DEBATED PROBLEMS OF PALEOCRYOLOGY OF THE PLEISTOCENE AND HOLOCENE OF WESTERN SIBERIA IN LIGHT OF NEW DATA

Yu. K. Vasil'chuk and V. T. Trofimov


UDC 551.345:551.583.7:551:576.3

Four major problems in the development of permafrost series in the Pleistocene and Holocene are discussed.

The history of formation of permafrost rocks of Western Siberia in different segments of the Quaternary has been treated in different ways by different researchers. In our report, we are discussing four debated paleocryological problems, whose solution in light of data we have obtained takes on a new rocks at the end of the Middle Quaternary and beginning of the Late Quaternary; second, the problem of development of frozen series in the Karginskii Stage, dated 30-22 thousand years ago; third, the problem of the thickness of permafrost series in the northern area of Western Siberia in the Sartan Stage of the Late Quaternary; fourth, the problem of the features of development of frozen rocks during the Holocene "optimum" and of the dynamics of cryogenic processes at that time in the Arctic. Each of these problems has been discussed repeatedly in the literature, and each has a vast bibliography. However, we will not discuss in detail the views of proponents of various viewpoints, but we will concentrate on attention on new facts and consequences deriving from them which often somewhat contradict generally accepted and customary views.

The solution to the first of these problems about the features of development of permafrost rocks at the end of the Middle and beginning of the Late Pleistocene has until recently entailed considerable difficulties, since there is less reliably interpreted factual material for it than for the others. Practically all researchers have considered that at present even within the northernmost regions of Western Siberia only epigenetically frozen Middle Quaternary deposits have been preserved (Salekhard, Sanchugovskii Formations). This viewpoint was mainly based on the assumption that at the beginning of the Late Pleistocene in the Kazantsyevskii, and then probably the Karginskii epochs and in the climatic "optimum" of the Holocene, syngenetically frozen shallow coastal-marine deposits of the regressive bed of the Salekhard Formation thawed (and most researchers recognize that they existed) and by now have frozen again, but epigenetically. New materials of regional projects [26, 27] and analysis of the cryolithological constituent of works of many Quaternary geologists who studied northern regions of Western Siberia showed that this conclusion is not wholly valid. Thin (to 5-6 m) Middle Pleistocene syngenetic series in the cross section of permafrost rocks of the northern part of the region, despite the effect of denudation processes and repeated changes in climate conditions, were preserved just the same.

This conclusion is based on the following facts. 1) In the cross section...
of the regressive bed of deposits of the Salekhard Formation and its age analogs, Katasonov [18] in the lower reaches of the Enisei R., and later colleagues of the Tyumen Expedition of MGU within the Yamal and Gydanskii Peninsulas (including their southern half) described silty sandstones with thin frequently bedded schlieren cryogenic texture, similar to those of younger series, which practically all researchers consider syngenetic. 2) In many regions of the northern area of Western Siberia in a series of Middle Quaternary deposits we have established shallow deposits of stratified ice, among which buried stratified ice has been identified as an independent genetic type [2]. Their presence in a whole series of cross sections testifies to the unconditionally syngenetic freezing of the enclosing series and to the absence of deep thawing of series close to the bedding surface in the course of subsequent geological history. 3) In the central and northern regions of the Yamal and Gydanskii Peninsulas, we have established [3,27,29] the wide distribution of syngenetically frozen deposits up to 10-12 m thick in the cross section of the Kazantsevskii Formation, which enclose thick syngenetic multiple ice veins. Their presence suggests severe climate conditions, preserved there during the Kazantsevskii period. Warming, if it did occur during this time, was not so significant as to cause the transition of mean annual temperatures of frozen Middle Quaternary deposits of the Yamal-Gydanskii province through zero into the area of positive temperatures. 4) The climate of subsequent "warm" epochs, the Karginskii and climate "optimum" of the Holocene, was as shown below also fairly severe and excluded universal thawing of ancient permafrost series in the extreme northern part of Western Siberia.

