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Zonal Diatom Scale of the Continental Neogene in Primorye (Most Southern Territory of the Russian Far East)*

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ABSTRACT: A significant stratigraphic and micropaleontological problem exists in the development of high-resolution biostratigraphic scales necessary when collecting basic data to construct a modern theory of Biospheric Stratigraphy and in determining the chronozone as a main operation unit. The chronozone should reflect general geobiological events which led to various conditions using the Paleobiosphere, which is a unique instrument used to mimic conditions of the ancient earth. The development and substantiation of zonal continental scales, which also include information on geobiological events, lag behind modern stratigraphy requirements The author's actual materials on the Far East Neogene diatom stratigraphic distribution allow us to decide this problem. The early Miocene is characterized by the intensive development of the *Aulacoseira*, *Alveolophora*, *Ellerbeckia*, *Pseudoaulacosira*, and *Melosira* genera. The global climate optimum has appeared between the early and middle Miocene. Many taxa of diatoms as well as the high species diversity of centric diatoms appeared and developed during the Middle–Late Miocene stage of diatom evolution. The Pliocene stage was marked by the appearance of the genera *Stephanodiscus*, *Cyclotella*, and *Pliocaenicus*. The greatest extinction of moderately warm-water species of centric births at the level of 3.6 million years corresponds to the growth and expansion of ice caps at both poles of the planet.

KEY WORDS: Neogene, diatoms, paleoclimate, stratigraphy, tectonic, the Far East

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INTRODUCTION

Single-cell diatom algae with an external siliceous skeleton represent the ortho-stratigraphic group, which is widely used in bio-stratigraphic structures due to the high rates of evolutionary changes with significant preservation in sediments. A high sensitivity to changes in the habitat parameters of the group made it a reliable tool for paleogeographic reconstructions, too. Therefore, the purpose of the present work is to develop a zonal diatom scale of the continental Neogene in Primorye using the most recent data on taxonomy and stratigraphic diatom distribution of Neogene diatoms as well as isotopic dating.

Zonal stratigraphy of continental strata has been repeatedly discussed and was posed as a primary task for the development of the Stratigraphic theory (Meyen, 1989; Gladenkov, 1991; Zhamoyda, 2007). For the first time, an attempt to determine diatom zones was made by studying the Neogene deposits of Primorye. Three diatom zones were singled out in the Miocene–Pliocene interval (Pushkar and Korotky, 1985). Based on this experience and the evolutionary development of diatoms during the Neogene of Primorye, variants of the diatom zonal scale were proposed (Moisseeva, 1995). Zones were related to a unified scheme of the Neogene and Pliocene of Primorye (Decisions..., 1994). However, the practice of geological mapping and further diatom studies have revealed a number of observations, both in the development of zonal scales and in the current paradigm of the unified regional scheme of the Cenozoic deposits in Primorye.

Together with the identified new stratigraphic units, the obtained data on absolute dating made it possible to revise the ages in a variety of the Neogene formations and horizons (Pavlyutkin et al., 2004; Pavlyutkin and Chekryzhov, 2007; Pavlyutkin and Petrenko, 2010). This revision led to the age sequence review of the Moisseeva’s diatom zones. The diatom zones proved to reflect not so much the evolutionary sequence in the development of diatoms, as to the heterochronous changes expressed in the facies of environments under the environmental parameters' alteration (Moisseeva, 1995).

A variety of taxonomic transformations in the Diatom classification, the description of the new Diatom taxons in the Neogene strata of Primorye (Dubrovina et al., 2014; Usoltseva et al., 2018), and the refinement of the diatoms’ stratigraphic distribution made it possible to amend the later revision of the biostratigraphic scheme (Likhacheva et al., 2009). The levels of the evolutionary appearance and disappearance of zonal markers were established by analyzing their recurrent occurrence in the lower and overlying strata, and correlating that with the stratigraphic distribution in the continental Neogene sequences of Baikal and California (Krebs et al., 1987; Khursevich, 2006).

MATERIALS AND METHODS

The actual material for diatom analysis was based on long-term field studies of the Neogene strata of Primorye. More than 30 outcrops with paleobotanic and radiometric characteristics were studied (Pavlyutkin et al., 1993, 2004; Pavlyutkin and Petrenko, 2010). In the study of diatom complexes in Neogene sediments priority was given to stratotypes and supporting horizon outcrops and formations (Fig. 1).

