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Eocene Diatoms and Silicoflagellates from the Kronotskii Bay Deposits (East Kamchatka)

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Abstract—Eocene diatoms and silicoflagellates from deposits of the Kronotskii Bay are the oldest known fossils of siliceous phytoplankton from the northwestern Pacific. More than 130 species of 59 diatom genera and 24 species of 5 silicoflagellate genera are identified. Three diatom assemblages of middle Eocene age (those of *Lisitzinia kanayai, Lisitzinia inconspicua* var. *triloba*, and *Praecymatosira monomembranaceae* zones) and one presumably corresponding in age to the middle–late Eocene (diatoms of *Rylandsia conniventa* Zone) are established. A diverse silicoflagellate assemblage described for the first time characterizes the *Dictyocha hexacantha* Zone. All the assemblages are supposed to have been formed mainly in bathyal environments and under a relatively high (almost subtropical) temperature of surface water.

Key words: diatoms, silicoflagellates, middle Eocene, Kronotskii Bay, East Kamchatka, paleoenvironment, northwestern Pacific.

The early Paleogene siliceous microplankton is found sporadically in the northern Pacific, because the intense biogenic siliceous sedimentation probably began in the Oligocene time (*Proceedings…*, 1995) to be increased in the Neogene (Baldauf and Barron, 1990). In addition, siliceous skeletons of the Early Paleogene microorganisms are poorly preserved in the marginal basins with bottom sediments of considerable thickness, where heat flow is high, favoring transformation of opal-A into opal-CT (Hein *et al.*, 1978). Finds of Paleogene siliceous microplankton are therefore of a great interest. The region of investigations is also of interest. In publications on the Lower Cenozoic biostratigraphy of East Kamchatka, there are controversial data on age and formation history of deposits in the region (Beniamovskii and Gladenkov, 1996; Levashova *et al.*, 2000). The reconstruction of Cenozoic history is also hampered by absence of reliable data on composition and age of deposits in the East Kamchatka continental slope (Seliverstov, 1998).

This article presents the results of study of diatoms and silicoflagellates from Cenozoic volcanogenic–sedimentary deposits of the Kronotskii Bay. First identifications by E.G. Lupikina, L.M. Dolmatova, and I.B. Tsoy suggested the late Eocene-Oligocene age for the diatom flora from these sediments (Seliverstov, 1998). Glezer *et al.* (1986) and Pushkar' (1987) who described comprehensively the Paleogene diatom assemblages were first to distinguish among them the middle Eocene and late Eocene–Oligocene assemblages. However, different age interpretations are known for assemblages from the same samples. Recent data on stratigraphic ranges of diatoms and newly established species of these fossils revived investigation of Paleogene diatoms from the Kronotskii Bay localities. Based on complex micropaleontological data (diatoms, radiolarians, palynoflora), two constituent parts the Kronotskii sedimentary sequence were distinguished (Tsoy *et al.*, 2000): the upper one with the late Miocene–Pleistocene assemblages and the lower subdivision with predominantly middle Eocene assemblages.

This work is dedicated to description of the Eocene of diatom and silicoflagellate assemblages, their taxonomic composition, age substantiation, and paleoenvironment interpretation included.

BRIEF OUTLINE OF GEOLOGY AND GEOPHYSICAL DATA

The Kronotskii Bay is bordered in the north by the Kronotskii Ridge, a submarine continuation of the synonymous peninsula. The southern end of the ridge is adjacent to the Kamchatka segment of the Kuril–Kamchatka trench. The shelf terrace 10–50 km wide extends into the continental slope to the depth of about 900 m (Seliverstov, 1998). The deep V-shaped structures (the Kronotskii, Ol'ga, and Zhupanovskii canyons) are incised into the acoustic basement the Kronotskii Bay shelf and slope. The largest canyons of the continental slope are as deep as 2 km. An upper part of the sequence is represented by the upper Miocene–Pleistocene volcanogenic-sedimentary deposits showing rhythmical subhorizontal bedding (Tsoy *et al.*, 2000). The maximal thickness (1.5–2 km) of these deposits is measured in the southern Kronotskii Bay. The lower, acoustically transparent part of sedimentary sequence is relatively persistent in thickness (400–700 m). The bedded and acoustically transparent units are separated by an unconformity that is most distinct in peripheral parts of the depression. The acoustically transparent sediments rest conformably on the acoustic basement composed of volcaniclastic rocks (tuffs, hyaloclastites).

MATERIALS AND METHODS

The sequence was sampled using gravity corer or dredging during Legs 9 and 12 of R/V "Vulkanolog" of the Far East Institute of Volcanology, Russian Academy of Sciences (Table 1; Fig. 1). N.I. Seliverstov headed the expeditions. The dredging intervals were selected based on previously obtained seismoacoustic profiles (Seliverstov, 1998).

The standard procedure and heavy K-Cd solution were used to extract diatom and silicoflagellate remains. Microfossils are identified under magnification of 1350, and valve calculation is performed under magnification of 900. Percentages of species are calculated, depending on abundance rate of fossils, for samples of 100, 200, or 300 specimens. Environmental reconstruction, mostly estimation of paleodepth, is based on proportions between oceanic and neritic species (Jousé, 1962; Koizumi, 1983; Yanagisawa, 1996), and relative temperatures of surface water are estimated based on occurrence frequency of warm-water (low-latitudinal) species of diatoms and silicoflagellates. The Paleogene diatom assemblages are macerated from 9 of 52 samples studied; 12 samples yielded the late Miocene–Pleistocene assemblages, and 31 samples are either barren or contain single unidentifiable remains. The Paleogene assemblages of diatoms and silicoflagellates from the Kronotskii Bay deposits are described below.

RESULTS

The Ol'ga Canyon. Sediments of the canyon walls were sampled by means of the gravity corer and dredging (Figs. 1, 2). The upper part of the canyon wall (depth interval 600–215 m, Sites V12-33-V12-35) is mainly composed of small-pebbled conglomerates, tuffaceous diatomites, and siltstones with admixture of pebble and tuffaceous sand (*Nauchno-tekhnicheskii…*, 1980). Diatoms of the Quaternary age were found in the tuffaceous diatomites only. Rocks sampled downward the slope (1120–740 m, Site V12-36) are the weakly lithified siltstone with single pebbles and interbeds of fine-grained sandstones, tuffaceous diatomite (a bed of alternating light-colored tuffaceous diatomite and dark gray mudstone), tuffaceous diatomite with sandstone interbeds and rare pebbles, black volcanomictic poorly sorted sandstone, and tuffaceous gravelstones (*Nauchno-tekhnicheskii…*, 1982). At the Site V12-37 (depth interval 1210–1186 m), black massive siltstones,

Table 1. Sampling sites in the Kronotskii Bay

Site	Latitude, N	Longitude, E	Depth, m
Leg 9 of R/V "Vulkanolog" in 1979			
V9-G4	54°13.8′	161°12.8′	1460
Leg 12 of R/V "Vulkanolog" in 1981			
The Zhupanovskii Canyon			
V12-22	53°34.3′	160°12.2′	887–652
V12-23	53°33.0′	160°11.0′	800–145
V12-24	53°35.0′	160°12.7′	870–720
V12-25	53°30.5′	160°20.4′	2080–1470
V12-26	53°30.7′	160°21.1′	1400–840
The Ol'ga Canyon			
V12-33	54°18.65′	161°08.8′	600–575
V12-34	54°18.3′	161°09.3′	450–215
V12-35	54°19.3′	161°08.3′	577–243
V12-36	54°15.9′	161°10.2′	1120–740
V12-37	54°11.6′	161°11.2′	1210–1186
V12-38	54°11.9′	161°11.4′	1756–1665
The Kronotskii Canyon			
V12-39	53°50.8′	160°43.7′	2703–1817

tuffaceous diatomites, and basalts were recovered. From the depth level of 1460 m (Site V90-D4), the 15-cm-long core of dense tuffaceous diatomite was obtained. The core consists of two different-colored beds, and the lower gray bed (15–9 cm) is in distinct uneven contact with the upper yellow bed (9–0 cm).

