ISSN 1995-4255, Contemporary Problems of Ecology, 2015, Vol. 8, No. 2, pp. 173–185. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © G.N. Bolobanschikova, D.Yu. Rogozin, A.D. Firsova, E.V. Rodionova, N.N. Degermendzhy, A.V. Shabanov, 2015, published in Sibirskii Ekologicheskii Zhurnal, 2015, No. 2, pp. 215–228.

Analysis of Diatom Algae from the Water Column and Bottom Sediments of Shira Lake (Khakassia, Russia)

G. N. Bolobanschikova[a], D. Yu. Rogozin[a, b], A. D. Firsova[c], E. V. Rodionova[c], N. N. Degermendzhy[d], and A. V. Shabanov[e]

[a] *Institute of Biophysics, Siberian Branch, Russian Academy of Sciences, ul. Akademgorodok 50/50, Krasnoyarsk, 660036 Russia*

[b] *Siberian Federal University, pr. Svobodnii 79, Krasnoyarsk, 660041 Russia*

[c] *Limnological Institute, Siberian Branch, Russian Academy of Sciences, ul. Ulan-Batorskaya 3, Irkutsk, 664033 Russia*

[d] *Krasnoyarsk State Medical University, ul. Partizana Zheleznyaka 1, Krasnoyarsk, 660022 Russia*

[e] *Institute of Physics, Siberian Branch, Russian Academy of Sciences, ul. Akademgorodok 50/38, Krasnoyarsk, 660036 Russia*

e-mail: galina.ibp@mail.ru, rogozin@ibp.ru, firsova@lin.irk.ru, rodionova@lin.irk.ru, nd1947@yandex.ru, alexch@nikel.akadem.ru

Received November 28, 2013; in final form, June 23, 2014

Abstract—Lake Shira as a meromictic lake is object of interest for paleolimnological studies. In May 2011 core samples were collected from the bottom of Lake Shira and the species composition of diatom algae, which serve as bioindicators of the state of the lake, were studied. In addition, in 2012, seasonal water samples and material from sediment traps were collected and the species composition of diatoms in them was analyzed. The results of the analysis showed that the lake, like in previous years of research, was dominated by *Cyclotella choctawhatcheeana* Prasad. Diatoms were found twice in the studied core above the white carbonate layers and were absent in other layers. The species living in the lake at present were observed down to the first white carbonate layer, including the predominant *Cyclotella choctawhatcheeana*. This fact presumably proves the consistency of the species composition of diatoms and the overall stable condition of the lake since 1946 (Rogozin et al., 2005). Down to the second white carbonate layer, the dominant species were *Aulcosira valida* (Grunow) Krammer and *Aulcosira italica* (Grunow) Simonsen. *Nitzchia sigmodea* (Nitzsch) W. Smith and *Fragilaria construens* var. *venter* (Ehrenberg) Grunow were also observed at these depths, dating approximately to 1655–1690. These are freshwater species that belong to the diatoms of arctic, alpine, and temperate latitudes, which develop in shallow waters under moderate temperature conditions. This fact suggests that Lake Shira was less salty in the middle and end of the 17th century than today.

Keywords: paleolimnology, diatom algae, meromictic lake, sedimentation, *Cyclotella choctawhatcheeana*, *Aulacoseira valida*, *Aulacoseira ambigua*

DOI: 10.1134/S1995425515020031

INTRODUCTION

Lake Shira (90.11′ E, 54.30 N, settlement of Zhemchuzhnyi, Shira district, Republic of Khakassia, Russia) is located in the northern part of the Republic of Khakassia, 17 km from town of Shira. The lake is meromictic, low salty, and slightly alkaline (pH of 8.9–9.2). During the summer season, the period of the most pronounced density stratification, mineralization in mixolimnion is about 15 g L^{-1}; in monimolimnion it is about 19 g L^{-1} (2002–2012) (Rogozin et al., 2005).

The area of the lake is 39.5 km^2 and there is a maximum depth of about 24 m. The terminal Lake Shira is fed by Son River, as well as atmospheric precipitation, groundwater, and anthropogenic input (Makeeva and Naumenko, 2012). From a depth of 12–13 m, the lake is characterized by stable anaerobic zone where the concentration of hydrogen sulfide in the bottom layers of water is around 15–20 mg/L. The study of sediments allows one to reconstruct paleoclimatic conditions. For this purpose it is necessary to compare the indicators of the state of Lake Shira in the past and at present. Diatoms have always been considered one of the best bioindicators of aquatic ecosystems and, due to this, the diatom analysis is widely used to monitor water pollution (Belyakova, 2006; Tracey et al., 1996).

The species composition and the vertical structure of phytoplankton in Lake Shira were studied earlier in 1946–2009. According to these studies, the species composition of microalgae includes 30–74 species of four series (blue-green, diatoms, green, and pyrrophite). All authors noted the predominance of blue-green algae (Makeeva and Naumenko, 2012). The data obtained in 1996 show that diatoms in Lake Shira are represented by the following species: *C. choctawhatcheeana*, formerly known as *C. tuberculata*

Makarova & Loginova (Genkal, 2012); *Diatoma vulgaris* Bory; *Navicula* sp., *Nitzschia* sp.; and *Stephanodiscus* sp. (Zotina and Tolomeev, 1997). In the summer *C. choctawhatcheeana* dominated (Zotina and Tolomeev, 1997). Apart from the fact that *C. choctawhatcheeana* is a common species, during all the period of research of the species composition of phytoplankton in Lake Shira, this species was noted as a dominant diatom species, as well as the dominant species of phytoplankton in general (Aleksandrovskaya et al., 1959; Degermendzhy et al., 1996; Cherepnina, 1997). In April 1997 and March 1998, pennate diatoms of *Navicula lanceolata* Ehrenberg and *Nitzschia palea* (Kützing) W. Smith (Zotina, 2000) dominate in the lower ice edge. According to (Kolmakov et al., 1993), diatom algae are most diverse in the southeastern part of the lake near the mouth of the River Son. The River Son supplies the lake with a rich algal flora with the dominant diatom *Stephanodiscus hantzschii* Grunow.

Results of the analysis of the water column in 2006–2009 (Makeeva and Naumenko, 2012) showed that diatoms constitute 59.4% of the total species composition of Lake Shira.

The first study of the pelagic plankton in the central part of the lake showed that it is represented by five species of Bacillariophyta with dominant *C. choctawhatcheeana*. In connection with this, the goal of our work was to study the fossil diatom composition of bottom sediments of meromictic Lake Shira (Khakassia), compare the data being obtained with modern ones, and obtain another data set for paleoclimatic reconstruction.

MATERIALS AND METHODS

Analysis of the Water Column

For the further analysis of diatoms in the bottom sediments, the phytoplankton in Lake Shira was investigated. The sampling was performed in the spring (May 25, 2012), summer (July 11, 2012), and autumn (September 4, 2012) in the central part of the lake at different depths (0, 2, 3, 5, 7, 9, 11, 13, 15, and 17 m).

In order to collect samples, a Jedi plankton net (gas no. 70) was used. Samples were stored in 70% alcohol and concentrated by siphoning to a volume of 30–50 mL. Then, cells were counted on a grid glass of 0.1 cm^3 (Vasser et al., 1989) under a light microscope (Axiostar Plus Zeiss, Germany). In order to determine small-cell algae species, samples were collected on a filter with a pore diameter of 1.2 μm (Millipore, United States), then coated with gold and analyzed with a Quanta 200 scanning electron microscope (FEI Company).

Analysis of Sedimentary Material

Sediment traps are open polypropylene cylinders 580 mm long, 103 mm in diameter, and with a transparent plexiglass bottom. The traps were exposed in the central deep part of the lake near the site with coordinates of 54°30′350 N and 90°11′350 E in the following periods (2012 year): March 14 to May 27, May 26 to July 7, July 8 to September 4, and September 4 to October, 24. The above exposure periods are conventionally referred to as March–May, June–July, July–September, and September–October.

