

Neogene diatoms from the deep Hole Central-1, the Bering Sea Chukchi shelf

Andrey Yu. Gladenkov

Geological Institute of Russian Academy of Sciences, Pyzhevskii per., 7, Moscow 119017, Russia
email: agladenkov@ilran.ru

ABSTRACT: A first report on the Neogene diatoms from the deep Hole Central-1 drilled on the Chukchi shelf of the Bering Sea is presented. The studied interval (609.5–623.5 meters below the sea floor) contains more than 70 diatom taxa in core samples collected from tuffaceous-diatomite sequence. The diatom flora is dominated by marine neritic-planktic and sublittoral taxa which implies deposition in productive shallow water environments. The occurrence of biostratigraphically-significant marine taxa *Pyxidicula zabelinae*, *Cosmiodiscus insignis*, and *Ikebea tenuis* indicate a Late Miocene age with a range of about 7.9 to 5.5 Ma.

INTRODUCTION

Deep Hole Central-1

Despite a series of deep-sea cores penetrating the upper Cenozoic sedimentary cover in the southern deep-water part of the Bering Sea during the DSDP and IODP expeditions (Creager et al. 1973; Takahashi, Ravelo and Alvarez Zarikian 2011; Takahashi et al. 2011), data from deep drilling from the Chukchi shelf, the northwest sector of the Bering Sea, has almost been absent. Nevertheless, shelf zones are integral parts of the Bering Sea basin, and their sedimentary and paleontological records are very important for deciphering of the Cenozoic geological history and oceanographic evolution of the Bering Sea and adjacent regions. That is why materials obtained on the first deep hole (Hole Central-1) drilled on shallow Chukchi shelf are of interest. This Hole (water depth, 90.1 m) was drilled in 2002 by Sibneft Oil Company 180 km to the east from the Cape Beringovskii of Chukotka, Russia, at the eastern periphery of the East Anadyr Depression (Text-figure 1) and penetrated a 2673.5-m-thick sedimentary section (Margulis et al. 2011). Results on vertical seismic profiling together with logging and lithological studies of slime and core samples made it possible to subdivide recovered sediments into a series of nine sequences dated mainly by dinocysts, spores and pollen, and benthic foraminifera (Margulis et al. 2011). Based on the obtained micropaleontological data and taking into account reference seismic horizons, these sequences of the Paleocene through Quaternary have been correlated with coeval stratigraphic units (regional stages and formations) used for onshore part of Anadyr region (Margulis et al. 2011). A number of core samples from the tuffaceous-diatomite sequence of the upper part of the section were also available for the study of fossil diatoms (Text-figure 2).

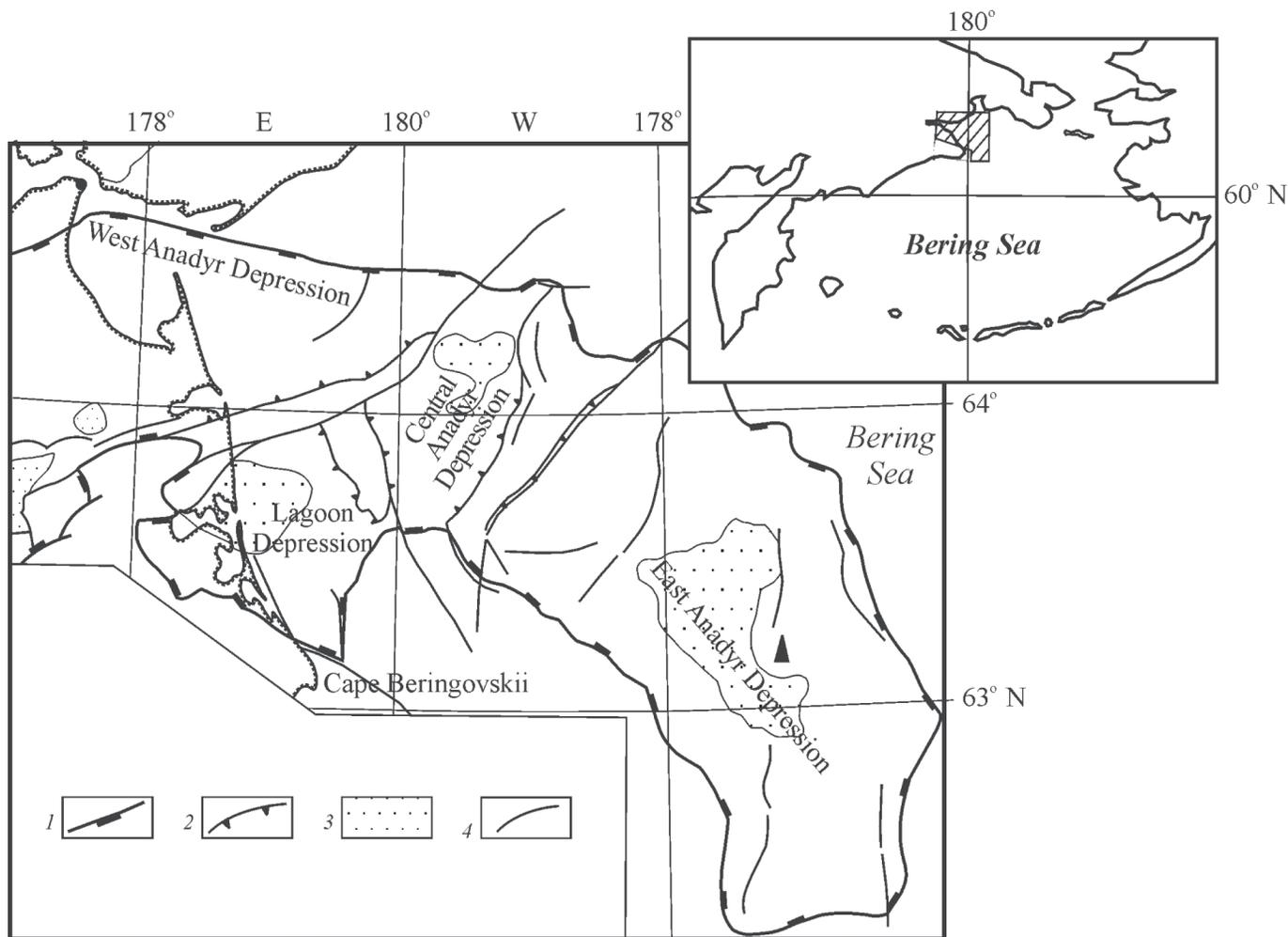
Significance of fossil diatoms

Fossil diatoms occur widely in deep-sea, near-shore and onshore upper Cenozoic stratigraphic sequences of the middle to high latitudes of the North Pacific area, including the Bering Sea and are the primary biostratigraphic tools for the precise dating and correlation of marine sediments in this region. The current high-resolution North Pacific Neogene diatom zonation includes numerous biohorizons based on datum levels, which have been