FIG. 1: Location of the Neogene deposits' outcrop groups in the southern part of Primorye: 1 – holostratotype of the Novokachalinskaya Formation (the Middle Miocene); 2 – hypostratotype of the Ust-Suifunskaya Formation (the Upper Miocene); 3 – hypostratotype of the Sineutesovskaya Formation (lower part of the Late Miocene); 4 – general outcrops of Shufansky horizon (the Pliocene); 5 – general outcrops of Nezhinskaya Formation (upper part of the Late Miocene)

As it is known, Meyen (1989) substantiated the principle of homotaxation as the third fundamental stratigraphic principle and called it the Huxley principle (1989). Huxley understood homotaxis as an identical sequence of fossil fauna or flora complexes in outcrops, which in this case are homotaxal. Meyen proposed to apply the concept of homotaxis for correlating outcrops not only on the paleontological, but also on any other features or reflected events, as paleoclimatic reconstructions, changing facial environments or the same sequence of paleoecosystems (Meyen, 1989). This principle allows conceding the non-simultaneous existence of identical or similar faunas (floras) in different parts of the planet or region and, at the same time, ascertaining sediment synchronization when a feature of the stratigraphic value observed in an outcrop is obtained (for example, paleoclimatic or specific tectogenesis). This principle plays an important role in the ecostratigraphic (event) scales development (Pushkar, 2012). However, the facial diversity of continental deposits entails a corresponding variety of diatom assemblage Under this condition, it is almost impossible to establish homotaxis with a biostratigraphic correlation only by changing the taxonomic composition of diatom complexes. Therefore, to determine homotaxal sequences for the outcrops of different facies, according to the additions of Meyen, it is important to clarify the causal relationship between the paleoclimatic rhythmic, the facial mode, and changes in the ecological structures of diatom assemblages.

The main steps for isolating biostratigraphic complexes, reflecting evolutionary stages in the development of diatom flora, and choosing types-indexes of certain zones are reduced to the following sequence (Pushkar, 2012; Pushkar et al., 2014): 1) the stratigraphic relationship analysis in the studied field outcrops using the Steno principle; 2) selection of peer layers with diatom flora to refer to primary age and genetic stratigraphic information, and their lateral tracking in various continental facies; 3) unification of even-aged layers of different facies into zones; 4) the analyzing the ecological structures' complexes changeability, which provides compliance with the Huxley's principle for the climatic factor. The zone should reflect the evolutionary stage in the development of diatom flora, and its age should be confirmed by data on absolute dating. At the same time, the species-index of the zone should be found, if possible, in river and lake facies. Facial diversity, traced in the same stratigraphical volume, implies determining the nature of the taxon disappearance (ecological or evolutionary) from the reference layer, therefore, the boundaries of the zones must not have only an evolutionary diatom but also an abiotic event characteristic (climate, tectogenesis, etc.).

RESULTS AND DISCUSSION

Compared to marine diatoms the continental ones have much higher speciation rates due to the terrestrial biotopes' diversity and the environmental parameters' changeability. These characteristics are also more sensitive to habitat fluctuations, which lead to a wide range of phenotypic variability; all of these factors, on the one hand, make them good tools for restoring the parameters of the paleoenvironment, and, on the other hand, complicate the correlation of the facial heterogeneous strata since they contain diatom complexes with incomparable taxonomic and ecological structures. From this point of view, the selection of referent layers, embracing genetically different even-aged facies with the unique features, is an important task in the development of zonal stratigraphy. Reference features can be paleoclimatic rhythmic and differences between the evolutionary stages of diatom development, which complexes represent a homotaxal sequence basic for the outcrops correlation and the establishment of corresponding zones with the characteristic of their stratigraphic boundaries (Fig. 2). When choosing the referent zones' features, preference was given to the genera *Alveolophora* Moisseeva & Nevretdinova, *Pseudoaulacosira* Lupikina & Khursevich, *Tetracyclus* Ralfs, *Cyclotella* (Kützing) Brébisson, and *Aulacoseira* Thwaites ("prae" forms and ring colonies), which are well traced in both lake and river facies. The genera *Actinocyclus* Ehrenberg, *Mesodictyon* Theriot & Bradbury, *Cyclotella*, *Pliocaenicus* Round & Hakansson, and *Stephanodiscus* Ehrenberg are significant additional evolutionary markers but are significantly less likely found in alluvial facies. The morphological variability of characteristics is very important, especially when considering the nature and configuration of connecting spikes, and the colonies shape of the genus *Aulacoseira*, which can later be used as a basis for the infrasonal units' separation at the phenozone level. The most indicative and zonal species of diatoms are presented in Plate.