The second problem, concerning the development of frozen series in the extreme northern part of the region in the Karginskii stage, will be discussed in greater detail, since we have significantly new data for it. Based primarily on materials from studying regions more to the south and neglecting the presence of syngenetic frozen series in cross sections of terraces III and II of the Yamal and Gydanskii Peninsulas with thick multiple ice veins [3,26,27], and also about the presence of thick pseudomorphs in these deposits in the southern regions of the cryolithzone [3], until recently most Western Siberian researchers have traditionally considered this stage of the Late Pleistocene to be universally warm and have even suggested the degradation of the frozen series. The Karginskii stage was compared with the classic interglacial stratigraphic plans of Europe and North America (Powderfoam, Farmdale, Plum Point, etc.), which are based on local materials. Moreover, it is appropriate to remember that even in the works of Milankovich [21] the Earth was divided into three areas which reacted differently to the change in radiation. Within the territories of distribution of continental ice, which in terms of heat capacity can be fully equated with severe permafrost in regions of immediate proximity to the Arctic, the rise between neighboring minimums (on diagrams of heat provision [authors note]) is smoothed or sometimes disappears entirely [21]. By the way, we note that on the curve of the permanent course of the totals of radiation and temperatures, compiled by Milankovich [21] based on analyzing changes in astronomical factors which condition the climate during a period 30-20 thousand years ago, the deepest minimum occurs during the last 60 thousand years. Recently, based on analyzing stable isotopes in the core of ice caps of Antarctica and Greenland, many researchers [19,34, etc.] also concluded that the climate at that time was severe, which served as a basis for establishing the hypothesis of the cover glaciation of the Arctic in that stage of Quaternary history.

New data from complex study of deposits, including cryolithology, spore-pollen, oxygen isotope, and chemical analyses of multiple ice veins and enclosing soils, analysis of microfauna and physicomechanical properties of the soil, radiocarbon dating of fossils, and analysis of earlier data on the distribution of syngenetic frozen series confirm the opinion repeated asserted by cryopedologists [3,26,27] that in the extreme northern area of Western Siberia (Yamal-Gydanskii) province permafrost series in the period 30-20 thousand years ago
Fig. 1. Paleontological-hydrogeochemical diagram of cross section of third (?) lagoon-sea terrace near the village of Seyakha: 1) stratified sand; 2) gray sandy loam; 3) shrubby upland peat with the prevalence of Betula sect. Nanae in upper part of cross section; 4) biomineral series, represented by frequent alternation of sandy loam and Hypnum lowland peat with prevalence of Drepanocladus fluitans and Scorpidium scorpioides fossils and the presence of Ledum palustre roots; 5) syngenetic multiple ice veins; 6) curve of degree of peat decomposition; 7) absolute age according to C¹⁴ in years (serial number at the Radiocarbon Laboratory of the Institute of Geology of the USSR indicated in parentheses); 8) point of outcropping of foraminifers; the sample contains 156 specimens, of which 71 are Eichia subalvatum Gudina, 31 are Prinaella pulchella Parker, 20 are Proteliphidium parvum Gudina, 11 are Discochis sp., 9 are Miliolinella cf. subrotunda (Montagu); sampling point from ice vein; 9) for determination of myospores, 10) for determining oxygen isotopes; 11) index of identified palynozones; 12) pollen of woody species; 13) pollen of shrubs, bushes, and grasses; 14) spores; pollen: 15) Pinus silvestris, 16) Pinus siberica, 17) Picea, 18) Abies, 19) Betula sect. Albae, 20) Alnus, 21) Salix, 22) Betula sect. Nanae, 23) Alnaster, 24) Cyperaceae, 25) Artemisia, 26) Gramineae, 27) Ericaceae, 28) Vario; spores: 29) Sphagnum, 30) Bryales, 31) Lycopodium, 32) Polipodiales. Quantitative composition of each of the elements of myospore assemblage is calculated as a percentage of the total. Ion composition of salts: anions 33) SO₄²⁻, 34) HCO₃⁻, 35) Cl⁻; cations 36) Ca²⁺, 37) Mg²⁺, 38) Na⁺ and K⁺.

did not thaw, but actively formed. The most interesting materials for this conclusion were obtained from cross sections at the mouth of the Seyakha-Zelenyi (eastern Yamal) and in the lower reaches of the Mongatalyang'yakha R., which flows within the Yavai Peninsula (northwestern Gydanskii Peninsula).
In the first region in exposures of the third (?) lagoon-sea terrace* a series of deposits is found which accumulates continuously from 30** to 15 (?) thousand years ago (Fig. 1). Revealed in the outcrop from top to bottom are the following:

Layer 1. 0.0-1.0 m. Dark brown peat; in areas its thickness increases to 1.1-1.5 m.