directly correlated to the magnetostratigraphy of the late Early Miocene to Quaternary (Barron 1980, 1992; Koizumi and Tanimura 1985; Koizumi 1992; Barron and Gladenkov 1995; Yanagisawa and Akiba 1998). Cenozoic marine diatoms of various ages from the Quaternary to Miocene are well represented in sea floor sediments (Jousé 1962; 1968; Kanaya and Koizumi 1966; Jousé, Mukhina and Kozlova 1969; Sancetta 1981a, 1981b; 1982; Sancetta and Silvestri 1986) and deep-sea cores in different parts of the Bering Sea (Koizumi 1973, 2010; Takahashi, Ravelo and Alvarez Zarikian 2011, Takahashi et al. 2011) and form the basis for detailed biostratigraphic and paleoenvironmental reconstructions. Relatively diverse Neogene diatom assemblages are also known from some onshore sections in the Bering Sea-side of northeast Kamchatka (Sheshukova-Poretskaya 1967; Oreshkina 1985; Gladenkov et al. 1992; Gladenkov, Gladenkov and Titova 2000; Volobueva et al. 1992; Gladenkov 1994, and others) and Alaska (Hanna 1970; Marincovich and Gladenkov 1999; 2001; Gladenkov 2003, 2006; Gladenkov et al. 2002) (Text-figure 3). The studies of diatom assemblages from these sections and their correlation with the North Pacific diatom zonation have allowed dating or refinement of the ages of a number of formations and regional stages. However, such data on fossil diatoms from the northwestern and northern parts of the Bering Sea region is quite poor. In general, they are limited by scarce materials from onshore boreholes drilled in the Khatyrka Depression, eastern part of the Koryak Upland, extending along the Bering Sea's coast (Mitrofanova and Boldyreva 1989; Agapitov and Mitrofanova 1999), and the Anadyr Depression (Agapitov 1991) (Text-figure 3). Published data on deep-cores on the Chukchi shelf zone are essentially absent. The present study of diatoms from the deep Hole Central-1 is the first description of Neogene diatom assemblages from the Bering Sea Chukchi shelf. These diatoms provide the principal basis for determining the age and paleoenvironmental reconstruction of the recovered host sediments.

MATERIALS AND METHODS

A total of 10 core samples in the interval from 609.5 to 623.5 meters below the sea floor (mbsf) collected from the 152-m-thick tuffaceous-diatomite sequence (composed of tuffaceous diatomites with interbeds of siltstones and clays) recovered at the Hole Central-1 were available for diatom analysis (Text-



TEXT FIGURE 1

Location of Hole Central-1 (black triangle) and main structural elements of the study area on Chukchi shelf of the Bering Sea (after Margulis et al. 2011). 1 - boundaries of the Anadyr Basin; 2 - boundaries of large structural elements; 3 - areas of troughs with the Cenozoic sedimentary sections more 5 km thick; 4 - major faults.

figure 2; Table 1). From top to bottom these samples are from the following intervals: 609.5-610.5, 611.5-612.5, 612.5-613.5, 613.5-614.5, 615.6-616.5, 616.5-617.5, 617.5-618.5, 620.5-621.5, 621.5-622.5, and 622.5-623.5 mbsf (Table 1; Text-figure 2).

The procedure of chemical treatment described by Gladenkov (2003) was used to process the samples. Strewn slides were prepared by spreading the pipette suspension onto a cover slip (size 24x24 mm), drying on a hot plate, and mounting in Naphrax (index of diffraction = 1.74). The slides were examined in their entirety under a Jeneval (Zeiss) light microscope at 400x, with identifications routinely checked at 1000x. Whenever possible, all diatom taxa were counted up to a maximum of 200 specimens (other than *Chaetoceros* spores). *Chaetoceros* spores were tabulated separately while counting the other taxa. After counting, the slides were scanned to record the presence of other diatom species missed among the first 200 specimens. When fewer than 200 diatom valves were encountered on a slide, all of the taxa were tabulated. The preservation of diatoms is listed as G (good), M (moderate), and P (poor) depending on the degree of destruction and dissolution of valves. The relative abundance is evaluated as A (abundant), C (common), F (few), and R (rare).

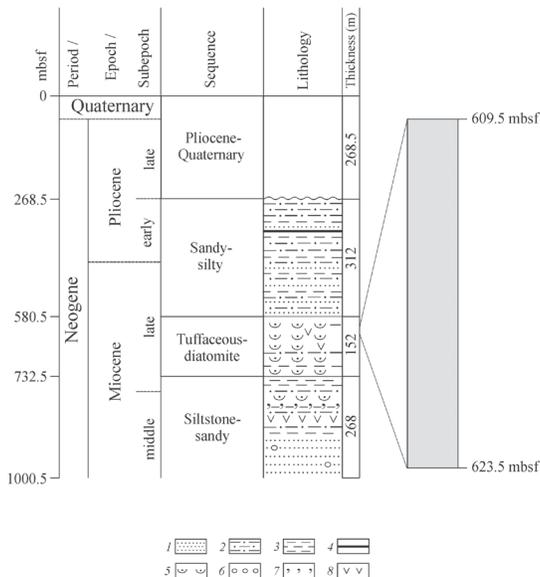
Numerical ages, geological epochs, subepochs and periods used herein according to the Cenozoic geochronologic scale after Berggren et al. (1995). The North Pacific Neogene diatom zonation follows Barron and Gladenkov (1995).

RESULTS AND DISCUSSION

Taxonomic composition and age of diatom flora

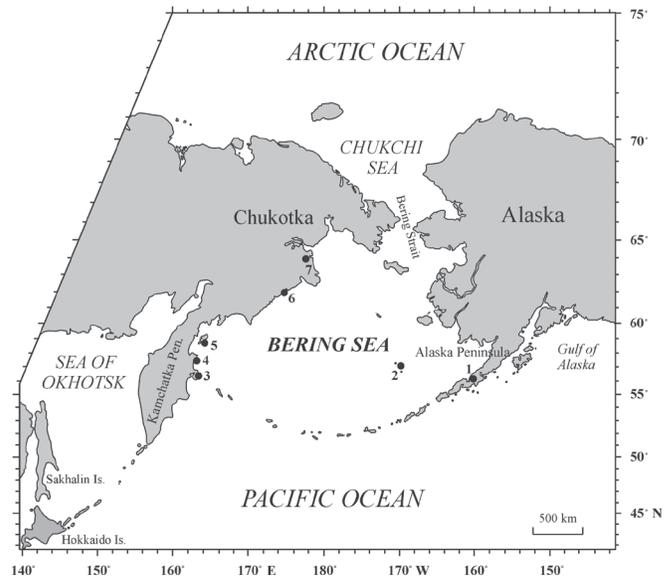
All the examined samples yield remains of diatoms (Table 1). In total more than 70 species and varieties of diatoms were identified in 10 samples. Their occurrences are shown in Table. Overall, diatoms are abundant to rare and well preserved to poorly preserved throughout the studied 14-m-thick interval. In general, the diatom flora consists of boreal and subarctic species typical of high to middle latitudes (Plate 1; Table 1). Except for two samples, the flora is persistently dominated by marine taxa, first of all, *Odontella aurita*, *Paralia sulcata*, and *Ikebea tenuis*. Diatoms from two samples mentioned above (from intervals 612.5-613.5 mbsf and 616.5-617.5 mbsf) are rare and dominated by nonmarine taxa of genus *Cyclotella*, whereas marine forms are almost absent here (Table 1).