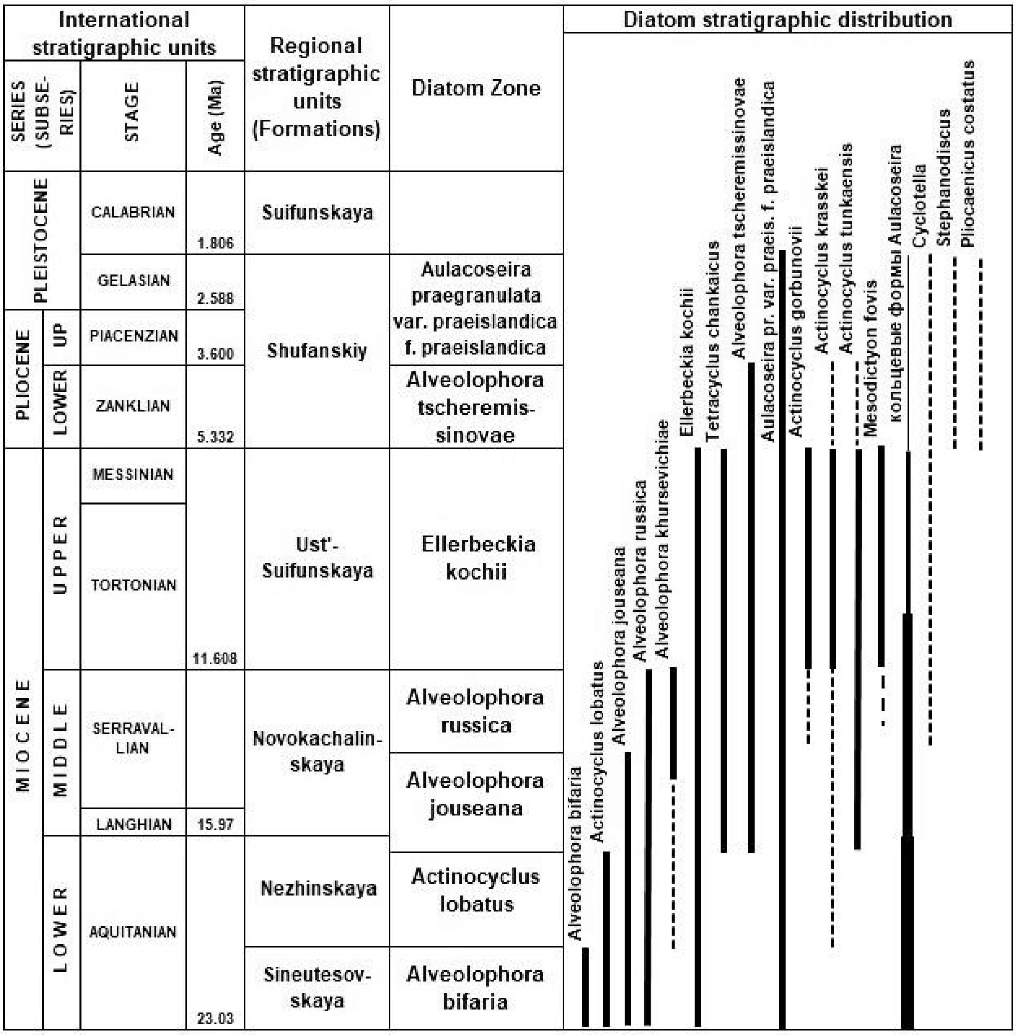
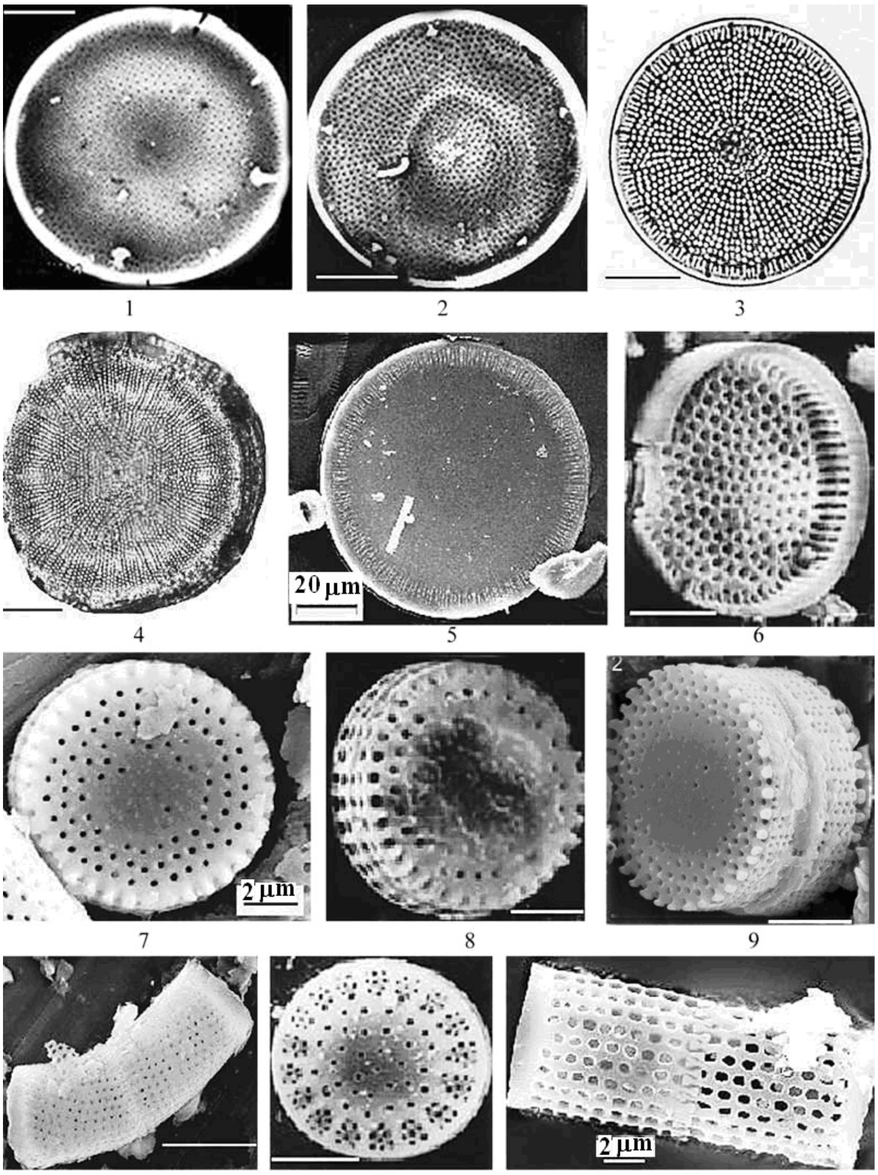