Layer 2. 1.0-1.3 m. Light brown silty sandy loam.

Layer 3. 1.3-3.8 m. Fine light gray flat-bedded frozen sand; its texture is sparsely stratified.

Layer 4. 3.8-6.6 m. Grayish brown, light, frozen sandy loam; cryotexture is sparsely reticulated.

Layer 5. 6.6-8.2 m. Dark gray frozen sandy loam with steely play; cryotexture is reticulated.

Layer 6. 8.2-23.0 m. Peat-mineral series, represented by alternation of brown, half-decomposed fibrous peat and dark gray sandy loam in the form of lenses, and also seams 0.1-0.4 to 0.8-1.0 m thick. Cryotexture is reticulated; total content of massive ice and schlieren ice reaches 60-70%.

In the peat-mineral series of layer 6 there is an extremely high content of macrotexture-forming, primarily multiple ice veins. Clearly identified are two generations of ice veins: the first, up to 15-16 m high, and the second, not more than 3-5 m high. The heads of these ice veins lie at different depth in the biomineral series: in the very bottom of layer 6 and at its roof. Such staged structure of the multiple ice vein complex unambiguously testifies to the synchronous growth of the veins and accumulation of the deposits enclosing them. It is interesting that the heads of the largest veins of the first generation emerge into the bed of sandy loam of layer 5, which covers layer 6, which on one hand, indicates the absence of an interruption in the accumulation of sediments, and on the other, the syngenetic formation of veins and during the time of accumulation of deposits of layer 5.

We should also mention the narrow (to 0.5 m wide), possibly epigenetic ice veins which lie in the uppermost area of the cross section: their heads are situated in the series of layer 1, and the tails emerge into the sand of layer 3. The total height of the veins reaches 2-2.5 m. They often have an extension in the form of soil peat veins to 1.0 m long, sometimes wholly replaced by soil veins.

The structure and texture of the ice of syngenetic and epigenetic veins are different. The first are composed of considerably larger isometric crystals. For epigenetic veins, the area of the crystals is smaller by a factor of 2-3, and their ice is often dark brown and yellow due to the large number of inclusions of the superjacent peat. In the body of syngenetic veins, the mineral

---

*Its age was previously dated Zyryanskii, then Zyryanskii-Karginskii.
**The base of the series is not revealed; it is found below the cut and is obviously older.
inclusions are usually represented by thepeat and sandy loam comprising the series of layer 6, but in the upper part of the largest veins, we note inclusions of sandy loam of layer 5, which are dispersed in a "chain" along the axial line to a depth of up to 2-2.5 m, confirming the synchronous formation of this part of the veins and sandy loams of layer 5.

Radiometric dating of organic material from the described series indicates the accumulation of deposits of layer 6 in the Karginskii stage; a sample from the base of the visible part of the series of layer 6 from a depth of 22 m from the surface is dated 30,100 ± 1500 years (IG-2477), and near the roof from a depth of 8.6 m the peat is dated 22,700 ± 300 years (IG-2473). Deserving attention is the circumstance that dates of samples taken between these samples revealed good convergence of dates and the absence of inversions: 22,600 ± 600 years from a depth of 10 m (IG-2475), 23,500 ± 400 years from a depth of 12 m (IG-2474), and 24,300 ± 300 years from a depth of 16.5 m (IG-2476). This lets us confidently speak of the continuous accumulation of the biominal series of layer 6 in the Karginskii period, i.e., 30-22 thousand years ago, and consequent-ly, about the Karginskii age of the syngenetic veins bedded in this series. Less definite is the age of the epigenetic veins in the upper part of the cross-section. We obtained a date for the organic material from a pseudomorphosis (or from soil, peat veins?) which extends one of the largest epigenetic veins from a depth of 3.8 m. Here the peat with an abundance of carbonized branches of dwarf birch is dated 9300 ± 100 years (IG-2472). It is quite obvious that epigenetic veins were formed later than this date. But we are inclined to think that this occurred after a comparatively brief time, i.e., there was not a significant interruption between the formation of the pseudomorphosis (?) and the ice vein over it. Otherwise, it is hard to explain the fact that the pseudomorphosis (?) only extends the ice vein, and is not intersected by it (i.e., does not wholly enclose the vein) or generally does not pass on the side. If this assumption is valid, then considering the number of elementary veins comprising the ice vein (about 70), we can state that it was formed in the period of 9.3-8.7 thousand years ago, i.e., at the end of the "pre-optimal" and beginning of the "optimal" stages of the Holocene [8].

