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GEOPHYSICS

Methane Anomalies in the Near-Water Atmospheric Layer above the Shelf of East Siberian Arctic Shelf

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Simultaneous measurements of methane in the near-water atmospheric layer and in the surface water layer were carried out for the first time in a shallow-water region of the East Siberian shelf. It follows from the data obtained that the regions of anomalously high values of methane concentration in the air (up to 8 ppm) spatially coincide with the patches of anomalously high concentrations of methane dissolved in water (up to $5 \cdot 10^2$ nM). The analysis of possible sources allowed us to formulate a hypothesis that the genesis of the distinguished anomalies can may be related to the deep sources of methane anomalies. Deep sources of methane include modern methane and/or ancient methane accumulated in the deposits of natural gas and methane gas hydrates.

During warm interglacial epochs, the high latitudes of the Northern Hemisphere deliver methane into the atmosphere maintaining methane concentrations in the Arctic atmosphere higher by 8–10% than that in the Antarctica atmosphere. During cold glacier epochs, this gradient decreases to practically insignificant levels [1]. Land ecosystems are considered the main sources of methane in the arctic region. A special role belongs to wetlands and thermal karst sink lakes underlining year-round by non-freezing talics regions. The total contribution of such ecosystems in the global methane cycle is estimated at 27–28% (140–145 Tg, where 1 Tg = 10^{12} g) [2]. It is known that the Barrow atmospheric monitoring station in Barrow (Alaska, United States) annually records increased concentrations of methane in the atmosphere. Their maximums are continue from the summer season to the autumnal–winter interseasonal period, when the production of land Arctic ecosystems decreases gradually and terminates [3]. Hence, the source maintaining high methane emission in the autumn–winter period should possess a potential related to the influence of the other factors that are endemic for the Arctic region.

Thus far, the role of marine Arctic ecosystems as methane sources has been considered insignificant. At the same time, data in [4, 5] indicate that the role of the Arctic Ocean (AO) is significantly underestimated. For example, the total flux contribution of methane into the atmosphere from the shallow-water part of the shelf only in the Russian seas of to the arctic region can reach the values comparable with the contribution of all continental seas the World Ocean [4]. In our opinion, the East Siberian Arctic shelf should be considered with special attention.

DESCRIPTION OF THE STUDY REGION

The study region includes the eastern sector of the shallow-water shelf of the Laptev Sea (including the estuary of the Lena River) and adjacent sector of the shelf of the East Siberian Sea (up to the estuary of the Indigirka River) (Fig. 1). A large part of this region is under the influence of the Lena River discharge. This region is characterized by a negligible slope of the seafloor bottom. Therefore, the coastline is rapidly displaced over large distances during the period of regressions (decrease in the sea level) and transgressions (increase in the sea level). These displacements result in

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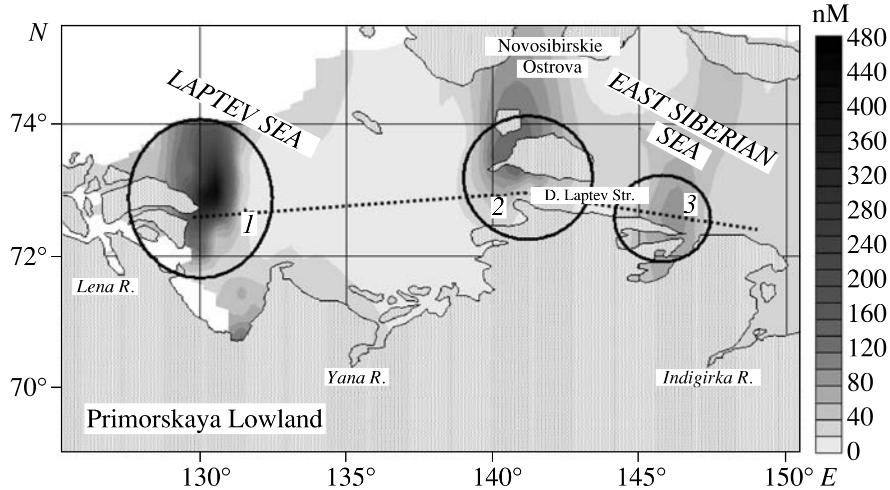

Fig. 1. Distribution of methane in the surface water layer in the study region (September 2005).

