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# Fossil diatom flora from the marine Paleogene stratigraphic key section of northeast Kamchatka, Russia

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The Oligocene diatom flora from the marine Paleogene stratigraphic key section of northeast Kamchatka is described for the first time. The fossil flora contains a number of taxa of moderate to poor preservation and low abundance. Analysis of stratigraphic occurrence of diatoms throughout the section has been conducted. Two diatom assemblages of different ages are recognized in different parts of the 900 m-thick Alugivayam Formation. The younger assemblage is characterized by the presence of *Cavitatus* sp. cf. *jouseanus* and *Odontella sawamurae*. Co-occurrence of these taxa may indicate the age of enclosing sediment not older than ~31 Ma (the early Oligocene). The older assemblage from the basal part of the Alugivayam Formation lacks the mentioned taxa but contains *Stephanopyxis* species such as *St. grunowii* and *St. marginata*. Most likely, its age is at the earliest Oligocene. It is shown that in the studied Paleogene stratigraphic section diatoms appear just above the Eocene/Oligocene boundary. Data obtained on diatoms and diatom biomarkers may indicate increased diatom productivity in the sea basin after the Eocene/Oligocene transition. The first data on diatom flora from stratigraphically well-controlled samples support the Oligocene age of the Alugivayam Formation in the Il'pinskii Peninsula section and contribute to regional correlations of the Oligocene strata in Kamchatka.

**Key words:** diatom, biostratigraphy, Paleogene, Oligocene, Pacific, Kamchatka

## Introduction

The stratigraphic section on the Il'pinsky Peninsula, northeast Kamchatka (Fig. 1), is a unique key section for the marine Paleogene of northeast Asia with a practically continuous and complete sequence composed of 2500 m-thick Paleocene through Oligocene sediments. Moreover, it is one of the northernmost known places in the North Pacific region where planktic foraminifera and calcareous nannofossils of the Paleocene and Eocene have been documented from different stratigraphic levels (BENIAMOVSKII et al. 1992, VOLOBUEVA et al. 1994, and others). Numerous mollusk-bearing horizons are also typical of the section. The assemblages of planktic foraminifera and coccolithophorids that are correlative with

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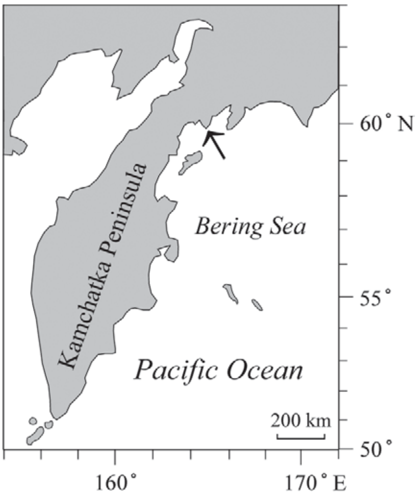


**Fig. 1.** Location of the Il'pinskii Peninsula (shown by black arrow) in Kamchatka

their analogues from standard Paleogene zones have been used to subdivide the host sedimentary succession and determine the age of established stratigraphic units. However, until recently the two upper formations (the Gailkhavilanvayam and Alugivayam, 1150 m thick in total) have been considered to be barren of both calcareous and siliceous planktic marine microorganisms, including diatoms. The initial data on the first finds of diatom remains from the Alugivayam Formations were reported only two years ago (A. GLADENKOV and Y. GLADENKOV 2007). Meanwhile, fossil diatoms are one of the primary biostratigraphic tools for the dating and correlation of the post-Eocene marine sediments in the middle to high latitudes of the North Pacific (the current North Pacific Oligocene to Quaternary diatom zonation includes more than 20 zones). The Oligocene age and position of its lower boundary in the Il'pinsky Peninsula stratigraphic section were determined based on assemblages of benthic foraminifera and mollusks. In general, the Alugivayam Formation was previously attributed to the Oligocene, while the underlying Gailkhavilanvayam Formation was referred to the upper Eocene. The present study of diatoms from the Alugivayam Formation is the first description of Cenozoic diatom flora from the section.