It should be emphasized that deposits of layers 3, 4, and 5 accumulated in subaqual conditions immediately after completion of the accumulation of the biominal series. The discovery by Nedesheva of well preserved foraminifers in sands of layer 3, along with textural features such as the presence of thin stratification and relatively high salinity, comprising 0.11-0.14% (which is 1.5 times higher than the mineralization of modern deposits of the Ob bay in this region, not greater than 0.07%), indicates their subaqual genesis. Their number in one sample exceeded 150 specimens, among which half is represented by the species Elphidium subolatum Gudina. These materials contradict the widespread opinion about the universal deep regression of the ocean in the post-Karginskii-Sartanskii period. True, recently information has appeared, primarily abroad, about the high state of the sea level in a whole series of regions of the Earth in the period from 20 to 10 thousand years ago, particularly in many recent publications of Morner [36]. It is quite likely that even in the northern area of Western Siberia the relative sea level in this period was fairly high, probably close to the modern level, which was probably the result of extensive subsidence of the coastline, which outstripped the possible decrease in the level of the polar basin.

As a result of analyzing the botanical composition of peat (analyst Turkina) two circumstances deserve mention. First, the biominal series is practically all composed of Hypnum lowland peat and second, the presence of Ledum palustre roots can suggest, according to Turkina, the autochthonous nature of part of the peat in the deposit). This is fairly hard to imagine, but deposits of layer 6 are probably similar to those which Popov [22] called spontaneous peat; they ac-
cumulated under conditions of the low seacoast plain (laida) of the bay.

Spore-pollen analysis (palynologist Serova) identified three palynozones, clearly distinguished in the cross section (Fig. 1). In the lower palynozone (A), which formed 30-24 thousand years ago, to judge by radiocarbon dating, pollen of grasses and shrubs predominated, among which Gramineae and Artemesia are most abundant, which indicates the comparatively arid climate of the vegetation period, probably drier than the modern continental climate. In the second palynozone (B), formed 24-15 thousand years ago, green moss spores dominate. In the lower part of this interval the content of macrofossils of green mosses is also very great in the biomineral series. In the period of formation of this palynozone the climate conditions of the vegetation period evidently became somewhat wetter and cooler than the previous stage. In the third palynozone (C), which encompasses the sand of layer 3, pollen of woody species dominates (to 82-86%), which probably reflects the change in composition of the vegetation of the surrounding territory, but the succession of sedimentary conditions, i.e., deepening of the sedimentary basin, which caused the suppression of the role of pollen of local plants in the spectrum which formed. This was also reflected in the sharp growth of the amount of redeposited myxospores in this interval and in the increase of chlorides in the composition of the aqueous extract.

We should mention the results of analyzing pollen and spores from ice veins of the Karginskii period (Fig. 1b). Noted is the fairly wide fluctuation of the major components of myxospore spectra in terms of depth in veins, and the nature of the curves on the diagrams from veins and from the deposits which enclose them is identical in individual intervals, which lets us correlate them in terms of age and also testifies to syngenesys of multiple ice veins.

We must pause on the results of analyzing stable oxygen isotopes from multiple ice veins of the described cross section. We must not only look at the results obtained, but also state our opinion on the reliability of their interpretation.

