Paleological permafrost interpretation of oxygen isotope composition of Late Pleistocene and Holocene wedge ice of Yakutia.

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PALEOLOGICAL PERMAFROST INTERPRETATION OF OXYGEN ISOTOPE COMPOSITION OF LATE PLEISTOCENE AND HOLOCENE WEDGE ICE OF YAKUTIA[1]

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The isotope distribution in the cryosphere is largely conditioned by global climatic changes. For this reason, reconstruction of paleoconditions must be based on correlation of data from very large areas in order to be meaningful,

In continuing to attempt a correlation of paleological permafrost conditions among different regions, we collected new data on the isotope composition of subsurface ice to supplement those already reported [1-3]. Our investigation of syngenetic wedge-ice units resulted in detailed oxygen-isotope diagrams, which were radiocarbon-dated to the end of the late Pleistocene (Bykovskiy Peninsula-Lena River delta and Stadukhin Channel of the Kolyma River) and the middle Holocene (Aleshka Terrace of the Kolyma River and the high terrace of the Mamontov Hill on the Aldan River). These sections had been previously studied, but their ages and genesis were interpreted in rather conflicting ways [4-7]. Our new data lead to more definitive conclusions about certain factors in their history.

The section through the wedge ice on the 20 to 25 m terrace of the Bykovskiy Peninsula is quite complex. One finds here a number consisting of a sequence of rhythmically-alternating partings of sand and gravel and pebble, as well of sandy loam, often with abundant organic matter (consisting of detritus and peat), and clay. The section consists of as many as 3 to 4 such stratified members, usually with a corresponding number of tiers of ice wedges, since the tops of the wedges commonly lie in the intervals of peat-containing sandy loam, while their bottoms (Fig. 1a) extend into the underlying sand and gravel. In some cases the overlying wedges penetrate the lower wedges and together form a single multitiered ice wedge. The presence of well-rounded gravel most probably indicates that the bulk of the sequence is alluvial in origin. The present-day floodplain sequence (the low-lying coastal area of the Bykovskiy Bay) exhibits an identical section, and there too the tops of the syngenetic wedges are associated with peat-containing soil in the upper part of the section, while their bottoms extend into the underlying gravel and sand.

We have rather reliable radiocarbon dates (Fig. 1a) for the time of emplacement of the ice wedges and the sedimentary sequence making up the terrace. Thus, the sequence began to develop about 40 thousand years ago and the development of the syngenetic wedges ended (according to earlier data [6]) not later than 28 to 30 thousand years ago. The chemical composition of the wedges indicates that they were formed in the immediate vicinity of the sea. We infer this from the relatively high mineral content of the ice, which exceeds 0.2 g/liter in almost the entire wedge sequence (25 specimens), with a predominance of bicarbonate, calcium and sulfate ions. It is only in the immediate vicinity of the surface that one encounters ice of very low salinity in which the dry residue does not exceed 0.09 g/liter; this ice obviously was formed epigenetically in the Holocene. The same conclusion is suggested by the oxygen isotope composition of the ice (49 specimens). While most of the ice has $\delta^{18}O$ ranging from -34.9 promilles to -29.8 promilles, the upper, Holocene ice wedge has $\delta^{18}O$ from -28.7 promilles to -26.8 promilles (in a present-day outgrowth of a syngenetic wedge on the coastal plain of Buor-Khay Bay, $\delta^{18}O$ = -24.2 promilles).

The isotope diagram clearly shows a period of most severe winters (more than 10° colder than those now occurring) about 40 to 28 thousand years ago. The winters in the period from 36 to 40 thousand years ago were also much more severe than at present. Thereafter the winters became milder, and in the intervals from 38 to 36 and 33 to 30 thousand years ago they were only 5 to 6° C colder than they are now.

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[1]Translated from: Paleomerzlotnaya interpretatsiya izotopno-kislorodnogo sostava pozdnepleystotsenovykh i golotsenovykh povtorno-zhil'nykh l'dov Yakutii. Doklady Akademii Nauk SSSR, 1988. Vol. 298, No. 2, pp. 425-529.