In the lower part of the canyon wall (depth interval 1756–1665 m, Site V12-38), the sequence is composed of tuffaceous diatomites alternating with black tuffaceous sandstones and pure sandstones, volcanomictic tuffaceous sandstone, mudstone, volcanogenic pebble, and rounded clasts of tuffaceous diatomites with fucoids. Samples of mudstone (V12-38-3) and tuffaceous sandstone (V12-38-2) contain unidentifiable diatom remains. The tuffaceous diatomites and siltstones yielded diverse siliceous microfossils: diatoms, silicoflagellates, and radiolarians. Four assemblages of diatoms and silicoflagellates have been distinguished.

The diatom assemblage (25 species) from Sample V12-36-1-4 of dense tuffaceous diatomite consists of abundant *Lisitzinia kanayai* (Fenner) Gleser and associated *Riedelia borealis* Sheshukova, *Paralia crenulata* (Grunow) Gleser, *Hemiaulus polycystinorum* Ehrenberg, *H. polymorphus* Grunow, *Stephanopyxis* spp., *Lisitzinia inconspicua* var. *trilobata* Gleser, *Azpeitia tuberculata* var. *atlantica* (Gleser et Jousé) Sims, *Coscinodiscus decrescens* Grunow, and other species (Table 2). Percentages of different ecological groups (55.5% of oceanic, 24% of neritic, and 1% of benthic species) indicate a bathyal habitat of this flora. Sili-

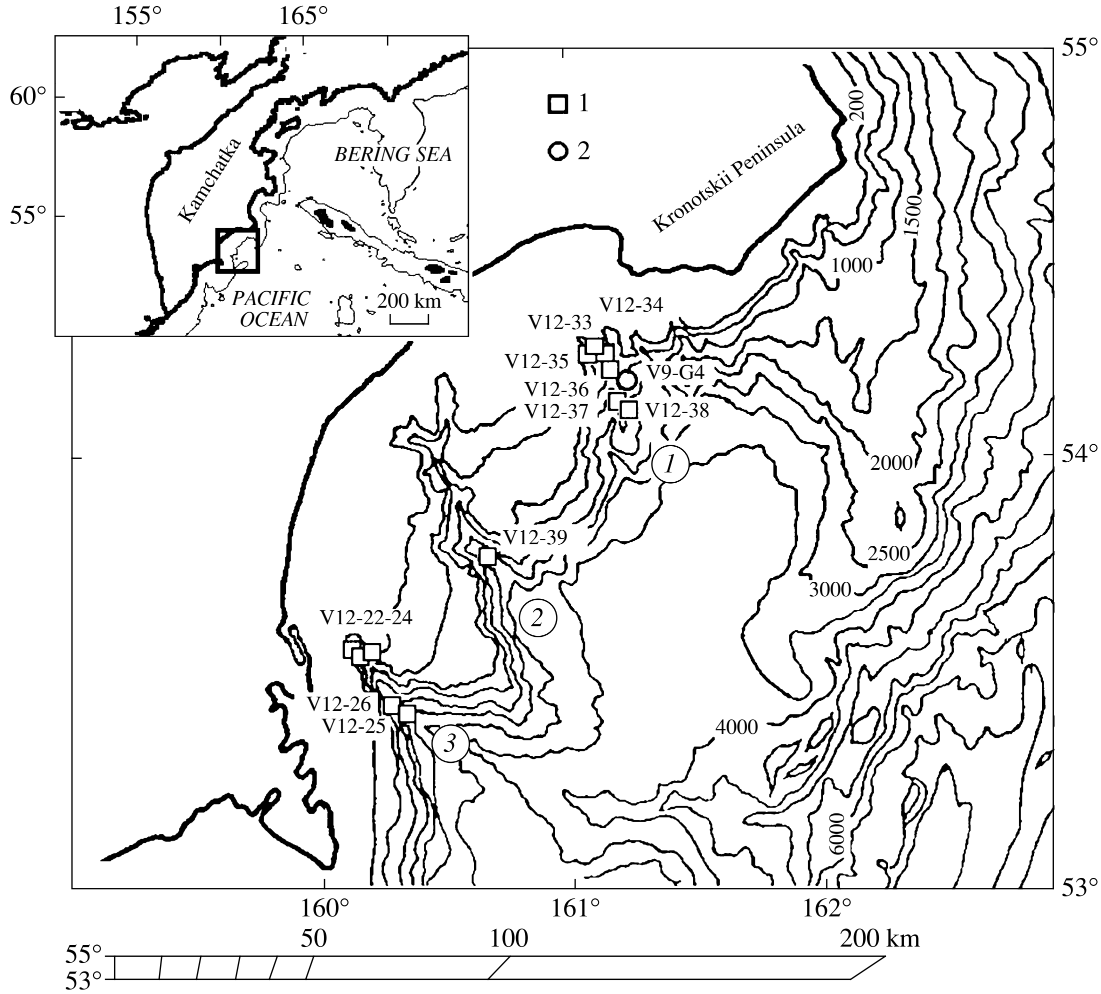

Fig. 1. Sampling sites in the Kronotskii Bay: (1) dredging site, (2) gravity core site; encircled numbers denote the Ol'ga (*1*), Kronotskii (*2*), and Zhupanovskii (*3*) canyons (bathymetry after Gnibidenko *et al.*, 1983).

coflagellates are represented by the middle Eocene warm-water *Naviculopsis foliacee* Deflandre.

Similar diatom assemblages from samples of siltstone (V12-36-1-1) and tuffaceous diatomite (V12-38-1) are dominated by different species (*Lisitzinia inconspicua* var. *trilobata* Gleser versus *Paralia crenulata* (Grunow) Gleser respectively). Both assemblages include diverse *Hemiaulus* and *Stephanopyxis* forms associated with *Azpeitia tuberculata* var. *atlantica* (Gleser et Jousé) Sims, *Asterolampra vulgaris* Greville, *Coscinodiscus decrescens* Grunow, *Navicula udintsevii* Schrader, *Praecymatosira monomembranaceae* (Schrader) Strelnikova, *Coscinodiscus tenerrimus* Jousé, *C. hajosiae* Fenner, *Costopyxis trochlea* (Hanna) Strelnikova, *Pterotheca aculeifera* Grunow, *Peponia* sp. and others (Table 2). The assemblages are of different ecological affinity: that from Sample V12-36-1-1 shows high percentages of the oceanic (45.3%) and warm-water (40.7%) species, whereas the other one from Sample V12-38-1 includes about 56.9% of neritic species. Rare silicoflagellates *Corbisema hastata globulata* Bukry, *Dictyocha deflandrei* Frenguelli ex Gleser, and *Naviculopsis foliacee* Deflandre were found in the latter sample only.

The tuffaceous diatomite beds sampled by gravity coring (Site V9-G4, depth 1460 m) bear two diatom assemblages. The assemblage of the lower bed (samples V9-G4-2947 and V9-G4-2949) consists of 48 species. Its obvious dominant is *Paralia crenulata* (Grunow) Gleser occurring as well preserved individual valves and as fragments of colonies. Stratigraphically important species of the assemblage are *Peponia barbadense* Greville, *Peponia* sp., *Praecymatosira monomembranaceae* (Schrader) Strelnikova, *Coscinodiscus hajosiae* Fenner, *Distephanosira architecturalis* (Bryn) Gleser, *Coscinodiscus* cf. *excavatus* Castracane, *Navicula udintsevii* Schrader, *Azpeitia tuberculata* var. *atlantica* (Gleser et Jousé) Sims, *Lisitzinia inconspicua* var. *inconspicua* Gleser, *L. inconspicua* var. *trilobata* Gleser and others (Table 2). Silicoflagellates are represented by *Corbisema triacantha* (Ehrenberg) Bukry et Foster and *Distephanus* sp. The assemblage demon-

