1984; Budantsev, 1997).

The Irgirni flora is remarkable because of combination of transit elements characteristic of Early Paleogene (*Ginkgo*, diverse coniferous, *Trochodendroides*, “*Acer arcticum*”) and relatively younger taxa: *Castanea*, *Fagus*, Betulaceae, *Rhododendron*, *Koelreutheria*, and others. In Japan, the Harutori flora from the Urohoro coal-bearing section (Kushiro) with many similar genera and species (in common or vicarious) is also characterized by joint occurrence of older transit taxa that are present in the Irgirni flora and representatives of recent genera more frequent in Late Paleogene and Miocene floras (Tanai, 1970). According to Tanai, plant remains have been collected largely from coal-bearing members underlying marine sediments of the Shirataka tongue sandwiched in the coal-bearing sequence. Japanese researchers reported on *Bellatudinium* finds from these marine sediments. With due account for many works of Japanese micropaleontologists, who specified the age of the Poronai Formation, Urohoro flora-bearing beds, and coal-bearing sediments of the Ishikari Group, Tanai revised in later works his earlier inference and accepted the middle Eocene age. Consequently, the Irgirni flora previously attributed by paleobotanists to the late Eocene can be of the same middle Eocene age. It should be noted that this flora is compositionally almost identical to the Ust'-Penzhina flora from synonymous formation of the Shestakovaya River mouth area in the northern Penzhina Estuary.

To construction of the regional Paleogene scale based on dinocysts. Dinocysts from Paleogene section of Kamchatka, which appear to be similar with their

associations in Sakhalin, northern Japan, and Bering Sea, can be used for constructing the regional Paleogene scale. The preliminary variant of such a scale was recently proposed for northern Japan (Kurita et al., 2000, p. 198, fig. 6). Earlier, similar attempt to construct the Cenozoic scale based on dinocysts was undertaken for the Bering Sea region (Matsuoka and Bujak, 1988). In addition to their undoubted merits, both scales have a disadvantage in common: succession of their units is discontinuous in some intervals, e.g., in the middle part of the lower Oligocene in the scale suggested for Japan and in the lower–upper Oligocene boundary interval and middle Miocene in the Bering Sea variant.

Because of rare sampling, none of these scales is applicable in Kamchatka in full measure. *Bellatudinium hokkaidoanum*, the important taxon of Eocene dinocyst assemblages of Japan (particularly, in Hokkaido), Sakhalin, and Kamchatka, is unknown so far in sections of the Bering Sea region. At the same time, the *Trinovantedinium boreale* Zone defined at the base of the Oligocene in the last region has no sense for Kamchatka, where this species is dominant in dinocyst assemblages beginning from the terminal Paleocene till lower Oligocene. Moreover, the Japanese scale that is more detailed as compared with the Bering Sea variant cannot be used in Kamchatka as well, because *Areosphaeridium diktyoplokum* is of sporadic occurrence here. This species is, however, abundant in sections of the Snatol (Shchenko, 1996) and Kovachina (this paper) formations. *Hexagonifera* sp. A, a zonal taxon from the upper lower Oligocene in the Japan scale is unknown so far in Kamchatka sections.

Trinovantedinium boreale, the dominant taxon that “controls” distribution of other organic-walled phytoplankton species in most samples from Upper Paleogene sections limits geographic range for application of the regional dinocyst scale. As was mentioned, this species is widespread in the Northwest Pacific region, particularly in Eocene and Oligocene sections of the Bering Sea, western Kamchatka, northern, eastern, and southwestern Sakhalin, Hokkaido, and northeastern Honshu (Kurita and Matsuoka, 1995). It is, however, unknown so far in Eocene and Oligocene sediments of the East China Sea (Yu, 1989; He and Wang, 1990), Arctic North America (Beaufort, Mackenzie) (Norris, 1986), and Alaska Peninsula. Dinocyst assemblages from these regions have a substantially higher potential for correlation with their East Atlantic and North European counterparts. They contain many taxa in common, species of a narrow stratigraphic range included, which are not found yet in the study region.

Judging from the composition of organic-walled phytoplankton in the Northwest Pacific region, the defined dinoflagellate zones or beds should represent concurrent-range units.

When constructing the regional scale, one should pay attention to *Vozzhennikovia* and *Spinidinium* spe-

