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RESEARCH PAPER

Freshwater centric diatoms from Middle Miocene deposits of the Khanka Depression, Primorye Territory (Far East of Russia)

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ABSTRACT

The centric diatom flora from the Middle Miocene deposits of the Khanka Depression of Primorye (Far East of Russia) was in detail studied. The centric diatoms were presented by 10 species and intraspecies taxa belonging to four genera (*Aulacoseira* Thwaites, *Alveolophora* Moiseeva et Nevretdinova, *Ellerbeckia* Crawford, *Melosira* Agard) and three orders (Aulacoseirales, Paraliales and Melosirales). A detailed study with the use of LM and SEM allowed us to establish the high morphologic variability of the predominant representatives of the genus *Aulacoseira*. The diagnoses for the *Alveolophora tscheremissinovae*, *Ellerbeckia kochii*, *Melosira undulata* species were supplemented. The comparison of the taxonomic compositions of the centric diatoms from the Khanka complex with the even-aged complexes from other regions has shown the wide spreading of the genus *Aulacoseira* taxa in the freshwater bodies during this time period.

Keywords: diatom, Centrophyceae, *Aulacoseira*, *Alveolophora*, *Ellerbeckia*, *Melosira*, Middle Miocene, Khanka Depression, Khanka diatom flora, Primorye Region

РЕЗЮМЕ

Лихачева О.Ю., Авраменко А.С., Усольцева М.В., Пушкарь В.С. Пресноводные центрические диатомеи из средне-миоценовых отложений Ханкайской депрессии Приморья (Дальний Восток России). Детально изучена центрическая диатомовая флора из среднемиоценовых отложений Ханкайской депрессии Приморья (Дальний Восток России). Центрические диатомеи представлены 10 видами и внутривидовыми таксонами, отнесенными к четырем родам: *Aulacoseira* Thwaites, *Alveolophora* Moiseeva et Nevretdinova, *Ellerbeckia* Crawford, *Melosira* Agard, трем порядкам Aulacoseirales, Paraliales и Melosirales. Детальное исследование с помощью СМ и СЭМ позволило установить высокую морфологическую вариабельность доминирующих представителей рода *Aulacoseira*. Дополнены диагнозы видов *Alveolophora tscheremissinovae*, *Ellerbeckia kochii*, *Melosira undulata*. Сравнение таксономических составов центрических диатомей ханкайского комплекса с одновозрастными комплексами из других регионов показало широкое распространение таксонов рода *Aulacoseira* в пресных водоемах в этот период.

Ключевые слова: Диатомовые водоросли, Centrophyceae, *Aulacoseira*, *Alveolophora*, *Ellerbeckia*, *Melosira*, средний миоцен, Ханкайская депрессия, ханкайская диатомовая флора, Приморский край

The diatoms are one of the most informative groups for the paleoecological investigations (Stoermer & Smol 1999, Lewis et al. 2008, Haywood et al. 2009, Manoylov et al. 2009). These algae are sensitive indicators responding to the environmental changes (Fritz et al. 1991, 1993, Reid 2005). At this time, not only ecological structure of the paleocommunities of diatoms and number of valves in deposits but also morphological traits of phenotypes of individual taxa are taken into account (Douglas & Smol 1999, Cherepanova et al. 2007, Cherepanova et al. 2010). The examination of the Neogene diatoms (including the Middle Miocene ones) is necessary for determining the age and genesis of deposits and performing the paleogeographical reconstructions.

The Middle Miocene was marked by the series of the key climatic events which have transformed the global systems of the atmosphere and ocean circulations and resulted in the considerable changes in biota (Zachos et al. 2001, Kürschner et al. 2008, Krapp & Jungclaus 2011). These events included the uplift of the Himalayas and Tibetan Plateau, change in intensity of the winter or summer Asian monsoon, and enhancing the aridity in Central Asia. The Himalayan Mountains began to form between 40 and 50 million years ago. The Himalayas had a height of more than 4,000 meters already by the end of the Early Miocene that led to formation of the regional climatic system on the outskirts of the Eurasian continent (Wang et al. 2003). The above mentioned events have considerably influenced on the climatic changes in the East Asia (Flower & Kennett 1994, Zhisheng 2000, Zhisheng et al. 2001, Jiang & Ding 2008, Royden et al. 2008). The Middle Miocene Climatic Optimum (14.5–17 Ma, maximum – 16 Ma) is one of the most important events and also the warmest period in the past 30 million years (Kennett 1982, Tsuchi & Ingle 1992, Zachos et al. 2001, Shevenell & Kennett 2004). The temperatures of the sea water and air over the land surface were higher from the Eocene to the present day (Tanai & Huzioka 1967, Kennett 1982, Tsuchi & Ingle 1992, Schoell et al. 1994). The similar trends in the climate changes were fixed for many regions of the Earth including Primorye Territory (Pavlyutkin 2005, Pavlyutkin et al. 2004). At the same time, the intensification of the East-Asian monsoon and emergence of the systems of warm and cold currents in the Sea of Japan have reduced the influence of the Middle Miocene Climatic Optimum in the south of the Russian Far East (Likhacheva et al. 2009).

On the territory of Russia, the Middle-Miocene continental deposits containing the diatom algae were found in several areas. For the first time, they were investigated in 1952 by A.P. Jousé (1952) from the locations in the vicinity of Khanka Lake (Primorsky Region). Jousé has promoted the development of studying the Middle Miocene diatom taxa by describing and documenting new taxa and by illustrating a number of previously undescribed forms. She has established the diatom complexes characteristic of the Middle Miocene. The stratigraphy of the USSR has entered a new stage of development due to study of the diatom complexes and its extensive correlation.

In the 1960s, there was a significant increase in the scope of geological surveys on the territories occupied by the continental Neogene deposits including Miocene ones: the south of the Khabarovsk and the Primorsky Territories; Tunka Basin, Transbaikalia in Baikal Region; Irtysh River, Tym, West Siberian Plain in the Western Siberia (Proshkina-Lavrenko 1974) and Yamal Peninsula (Polyakova & Danilov 1989). By the 1970s, a number of deposit sites were analyzed for diatoms and the first diatom Neogene biostratigraphy in the USSR has appeared. The reconstruction of Neogene climate was also based upon diatom analyses. The remains of centric diatoms in these sediments are one of the major organogenic components. The studies of Neogene diatoms in the USSR were in detail described in the extensive report published in 1974 (Proshkina-Lavrenko 1974).

A new stage in research of the continental deposits from East of Russia is associated with the beginning of the 21st century. The Middle-Late Miocene continental sediments were studied in Transbaikalia: Vitim Upland (Chernyayeva et al. 2007, Rasskazov et al. 2007, Usoltseva et al. 2010, Usoltseva & Khursevish 2013), Chara Basin (Chernyaeva & Moiseeva 2003, Enikeev 2008), Tunka Basin (Proshkina-Lavrenko 1974, Popova et al. 1989, Likhoshway et al. 1997), Barguzin Basin (Hassan et al. 2019, Usoltseva et al. 2020) and the Southern Baikal hollow (Chernyaeva & Popova 1993, Mats 2013, Rasskazov et al. 2014) and Upper Miocene deposits from Baikal Lake (Khursevich et al. 2005, Kuzmin et al. 2009).

The freshwater diatom flora was also found in the Lower Miocene deposits from Yamato and Krishtofovich Rises in the Sea of Japan (Usoltseva & Tsoy 2010, Tsoy & Usoltseva 2015, Tsoy 2017). New fossil diatom species of *Aulacoseira* (Tanaka et al. 2008, Tanaka & Nagumo 2011a, b), *Actinocyclus* (Tanaka & Nagumo 2014, Hayashi et al. 2012) and *Tetracyclus* (Saito-Kato et al. 2011) from Miocene deposits of Japan and Sea of Japan were described. Diatoms were also found in the Middle Miocene Shanwang Formation, Shandong Province, East China (Li et al. 2010).

The studies of the Middle Miocene diatom flora of the Khanka Lake area begun by Jousé (1952) were continued by Moiseeva (Moiseeva 1971, 1995). Later, Tsarko (Moiseeva 1971, 1995, Moiseeva & Tsarko 1990), Pushkar, Cherepanova and Likhacheva (Pavlyutkin et al. 1993, Pavlyutkin et al. 2004, Pushkar & Likhacheva 2007) have also joined with the research. The valve morphology of the genus *Tetracyclus* Ralfs from these deposits was studied by Usoltseva and Dubrovina with co-authors (Dubrovina et al. 2011, Dubrovina et al. 2014). However, the dominant *Aulacoseira* Thwaites and other centric taxa were not previously described. The appropriate morphological characters for taxonomic separation of *Aulacoseira* are still largely unclear. The species of the genus *Aulacoseira* are quite variable. Plasticity of morphological features makes identification of *Aulacoseira* species difficult. The studies carried out for ultrastructure of "prae" of Aulacoseira taxa using the electron microscopy are few in number (Usoltseva & Likhoshway 2005, 2007, Usoltseva et al. 2011). The accurate identification of diatom species is necessary for taxonomy, stratigraphy, paleoenvironmental reconstructions and decipher of the past climatic changes. The electronic microscopy can partially resolve these problems providing the additional information for classification of *Aulacoseira*.