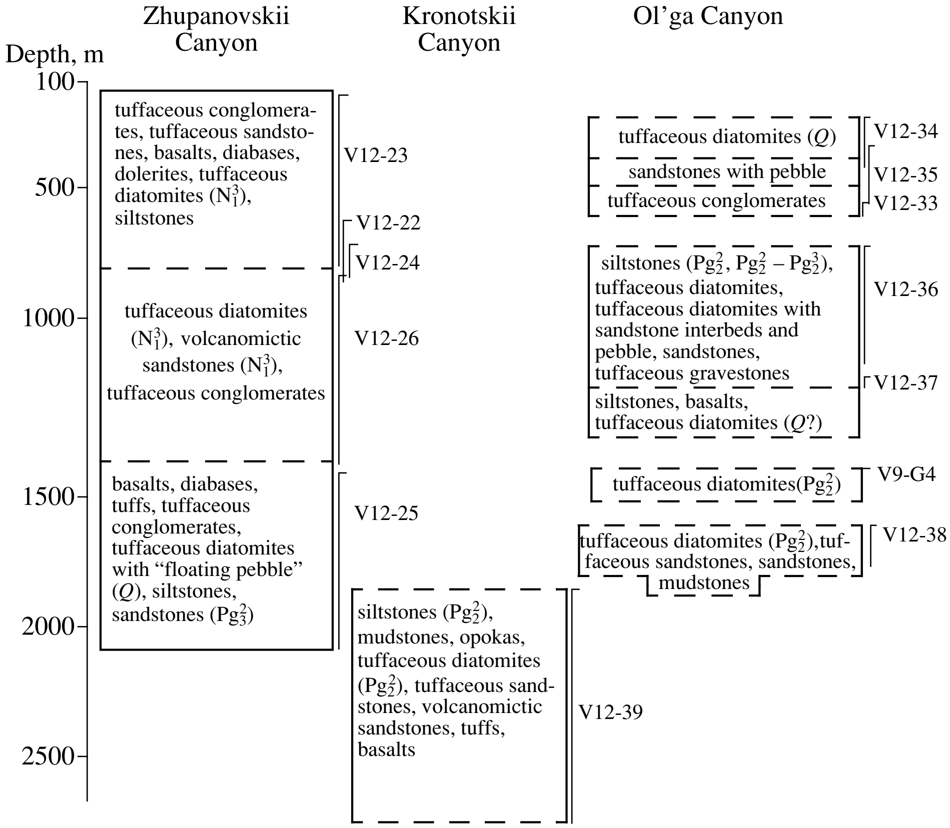

Fig. 2. Lithology and age (based on diatoms and silicoflagellates) of sequence intervals sampled in the Kronotskii Bay canyons, East Kamchatka; (V9-G4, V12-22-V12-39) site numbers; age indices: (Pg_2^2) middle Eocene, ($Pg_2^2 - Pg_2^3$) middle–upper Eocene. (Pg_3^2) upper Oligocene, (N_1^3) upper Miocene, (Q) Pleistocene.

strates the distinct predominance (71–77%) of neritic species over the oceanic (12–20%) and less abundant warm-water (6–10%) forms.

The diatom assemblage from the upper bed (Sample V9-G4-2948) is similar though less diverse (25 species) and lacking dominating species. Its characteristic taxa are abundant *Hemiaulus* forms, *Paralia crenulata* (Grunow) Gleser, *Proboscia interposita* (Hajós) Jordan et Priddle, *Distephanosira architecturalis* (Brun) Gleser, and *Praecymatosira monomembranaceae* (Schrader) Strelnikova. Characteristic of the assemblage is predominance of oceanic species (45.6%), reduced content of neritic forms (39.2%), and increased percentage of warm-water taxa (about 30%).

The layered siltstone sample (V12-36-1-2) is remarkable owing to high abundance and diversity of diatoms and silicoflagellates, species composition of which is peculiar. The diatom assemblage lacking dominants consists of 81 species, mostly of abundant and diverse representatives of *Hemiaulus, Azpeitia, Coscinodiscus, Asterolampra*, and *Chaetoceros* genera. It includes the following species known predominantly from the middle–upper Eocene deposits of different latitudes: *Hemiaulus incisus* Hajós, *Pyxilla gracilis* Tempére et Forti, *Trinacria excavata* Heiberg, *Rylandsia conniventa* Gleser, Dolmatova et Lupikina, *Coscinodiscus gombosii* Gleser, Dolmatova et Lupikina, *Kisseleviella cuspidata* Gleser, Dolmatova et Lupikina, *Coscinodiscus hajosiae* Fenner, *Pinnularia* aff. *antiqua* Tscheremissinova, *Asterolampra vulgaris* Greville, *A. praeacutiloba* Fenner, *A. schmidtii* Hajós, *Pseudotriceratium radiosoreticulatum* Grunow, *Pseudopodosira corolla* (A. Schmidt) Hajós, *Thalassiosira dubiosa* Schrader, *Sceptroneis vermiformis* Schrader, *Distephanosira architecturalis* (Brun) Gleser, and others. Taxa of the assemblage represent oceanic (59.2%), neritic (28.8%), and benthic (6%) forms. There is a single fresh-water form *Aulacoseira* sp. among them. Percentage of supposed warm-water species is high (44%).

The sample yielded abundant and diverse silicoflagellates (24 species) representing marine unicellular algae with siliceous skeletons. These are *Naviculopsis foliaceae* Deflandre, *Corbisema hastata globulata* Bukry, C. apiculata (Lemmermann) Hanna, *Bachmannocena apiculata inflata* Bukry, *B. paulschulzii* Bukry, *Dictyocha hexacantha* Schulz, *D. spinosa* (Deflandre) Gleser, *D. deflandrei* Frenguelli ex Gleser and others (Table 3).

Table 2. Diatoms from the Kronotskii Bay deposits

Diatom assemblage		*L. kanayai*		*L. inconspicua* v. *trilobata*		*P. monomembranaceae*			*R. conniventa*
Taxonomic composition	Ecology	V12-39-1-4	V12-36-1-4	V12-36-1-1	V12-38-1	V9-G4-2947	V9-G4-2949	V9-G4-2948	V12-36-1-2
Actinocyclus ingens Rattray	pow				3.3				*
Actinoptychus senarius Ehrenberg	b		0.5	0.3	1.3	0.3			2.0
Actinoptychus sp.	b				1.0	0.3		0.3	
Anaulus sp.	b								*
Arachnoidiscus indicus Ehrenberg	b	1.0						0.3	0.4
Arachnoidiscus spp.	b	1.0		0.3	0.3	0.3	0.3		*
Asterolampra insignis A. Schmidt	pow					0.3			0.4
Asterolampra marylandica Ehrenberg	pow								*
Asterolampra praeacutiloba Fenner	pow								0.2
Asterolampra punctifera (Grunow) Hanna	pow								0.4
Asterolampra schmidtii Hajós	pow								0.4
Asterolampra spp.	pow								0.4
Asterolampra vulgaris Greville	pow	1.0		0.3					0.4
Aulacodiscus cf. *lahusenii* Witt	b								*
Aulacodiscus inflatus var. *spinifer* Brun	b								0.2
Aulacodiscus lahusenii Witt	b								0.2
Aulacoseira sp.	fw								0.2
Azpeitia (Coscinodiscus) gombosii Gleser, Dolmatova et Lupikina	pow						0.3	0.3	6.0
Azpeitia oligocenica (Jousé) Sims	pow						0.3		0.2
Azpeitia sp.	pow					0.3			
Azpeitia tuberculata var. *atlantica* (Gleser et Jousé) Sims	pow		0.5	8.7	0.6		0.3	0.7	1.6
Biddulphia sp.	b	1.0			0.3				
Biddulphia tuomei (Bailey) Roper	b	1.0		0.3	0.3				
Bipalla (*Melosira*) *oamaruensis* (Grove et Sturt) Gleser	pn			0.3					
Brightwellia sp. (*B.* cf. *imperfecta* Jousé)	pow								0.2
Cavitatus cf. *jouseanus* Sheshukova	pow							0.3	0.2
Cestodiscus spp.	pow				0.3				*
Chaetoceros (*Xanthiopyxis*) *panduraeformis* (Pantocsek) Gombos	s		0.5			0.3			0.2
Chaetoceros spp.	s	2.0	0.5		2.0		0.3	0.7	8.0
Clavicula polymorpha Grunow et Pantocsek	b			0.3					*
Coscinodiscus aff. *excavatus* Castracane	pow					0.3	0.3	0.3	
Coscinodiscus apiculatus var. *ambiguus* Grunow	po				0.3				
Coscinodiscus argus Ehrenberg	po	1.0			0.3		1.3		0.4
Coscinodiscus asteromphalus Ehrenberg	pow								0.4
Coscinodiscus decrescenoides Jousé	po	1.0							
Coscinodiscus decrescens Grunow	po	1.0	4.0	2.7	0.3		0.3		10.0
Coscinodiscus hajosiae Fenner (=*Hyalopoda spiralis* (Hajós) Kozyrenko et Jackovschikova, Strel'nikova *et al.*, 1998)	po				0.3		0.3	0.3	2.0
Coscinodiscus marginatus Ehrenberg	po	1.0			0.7	0.7	3.0	1.7	
Coscinodiscus mirabilis Jousé	po	1.0			0.3				*
Coscinodiscus monicae Grunow	po								*
Coscinodiscus oculus iridis Ehrenberg	po	1.0		0.3			0.3		0.4
Coscinodiscus sectoralis Gleser, Dolmatova et Lupikina	p								0.8

Table 2. (Contd.)