FIG. 2: Stratigraphic distribution of diatoms and zonal diatom scales of the Neogene deposits in Primorye. Local stratigraphic units are listed in accordance with the Unified Regional Scale of the Neogene (Decisions..., 1994; Pavlyutkin and Petrenko, 2010)



1 2 3 4 5 6 7 8 9 10 11 12

PLATE: Zonal species of diatoms: *1 – Actinocyclus gorbunovii* var. *gorbunovii* Bradbury & Krebs; *2 – A. krasskei* f. krasskei Bradbury & Krebs; *3 – Mesodictyon fovis* Theriot, Bradbury & Krebs; *4 – Actinocyclus lobatus* (Rubina) Rubina & Khursevich; *5 – Ellerbeckia kochii* (Pantocsek) Moisseeva; *6 – Alveolophora bifaria* (Moisseeva & Nevretdinova) Khursevich; *7 – A. tscheremissinovae* (Khursevich) Khursevich; *8 – A. jouseana* (Moisseeva) Moisseeva; *9 – A. khursevichiae* Usoltseva, Pushkar & Likhacheva; *10 – Aulacoseira praegranulata* var. *praegranulata* f. *curvata* (Jousé) Moisseeva; *11 – Alveolophora russica* Usoltseva, Kociolek & Khursevich; *12 – Aulacoseira praegranulata* var. *praegranulata* f. *praegranulata* (Jousé) Moisseeva (*1, 2, 6* – photo Khursevich). The line-scale without numeric values in the photo is equal to 10 μm