The study purpose is a detail study of the Middle Miocene freshwater centric diatoms from the Khanka deposits (Primorye Territory, Far East of Russia) formed at temperatures higher than today using both light and electron scanning microscopes.

STUDY AREA

The Khanka Depression is situated in the west of Primorsky Territory (Fig. 1). The deposits forming the hollow have resulted from the tectonic and magmatic processes and presented by the Mesozoic and Cenozoic sedimentary and volcanogenic rocks. Of the Late Cretaceous–Early Paleogene, the tectonic-magmatic activation is characteristic. In the Eocene-Oligocene, the depression plunges, alluvial and lacustrine sediments accumulate in it. A volcanism with the felsic and moderately felsic eruptions was one of the most important events in the Miocene. From the beginning of the Middle Miocene, the process of sedimentation in lakes located in the floodplain of a large river or in its delta continues. In the Pliocene, acidic volcanism gives way to basaltic volcanism. The depression plunging intensity increases causing the river system restructuring. In the Pliocene, a geological and geomorphological situation similar to the present one has developed. However, the formation of some morphostructures has continued in the Quaternary as well. This is shown by volcanism, seismic activity which caused the changes in the area of Khanka Lake.

The modern terrain of the Khanka Depression is low-contrast and characterized by low-mountain ridges with flattened watersheds and gentle slopes. Absolute relief elevations of the watershed areas within the limits of depression are 120–140 m, while 400–600 m in its framing. The maximum elevation is 780 m a.s.l. The climate is monsoonal. Winters are dry with a lack of snowfall; summers are warm and rainy. The average annual temperature is +3°C, the average temperature of the coldest month (January) is -18.4°C, and the warmest month is August (+20.7°C). The average annual precipitation is 527 mm of which 40 mm falls in winter.

MATERIAL AND METHODS

The investigated samples were collected from the Middle Miocene diatomite-bearing deposits in the Khanka Depression (Primorye Territory, Far East of Russia). The five samples were taken by Pavlyutkin in 2004 from section 9149 (diatom collection of Prof. Pushkar) and thirty five samples were taken by Likhacheva in three neighboring sections (Fig. 1): № L-03/2 (45°09'14.3" and 132°00'23.3") and L-04/1 (45°09'11.8" and 132°00'126.00") in 2008, L-02 (45°01'00.0" and 132°00'25.1") in 2010–2011. The sections are located on the western shore of Khanka Lake between the settlements of Turiy Rog and Novokachalinsk (northwest of the Khanka Depression). According to Pavlyutkin, this flora is named to as Khanka flora (2005).

The western shore of Khanka Lake in segment being of interest to us is the abrasion scarp with a narrow broken strip of sand and pebble beach (Fig. 1). The deposits are represented by pebbles, sandstones and thin-layered tuff-alevrolites and tuffaceous diatomites. This sedimentary stratum belongs to the Novokachalinskaya Formation (Pavlyutkin et al. 2004). The deposits of this suite overlie the Upper Pliocene coal-bearing deposits and are overlapped by the Upper Pliocene clays. The age of the Novokachalinskaya Formation rocks was determined according to data of the paleobotanic, palynological and diatom analyses as the Middle Miocene (Pavlyutkin et al. 2004, Pavlyutkin 2005). The Middle Miocene volcanites from Novokachalinskaya Formation were dated 18.1–14.9 Ma (Pavlyutkin et al. 1993, Likhacheva at al. 2009). The Middle Miocene corresponds to the Langhian and Serravallian stages according to the International Chronostratigraphic Scale (Cohen et al. 2021).

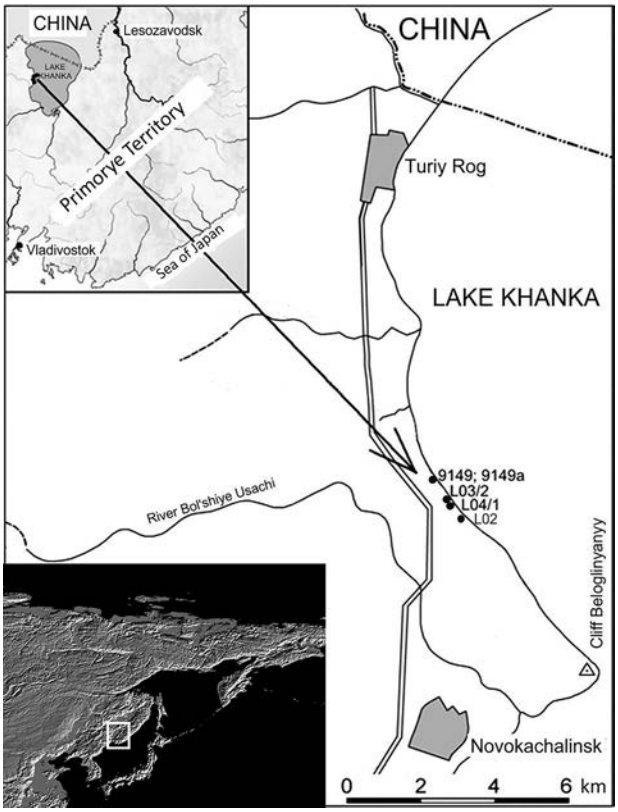

Figure 1 Study area. Locations of sampling sites are shown with black dots on the western shore of the Khanka Lake of Primorye

The samples were treated by the standard procedure using hydrogen peroxide (Proshkina-Lavrenko 1974). Taxonomic analysis, counting of diatom valves, and measurements of the diameter, length, and width of the valves were performed on Amplival Carl-Zeiss and Axioskop 40 Carl Zeiss light microscopes (LM) using a 18×18 mm cover glass at a magnification of ×1000 with an immersion liquid at the Center for Collective Use of Federal Scientific Center of the East Asia Terrestrial Biodiversity, Far East Branch, Russian Academy of Sciences. 250–300 diatom valves were counted to determine the percentage of individual species in diatom taphocenoses (diatom fossil community). Morphological features of valves were also examined with a Carl Zeiss EVO 40, Merlin and Philips 525M scanning electron microscope (SEM) at a magnification of up to 15,000. The sediment remaining after the preparation of the specimen for LM studies was dried. The resulting powder was applied on the special tables with glued bilateral carbon tape. The samples were sputter coated with gold in a vacuum chamber (JEOL JFC-1600 auto fine coater).

The taxonomical features of the genus *Aulacoseira* are form and dimensions of the valves, a form of rimoportulae and their location on the valve as well as the frequency of particular valve characters such as the number of rows of areolae in 10 μm and the areolar density in 100 μm^2 on the mantle and ratio between valve height and diameter (Krammer & Lange-Bertalot 1991). We have also measured a height and diameter of valves and determined the correlation coefficients (Cv) of these features (Ershova 2015).

Classification of centric diatoms follows the systematics as proposed by Round et al. (1990) was modified by Nikolaev & Harwood (2001). All described species are recognized taxonomically valid (Guiry & Guiry 2021).

RESULTS

Diatoms of the Coscinodiscophyceae class dominate in the Middle Miocene deposits of the Khanka Depression. This class is represented by two subclasses, three orders and four genera, which include 10 species and intraspecific taxa.

The Paraliophycidae subclass is represented by two orders (Aulacoseirales and Paraliales); each of them contains one family (Aulacoseiraceae и Radialiplicataceae). The Aulacoseiraceae includes two genera: *Aulacoseira* and *Alveolophora* Moiseeva et Nevretdinova, while the Radialiplicataceae one genus (*Ellerbeckia* Crawford). One species, three varieties and six forms were identified in the genus *Aulacoseira*:

A. praegranulata var. *praeislandica* f. *praeislandica* (Jousé) Moiseeva
A. p. var. *praeislandica* f. *curvata* (Jousé) Moiseeva
A. p. var. *praegranulata* f. *praegranulata* (Jousé) Simonsen
A. p. var. *praegranulata* f. *curvata* (Jousé) Simonsen
A. p. var. *praeangustissima* f. *praeangustissima* (Jousé) Moiseeva
A. p. var. *praeangustissima* f. *curvata* (Jousé) Moiseeva.

Two species were identified in *Alveolophora*:

A. tscheremissinovae Khursevich
A. khursevichiae Usoltseva, Pushkar & Likhacheva.

The last mentioned species was recently described and found only in the Middle Miocene deposits of the Khanka Lake area. One species was identified in *Ellerbeckia*:

E. kochii (Pantocsek) Lupikina.

The subclass Melosirophycidae is represented by one order containing one family (Melosiraceae) represented by the genus *Melosira* Agardh, which includes only one species (*Melosira undulata* (Ehrenberg) Kützing).

This flora may be treated as the *Aulacoseira* flora because the rock-forming taxa are represented by the genus *Aulacoseira*. The dominant taxon is *A. praegranulata* var. *praeislandica* f. *praeislandica*. Its percentage in the diatom paleocommunities reaches 84.7 %. *A. praegranulata* var. *praeislandica* f. *curvata* has percentage of up to 7.27 %, *A. praegranulata* var. *praegranulata* f. *praegranulata* up to 2 %. Other taxa occur in low frequencies (<1%).

SYSTEMATIC DESCRIPTIONS

AULACOSEIRACEAE

Aulacoseira praegranulata (Jousé) Simonsen, 1979, Bacillaria 2: 62.