Diatom assemblage		*L. kanayai*		*L. inconspicua* v. *trilobata*		*P. monomembranaceae*			*R. conniventa*
Taxonomic composition	Ecology	V12-39-1-4	V12-36-1-4	V12-36-1-1	V12-38-1	V9-G4-2947	V9-G4-2949	V9-G4-2948	V12-36-1-2
Coscinodiscus sp. A (sensu Barron, Mahood, 1993)	p			0.3					
Coscinodiscus spp.	p	6.0	1.5	0.7	4.7	0.3	5.7	6.0	0.8
Coscinodiscus subtilis Ehrenberg	p						0.3		*
Coscinodiscus tenerrimus Jousé	p			1.3					0.6
Costopyxis schulzii (Steinecke) Gleser	s				0.7				
Costopyxis trochlea (Hanna) Strelnikova	s				1.0				
Craspedodiscus (*Porodiscus*) *splendidus* (Greville) Gombos	pow				0.3				
Craspedodiscus klavsenii Gründler	pow								*
Craspedodiscus moelleri A. Schmidt	pow	1.0							
Cymatosira spp.	p					0.3			0.2
Distephanosira (*Melosira*) *architecturalis* (Brun) Gleser	pn	1.0		0.3		0.3		10.3	0.8
Drepanotheca (*Eunotogramma*) *bivitata* (Grunow et Pantocsek) Schrader	b					0.3			
Endictya spp.	po			0.3			0.3		*
Entopyla frickei Hanna	b	1.0							0.2
Ethmodiscus sp.	po								*
Eupodiscus cf. *oamaruensis* Grunow	p								0.2
Genus et species indet. 1 (sensu Gombos, 1983)	p								*
Genus et species indet. 2 (sensu Gombos, 1983)	p			0.3					
Hemiaulus cf. *vesicarius* Strelnikova	p				1.0				
Hemiaulus incisus Hajós	pow								4.8
Hemiaulus polycystinorum Ehrenberg	pow	1.0	8.0	10.2	1.7	3.3	0.3	24.0	6.0
Hemiaulus polymorphus Grunow	pow	1.0	10.0	10.2	2.0	0.7	0.7	2.0	6.0
Hemiaulus polymorphus v. *frigida* Grunow	pow				0.7				
Hemiaulus spp.	pow	5.0	0.5	9.3	5.3	2.3	2.7	1.3	8.0
Hemiaulus subacutus Fenner	pow				0.7				
Hyalodiscus scoticus (Kutzing) Grunow	pn				0.3				
Hyalodiscus spp.	pn	2.0		0.3	0.3		0.3		0.2
Istmia sp.	b	1.0							
Kisseleviella cuspidata Gleser, Dolmatova et Lupikina	pn								0.8
Liradiscus ovalis Greville	s	1.0							6.2
Lisitzinia brachiatum (Brightwell) Gleser	p				*				
Lisitzinia inconspicua (Greville) Gleser var. *inconspicua* Gleser	p			0.3	0.3	1.0	0.3	0.7	
Lisitzinia inconspicua (Greville) Gleser var. *trilobata* Gleser	p	*	1.0	30.6	11.3	0.3			
Lisitzinia kanayai (Fenner) Gleser	pw	34.0	24.5	0.3					
Lisitzinia sp. (*Triceratium* sp. sensu Barron *et al*., 1984)	p		0.5						
Navicula udintsevii Schrader	p			0.3	0.3	0.3	0.3	0.3	
Odontella fimbriata (Greville) Schrader	p			0.3					
Odontotropis carinata Grunow ?	pn			0.3					
Odontotropis sp.	pn								1.2
Paralia crenulata (Grunow) Gleser	pn		7.0	0.3	41.3	73.3	66.7	22.3	
Paralia polaris (Grunow) Gleser	pn	2.0		0.3	0.7		0.3		*
Paralia sulcata (Ehrenberg) Cleve	pn	1.0			0.3			0.3	1.6
Peponia barbadense Greville	pn					*			
Peponia sp. (=*Peponia* sp. 1 sensu Fenner, 1978)	pn				0.3	0.7	0.3	1.7	
Pinnularia aff. antiqua Tscheremissinova	b								0.2

Table 2. (Contd.)

Diatom assemblage		*L. kanayai*		*L. inconspicua* v. *trilobata*		*P. monomembranaceae*			*R. conniventa*
Taxonomic composition	Ecology	V12-39-1-4	V12-36-1-4	V12-36-1-1	V12-38-1	V9-G4-2947	V9-G4-2949	V9-G4-2948	V12-36-1-2
Praecymatosira monomembranaceae (Schrader) Strelnikova	p			5.0		7.3	2.0	7.0	
Proboscia cf. *interposita* (Hajós) Jordan et Priddle	po	1.0				1.7	5.7	8.0	2.0
Proboscia interposita (Hajós) Jordan et Priddle	po	1.0	2.0	1.3	0.7	1.3	3.0	6.7	*
Pseudopodosira corolla (A. Schmidt) Hajós	pn								*
Pseudopyxilla americana (Ehrenberg) Forti	s					0.3			
Pseudopyxilla sp.	s				0.3				
Pseudotriceratium radiosoreticulatum Grunow	pn			0.3					1.6
Pterotheca aculeifera Grunow	s				1.7				
Pterotheca danica Grunow	s	1.0	0.5			0.3	0.3		
Pyxilla gracilis Tempère et Forti	pn				0.3				1.6
Pyxilla spp.	pn	1.0		0.3	0.3	0.3			0.4
Rhizosolenia spp.	po								0.4
Riedelia borealis Sheshukova	p	5.0	14.0	0.3	1.7				
Riedelia claviger (A. Schmidt) Schrader et Fenner	p								*
Riedelia pacifica Jousé	p		1.0	0.3					
Riedelia sp. 1 (sensu Schrader, Fenner, 1976)	p		5.0	0.3					*
Rutilaria spp.	b							0.3	0.2
Rylandsia biradiata Greville	pow	1.0				*	0.3		
Rylandsia conniventa Gleser, Dolmatova et Lupikina	pow								2.4
Sceptroneis pesplanus Schrader	b			0.3		0.3			
Sceptroneis spp.	b								0.4
Sceptroneis tenue Schrader et Fenner	b				0.3				*
Sceptroneis vermiformis Schrader	b								1.0
Stellarima microtrias (Ehrenberg) Hasle et Sims	pow	3.0	1.0	2.0	0.3				7.2
Stellarima stellaris (Roper) Hasle et Sims	pow	1.0				0.3	0.3		*
Stephanogonia sp.	s				0.3				
Stephanopyxis cf. *aciculatus* Dolmatova	pn								*
Stephanopyxis cf. *broschii* Grunow	pn								0.4
Stephanopyxis cf. *superba* Grunow	pn	1.0							
Stephanopyxis ferox (Greville) Ralfs	pn		2.0						
Stephanopyxis grunowii Grove et Sturt	pn	1.0	2.0	0.3	0.3	0.3			
Stephanopyxis marginata Grunow	pn	2.0	2.0	0.7	0.7	0.3	0.3	0.3	*
Stephanopyxis spp.	pn	10.0	10.0	4.3	5.7	0.7	2.0	3.7	0.4
Stephanopyxis turris (Greville et Arnott) Ralfs	pn	1.0	1.0	4.3	1.0	0.3	0.3		5.6
Stephanopyxis turris var. *intermedia* Grunow	pn				0.3				
Stictodiscus hardmanianus Greville	b					0.3			0.2
Stictodiscus spp.	b	1.0	0.5		1.0				
Thalassiosira dubiosa Schrader	p								0.8
Thalassiosiropsis wittiana (Pantocsek) Hasle	p								*
Triceratium arcticum Brightwell	b						0.3		
Trinacria excavata Heiberg	p								1.6
Total, %		100	100	100	100	100	100	100	100

Note: (p) planktonic, (b) benthic, (n) neritic, (o) oceanic, (w) warm-water diatoms, and (s) spores; taxa identified after counts are indicated by asterisk; ecological affinity is in accord data of Sheshukova-Poretskaya (1967), Baldauf and Barron (1987), and Fenner (1985).

