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Microbial Processes in the Kanda Bay, a Meromictic Water Body Artifically Separated from the White Sea

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Abstract—Sings of meromixis are found by means of microbiological and biogeochemical investigations in the southernn part of the Kanda Bay, an artificial water body separated front the White Sea with a railway dam. The concentration of oxygen in the bottom layer attained 1.9 mmol/L, intensity of the process of microbial sulfate reduction, 3.0 μmol of sulfur/(L day). The concentration of dissolved methane, 3.7 μmol/L. Isotopic composition of carbon in methane ($\delta^{13}C$ (CH_4) = –79.2‰) indicates to its microbial genesis. At present, Kanda Bay is a sole in Russia man-made marine water body for which there are data on the rate of microbial processes responsible for formation of bottom water layer containing hydrogen sulfide and methane.

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Among lakes of marine origin formed by separation of lagoons and bays the water bodies received the name of meromictic water bodies stand aside. The meromictic water bodies are characterized by presence of the anaerobic zone in monimiolimnion. As a rule, the anaerobic conditions are created by microbial destruction of organic matter accompanied by depletion of dissolved oxygen. In the presence of sulfate ions in monimolimnion of such water bodies, the processes of microbial sulfate reduction are activate, followed by formation of hydrogen sulfide. Activation of sulfate reduction is described for marine water bodies variously isolated from the open sea. A stable anaerobic zone in the bulk of water is present in meromictic Lake Mogilnoe on Kildin Island, fjord Framwaren in the southern Norway, in the Black Sea [1–4]. Less stable situation is characteristic of two deep-water depressions of the Caspian Sea [5]. Numerous small stratified water bodies are known at the coast of Kandalaksha Bay of the White Sea. They are unique as to their origin as they are formed by separation from the sea by rapid elevation of the land (about 40 cm during the past 100 years) and further freshening [6, 7]. In the process of separation from the sea the marine biota is replaced by freshwater one, alleviation of flushing leads to accumulation of a considerable quantity of sediment and to distribution of hydrogen sulfide in monimolimnion [8]. Sulfate reducing bacteria are not the only anaerobic microorganisms participating in transformation of organic compounds. Under anaerobic conditions, formation of methane is provided by methanogenic archei participating, along with sulfate reducing bacteria, in the terminal phase of decomposition of organic matter [2].

Contamination with hydrogen sulfide is characteristic also of artificially separated marine areas, such as Kislaya Bay (west of Murmansk). The process of contamination continued for four years of construction of Kislogubskaya Power Station, when its basin was separated from the sea with a temporary dam [9] and also in waters of Dolgaya (Glubokaya) Gulf (Solovetskiy Island) which was separated from Onega Bay with an artificial dam in 1856 [10]. Urgency of investigation of such water bodies depends, first of all, on the necessity of prognosis of negative consequences of contamination with hydrogen sulfide in marine water areas due to construction of dams, weirs, tidal power stations, etc.

The basin of Kanda Bay is an artificial water body, because, since 1916, the water area with complicated