Description. Frustules are short or long cylinders. The diatom can be found from short chains of 2–3 cells to long chains of 4–15 cells. Valves are thick-walled. They are straight or curved on central axis. The areolae on the mantle are situated in straight or curved rows. The areolae are varying from rounded to round-square in shape. Detail on the external valve surface showing the areolae occluded by rotae (in the majority of valves the membrane is destroyed). Sometimes on a mantle are available small perforations, randomly located between rows of areolae. Structureless collar is quite short. The ring furrow usually isn't expressed. Rimoportulae are located along one ringleist. The spines occur regularly between the last areola in a row on the mantle. Spines are tapering or have a spade-shape at the end.

It's a freshwater extinct species, known from Oligocene and Early Pleistocene sediments (33.9–0.781 Ma).

var. *praegranulata* (Jousé) Simonsen

Frustules are long cylinders. Valves are curved or straight on central axis, 5.73–10 μm in diameter. Areolae on the flat valve face are situated distantly. Valves are 5.97–21.88 μm in height. Rows of mantle areolae are straight or curved to the right, 9–14 rows in 10 μm, the areolar density in 100 μm^2 are 76–180. The ratio between valve height and diameter varies from 1.3 to 3.27 (average 2.37). The collar is mostly short. Spines are spade-shaped.

f. *praegranulata* – *Melosira prae-granulata* [(Ehrenberg) Ralfs] Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241. – *M. praegranulata* Jousé f. *praegranulata*, 1971, in Moiseeva: 26–27

Frustules along central axis are straight (Fig. 2: A–D; Table 1).

f. *curvata* – *Melosira prae-granulata* [(Ehrenberg) Ralfs] f. *curvata* Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241

Frustules along central axis are curved (Fig. 2: E).

var. *praeislandica* (Jousé) Moiseeva, in Glezer et al. 1992: 85

Frustules are short or long cylinders, in valve view are round. Valves are thick-walled. They are curved or straight on pervalvar axis, 4.84–27 μm in diameter (diameter is equal to height of a valve or exceeds it). Valves are 2.0–17.95 μm in height. Rows of mantle areolae are straight or curved to the right, 8–12 rows, sometimes to 18, in 10 μm, the areolar density in 100 μm^2 are 52-208, sometimes to 236. Areolae on the flat valve face are situated distantly or closely. The ratio between valve height and diameter varies from 0.14 to 2.67 (average 0.87). The collar is short.

f. *praeislandica* – *Melosira prae-islandica* (O.Müller) Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241. – *M. prae-distans* [(Ehrenberg) Ktz.] Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241. – *M. praeislandica* Jousé f. *praeislandica* in Moiseeva, 1971: 28–29. – *M. praedistans* f. *praedistans* Moiseeva, 1971: 25

Frustules along central axis are straight (Fig. 3: A–C, G–J, K (top), L–N, Q–T; Table 1).

f. *curvata* – *M. prae-islandica* f. *curvata* Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241. – *M. praedistans* f. *curvata* Moiseeva, 1971: 26

Frustules along central axis are curved (Fig. 3: D–F, K (bottom)).

var. *praeangustissima* (Jousé) Moiseeva, in Glezer et al. 1992: 84

Frustules are long and narrow cylinders. Valves are curved or straight on central axis, 2.92–7.36 μm in diameter. Valves are 14.04–23.5 μm in height. Valves are much longer,

Table 1. Observed morphological variation in the varieties of the species *Aulacoseira praegranulata*.

Taxa	Valve mantle height (h)				Valve diameter (d)				Height / Diameter ratio (middle)	Areolar density in 100 μm^2 on the mantle	Number of rows in areolae in 10 μm
	Min–Max middle, μm	Number of valve measured	σ	Cv	Min–Max, middle, μm	Number of valve measured	σ	Cv			
var. *praegranulata* f. *praegranulata*	5.97–21.88 16.6±0.6	37	3.5	21.3	5.73–10.0 7.4±0.2	34	1.0	14.1	1.3–3.27 (2.38)	76–180	9–14
var. *praeislandica* f. *praeislandica*	1.86-17.95, 10.1±0.1	406	2.9	28.3	4.84–27.0, 13.3±0.2	478	3.6	26.8	0.14–2/67 (0.87)	52–208 (236)	8–12 (18)
var. *praeangustissima* f. *praeangustissima*	14.04-23.5, 18.8±0.8	12	2.8	14.9	2.92–7.36, 5.14±0.2	17	1.0	18.0	2.84–6.34 (4.14)	36–112	9–10

Note. Cv is the coefficient of variation; σ is the standard deviation; ± the standard error of the mean

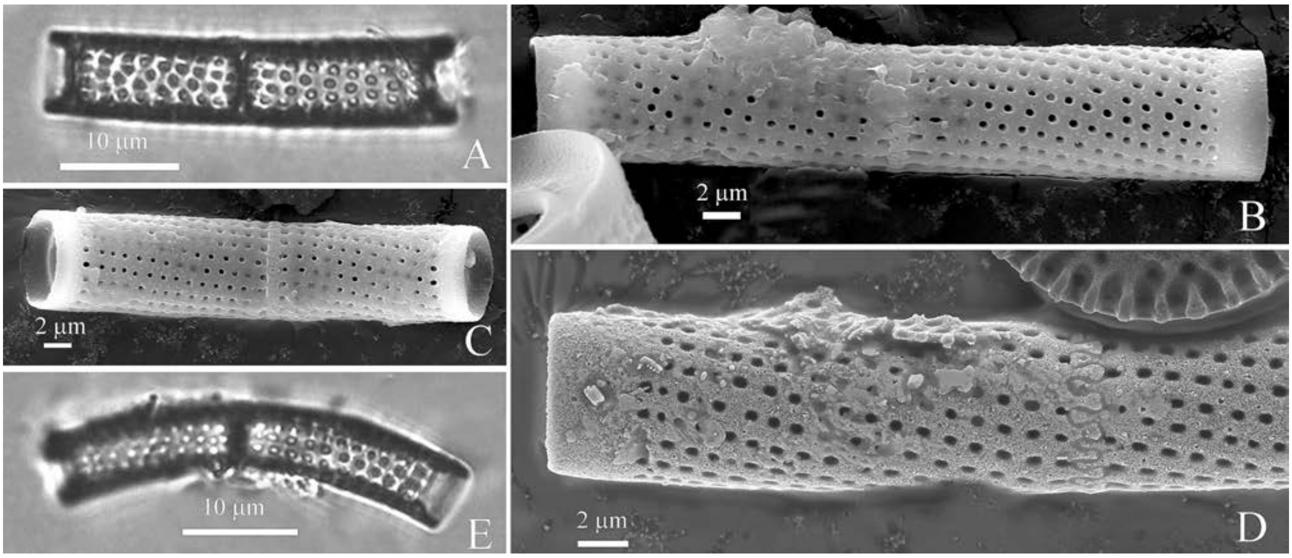

Figure 2 *Aulacoseira praegranulata* var. *praegranulata* f. *praegranulata* (Jousé) Simonsen. A–D – valves are straight along central axis; A – valve mantle view (LM); B, D – valve mantle view, the areolae on the mantle are arranged in curved rows (SEM); B – perforations irregularly located between the rows of areolas on the valve mantle; C – valve with short structureless collar (SEM); B–D – valves with spade-shaped linking spines (SEM). *Aulacoseira praegranulata* var. *praegranulata* f. *curvata* (Jousé) Simonsen. E – valve is curve along central axis (LM)

then wide. Rows of mantle areolae are straight or curved to the right, 9–10 rows in 10 µm, the areolar density in 100 μm^2 are 36–112. Areolae on the flat valve face are situated distantly. The ratio between valve height and diameter varies from 2.84 to 6.34 (average 4.14). The collar is short.

f. *praeangustissima* – *M. prae-granulata* var. *praeangustissima* [(O.Müller) Hust.] Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241

Frustules along central axis are straight. (Fig. 4: A, B, D; Table 1).

f. *curvata* – *M. prae-granulata* var. *praeangustissima* [(O.Müller) Hust.] f. *curvata* Jousé, 1952, Trudy instituta geografii AN SSSR 6(51): 241

Frustules along central axis are curved. (Fig. 4: C).

Comment. Auxospores were found. Auxospores have hemispherical front part of valve and differ from valve more rough structure and well expressed ring-shaped diaphragm.

Alveolophora tscheremissinovae Khursevich. This name is currently regarded as a synonym of *Miosira tscheremissinovae* (Khursevich) Khursevich, 2012, in Khursevich & Kociolek 141: 347

Description. Frustules are short cylinders. Frustules in valve view are round, 8.4–11.3 µm in diameter. Valves are thick-walled. Valves are 1.5–2.9 µm in height. Mild areolae on the valve face are situated in the near-margin surface, in radial rows, 8 rows in 10 µm. Radial rows of areolae are located in narrow (3–4 rows) sectors, which are divided by direct costal thickenings. Rimoportulae have the form of curved tube (3–5 on a valve), form ring in margin (if 5) or central (if 3) zone of a face part of valves. At margin zone of the valve there are poorly expressed pseudosepta. Areolae on the mantle are situated in straight rows (14–18 in 10 µm, two areolae in each row). Spines are short, spade-shaped are located on border of face part of valves and mantle (Fig. 5).

