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## GEOPHYSICS

# The Great Siberian Rivers As a Source of Methane on the Russian Arctic Shelf

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The methane marine cycle in the Arctic region has not received due attention thus far, since the role of the Arctic Ocean in the global methane cycle was widely held to be insignificant by the scientific community. At the same time, some authors have clearly shown that this role seems to have been substantially underestimated [1–3]. The Arctic Ocean represents not only a giant petroliferous superbasin enclosing huge reserves of natural hydrocarbons, but also an estuary of the world's largest rivers, the drainage systems of which are underlain by thick layers of permafrost hosting enormous reserves of organic carbon. Degradation of permafrost and involvement of old organic carbon into the present-day biochemical cycle determine, to a large measure, the role of Arctic marine ecosystems and others in both the regional and global methane cycles. In this connection, study of the role of great Siberian rivers as methane sources on the Russian Arctic shelf is especially topical.

## MATERIALS AND METHODS

We present results of study of dissolved methane in estuaries of the three largest Siberian rivers (Ob, Yenisei, and Lena) obtained in September 2005, during a joint Russian–American expedition along the Northern marine track.

Water samples were collected into hermetically sealed 0.5-l glass vessels from different horizons using Niskin bathometers. Dissolved gases were extracted by static paraphase analysis at a constant temperature [4, 5]. Methane in the equilibrium gas phase was analyzed on a MicroTech-8160 SRI gas chromatograph equipped with a flame-ionization detector. Helium was used as the carrier gas. Gas standards of the Airliquid Company (United States) were used for calibration. The permissible error of analysis did not exceed 1%. Methane concentrations were calculated taking into account constants of methane solubility by the procedures suggested by the authors of [6] and modified by the authors of [7]. The temperature and seawater salinity accepted in calculations were determined for each station using a Seabird 19 hydrological probe. We also generalized our previous data on the methane content in lakes located in the vicinity of Tiksi and the Primorskaya Lowland (Fig. 1). The statistically treated data are presented graphically using the Statistics 6.0 and Grapher 6.0 software packages. The schematic mapping was carried out by the kriging method using the Surfer 8.0 graphics editor.

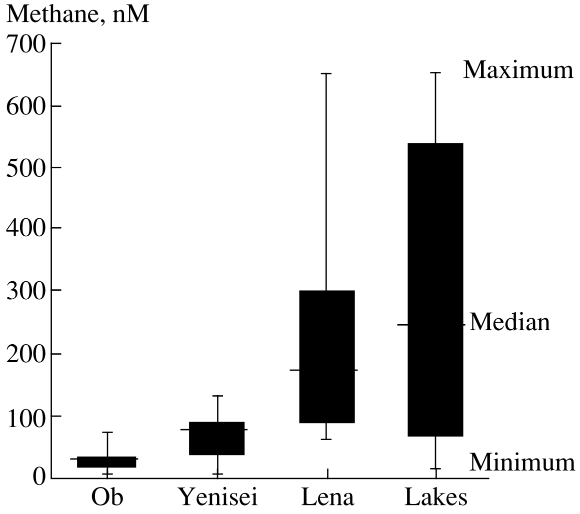

**Fig. 1.** Averaged data on the dissolved methane content in estuaries of three rivers (Ob, Yenisei, and Lena), as well as in lakes of the Primorskaya Lowland (data for 1994).

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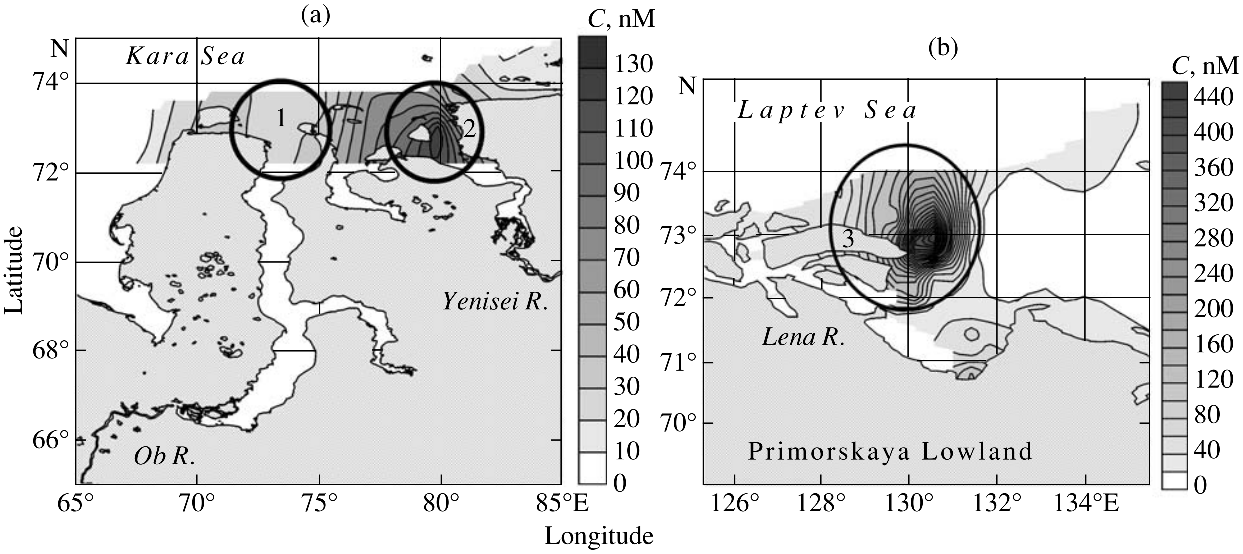