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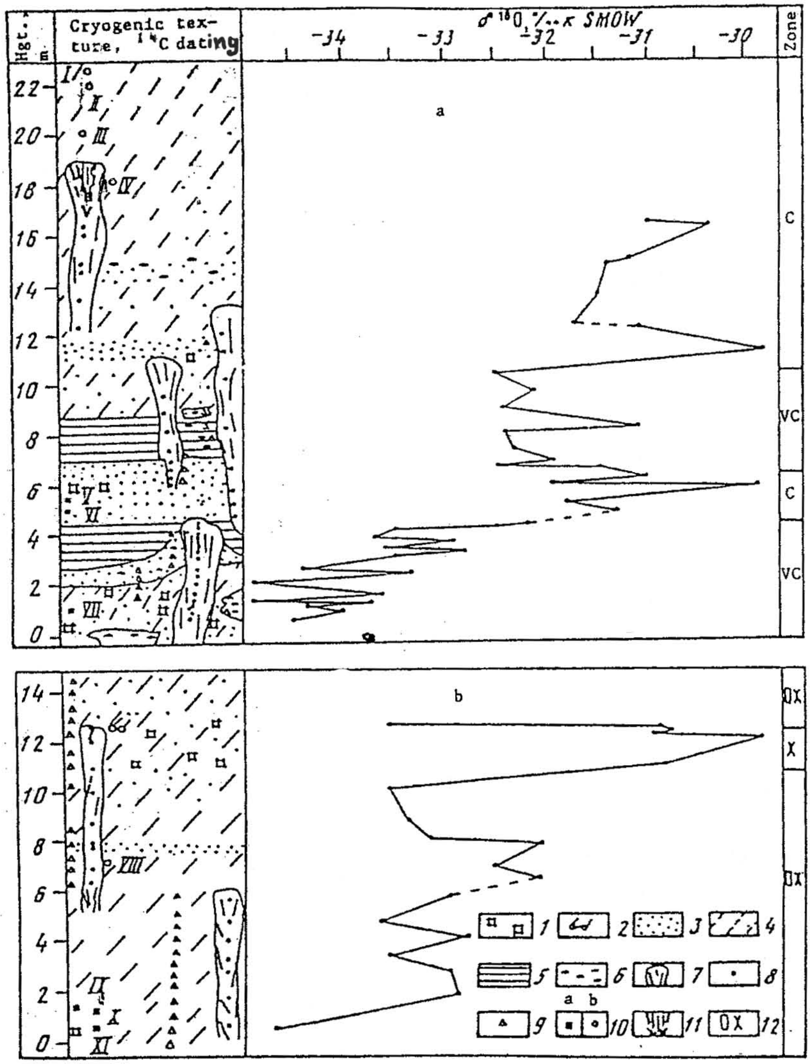

Fig. 1. Oxygen isotope diagrams of late Pleistocene syngenetic ice wedges in organomineral sequences of the 25-meter terrace on the Bykovskiy Peninsula (a) and 15-meter yedoma (eroded terrace) on the Stadukhin Channel of Kolyma River (b). *1)* Peat and plant detritus; *2)* Wood; *3)* Sand; *4)* Sandy loam; *5)* Clay; *6)* Gravel and pebble; *7)* Syngenetic ice wedges; *8-10)* Sampling: *8)* for oxygen isotope, hydrochemical and palynological analysis, *9)* for geochemical, palynological and particle-size analysis *10)* for radiocarbon analysis with collections by author (a) and data of other investigators (b): *I)* 21630 ± 240 (LU-1328), *II)* 22070 ± 410 (LU-1263), *III)* 28500 ± 1690 (LU-1329), *IV)* 33040 ± 810 (LU-1330), *V)* 40200 ± 800 (GIN-4597), *VI)* 40400 ± 1200 (GIN-4593), *VII)* 40800 ± 1200 (GIN-4591), *VIII)* 21600 ± 200 (GIN-4334), *IX)* 26000 ± 1100 (GIN-3980), *X)* 27000 ± 600 (GIN-3981), *XI)* 31500 ± 1100 (GIN-3983) years ago, *11)* Holocene epigenetic ice wedge intruded into an ancient ice vein; *12)* Indicators of oxygen isotope zones; C, cold; VC, very cold.

The geocryological history of the maritime lowlands of Yakutia in later periods is described in diagrams published earlier [2, 3]. It can also be read from the oxygen isotope diagram drawn up for the syngenetic ice wedges of the Yedoma sequence on Stadukhin Channel (Fig. 1b). In this case the wedges are about 14 m high. They are generally narrow (1 to 1.5 m wide), occur 3 to 4 m apart, and are ribbon-shaped. The sandy loams hosting them contain rather small amounts of organic material, which was used to date the beginning of wedge development to between 30 to 27 thousand years ago. The accumulation of the sequence most probably ended no later than 15 to 16 thousand years ago The wedge complex developed under rather severe climatic conditions, as indicated by a spore-pollen analysis of the surrounding layers and of the wedges themselves. Both the host rocks and the wedges contain sporadic tree pollen,