cies in addition to *Trinovantedinium boreale*. Kurita and Matsuoka (1995) along with other experts noted morphological similarity between all three genera (small sizes, belonging to the group of cavate cysts, intercalary archeopyle, regular coverage of envelopes by short spines) and emphasized their phylogenetic relations. *Trinovantedinium* was first described as a recent genus. As was noted, this taxon that appeared in the Northwest Pacific at the Paleocene–Eocene boundary time acquired maximal abundance in the second half of the Eocene and early Oligocene. In Hokkaido and Sakhalin, it became extinct in the late Oligocene and initial Miocene, respectively. In the North Atlantic and eastern United States, the genus is known since the Neogene with maximal abundance in the Holocene. *Spinidinium* and *Vozzhennikovia* cysts are recorded only in Paleogene sediments. In the Paleocene–Eocene boundary beds of the Haboro Formation, representatives of all three genera were found together (Kurita and Obuse, 1994; Shchenko, 1996), and their autonomous status was doubted. The genus *Spinidinium* incorporating tens of species, half of which are usually confined to Lower Paleogene sediments and almost never occur in the Oligocene, is accepted to be the ancestor of the other genera. Appearing in the Cretaceous, this genus and species *Spinidinium* sp. A in particular are widespread in Middle Eocene sections of the Far East. Mass accumulations of this species are recorded in the Kovachina Formation. It is also registered in most samples from the Amanina Formation, although in reduced quantity (below 10 specimens per sample). The joint occurrence of *Spinidinium Soanella* sp., *Lentinia serrata*, *Areosphaeridium diktyoplokum*, and *Bellatudinium hokkaidoanum* in the Amanina Formation is a ground to limit the formation age by the Eocene and to include *Spinidinium* sp. A into the taxa set that can be used for constructing the pre-Oligocene portion of the regional dinoflagellate scale. As was mentioned, the middle Eocene age of the Amanina Formation basal layers cannot be ruled out. *Spinidinium rotundatum* previously referred to the relevant genus was subsequently attributed to the genus *Vozzhennikovia*. In Japanese sections, stratigraphic range of *Spinidinium* is also limited largely by the Eocene. Only in Sakhalin and central Hokkaido, *Spinidinium* sp. C existed until the late Oligocene (Kurita and Kasuoki, 1997; Kurita et al., 2000).

The genus *Vozzhennikovia* is known to occur in the uppermost Paleocene to the mid-Eocene sediments in sections examined in Kamchatka (Shchenko, 1996). In this region, it becomes extinct prior to the disappearance of *Spinidinium*.

Of substantial significance for constructing the regional scale are also several taxa, which are known from Paleogene dinocyst assemblages of other Boreal regions in Eurasia (*Areosphaeridium diktyoplokum*, *Enneadocysta arcuata*) and endemic species of the Northwest Pacific region with a relatively narrow stratigraphic range (*Bellatudinium hokkaidoanum*).

As was mentioned, some of the Northwest Pacific sections enclose intervals with mass accumulations of *Paralecaneia indentata* and *Micrhystridium* that is explained by shoaling and partial freshening of sedimentation basins. These stratigraphic intervals can be defined in the rank of beds. Such a situation is characteristic not only of the lower Oligocene in Kamchatka, but also of northern Japan and Sakhalin. It is noteworthy that these taxa are always accompanied by notable quantities of *Trinovantedinium boreale* and *Spiniferites* specimens. Representatives of the last genus were widespread during the Early Paleogene in open seas with normal salinity. In the Oligocene, the genus was of euryhaline type and dwelt mostly in brackish-water basins of the Miocene time. It can be assumed that the upper part of the Gakkhin Formation in Kamchatka accumulated concurrently with uppermost layers of the Shirasaka Formation of the Dzeban basin (northeastern Honshu) and the Momijiyama Formation of Hokkaido.

The basal part of the Utkholok Formation corresponding to the lower Oligocene comprises an interval with a notable content of *Lejeunecysta* spp., *Phthanoperidinium*, *Selenopemphix*, *Impagidinium*, *Spiniferites* (many species), and other taxa parallel to high concentration of *Trinovantedinium boreale* and disappearance of characteristic Eocene dinocysts at this level. The interval corresponds to the Nyubetsu Formation (Shiranuka area) in sections of northeastern Hokkaido and to the Shirasaka Formation (Dzeban basin) in northeastern Honshu.

Position of beds with *Wetzeliella articulata*, *Enneadocysta arcuata*, and other taxa in the section northeastern Chemurnaut Bay (Sample 1/20, determination by G.M. Brattseva) (*The Lower Paleogene...*, 1997) remains unclear. Until revisiting this section, we refrain from discussion of the beds position in the regional scale because it is inconsistent with the inferred Paleocene age of sediments in the Chemurnaut Bay, whereas *Wetzeliella* is known worldwide in marine sediments only since the Eocene.

Similar to *T. boreale*, prasinopytes and acritarchs disappear in the Utkholok Formation. Instead, the formation recorded appearance of abundant *Tectatodinium* spp. and *Impagidinium velorum*, which are characteristic of the upper lower Oligocene sediments in the Bering Sea segment of the Northwest Pacific.

Without additional data on organic-walled phytoplankton from Paleogene section of Kamchatka, which could be obtained, we discriminate successive assemblages characterizing the bed-ranked stratotypes (Fig. 5). We regard them as sedimentary members, each containing a particular dinocyst assemblage that differs from over- and underlying assemblages.

(1) The *Apectodinium homomorphum*–*Vozzhennikovia aperture* Beds (Napana Formation, Khairyuzova River, Paleocene–Eocene boundary interval; Shchenko, 1996). In addition to index species, the assemblage includes *Paleoperidinium sibiricum* and *Glaphyrocysta*

undulata. A similar assemblage is described from the Haboro Formation of central Hokkaido (Kurita and Obuse, 1994). By occurrence of characteristic taxa, it is readily correlated with assemblages from the Paleocene–Eocene boundary layers in West and Central Europe, the East European platform, and West Siberia.