Sediment traps were linked by an anchored caprone cord with a buoy at the upper end to fix the cord in a vertical position. The buoy was situated at a depth of 2–3 m from the water surface to diminish the wave effect, and also to prevent it from freezing. In summer and autumn periods an additional signal 1.5 L buoy was attached to the buoy with a thin cord. It floated on the surface to show the location of traps. The traps, exposed under the ice cover in March, were found and extracted in May by trawling with two boats. In the March–May period, traps were placed at depths of 15 and 20 m; in other periods they were at depths of 13, 15, and 20 m. At every depth horizon, two traps were exposed; the data were averaged for each horizon.

After exposure and trawling to the lake shore, the traps were kept upright during four hours. Then, the upper parts of traps were drained through openings 100 mm above the bottoms. The residue was thoroughly mixed with the remaining volume of water (900 mL). The resulting suspension was poured into plastic containers and hermetically sealed.

Three samples (1.5 mL each) from each trap were collected then oven-dried within 24 h at a temperature of 100°C. The dried precipitate was treated by 30% hydrogen peroxide solution being heated in a solid state thermostat up to a temperature of 90°C for 4 h at a constant addition of peroxide solution (Vasser et al., 1989). After cooling, samples were washed with distilled water to remove peroxide using centrifugation (5 times) and diluted with distilled water to a final volume of 1.5 mL. Then 20 μL aliquots were taken from the volume, placed as drops on the cover glass, and dried. The drop square was determined as that of an ellipse. The number of diatom cells in a drop was counted under a Carl Zeiss FL 40 fluorescence microscope (×100) with immersion oil. Test samples were previously fixed with Canadian balsam (Vasser et al., 1989). The number of cells in a drop was recalculated in terms of the total number of all samples in all sedimentary material of a trap and weighed in a volume of 900 mL. The sediment flow was calculated based on the total amount of cells trapped, the time of exposure of a trap, and the cross section of a trap.

To determine the species composition, the samples were analyzed with a Hitachi scanning electron microscope TM-3000 (×20–×30000) in Krasnoyarsk Scientific Center, Siberian Branch, Russian Academy of Sciences (KSC SB RAS), on a 10 cm microscope stage while controlling volumes and proportions (drop diameter ≈1 cm; test sample volume is 20 μL + 10 μL of ethyl alcohol. Drying was done with a drier).

Core Analysis

A 400 mm long sample was collected in May 2011 with a box-shaped corer developed at the Institute for Biology of Inland Waters (IBIW), Russian Academy of Sciences (Borok, Russia), which allows one to sample a 160 × 160 mm square area at the maximum depth of sampling the bottom sediments of up to 440 mm.

After the sample collected with a box-shaped corer is transported to the lake shore, cores were immediately taken from it with plastic tubes with an inner diameter of 45 mm. The tubes were hermetically sealed on both ends and stored upright at +4°C. In the laboratory, the core was cut lengthwise and separated into halves with two thin stainless steel plates inserted into the incision. After separation of the core, plates were removed by displacement in the transverse direction. This allowed us to keep the cut surface undamaged and preserve visible horizontal layered inhomogeneities. The core halves were kept at low light in air for 24 h to have color differences more vivid. Then, a color photo of each core with a fixed millimeter ruler was taken. After that, the core halves were separated into cross sections (slices) in increments of 5–10 mm. All samples were stored in airless plastic bags at –20°C in the darkness (Rogozin et al., 2011).

During the selection of samples, the upper core layers were washed and missed. Due to this, in order to tie samples to a uniform depth scale, the upper boundary of the first "white" layer was used as a reference point 130 mm from the interface surface of "water–bottom sediments." The exact position of this boundary was previously defined (Kalugin et al., 2013).

The visual counting of the layers demonstrated that the upper boundary of the first white carbonate layer corresponds to 1945 (Kalugin et al., 2013). The first white carbonate layer begins at a depth of 130 mm (conventional boundary of the 1st white layer, as determined by the sample of "box 2010") and ended at a depth of 160 mm. The second white layer begins at a depth of 360 mm (Fig. 1).

The age of studied intervals was estimated by counting the separate annual layers, the nature of which was confirmed by the occurrence of the peak of artificial radioactive isotope ^{137}Cs, corresponding to 1963 (the year of global fallouts from nuclear tests) in the section (Rogozin et al. 2011; Kalugin et al., 2013).

After separation of the core into slices, we obtained 62 test samples which were treated by 30% hydrogen peroxide according to the standard procedure (*Diatomovye...*, 2002; Cherepnina, 1977). A qualitative analysis of samples was performed with a Quanta 200 scanning electron microscope (FEI Company) (Department of Cell Ultrastructure, Limnological Institute, Siberian Branch, Russian Academy of Sciences). The samples were analyzed by SEM.

The mixture of 10 μL of ethanol and 20 μL of the test sample +10 μL of ethanol was placed in a 1-cm stainless steel sterile stage then dried with an incandescent lamp

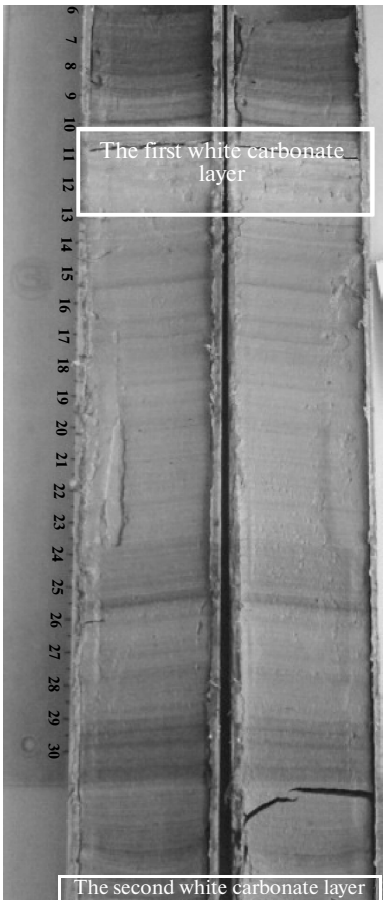

Fig. 1. Core from the upper part of bottom sediments of Lake Shira (Khakassia), May 2011.

for an hour and coated with gold. After that, stages were placed in the SEM under examination at increasing magnification from ×1500 to ×5000. The core samples were analyzed by SEM to a depth of 190–195 mm. The other core samples were analyzed with a TM-3000 Hitachi scanning electron microscope. For a more accurate determination of the species composition, some samples were examined with a Hitachi S-5500 scanning electron microscope (Kirensky Institute of Physics of Russian Academy of Sciences, Center for Collective Use of Krasnoyarsk Scientific Center, Siberian Branch, Russian Academy of Sciences). In order to determine diatom species, field guides and systematic reports were used (Zabelina et al., 1951; *Diatomovye...*, 2002; Genkal and Trifonova, 2009; Lange-Bertalot, 2001; Levkov, 2009); to clarify the authors of species the site http://algaebase.org was used.