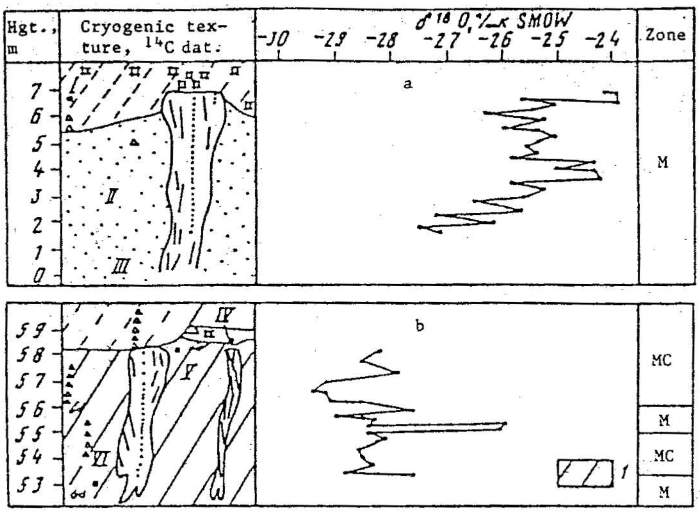

Fig. 2. Oxygen isotope diagrams for ice wedges of Holocene age in upper part of Aleshka Terrace, lower Kolyma River (a) and upper part of high terrace on Mamontov Hill, Aladan River (b): *1*) Loam. Zones: M, moderate (close to present-day), MC, moderately cold; *I*) 6780 ± 40 (GIN-4589), *II*) 14980 ± 100 (MAG-470), *III*) 15000 ± ± 200 (MAG-468), *IV*) 4800 ± 40 (GIN-4607), *V*) 3500 ± 400 (GIN-4604), *VI*) 38400 ± ± 500 (GIN-4603). Other symbols as in Fig. 1.

but the pollen of shrubs and herbs is strongly dominant, constituting more than 70 percent of the pollen spectrum in almost all specimens.

This conclusion as to the harshness of the climate in which the wedges developed is convincingly supported by their oxygen isotope composition (19 specimens). Thus the $\delta^{18}O$ in the wedges ranges from -34.7 promilles to -29.9 promilles (in the floodplain of the same area, an offshoot of a syngenetic wedge vein had $\delta^{18}O$ from -27.0 promilles to -25.3 promilles). Extremely low concentrations of the heavy oxygen isotopes ($\delta^{18}O$ < -33 promilles), indicative of the most severe winter conditions in the period of wedge development, are found in the lower half of the diagram and in its uppermost zone, representing respectively the time intervals of 30 to 25 and 15 to 17 thousand years ago (the specimen from the middle of the sequence, used for dating, was collected by N.N. Kudryavtseva). Values of $\delta^{18}O$ exceeding -31.0 promilles in the intermediate part of the diagram indicate that the winters were less cold in the intervening time. The change in conditions is also partially reflected in the differences in the mineral content of the wedges. In the lower zone the concentration of dry residue is as much as 0.15 g/liter, while in the upper zone it generally does not exceed 0.10 g/liter.

Results that are extremely interesting in terms of paleological permafrost reconstructions were obtained from an analysis of stable oxygen isotopes in ice wedges of the Aleshkin Terrace and Mamontov Hill (Fig. 2). These wedges were assumed to be syngenetic and were previously dated to the end of the late Pleistocene on the basis of the age of their host sediments [4, 5, 9]. Our investigations indicate that this result is not entirely correct.

In the sequence of the Aleshkin Terrace on the lower Kolyma River, the ice wedges occur almost to the surface in a sand sequence overlain by sandy loam and peat up to 1 m thick. The transitions between layers are gradual, the sand is very silty in its upper zone, and peat hummocks are found in the upper part of the layer of loam. The wedges are as much as 5 m high and as much as 1.8 m wide in their upper sections (see Fig. 2a). Plant remains of this sequence were earlier dated [9] as about 15,000 years old; we obtained a date of 6780 ± 40 years on peat hummocks from the overlying sandy loam, indicating that the upper part of the sequence was Holocene (specimen GIN-4589). The presence of similar peat hummocks in a wedge in the soil that abuts directly the top of the underlying ice wedge indicates that the latter is very probably of Holocene age. This is confirmed by oxygen isotope determinations (29 specimens), indicating that $\delta^{18}O$ ranges from -27.5 promilles to -23.9 promilles over the entire height of the wedges, i.e., varies in essentially the same range as in present-day offshoots of the wedges and in Holocene wedges on the floodplains and in alas of the Kolyma area [2, 3]. Thse wedges[2] most likely were formed in the first half of the Holocene under winter conditions similar to those of the present. This result indicates that the Holocene "optimum" was not very pronounced in this area and that it had particularly little effect on the winter parts of the paleoclimate.