Determining a precise age for diatom flora has proven



TEXT-FIGURE 2

Generalized stratigraphic column of the upper part of Hole Central-1 (modified from Margulis et al. 2011), with grey rectangle showing the interval with core samples collected for a study of fossil diatoms. 1 - 10 - lithology: 1 - sand, sandstone; 2 - silt, siltstone; 3 - clay, shale; 4 - coal; 5 - diatomite; 6 - pebble inclusions; 7 - glauconite; 8 - pyroclastic material. Abbreviation used: mbsf – meters below the sea floor



TEXT-FIGURE 3

Locations of main onshore stratigraphic sections (black circles) in the Bering Sea region where Neogene marine diatom assemblages have been documented and studied. 1 – Alaska Peninsula, the Sandy Ridge stratigraphic section, 2 – Pribilof Islands; 3 – Cape Kamchatskii Peninsula, 4 – Ozernoi Bay, Cape Tupoi, 5 – Karaginskii Island, 6 – Khatyrka Depression, eastern part of the Koryak Upland, 7 – the Anadyr Depression

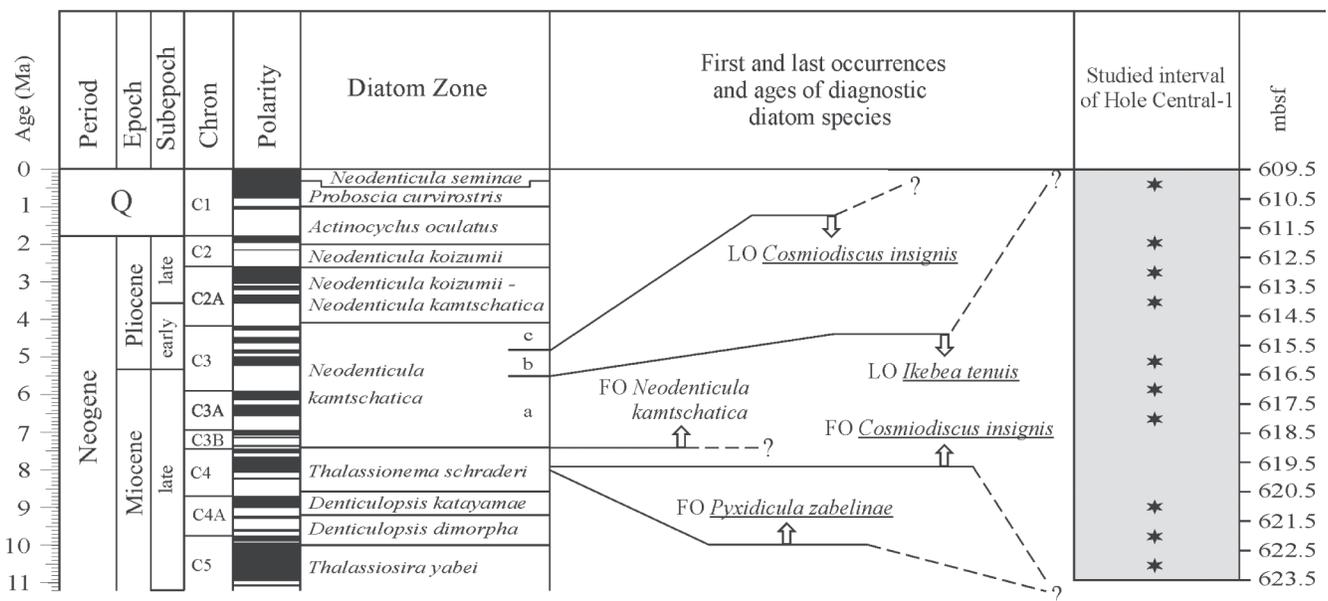
difficult, owing to the absence of many biostratigraphically significant and age-diagnostic marine planktic taxa, primarily from the genera *Denticulopsis* and *Neodenticula* that are characteristic of the North Pacific Neogene diatom zones. The most biochronologically important found taxa are *Pyxidicula zabelinae*, *Ikebea tenuis*, and *Cosmiodiscus insignis*. The most recent data based on their occurrences in deep-sea cores indicates that in the middle- to high-latitude North Pacific *Cosmiodiscus insignis* had its first occurrence (FO) at about 7.9 Ma and the last occurrence (LO) at about 4.8 Ma, *Ikebea tenuis* had LO at 5.6-5.5 Ma, and *Pyxidicula zabelinae* had its first occurrence (FO) at 8.0 Ma (Barron and Gladenkov 1995; Yanagisawa and Akiba 1998; Barron 2003). Thus, co-occurrence of these marine taxa indicates an age range of 7.9-5.5 Ma, i.e. a Late Miocene range from the upper part of the North Pacific *Thalassionema schraderi* Zone to a top of subzone “a” of *Neodenticula kamtschatica* Zone (Text-figure 4). It should be noted that studied flora lacks *Thalassiosira oestrupii*, which marks the boundary between subzone “a” and younger subzone “b” of *Neodenticula kamtschatica* Zone by its FO at 5.5 Ma (Barron and Gladenkov 1995). A number of species such as *Bacterosira fragilis*, *Detonula confervacea*, and *Thalassiosira jouseae* having their FOs within a narrow interval just above the FO of *Thalassiosira oestrupii* (Akiba 1986) and later on widely distributing in the North Pacific, are also absent in the examined samples. A lack of the mentioned taxa may serve as circumstantial evidence for an upper age limit of not less than 5.5 Ma.