RESULTS

Diatoms of the Water Column

Spring samples (May 25, 2012) at depths of 0, 2, 3, 5, 7, 9, and 11 m dominate four algae species of *Planktolyngbya contorta* (Lemmermann) Anagnostidis &

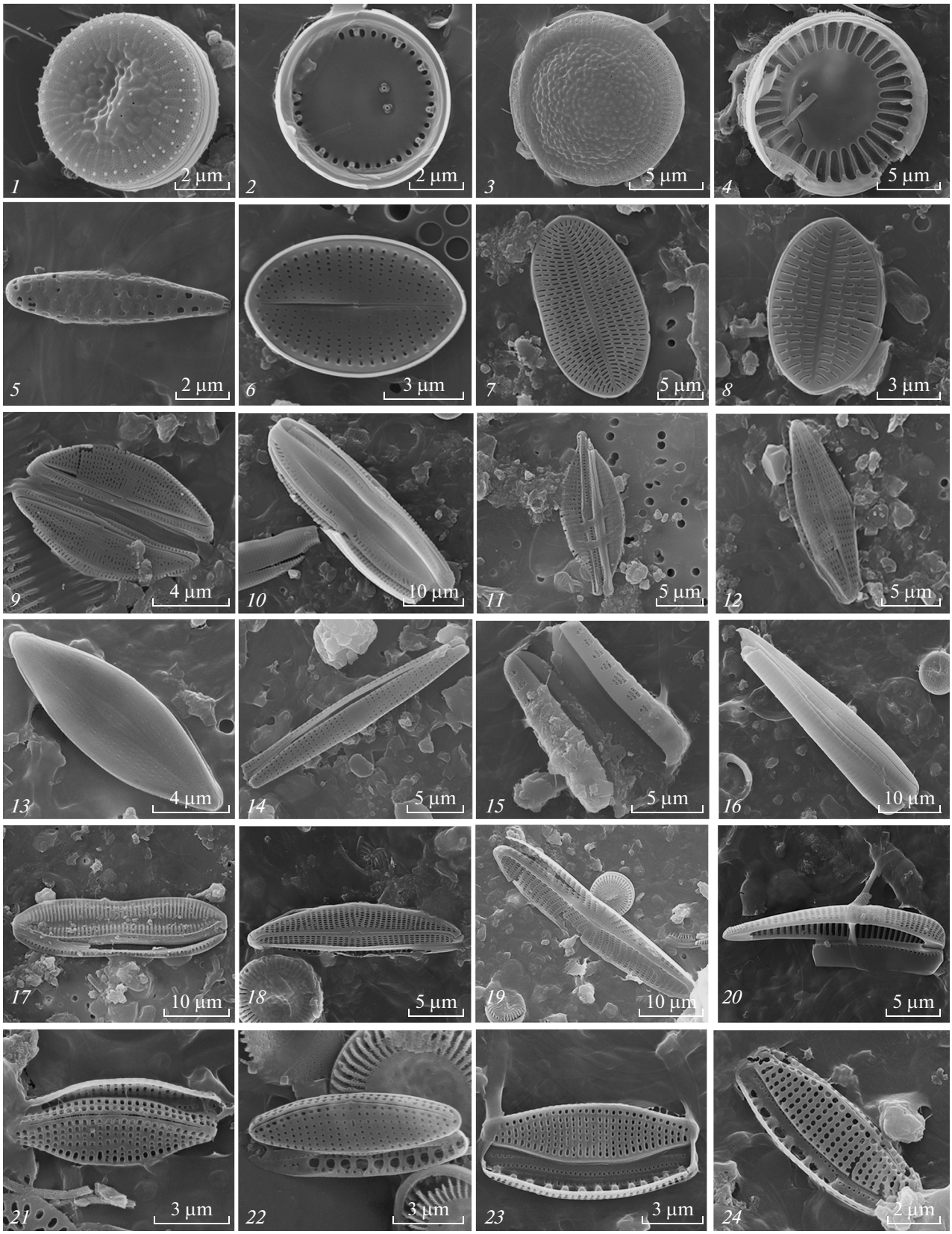
1
2 μm
2
2 μm
3
5 μm
4
5 μm
5
2 μm
6
3 μm
7
5 μm
8
3 μm
9
4 μm
10
10 μm
11
5 μm
12
5 μm
13
4 μm
14
5 μm
15
5 μm
16
10 μm
17
10 μm
18
5 μm
19
10 μm
20
5 μm
21
3 μm
22
3 μm
23
3 μm
24
2 μm

Fig. 2. Diatom algae from the water column of Lake Shira in the spring, summer, and autumn periods: (*1*, *2*, *3*) *Cyclotella choctawhatcheeana*; (*4*) *C. meneghiniana* Kützing; (*5*) *Martyana martyi* (Héribaud) Round; (*6*) *Cocconeis placentula* var. *lineata* (Ehrenberg) van Heurck; (*7*) *C. placentula* Ehrenberg var. *placentula*; (*8*) *C. euglyptoides* (Geitler) Lange-Bertalot; (*9*) *Halamphora* sp. (Kützing) Levkov; (*10*) *Amphora aequalis* Krammer; (*11*) *H. coffeaeformis* (C. Agardh) Levkov; (*12*) *Navicula cryptocephala* Kützing; (*13*) *N. menisculus* Schumann; (*14*) *Fragilaria* sp.; (*15*) *Opephora olsenii* Müller; (*16*) *Gomphonema olivaceum* (Hornemann) Brébisson; (*17*) *Tryblionella acuminata* W. Smith; (*18*) *Seminavis pusilla* (Grunow) E.J. Cox & G. Reid; (*19*) *N. cincta* (Ehrenberg) Ralfs; (*20*) *Rhoicosphenia curvata* (Kétzing) Grunow; (*21*) *Nitzschia microcephala* Grunow; (*22*) *N. acidoclinata* Lange-Bertalot; (*23*) *N. perminuta* (Grunow) M. Peragallo; (*24*) *N. frustulum* var. *subsalina* Hustedt.

Komaárek (Cyanobacteria), *S. choctawhatcheeana* (Bacillariophyta), *Oocystis lacustris* Chodat (Chlorophyta), and *Rhodomonas salina* (Wislouch) D.R.A. Hill & R. Wetherbee (Cryptophyta). The highest abundance and biomass volume of *S. choctawhatcheeana* was noted in a 3-m layer (129.5 thousand. cells a liter and 77.9 mg/m^3, respectively). The highest abundance of *S. choctawhatcheeana* was noted in the autumn season in the 9-m layer (657 thousand cells a liter; biomass of 128 mg/L). Figure 2 presents the species compositions in spring, summer, and autumn periods.

Near the transition to the chemocline zone with anaerobic conditions at a depth of 13 m, the number of dominant species is sharply reduced. At this, the small-cell cyanobacteria *Synechocystis* become dominant. The total species composition of diatom plankton of Shira Lake for the year 2012 is presented in the table.

Diatoms in Sedimentary Material

The results of a qualitative analysis showed that *C. choctawhatcheeana* is the dominant diatom species in all studied periods both in the sedimentary material of traps and water column samples. Along with *C. choctawhatcheeana*, traps sporadically contained the following types: *Amphora* sp., *A. aequalis*, *Synedra* sp., *Navicula menisculus*, and others (Fig. 3).

Seasonal dynamics in a number of diatoms in traps shows that diatom cells were abundant in the spring–summer period (May–July; Fig. 4). At this time, the