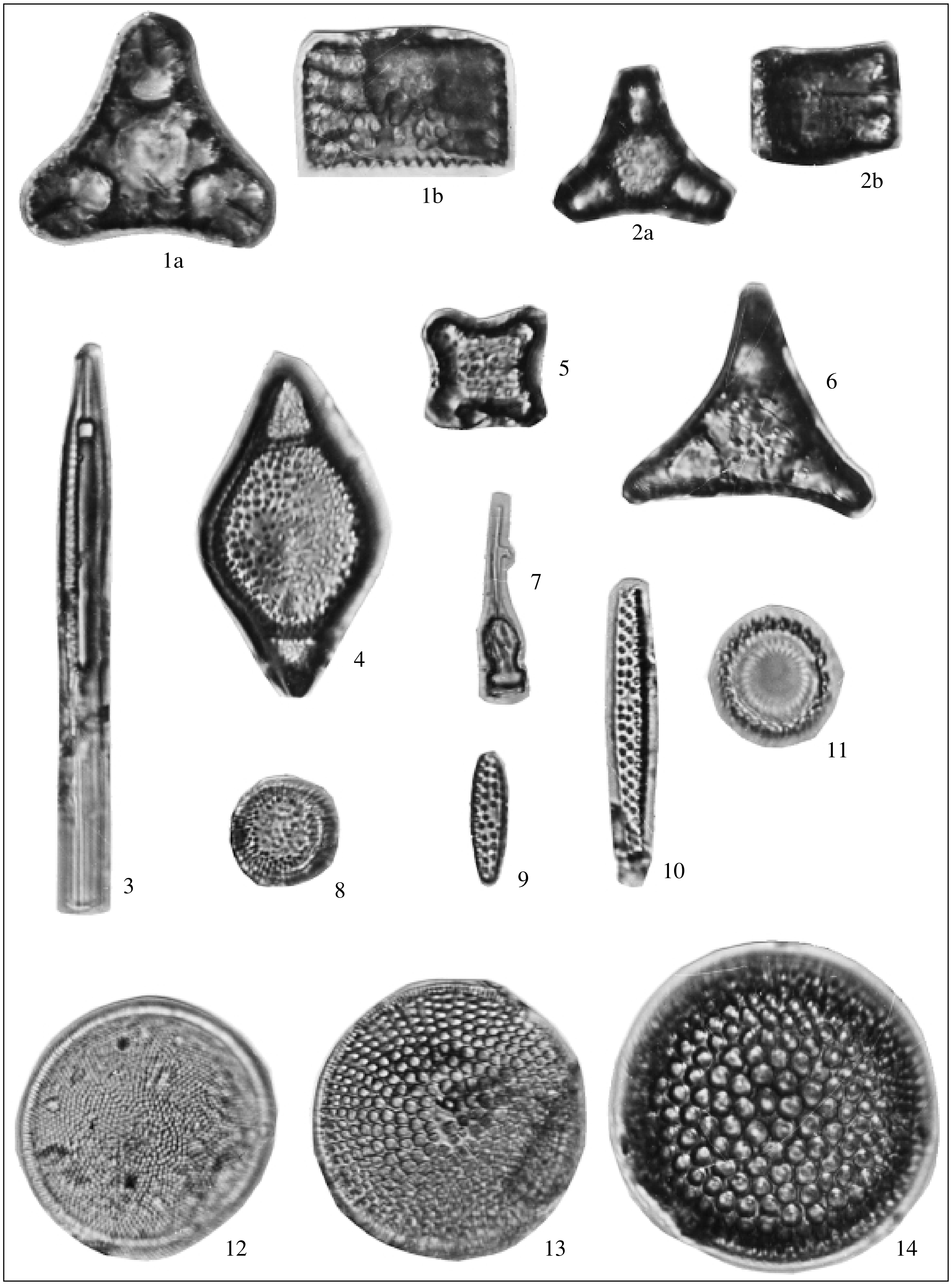

Plate 1. Characteristic species of the middle Eocene diatom assemblages from the Kronotskii Bay deposits (East Kamchatka)

(1) *Lisitzinia kanayai* (Fenner) Gleser: (1a) valve view, (1b) belt view, ×1300; (2): *Lisitzinia inconspicua* (Greville) Gleser, var. *triloba* Gleser: (2a) valve view, (2b) belt view, ×1300; (3) *Riedelia borealis* Sheshukova, ×1300; (4) *Peponia* sp., ×1300; (5) *Lisitzinia inconspicua* var. *inconspicua* Gleser, ×1300; (6) *Lisitzinia brachiatum* (Brightwell) Gleser, ×1300; (7) *Pterotheca aculeifera* Grunow, ×650; (8) *Distephanosira architecturalis* (Brun) Gleser, ×1300; (9, 10) *Praecymatosira monomembranaceae* (Schrader) Strelnikova, ×1300; (11) *Paralia crenulata* (Grunow) Gleser, ×1300; (12) *Coscinodiscus hajosiae* Fenner; (13) *Azpeitia tuberculata* var. *atlantica* (Gleser et Jousé) Sims; (14) *Coscinodiscus decrescens* Grunow.

Specimens: (1a, 1b, 3) from Sample V12-39-1-4; (2a, 2b, 6, 7, 12) from Sample V12-38-1; (4, 5, 8, 10, 11, 14) from Sample V9-G4-2949; (9) from Sample V9-G4-2948; (13) from Sample V12-36-1-1.