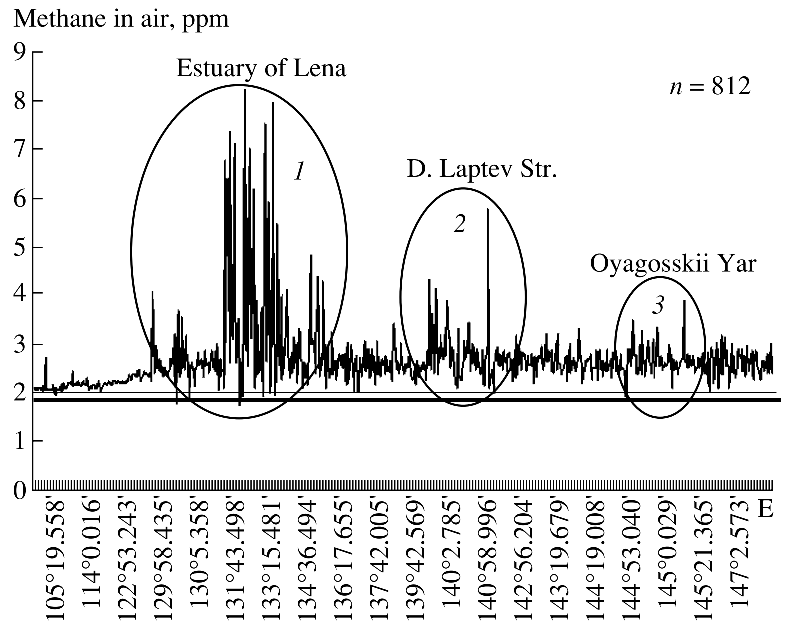

Fig. 2. Methane concentration in the near-water atmospheric layer along the route of the ship (location of the section is shown in Fig. 1 with a dashed line).

weak freezing of bottom sediments during the regression periods and their strong degradation during transgression periods [6]. According to [7], the thickness of perennial frozen rocks (hereafter, permafrost) in this region varies from a few meters to a few hundred meters [7]. The width of the shallow-water shelf reaches 500 km. Its relatively flat surface is underlain by paleovalleys of ancient rivers, which empty into the Laptev Sea 250–300 km north of the present coastline [8, 9]. The location of paleovalleys generally coincides with the location of tectonic faults (Fig. 3), the seismic activity of which persists to this day.

MATERIALS AND METHODS

Air sampling was carried out using a reinforced vinyl sampler fitted to an external meteorological mast installed at the bow of the ship. Continuous recording of wind speed, and direction, and other meteorological parameters was carried out along the route of the ship using a LiCor 1440 automatic meteostation. The mean height of air sampling was equal to 5 m above the sea level. The air from the near-water atmospheric layer was continuously pumped through a loop of the faucet of a SRI–8160C gas chromatograph equipped with a flame ionization detector. Inflow of air to the gas chromatographic channel (silicagel column) was performed