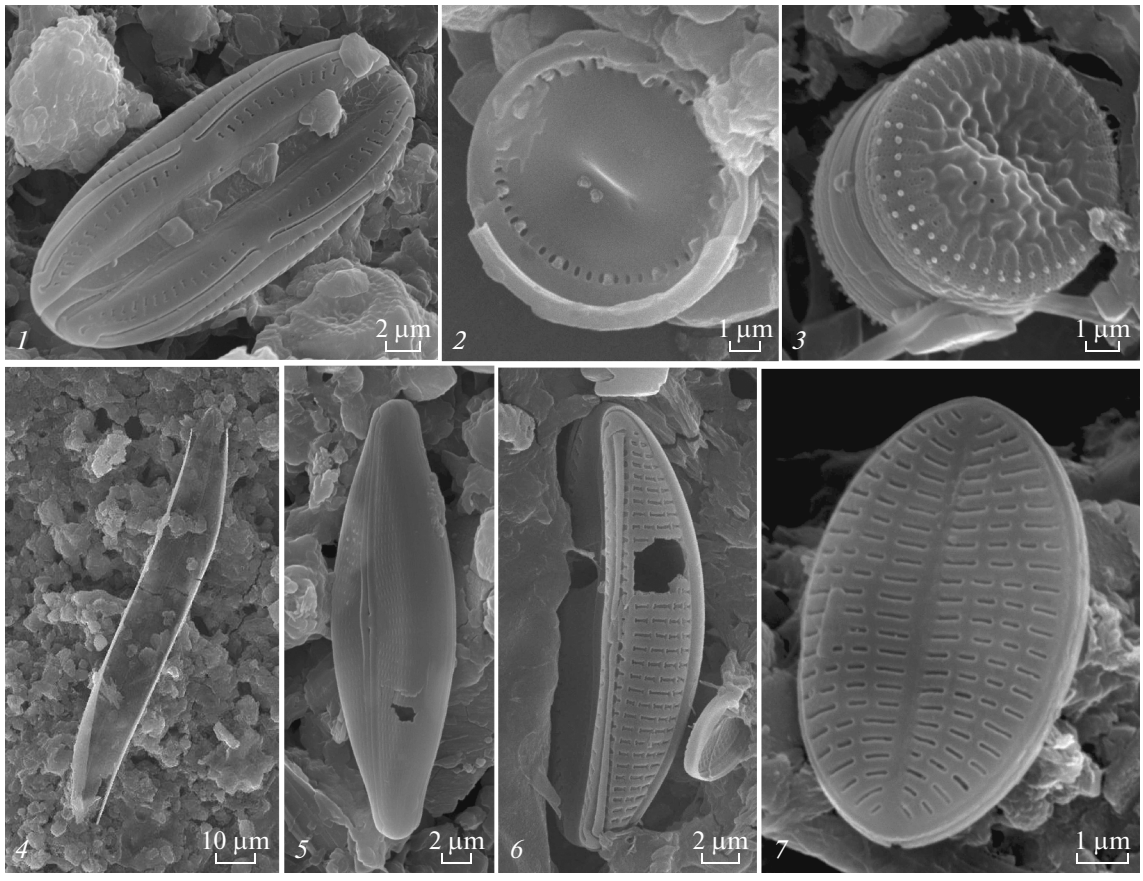

Fig. 3. Diatom algae from sediment traps: (*1*) *Amphora aequalis* Krammer; (*2*, *3*) *Cyclotella choctawhatcheeana*; (*4*) *Synedra fasciculata* Ehrenberg; (*5*) *Navicula menisculus* Schumann; (*6*) *Amphora aequalis* Krammer; (*7*) *Cocconeis euglyptoides* (Geitler) Lange-Bertalot.

Taxonomy of diatom algae from the water column of Lake Shira (Khakassia, Russia)

Taxon	Halobity	pH	Geography	Location
Series Bacillariophyta				
Class Centrophyceae				
Family Aulacoseiraceae Moisseeva				
Genus *Aulacoseira* Thwaites				
Aulacoseira valida (Grunow) Krammer	ind	alf	bor	p
A. ambigua (Grunow) Simonsen	ind	alf	bor	p, b
Family Stephanodiscaceae Makarova				
Genus *Cyclotella* (Kützing) Brébisson				
Cyclotella sp.	–	–	–	–
C. meneghiniana Kützing	hl	i	c	p
C. choctawhatcheeana Prasad	hl		Ha	p
Genus *Stephanodiscus*				
Stephanodiscus sp.	ind	alb	bor	p
S. hantzschii Grunow	ind	alb	bor	p
Class Pennatophyceae				
Order Araphales				
Family Fragilariaceae (Kützing) De Toni				
Genus *Fragilaria* Lyngbye				
Fragilaria sp.	ind	alf	bor	–
F. construens var. venter (Ehrenberg)	ind	alf	c	–
Genus *Martyana* Round				
Martyana martyi (Héribaud) Round	–	–	–	–
Genus *Opephora* Petit				
Opephora olsenii Møller	hl	–	–	–
Genus *Synedra* Ehrenberg				
Synedra sp.	–	–	–	–
Family Diatomaceae Dumortier				
Genus Diatoma Bory				
Diatoma vulgaris Bory	ind	alf	bor	–
Order Rhaphales				
Family Naviculaceae West.				
Genus *Cocconeis* Ehrenberg				
Cocconeis sp.	–	–	–	–
C. euglyptoides (Geitler) Lange-Bertalot	ind	alf	c	p, b
C. placentula Ehrenberg var. *placentula*	ind	alf	alf	p, b
C. placentula var. *lineata* (Ehrenberg) Van Heurck	ind	alf	–	
Genus *Navicula* Bory				
Navicula sp.	–	–	c	–
N. cincta (Ehrenberg) Ralfs	hl	alf	c	–
N. cryptocephala Kützing	hl	alf	c	b
N. lanceolata Ehrenberg *radiosa* Kützing	hl	alb	c	b

Table (Contd.)

Taxon	Halobity	pH	Geography	Location
Order Naviculales				
Family Diadesmidaceae				
Genus *Diadesmis* Kützing				
Diadesmis sp.	ind	i		b
Family Rhoicospheniaceae Mann				
Genus *Rhoicosphenia* Grunow				
Rhoicosphenia curvata (Kützing) Grunow				
Family Cymbellaceae (Kützing) Grunow				
Genus *Amphora* Ehrenberg	–	–	–	–
Amphora sp.	–	–	–	–
A. aequalis Krammer	–	–	–	–
A. aff. *aequalis* Krammer	–	–	–	–
Genus *Halamphora* Kützing (Cleve) Levkov				
Halamphora sp.	mh	alf	c	b
H. veneta (Kützing) Levkov	hl	alf	c	b
H. coffeaeformis (C. Agardh) Levkov	mh	alf	c	b
Genus *Seminavis* Mann				
Seminavis pusilla (Grunow) E.J.Cox & G. Reid	hl	i	c	–
Family Gomphonemataceae (Kützing); Grunow				
Genus *Gomphonema* Ehrenberg				
Gomphonema olivaceum (Hornemann) Brébisson	ind	alf	c	–
Family Epithemiaceae Grunow				
Genus *Epithemia* Brébisson				
Epithemia sorex Kützing	hl	alf	c	b
Family Rhopalodiaceae				
Genus *Rhopalodia* O. Müller				
Rhopalodia gibberula (Ehrenberg) O. Müller	hl	alf	c	–
Family Nitzschiaceae				
Genus *Nitzschia* Grunow				
Nitzschia sp.	–	–	–	–
N. acidoclinata Lange-Bertalot	–	–	–	b
N. frustulum var. *subsalina* Hustedt	–	–	–	b
N. inconspicua Grunow	–	–	–	b
N. microcephala Grunow	hl	alb	–	b
N. palea (Kützing) W. Smith	ind	i	bor	b
N. perminuta (Grunow) M. Peragallo	hl	alb	bor	b
N. sigmoidea (Nitzsch) W. Smith	ind	alf	c	b
Genus *Tryblionella* W. Smith				
Tryblionella acuminata W. Smith	mh	alf	c	–
T. angustata W. Smith	ind	alf	bor	b
T. levidensis W. Smith	hl	alf	bor	b

Halobity: (mh) mesohalobes, (hl) halophiles, (hb) halophobes, (i) indifferent.
Attitude to pH: (alf) alkaliphiles, (alb) alkalibiontes, (acf) acidophiles, (ind) indifferent.
Location: (b) bottom, (p–b) plankton bottom, (p) plankton.
Geographical confinement (geography): (c) cosmopolitan, (bor) boreal, (Ha) Holarctic; "–" no data.

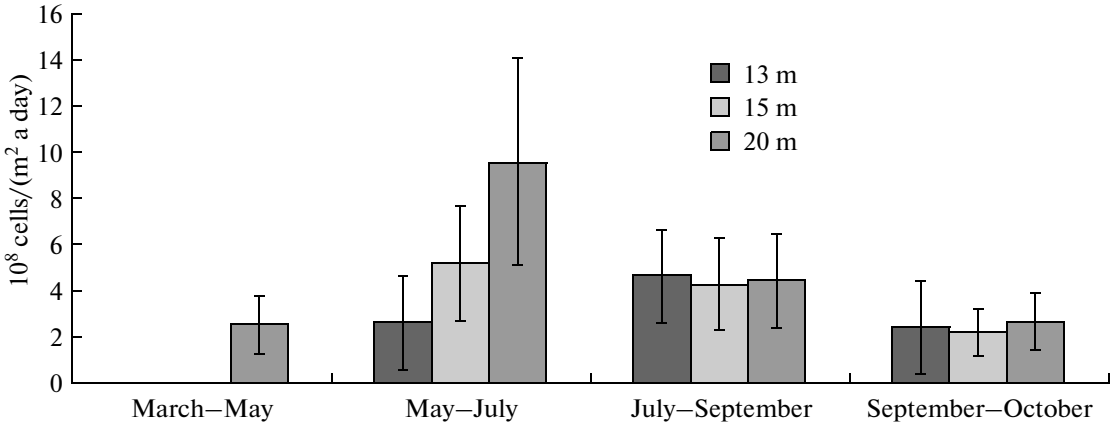

Fig. 4. Dynamics of sediment flow of diatom algae of Lake Shira in 2012. Periods of exposition of sediment traps are plotted on the horizontal axis.