It is also interesting to mention that one of the consistent and common species observed is *Kisseleviella carina* (Table 1; Plate 1). On the one hand, since *Kisseleviella carina* usually is most typical of the Oligocene and Early Miocene marine assemblages, it can be assumed that the found specimens are reworked. On the other hand, the age of its real extinction is finally unclear. As it was reported by Akiba and Yanagisawa

(1986), in general *Kisseleviella carina* is common to abundant from the North Pacific Early Miocene *Thalassiosira fraga* Zone to early Middle Miocene *Denticulopsis lauta* Zone. On the other hand, Gladenkov and Barron (1995) documented the consistent occurrence of *Kisseleviella carina* at least through the Middle Miocene *Denticulopsis hyalina* Zone from deep-sea core material in the western subarctic Pacific. Moreover, according to available data *Kisseleviella carina* is typical of even younger diatom assemblages from some sequences in Japan (Koizumi 1977) and DSDP Site 192 drilled at the northwest end of the Emperor Seamount Chain in the western subarctic Pacific (Koizumi 1973, 2010) - up to the Late Miocene horizons correlative with the North Pacific *Thalassionema schraderi* Zone and lower part of *Neodenticula kamtschatica* Zone. Since this species was presumably neritic in its character (Akiba 1986), it might have a longer stratigraphic range for the upper limit of occurrence in marine coastal areas in comparison with the open sea. Therefore the presence of *Kisseleviella carina* specimens *in situ* in the studied sediments from Hole Central-1 cannot be finally excluded.

Diatom paleoenvironments

As it has been mentioned above, in general, the diatom flora from the Hole Central-1 is composed by boreal and subarctic species typical of high to middle latitudes. Overall, the assemblages are dominated and subdominated by marine neritic-planktic and sublittoral taxa (including *Paralia sulcata*, *Odontella aurita*, *Chaetoceros* spores, *Actinocyclus senarius*, *Actinocyclus octonarius*, and *Stephanopyxis* spp.) that are accompanied by benthic and nonmarine forms. The presence of the Neogene cool-water species *Pyxidicula zabelinae*, *Cosmiodiscus insignis* and *Porosira punctata* typical of coastal environments of the Bering Sea and northwest Pacific (Barron 1980, 2003) is documented. Oceanic and open-sea planktic elements are rare



TEXT-FIGURE 4

North Pacific diatom zonation of Barron and Gladenkov (1995) for the last 11 Ma, correlated with the geochronologic and geomagnetic polarity time scales after Berggren et al. (1995), showing first and last occurrences of the age-diagnostic diatom species (underlined) present in the studied interval (grey rectangular) of Hole Central-1 indicating its Late Miocene age.

Asterisks show the stratigraphic levels with diatom-bearing samples. Abbreviations used: Q - Quaternary; a-c - subzones; FO - first occurrence; LO - last occurrence.

or practically absent. Hence, the absence of the marine planktic species *Neodenticula kamschatica*, which appeared at 7.4 Ma and is widely distributed in the North Pacific region from the Late Miocene to Early Pliocene, cannot be completely ruled out due to paleoecological exclusion. The flora lacks typically warm-water species, but diatoms associated with sea ice are also not found. Such features of taxonomic composition and structure imply deposition in productive, relatively cold and shallow water (shallower than 100 m) of marine shelf. Data on the Neogene marine mollusks and benthic foraminifera from tuffaceous-diatomite sequence at Hole Central-1 (Margulis et al. 2011) may support this conclusion.

Two documented stratigraphic levels, which possess rare diatoms but are practically lacking in marine forms, are dominated by nonmarine taxa that may be indicative either of environments caused by considerable shoaling of the shelf zone or by sedimentation under the influence of the river flow. On the other hand, the possible erosion of sediments at that time also cannot be excluded.

SUMMARY COMMENTS

The 14-m-thick stratigraphic interval of the 152-m-thick tuffaceous-diatomite sequence at the Hole Central-1 drilled on the Bering Sea Chukhi shelf contains Neogene diatom flora of different preservation and abundance. A total of about 70 species and varieties of diatoms were identified in 10 samples examined. The co-occurrence of biostratigraphically-significant marine taxa including *Pyxidicula zabelinae*, *Cosmiodiscus insignis*, and *Ikebea tenuis* may indicate the Late Miocene age of about 7.9 to 5.5 Ma. Overall, both the dominant and common elements of the studied flora imply deposition on a shallow continental shelf characterized by relatively cold waters. Against the background, two samples contain rare diatoms practically lacking marine forms and dominated by nonmarine taxa, which may imply episodes of shelf's shoaling and sedimentation under the influence of river

flow, or possible process of erosion.

ACKNOWLEDGMENTS

I thank Dr. Lazar S. Margulis of All-Russia Petroleum Research Exploration Institute, St. Petersburg, Russia, for sharing his geological knowledge on the Hole Central-1 and samples for diatom analysis. I also thank Dr. John A. Barron of U.S. Geological Survey and anonymous reviewer for their critical reviews of the manuscript and helpful comments. This work was partially supported by project no. 13-05-00115 of Russian Foundation for Basic Research and Program no. 28 of the Presidium of Russian Academy of Sciences.

APPENDIX

TAXONOMIC NOTES

A number of diatom species mentioned and listed in the paper call for taxonomic clarification. Usually in the literature some of these taxa were cited under another names following the first descriptions done in 1960-s. However, results from taxonomic studies on fossil marine diatoms and conclusions on synonyms particularly from more recent Russian papers are taken into account here. Because these taxa are typical of the North Pacific Neogene and have significance for paleoenvironmental reconstructions or age determinations (first of all, *Pyxidicula zabelinae*), brief remarks and comments are useful. Diatom terminology follows that of Anonymous (1975).

Hyalopyxis concava (Sheshukova) Makarova 1989: p. 35, pl. I, figs. 1-7, Pl. II. figs. 1-6.

Synonym: *Trochosira concava* Sheshukova in Sheshukova-Poretskaya 1967: p. 138, pl. XI, figs. 7a-b, pl. XIII, fig. 3.

Remarks. Morphology of specimens referred to as *Trochosira concava* has been studied in detail with a scanning electron

TABLE 1

Occurrences and relative abundance of diatoms from the Hole Central-1 (samples from the interval 609.5 - 623.5 meters below the sea floor).

