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GEOCHEMISTRY

Reconstruction of the Holocene Climate of Transbaikalia: Evidence from the Oxygen Isotope Analysis of Fossil Diatoms from Kotokel Lake

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Fossil diatoms or Bacillariophyta are microscopic unicellular organisms with siliceous cell—frustule consisting of two separate valves that play an important role in marine and lake sedimentation. The data of diatom analysis provide reliable spatial and temporal reconstructions of the natural environment and the climate of past geological epochs [1].

The possibility of investigation of fossil Bacillariophyta by the oxygen isotope method in order to obtain paleoinformation was originally demonstrated by L. Labeyrie [2]. The plotted isotope curves indicate variations in the temperature and isotope composition of water ($\delta^{18}O_w$) [2, 3], which, in turn, is controlled by the isotope composition of atmospheric precipitation ($\delta^{18}O_{atm}$) and hydrological peculiarities of the studied water reservoir [4].

For the Central Asian region, oxygen isotope records with the low age resolution were obtained from interglacial deposits of Lake Baikal [5, 6]. The large sizes of its basin (an area of ~31 500 km^2 and an average depth of ~745 m) and catchment area (~560 000 km^2), significantly average paleoclimatic signal, and depletion of bottom sediments in organic matter complicates radiocarbon dating. Kotokel Lake (an area of ~69 km^2 and an average depth of 5–6 m) located on the eastern side of Lake Baikal (Fig. 1) is more promising for obtaining information on the Late Quaternary climate of Transbaikalia [7]. The high concentration of organic matter and the absence of the reservoir effect allow to date deposits of this lake reliably, and the position of the catchment basin (an area of ~183 km^2) at the boundary between the taiga and steppe zones provides a high sensitivity of the lake ecosystem to variations in the heat and water supply [7].

In this paper we report the results of oxygen isotope analysis of fossil diatoms from the column of bottom sediments (KTK2: 52°47′ N, 108°07′ E, depth 3.5 m, total core length of 1253 cm) from Kotokel Lake dated by the AMS ^{14}C method and likely reasons for variation of the isotope signal are discussed.

Fossil diatoms were extracted by the multistage methodology [8] from the upper 500-cm layer of sediments, which was formed during last 11 500 years and is represented by blackish-brown gyttja [7]. The methods of scanning electron microscopy and energy-dispersive spectroscopy demonstrated the absence of a visible admixture of terrigenous material in the obtained samples and a low concentration of Al_2O_3 (<1.61%), which makes them suitable for isotope investigations. Decomposition of diatoms for the isotope analysis was performed using laser under BrF_5 atmosphere after sample dehydration in a helium flow [9]. $\delta^{18}O$ was measured on a PDZ Europa 2020 mass spectrometer at the Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany. The error of $\delta^{18}O$ analysis was ±0.25‰ (1σ). The correctness of the obtained $\delta^{18}O$ values was controlled by regular measurements of the BFC standard [9]. The average time resolution of the isotope record determined with account for the age model [7] was 150 years.

We studied the isotope composition of water samples from Kotokel Lake and related rivers and compared the data obtained with the isotope composition of atmospheric precipitation of the Baikal region (samples of the authors and the GNIP database for Irkutsk) in order to estimate modern hydrological conditions and reveal the factors controlling $\delta^{18}O$ of fossil diatoms. The isotope analysis of water samples