Zone *Alveolophora bifaria* (Moisseeva & Nevretdinova) Khursevich (holostratotype of the Sineutesovskaya Formation, lower part of the Lower Miocene). The upper boundary is determined by the extinction of index species and the first appearance of the species *Actinocyclus krasskei* f. *krasskei* Bradbury & Krebs and *Alveolophora khursevichiae* Usoltseva, Pushkar & Likhacheva. The lower boundary is not known. A good indicator of this zone is the high occurrence of *Actinella brasiliensis* Grunow and ring colonies *Aulacoseira* (reference feature). A typical diatom complex, reflecting the evolutionary stage in the development of diatoms from the early Miocene, is represented by *Aulacoseira praegranulata* (Jousé) Simonsen var. *praegranulata* f. *praegranulata* + f. *curvata*, *A. praegranulata* var. *praeislandica* (Jousé) Moisseeva + f. *curvata* (Jousé) Moisseeva, *A. elliptica* Usoltseva et Tsoy, *Alveolophora russica* Usoltseva, Kociolek & Khursevich, *A. jouseana* (Moisseeva) Moisseeva, *A. bifaria*, *Ellerbeckia arenaria* f. *teres* (Brun) Crawford, *E. kochii* (Pantocsek) Moisseeva, *Actinocyclus lobatus* (Rubina) Rubina & Khursevich, *Actinella brasiliensis*, and *Desmogonium guianense* Ehrenberg f. *antiqua* Lupik. A similar complex was also found in the freshwater sediments of the Lower Miocene referred to Ullyn Plateau of the Sea of Japan (Tsoy and Usoltseva, 2016).

The diatom complex of the zone indicates a warm climate in the southern part of the Far East, as is evidenced by paleobotanical data (Pavlyutkin and Petrenko, 2010) and the activation of the East Asian monsoon. The reason for such climatic changes in the Early Miocene appeared to be the increased tectonic activity of the Eurasian continent margin expressed in the Tibetan plateau uplift. This led to the atmospheric flow redistribution and the increase of the thermal contrast between the mainland and the ocean. The East Asian baric maximum, formed at that time, became a significant regional climatic factor, which examined a tremendous impact on various environmental components in temperate latitudes of Eastern Asia in the Cenozoic (Wang et al., 2003). The second important factor that determined the regional climate was in the beginning of the Sea of Japan discovery and Japan's drift to the East (Iijuma et al., 1990; Pavlyutkin and Golozubov, 2010). The lower part of the zone is dated to 25.3 Ma, and the upper – to 20.9 Ma (Pavlyutkin et al., 1993).

Zone *Actinocyclus lobatus* (Rubina) Rubina & Khursevich (Nezhinskaya Formation, upper part of the Lower Miocene). The lower boundary is set at the evolutionary extinction of *Alveolophora bifaria*, and at the first appearance of *A. khursevichiae* and *Actinocyclus krasskei* f. *krasskei*. The upper boundary is established at the extinction of the index-species and the first evolutionary appearance of *Actinocyclus tunkaensis* Khursevich and *Alveolophora tscheremissinovae* (Khursevich) Khursevich, Dubrovina et al. The distinctive diatom complex is represented by *Aulacoseira praegranulata* var. *praegranulata* f.

praegranulata et f. *curvata* (Jousé) Moisseeva, *A. praegranulata* var. *praeislandica* (Jousé) Moisseeva et f. *curvata* (Jousé) Moisseeva, *A. italica* (Kützing) Simonsen, *Alveolophora russica*, *A. jouseana*, *Ellerbeckia arenaria* f. *teres*, *E. kochii*, *Melosira undulata* (Ehrenberg) Kützing, *Actinocyclus lobatus*, and *A. krasskei* f. *krasskei*.

The genus *Tetracyclus* frequently occurs among the benthic species. The ecological structure of the zone's complexes tends towards an increase in climate warming. At that time, the water area of the Sea of Japan expands, and the thermal contrast between the western and eastern surface water masses occurs (Pavlyutkin and Golozubov, 2010). The synergetic effect of the marginal seas in the North-West Pacific and under monsoon influence on the regional climate started the formation of a wide lake system and the beginning of the diatomite deposit formation. (Likhacheva, 2009). The zone is dated 22.87; 20.2 (foundation); 20.1; 19.7; 18.8; 18.1 (roofing) Ma (Pavlyutkin et al., 1993).