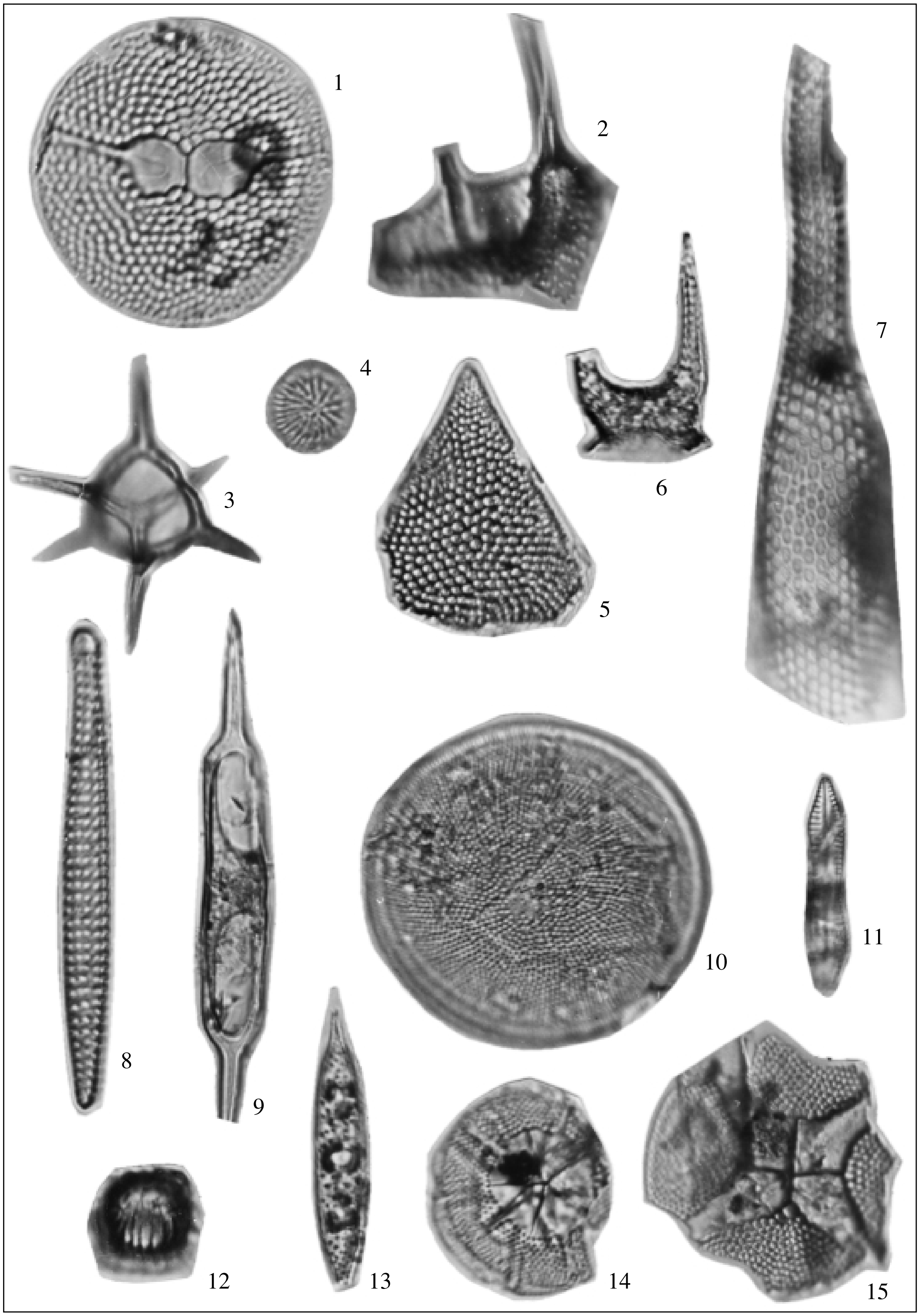

Plate 2. Characteristic diatom species of the middle (?)-late Eocene and silicoflagellates from the Kronotskii Bay deposits

(1) *Rylandsia conniventa* Gleser, Dolmatova et Lupikina, ×1300; (2) Genus et species indet. 1 (sensu Gombos, 1983), ×1500; (3) *Dictyocha hexacantha* Schulz, ×1500; (4) *Thalassiosira dubiosa* Schrader, ×1500; (5) *Pseudotriceratium radiosoreticulatum* Grunow, ×1300; (6) *Hemiaulus incisus* Hajós, ×1300; (7) *Pyxilla gracilis* Tempére et Forti, ×1300; (8) *Sceptroneis vermiformis* Schrader, ×1300; (9) *Naviculopsis foliaceae* Deflandre, ×600; (10) *Coscinodiscus hajosiae* Fenner, ×1300; (11) *Pinnularia* aff. *antiqua* Tscheremissinova, ×1500; (12) *Costopyxis trochlea* (Hanna) Strelnikova, ×1300; (13) *Kisseleviella cuspidata* Gleser, Dolmatova et Lupikina, ×1300; (14) *Asterolampra punctifera* (Grunow) Hanna, ×1300; (15) *Asterolampra praeacutiloba* Fenner, ×1000.

All specimens are from Sample V12-36-1-2.

The silicoflagellate assemblage is dominated by the warm-water *Naviculopsis foliaceae* Deflandre and includes diverse and abundant *Corbisema* species, which are also suspected to be of the warm-water origin (Bukry, 1987) because of their abundance in the low latitudes. The high content of *Dictyocha hexacantha* Schulz is also characteristic of the low and, to a lesser extent, of moderate latitudes.

The Kronotskii Canyon. The lower part of the sequence (Site V12-39, depth interval 2703–1817 m) is composed here of volcanomictic and tuffaceous sandstones, coarse-grained tuffs, basalts, tuffaceous diatomites, carbonaceous siltstones, opokas, and siliceous mudstones. Diatoms were found in the siltstones (sample V12-39-1-4). Other rocks are either barren or contain single unidentifiable remains.

The diatom assemblage is analogous of that of the Ol'ga Canyon (Sample V12-36-1-4), dominated by zonal species *Lisitzinia kanayai* (Fenner) Gleser of the middle Eocene. It also includes less frequent though diverse of *Hemiaulus* and *Stephanopyxis* forms associated with single *Lisitzinia inconspicua* var. *trilobata* Gleser, *Asterolampra vulgaris* Greville, *Coscinodiscus decrescens* Grunow, *Distephanosira architecturalis* (Brun) Gleser, *Riedelia borealis* Sheshukova and others (Table 2). As in the Ol'ga Canyon, the assemblage predominantly consists of oceanic (57%) and low-latitude (47%) species, which suggest similar paleoenvironments for both assemblages. Silicoflagellates are represented by *Dictyocha deflandrei* Frenguelli ex Gleser. According to V.V. Shastina, associated radiolarians constitute the *Artobotrus auriculaleporis* assemblage (Tsoy *et al.*, 2000). This assemblage is correlative with radiolarians of the middle Eocene *Artobotrus norvegiensis* Zone and of the middle–upper Eocene *Phacodiscus testatus grandis* Beds of the Norwegian Sea.

The Zhupanovskii Canyon. The sampled interval was the upper part of the section (Sites V12-22, V12-23, V12-24, and V12-26, depth interval 1400–145 m) mainly represented by tuffaceous diatomites, tuffaceous conglomerates, volcanomictic sandstones, and siltstones. The tuffaceous diatomites and sandstones yielded diatom assemblages of the late Miocene–Pliocene, some of which contain the reworked Paleogene species. The deeper interval (2080–1470 m) was dredged at the Site V12-25. The recovered samples represent basalts, tuffs, tuffaceous conglomerates, tuffaceous diatomites, siltstones, and sandstones. The tuffaceous diatomites contain diatoms of Quaternary age. Sandstone Sample 25-3-2 yielded the upper Eocene diatom assemblage of the *Stephanopyxis marginata-Goniothecium decoratum* Zone (Pushkar', 1987). However, the assemblage may be reworked because typical middle Eocene species (e.g., *Triceratium barbadense* Greville, *T. mirabile* Jousé, *Sheshukovia (Triceratium) inconspicua* Gleser, *Praecymatosira monomembranaceae* (Schrader) Strelnikova) are associated with characteristic Oligocene forms (e.g., *Lisitzinia ornata* Jousé, *Coscinodiscus vigilans* Schmidt, *Actinocyclus* sp.). Popova (1989) described the middle Eocene radiolarian assemblage from the Zhupanovskii Canyon, but she did not indicate the site and sample numbers, and stratigraphic allocation of the assemblage thus remains ambiguous.

DISCUSSION

Investigated deposits of the Kronotskii Bay yielded diatom assemblages of the Paleogene age. They characterize lower parts of the largest submarine Ol'ga and Kronotskii canyons.

Assemblage 1 is macerated from tuffaceous diatomites and siltstones (Samples V12-39-1-4, V12-36-1-4). Its dominating species is *Lisitzinia kanayai* (Fenner) Gleser. The assemblage contains *Riedelia borealis* Sheshukova, *Coscinodiscus decrescens* Grunow, *Hemiaulus polycystinorum* Ehrenberg, *H. polymorphus* Grunow, *Lisitzinia inconspicua* var. *trilobata* Gleser, *Rylandsia biradiata* Greville, *Asterolampra vulgaris* Greville, *Azpeitia tuberculata* var. *atlantica* (Gleser et Jousé) Sims, *Craspedodiscus moelleri* A. Schmidt, *Distephanosira architecturalis* (Brun) Gleser, *Entopyla frikei* Hanna, and others.