**Fig. 2.** Distribution of dissolved methane in the surface water layer in estuaries. (a) Ob and Yenisei; (b) Lena.

## RESULTS AND DISCUSSION

According to the data obtained, the concentration of dissolved methane in the surface water layer in river estuaries varied from 7 to 700 nM, indicating a 2- to 200-fold supersaturation of the surface water layer relative to the atmosphere (Fig. 1). The methane concentration in the Ob River estuary (Fig. 2a, area 1) was the lowest and varied from 7.4 to 41.3 nM ($m = 30.0 \pm 5.48$ nM, $n = 11$). The methane concentration in the Yenisei estuary (Fig. 2a, area 2) varied from 7.1 to 130.8 nM ($m = 75.3 \pm 14.2$ nM, $n = 8$). The highest methane concentration established in the Lena estuary (Fig. 2b, area 3) varied from 61.6 to 651.2 nM ($m = 240.0 \pm 39.3$ nM, $n = 20$).

To explain the revealed variations is not a simple problem due to the widespread opinion that rivers cannot be an essential methane source on the shelf since the methane lifetime in a well-aerated river water is substantially shorter than the time of its delivery on the shelf. If we assume that rivers carry out residual amounts of methane delivered from drainage areas, rivers with larger drainage areas and runoff volumes should carry out a greater amount of methane. It is evident that the Yenisei River (drainage area $2594 \cdot 10^3$ km$^2$, annual discharge 620 km$^3$) is the greatest among the three rivers. The Ob ($2545 \cdot 10^3$ km$^2$, 429 km$^3$) and Lena ($2486 \cdot 10^3$ km$^2$, 525 km$^3$) rivers occupy the second and third place, respectively. Hence, the revealed regularity in distribution of the methane concentration in estuary water cannot be explained by the quantitative characteristics of the rivers. In our opinion, the presence of extra sources is related to the basic component (permafrost) that distinguishes drainage areas of the three rivers.

The Ob River basin is known to be located in a region partially underlain by discontinuous and sporadic permafrost. Drainage areas of the Yenisei River are mainly underlain by discontinuous and insular permafrost. The Lena River basin is completely underlain by continuous permafrost. Stages of permafrost degradation (thermokarst development) are manifested in consecutive formation of thermokarst depressions, accumulation of seasonal meltwater in them, and the consequent formation of thermokarst lakes. The further development of lakes is concluded with their draining and drying [8]. Development of lakes on a territory is one of the indications of early stages of permafrost degradation. It is well known that thermokarst lakes promote the involvement of old organic material into the present-day biogeochemical cycle due to the formation of taliks underneath lakes (thermokarst lakes), where a temperature above 0°C and anaerobic conditions are sustained year-round and, hence, conditions favorable for methane production are created. Methane concentrations in such taliks can reach $10^3$–$10^5$ μg/l [9, 10]. According to [8], the growth of soil and air temperatures in Siberia over the last three decades fostered 12% expansion of the lake area in continuous permafrost regions, whereas an equivalent (11–13%) reduction of the lake area took place in regions of discontinuous and sporadic permafrost. According to [11], the availability of old organic material buried in permafrost of Siberian alasses increases from west to east. This trend coincides with an increase in the permafrost area and thickness. The facts presented above indicate an eastward displacement of areas of the active degradation of permafrost in Siberia. In our opinion, the higher content of methane in river estuaries located to the east is a biogeochemical manifestation of this process. For this reason the methane content in the Yenisei estuary, where the permafrost degradation process has terminated, is higher than in the Ob estuary, where the permafrost degradation process has stabilized. In the Lena estuary, where permafrost degradation in the basin is in progress, the methane content is substantially higher than in the Ob and Yenisei estuaries.

The variations described above are probably related to intensification of the heating effect of the Atlantic Ocean (cyclonic mode of atmospheric circulation) over the last three decades. This is reflected in the deeper penetration of warm air masses into eastern areas of the Russian Arctic region. Permafrost degradation under conditions of global warming accelerates the dynamics of the subaerial hydrological cycle, which, in turn, affects practically all components of the Arctic ecosystem, including the carbon cycle.

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