## Materials and methods

In order to collect additional geological and paleontological material, fieldwork in the western part of the Il'pinskii Peninsula was conducted recently by the joint Russian-Japanese scientific group. In particular, the work was aimed at collecting samples for diatom analysis from the Gailkhavilanvayam and Alugivayam formations. The Gailkhavilanvayam Formation (~250 m thick) is composed of alternating tuffaceous siltstones, tuffaceous argillites, and tuffstones with thin interbeds of silicic tuffs (Fig. 2). The formation contains abundant concretions of variable sizes and shapes. The base of the formation is corresponds to the Laparelam lithologic marker »horizon« 7.5 m thick composed of light-colored silicic ash tuff. The overlying Alugivayam Formation (900 m thick) is composed of tuffaceous siltstones and shales with interbeds and lenses of tuffstones. The deposits con-

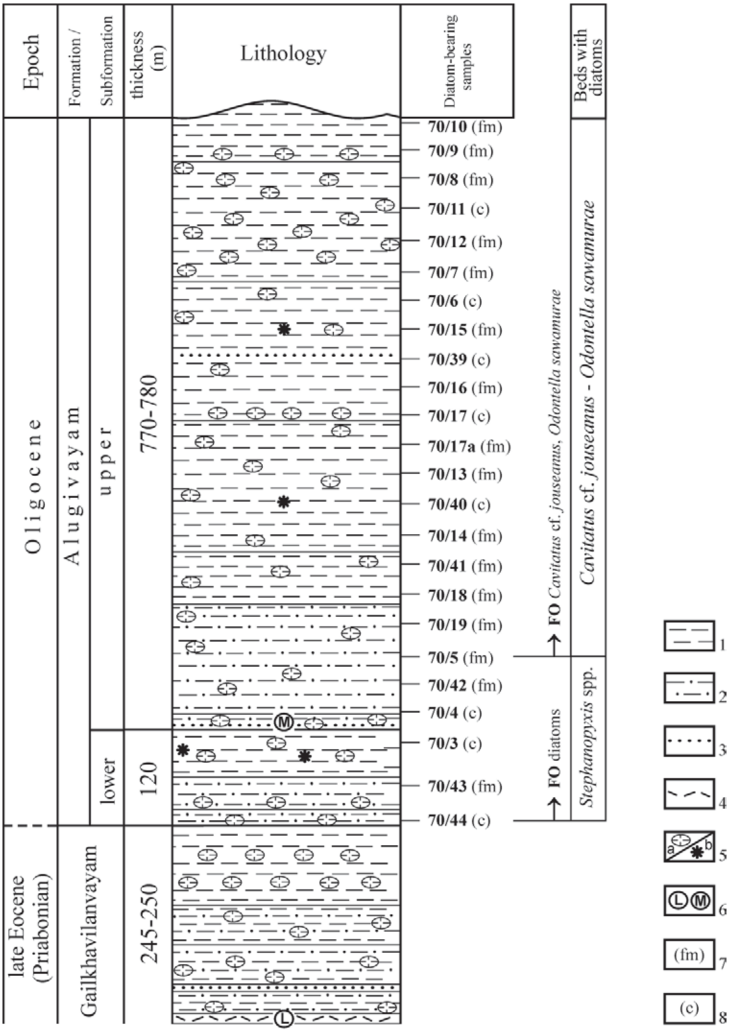


**Fig. 2.** Generalized stratigraphic column of the Alugivayam Formation and underlying strata of the Il'pinskii Peninsula stratigraphic section, northeast Kamchatka, with indicated position of diatom-bearing samples, and defined beds with diatoms (modified from A. GLADENKOV and Y. GLADENKOV 2007). 1 – shale, tuffaceous shale; 2 – siltstone, tuffaceous siltstone; 3 – sandstone, tuffstone. 4 – silicic tuffs; 5 – carbonate concretions (a) and glendonites (b); 6 – the Laparelam (L) and Mulatkhan (M) lithologic marker »horizons«; 7 – samples from interiors of mollusk shells; 8 – samples from carbonate concretions; FO – the first occurrence.

tain shape- and size-variable carbonate concretions either isolated or clustered into layers inclusive. Besides, there are glendonites and »floating« pebbles in the rocks. The formation is subdivided into the lower (120 m thick) and upper (approximately 780 m thick) subformations. The Mulatkhan lithologic marker »horizon« (10 m thick) at the base of the Upper Alugivayam Subformation is composed of tuffstones, gravelstones, and tuffaceous siltstones. The contact with the underlying Gailkhavilanvayam Formation is conformable.

