Microbial Processes of the Carbon and Sulfur Cycles in Lake Shira (Khakasia)

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Abstract—Microbiological and biogeochemical studies of the meromictic saline Lake Shira (Khakasia) were conducted. In the upper part of the hydrogen-sulfide zone, at a depth of 13.5–14 m, there was a pale pink layer of water due to the development of purple bacteria (6 × 10^5 cells/ml), which were assigned by their morphological and spectral characteristics to Lamprocystis purpurea (formerly Amoebobacter purpureus). In August, the production of organic matter (OM) in Lake Shira was estimated to be 943 mg C/(m²·day). The contribution of anoxygenic photosynthesis was insignificant (about 7% of the total OM production). The share of bacterial chemosynthesis was still less (no more than 2%). In the anaerobic zone, the community of sulfate-reducing bacteria played a decisive role in the terminal decomposition of OM. The maximal rates of sulfate reduction were observed in the near-bottom water (114 μg S/(l·day)) and in the surface layer of bottom sediments (901 μg S/(dm³·day)). The daily expenditure of Corg for sulfate reduction was 73% of Corg formed daily in the processes of oxygenic and anoxygenic photosynthesis and bacterial chemosynthesis. The profile of methane distribution in the water column and bottom sediments was typical of meromictic reservoirs. The methane content in the water column increased beginning with the thermocline (7–8 m) and reached maximum values in the near-bottom water (17 μl/l). In bottom sediments, the greatest methane concentrations (57 μl/l) were observed in the surface layer (0–3 cm). The integral rate of methane formation in the water column and bottom sediments was almost an order of magnitude higher than the rate of its oxidation by aerobic and anaerobic methanotrophic microorganisms.

Key words: Lake Shira, anoxygenic photosynthesis, purple sulfur bacteria, sulfate reduction, production and oxidation of methane.

The meromictic Lake Shira (90°14' E, 54°30' N) is situated in the northern part of Khakasia 17 km to the east of the regional center Shira within a large synclinal structure made up of red sandstone, aleurolite, argillite, and grit-stone of the oidan suite of the Upper Devonian. The lake’s length is 9.35 km; its maximal width is 5.3 km; the coastline is 24.5 km long; the maximal depth is 23 m; and the average depth is 11 m. The water supply is provided by the Son River, rains, and anthropogenic contributions. The unique sulfate-chloride–sodium–magnesium mineral composition of the lake water has no analogues in composition and therapeutic properties.

Detailed hydrochemical studies of Lake Shira conducted in the summer period showed that, beginning at a depth of 13–14 m, this reservoir is characterized by a stable anaerobic zone containing dissolved hydrogen sulfide. In the near-bottom layers at a depth of 22 to 23 m, the hydrogen sulfide content was estimated to be from 15 to 20 mg/l [1]. The high content of sulfate ions (about 10 g/l), the appearance of hydrogen sulfide in the water column, as well as the high number of sulfate-reducing bacteria [2], give evidence in favor of a possible active role of sulfate reduction in the degradation of organic matter (OM) in this reservoir.

In August 2001, a joint expedition of researchers from the Institute of Microbiology (Russian Academy of Sciences), Tomsk State University, and the Institute of Biophysics, Siberian Division (Russian Academy of Sciences), was organized. Complex microbiological and biogeochemical investigations were carried out to qualitatively assess the rates of oxygenic and anoxygenic photosynthesis and sulfate reduction in Lake Shira. In addition, methane distribution was studied in the water column and bottom sediments, and the rates of its microbial oxidation and production were determined.

MATERIALS AND METHODS

The work on Lake Shira was carried out in August 23–29, 2001. Water and bottom sediments were sampled in the deepest zone (depth, 22.5 m) of the lake at 54°30.334’ N, 90°11.418’ E.
Water samples were taken using 0.9-l Niskin plastic horizontal bathometer as well as a 1.7-l two-compartment glass bathometer, with a built-in thermometer. Bottom sediments were sampled with a limnological stratimeter with a 6-cm metallic tube.

The total number of microorganisms was determined on 0.2-μm polycarbonate membrane filters by the fluorescence method using diamidino-4,6-phenyl-2-indole dihydrochloride (DAPI) as a dye [3].

The rates of the microbial processes of sulfate reduction, methane oxidation and methane production, and carbon dioxide assimilation in the light and in the dark were determined by the radioisotope method using the following sulfur- and carbon-labeled compounds: Na$_2^{35}$SO$_4$, NaH$^{14}$CO$_3$, $^{14}$CH$_3$H, and $^{14}$CH$_3$COONa. Labeled compounds (0.1 to 0.2 ml) were injected into 5-ml syringes (bottom sediments) or into 50-ml glass flasks (water samples) with a microsyringe and incubated under in situ conditions on capron halyards. The dark flasks were wrapped in foil. The duration of incubation for determining the rate of carbon dioxide assimilation in the light and in the dark was a light day. Upon completion of incubation with $^{14}$C-bicarbonate, water samples were fixed with glutaraldehyde and then filtered through 0.2-μm capron membrane filters.

The duration of incubation for other processes was 24 h. After completing the incubation with labeled substrate, the water and sediment samples were fixed with 0.5–1 ml of concentrated KOH. The samples were then transported to the Institute of Microbiology, where the rates of microbial processes were determined by the techniques described earlier [4–6].

The sample content of methane was determined by the phase-equilibrium degassing method [7] on a Chrom-5 gas chromatograph equipped with a flame-ionization detector. The sulfate and chlorine contents were determined with a Biotronik ionic chromatograph (Germany); the contents of oxygen and hydrogen sulfide were determined using Aquamerk standard kits of reagents (Germany). The temperature, salinity, turbidity for determining the rate of carbon dioxide assimilation in the light and in the dark was a light day. Upon completion of incubation with $^{14}$C-bicarbonate, water samples were fixed with glutaraldehyde and then filtered through 0.2-μm capron membrane filters.

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