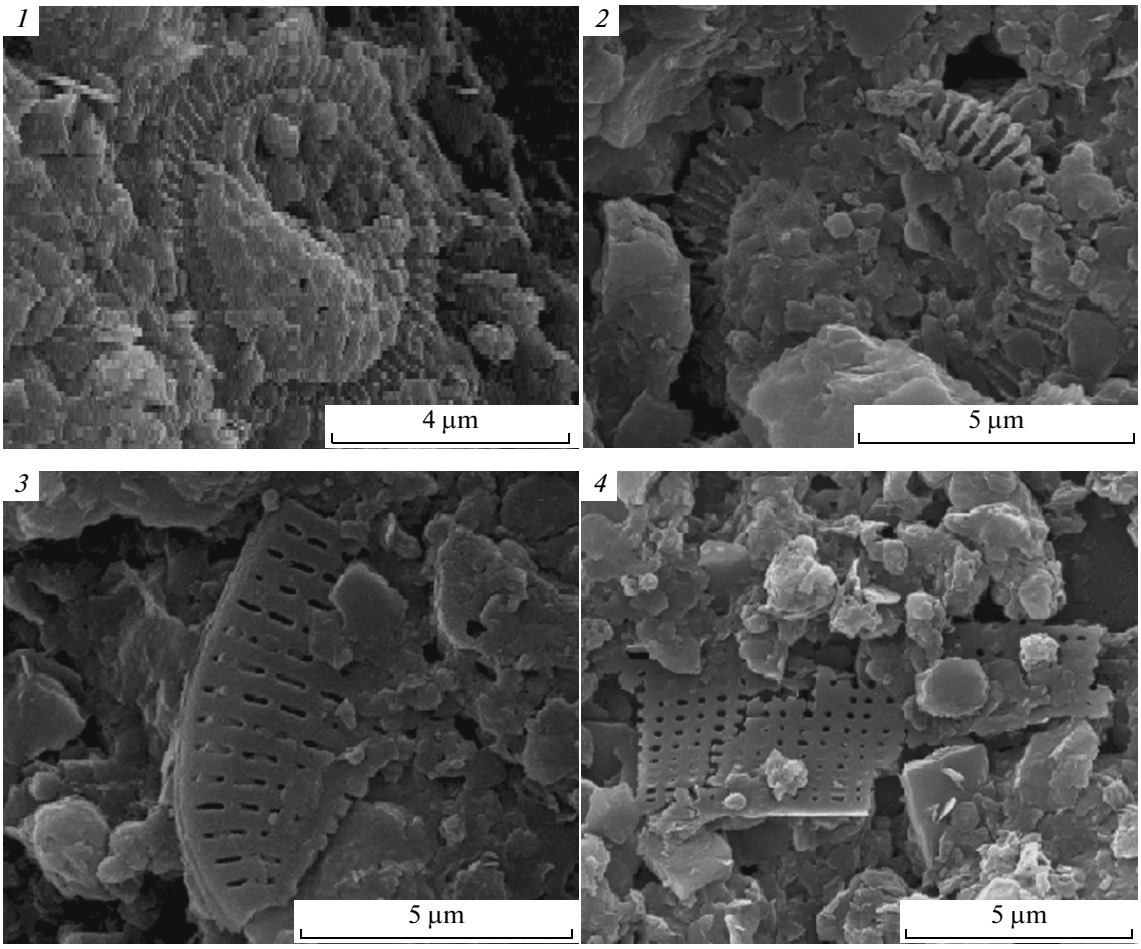

Fig. 5. Diatoms in the core, depth of 60–70 mm (presumably): (*1*, *2*) fragment of diatom valve *C. choctawhatcheeana*; (*3*) fragment of diatom valve *Cocconeis* sp.; (*4*) fragment of diatom valve *Nitzchia* sp.

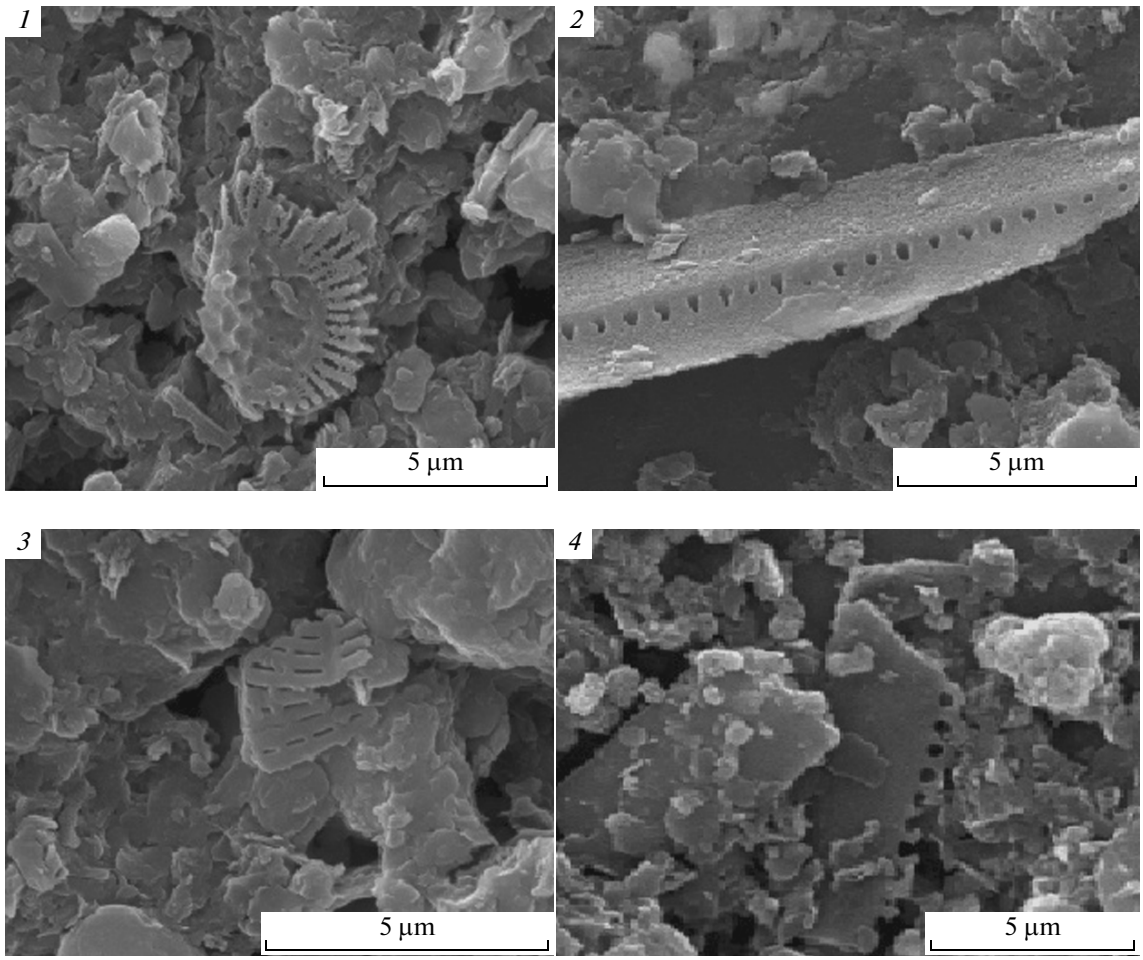

Fig. 6. Diatoms in the core, depth of 85–110 mm (presumably): (*1*) *Cyclotella* sp.; (*2*, *4*) *Nitzschia* sp.; (*3*) *Cocconeis* sp.

maximum sediment flow of cells was (9.6 ± 4.5) × 10^8 cells/(m^2 a day) (the trap at a depth of 20 m; Fig. 4).