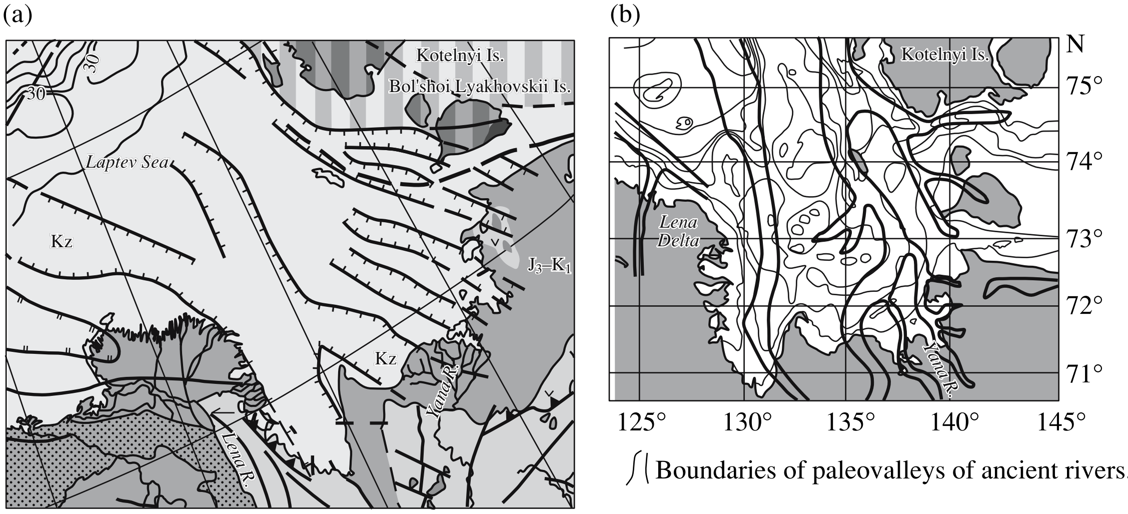

Fig. 3. Location of tectonic faults and paleovalleys in the study region:. (a) faults are shown with (lines crossed by tics); (b) paleovalleys.

automatically every 15 minutes. Standard gas mixtures manufactured by Airliquid Company (United States) were used for calibrating the chromatograph. Helium was used as the carrier gas. The total error of measurements did not exceed 1%. The obtained data were filtered based on two indicators: (1) possible pollution of air samples by exhaust gases of the ship; (2) possible lateral transport of air masses from land. Filtration related to the first indicator was performed by superimposing the curve of carbon dioxide, which concentration was measured synchronously with methane, and by the three-point median filtration, which is most effective in the case of rough ejections. Filtering related to the second indicator was performed using the wind direction as a filter.

Methane concentrations in water were determined by the method described earlier in [4]. The calculated methane concentrations were processed statistically and presented in graphic form using the standard Statistica 6.0 and Surfer 8.0 software packages.

RESULTS AND DISCUSSION

Figure 1 shows the spatial distribution of methane concentrations in the surface water layer. As seen from the figure, the methane concentrations in the research region were distributed non-uniformly. One can clearly see three regions (numbered circles in Fig. 1), with anomalously high concentrations values (hereafter, these regions are highlighted with circles and numbered; below they will be called patches) relative to equilibrium concentrations in the atmosphere, which are equal to 3.5–4.0 nM in each region. Patch 1 is projected to the northeastern part of the Lena estuary and spreads to the north up to 74° N (boundary of the study region) and to the east up to 132° E. Methane concentrations in the water in this area reached anomalously high values ($\sim 5 \cdot 10^2$ nM). Patch 2 geographically coincides with the location of D. Laptev Strait and the western end of Bol'shoi Lyakhovskii Island. Methane concentrations in this region reached $\sim 1–2 \cdot 10^2$ nM. Patch 3 coincides with the location of Oyagosskii Yar. Here, methane concentrations in the surface layer varied within $0.5–1 \cdot 10^2$ nM.

According to our data, the curve of methane distribution in the near-watersurface atmospheric layer correlates well with the data obtained for the surface water layer (Fig. 2). One can see that methane concentrations in the near-water atmospheric layer were significantly higher than the background concentrations at these latitudes (1.85 ppm) [3]. The regions of anomalously high concentrations (3–8 ppm) are also shown with circles and numbersed. A comparison of Figs. 1 and 2 clearly demonstrates the coincidence of patches of high methane concentrations in the near-surface water layer with the regions of anomalies in the air. This can be considered as revealing detection of powerful sources of methane emission into the atmosphere in the study region. The nature of these sources can be different. First of all, it is necessary to separate the land and water sources. While estimating the potential of possible water sources, we should distinguish the contribution of fresh-water and marine ecosystems (lateral and vertical transport, and in situ production).