Freshwater extinct species and known from Miocene deposits (23.03–5.33 Ma).

Comment. The smallest valves we measured were 8.4 µm in diameter. It is smaller than that of the typical forms described in Khursevich (1994). The valves have 3–5 rimoportulae, which is less than of typical forms. The valves have 14–18 areolae on the mantle in 10 µm, two areolae in each row. The typical forms have 8–12 areolae on the mantle in 10 µm, 2–3 areolae in each row.

Alveolophora khursevichiae Usoltseva, Pushkar & Likhacheva (Usoltseva et al. 2018, Fig. 2–24).

RADIALIPLICATACEAE

Ellerbeckia kochii (Pantocsek) Lupikina 1991: 59. – *Melosira kochii* Pantocsek, 1905: 62. – *M. arenaria* var. *hungarica* Pantocsek, 1905: 59. – *M. varennarum* Peragallo et Hèribaud, in Hèribaud, 1893: 189. – *M. scabrosa* Øestrup *sensu* Moiseeva, 1971: 30–31. – *Paralia varennarum* (Peragallo et Hèribaud) Loseva, 1981: 77. – *P. kochii* (Pantocsek) Moiseeva, 1987, in Moiseeva & Genkal: 1502

Description. Frustules tightly united by linking structures on valve faces to form long chains. Frustules are broadly cylindrical, complex. Valves are 15.8–57.1 µm in diameter, 4–17 µm in height. Linking structures or relief valve represented by radial ridges of different lengths (9–12 in 10 µm) in the submarginal zone or the valve face and corresponding structures of intaglio valve are radial grooves. Ridges are up to 1/3 or 1/2 of the valve radius. Remainder of the valve face is covered by unevenly located tuberous, different outlines silicified thickenings. Valve mantle penetrated by pores 17–30 in 10 µm of the vertical row. Vertical rows of pores (20–25 m 10 µm) separated by narrow ribs. Externally, relief valve with stepped mantle concave, flat are more often, intaglio valve with plain mantle convex. Original tube processes (2–3 in 10 µm) formed by six ribs curved spirally upwards and alternate with pores on internal surface or valve mantle. Externally tube processes terminate

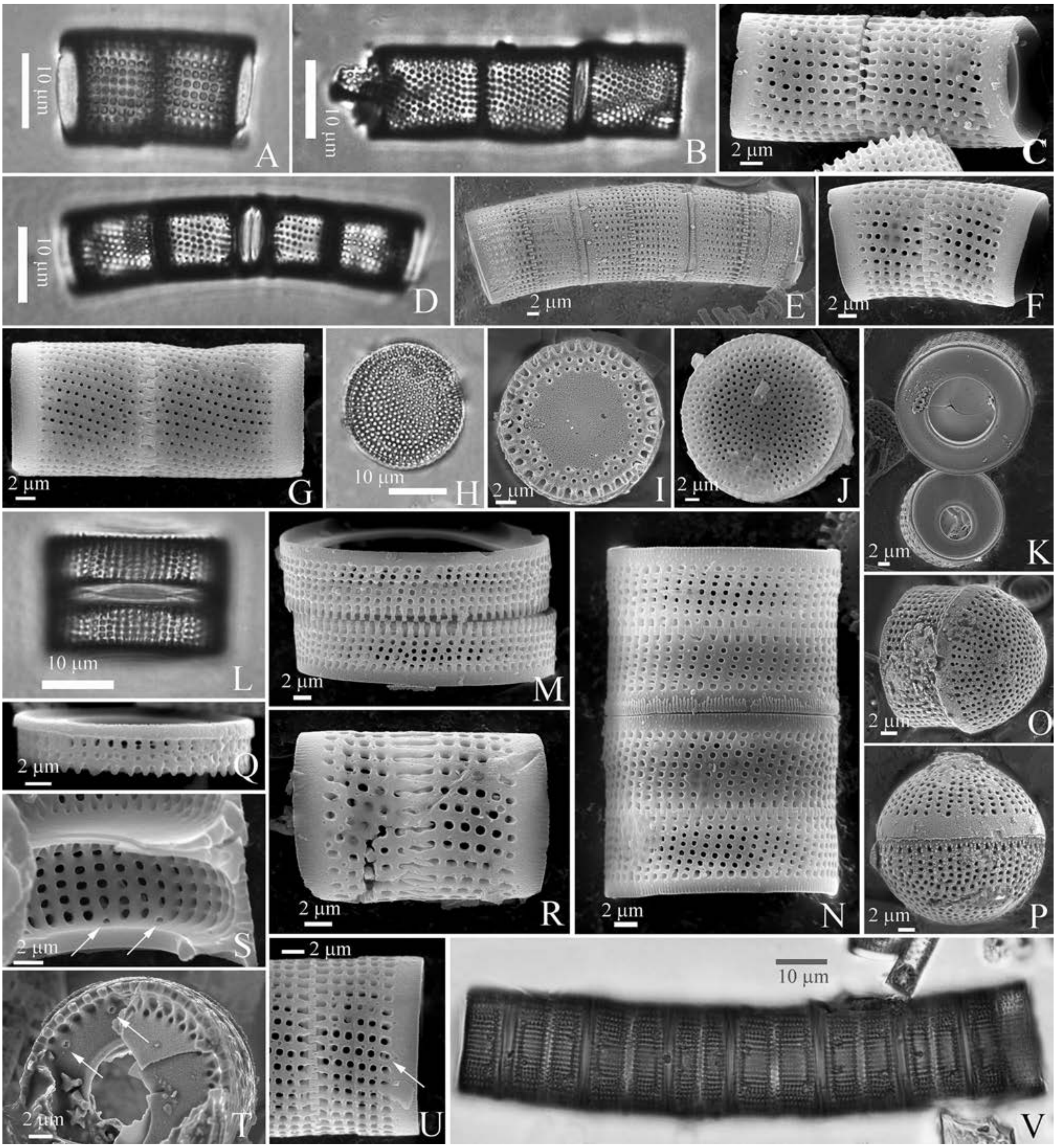

Figure 3 *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* (Jousé) Moiseeva (A–C, G–T, K–N, Q–T, V): valves are straight along central axis; A, C, F, L, M, R, U, T, V – valve mantle view, the areolae on the mantle are arranged in straight rows (A, L, V – LM; C, F, M, R, U, T – SEM); B, G, N – valve mantle view, the areolae on the mantle are arranged in curve rows (B – LM; G, N – SEM); L–N, Q, V – low-cylindrical frustules (N, Q – SEM; A–G, L–N, R, V – chains consisting of some valves; C, F, Q – perforations irregularly located between the rows of areolas on the valve mantle; K (valve located at the photo top) – ringleist of straight valve (SEM); H–J – external valve face (H – LM; I–J – SEM); O – post-auxospore chain with hemispherical initial valve (SEM); P – spore (SEM); S, T – fragments showing views of broken ringleist with rimoportulae (arrows) (SEM), U – valve mantle view with the external opening of the rimoportula (arrow) (SEM); Q, R – valves with tapering linking spines; C, F, G, M, N, U – valves with spade-shaped linking spines; *Aulacoseira praegranulata* var. *praeislandica* f. *curvata* (Jousé) Moiseeva (D–F, K): valves are curve along central axis; D–F – valve mantle view (D – LM; E–F – SEM), K (valve located at the photo bottom) – ringleist of curve valve (SEM).

by openings. They are located irregularly in two rings. Mantle edge is crenulate. Crenulations entwine with similar structures on valvocopula. Valvocopula ornamented of thin pores: 12–25 pores in 10 μm or vertical rows, 16–30 pores in 10 μm or horizontal rows. Valves united by means or a circular interlocking diaphragm, located along the mantle rim in valves plane. Diaphragm relief represented by a system or alternating shallow radial furrows and ribs (Fig. 6). Freshwater extinct species and known from Miocene, Pliocene (5.332–1.806 Ma), Lower Pleistocene (1.806–0.781 Ma).