Samples of carbonate concretions and the interiors of fossil mollusk shells were collected for diatom analysis during fieldwork. Collection of such material was critical as diatoms were absent in the enclosing matrix as shown by previous studies. The concretions and interiors of mollusk shells were sampled because in some cases diatoms are present in fine sediment within concretions or shells and are thereby protected from mechanical and chemical abrasion in the course of sedimentation or during fossilization and catagenesis (BARRON and MAHOOD 1993, GLADENKOV 2003, 2007).

Due to the induration of the sediments and the low concentration of diatoms, a procedure including a treatment by acetic acid and sodium pyrophosphate and subsequent centrifugation with heavy liquid was used to process the samples (GLADENKOV 2003). Strewn slides were prepared on 18 × 18 mm cover glasses and mounted in Naphrax mounting medium (index of diffraction = 1.74) on glass slides. The slides were examined in their entirety under a Jeneval (Zeiss) light microscope at 400×, with identifications routinely checked at 1000×. Because of low abundance of diatoms, all valves were encountered on a slide and all of the taxa were tabulated for each strewn slide. The preservation of diatoms is listed as M (moderate), and P (poor) depending on the degree of destruction and dissolution of valves. The relative abundance is evaluated as F (few, more than 100 valves), R (rare, 10–100 valves), and VR (very rare, less than 10 valves). Numerical ages, geological epochs, subepochs and periods are used herein according to the Cenozoic geochronologic and geomagnetic polarity scales (BERGGREN et al. 1995).

## Results

All 10 samples collected from the Gailkhavilanvayam Formation are barren of siliceous microfossils. Fossil diatoms (Tab. 1) were found in the 24 examined samples (16 samples are fossil mollusks and 8 are carbonate concretions) from the Alugivayam Formation (Figs. 2, 3, Tab. 1). Overall, diatoms are rare to very rare and moderately to poorly preserved. The first occurrence of diatoms is in sample GIN 70/44 from the basal part of the Lower Alugivayam Subformation. In particular, the appearance of *Stephanopyxis* spp., *St. grunowii* and *St. marginata* is documented at this level (7 m above the base of the Alugivayam Formation). The stratigraphically lowest sample yielding *Cavitatus* sp. cf. *jouseanus* and *Odontella sawamurae* is sample GIN 70/5 from the Lower Alugivayam Subformation (about 215 m above the base of the Alugivayam Formation). Both these taxa range to the top of the section in sample GIN 70/10 (880 m). *Ikebea tenuis* occurs from sample GIN 70/19 (260 m) to sample GIN 70/9 (840 m), and *Paralia sulcata* from sample GIN 70/3 (105 m) to sample GIN 70/9. *Chaetoceros* spp. spores range from sample GIN 70/4 (145 m) to the top of the section, and *Trochosira* sp. cf. *spinosa* from sample GIN 70/18 (300 m) to the top of the section in sample GIN 70/10 (880 m). Samples GIN 70/43 (50 m) and GIN 70/19 (260 m) yield *Kisseleviella* sp., while sample GIN 70/3 (105 m) contains *Pyxilla* sp. *Stellarima microtrias* occurs from sample GIN 70/14 (370 m) to sample GIN 70/15 (620 m), while *Hemiaulus polymorphus* from sample GIN 70/19 (260 m) to sample GIN 70/1 (760 m).

The typical diatom flora from the Alugivayam formation is characterized by marine neritic-planktic and sublitoral taxa. Low abundance of diatoms and their poor to moderate preservation may probably indicate abrasion and dissolution of valves during sedimentation and/or diagenesis.

**Tab. 1**. Stratigraphic occurrence and relative abundance of marine diatoms from the Alugivayam Formation, the Il'pinskii Peninsula stratigraphic section, northeast Kamchatka. Preservation: **m** – moderate, **p** – poor. Numbers of valves of diatoms counted in each sample are shown. Relative abundance: **F** – few; **R** – rare; **VR** – very rare. Partial boxes within the Table indicate the first observations of biostratigraphically important taxa in the Alugivayam Formation.