Interpretation of results of analyzing stable oxygen isotopes from syngenetic polygonal vein complexes, we feel, has many advantages over similar operations done based on determinations on foraminifers from deepwater bottom columns and cores of ice caps. One of the main advantages is the possibility of accurate chronological connection of the oxygen isotope diagrams of multiple vein syngenetic ice with the aid of parallel radiocarbon dating of the deposits enclosing the veins, which usually contain an admixture of organic material, well preserved in permafrost, and also the more unambiguous interpretation of the obtained results. Actually, disagreements of researchers occupied with isotope studies of foraminifers are well known. According to Emiliani [31,32], variations of the isotope composition of the foraminifer shells reflect a 70% variation of the temperature of the medium. Emiliani's statement is solidly based: his many years of study, careful and exhaustive laboratory experiments of Epstein, Yuri, and their colleagues, who grew marine mollusks containing calcite at certain water temperatures, as a result of which the well-known temperature-isotope water-carbonate scale was obtained [35]. No less authoritative are the estimates of Shackleton [37,38] and his supporters, who agree that the main cause of the up to 80% variations in the content of heavy oxygen isotopes is the change in salinity of sea water, caused by the removal of part of the water from the ocean in the glaciation period. Even in this case, the correctness of the conclusions is almost indisputable: collected plankton foraminifers in the isothermal layer of the Indian Ocean displayed considerable differences in isotope ratio. Moreover, Shackleton fairly validly showed that the bottom temperatures of the Atlantic, particularly the Caribbean Sea (whose benthic foraminifers Emiliani used to reconstruct paleotemperatures according to isotope ratio), are in

72
many ways determined by temperatures of bottom water of the Arctic, which varied little during the entire Pleistocene.*

The interpretation of analysis results is just as ambiguous as the time connection of the diagrams of isotope distribution in deepwater columns is unreliable. We know that radiocarbon dating of carbonate fossils is still comparatively poorly calibrated and very often gives quite contradictory results. Sulerzhitskii, who looked especially at the reliability of radiocarbon age and reliability of dates, proposed that we even exclude C\(^{14}\) dates of mollusk shells in justifying the age of geological series [1]. In addition the slow rate of accumulation of bottom deposits requires highly scrupulous attention to stratigraphic models, and if we consider the activity of burrowing organisms, which, by the way, are in most cases the reason why dating results are underestimated, we can understand the disagreements of researchers who work with even the same materials of analytical studies of isotopes of foraminifers. Van Dong and Matteieu cite Ku's estimates of about 100 thousand years for the age of foraminifers in Arctic deepsea columns according to thorium-proactinium dates from a depth of 10 cm, whereas they themselves, determining the age of foraminifers according to C\(^{14}\) from depths of 2.5, 6.5, and 10.5 cm, respectively, obtained dates of 6700 ± 250, 10,500 ± 850, and 14250 ± 1400 years [7]. It is noteworthy that analysis of isotope composition and the amount of plankton foraminifers in columns of the Arctic Ocean between the Chukchi Plateau and the Alpha Ridge [7] does not provide grounds for assuming that during the last 30 thousand years there were periods when the Arctic could have been less glaciated than now.

No less significant are difficulties with interpreting paleotemperatures for those who study isotopes in cores of polar ice caps. Complications of paleoreconstructions in this case are due first to the impossibility at the modern stage of reliably dating the ice, and second to the mobility of the ice, which led to the fact that the ice formed in the past often occurs in the column at various depths in different places of the glacier. This forces researchers to find all possible ways to consider possible errors and introduce corresponding corrections (see, for example, [19]).

These complications are not typical of oxygen isotope studies of multiple vein syngenetic ice. By the way, we do not exclude the possibility that this view of this problem is temporary. The complexities in interpretation appear as soon as wide-ranging works in this direction begin.