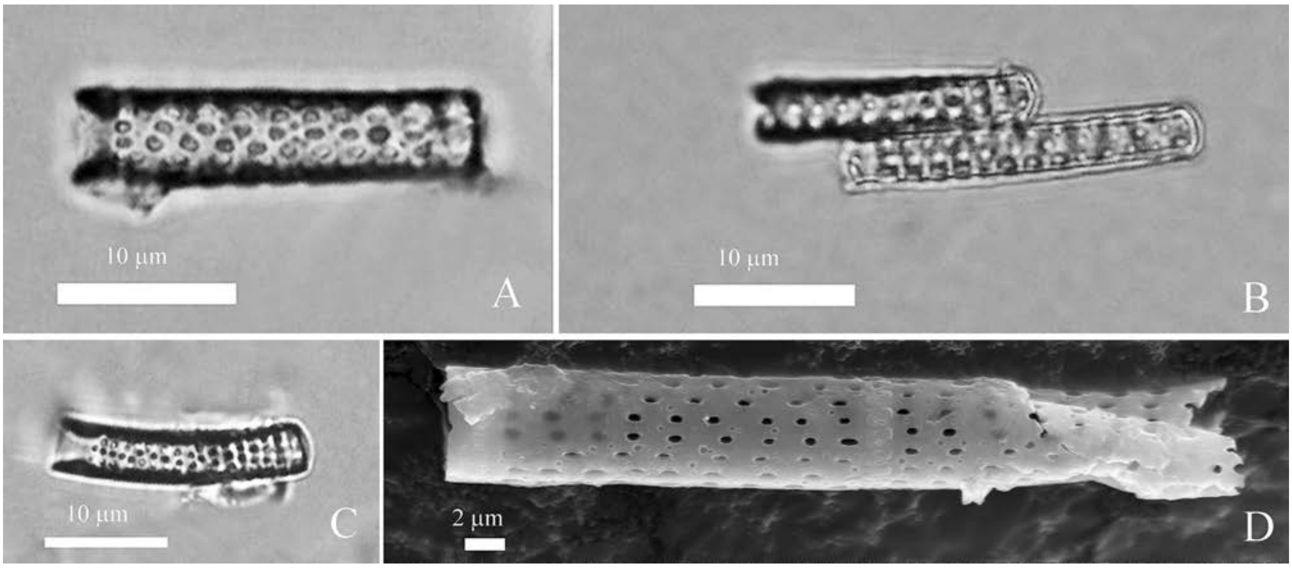

Figure 4 *Aulacoseira praegranulata* var. *praeangustissima* f. *praeangustissima* (Jousé) Moiseeva (A, B, D): valves are straight along central axis; A, B, D – long cylindrical frustules (A, B – LM; D – SEM); D – valve with high collar and perforations irregularly located between the rows of areolas on the valve mantle; *Aulacoseira praegranulata* var. *praeangustissima* f. *curvata* (Jousé) Moiseeva (C): valve is curve along central axis; C – valve with spade-shaped linking spines (LM)

Comment. The smallest valves we measured were 15.8 µm in diameter and 4 µm in height. It is smaller than that of the typical forms: 30–70 µm in diameter, 10–17 µm in height (Kuzmin et al. 2009), 34–65 µm in diameter, 15–17 µm in height (Moiseeva 1971).

MELOSIRACEAE

Melosira undulata (Ehrenberg) Kützing, 1844: 54. – *Gallionella undulata* Ehrenberg, 1840: 211.

Description. Frustules are barrel-shaped, with a flat valve face forming a very small pseudosulcus. Valves 14.35–54.1 µm in diameter, ornamented with radiating rows of striae of different lengths on the face, about 12–16 in 10 µm. Striae on the valve face are dichotomously branched and radiate from a hyaline central area. Valves are 7.65–31.28 µm in height. The mantle ornamentation is composed of parallel fine punctae arranged along the pervalvar axis, 16–22 in 10 µm. Rimoportulae form a ring one-fourth to one-third the distance between the valve and the girdle edge. Several rimoportulae are also present on the surface of the valve. Although the external mantle walls are parallel, the inner surface of the wall is clearly undulated. The undulation is seen as a varying thickness of the wall, with the thickest portion about two- thirds below the valve face. Spines are small and barely distinguishable (Fig. 7). Freshwater species and known from Miocene to the present.

Comment. The smallest valves we measured were 7.65 µm in height. It is smaller than that of the typical forms: 20–35 µm (Hustedt 1930), 18–32 µm (Moiseeva 1971), 28–47 µm (Krammer & Lange-Bertalot 1991).

DISCUSSION

The researchers studied previously the Khanka diatom flora have also noted a dominance of centric taxa in the Middle Miocene deposits. Jousé (1952) has found 12 species and intraspecific taxa of the genus *Melosira* (Table 2). Moiseeva (1971) has identified eight taxa belonging to this genus (Table 2). Pushkar and Cherepanova have studied the Middle Miocene deposits from natural rock outcrops and sediment cores. The taxonomic composition of the centric flora was supplemented. Pushkar and Cherepanova have identified 14 taxa of the *Melosira*, *Aulacoseira*, *Paralia*, *Alveolophora* (Pavlyutkin et al. 2004). Likhacheva et al. (2009) used the LM and SEM to determine the taxonomic composition of the Khanka flora and found 15 centric taxa relating to genera *Melosira*, *Aulacoseira*, *Ellerbekia*, *Alveolophora*. Likhacheva and colleagues (Likhacheva et al. 2009, Likhacheva 2013) have provided the Neogene diatom biostratigraphic scheme for Primorye, including the Middle Miocene of the Khanka Depression, using the latest evidences in taxonomy and biostratigraphic distribution of Neogene diatoms. According to the data presented above, the Khanka centric diatom flora has shown low taxonomic diversity: 10 diatom species and intraspecies taxa belonging to four genera (Table 2).

A special attention in this study was paid to investigating the dominant representatives of the genus *Aulacoseira* belonging to the "prae" group of which a great number of intermediate forms is characteristic. The species of *Aulacoseira* described in this report have been separated by more or less obvious, even if variable, morphological discrepancies in height and diameter of valves (Table 1). Analysis of the valve characteristics for three *Aulacoseira* varieties showed that diameter of *A. praegranulata* var. *praegranulata* f. *praegranulata* is less variable (Cv=14.1) than the height of valve (Cv=21.3). Both diameter (Cv=18.0) and height of valve (Cv=14.9) of *A. praegranulata* var. *praeangustissima* f. *praeangustissima* are constant. For *A. praegranulata* var. *praeislandica* f. *praeislandica*, both diameter (Cv=26.8) and height of valve (Cv=28.3) are variable. If the value of the variation coefficient does not exceed 33 %, the sample is

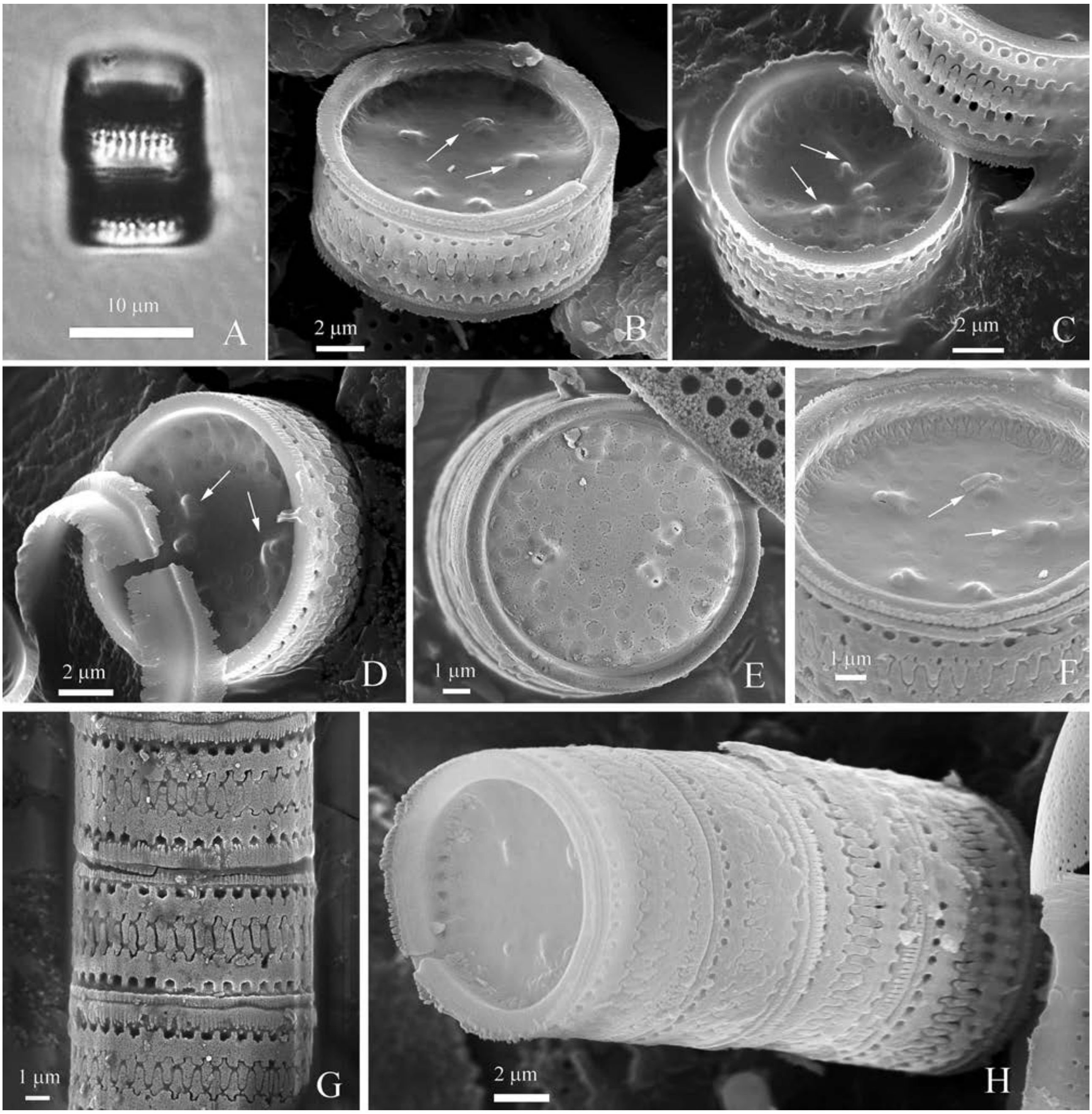

Figure 5 *Alveolophora tscheremissinovae* Khursevich: A, G – valve mantle view (A – LM, G – SEM), B–F, H – internal valve views with rimoportulae (arrows) (SEM); B–D, G–H – valve with short spatulate linking spines, H – chain consisting of some valves

homogeneous (Ershova 2015). The coefficients of variation for the valve diameter and height of *A. praegranulata* var. *praeislandica* f. *praeislandica* are less than 33 %, but higher than those for other two varieties. This value of the coefficient is determined by a wide range of valve mantle and diameter; this taxon has a high mantle and small diameter (Fig. 3A–D, G) and low mantle and large diameter (Fig. 3L–N, V, Q). Jousé (1952) has also found the diatoms with similar characteristics in the Miocene sediments of the Khanka Lake area. Jousé has described two species: *Melosira prae-islandica* (O. Müler) Jousé and *Melosira prae-distans* Jousé (hereinafter the spellings of taxa are according to the authors).