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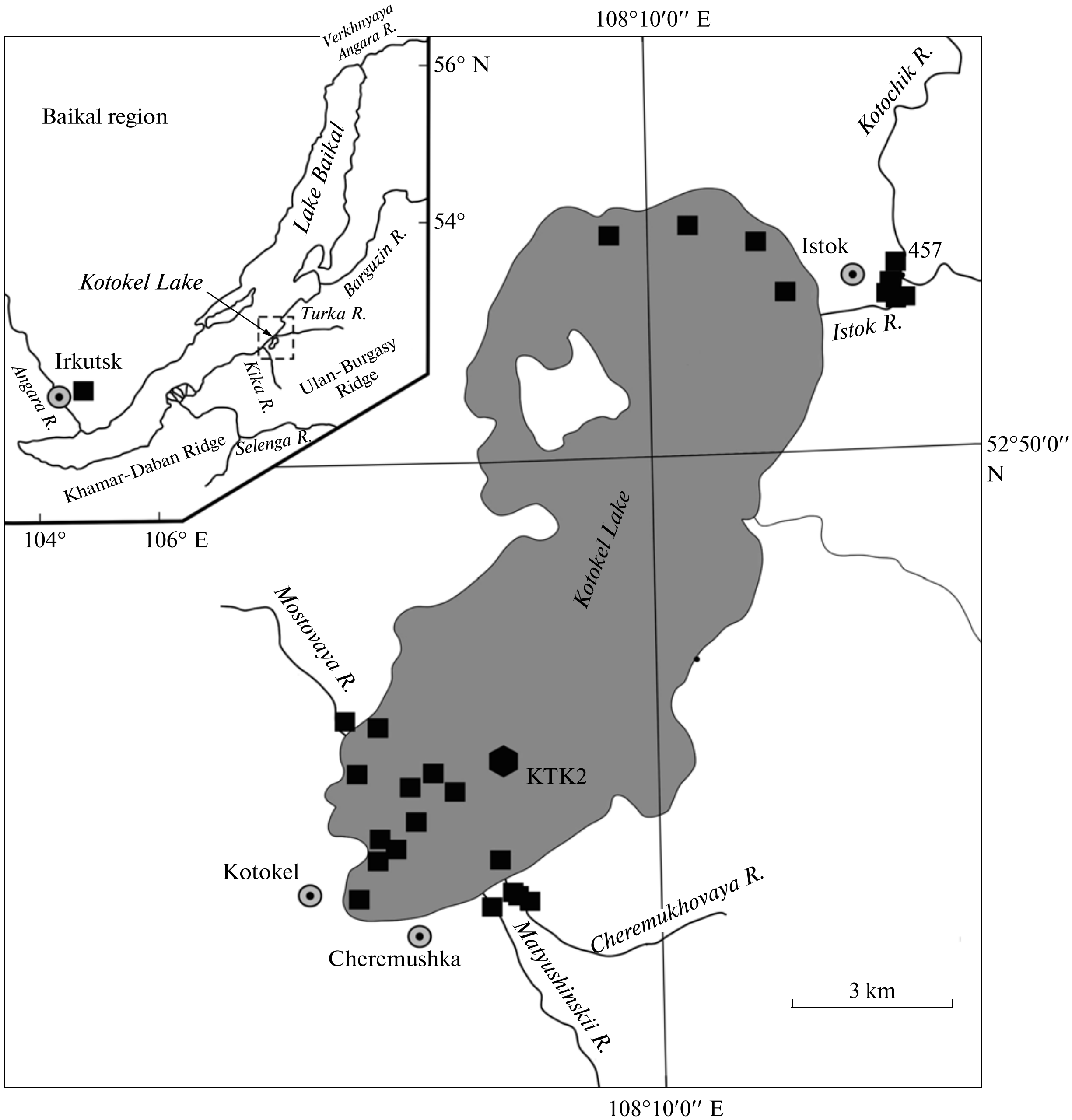

Fig. 1. Area of investigations: Baikal region; Kotokel Lake with place of drilling of KTK2 core (black hexagon) and points of water sampling (black squares).

(Fig. 1) was performed on a Finnigan MAT Delta-S mass spectrometer. The errors of δD and $\delta^{18}O$ measurement (1σ) were ±0.8 and ±0.1‰, respectively.

The $\delta^{18}O$ and δD values for water from Kotokel Lake range from –10.8 to –13.7‰ and from –101.2 to –113.9‰, respectively. The measured values on the diagram $\delta^{18}O$ vs. δD (Fig. 2) plot to the right of the Global Meteoric Water Line (GMWL) following the linear dependence $\delta D = 4.8\delta^{18}O–48$ ($R^2 = 0.96$), the slope of which corresponds satisfactorily to the coefficient 5 for the theoretical evaporation line (EL) [10]. Consequently, the obtained dependence characterizes the isotope fractionation caused by evaporation. The isotope composition of meteoric water before evaporation corresponds to the point of EL and GMWL crossing. The values of $\delta^{18}O$ and δD at this point are –18.5‰ and –140‰, respectively. These values are lower than the mean weighted annual values of $\delta^{18}O_{atm} = –16.2$‰ and $\delta D_{atm} = –124.1$‰ (the GNIP database [11]) for the Baikal region and close to the average values of $\delta^{18}O = –19.8$‰ and $\delta D = –145.9$‰ characterizing the isotope composition of river waters