| Above a base of the Alugivayam formation (m) | 7 | 50 | 105 | 145 | 180 | 215 | 260 | 300 | 335 | 370 | 410 | 450 | 490 | 520 | 550 | 585 | 620 | 655 | 695 | 730 | 760 | 795 | 840 | 880 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample #GIN- 70/ | 44 | 43 | 3 | 4 | 42 | 5 | 19 | 18 | 41 | 14 | 40 | 13 | 17a | 17 | 16 | 39 | 15 | 6 | 7 | 12 | 11 | 8 | 9 | 10 |
| Relative abundance | F | VR | R | VR | R | R | R | R | R | VR | R | R | R | R | R | VR | R | VR | R | VR | VR | R | VR | VR |
| Preservation | m–p | p | p | p | p | m | m–p | m–p | p | m–p | m–p | m–p | p | p | p | p | p | p | p | p | p | p | p | p |
| *Arachnoidiscus* sp. | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| *Azpeitia* sp. | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| *Cavitatus* sp. cf. *jouseanus* (Sheshukova) Williams | | | | | | 3 | 4 | 3 | 2 | 2 | 2 | 1 | | 3 | 4 | 1 | 3 | 1 | 2 | 1 | | 2 | 1 | 1 |
| *Chaetoceros* spp. spores | | | | 1 | 2 | 2 | 5 | 3 | 3 | 2 | 3 | 16 | 21 | 11 | 3 | 2 | 9 | 5 | 5 | 3 | 4 | 3 | 3 | 2 |
| *Cocconeis* spp. | | | 1 | 2 | 1 | | 1 | | | | 1 | | | | | | | 1 | | | | | | 1 |
| *Coscinodiscus argus* Ehrenberg | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| *C. marginatus* Ehrenberg | | | | | | | 1 | | | | | | | | | | | | | | | | 1 | |
| *Coscinodiscus* spp. | 1 | | | | | 1 | | | | | | 1 | | | | | | 3 | | 1 | | | | |
| Genus *et* species indet. | 1 | 1 | 4 | 3 | 3 | | 1 | | | | | | | | | | | | | 1 | | 1 | 1 | |
| *Hemiaulus polymorphus* Grunow | | | | | | | 2 | | 1 | | | 1 | | 2 | | | 1 | | | | 1 | | | |
| *Hemiaulus* spp. | 2 | | 4 | | | | | | | | | | | | | | | | 1 | 1 | | | | |
| *Hyalodiscus* sp. | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| *Ikebea tenuis* (Brun) Akiba | | | | | | | 3 | 1 | 2 | 1 | 3 | | 1 | 2 | | | | | 1 | | | | 1 | |
| *Kisseleviella* sp. | | 1 | | | | | 1 | | | | | | | | | | | | | | | | | |
| *Odontella sawamurae* Akiba | | | | | | 2 | 1 | | | | | | | | | | | | 2 | | | 8 | | 1 |
| *Paralia sulcata* (Ehrenberg) Cleve | | | 1 | | 2 | 1 | 2 | 3 | 1 | | | 1 | 1 | | | 1 | | | | | | | 1 | |
| *Ploiaria* sp. | | | | | | 2 | | | | | | | | | | | | | | | | | | |

