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NEW DATA ON THE CONCENTRATIONS OF STABLE OXYGEN ISOTOPES IN SYNGENETIC LATE PLEISTOCENE WEDGE ICE OF THE LOWER KOLYMA RIVER [1]

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The development of correct paleofrost reconstructions is hindered by the lack of criteria for reliable, unambiguous evaluation of the changes in factors that governed the geocryologic situation in the past. One direct indicator of the presence of a permafrost zone, or rather of "a very cold" permafrost zone, with low (not exceeding -2° to -3° C) mean annual subsoil temperatures, is the finding of syngenetic wedge (foliated ground) ice. A most promising method of classifying syngenetic ice in terms of the temperature of its formation is oxygen isotope analysis. This technique is particularly effective in the case of thick ice wedges. The latter are formed in such a way that one is almost certain of the presence of vertical ice stratification, i.e., an increase in its age with depth. Northern Yakutia is one

[1]Translated from: Novyye dannyye po soderzhaniyu stabil'nykh izotopov kisloroda v singeneticheskikh povtorno-zhil'nykh l'dakh pozdnepleystotsenovogo vozrasta nizoviy r. Kolymy. Doklady Akademii Nauk SSSR, 1985, Vol. 281, pp. 904-907.

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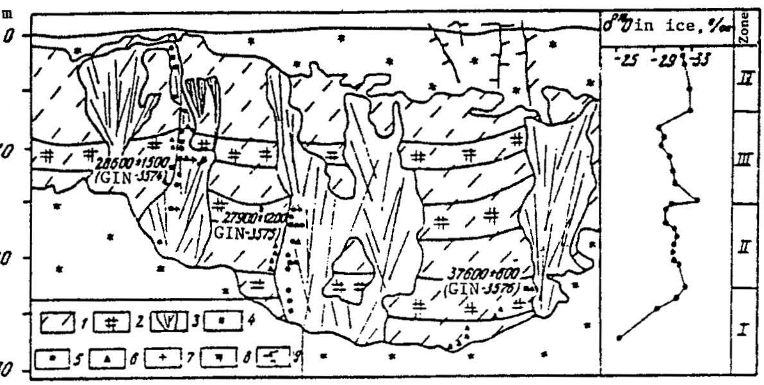

Fig. 1. Oxygen isotope diagram of organomineral complex on lower Kolyma River (about 0.5 km north of Zelenyy Mys), containing polygonal wedge ice.

1) Silty loam; 2) Plant (peat) detritus; 3) Wedge ice; 4-7) sampling sites: 4) for radiocarbon analysis, 5) for oxygen isotope analysis, 6) for spore and pollen analysis, 7) for hydrochemical analysis; 8) Snow cover; 9) Larch.

area where extremely thick wedge ice is widespread, and data on it are extensively used in paleoreconstruction [1-3].

Our new data on a section of a late Pleistocene organomineral stratum on the right bank of the lower Kolyma River that includes a representative (both along the vertical and over the entire volume of the ice) polygonal wedge ice complex allow us to reach very definite conclusions as to the climatic changes that have occurrence in this area in the late Pleistocene (at least during the time in which this stratum was deposited).

The exposure of the above stratum, produced by a temporary watercourse, is more than 30 m high, but during the observations the bottom 3 m was covered by talus. The section clearly falls into two parts (Fig. 1). The upper 0 to 10 m interval, containing less ice, consists of homogeneous, practically unstratified dark gray heavy sandy loam with a high silt content. The lower, 10 to 27 m interval, with a higher ice content, contains three dark gray sandy loam members 1.8, 2.3 and 3.4 m thick, respectively, saturated with organic matter consisting of roots and twigs of small shrubs and stubble of grasses and mosses. These members are separated by layers of sandy loam with no vegetative residues, 3.3 to 3.6 m thick.

The most important structural characteristic of this section is the presence of a complex of syngenetic wedge ice. Thick wedges, cutting through the entire stratum, are the dominant form of the ice. The visible height of these wedges exceeds 26 m.

Samples were collected from the stratum hosting the wedge ice and from the wedges themselves (we collected 26 specimens from two adjoining wedges in the 1 to 27 m depth interval (see Fig. 1). The content of the stable, heavy ^{18}O oxygen isotope was determined, and palynological, hydrochemical and radiocarbon analyses were run on all samples. From our data we were able to draw a diagram of the distribution of oxygen isotopes with depth, which shows four contrasting oxygen isotope zones differing in the behavior of the distribution curve for $\delta^{18}O$ (see Fig. 1).

Before proceeding to the interpretation of the data in terms of paleotemperature, we need to discuss the degree of preservation of the primary isotope "record." Of all possible modes of chemical exchange that could alter the oxygen isotope composition in the absence of gradients in the external conditions (in particular temperature), self-diffusion would be the most active. A change in concentration as a result of diffusion in crystalline bodies (such as ice) is described by Fick's second law in integral form [4]. The Fick's law equations in this form are relatively simple to solve, the principal problem being the determination of the self-diffusion coefficient under the integral.