(2) The *Bellatudinium hokkaidoanum*–*Areosphaeridium diktyoplokum*–*Spinidinium A* Beds (Kovachina Formation of the Tochilo section, terminal middle Eocene). The assemblage contains also *Nematosphaeridium lemiscata*, cf. *Soaniella* sp., *Spinidinium macmurdoense*, and acritarchs *Paucilobimorpha tripus* and *P. triradiata*. This assemblage is reliably correlative with that of the *Spinidinium A* + *Areosphaeridium diktyoplokum* zones of the Takaradai Formation in Sakhalin and the *Bellatudinium hokkaidoanum* assemblage from the Shirrirumappu Member of the lower Poronai Formation in the Yubari basin.

(3) The *Phthanoperidinium benettii*–*Lejeunecysta* spp.–*Palaeoperidinium pyrophorum* Beds (Amanina, Rategin, and, probably, lower Gakkhin formations, upper Eocene). Accompanying taxa are *Hystrichosphaeropsis* sp., *Cyclopsiella elliptica*, *Phelodinium* sp., *Palaeocystodinium golzowense*, *Impagidinium* spp., *Phthanoperidinium* spp. The group *Lejeunecysta* spp. includes species *L. hyalina*, *L. convexa*, *L. granosa*, and others. Typical Eocene *Spinidinium* spp., *Enneadocysta* sp., and *Lentinia serrata* are also present, particularly in basal layers of the Amanina and Rategin formation. *Trinovantedinium boreale* is abundant primarily in the basal part of the Amanina Formation. The assemblage is readily correlative with that from the *Trinovantedinium boreale* Zone of central Hokkaido.

(4) The *Paralecaneia indentata*–*Micrhystridium* spp.–*Trinovantedinium boreale* Beds (upper part of the Gakkhin Formation, lower Oligocene). Associated taxa are *Achomosphaera ramulifera*, *Kallosphaeridium* spp., *Lejeunecysta hyalina*, *Spiniferites* spp., and others. The assemblage marks shoaling and freshening of the basin. Assemblages of similar composition and age are known from the Momijiyama (Hokkaido) and Asagai (Dzeban basin, northeastern Honshu) formations.

(5) The *Impagidinium* spp.–*Lejeunecysta* spp. Beds (upper part of the Gakkhin Formation, immediately prior to basin shoaling and freshening recorded in its uppermost part, lower Oligocene). The relevant section interval is remarkable because of notable prevalence of *Impagidinium* and *Lejeunecysta* cysts (over 50 and up to 25%, respectively). Content of *Trinovantedinium boreale* is reduced to 10%. In addition to index taxa, the assemblage includes *Paralecaneia indentata*, cf. *Gerlachodinium* sp., cf. *Alterbidinium* sp. (probably redeposited), and *Phthanoperidinium* sp.

(6) The *Impagidinium velorum*–*Tectatodinium* spp. Beds (Utkholok Formation, lower Oligocene). Associated taxa are *Selenopemphix nephroides*, *Hystrichosphaeropsis* sp., *Impagidinium* spp., *Spiniferites* spp. Based on zonal species, the assemblage is correlated

with the lower Oligocene *Impagidinium velorum* Zone of the Bering Sea.

CONCLUSIONS

(1) Our study of organic-walled phytoplankton assemblages from Eocene and Oligocene sections of western Kamchatka shows that they are close in composition to assemblages from coeval sediments of Japan, Sakhalin, and the Bering Sea, and this is a ground for correlation of regional stratigraphic units and their dating.

(2) Beds defined in the composite section of Kamchatka contain phytoplankton assemblages, which are correlative with assemblages of upper Paleocene–lower Oligocene zones or beds known in the Northwest Pacific region within the distribution area of *Trinovantedinium boreale*.

(3) Based on additional data obtained by analysis of organic-walled phytoplankton assemblages, the Snatol Formation appears to be corresponding to the middle Eocene, Kovachina Formation to the terminal middle Eocene, Amanina and Rategin formations to the late Eocene, Gakkhin and Utkholok formations to the early Oligocene. Because the sampling density is inadequate, these age estimates should be additionally substantiated.

(4) The *Impagidinium velorum*–*Tectatodinium* spp. Beds are the early Oligocene in age. The role of *Trinovantedinium boreale* is negligible.

(5) The euryhaline species *Trinovantedinium boreale* widespread in Paleogene sections of the Northwest Pacific is a leading component in most of examined samples. It is comparable in abundance with *Paralecaniella indentata* and *Micrhystridium* in sediments accumulated in low-salinity environments, on the one hand, and occurs in association with *Impagidinium*, *Cordosphaeridium*, *Areosphaeridium*, *Enneadocysta*, and other taxons dwelling in open seas, on the other.

Ages of formations in Eocene–lower Oligocene sections of western Kamchatka and relevant correlation with sections in adjacent regions based on defined succession of beds with dinocysts differ sometimes from those substantiated earlier by foraminifers (Serova, 2001) and mollusks.

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