Depth (meters below the sea floor)	609.5-610.5	611.5-612.5	612.5-613.5	613.5-614.5	615.6-616.5	616.5-617.5	617.5-618.5	620.5-621.5	621.5-622.5	622.5-623.5
	M	M	M-P	M	M	M	G-M	M	M-P	G-M
Abundance	F	F	R	C-F	C-F	R	A	F	F	C-F
<i>Actinocyclus octonarius</i> Ehrenberg	1	2	1	3	3	1	6	6	3	3
<i>Actinocyclus</i> Ehrenberg spp.		+					+	1	+	1
<i>Actinocyclus senarius</i> (Ehrenberg) Ehrenberg	4	5		8	7		37	3	1	8
<i>A. splendens</i> (Shadbolt) Ralfs										
<i>A. vulgaris</i> Schumann				+					+	+
<i>Actinocyclus</i> Ehrenberg sp.					+					
<i>Arachnoidiscus</i> sp. cf. <i>ehrenbergii</i> Bailey		+		+			+	+	+	+
<i>Azpeitia</i> sp. cf. <i>vetustissima</i> (Pantocsek) Sims							+			
<i>Azpeitia</i> Peragallo sp.								+		+
<i>Cestodiscus</i> Greville sp.		+					+	+	+	+
<i>Clavícula</i> sp. cf. <i>polymorpha</i> Grunow et Pantocsek							+			
<i>Cocconeis antiqua</i> Tempère et Brun				+	+		1		+	+
<i>C. costata</i> Gregory				+			+	+		+
<i>C. scutellum</i> Ehrenberg	+	+			+		+	+	+	1
<i>C. vitrea</i> Brun					+		+	+	+	+
<i>Cocconeis</i> Ehrenberg spp.							+	+	+	+
<i>Coscinodiscus asteromphalus</i> Ehrenberg	+	+		+	+		+	+	+	+
<i>C. marginatus</i> Ehrenberg	6	15	1	13	10		7	4	10	6
<i>Coscinodiscus</i> Ehrenberg spp.	1	2	1	+	+	1	1	3	3	4
<i>Cosmodiscus insignis</i> Jousé	1	2		1	3		5	4	3	3
<i>C. intersectus</i> (Brun) Jousé	2	2		2	1		4	1	2	3
<i>Cyclotella</i> Kützing ex Brébisson spp.	3	1	38	2	1	34	3	3	6	+
<i>Delphineis</i> Andrews sp.	+	+			+		+			+
<i>Dimerogramma</i> Ralfs sp.	+	+						+		+
<i>Diploneis</i> sp. cf. <i>smithii</i> (Brebisson) Cleve							+			
<i>Diploneis</i> sp. cf. <i>subcincta</i> (Schmidt) Cleve	1		1	2	2		1	2	+	+
<i>Entopyla australis</i> var. <i>gigantea</i> (Greville) Fricke							+	+	+	
Genus et sp. indet.		+		+	+		+	+	+	1
<i>Goniothecium rogersii</i> Ehrenberg				+			2	2	+	+
<i>Goniothecium</i> Ehrenberg sp.		+		+			2	+	+	+
<i>Grammatophora</i> Ehrenberg sp.		+		+	+		+			1
<i>Hemiaulus polymorphus</i> Grunow	2	+		5	4		2	6	+	+
<i>Hemiaulus</i> Ehrenberg sp. (" <i>pyxiloides</i> ")		+		+	+		+		+	+
<i>Hyalodiscus dentatus</i> O. Korotkevich				+				+		
<i>H. obsoletus</i> Sheshukova				+	+		+			+
<i>Hyalodiscus</i> Ehrenberg sp.	+	1	1	+	+		+	2	1	+
<i>Hyalopyxis concava</i> (Sheshukova) Makarova	4	5		3	3		1	3	4	5
<i>Ikebea tenuis</i> (Brun) Akiba	63	36		41	23		27	21	36	6
<i>Kisseleviella carina</i> Sheshukova	8	26		9	21		1	9	10	10
<i>Kisseleviella</i> sp. cf. <i>carina</i> Sheshukova		4		+	2		+	+	+	+
<i>Liradiscus ovalis</i> Greville	+	+		+	1		+	2	1	1
<i>Navicula</i> Bory spp.				+				+		
<i>Neodelphineis</i> sp. cf. <i>pelagica</i> Takano					+					
<i>Odontella aurita</i> (Lyngebye) Agardh	52	17		56	57	1	49	29	61	66
<i>O. tuomevi</i> (Ehrenberg) Gleser		+							+	+
<i>Paralia polaris</i> (Grunow) Gleser				+			+			+
<i>P. sulcata</i> (Ehrenberg) Cleve	36	52	2	39	44	2	27	59	36	55
<i>Pinnularia</i> Ehrenberg sp.					+					+
<i>Pleurosigma</i> Smith sp.										+
<i>Porosira punctata</i> (Jousé) Makarova								+		
<i>Pseudopyxilla</i> sp. cf. <i>directa</i> (Pantocsek) Forti										+
<i>Pseudotriceratium adpersum</i> (Mann) A. Gladenkov	+	+		+	+		1	+	+	+
<i>Ps. kamschaticum</i> A. Gladenkov	+							+		+
<i>Ps. notable</i> (O. Korotkevich) Gleser	1	2		2	2		1	2	+	2
<i>Ps. rusticum</i> (Mann) A. Gladenkov	1	+		1	+		+			+
<i>Pyxidicula zabelinae</i> (Jousé) Makarova et Moisseeva	2	3		5	3	1	4	10	7	4
<i>Pyxilla</i> Greville sp.							+			
<i>Rhabdonema japonicum</i> Tempère et Brun		+					+			1
<i>Rhaphoneis ampiceros</i> Ehrenberg		+		+	+		+			1
<i>Rhaphoneis</i> Ehrenberg spp.	1	1		1	1		+	+	+	+
<i>Rhizosolenia hebetata</i> (Bailey) Gran group	+	+		+	1		+	4		+
<i>Rh. styliformis</i> Brightwell							+			+
<i>Rocella nitida</i> (Gregory) Fenner		+		+	+		+		+	+
<i>Sheshukovia condecora</i> (Brightwell) Gleser		+		+	+		+	+	+	1
<i>Stellarima microtrias</i> (Ehrenberg) Hasle et Sims	3	9		4	4		5	5	9	7
<i>Stephanopyxis neogenica</i> Dolmatova + <i>St. turris</i> (Greville et Arnott) Ralfs	5	10		2	3		10	11	1	4
<i>Stictodiscus kittonianus</i> Greville + <i>St. hardmanianus</i> Greville					+		+	2	1	2
<i>Synedra</i> Ehrenberg sp.							+			+
<i>Thalassionema nitzschioides</i> (Grunow) Mereschkowsky								+	+	+
<i>Thalassiosira manifesta</i> Sheshukova	1	5		1	4		2	1	1	2
<i>Th. sheshukovae</i> Makarova					+					1
<i>Xanthiopyxis</i> (Ehrenberg) Ehrenberg spp.	2	+		+	+		1	5	4	1
Resting spores of <i>Chaetoceros</i> Ehrenberg spp.	76	64	1	48	65		41	69	52	61
Total number of valves counted except for <i>Chaetoceros</i> resting spores	200	200	45	200	200	40	200	200	200	200

Preservation: G = good, M = moderate, P = poor. Relative abundance: A = abundant, C = common, F = few, R = rare, plus sign (+) indicates diatom specimens recorded after the count.

microscope (SEM) by Makarova (1989) from the Neogene material provided by Sheshukova-Poretskaya. The observations revealed the specific morphological features typical of these specimens including a ring of perforations located at the boundary between valve face and mantle, and a rarefied ring of labiate processes located at the upper part of mantle. Since the combination of studied morphological features are not characteristic either for genus *Trochosira* or other genera of centric diatoms, the taxon was transferred from genus *Trochosira* Kitton to new genus *Hyalopyxis* by Makarova in 1989.