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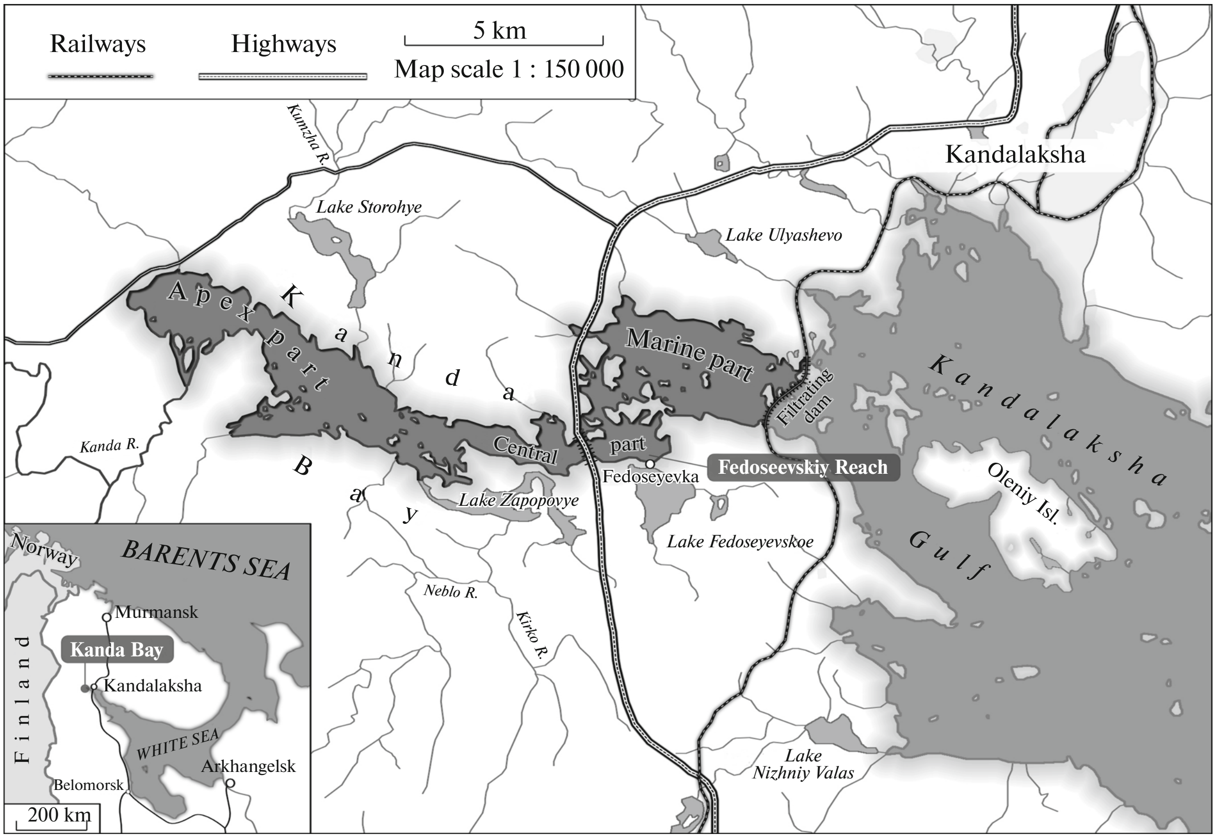

Fig. 1. Schematic map of Kanda Bay.

shoreline has been separated from Kandalksha Bay of the White Sea by a railway dam [11]. The bay receives the Kanda River and numerous streams. Kanda Bay belongs to inland waters of the Russian Federation. The stretch of railway crossing Kanda Bay had been built from September 1915 till November 1916. A filtration dam was built in marine shallow area. To the base of dam large boulders were laid; as the dam grew, smaller boulders and stones were used. As a result, the tidal water might pass through the dam. As a way for small vessels and fish a channel was left with a single-span bridge. In 1942, during World War II, the channel connecting the gulf with the sea was filled up. The reason to do this was the fact that German aircraft bombed bridges first of all. As a result the water masses of Kanda Bay were connected with the sea very weak, solely by filtration through the dam. In 1972, a fishway was built in the dam for fish passing. The water exchange of Kanda Bay with the sea slightly increased and marine and migratory fish might swim to the gulf. Anthropogenous transformations of the gulf changed its hydrological and hydrochemical conditions. According to the institute SevNIIProekt (Petropavlovk city), in 1981–1982 in Kanda Bay there was an expressed water stratification with a fresh surface layer and deep-water stagnant zones filled with brackish water with a considerable concentration of dissolved hydrogen sulfide [11]. The filtering railway dam through the gulf is situated 700 m from the boundaries of the Kandalaksha Bay wetlands of international significance and the boundaries of Kandalsksha Reserve. Thus, a regular monitoring of changes occurring in Kanda Bay is necessary.

The aim of the present study was determination of unbiased quantitative characteristics of intensity of microbial processes which are regulators of cycles of carbon and sulfur in water of Kanda Bay. There are no previous microbiological and biogeochemical investigations in Kanda Bay.

The materials for investigation are obtained in January 2015 and February–March 2016. Sounding and sampling were made from the ice surface. Investigations of marine water area and tail area of Kanda Bay demonstrated that the water of local depressions (Fig. 1) contains dissolved oxygen all over from the under-ice horizon to the bottom. In the surface layer there was no sign of hydrogen sulfide. However, in the central part of Fedoseevka Broad (the southern part of Kanda Bay, Fig. 1) there were all signs of meromixis (Fig. 2).