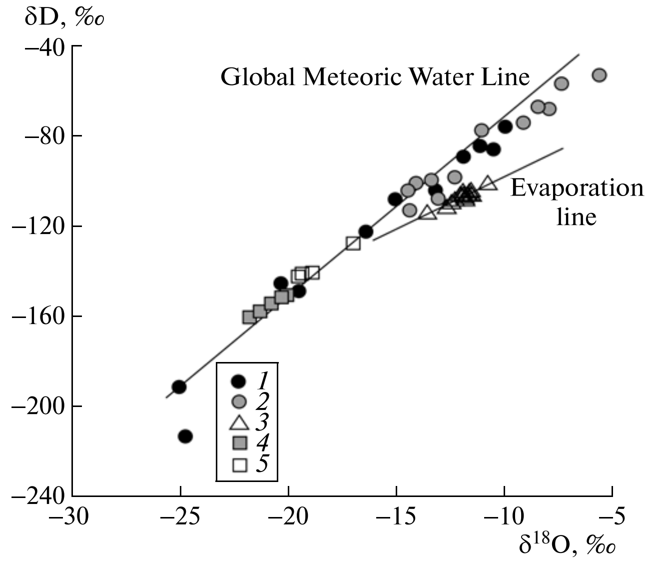

Fig. 2. Isotope composition of water from Kotokel Lake, related rivers, and atmospheric precipitation of the Baikal region. (*1*) Atmospheric precipitation (GNIP database); (*2*) rain, Irkutsk; (*3*) water from Kotokel Lake; (*4*) water of the Istok and Kotochik rivers; (*5*) water of rivers flowing into Kotokel Lake.

flowing into the lake in summer. The absolute values $\delta^{18}O$ and δD of river waters suggest a significant portion of waters formed at the expense of melting of seasonal ice and snow in them.

The isotope characteristics of rain water (on average, $\delta^{18}O = -11‰$, $\delta D = -85‰$) are quite consistent with the GNIP database [11]. The $\delta^{18}O$ values of winter precipitation are significantly lower (–25‰) [11]. This provides evidence for the dependence of $\delta^{18}O_{atm}$ on the temperature of condensation [10]. The isotope composition of atmospheric precipitation is controlled by the trajectory of water entrance in the region as well [12]. Currently Atlantic air masses supply the Baikal region with moisture during the year, whereas southern and southeastern cyclones are active in July–August [7]. Water transport from the ocean to the continent is accompanied by a gradual decrease of $\delta^{18}O_{atm}$ and δD_{atm} [10]. Most likely atmospheric precipitation coming to the Baikal region from the south and southeast is more enriched in $\delta^{18}O$ in comparison with precipitation of Atlantic origin.

The performed analysis demonstrated that variations of the isotope composition of the Kotokel Lake water were controlled by variations of the isotope composition of atmospheric precipitation, the portion of snow melt water flowing into the lake, and evaporation.

The $\delta^{18}O$ values of fossil diatoms of Kotokel Lake during the past 11 500 years (the calendar age is indicated hereinafter) vary between 23.7 and 30.3 gradually decreasing upwards through the section (Fig. 3). The obtained values predominantly reflect the conditions of blooming of Aulacoseira granulata diatom species dominating in Holocene deposits (45–98%) [7] in summer, when the surface layer of water is warmed up to +25°C [13]. A gradual decrease of $\delta^{18}O$ values in fossil diatoms in the Holocene may be interpreted as the trend of a general cooling synchronous to the total decrease of summer insolation at the middle latitudes of the northern hemisphere (Fig. 3). Accounting for the temperature coefficient of +0.36‰/°C for atmospheric precipitation of Irkutsk [14], the shift of $\delta^{18}O$ in fossil diatoms by 6.6‰ (Fig. 3) requires a decrease in the mid-annual air temperature in the Baikal region in the Holocene by 20°C, which is improbable. Consequently, a climate cooling resulting from insolation decrease only partly explains the change of $\delta^{18}O$ in fossil diatoms. Interpretation of the obtained record (Fig. 3) requires accounting for other factors as well.

The isotope data from China (Fig. 3) provide evidence for strengthening of summer monsoon circulation in East Asia in the Early Holocene [15]. At the same time, as is evident from the data of pollen analysis, the influence of Atlantic air masses on the climate of Kazakhstan and South Siberia was weaker than present [7]. From the Middle Holocene, atmospheric circulation is reconstructed in Central Asia, which results from weakening of the summer monsoon and strengthening of the western transport of air masses [7]. The high values of $\delta^{18}O$ in fossil diatoms of Kotokel Lake (Fig. 3) characterizing the first half of the Holocene provide evidence for the less significant contribution of Atlantic air masses in the water balance of the region and for the high portion of atmospheric precipitation of Pacific origin in comparison with modern values, as well as for a decrease in snow supply and increased evaporation of lake water in summer.

Warming causes melting of snow and ice formed in the colder periods in the mountains of the region and results in intense incorporation of water with low $\delta^{18}O$ values into the lake. The short-term decrease of $\delta^{18}O$ in fossil diatoms 10 800, 9300, 6200, and 1200 years ago accompanied by an increase of the diatom concentration (Fig. 3) provides evidence for significant introduction of melt water into the lake as a result of air temperature increase.