Ikebea tenuis (Brun) Akiba
Plate 1, figures 8, 14, 16, 22

Ikebea tenuis (Brun) AKIBA 1986, p. 439-440, pl. 19, figs. 1-5.
Synonym: *Goniothecium tenue* BRUN 1894.

Remarks. Taking into account a heterovalve outline and other structural differences, Akiba (1986) proposed a new combination and transferred this peculiarly shaped extinct Cenozoic diatom from genus *Goniothecium* Ehrenberg to genus *Ikebea* Komura.

Porosira punctata (Jousé) Makarova 1988 a: p. 1184, pl. I, figs. 1-16.

Thalassiosira punctata JOUSÉ 1961, p. 64, pl. I, figs. 7-8, pl. III, fig. 3. – SHESHUKOVA-PORETSKAYA 1967: p. 151, pl. XIV, fig. 10, pl. XVII, figs. 1 a-b.

Remarks. Specimens referred to as *Thalassiosira punctata* have been studied with SEM by Makarova (1988 a) from the Neogene material collected in Sakhalin and provided by Sheshukova-Poretskaya. Revealed morphological features including form and location of labiate process, and structure of strutted processes have made it possible to propose a new combination and transfer the taxon from genus *Thalassiosira* Cleve to genus *Porosira* Jørgensen.

Pyxidicula zabelinae (Jousé) Makarova and Moisseeva
Plate 1, figure 3

Pyxidicula zabelinae (Jousé) MAKAROVA and MOISSEVA 1986: p. 244-245, pl. I, figs. 1-15, pl. II, figs. 1-15.

Basionym: *Thalassiosira zabelinae* JOUSÉ 1961, p. 66-67, pl. II, figs. 1-7. – SHESHUKOVA-PORETSKAYA 1967: p. 149, pl. XVI, figs. 2 a-d.

Synonym: *Thalassiosira usatschevii* JOUSÉ 1961, p. 64-65, pl. I, fig. 10, pl. III, fig. 6. – also figured in SHESHUKOVA-PORETSKAYA 1967: p. 150, pl. XV, figs. 3 a-d.

Remarks. Specimens referred to as *Thalassiosira zabelinae* and *T. usatschevii* have been studied with SEM by Makarova and Moisseeva (1986) from the Neogene of Sakhalin. This observation did not show differences in morphology of the specimens but demonstrated that they were identical. SEM observation revealed that among the morphological features typical of these specimens are areolae with internal cribra, a ring of small labiate processes located at the marginal zone of valve, and occasional labiate processes near a top of valve. However, specimens lacking strutted processes on the valves that are typical of genus *Thalassiosira*. Based on obtained results the studied species have been combined and transferred from genus *Thalassiosira* Cleve to genus *Pyxidicula* Ehrenberg.

Thalassiosira manifesta Sheshukova
Plate 1, figure 21

Thalassiosira manifesta Sheshukova in SHESHUKOVA-PORETSKAYA 1964, p. 72, pl. I, figs. 6-7. – SHESHUKOVA-PORETSKAYA 1967, p. 147, pl. XIV, figs. 9 a-b.

Remarks. This species resembles *T. nansenii* Scherer and Koç 1996. Both taxa are characterized by slightly convex valve, hyaline margin, irregularly shaped small size areolae arranged in bowed radial rows with distinctive or occasional bifurcation, visible marginal processes, and one to few central processes in the central area. A fact that *T. manifesta* is synonymous with *T. nansenii* cannot be finally excluded. However, Scherer and Koç (1996) note that *T. nansenii* is a bipolar diatom and occurs in the high-latitude Lower Oligocene to Lower Miocene strata. In contrast, *T. manifesta* has an age range from the latest Middle Miocene to Pliocene and is typical of the North Pacific. Moreover, specimens of *T. manifesta* from the North Pacific Late Miocene have been studied with SEM by Makarova (1988 b). This observation revealed one to few strutted processes (with internal openings surrounded by two satellite pores) at the valve center; several rings of marginal strutted processes (with internal openings surrounded by two to four satellite pores) with quincunx arrangement, and one labiate process located off the valve margin. Further study of specimens referred to as *T. nansenii* under the SEM should clarify their taxonomic position, because structure of strutted processes and other morphological features of *T. nansenii* are presently unknown.

Thalassiosira sheshukovae Makarova 1988 a: p. 1185, pl. II, figs. 1-11.

Synonyms: *Pseudopodosira elegans* Sheshukova in SHESHUKOVA-PORETSKAYA 1964, p. 75-76, fig. 3, pl. II, figs. 4-5. – SHESHUKOVA-PORETSKAYA 1967, p. 178, pl. XXIV, fig. 3, pl. XXV, fig. 4.

Remarks. SEM observations of specimens referred to as *Pseudopodosira elegans* have been done by Makarova (1988 a) using the Neogene material collected in Sakhalin and provided by Sheshukova-Poretskaya. They revealed a group of strutted processes (with internal openings surrounded by two satellite pores) at the valve center, a ring of strutted processes (with internal openings surrounded by four satellite pores) located on the boundary between the mantle and valve face, and one labiate process occurred between at the margin and enclosed by two strutted processes. Taking into account presence of these morphological features Makarova (1988 a) transferred the taxon from *Pseudopodosira* Jousé to *Thalassiosira* Cleve, i.e. she proposed a new combination. However, due to the name *Thalassiosira elegans* having been already occupied, new species *Thalassiosira sheshukovae* was proposed.