There are no data from direct, *in situ*, determinations of the self-diffusion coefficient D in buried ice, and there exist only very few exact determinations of D in any ice, even in the laboratory. Study of diffusion of tritium-tagged water in an ice specimen from the Mendenhall Glacier (Alaska) at -10° C gave a value of $D = 2.51 \times 10^{-15}$ m²/sec [5], and another experimental study determined the self-diffusion coefficient for $H_2{}^{18}O$ in ice at -1.5° to -2° C as 10×10^{-15} m²/sec [6]. Several figures of the same order of magnitude are presented by Eyzenberg and Kautzman [7], and accordingly in our calculations we used D values between 2 and 10×10^{-15} m²/sec.

Evaluating the integral, after substituting these values of D into it, by means of tables [8] enabled us to estimate the extent of self-diffusion in the case of various concentration gradients of the stable isotope and over various time intervals. Our most important finding was that even at gradients of $\delta^{18}O$ exceeding 10 promilles (in our tests they were much lower) and for time periods of as much as 10^5 years, the change in concentration of heavy oxygen isotope as a result of self-diffusion would not exceed 0.01 promille, i.e., the change in concentration would not exceed the error of measurement by mass spectrometry.

We also note a conclusion which seems to us rather important. Even such low rate of diffusion as that cited above will, over a long time even, out or smooth the peaks in the original curve. Accordingly, the very fact that these peaks have persisted, i.e., that there are considerable variations in the ^{18}O content, suggests that it is valid to use oxygen-isotope data in paleogeocryological reconstructions, even in the case of very old ice.

Paleotemperature analysis of variations in the concentration of stable oxygen isotopes involves their comparison with the concentration of ^{18}O in present-day syngenetic ice and snow. In present-day offshoots of syngenetic ice wedges on the flood plain of the Kolyma River, the concentration of $\delta^{18}O$ ranges from -24.6 promilles to 127 promilles (data for offshoots no more than 100 years old). The value measured by us for the first autumn snow was $\delta^{18}O$ = -21.1 promilles, while Vtyurin et al. [9] give -28.5 promilles for snow falling in February-March and -23.9 promilles for June snow. It is evident that the Pleistocene wedge ice was 3 to 10 promilles lower in this oxygen isotope at almost all depths.

For numerical solution of the problem we used a slightly altered version of Dansgaard's empirical formula [10]

$$\Delta t = \frac{\delta^{18}O_{pres} - \delta^{18}O_y}{0{,}695}, \qquad (1)$$

where Δt is the temperature difference (°C) between the present and the time in question y, $\delta^{18}O_{pres}$ is the ^{18}O concentration of present-day wedges, and $\delta^{18}O_y$ is the concentration in wedges of time y.

Substituting the resultant values for $\delta^{18}O$ into Eq. (1), we found that although the mean winter temperature fluctuated widely during the time of formation of the wedges in the rocks near the village of Zelenyy Mys, it was 5 to 15° lower than present temperatures over almost the entire period.

The results of oxygen isotope determinations are corroborated by analysis of spore and pollen spectra in the sediments and in the ice wedges themselves. The spectra in the sediments show a high concentration of grass pollen, reaching 84 percent of the total spore and pollen content. The pollen of woody plants is extremely scarce throughout the section, never reaching 30 percent, even where there is a high concentration of pollen of allochthonous rather than local origin. This fact, and especially the large (as much as 35 percent) content of pollen of the cryophyllic plant *Selaginella sibirica* at all depths, suggests extremely unfavorable growth conditions during the deposition of the sediments, i.e., low summer temperatures. Although the spore and pollen spectra from the wedge ice vary with depth, they largely resemble the spectra in the host sediments, with grass pollen accounting for 41 to 93 percent, tree pollen for 1 to 20 percent and *Selaginella* for 33 percent. This confirms our original postulate that the wedge ice is syngenetic with the sediments, and that the wedges originated in a harsh climate.

We note two results of the hydrochemical studies: (1) total salinity of the ice is low, although it is significant, i.e., 0.10 to 0.12 g/liter; (2) bicarbonate content is significant (0.07 to 0.08 g/liter). This last fact is probably due to the effect of liquid water, which for a short time flowed along frost cracks in the subsoil and dissolved the carbonates abundantly present in the host rocks (carbonate solubility in water at low temperatures is high).