**Tab. 1.** – Continued

| Above a base of the Alugivayam formation (m) | 7 | 50 | 105 | 145 | 180 | 215 | 260 | 300 | 335 | 370 | 410 | 450 | 490 | 520 | 550 | 585 | 620 | 655 | 695 | 730 | 760 | 795 | 840 | 880 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample #GIN- 70/ | 44 | 43 | 3 | 4 | 42 | 5 | 19 | 18 | 41 | 14 | 40 | 13 | 17a | 17 | 16 | 39 | 15 | 6 | 7 | 12 | 11 | 8 | 9 | 10 |
| Relative abundance | F | VR | R | VR | R | R | R | R | R | VR | R | R | R | R | R | VR | R | VR | R | VR | VR | R | VR | VR |
| Preservation | m–p | p | p | p | p | m | m–p | m–p | p | m–p | m–p | m–p | p | p | p | p | p | p | p | p | p | p | p | p |
| *Pyxilla* sp. | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| *Rhabdonema* sp. | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| *Sceptroneis* sp. | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| *Stellarima microtrias* (Ehrenberg) Hasle *et* Sims | | | | | | | | | | 1 | | 1 | | | | | 1 | | | | | | | |
| *Stephanopyxis grunowii* Grove *et* Sturt | 6 | | | | 1 | 1 | | 1 | | | | | | | | | | | | | | | | |
| *St. marginata* Grunow | 3 | | 1 | | | | 1 | | | | | | 1 | | | | | | | | | | | |
| *St. spinosissima* Grunow | | | | | | 1 | | | | | | | | | | | | | | | | | | |
| *St. superba* (Greville) Grunow | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| *St. turris* (Greville *et* Arnott) Ralfs | | | | | | 2 | 2 | 3 | 1 | | | 7 | 6 | | | 1 | | | 2 | | | | | |
| *Stephanopyxis* spp. | 88 | | | | 3 | | | | | | 2 | 4 | 19 | | 4 | | | | | | | | | |
| *Trochosira* sp. cf. *spinosa* Kitton | | | | | | | | 2 | 1 | 2 | | | | | | | | | | 1 | | 3 | 1 | 1 |
| *Xanthiopyxis panduraeformis* Pantocsek | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| *Xanthiopyxis* sp. cf. *ovalis* Lohman | 2 | | | | | | 1 | | | | | 1 | 2 | | | | | | | | | | | |
| *Xanthiopyxis* sp. | | | 4 | | 1 | 1 | | | | | | | | | | | | | | | | | | |

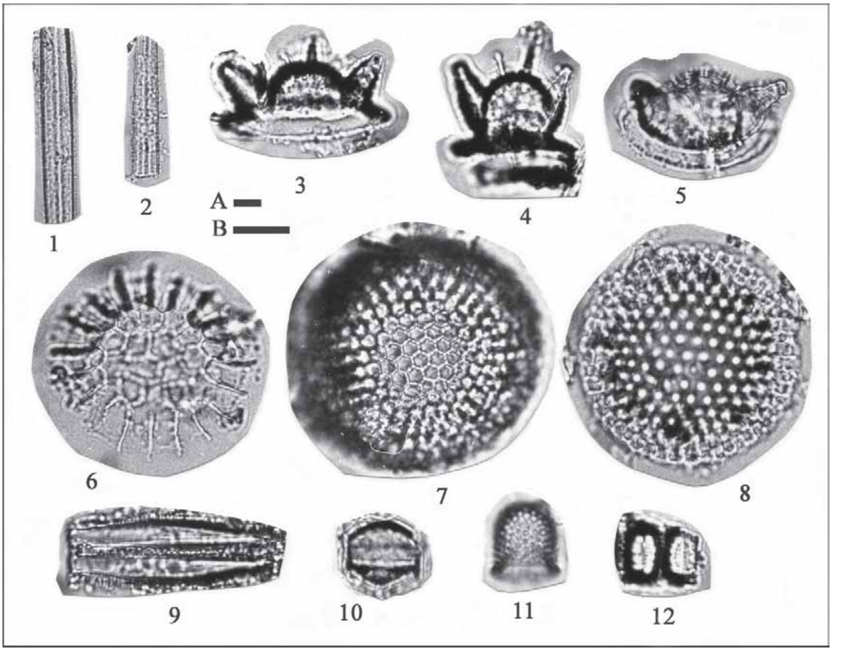


**Fig. 3.** Diatoms from the Alugivayam Formation. **1, 2** – *Cavitatus* sp. cf. *jouseanus* (Sheshukova) Williams; **3–5** – *Odontella sawamurae* Akiba; **6** – *Stephanopyxis marginata* Grunow; **7** – *St. turris* (Greville *et* Arnott) Ralfs; **8** – *St. grunowii* Grove *et* Sturt; **9** – *Ikebea tenuis* (Brun) Akiba; **10** – *Chaetoceros* sp. (spore); **11** – *Stephanopyxis* sp.; **12** – *Trochosira* sp. cf. *spinosa* Kitton. Scale bars = 10 µm (A: for 1–2; B: for 3–12).