A large number of representatives of the genus *Melosira* was transferred by Simonsen (1979) to the genus *Aulacoseira*. Thus, this genus included only *A. praegranulata* (Jousé) Simonsen with form of *curvata* and *A. praeislandica* (Jousé) Simonsen. Temniskova & Vodenicharov (1981) have investigated *A. praeislandica* and *Melosira praedistans* in the Lower Pliocene freshwater diatomite from South-Western Bulgaria. The ultrastructures of valves and biometric investigations did not show the clear differences between the species. The authors concluded that these taxa belong not only to the same genus but also to the same species of *A. praeislandica*. As a result, the diagnosis of this species was expanded. Officially, these two species were later included in synonymy of *A. praegranulata* var. *praeislandica* f. *praeislandica* (Glezer et al. 1992). Usoltseva & Likhoshway (2005) have studied the original material from the Middle Miocene deposits of the Khanka Depression

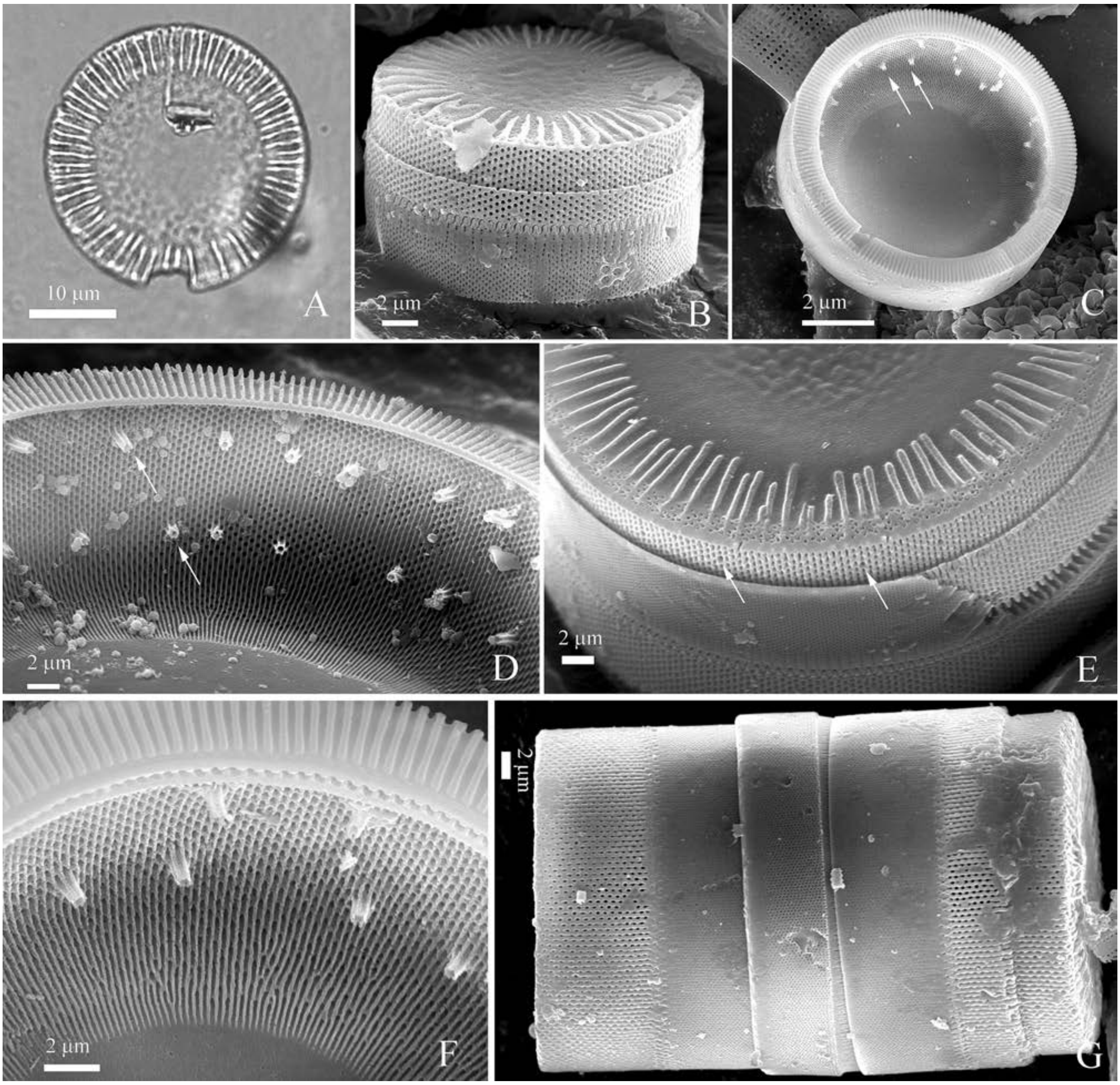

Figure 6 *Ellerbeckia kochii* (Pantocsek) Lupikina: A, B, E – valve face views with short radial ridges (A – LM; B, E – SEM); B, E, G – valvocopula consists of thin pores in vertical rows (G – SEM); B, E – radial ridges in the valve submarginal zone (SEM); C, D, F – structure of tube processes on internal valve mantle (arrows) (SEM); E – valve mantle view with the external opening of tube processes (arrows); C, D – internal valve mantle with two rings of tube processes (arrows); D, F – internal valve mantle structure

taken by Jousé in 1952. They have investigated all species of *Melosira praedistans*, *M. praeislandica* and *M. praegranulata* by SEM. It was found that there are no clear differences between these species in both the valve forms and the elements of the frustules ultrastructure (Usoltseva & Likhoshway 2005). The studied diatom taphocenoses are a set of valves which were accumulated in sediments over many thousands and even millions of years. They include valves formed in different seasons of year and at different stages of the life cycle of algae, thus, probably, we observe a wide range of fluctuations in the height and diameter of the valves.

One of the criteria for the identification of *Aulacoseira* is the valve height to valve diameter ratio (H/D) (Table 1). The H/D of *A. praegranulata* var. *praegranulata* f. *praegranulata* is 1.3–3.27, the average value of H/D ratio is 2.37, and for most valves this indicator is within 2.21–2.95. The H/D of *A. praegranulata* var. *praeangustissima* f. *praeangustissima* is 2.84–6.34, in average, 4.14 and most valves are limited to 3.23–4.49. The H/D of *A. praegranulata* var. *praeislandica* f. *praeislandica* is 0.14–2.67, in average, 0.87.

The form and localization of rimoportulae are important diagnostic features of *Aulacoseira* (Likhoshway & Crawford 2001). The investigation showed that the rimoportulae of the studied species are located on the border with the ringleist (Fig. 3S). The similar "sessile" rimoportulae were noted (Usoltseva & Likhoshway 2005) for the *Aulacoseira* species from the Jousé original material.

The diatoms have shortish structureless collar (Fig. 2B–D, Fig. 3C,F,G,U, Fig. 4A), the sulcus was not usually obscure; the areoles were locular (Fig. 2, 3, 4).