Data of the oxygen isotope analysis of fossil diatoms from bottom sediments of Kotokel Lake allowed us to reconstruct the mechanisms of climatic changes in Transbaikalia in the Holocene. Variations in the natural environment and climate of the region are mainly controlled by solar insolation and related changes in atmospheric circulation, which control the share of atmospheric precipitates and their intra-annual distribution. Prevalence of summer atmospheric precipitation in the region results in weighting of the isotope composition of lake water and increase of $\delta^{18}O$ in diatoms, whereas increase of snow portion

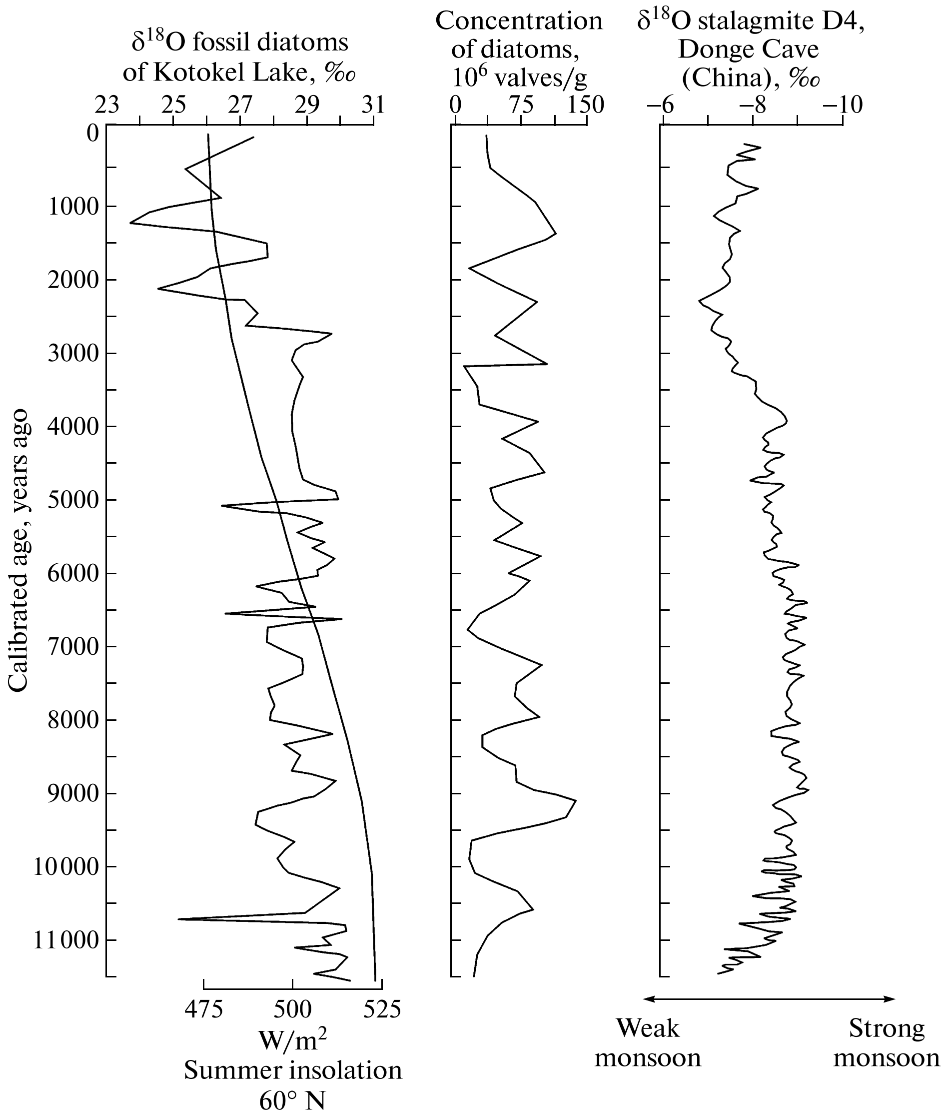

Fig. 3. Oxygen isotope composition and total concentration of fossil diatoms in Holocene deposits of Kotokel Lake and curves of summer insolation (60° N) [7] and oxygen isotope composition of stalagmite D4 from Donge Cave (China) as an indicator of East Asian summer monsoon activity [15].

causes the opposite effect. The obtained oxygen isotope record satisfactorily corresponds to general climate fluctuations in the northern hemisphere reflecting the complexity of the interaction between the global (solar insolation and atmospheric circulation) and local (evaporation, snow melt water) climate-forming factors on environments of Transbaikalia.

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