REFERENCES

- AGAPITOV, D. I., 1991. New data on stratigraphy of Neogene and Paleogene deposits in the Anadyr Depression. In: Il'ev, A. Ya., Ed., *Geology and stratigraphy of the Cenozoic deposits in the northwest Pacific*, 70-95. Vladivostok: Far East Branch of the USSR Academy of Sciences (in Russian).
- AGAPITOV, D. I. and MITROFANOVA, L. I., 1999. Stratigraphy of the Neogene deposits of the Khatyrka Depression (Chukotka). *Tikhookeanskaya Geologiya* 18: 123-133 (in Russian).
- AKIBA, F., 1986. Middle Miocene to Quaternary diatom biostratigraphy in the Nankai Trough and Japan Trench, and modified lower Miocene

- through Quaternary diatom zones for the middle-to-high latitudes of the North Pacific. In: Kagami, H., Karig, D. E., Coulbourn, W. T. et al., *Initial Reports of the Deep Sea Drilling Project, Vol. 87*. 393–481. Washington, DC: U. S. Government Printing Office.
- AKIBA, F. and YANAGISAWA, Y., 1986. Taxonomy, morphology and phylogeny of the Neogene zonal marker species in the middle-to-high latitudes of the North Pacific. In: Kagami, H., Karig, D. E., Coulbourn, W. T. et al., *Initial Reports of the Deep Sea Drilling Project, Vol. 87*, 483–554. Washington, DC: U. S. Government Printing Office.
- ANONYMOUS, 1975. Proposals for a standardization of diatom terminology and diagnoses. *Nova Hedwiga, Beihefte*, 53: 323–354.
- BARRON, J. A., 1980. Lower Miocene to Quaternary diatom biostratigraphy of Leg 57, off northeastern Japan, Deep Sea Drilling Project. In: Scientific Party, Eds., *Initial Reports of the Deep Sea Drilling Project, Vol. 56, 57*, 641–685. Washington, DC: U. S. Government Printing Office.
- BARRON, J. A., 1992. Neogene diatom datum levels in the Equatorial and North Pacific. In: Ishizaki, K. and Saito, T., Eds., *Centenary of Japanese Micropaleontology*: 413–425. Tokyo: Terra Scientific Publishing Company.
- , 2003. Planktonic marine diatom record of the past 18 m. y.: appearances and extinctions in the Pacific and Southern Oceans. *Diatom Research*, 18: 203–224.
- BARRON, J. A. and GLADENKOV, A. Y., 1995. Early Miocene to Pleistocene diatom stratigraphy of Leg 145. In: Rea, D. K., Basov, I. A., Scholl, D. W. and Allan, J. F., Eds., *Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 145*, 3–19. College Station, TX: Ocean Drilling Program.
- BERGGREN, W. A., KENT, D. V., SWISHER, C. C., III and AUBRY, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W. A., Kent, D. V., Aubry, M.-P. and Hardenbol, J., Eds., *Geochronology Time Scales and Global Stratigraphic Correlation*, 129–212. Tulsa, OK: Society for Sedimentary Geology (SEPM). Special Publication 54.
- CREAGER, J. S., SCHOLL, D. W., BOYCE, R. E. et al., 1973. *Initial Reports of the Deep Sea Drilling Project, Vol. 19*. Washington, D. C.: U. S. Government Printing Office, 913 pp.
- GLADENKOV, A. Yu., 1994. Diatom assemblages from the Pliocene–Pleistocene boundary beds in Kamchatka, Russia. *Micropaleontology*, 40: 79–94.
- , 2003. Diatom biostratigraphy of the Neogene Milky River Formation, Alaska Peninsula, southwestern Alaska. *Proceedings of the California Academy of Sciences*, 54: 27–64.
- , 2006. Neogene diatoms from the Sandy Ridge Section, Alaska Peninsula: significance for stratigraphic and paleogeographic reconstructions. *Stratigraphy and Geological Correlation*, 14: 79–97.
- GLADENKOV, A. Yu. and BARRON, J. A., 1995. Oligocene and early Middle Miocene diatom biostratigraphy of Hole 884B. In: Rea, D. K., Basov, I. A., Scholl, D. W. and Allan, J. F., Eds., *Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 145*, 21–42. College Station, TX: Ocean Drilling Program.
- GLADENKOV, A. Yu., OLEINIK, A. E., MARINCOVICH, L., Jr. and BARINOV, K. B., 2002. A refined age for the earliest opening of Bering Strait. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 183: 321–328.
- GLADENKOV, Yu. B., BARINOV, K. B., BASILIAN, A. E., et al., 1992. *Detailed division of the Neogene of Kamchatka*. Moscow: Nauka Publishers, 208 pp. (in Russian).
- GLADENKOV, Yu. B., GLADENKOV, A. Yu. and TITOVA, L. V., 2000. Lower Miocene of East Kamchatka region. *Geology of the Pacific Ocean*, 15: 685–714.
- HANNA, G. D., 1970. Fossil diatoms from the Pribilof Islands, Bering Sea, Alaska. *Proceedings of the California Academy of Sciences*, ser. 4, 37: 167–234.
- JOUSÉ, A. P., 1961. Miocene and Pliocene marine diatoms from the Far East. *Botanicheskie materialy otdela sporovykh rastenii Botanicheskogo Instituta Akademii Nauk S. S. S. R.*, 14: 59–70 (in Russian).
- , 1962. *Stratigraphic and paleogeographic researches in the northwest Pacific*. Moscow: USSR Academy of Sciences Publishers, 260 pp. (in Russian).
- , 1968. The importance of algae in the knowledge of geological history of modern seas and oceans. In: Jousé, A. P., Ed., *Fossil diatoms of the USSR*, 5–16. Moscow: Nauka Publishers (in Russian).
- JOUSÉ, A. P., MUKHINA, V. V. and KOZLOVA, O. G., 1969. Diatoms and silicoflagellates in the surface layer of sediments from the Pacific Ocean. In: Bezrukov, P. L., Ed., *The Pacific Ocean. Vol. 7: Microflora and microfauna in the modern sediments of the Pacific Ocean*, 7–47. Moscow: Nauka Publishers (in Russian).
- KANAYA, T. and KOIZUMI, I., 1966. Interpretation of diatom thanatocoenoses from the north Pacific applied to a study of core V20–130 (Studies of a deep-sea core V20–130. Part IV). *Science Reports of the Tohoku University, Sendai, Second Series (Geology)*, 37: 89–130.
- KOIZUMI, I., 1973. The Late Cenozoic diatoms of Sites 183–193, Leg 19, Deep Sea Drilling Project. In: Creager, J. S., Scholl, D. W., Boyce, R. E. et al., *Initial Reports of the Deep Sea Drilling Project, Vol. 19*, 805–855. Washington, DC: U. S. Government Printing Office.
- , 1977. Diatom biostratigraphy in the North Pacific region. In: Saito, T. and Ujiie, H., Eds., *Proceedings of the First Congress on Pacific Neogene Stratigraphy, Tokyo 1976*, 235–253. Tokyo: Kaiyo Shuppan Co. Ltd.
- , 1992. Diatom biostratigraphy of the Japan Sea: Leg 127. In: Pisciotto, K. A., Ingle, J. C., Jr., von Breymann, M. T., Barron, J. A. et al., *Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 127/128 (Pt. 1)*, 249–289. College Station, TX: Ocean Drilling Program.
- , 2010. Revised diatom biostratigraphy of DSDP Leg 19 drill cores and dredged samples from the subarctic Pacific and Bering Sea. *JAMSTEC Report of Research and Development*, 10: 1–23.
- KOIZUMI, I. and TANIMURA, Y., 1985. Neogene diatom biostratigraphy of the middle latitude western North Pacific, Deep Sea Drilling Project Leg 86. In: Heath, G. R., Burckle, L. H., D’Agostino, A. E. et al., Eds., *Initial Reports of the Deep Sea Drilling Project, Vol. 86*. 269–300. Washington, DC: U. S. Government Printing Office.
- MAKAROVA, I. V., 1988 a. New combinations of taxa from the Late Miocene and the Early Pliocene diatom floras of the Sakhalin. *Botanicheskii Zhurnal*, 73 (8): 1183–1186, pls I–II (in Russian).
- , 1988 b. *Diatom algae from the seas of the USSR: genus *Thalassiosira* Cl.* Leningrad: Nauka Publishers, 117 pp. (in Russian).
- , 1989. New genus of centric diatoms. *Novitates Systematicae Plantarum Non Vascularium*, 26: 34–35. Leningrad: Nauka Publishers (in Russian).
- MAKAROVA, I. V. and MOISSEYEVA, A. I., 1980. A new species of the genus *Pyxidicula* (Bacillariophyta). *Botanicheskii Zhurnal*, 71: 244–245 (in Russian).