The freshened layer of the water corresponded to the under-ice water layer. Halo- and thermocline were weakly expressed and were at the depth 9–10 m (Fig. 2a). Redox potential abruptly changed within this horizon. The content of oxygen in the under-ice layer corre-

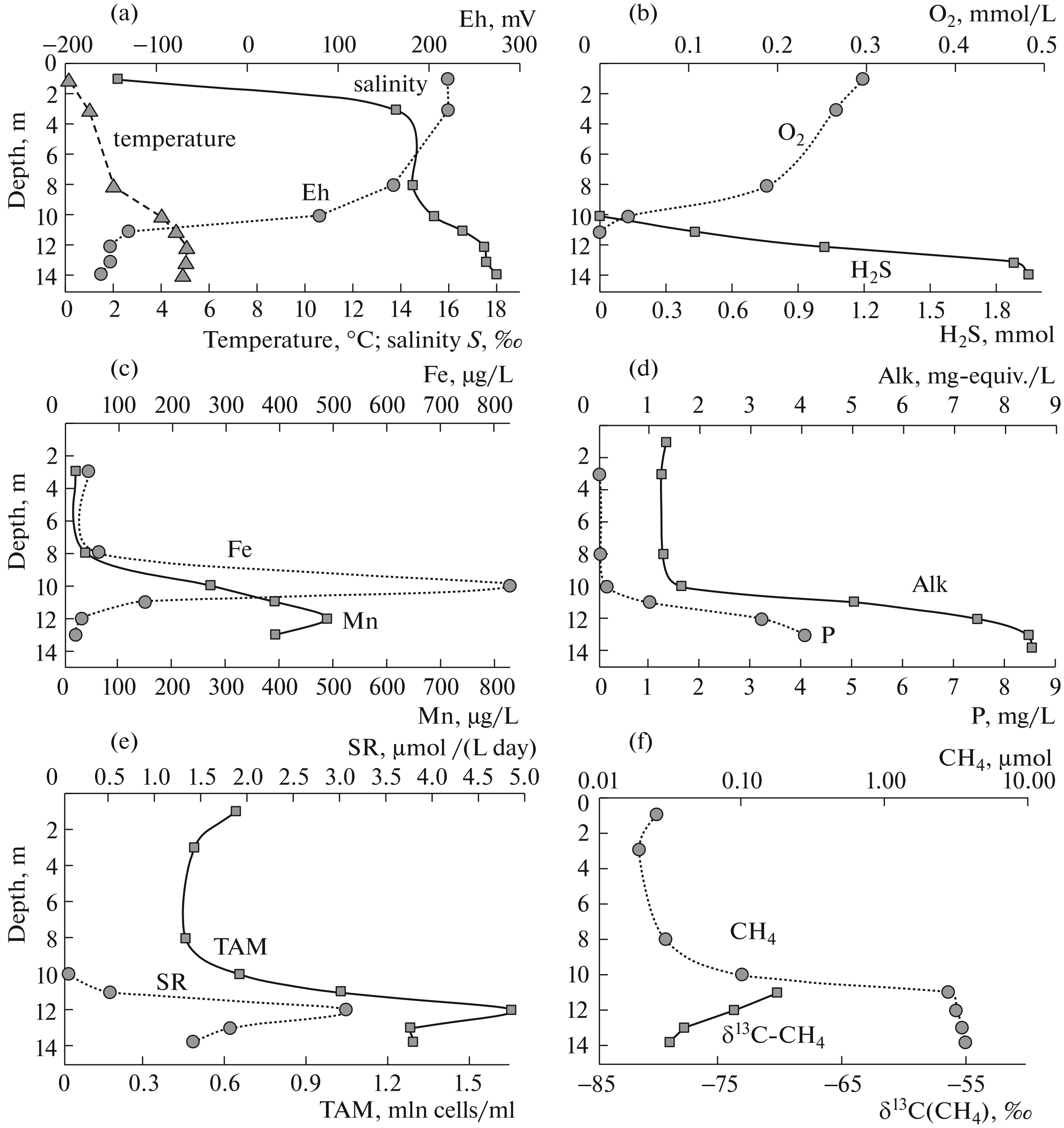

Fig. 2. Principal hydrological, biogeochemical, nucirobiological, and isotope-geochemical characteristics of water column of Fedoseevka Broad (Kanda Bay). (a) Temperature, salinity S, redox potential Eh; (b) concentration of hydrogen sulfide and oxygen; (c) concentration of iron and manganese (the sum of dissolved and colloid fractions); (d) alkali reserve Alk, concentration of total phosphorus P (mineral and organic); (e) total abundance of microorganisms TAM, intensity of sulfate reduction SR; (f) concentration of methane and isotopic composition of carbon in methane, $\delta^{13}C$-CH_4.

sponded to 0.3 mmol/L. Deeper, the concentration of O_2 gradually decreased to minimum values at the depth 10 m (0.03 mmol/L, Fig. 2b). At 11 m, the concentration of hydrogen sulfide was 0.42 mmol/L, and in the bottom layer, 1.93 mmol/L. Distribution of heavy metals over depths (Fig. 2c) is controlled by two processes [12]: oxidation of two-valent forms of manganese and iron in mixolimnion (within 8 m from the surface) with formation of colloid particles (mainly, of oxyhydroxids of iron (III) with other metals trapped during co-sedimentation and sorption) whose sedimentation rate in the halocline layer drastically changes leading to formation of the local maximum of concentrations; reduction of oxidized forms of manganese Mn(IV) and Fe(III) in the zone sulfate reduction (below 12 m) with formation of less soluble compounds, probably of iron sulfide, also trapping as admixtures the metals having affinity with iron (Co, Zn, Pb, and Cd). The concentrations of mineral and organic phosphorus (Fig. 1d) in the surface horizon to the depth of 8 m were minimal (0.012–0.014 mg/L), increased to 0.12 mg/L art the depth of 10 m, and

Comparative characteristic of parameters of anaeroxia in the monimolimnion of Fedoseevka Broad and in the known meromictic water bodies