We encountered a similar situation in investigating the ice wedges Mamontov Hill on the Aldan River. Here the wedges lie in the upper part of lake and marsh sediments that top the sequence of a high 60-meter terrace. The sediments consist of dark-gray loams containing an obliquely cellular (rhomboid) moderately streaky cryotexture, and are 9 to 12 m thick. The loams are overlain by a 2-meter layer of pale yellow sandy loam, sometimes separated from them by a parting of peat less than 0.5 m thick. Immediately beneath the peat or the sandy loam are the tops of the ice wedges (in some cases the peat occurs above the ice wedges in the form of soil wedges as much as 0.5 m high and less than 1 m wide, abutting directly on the ice wedges), which are as much as 5 m high and 1.0 m wide in their upper parts (see Fig. 2b). This large size suggests that the veins were syngenetic with the dark gray loams [4]. The loam accumulation was dated to between 38 to 35 thousand years ago on the basis of the ^{14}C in wood (see Fig. 2b); a date of about 36,000 years had been obtained earlier [4]. But we believe that the development of the wedges does not date from this period. Dating on pure autochthonous peat (at a depth of 2 m), taken from a soil wedge that is probably synchronous with the underlying ice wedge gives an age of 4800 ± 40 years (specimen GIN-4607), suggesting that the ice wedges are of Holocene age, although they formed syngenetically with the overlying sandy loam and peat, during the continuing sedimentation. Oxygen isotope analysis of the ice (29 specimens) confirms this conclusion.[3] The $\delta^{18}O$ figure for the main bodies of the wedges ranges from -29.2 promilles to -25.9 promilles, and it is only in the wedge bottoms, which contain segregated ice and ice formed from marsh water during the initial stages of ice cracking, that $\delta^{18}O$ ranged from -22.7 promilles to -16.5 promilles. In a present-day offshoot above syngenetic ice vein on the floodplain of the Aldan River, $\delta^{18}O$ ranges (4 determinations) from -26.3 promilles to -24.9 promilles, i.e., the Holocene ice was generally 1.5 to 3 percent lighter than present-day ice, idnicating a more severe geocryological situation during the ice emplacement. This period coincides with the Holocene optimum, i.e., the period of high summer temperatures [10]. Thus, in the first half of the Holocene the geocryologic conditions in central and northern Yakutia were in any case no milder than at present, and the continental character of the climate become increasingly more pronounced toward the center of the continent.

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[2] A team from Moscow University subsequently found late Pleistocene wedges with an isotopic composition ranging from -31 promilles to -30 promilles in another part of the sequence.

[3] A Holocene date for the freezing of the loam surrounding the wedges is also indicated by the heavy isotope composition of the textured ice streaks ($\delta^{18}O$ from -17.7 promilles to -15.6 promilles).

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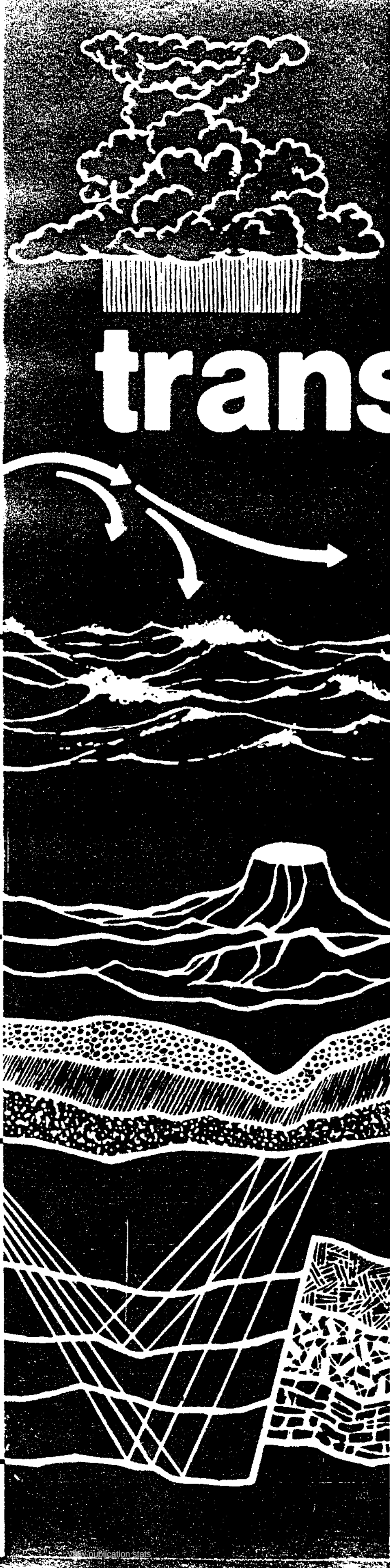

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