According to presence of abundant *Lisitzinia (Triceratium) kanayai*, the assemblage is correlated with diatoms of synonymous zone established in low latitudes (Fig. 3). According to Fenner (1984), this zone corresponds to calcareous nannoplankton zones NP14-NP15 of the lowermost middle Eocene (lower Lutetian). The assemblage includes *Rylandsia biradiata* Greville and *Lisitzinia inconspicua* var. *trilobata* Gleser, which have their first occurrences in this zone. The zonal species domination makes the assemblage similar to that from the Kellogg Shale of northern California, where this subdivision is dated back to the middle Eocene and corresponds to zone P12 of planktonic foraminifers and to the interval CP13c-CP14a of nannoplankton zonation (42.0–45.0 Ma, upper Lutetian-lower Bartonian; Barron *et al.*, 1984). Radiolarian faunas of the Kronotskii Canyon and Kellogg Shale also include some species in common (Tsoy *et al.*, 2000). The low-latitude oceanic species dominating in diatom assemblage are indicative of relatively deep-water (bathyal?) and warm (nearly subtropical) environments.

Assemblage 2 is established in tuffaceous diatomites and siltstones (Samples V12-38-1, V12-36-1-1). Being similar to the previous one, this assemblage is dominated by another typical Eocene species *Lisitzinia inconspicua* var. *triloba* Gleser and includes *Lisitzinia inconspicua* var. *inconspicua* Gleser, *Navicula udintsevii* Schrader, *Costopyxis trochlea* (Hanna) Strelnikova, *Pyxilla gracilis* Tempére et Forti, *Riedelia pacifica* Jousé, *Coscinodiscus tenerrimus* Jousé, and others. Similar diatom assemblages are characteristic of volcanogenic–sedimentary Ushchel'e sequence, upper

Table 3. Silicoflagellates from the Kronotskii Bay deposits

Silicoflagellates	V12-39-1-4	V12-36-1-4	V12-36-1-1	V12-38-1	V9-G4-2947	V9-G4-2949	V9-G4-2948	V12-36-1-2
Bachmannocena apiculata inflata Bukry								16
Bachmannocena paulschulzii Bukry								7
Corbisema apiculata (Lemmermann) Hanna								1
Corbisema glezerae Bukry								8
Corbisema hastata globulata Bukry				1				20
Corbisema hastata hastata (Lemmermann) Bukry								1
Corbisema lamillifera (Gleser) Bukry								1
Corbisema ovalis Perch-Nielsen								1
Corbisema sp.								1
Corbisema triacantha (Ehrenberg) Bukry et Foster						1		1
Dictyocha spinosa (Deflandre) Gleser								1
Dictyocha deflandrei Frenguelli ex Gleser	1			1				1
Dictyocha frenguellii Deflandre								1
Dictyocha hexacantha Schulz								10
Dictyocha pentagona (Schulz) Bukry et Foster								4
Dictyocha sp. (asperoid) sensu Bukry, 1987								1
Dictyocha sp.								10
Distephanus cf. *bolivinensis bolivinensis* (Frenguelli) Bukry								2
Distephanus crux (Ehrenberg) Haeckel				1				1
Distephanus quinquangellus Bukry et Foster								4
Distephanus sp.						1		
Naviculopsis biapiculata (Lemmerman) Frenguelli								3
Naviculopsis constricta (Schulz) Frenguelli								1
Naviculopsis foliacee Deflandre		1		2				55
Total	1	1		5		2		151

Kubovaya Subformation, and Kozlovskaya Formation of the Kronotskii Peninsula (*Strukturno-veshchestvennye…*, 1995). Based on planktonic and benthic foraminifers and nannoplankton, these subdivisions are referred mostly to the Bartonian *Reticulofenestra umbilica* and NP16-NP17 zones of the middle Eocene (*Strukturno-veshchestvennye…*, 1995; Shcherbinina, 1997). Diatom assemblages from the on-land formations and from the Ol'ga of the Kronotskii Bay canyons include the following species in common: *Coscinodiscus argus* Ehrenberg, *C. monicae* Rattray, *Sheshukovia* (=*Lisitzinia*) *inconspicua* var. *triloba* Gleser, *Coscinodiscus decrescens* Grunow, *Hemiaulus polymorphus* Grunow, *H. polycystinorum* Ehrenberg, *Riedelia borealis* Sheshukova, *Actinocyclus ingens* Rattray, and others. V.V. Shastina also noted some common elements in corresponding radiolarian faunas (Tsoy *et al.*, 2000).

The assemblage under discussion includes some species typical of the middle Eocene *Trinacria excavata* f. *tetragona* and *Craspedodiscus oblongus* zones of the Norwegian Sea (Dzinoridze *et al.*, 1978; Fenner, 1985). It also shows similarity to the assemblage of non-formal *Lisitzinia (Triceratium) inconspicua* var. *trilobata* Gleser Zone of the uppermost middle Eocene, which was established in the Bateque Formation of California (McLean and Barron, 1988). The zonal species occurs in abundance in the upper part of the middle Eocene Kellogg section of California. Some species of the assemblage are present in the middle Eocene assemblage of the Kreyenhagen Shale (Oro Loma section) of the western San Joaquin valley, California (McLean and Barron, 1988) and in the South Atlantic (Fenner, 1978). The Bateque Formation is referred to the uppermost middle Eocene (upper subzone CP14a to lower subzone CP14b). These data suggest the terminal middle Eocene age of Assemblage 2. The inferred younger age of the assemblage is consistent with data on associated radiolarians, which are characteristic of

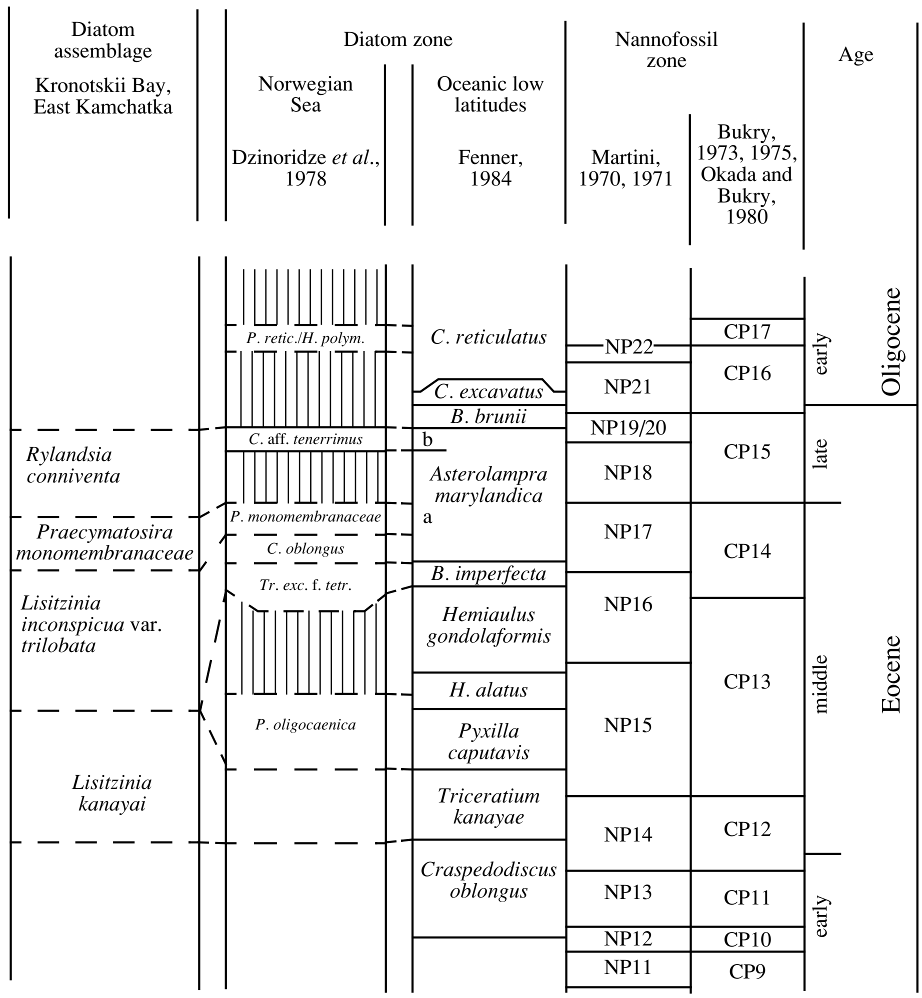

Fig. 3. Of the Diatom assemblages of the Kronotskii Bay (East Kamchatka) correlated with diatom zones of the Norwegian Sea and oceanic low latitudes, and with nannoplankton zonation.

the upper Eocene and even Oligocene deposits (Tsoy *et al.*, 2000). Assemblage 2 was formed in cooler environments than Assemblage 1, as it is evident from abundance of *Lisitzinia inconspicua* var. *triloba*, which is widespread in high latitudes of the Norwegian Sea (Barron *et al.*, 1984). Assemblage 2 contains a greater amount (up to 57%) of neritic species.