Zone *Alveolophora jouseana* (Moisseeva) Moisseeva (the lower part of the Novokachalinskaya Formation holostraotype; the uppermost part of the Lower Miocene is the lower part of the Middle Miocene). The lower boundary is determined by the upper boundary signs of the *Actinocyclus lobatus* zone, as well as by the evolutionary disappearance of the range of oval *Aulacoseira,* distinctive for the Lower Miocene (Tsoy and Usoltseva, 2016. The upper boundary is determined by the extinction of the index-species *A. jouseana* and the appearance of the *Actinocyclus gorbunovii* Bradbury et Krebs. Relative abundance of genus (42) and species (98) is present in the diatom complex of the zone with a low degree of their dominance. Generally, these are the sublittoral, tychopelagic, and planktonic species of the *Aulacoseira genera*: *Aulacoseira praegranulata* var. *praegranulata* (Jousé) Moisseeva + *praeangustissima* (Jousé) Moisseeva + *praegranulata* var. *praeislandica* (Jousé) Moisseeva, *A. distans* (Ehrenberg) Simonsen, and *A. italica* (Kützing) Simonsen f. *italica*. The species *Alveolophora russica*, *A. jouseana*, *Ellerbeckia kochii*, *E. arenaria* (Moore ex Ralfs) Crawford var. *teres* (Brun) Crawford, *Actinocyclus gorbunovii* + *A. gorbunovii* var. *fossa* Bradbury et Krebs, *A. krasskei* (Krasske) Bradbury et Krebs + f. *krasskei* Bradbury & Krebs, and *Actinella brasiliensis* et *Melosira undulata* with wide morphological variability are also of considerable value in the complex.

Benthic and rheophilous species, representatives of the genera *Tetracyclus* Ralfs, *Eunotia* Ehrenbegr, *Achnanthes* Bory, *Navicula* Bory, *Pinnularia* Ehrenbegr, and *Cymbella* Agardh, constitute up to 13% of the flora composition. In general, the ecological structure of the complex indicates its sublittoral genesis in a sufficiently heated (warm-water species up to 42%) lake with the river flow influence (reference index). The warm nature of the complex shows the main climatic optimum at the border of the early and middle Miocene (reference index) – Monterey carbon excursion (Wang et al., 2003).

The low diatoms dominance and their relatively wide species diversity (128 species belonging to 39 genera) points to the frequent changes in environmental conditions with a tendency to pronounced warming. This circumstance ensured a high bio-productivity of diatoms ($21.11 \cdot 10^7$ valves $\cdot$ cm^{-2} $\cdot$ thousand $years^{-1}$), which led to the formation of diatomite strata (reference index) with a thickness reaching up to 10–15 m. At the beginning of the Middle Miocene, the spreading of the Sea of Japan and South China is being completed in the continental margin tectogenesis. Apparently, the formation of the marginal seas in the Western Pacific was integrated (Wang et al., 2003). The contrast between the summer and winter monsoons, which influenced the regional climate, was becoming clearer. However, a weakened winter monsoon with an intense summer did not serve as an environmental barrier for the subtropical diatoms development. A series of datings in the range of 18.1–14.9 million years were obtained for the complex (Pavlyutkin et al., 1993, 2004).

Zone *Alveolophora russica* Usoltseva, Kociolek & Khursevich (the upper part of the Novokachalinskaya Formation holostratotype, the upper part of the Middle Miocene). The upper zone boundary is determined by the extinction of the index species and *Alveolophora khursevichiae*. The diatom complex consists of 68 species belonging to 34 genera and is characterized by the sublittoral structure change to the pelagic; the role of planktonic species increased, mainly due to *Aulacoseira praegranulata* (up to 58.5%, but in the complete absence of *curvata* forms). A significant part of the complex belongs to *Melosira undulata* (13%). The occurrence of *Alveolophora russica* is more frequent(up to 15.6%). A lower species diversity (in comparison to the underlying complex), the indistinct morphological species variability of *Aulacoseira*, *Melosira*, and *Tetracyclus* of polymorphic genera and a pronounced dominance of *A. praegranulata* (58.5%), which indicates a more constant environmental condition of diatoms, was recorded for the complex. A considerable proportion of plankton species (up to 78.7%) indicates that lake water bodies have become wider and deeper. The benthos group is represented by *Tetracyclus lacustris* Ralfs, *T. ellipticus* var. *lancea* f. *lata* Ehrenberg, *Tabellaria fragilarioides* Lupikina (up to 14% in total). Species development of *Cyclotella* and *Stephanodiscus* genera is a typical feature of the corresponding stage in the diatom flora evolution. Considering that the first representatives of the *Cyclotella* genus appeared in the second half of the Middle Miocene (Krebs et al., 1987; Khursevich, 2006), the diatom complex of the *Alveolophora russica* zone should be dated to the latter half of the Middle