In traps of the summer period (July–September) the flow of cells was approximately equivalent: (4.7 ± 2.2) × 10^8 cells/(m^2 day), 4.4 ± 2.1) × 10^8 cells/(m^2 day), (4.3 ± 2.0) × 10^8 cells/(m^2 day) at depths of 13, 15, and 20 m, respectively.

Autumn traps (September–October) are characterized by the most uniform distribution throughout all depths. The peak value of the flow was recorded at a depth of 20 m: (2.7 ± 1.3) × 10^8 cells/(m^2 day).

In spring traps (March–May), diatoms were not found out at a depth of 15 m; In the trap at a depth of 20 m, the flow of cells was (2.7 ± 1.3) × 10^8 cells/(m^2 a day).

Results of the Core Analysis

The first occurrence of diatoms in the core was recorded before the first carbonate white layer at depths of 60 to 70 mm, which dates back to 1980–1975 (Fig. 5) (Rogozin et al., 2011). The occurrence of highly broken valves of *C. choctawhatcheeana* (Fig. 5), and fragments of valves of the genera of *Cocconeis* sp. and *Nitzchia* sp. (Fig. 5, *2*, *3*) indicates their probable similarity with the modern diatom species. The study of the samples from other cores allows us to make a more accurate conclusion about the similarity between ancient and modern diatom species compositions. In layers in a depth interval of 75–95 mm, the algal flora was not found.

The next depth interval incorporating valves of diatoms is from 85 to 110 mm, dating back to 1967–1955. In these layers the same representatives of algal flora are noted: *Cyclotella* sp., *Nitzschia* sp., *Cocconeis* sp. (Fig. 6). In the depth interval of 120–310 mm (including the first white layer of 130–160 mm), diatoms were not found.

At a depth of 310–315 mm before the 2nd white carbonate layer, which dates back approximately to 1690–1683 years, rare structurally well preserved diatoms *Nitzschia sigmoidea* are noted (Fig. 7). At a depth of 335–355 (about 1655–1627), the dominant species were *Aulacoseira ambigua* and *A. valida* (Figs. 8 and 9).

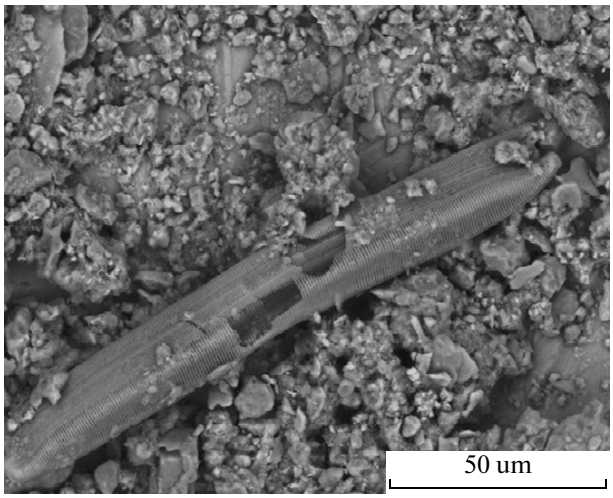

Fig. 7. Diatom in the core, depth of 310–315 mm: *Nitzschia sigmoidea*.

In addition, at that depth (310–355 mm; about 1690–1683), diatoms *Fragilaria construens* var. *venter* occur (Fig. 10).

DISCUSSION OF RESULTS

Results of an analysis of water and sediment samples shows that the diatom species composition of Shira Lake (Popova, 1946) has been stable since 1946. As in previous years, the dominant diatom species is *C. choctawhatcheeana*, a planktonic, saltwater, and marine species widespread in eutrophic reservoirs (Genkal, 2012). The samples of benthic species such as *Amphora aequalis*, *Cocconeis euglyptoides*, and *C. placentula* identified in samples are indifferent species; i.e., they could have developed under different levels of salinity.

The study of core samples showed that, in the upper part of the vertical profile, the distribution in the number of diatoms is heterogeneous. Above white carbonate layers, there has been noted a sharp increase in the occurrence of diatoms and their abundance. Diatoms are absent in other stratigraphic layers.

A comparative analysis of water samples and the material from traps with core samples made since 1946 (Aleksandrovskaya et al., 1959) showed that the species composition of diatoms of Lake Shira is similar to the modern diatom composition (Aleksandrovskaya and et al., 1959; Degermendzhy et al., 1996; Zotina, 2000; Zotina and Tolomeev, 1997; Kolmakov et al., 1993; Makeeva and Naumenko, 2012; Popova, 1946; Cherepnina, 1977; Levkov, 2009). The diatom species compositions from about 1690–1683 and 1655–1627 differ from the modern composition. According to the occurrence of valves of colonial algae from alpine, arctic, and temperate latitudes, *Aulacoseira valida* (plankton, meso- and highly-eutrophic species, shallow lakes, indifferent), *A. ambigua* (plankton, bottom, indifferent, mesotrophic species), and *Fragilaria construens* var. *venter* (benthic, indifferent, oligotrophic species), we can assume that Lake Shira in the middle to late 17 century was a mesotrophic reservoir with a moderate depth and low-alkaline medium and a low salinity compared to the modern species. The occurrence of Arctic–Alpine species of *A. valida*, *A. ambigua*, *F. construens* var. *venter* evidences that climatic conditions could have been colder than nowadays.

The difference in the level of salinity of the lake is confirmed by the results of a qualitative and quantitative analysis of the core samples. Representatives of diatom species collected up to the 1st white layer are represented only by fragments valves, rarely whole semi-valves and whole valves, whereas up to the 2nd white layer valves of diatoms collected are very well preserved structurally and morphologically. This phenomenon is apparently associated with variations in the

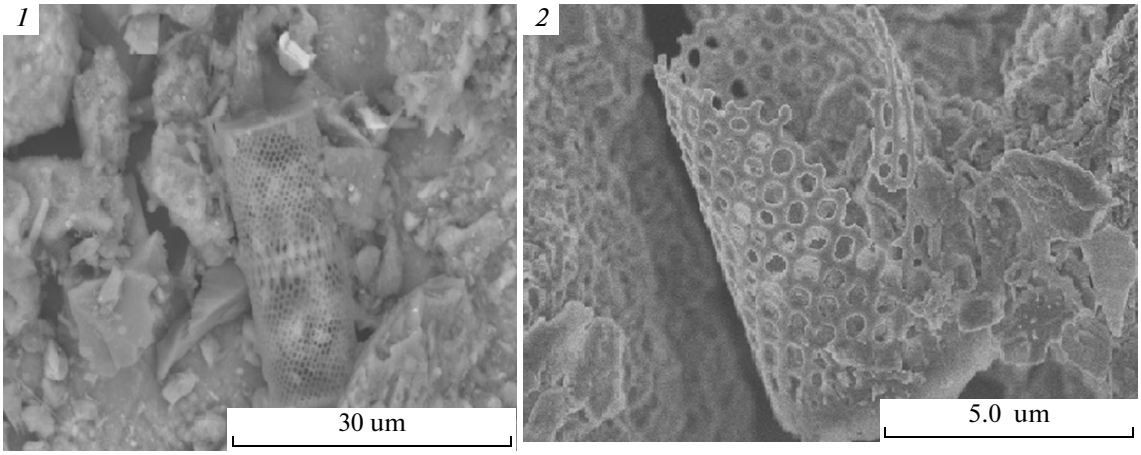

Fig. 8. Dominant diatom species in the core, depth of 335–355 mm: (*1*) *Aulacoseira valida*; (*2*) *A. ambigua*.