Assemblage 3 (samples V90-G4-2947, V9-G4-2948, V9-G4-2949) includes the zonal species *Praecymatosira monomembranaceae* (Schrader) Strelnikova associated with *Peponia barbadense* Greville, *Peponia* sp., *Coscinodiscus hajosiae* Fenner, *Distephanosira architecturalis* (Brun) Gleser, *Navicula udintsevii* Schrader, *Rylandsia biradiata* Greville, and others. The dominant is *Paralia crenulata* (Grunow) Gleser occurring in abundance in the Paleogene deposits of the Urals and southern Kazakhstan (Jousé, 1978). Closely related forms characterize the upper Eocene beds of the equatorial Atlantic (Glezer and Jousé, 1974). The zonal species *Praecymatosira monomembranaceae* (Schrader) Strelnikova was described from the middle Eocene of the Vöring Plateau of the Norwegian Sea (Schrader and Fenner, 1976; Dzinoridze *et al.*, 1978; *Istoriya…*, 1979; Goll, 1989) and from the southern Atlantic (Hajós, 1976). The assemblage with *Praecymatosira monomembranaceae* (= *Cymatosira* sp. B) characterizes the synonymous zone of the Norwegian Sea (Dzinoridze *et al.*, 1978). According to Fenner (1985), this zone corresponds in scope to the *Trinacria excavata* f. *tetragona* and *Coscinodiscus oblongus* zones of the lowermost middle Eocene. Another characteristic species *Peponia* sp. was previously found only in the middle Eocene beds of the San Paulo Plateau of the South Atlantic (Fenner, 1978). Strel'nikova (1992) attributed the zone to the lower part of the middle Eocene.

According to presence of zonal species *Praecymatosira monomembranaceae* (Schrader) Strelnikova and some taxa characteristic of the synonymous zone (e.g., *Lisitzinia inconspicua* Gleser, *Coscinodiscus hajosiae* Fenner) and of the middle Eocene strata in high and low latitudes, Assemblage 3 can be attributed to the *Praecy-*

matosira monomembranaceae Zone of the uppermost middle Eocene. The assemblage composition reflects a transition from neritic to bathyal environments.

Assemblage 4 from siltstone Sample C12-36-1-2 contains *Hemiaulus incisus* Hajós, *Pyxilla gracilis* Tempére et Forti, *Trinacria excavata* Heiberg, *Rylandsia conniventa* Gleser, Dolmatova et Lupikina, *Coscinodiscus* (*Azpeitia*) *gombosii* Gleser, Dolmatova et Lupikina, *Kisseleviella cuspidata* Gleser, Dolmatova, et Lupikina, *Pinnularia* aff. *antiqua* Tscheremissinova, *Asterolampra vulgaris* Greville, *A. punctifera* (Grunow) Hanna, *Pseudotriceratium radiosoreticulatum* Grunow, *Thalassiosira dubiosa* Schrader, *Pseudopodosira corolla* (A. Schmidt) Hajós, *Sceptroneis vermiformis* Schrader, and others. The most characteristic species is *Rylandsia conniventa* Gleser, Dolmatova et Lupikina, which was found exactly in this sample and described for the first time (Gleser *et al.*, 1986). Representatives of the genus *Rylandsia* occur in the middle–upper Eocene deposits (Fenner, 1985; Barron and Baldauf, 1995). The *Rylandsia inequiradiata* Zone of upper Eocene–lower Oligocene was established in the South Ocean (Gombos and Ciesielski, 1983; Fenner, 1985). *Rylandsia biradiata* Greville is index species of the middle–upper Eocene beds (subzone "b") of the *Asterolampra marylandica* Zone in low latitudes (Fenner, 1984, 1985). Correlating these zones with the geomagnetic polarity scale of Cande and Kent (1992), Barron and Baldauf (1995) suggested their upper Eocene age.

In spite of presence of some Oligocene species (e.g., *Hemiaulus incisus* Hajós, *Pyxilla gracilis* Tempére et Forti, *Asterolampra punctifera* (Grunow) Hanna, *Pseudotriceratium radiosoreticulatum* Grunow, and others), Assemblage 4 should be attributed to the late Eocene, as it is lacking species characteristic of the lower Oligocene zonal assemblages from the northwestern Pacific (Oreshkina, 1996; Gladenkov and Barron, 1995; Gladenkov, 1998; Tsoy, 2002). Assemblage 4 can be conventionally defined as the *Rylandsia conniventa* assemblage, stratigraphic and geographic ranges of which need to be specified.

Silicoflagellates macerated from the same sample (Table 3) also evidence that Assemblage 4 is not younger than the late Eocene. They characterize the *Dictyocha hexacantha* Zone of the uppermost middle–lowermost upper Eocene in low and middle latitudes (Bukry and Foster, 1974; Bukry, 1977). These are *Dictyocha hexacantha* Schulz and *Corbisema ovalis* Perch-Nielsen, ranges of which are limited by this zone. Associated *Dictyocha deflandrei* Frenguelli ex Gleser, *D. frenguellii* Deflandre, and *D. pentagona* (Schulz) Bukry et Foster have their first occurrences in the zone, and *Dictyocha spinosa* (Deflandre) Gleser, *Bachmannocena paulschulzii* Bukry, and *Naviculopsis foliaceae* Deflandre disappear at the upper boundary of the zone (Bukry, 1981, 1984; Perch-Nielsen, 1985). Other species of wider stratigraphic range are nevertheless typical of the *Dictyocha hexacantha* Zone. The zonal index species is known from the middle Eocene Kellogg Shale, the middle–upper Eocene Kreyenhagen Formation of California (Barron *et al.*, 1984), and from the upper Eocene Oamaru Formation of New Zealand (Bukry, 1987).

Thus, silicoflagellates undoubtedly characterize the *Dictyocha hexacantha* Zone of the uppermost middle–lowermost upper Eocene. Since the diatom flora is represented by species typical of the same age interval, diatoms of the *Rylandsia conniventa* assemblage and silicoflagellates of the *Dictyocha hexacantha* Zone are supposed to correspond in age to the terminal middle-late Eocene.

The assemblage includes some diatom and silicoflagellate species of wider stratigraphic ranges, which are known from the Ommai Formation[1] and from the Telegraficheskii Cape Formation (lower reaches of the Anadyr River) of the upper Eocene (Sheshukova-Poretskaya, 1967; Nevretdinova, 1982). Some diatom species of the assemblage were also found in the Cape Tons Formation of the Karaginskii Island (Oreshkina, 1982, 1996), but they are associated with characteristic Oligocene forms.

It is to be noted that the middle Eocene interval in oceanic sediments of the Detroit Seamount not far away from the Kronotskii Bay (ODP Sites 883 and 884) is characterized predominantly by calcareous planktonic foraminifers and nannoplankton (*Proceedings…*, 1995; Basov, 1997). There are no diatoms in this interval, and rare radiolarians are represented by species typical of low latitudes, which are absent in the Kronotskii assemblages (Tsoy *et al.*, 2000).

CONCLUSIONS

Three diatom assemblages of middle Eocene age (those of *Lisitzinia kanayai*, *Lisitzinia inconspicua* var. *triloba*, and *Praecymatosira monomembranaceae* zones) and one presumably corresponding in age to the middle–late Eocene (diatoms of *Rylandsia conniventa* Zone) are established in volcanogenic–sedimentary deposits of the Kronotskii and Ol'ga canyons. The diverse silicoflagellate assemblage from these deposits is described for the first time and characterizes the *Dictyocha hexacantha* Zone. All the assemblages are supposed to have been formed mainly in bathyal environments and under a relatively high (almost subtropical) temperature of surface water.

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[1] The early Eocene planktonic and benthic foraminifers found in the Ommai Formation imply that it should be attributed to the lower–middle Eocene (*Resheniya…*, 1998).

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