Miocene. In addition, species *A. jouseana* in this complex is replaced to *A. russica*. Also, the occurrence of *A. khursevichiae*, in abundance here, makes it possible to consider it the most important marker of the zone and the upper boundary of Serravalian Stage (reference index). It was noted that there is almost a complete (with rare exceptions) absence of the genera *Actinocyclus* and *Mesodictyon* with the dominance of the species belonging to *Aulacoseira* genus. The zone is characterized by a high species polymorphism of *Melosira*, *Aulacoseira*, and, especially, *Tetracyclus* genera (reference index). The zone complex, reproducing a specific evolutionary stage in the diatoms' development, contains 28–35% of extinct taxa. Diatoms' bioproductivity decreases noticeably and amounts to $14.98 \cdot 10^7$ valves $\cdot$ cm^{-2} $\cdot$ thousand $years^{-1}$, which indicates a cooling of the climate in the absence of sharp fluctuations. For this particular time, the contrast between the summer and winter monsoons appears to be enhanced due to the intensification of the winter monsoon, which was confirmed by leaf flora findings by Pavlyutkin et al. (2004). A clear occurrence of the Siberian anticyclone was synergistically associated with the global cooling of the planet during that time (Wang et al., 2003). Primorye still has an extensive network of lakes with diatomite strata. The age of the zone is 14.9–11.8 million years (Pavlyutkin et al., 1993, 2004).

Zone *Ellerbeckia kochii* (Pantocsek) Moisseeva (Hypostratotype of the Ust-Suifunskaya Formation, the Upper Miocene). Its age is 11.8–5.3 million years. *Alveolophora russica* and *A. khursevichiae* disappear at the lower boundary. The upper boundary shows the petering out of the species-index as well *Tetracyclus chankaicus* Dubrovina, Usoltseva, Pushkar & Likhacheva, *Actinocyclus gorbunovii*, and *Mesodictyon fovis*; whereas the species of *Pliocaenicus* and *Stephanodiscus* genera appear. A typical complex is represented by *Alveolophora praegranulata* var. *praeislandica* (Jousé) Moisseeva, *A. praegranulata* var. *praegranulata* f. *praegranulata* (Jousé) Moisseeva, *A. italica* (Kützing) Simonsen, *A. italica* var. *valida* (Grunow) Simonsen, *Ellerbeckia kochii*, *Mesodictyon fovis* Theriot, Bradbury & Krebs, *Tetracyclus lacustris* Ralf, *T. ellipticus* var. *lancea* (Ehrenberg) Hust., *Fragilariopsis bicapitata* var. *lineolata* (Moisseeva), *Fragilariopsis nitzschioides* var. *kamtschatica* Lupik., *F. miocenica* var. *tetranoides* Moisseeva, *Eunotia majuscula* Moisseeva, *E. nikolskiae* Moisseeva, and *Gomphonema miocenica* Moisseeva. The diatom complex structure points out a cold climate with the intensification of the winter monsoon. This period embraces two global coolings, known as the Messinian crisis (Wang et al., 2003).

The significantly larger share of benthic diatom complexes in environmental structures, especially the rheophilic diatoms of *Fragilaria*, *Fragilarimorhpa*, *Staurosira*, *Achnanthes*, *Planothidium*, and *Tetracyclus* genera (up to 45% in total) reveals that Sikhote-Alin tectogenesis and the formation of high-order rivers was completed and has resulted in the replacement of lake facies by lacustrine-alluvial and alluvial ones within the boundaries of Primorye (reference index).