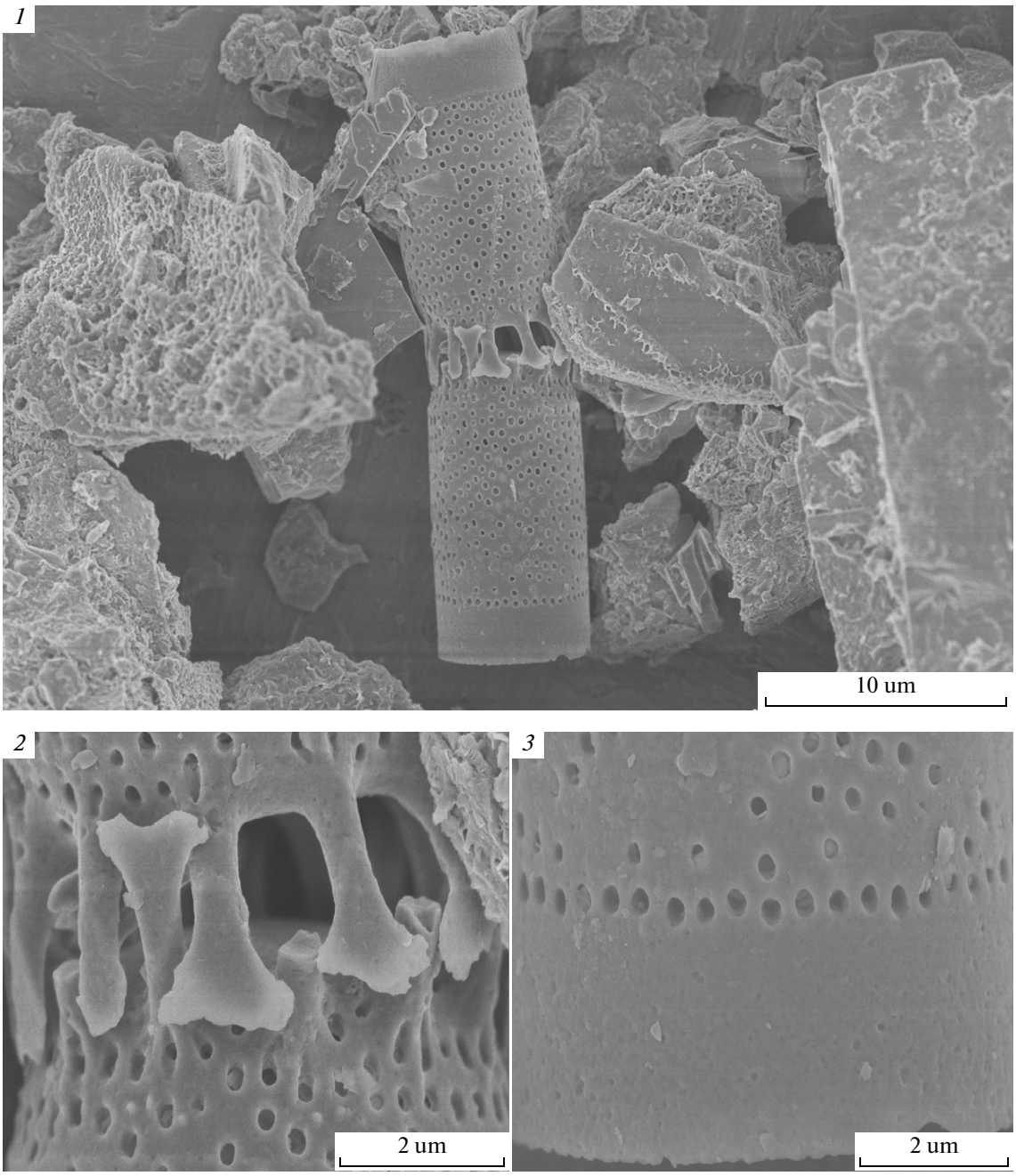

Fig. 9. Diatom in the core, depth of 335–355 mm: (*1*, *2*, *3*) *Aulacoseira valida*.

pH level and the salinity level of water mass (pH ≥ 7 in freshwater). Nowadays, the water of Lake Shira is highly alkaline (pH ranges from 8.9 to 9.2), that is, resulted in the partial damage of diatom valves during their occurrence in the mud of bottom layers.

The maximum abundance and diversity of diatoms to the 1st white layer are recorded at depths of 105–110 and 110–115 mm, which dates back to the period of 1967–1955 years. However, the number of diatom valves here is lower than at the depth of 335–340 mm, dating back approximately to the period of 1655–1627, where before the 2nd white layer the maximum number of diatoms was recorded (Fig. 1). It differs by several orders: the sample with a weight of 0.06 g contained about 7.2×10^5 valves. Diatom algae are equally well developed both in fresh and salty waters. Due to this, the difference in number of diatoms cannot be related to the level of mineralization in Lake Shira as a factor influencing the diversity and number of diatom cells in the water column.

The small number of diatoms in the upper sedimentary layers can probably be connected with the

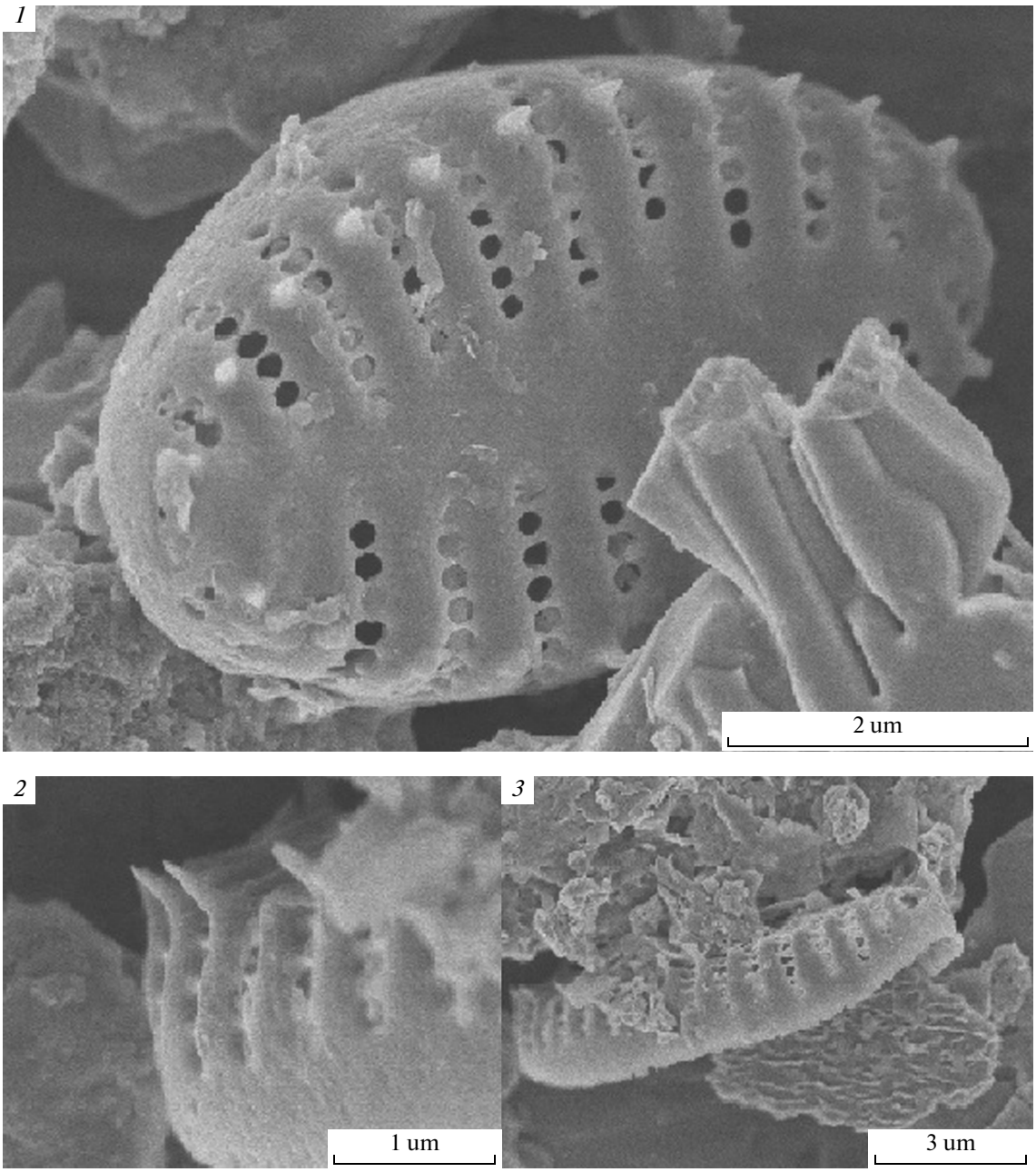

Fig. 10. Diatom in the core, depth of 335–355 mm: (*1*, *2*, *3*) *Fragilaria construens* var. Venter.