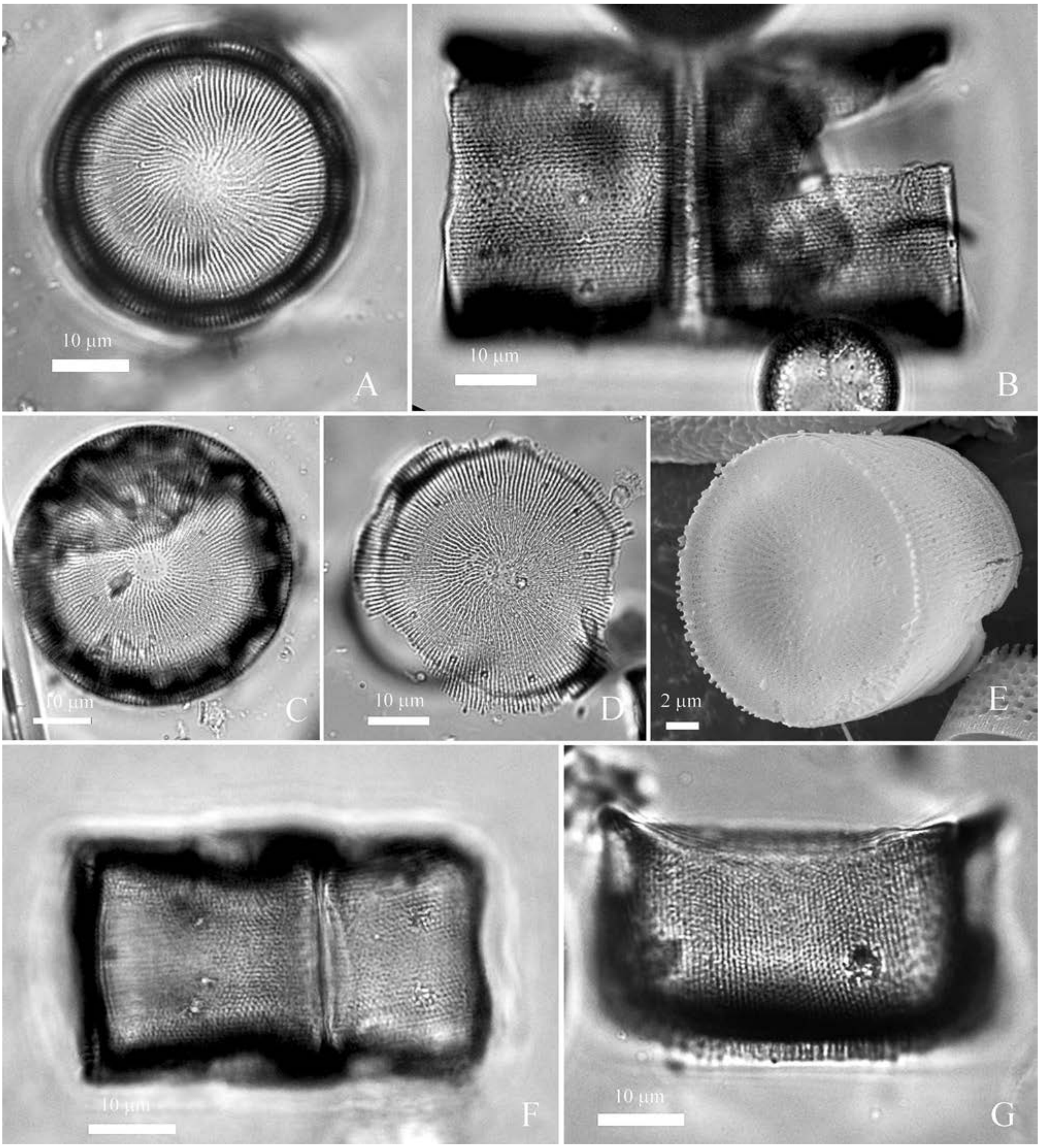

Figure 7 *Melosira undulata* (Ehrenberg) Kützing: A, C–E – external valve face (A, C–D – LM; E – SEM); B, F, G – valve mantle view showing undulate inner surface of the wall (LM); D – external valve face views showing the position of rimoportulae

The diagnoses of *Alveolophora tscheremissinovae*, *Ellerbeckia kochii* and *Melosira undulata* were supplemented. It has been established that the minimum valve diameter of *A. tscheremissinovae* (8.4 µm) is smaller than that of the typical forms – 10–24 µm (Khursevich 1994). The valve had a smaller number of rimoportulae (3–5), whereas the typical forms had 4–12. On the contrary, the number of areola rows on the mantle is larger (14–18 rows per 10 µm), while 8–12 rows in 10 µm in the typical forms. The valves of *E. kochii* had a smaller diameter (from 15.8 µm) than that indicated in the diagnosis (from 30 µm) (Glezer et al. 1992) and a lower height of valve (from 4 µm to 17 µm). The height of *E. kochii* valve is 10–15 µm (Glezer et al. 1992).

According to the diagnoses of various researchers, the minimum height of *M. undulata* valve is 20 µm (Hustedt 1930), 18 µm (Moiseeva 1971) and 28 µm (Krammer & Lange-Bertalot 1991). *M. undulata* from Novokachalinskaya Formation had a lower valve height which is 7.65 µm.

The Khanka diatom flora has been studied for more than 70 years, but there are still many questions concerned its systematics and taxonomic composition. First of all, the western lake shore exposed the Middle Miocene deposits

Table 2. Freshwater centric diatom flora from Middle Miocene deposits of the Khanka depression based on this paper and references

Centric taxa	Present study	Jousé (1952)	Moiseeva (1971)	Pushkar, Cherepanova (Pavlyutkin et al. 2004)	Likhacheva (2013), Likhacheva et al. (2009)
Aulacoseira praegranulata var. *praeislandica* f. *praeislandica*	+	**Melosira prae-islandica, M. prae-distans*	** M. praeislandica* f. *prae-islandica, M. praedistans* f. *praedistans*	*A. praegranulata* var. *praeislandica* f. *praeislandica, A. praedistans*	+
A. praegranulata var. *praeis-landica* f. *curvata*	+	**M. prae-islandica* f. *cur-vata* Jousé	**M. praedistans* f. *curvata, *M. praeislandica* f. *curvata*	+	+
A. praegranulata var. *praegra-nulata* f. *praegranulata*	+	**M. prae-granulata*	**M. praegranulata* f. *prae-granulata*	+	+
A. praegranulata var. *praegra-nulata* f. *curvata*	+	**M. prae-granulata* f. *curvata*	**M. praegranulata* f. *curvata*	+	+
A. praegranulata var. *praean-gustissima* f. *praeangustissima*	+	**M. prae-granulata* var. *prae-angustissima*	–	+	+
A. praegranulata var. *praeangustissima* f. *curvata*	+	**M. prae-granulata* var. *prae-angustissima* f. *curvata*	–	+	–
A. moisseevii Akiba et Tsoy	–	–	–	+	–
A. italica var. *italica* (Kützing) Simonsen	–	–	–	+	+
A. italica var *italica* f. *curvata* (Pantocsek) Davydova	–	–	–	–	+
Ellerbeckia kochii	+	–	*Melosira scabrosa*	*Paralia kochii*	+
Ellerbeckia arenaria var. *teres*	–	–	–	+	+
Melosira undulata	+	+	*Melosira undulata* var. *undulata* (Ehrenberg) Kützing	+	*Melosira undulata* var. *undulata*
Melosira italica f. *miocenica*	–	+	–	–	–
M. italica var. *tenuissima* f. *miocenica*	–	+	–	–	–
M. japonica	–	+	–	–	–
M. varians Agardh	–	+	–	–	–
Alveolophora khursevichiae	+	–	–	–	–
A. tscheremissinovae (=*Miosira tscheremissinovae*	+	–	–	–	+
A. jouseana	–	–	–	+	+
A. areolata	–	–	–	+	+
Miosira antiqua	–	–	–	–	+
Taxa counts by the source	**10 taxa of 4 genera**	**12 taxa of one genus**	**8 taxa of one genus**	**14 taxa of 4 genera**	**15 taxa of 4 genera**

Note: (+) taxon is present, (–) taxon is absent.
* Today, some species of the genus *Melosira* were transferred to *Aulacoseira* (Simonsen 1979).
The spellings of taxa are according to the authors.

crumbles constantly and reveals more and more layers of rocks. Consequently, within this period of time, the diatomologists could study the samples from different layers, which could be accumulated in different parts of the ancient lake (sublittoral, pelagic zone), and, possibly, even in different lakes. Pavlyutkin (2005), on the basis of the lithological-facies analysis, notes that, in the Middle Miocene time on this territory, there were lakes located at the floodplain of a large river (floodplain lakes) or at its delta (delta lakes). Nikolskaya (1952), Ivashinnikov (1978) argue that the Middle Miocene is a time of lacustrine transgression in this area. Other researchers believe that a basin similar to the present-day Khanka Lake was absent in the Miocene, and "lake baths" were in its place (Khudyakov et al. 1972, Pavlyutkin 1986, 2005). This is indicated by groups of facies of floodplains, lakes and flowing lakes (Ablaev et al. 1994). Data reported by Jousé (1952) can be a prime example of the difference in diatom flora sampled from different habitats. Jousé has studied two sections located on the western shore of the lake. The sediments of one of the sections contained the *Melosira* representatives with thin valves and plenty of spines located along the margin of the valve; the rough silicified frustules of this genus were found in sediments of another section. Jousé has noted that the structure of forms with thin valves was very subtle, sometimes barely visible and close to the structure of modern *Melosira* (= *Aulacoseira*) *italica* Kützing including the following taxa: *Melosira italica* f. *miocenica* Jousè, *M. italica* var. *tenuissima* f. *miocenica* Jousé, *M. japonica* Pantocsek. Unfortunately, the thin-walled taxa discovered by Jousé cannot be compared either with fossil or with modern ones, since there are only brief diagnoses without micrographs in the paper (Jousé 1952).

Strange as it may sound, the next problem complicating the comparative analysis of the Khanka diatom flora is the development of the instrumental base. The introduction of electron microscopy into the morphological studies after the 1970s made it possible to carry out a detailed study of the diatom valves ultrastructure and revolutionized the taxonomy of diatoms (Loseva 2002). As a result, a majority of the *Melosira* taxa specified in the Jousé and Moiseeva papers were transferred to another genus – *Aulacoseira*. *Melosira prae-islandica* (O. Müller) Jousè and *M. prae-distans* Jousé described by Jousé were included as synonymics of *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* (Simonsen) Moiseeva (Glezer et al. 1992).