- MARINCOVICH, L., Jr. and GLADENKOV, A. Yu., 1999. Evidence for an early opening of the Bering Strait. *Nature*, 397: 149–151.
- , 2001. New evidence for the age of Bering Strait. *Quaternary Science Reviews*, 20: 329–335.
- MARGULIS, L. S., AGAPITOV, D. D., MARGULIS, E. A., et al., 2011. First data on the Cenozoic section of the Bering Sea Chukchi shelf. *Stratigraphy and Geological Correlation*, 19: 221–232.
- MITROFANOVA, L. I. and BOLDYREVA, V. P., 1989. Subdivision and correlation of Neogene sedimentary sections of the northwest Pacific (the Khatyrka Depression). In: Kornev, O. S., Ed., *Age of geological formations of the Okhotsk Sea region and adjacent territories*, 34–47. Vladivostok: Far East Branch of the USSR Academy of Sciences (in Russian).
- ORESHKINA, T. V., 1985. Diatom assemblages and stratigraphy of the upper Cenozoic off Kamchatka region of the Pacific Ocean. *Izvestiya Akademii Nauk SSSR, Geology Series*, 5: 60–73 (in Russian).
- SANCETTA, C., 1981a. Diatoms as hydrographic tracers: example from Bering Sea sediments. *Science*, 211: 279–281.
- , 1981b. Oceanographic and ecologic significance of diatoms in surface sediments of the Bering and Okhotsk seas. *Deep-Sea Research*, 28A: 789–817.
- , 1982. Distribution of diatom species in surface sediments of the Bering and Okhotsk seas. *Micropaleontology*, 28: 221–257.
- SANCETTA, C. and SILVESTRI, S., 1986. Pliocene–Pleistocene evolution of the North Pacific Ocean–atmosphere system, interpreted from fossil diatoms. *Paleoceanography*, 1: 163–180.
- SCHERER, R. P. and KOÇ, N., 1996. Late Paleogene diatom biostratigraphy and paleoenvironments of the northern Norwegian–Greenland Sea. In: Thiede, J., Myhre, A. M., Firth, J. V., Johnson, G. L. and Ruddiman, W. F., Eds., *Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 151*, 75–99. College Station, TX: Ocean Drilling Program.
- SHESHUKOVA-PORETSKAYA, V. S., 1964. New and rare diatoms from the Neogene of Sakhalin and Kamchatka. *Novitates Systematicae Plantarum Non Vascularium*, 1: 69–77. Moscow - Leningrad: Nauka Publishers (in Russian).
- , 1967. *Neogene marine diatoms of Sakhalin and Kamchatka*. Leningrad: Leningrad State University Press, 432 pp. (in Russian).
- TAKAHASHI, K., RAVELO, A. C. and ALVAREZ ZARIKIAN, C. A., 2011. IODP Expedition 323: Pliocene and Pleistocene paleoceanographic changes in the Bering Sea. *Scientific Drilling*, 11: 4–13.
- TAKAHASHI, K., RAVELO, A. C., ALVAREZ ZARIKIAN, C. A. and the Expedition 323 Scientists, 2011. *Proceedings of the Integrated Ocean Drilling Program, Vol. 323*. College Station, TX: Ocean Drilling Program.
- VOLOBUEVA, V. I., BELAYA, B. V., DOLMATOVA, L. M., GREVTSEV, A. V., MINYUK, P. S., NARKHINOVA, V. E., POLOVOVA, T. P. and SHIRAYA, O. A., 1992. *Key section of marine Neogene of Northeast Asia in Karaginsky Island. Pt. 1. Stratigraphy*. Magadan: SVKNII, Far East Branch of Russian Academy of Sciences, 109 pp. (in Russian).
- YANAGISAWA, Y. and AKIBA, F., 1998. Refined Neogene diatom biostratigraphy for the northwest Pacific around Japan with an introduction of code numbers for selected diatom biohorizons. *The Journal of the Geological Society of Japan*, 104: 395–414.

Received April 23, 2013

Accepted May 7, 2013

Published September 18, 2013

PLATE 1

Fossil marine taxa typical of diatom assemblage from the studied interval (609.5 to 617.5 mbsf) of Hole Central-1 (photos were taken under a light microscope). a, b – valve in different focus. Black line segments are scale bars = 10 microns

- | | |
|---|---|
| 1, 2 <i>Cosmodiscus insignis</i> Jousé; | 9, 10 <i>Kisseleviella carina</i> Sheshukova; |
| 3 <i>Pyxidicula zabelinae</i> (Jousé) Makarova et Moiseeva; | 11, 17 spores of <i>Chaetoceros</i> ; |
| 4 <i>Coscinodiscus marginatus</i> Ehrenberg; | 18 <i>Actinoptychus senarius</i> (Ehrenberg) Ehrenberg; |
| 5 <i>Actinocyclus octonarius</i> Ehrenberg; | 19, 20 <i>Paralia sulcata</i> (Ehrenberg) Cleve; |
| 6, 7 <i>Odontella aurita</i> (Lyngbye) Agardh; | 21 <i>Thalassiosira manifesta</i> Sheshukova; |
| 8, 14, 16, 22 <i>Ikebea tenuis</i> (Brun) Akiba; | |