negative impact of salinity and pH on the preservation of diatom valves. Under such unfavorable conditions, diatom valves are usually completely broken and it is difficult to estimate their number numerically. In order to explain this phenomenon in precise terms, it is necessary to calculate the sedimentation rate base based on diatoms and calculate the index of saprobity of diatoms during the further study of benthic sediments of Lake Shira.

ACKNOWLEDGMENTS

We are grateful to an anonymous reviewer for useful advice.

This work was supported by Russian Foundation for Basic Research, project no. 13-05-00429-a and the Biodiversity Program for Basic Research, Russian Academy of Sciences, project no. 30.8.

REFERENCES

Aleksandrovskaya, M.A., Goncharova, M.N., Komarova, N.M., Malakhov, A.M., Skornyakov, V.A., Churakov, V.K., Tsytsrin, G.V., and Shmideberg, N.A., *Gidromineral'nye resursy raiona ozera Shira (otchet o rabotakh 1957–1958 gg.)* (Hydromineral Resources of the Shira Lake Region: A Report on Scientific Works of 1957–1958), Moscow: Mosk. Gos. Univ., 1959, vol. 1, no. 117; vol. 2, no. 118.

AlgaeBase—a database of information on algae that includes terrestrial, marine, and freshwater organisms. http://algaebase.org

Belyakova, G.A., *Vodorsli i griby. Botanika* (Algae and Fungi. Botany), Moscow: Akademiya, 2006, vol. 2.

Cherepnina, G.I., Phytoplankton and its production in the southern lakes of Krasnoyarsk krai, in *4 Vses. Limnol. Soveshch. "Krugovorot veshchestv i energii v vodoemakh. Elementy bioticheskogo krugovorota," Tezisy dokladov* (The 4 All-Union Limnological Meeting "Cycles of Matter and Energy in Reservoirs. Elements of Biotic Cycle," Abstracts of Papers), 1977, pp. 74–77.

Degermendzhy N.N., Zotina, T.A., and Tolomeev, A.P., Structure and functions of planktonic communities of the Shira Lake ecosystem: review and experiments, *Sib. Ekol. Zh.*, 1996, no. 5, pp. 439–452.

Diatomovye vodorosli Rossii i sopredel'nykh stran. Iskopaemye i sovremennye (Diatoms of Russia and Adjacent Countries: Fossil and Modern), Makarova, I.V., Ed., St. Petersburg: S.-Peterb. Gos. Univ., 2002, vol. 2, no. 3.

Genkal, S.I., Morphology, taxonomy, ecology, and distribution of *Cyclotella choctawhatcheeana* Prasad (Bacillariophyta), *Inland Water Biol.*, 2012, vol. 5, no. 2, pp. 169–177.

Genkal, S.I. and Trifonova, I.S., *Diatomovye vodorosli-planktona Ladozhskogo ozera i vodoemov ego basseina* (Diatoms in Plankton of Lake Ladoga and Its Basin), Rybinsk: Rybinsk. Dom Pechati, 2009, p. 72.

Kalugin, I., Darin, A., Rogozin, D., and Tretyakov, G., Seasonal and centennial cycles of carbonate mineralisation during the past 2500 years from varved sediment in Lake Shira, South Siberia, *Quat. Int.*, 2013, vols. 290–291, pp. 245–252.

Kiselev, I.A., *Plankton morei i kontinental'nykh vodoemov* (Plankton of the Seas and Continental Reservoirs), Leningrad: Nauka, 1969, vol. 1.

Kolmakov, V.I., Gaevskiy, N.A., Gol'd, V.M., et al., *Izuchenie fitoplanktona ozera Shira* (Study of phytoplankton of the Lake Shira), Available from VINITI, 1993, Krasnoyarsk, no. 2669-B93.

Lange-Bertalot, H., *Navicula* sensu stricto. 10 Genera separated from *Navicula* sensu lato. *Frustulia*, in *Diatoms of Europe: Diatoms of the European Inland Waters and Comparable Habitats*, Lange-Bertalot, H., Ed., Ruggell, Germany: A.R.G. Gantner Verlag, 2001, vol. 2, pp. 1–526.

Levkov, Z., *Amphora* sensu lato, in *Diatoms of Europe: Diatoms of the European Inland Waters and Comparable Habitats*, Lange-Bertalot, H., Ed., Ruggell, Germany: A.R.G. Gantner Verlag, 2009, vol. 5, pp. 5–916.

Likhoshvai, E.V., Pomazkina, G.V., and Nikiteeva, T.A., Centric diatoms from Miocene deposits of Baikal rift zone (Tunkinskaya Depression), *Geol. Geofiz.*, 1997, vol. 38, no. 9, pp. 1445–1452.

Makeeva, E.G. and Naumenko, Y.V., Data on the flora of algae *Bacillariophytha* of Shira Lake (Russia, Khakassia), *Contemp. Probl. Ecol.*, 2012, no. 3, pp. 351–359.

Popova, T.G., To study of algal flora of the reservoirs of Northern Khakassia, *Izv. Zap.-Sib. Fil., Akad. Nauk SSSR, Ser. Biol.*, 1946, part 1, pp. 41–72.

Rogozin, D.Yu., Degermendzhy, A.G., Pimenov, N.V., Kosolapov, D.B., and Chan'kovskaya, Yu.V., Thin-layer vertical distributions of purple sulfur bacteria in chemocline zones of meromictic Lakes Shira and Shunet (Khakassia), *Dokl. Biol. Sci.*, 2005, vol. 400, nos. 1–6, pp. 54–56.

Rogozin, D.Y., Zykov, V.V., Degermendzhy, A.G., Kalugin, I.A., and Daryin, A.V., Carotenoids of phototrophic organisms in bottom sediments of meromictic Lake Shira (Siberia, Russia) as an indicator of past stratification, *Dokl. Biol. Sci.*, 2011, vol. 439, no. 1, pp. 228–231.

Tracey, B., Lee, N., and Card, V., Sediment indicators of meromixis: comparison of laminations, diatoms, and sediment chemistry in Brownie Lake, Minneapolis, USA, *J. Paleolimnol.*, 1996, vol. 15, no. 2, pp. 129–132.

Vasser, S.P., Kondrat'eva, N.V., Masyuk, N.P., et al., *Vodorosli. Spravochnik* (Algae: Handbook), Kyiv: Naukova Dumka, 1989.

Zabelina, M.M., Kiselev, I.A., et al., *Opredelitel' presnovodnykh vodoroslei SSSR, Vyp. 4: Diatomovye vodorosli* (Guidance for Identification of Freshwater Algae in the Soviet Union, No. 4: Diatoms), Moscow: Sovetskaya Nauka, 1951.

Zotina, T.A., Vertical distribution of phytoplankton in saline Lake Shira, *Gidrobiol. Zh.*, 2000, vol. 36, no. 1, pp. 38–46.

Zotina, T.A. and Tolomeev, A.P., Species composition and vertical structure of phyto- and zooplankton in Lake Shira, *Vestn. Khakas. Gos. Univ., Ser. 4: Biol., Med., Khim.*, 1997, no. 4, pp. 69–71.

Translated by D. Voroschuk