## Discussion

Initial analysis of molluscan and diatom assemblages from the Alugivayam Formation made it possible to distinguish the »beds with mollusks« and »beds with diatoms« (A. GLADENKOV and Y. GLADENKOV, 2007). Analysis of diatoms from different stratigraphic levels allows recognition of the beds with *Stephanopyxis* spp. in the lower part of the Alugivayam ranging approximately from the base of the formation to level of 215 m above this base, and the beds with *Cavitatus* cf. *jouseanus* – *Odontella sawamurae* in the higher stratigraphic interval (Fig. 2). A base of the former beds is characterized by appearance of diatoms in the section, and a base of the latter beds is marked by the first occurrences of *Cavitatus* cf. *jouseanus* and *Odontella sawamurae*. Determining a precise age for the defined units has proven difficult owing to the absence of most of age-diagnostic Cenozoic marine taxa. The most biochronologically-important taxa found are *Cavitatus* cf. *jouseanus* and *Odontella sawamurae*. In particular, their occurrence is of some significance for estimating the lower age limit of the beds characterized by the presence of these taxa. It is known that *Cavitatus* is the extinct cosmopolitan marine genus including a number of planktonic species. *Cavitatus jouseanus* is the oldest species within this genus and widespread in Oligocene to Miocene sediments. According to available data, in the North Pacific region the first representatives of *Cavitatus* (*C. jouseanus*) appear in the early Oligocene (AKIBA et al. 1993, GLADENKOV and BARRON 1995, and others). Their first occurrence is within the early Oligocene *Rhizosolenia oligocaenica* Zone of the North Pacific diatom zonation (Fig. 4). The first occurrence of *Cavitatus jouseanus* marks a base of the Subzone b within the *Rhizosolenia oligocaenica* Zone at ~31 Ma (GLADENKOV 1998, 1999). A top of the *Rhizosolenia oligocaenica* Zone defined by the first occurrence of

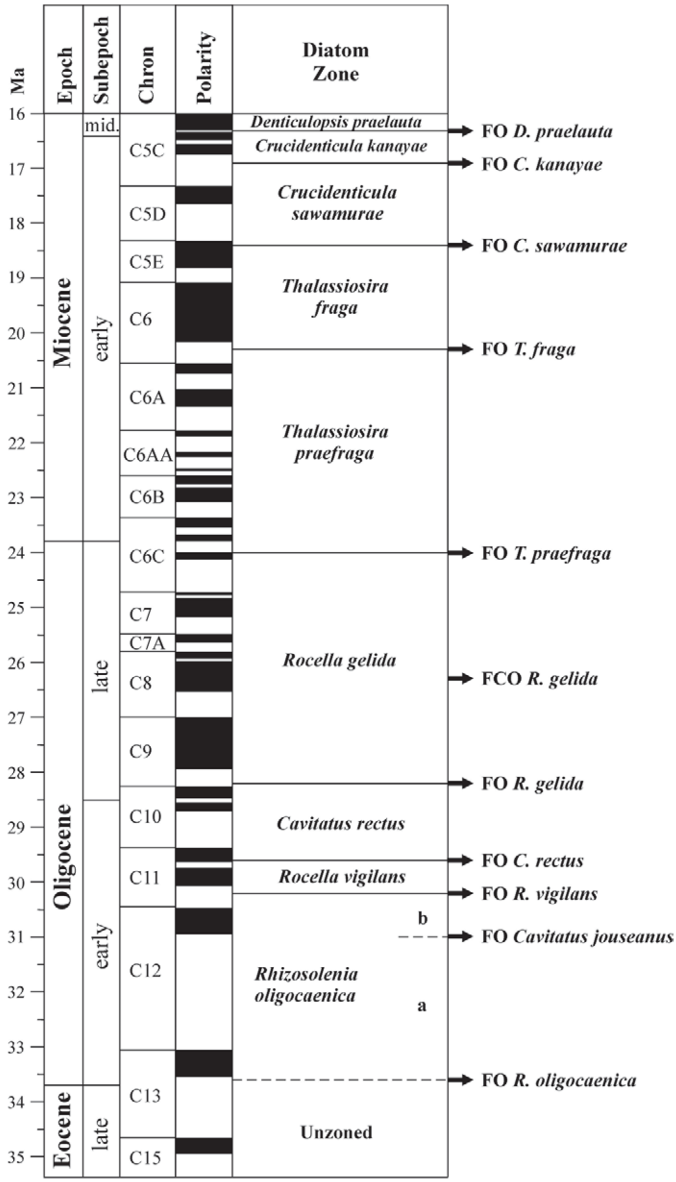


**Fig. 4.** The North Pacific Oligocene through early Miocene diatom zones (after BARRON and GLADENKOV 1995, GLADENKOV and BARRON 1995, GLADENKOV 1998, 1999) correlated to the geochronologic and geomagnetic polarity time scales of BERGGREN et al. (1995). **FO** – the first occurrence; **FCO** – the first common occurrence; **a–c** – subzones; **mid.** – middle.