The complex is dated to 8.6; 8.8; 10.7; 10.8; 11.8 million years (personal message by Satoshi Okamura–Satoshi Okamura–Hokkaido University, Japan).

Zone *Alveolophora tscheremissinovae* (Shufansky horizon, the Lower Pliocene). The upper boundary of the zone is set at the extinction of the index species. The age of the zone is 5.3–3.6 million years. The diatom complex is featured by *Alveolophora tscheremissinovae* Khursevich, *Aulacoseira praegranulata* var. *praeislandica* (Jousé) Moisseeva, *Melosira undulata*, *Ellerbeckia arenaria* f. *teres* (Brun) Crawford, *Fragilariforma bicapitata* (Mayer) Williams et Round, *Cymbella tumida* (Bréb.) Van Heurck et *Sellaphora americana* (Ehrenberg) Mann, and *Cymbella australica* (A.S.) Cl. Extinct species are represented by 10% only (reference index). The established species diversity is wider, compared to the previous complex; also, a small quantity of warm-water species is reported, which corresponds to a slight climate warming at the beginning of the Pliocene.

Zone *Aulacoseira praegranulata* (Jousé) Simonsen **var. *praeislandica* f. *praeislandica*** (Shufansky horizon, the Upper Pliocene). The upper boundary corresponds to the extinction level of the index species. The zone age is 3.6–1.92 million years. The age-related complex, reflecting the evolutionary stage in the development of diatoms, is represented by *A. praegranulata* var. *praeislandica*, *A. distans*, *A. praegranulata* var. *praegranulata*, *A. italica*, *Melosira undulata*, *Ellerbeckia arenaria* f. *teres*, *Eunotia clevei* Grunow, and *Tetracyclus ellipticus* var. *lancea* (Ehrenberg) Hust. The coarse valves *A. praegranulata* are the only extinct species here. The complex shows a new wave of cooling and cold conditions stabilization. The winter monsoon occupies a dominant position in the monsoon circulation. The formation of the modern climate system of the Earth (Wang et al., 2003) was determined at this point of time, where the coexistence and expansion of polar ice caps started (the transition of the planet from the Green house mode to the Ice house mode).

CONCLUSIONS

The analysis of the stratigraphic diatoms' distribution substantiates the identification of 7 diatom zones in the Lower Miocene–Pliocene interval, which reproduce specific evolutionary stages of the diatom flora development in the southern part of the Russian Far

East. These zones are determined by global climate changes and the regional East Asian monsoon associated with the Himalayan tectogenesis. The character of the environmental change of sedimentogenesis in Primorye, from lacustrine to alluvial, derived from the formation of a high-order river network after the Sikhote-Alin mountain tectonic system was completed in the Late Miocene. This influenced the entire characteristics of the seaside Neogene diatom flora in Primorye, which has a high level of endemicity. The genera *Mesodictyopsis* and *Tertiariopsis*, which are abundantly found in the sediments of the Baikal and the Tunkinskaya depression, did not evolve in the Neogene freshwater bodies of Primorye. The Early Miocene stage is characterized by the intensive development of not only the *Aulacoseira*, *Alveolophora*, and *Ellerbeckia* genera, but also *Pseudoaulacosira*, *Melosira*. The abundance of ring colonies of the genus *Aulacoseira* is noted. The Middle Late Miocene stage corresponds to the greatest species diversity of freshwater centric diatoms (15 genera, up to 65 species). The total composition of diatom flora numbers up to 35% of extinct species and varieties. The Pliocene stage was marked by the emergence and species development of the genera *Stephanodiscus*, *Cyclotella*, and *Pliocaenicus*.

The same staging is also typical for the continental Neogene of the Baikal region, but the degree of domination of one or another taxon varies, which indicates the flora endemicity in Baikal and Primorye. The global climate optimum appeared at the end of the early Miocene and at the beginning of the middle Miocene, though it was smoothed down in the South of the Far East due to the intensification of the East Asian monsoon and the emergence of warm and cold current systems in the Sea of Japan. It is this frontier that was significant for the evolution of many centric diatoms and their high bio-productivity, which puts it at the level of stratigraphic mark. This period is characterized by the growth of species diversity and the appearance of many taxa. The greatest extinction of moderately warm-water species of centric genera at the age of 3.6 million years corresponds to the growth and expansion of ice caps at both poles of the planet.

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