Water body	Month and year of survey	H_2S, mmol/L	CH_4, μmol/L	SR*, μmol/(L day)	Source
Lake Shira	February 2001	0.3–0.5	0.3–0.6	0.4–0.7	[13]
Lake Shunet	February 2001	2.0–3.8	20–36	4.5–6.2	[13]
Lake Mogilnoe	March 2002	0.9–3.0	10–16	3.0–4.9	[2]
Kanda Bay	January 2015, February 2016	1.0–1.9	2–3.5	1.4–3.0	Present communication

*SR is the intensity of sulfate reduction.

abruptly increased in bottom layers (to 3.8 mg/L for P_{min} and 0.19 mg/L for P_{org}).

The total abundance of microorganisms (TAM, expressed as the quantity of cells in 1 mL) in mixolimnion of Fedoseevka Broad ((0.45–0.65) × 10^6 cells/mL) corresponded to the values common for the winter season in oligo-mesotrophic water bodies. In the chemocline layer the value of TAM reached the local maximum (1.65 × 10^6 cells/ml) characteristic of meromictic water bodies. The results of experiments with addition of $Na_2^{35}SO_4$ demonstrated that in all samples of hydrogen sulfide water the process of microbial sulfate reduction goes on whole intensity attained 3.0 μmol S per liter in 24 hours. The concentration of hydrogen sulfide in the bottom layer reached 1.9 mmol/L (Fig. 2e). It follows that hydrogen sulfide present in deep water of Fedoseevka Broad could not be formed during one winter season.

The concentration of dissolved methane in mixolimnion varied from 19 to 29 nmol/L, which slightly surpassed its content in the atmosphere (Fig. 2f). In the chemocline layer and in the bottom water layer, the concentration of dissolved methane reached 2.8–3.7 mmol/L. The distribution of methane content indicates to its release from bottom deposits. The isotopic composition of carbon in dissolved methane from the bottom water layer ($\delta^{13}C$ (CH_4) = –79.2‰) indicates to its recent microbial genesis. The content of light isotope of carbon in methane in the chemolcline layer was lower than the corresponding values in the lower horizons ($\delta^{13}C$ (CH_4) = –70.4‰, Fig. 2f). This change in isotopic composition of carbon in methane indiocates to fractioning effect happening at microbial consumption of mainly light isotope of carbon.