*Rocella vigilans* is at the level of 30.2 Ma (GLADENKOV and BARRON 1995, GLADENKOV 1998). Thus, the finds of *Cavitatus* cf. *jouseanus* may indicate an age not older than ~31 Ma for diatom flora from the upper part of the Alugivayam Formation. On the other hand, the presence of *Odontella sawamurae* is also important. This extinct marine species is typical of the northwestern Pacific marginal sediments and is documented from the Oligocene to early Miocene deposits of Japan, Sakhalin, and Kamchatka (MORITA et al. 1996, GLADENKOV at al. 2000, ORESHKINA 2009, and others). Among these localities, the oldest finds of *Odontella sawamurae* are known from Hokkaido Island and confined to the early Oligocene *Rocella vigilans* Zone (30.2 to 29.6 Ma) (MORITA et al. 1996). However, in sequences from the island slope of the Kuril-Kamchatka Trench *Odontella sawamurae* ranges from an older interval of the early Oligocene corresponding to the *Rhizosolenia oligocaenica* Zone (TSOI 2002). These data suggest that the 30.2 to 29.6 Ma age for the first occurrence of *Odontella sawamurae* from Hokkaido may not apply in more northern regions, such as northeast Kamchatka, where this datum level is maybe older. Thus, the presence of *Odontella sawamurae* and its co-occurrence with *Cavitatus* cf. *jouseanus* do not conflict with a lower possible limit for the early Oligocene enclosing sediments of not more than ~31 Ma. It follows that diatom assemblage from the underlying beds with *Stephanopyxis* spp. lacking both *Cavitatus* cf. *jouseanus* and *Odontella sawamurae*, and *Ikebea tenuis*, is older and perhaps its age may be dated as the earliest Oligocene.

An early Oligocene age for the diatom assemblages is supported by data obtained on benthic fossil groups. Particularly, a transition from the late Eocene *Plectofrondicularia packardi – Caucasina eocaenica kamtschatica* benthic foraminifera assemblage to the Oligocene *Haplophragmoides laminatus – Melonis chimokiensis* assemblage is documented at the boundary between the Gailkhavilanvaym Formation and Alugivayam Formation (BENIAMOVSKII et al. 1992, VOLOBUEVA et al. 1994). The recent data on magnetostratigraphy indicate that a base of the normal-polarity Chron 13n (at 33.5 Ma) is located just above a boundary between the Gailkhavilanvaym and Alugivayam formations, and the early Oligocene reverse-polarity Chron 12r is compressed in the Alugivayam Formation (MINYUK and GLADENKOV 2007).

The latest data on highly branched isoprenoids (the typical diatom biomarkers) from the Il'pinskii Peninsula section should be especially emphasized. It has revealed that concentrations of isoprenoids increase drastically just above the boundary between the Gailkhavilanvaym and Alugivayam formations (SHIINE et al. 2008). This means these concentrations in the lower Oligocene sediments are clearly higher than those from upper Eocene, indicating a higher diatom productivity after the Eocene/Oligocene boundary (SHIINE et al. 2008).

## Conclusions

The Alugivayam Formation of the Il'pinskii Peninsula stratigraphic section, northeast Kamchatka, contains Oligocene marine diatom assemblages of moderate to poor preservation and low abundance. The presence of *Cavitatus* cf. *jouseanus* and *Odontella sawamurae* in the younger diatom assemblage may indicate the early Oligocene age with a lower possible limit for the enclosing sediments of not more than ~31 Ma. An age of the older assemblage from the underlying strata of the Alugivayam Formation is inferred as the earliest Oligocene. The data on diatoms from stratigraphically well-controlled samples support and refine the Oligocene age of the Aluginskaya Formation in the Il'pinskii Peninsula section. Information obtained on the age of diatom-bearing deposits contributes to regional correlations of the Oligocene strata in Kamchatka. Data on diatoms together with the latest data on diatom biomarkers from the section indicate increased diatom productivity in the sea basin after the Eocene/Oligocene transition.

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