The time at which the wedges were formed can be very reliably determined by radiocarbon dating of the host sediments, or rather their organic component, the allochthonous detritus. A specimen from a depth of 23.7 m was dated to 37,600 ± 800 years (GIN-3576), that from a depth of 26.4 to 27,900 ± 1200 years (GIN-3575), and that from 12.0 m to 282,600 ± 1300 years (GIN-3574). Similar dates are given by Lozhkin [11]. This suggest that our dates are reliable and that the wedges were formed in the time interval of 40,000 to 16,000 (or 18,000) years ago (the upper limit based on the fact that the tops of the wedges lie more than 10 m above sediments dated at 28,000 years). We can therefore postulate extremely harsh climatic conditions throughout this time interval, and confidently assume that during the period for which the oxygen isotope diagram was obtained, i.e., 37,000 to 16,000 (or 18,000) years ago, the climatic conditions were considerably harsher than at present. Thus the winter temperatures were 5 to 15° lower than at present. Note similar ^{18}O concentrations were found in wedge ice of Vorontsov Gorge [9] and in the north of Tuktoyaktuk Peninsula (northwestern Canada) [12]. The sediments surrounding the wedges in these areas had ages similar to ours. Note also that even in West Siberia, an area extremely far from the Kolyma area of our work and differing considerably from it in geological development, Vasil'chuk and Trofimov [13] found organo-mineral complexes with polygonal wedge ice that developed synchronously to our sediments, again under climatic conditions harsher than those of the present (judging by the very low heavy oxygen content of the wedge ice). This indicates that an extremely harsh climate dominated in the Subarctic Region in the late Pleistocene, ruling out even partial degradation of permafrost in all of these polar areas.

REFERENCES

1. Popov, A.I. Vestn. Mosk. gosud. univ., Ser. geogr., No. 6, pp. 60-66, 1982.
2. Kaplina, T.N. and R. Ye. Giterman. Izv. Akad. Nauk SSSR, Ser. geol., No. 6, pp. 79-83, 1983.
3. Tomirdiaro, S.V. Lessovo-ledovaya formatsiya Vostochnoy Sibiri v pozdnam pleystotsene i golotsene (The Loess-Ice Association of East Siberia in the Late Pleistocene and Holocene), Nauka Press, Moscow, 1980.
4. Zeit, W. Diffusion in Metals, Russian transl., Moscow, 1958.
5. Itagaki, K. J. Phys. Soc. Japan, 19, No, 6, p. 1081, 1964.
6. Kuhn, W. and M. Thurkauf. Helv. chim. acta., 41, No. 4, pp. 938-971, 1958.
7. Eyzenberg, D. and V. Kautsman. Struktura i svoystva vody (Structure and Properties of Water), Gidrometeoizdat Press, Leningrad, 1975.
8. Comrie, L.J. Chamber's Six Figure Tables, Van Nostrand, 1949. Russian transl., 1964.
9. Vtyurin, B.I., N.S. Bolikhovskaya et al. Byul. Kommissii po izucheniyu Chetvertichn. perioda (Bulletin of the Commission on the Study of the Quaternary Period), No. 53, pp. 12-21, 1984.
10. Dansgaard, W. Tellus, 16, No. 4, pp. 436-468, 1964.
11. Lozhkin, A.V. Doklady Akad. Nauk SSSR, 235, No. 2, pp. 435-437, 1977.
12. Ross, J. Geol. Surv. Canada, Pap. 83-1B, pp. 67-74, 1983.
13. Vasil'chuk, Yu. K. and V.T. Trofimov. Dokl. Akad. Nauk SSSR, 275, No. 2, pp. 425-428, 1984.

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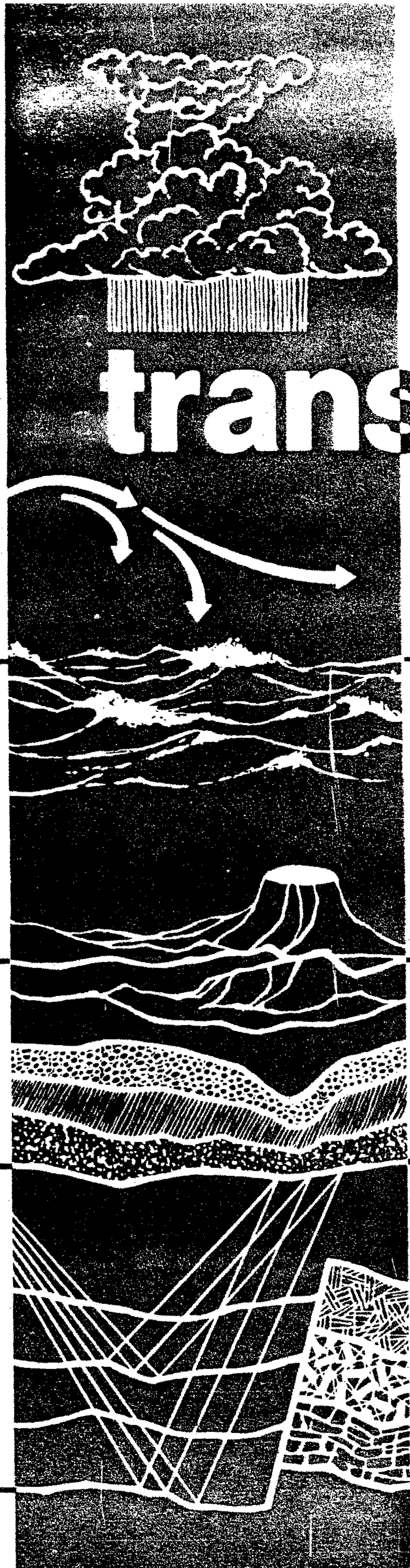

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