So, *Melosira scabrosa* Øestrup found by Moiseeva (1971) in the Miocene deposits of the Khanka Lake area was transformed in 1986 to *Paralia scabrosa* (Øestrup) Moiseeva (Moiseeva 1986); currently, this taxon is *Ellerbeckia arenaria* var. *teres* (Brim) Crawford (Glezer et al. 1992). According to the diagnosis and LM microphotographs, *Meloira scabrosa* (Moiseeva 1971) is characterized by short ridges up to 1/3 or 1/2 of the valve radius (7–9 in 10 µm), which is similar to the *Ellerbekia kochii* found by us. *E. kochii* differs from *E. arenaria* var. *teres* by a length of ridges on the valve face and the features of tube processes on the internal surface. The ridges on valve face of *E. kochii* are shorter than 1/3 of the valve radius, the number of ridges is 6–10 in 10 µm, original tube processes (2–3 in 10 µm) are formed by 4–6 ribs curved in spiral order, whereas valves of *E. arenaria* var. *teres* are characterized by short ridges up to 1/3 of the valve radius, 4–6 in 10 µm, the polyhedrous tube processes are formed by four, rarely, two ribs (Glezer et al. 1992). The number of ribs forming the polyhedrous tube processes can be counted only using SEM. Often, *E. kochii* has considered in *E. arenaria* var. *teres* volume (Glezer et al. 1992). Additional studies of *Ellerbekia* morphology are necessary for a correct diagnostics of taxa from this genus.

It is rather difficult to compare data on the quantitative participation of taxa in the diatom taphocoenoses. It is associated with different systems of diatom counting used by the researchers. Jousé (1952) and Moiseeva (1971) have used the Visloukh grading scale with following categories: separately, rare, not infrequently, frequently, over and over again and in the mass. At present, the diatomologists calculate the percentage of diatom taxa in the taphocenoses. This makes possible to understand the ratio of taxa in the fossil community. Thus, even a short list of problems shows that further study of the Khanka diatom flora is needed.

Nevertheless, owing to the accumulated data and detailed examination carried out by us, the Middle Miocene diatom centric flora was sufficiently characterized in order to assess its image and perform comparison with the even-aged diatom floras studied from continental deposits of other regions. Unfortunately, there is no one continuous sequence of Neogene (23–1.8 Ma) continental deposits of the Far East of Russia. There are only separated sections located at different points of the region which makes their correlation difficult. In addition, the continental diatoms, in comparison with the marine ones, have high rates of speciation due to the diversity of terrestrial biotopes and variability of ecological parameters. They are also sensitive to fluctuations of the environmental conditions which results in a wide range of phenotypic variability. The listed diatom features make them a good tool for reconstructing the paleoenvironmental parameters. However, they complicate the correlation of faciesly heterogeneous strata, since deposits may contain the diatom complexes with incommensurable ecological structures (Likhacheva et al. 2009). When identifying the diatom complexes and their using for local and regional correlation, it is necessary to be founded, first of all, on the diatom evolution. Undoubtedly, this process should be considered in combination with the geological and paleogeographical events fixed on this territory. The understanding of these regularities increases validity of constructions based on analysis of floras. The established phasing provides the possibility to creating the zonal stratigraphic continental scales. The maximal certainty is characteristic of the biostratigraphic zonal scales where the changes of the paleoecosystems with close living environment and, in the aggregate, constituting the chronology of the paleobiosphere variations during specified time interval are reflected. At present, the zonal biostratigraphic scales for the Neogene of Primorye (Likhacheva et al. 2009) and Russian Far East (Moiseeva 1995) were successfully developed; the age distribution of diatom complexes was determined. This allows us to compare the Middle Miocene centric flora of the Khanka Depression with the even-aged complexes from other regions of Far East.

The Middle Miocene centric diatom flora of the Khanka Depression has a particular similarity to the even-aged floras from other regions of Primorye Territory: the Tony Lake area (basin of the Samarga River) and the basin of Suputinka River (Moiseeva 1971), and also from Baikal region (Popova et al. 1989, Chernyaeva et al. 2007, Enikeev 2008), and eastern China (Li et al. 2010). In floras from all the areas, the centric taxa dominate. *Melosira praeislandica* f. *praeislandica* (= *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica*) dominates in deposits of Tony Lake area and the basin of Suputinka River. *Melosira scabrosa* (= *Ellerbekia kochii*) dominates in the diatom complex from the basin Supputinka River. *Melosira undulata* is absent in the deposits from the Tony Lake area. This is the difference between these floras and the Khanka flora. The *Melosira* (= *Aulacoseira*) genus has dominated in the Middle Miocene deposits of the Chara Basin located in the eastern part of the Baikal-Stanovoy Upland (Enikeev 2008). In these deposits, there are following taxa from the genus *Melosira*: *Melosira praedistans* Jousé, *Melosira* sp. (aff. *canadensis*), *M. distans* (Ehrenberg) Kützing, *M. distans* var. *alpigena* Grunow, *M. italica* (Ehrenberg) Kützing, *M.* aff. *praegranulata* Jousé. *Paralia scabrosa* (Østrup) Moiseeva is subdominant. The diatom photos are absent in the Enikeev article, therefore, we can only assume that, judging by mention of name *Melosira* genus renamed at present as *Aulacoseira* and those renamings which we fore mentioned, in the Middle Miocene complex of the Chara Basin, the *Aulacoseira praegranulata* var. *praeislandica* f. *praeislandica* and *Ellerbekia* *kochii* were found. *Aulacoseira praegranulata* var. *praegranulata*, *A. praegranulata* var. *praeislandica*, *Pseudoaulacosira moisseeviae* (Lupikina) Lupikina & Khursevich ex Usoltseva & Houk dominate in Dzhilinskaya Depression deposits of Western Transbaikalia; *Alveolophora jouseana* (Moiseeva) Moiseeva, *Melosira undulata*, *Aulacoseira baicalensis* (K. Meyer) Simonsen take lesser part (Chernyaeva et al. 2007). *Aulacoseira* cf. *distans* (Ehrenberg) Simonsen and *Melosira youngi* Skvortsov were found in the Middle Miocene Shanwang Formation, Shandong Province, East China (Li et al. 2010). Thus, this may be regarded as a wide distribution of centric taxa in the Middle Miocene water bodies of the entire Far East.

It is interesting to note that the freshwater centric diatoms were quite widely distributed in the Miocene of Europe (Khursevich 2007), Turkey (Servant-Vildary et al. 1988), USA, Oregon (Ledgerwood & Tassell 2006) and so on. These are also the represernatives of the genus *Aulacoseira*. The record of the genus *Aulacoseira* goes back not less than 45 million years (Khursevich 1995, Krebs 1994), and habitation of this genus in the Tertiary lacustrine deposits is natural occurrence (Haworth & Sabater 1993, Khursevich 1995). Probably, such wide occurrence and dominance of the representatives of this taxon in the Middle Miocene is related to the particular evolutional stage of development of diatoms when the maximum generic and species diversity of the freshwater centric diatoms is observed. Likely, the quick evolution of this genus is a result of the global climatic phenomena, particularly, climatic optimum of the Middle Miocene which followed on the cold spell of Oligocene. According to the data of paleobotany (Bondarenko et al. 2019), the lukewarm conditions were established for the Late Oligocene (24.0 ± 3.0 mil. years) in Primorye. According to the data for diatom algae (Likhacheva et al. 2009), the warming has begun in the Miocene and reached a peak in its middle. The Middle Miocene was warmest within a period of 30 million years (Zachos et al. 2001).

CONCLUSION

The freshwater centric diatoms of the *Aulacoseira*, *Alveolophora*, *Ellerbeckia* and *Melosira* genera from the Middle Miocene deposits of Primorye (Far East of Russia) were studied in detail usimg the light and scanning electron microscopes.

As a result, the considerable morphological variability of predominant representatives of the genus *Aulacoseira* was established. The measurements of the valve heights and diameters of *Aulacoseira* taxa have shown that *A. praegranulata* var. *praeislandica* f. *praeislandica* are characterized by high variability of these parameters; *A. praegranulata* var. *praegranulata* f. *praegranulata* has the constant characteristics; *A. praegranulata* var. *praeangustissima* f. *praeangustissima* has the constant heights of valves.

The diagnoses of *Alveolophora tscheremissinovae*, *Ellerbeckia kochii* and *Melosira undulata* were supplemented.

Unfortunately, we don't find the centric taxa previously identified by others researchers such as *Alveolophora jouseana* (Moiseeva) Moiseeva, *Alveolophora areolata* Moiseeva (Pavlyutkin et al. 2004, Likhacheva et al. 2009), oval *Miosira antiqua* (Moiseeva) Khursevich and taxa of *Actinocyclus* Ehrenberg, *Mesodictyon* E.C. Theriot & J.P. Bradbury genera (Likhacheva et al. 2009). Additional researchs are necessary for complete evaluation of the taxonomic composition. New data from Middle Miocene-Holocene diatomaceous sediments of the Khanka Depression need to be investigated. The samples selected from the continuous sections that preserve the consistent lake history will provide the additional data for objective paleogeographic reconstruction and the diatom flora evolution in the past.

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