Since the route of the ship was very close to the coast, the influence of land sources could be important in the condition if water masses were transported from land to sea. However, the analysis of the meteorological data showed that during the works, the winds of northern directions dominated during the investigation. Therefore, we can exclude the role of lateral transport of land water masses in the formation of the anomalies in the air.

Determination of the contribution of fresh-water (rivers, lakes, and ground waters) and marine ecosystems seems a difficult task because the East Siberian shallow-water shelf not only plays the role of the estuary of Siberian rivers, which accumulate methane transported from the regions of rivers discharge areas, but it also serves as a reservoir for the discharge of methane accumulated in the permafrost sink along talic zones from the zones of alasses drainage, swampy soils, lacustrine talics, and the seasonal thawing layer above the permafrost. According to [10], the permafrost sink can account for up to 20% of the total sink, while the methane concentrations in the permafrost of young alasses in the Lena delta area reach $6 \cdot 10^5$ ppm [11]. We should take into account the following fact: unlike methane intensely oxidized by aerated river waters, methane transported with the permafrost sink can avoid oxidation. It is possible that both the river and permafrost sinks make a specific contribution to the formation of all patches of anomalously high methane concentrations in the water. At the same time, their influence is obviously not enough to explain the significant extension and the meridional direction of these patches, because the coastal East Siberian Current, which dominate in this region, transports the river discharge waters in the latitudinal (eastern) direction.

In our opinion, the genesis of the found anomalies described above is most probably related to geological structures (e.g., tectonic faults), paleovalleys of ancient rivers, and flooded thermal karst lakes and lagoons underlain by penetrative talics, as well as, possibly destructed deposits of gas hydrates. Indeed, the geological history of this region evidences that the coastline was displaced 800–900 km to the south during the periods of transgressions. Consequently, a large number of thermokarst lakes underlain by talics were flooded and/or transformed into thermokarst lagoons [12]. Since talics represent the thawedmelted part of the bottom permafrost, they are characterized by a positive temperature throughout the year and a favorable environment facilitates anaerobic methane production. Downward development of talics (usually to a depth of $4R$, where R is the radius of the lake) can lead to the destruction of secondary (relict) gas hydrates formed during the periods of repeated freezing of rocks and included into the permafrost structure [13]. The study region is also marked by coincidence of the projection of tectonic faults coincides with the location of ancient paleovalleys of rivers. Hence, there is high probability of the formational of throughpass penetrative talics under river beds formed by the influence of upgoing ascending geothermal fluxes. According to [14], whose geothermal fluxes in faults zones reach 100 mW/m^2 or more [14]. According to [12], such fluxes are sufficient for destructing the stability zone of gas hydrates located beneath the permafrost. Methane emission from deep gas deposits usually resembles a jet (large accumulations of bubbles with different diameters [15]). Since the study region represents a shallow shelf, the jet-shaped methane from flux can easily avoid oxidation, and reach the atmosphere taking into account the fact of shallow depths in the shelf region. The time stability of methane patches (for example, a methane anomaly in the D. Laptev Strait was first recorded in September 2004) and homogeneity within the boundaries of the water column also confirm our hypothesis put forward here. Thus, we can conclude that all methane sources on the East Siberian shelf are related to the genesis and historical evolution of both oceanic and land cryozones. Permafrost degradation enhanced by the influence of global warming can lead to destruction of the impermeable coating cap preventing the emission of methane from sub-aquatic gas deposits (including primary and relict gas hydrates) from submarine gas deposits and to a possible catastrophic change in the regional methane balance.

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