It is proper to compare principal quantitative parameters characterizing the hypoxia level (the content of hydrogen sulfide, methane, and intensity of sulfate reduction) in hypolimnion of Fedoseevka Broad with the corresponding data [13] known for well investigated meromictic water bodies (Table 1). Comparative analysis demonstrated that by the level of hypoxia Fedoseevka Broad is somewhat behind of Lake Mogilnoye and an eutrophic continental Lake Shunet (winter survey) but comparatively "outpaces" Lake Shira by this parameter (winter survey).

Absence of anaerobic waters in local mainstream depressions of the Kanda River within limits of marine and tail areas of Kanda Bay indicates to efficiency of water exchange through the filtering dam and the open water course. Fedoseevka Broad may be a relic water body retaining the hypolimnion layer in the Kanda paleochannel after construction of a closed dam (Fig. 1). Thus, at present, Kanda Bay is a sole Russian artificial inland marine water body for which quantitative data on the rates of microbial processes responsible for origin and support of the anaerobic water layer containing hydrogen sulfide and methane have been obtained.

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REFERENCES

1. Deryugin, K.M., *Tr. Petergof. Est.-Nauch. Inst.,* 1925, no. 2, pp. 1–112.
2. Ivanov, M.V., Rusanov, I.I., Pimenov, N.V., et al., *Mikrobiologiya,* 2001, vol. 70, no. 5, pp. 675–686.
3. Strelkov, P., Shunatova, N., Fokin, M., et al., *Polar Biol*., 2014, vol. 37, pp. 297–310. doi doi 10.1007/s00300-013-1431-4
4. Dyrssen, D.W., Hall, P.O.J., and Haraldsson, C., *Aquat. Geochem*., 1996, vol. 2, pp. 111–129.
5. Ivanov, M.V., Savvichev, A.S., Klyuvitkin, A.A., et al., *Doklady Akad. Nauk,* 2013, vol. 453, no. 1, pp. 76–81.
6. Pantyulin, A.N. and Krasnova, E.D., in *Materialy XIX Mezhdunarodnoi nauchnoi konferentsii (Shkoly) po morskoi geologii* (Proceedings of the XIX International Conference/Workshop on Marine Geology), Moscow: GEOS, 2011, vol. 3, pp. 241–245.

7. Krasnova, E., Kharcheva, A., Milutina, I., et al., *J. Mar. Biool. Assoc. UK,* 2015. doi http://dx.doi.org/ doi 10.1017/S0025315415000582

8. Losyuk, G., Kokryatskaya, N., and Krasnova, E., *EARSeL Proc.,* 2015, vol. 14, pp. 49–54.

9. Semenov, V.N., *Sistematika i ekologiya morskikh basseinov Severa na raznykh etapakh izolyatsii* (The Systematics and Ecology of Sea Basins of the North at Different Stages of Isolation), Apatity: Murm. Morsk. Biol. Inst. Kol'sk. Fil. Akad. Nauk SSSR, 1988.

10. Ninburg, E.A., *Priroda,* 1990, no. 7, pp. 44–49.

11. Ivanov, N.O., Kitaev, V.P., abd Chechenkov, A.V., in *Itogi i perspektivy izucheniya biologicheskikh resursov Belogo morya* (Results and Prospects of the Exploration of the White Sea Biological Resources), Leningrad: Zool. Inst. Akad. Nauk SSSR, 1983, pp. 37–44.

12. Savenko, A.V., Demidenko, N.A., Savvichev, A.S., and Pokrovskii, O.S., in *Materialy XXI Mezhdunarodnoi nauchnoi konferentsii (Shkoly) po morskoi geologii* (Proceedings of the XXI International Conference/Workshop on Marine Geology), Moscow: GEOS, 2015, vol. 3, pp. 271–275.

13. Savvichev, A.S., Rusanov, I.I., Rogozin, D.Yu., et al., *Mikrobiologiya,* 2005, vol. 74, no. 4, pp. 552–561.

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