Analysis has shown that variations in the content of δ\(^{18}\)O in syngenetic ice veins of the Karginskii age ranged from -21.4 to -24.8 parts per thousand (Table 1, Fig. 2d; according to results of determinations of 9 samples in the Laboratory of the IVF of the AS USSR, presented in collaboration with Esikov). These are fairly large variations in the composition of isotopes, which suggest the variations of the paleotemperature conditions in time (variations in the basic mean winter temperatures were probably at least 5°). However, such variations occurred in a range temperature of temperatures much lower than modern. This conclusion is based not only on recalculation of paleotemperatures according to the well-known formula of Dansgaard [33], but mainly the compilation of isotope composition of veins of the Karginskii period with the oxygen isotope content in modern syngenetic multiple vein ice. Analysis of the content of δ\(^{18}\)O

* A thorough analysis of the sources of errors in isotope studies in foraminifers is presented in Bowen's monograph [6].
Fig. 2. Content of stable oxygen isotopes: a, b) in foraminifera shells from bottom columns of Caribbean Sea, after [24], a) column F-6304-8, b) F-6304-9; c) in core of ice from Greenland, column of Camp Century, after [34]; d) in ice cap of Antarctic, column of Vostok station, after [19]; e) in multiple vein ice of the Yamal-Gydanskii province. Absolute age according to C\(^{14}\) dating: 1) 5300 ± 100, 2) 12,600 ± 700, 3) 12,600 ± 700, 4) 62,800 ± 2000, 5) 4225 ± 100, 6) 9620 ± 140, 7) 12,610 ± 175, 8) 17,880 ± 200, 9) 23,850 ± 400, 10) 26,600 ± 1000, 11) 67,000 ± 2000, 12) 9300 ± 100, 13) 9560 ± 130, 14) 22,700 ± 300, 15) 23,500 ± 400, 16) 24,300 ± 300, 17) 30,100 ± 1500.

in the elementary annual vein in the modern syngenetic vein, forming now in the same climate zone on the laida of the Ob bay at the mouth of the Ngapkaiyakha R. (Gydanskii Peninsula), showed that the values of δ\(^{18}\)O in it are 18.3-18.7 parts per thousand. Thus, the Karginskii multiple vein ice turned out to be
Table 1

Oxygen Isotope Composition of δ¹⁸O of Late Pleistocene and Holocene Multiple Vein Ice and Preliminary Values of Mean Winter Air Temperature Relative to Modern Δt, °C

<table>
<thead>
<tr>
<th>Period</th>
<th>Validation of vein age</th>
<th>δ¹⁸O, ‰</th>
<th>Δt, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karginskii epoch of Late Pleistocene</td>
<td>veins are bedded in series containing a series of radiocarbon dates from 30 to 22 thousand years</td>
<td>-21.4-24.8</td>
<td>-4±9</td>
</tr>
<tr>
<td>&quot;Pre-optimum&quot; stage of Holocene</td>
<td>according to ¹⁴C over vein peat date is 9560 ± 130 (IG-2651)</td>
<td>-14.1-15.9</td>
<td>+3±6(?)</td>
</tr>
<tr>
<td>Stage of Holocene &quot;optimum&quot;</td>
<td>date of peat from pseudomorphosis (?) under vein is 9300 ± 100 (IG-2472)</td>
<td>-19.0-20.3</td>
<td>-1±3</td>
</tr>
<tr>
<td>Modern stage</td>
<td>thin veined growth on high laga in upper part of cross section</td>
<td>-18.3-18.7</td>
<td>0</td>
</tr>
</tbody>
</table>

Note. To calculate Δt, °C we used the modified Dansgaard formula [33]: Δt = δ¹⁸O_mpg-δ¹⁸O_X / 0.695

Isotopically lighter than modern ice by 3-6.5 parts per thousand, which corresponds to 4-9 °C (Table 1). These materials, as we now believe, indicate the considerably more arid, but inhomogeneous winter climate conditions which prevailed in the Karginskii period, compared to modern. They also agree well with the features of the cryogenic structure of the investigated cross section: with the presence of very thick ice veins. By the way, thicker veins are not known in Western Siberia either in younger or older Late Pleistocene series.

We should emphasize that we have given a detailed description of the cross section of deposits of the Karginskii period near the village of Seyakha, since the most interesting and complex material was obtained there. But similar biomineral series containing thick syngenetic multiple vein ice were also described by us in Yavai at the mouth of the Mongatalyang'yakha R., by Sheshin on the Mamont Peninsula near Matyuisale, by Sulerzhitskii on Taimyr on Mys Sablera [1], and also by geologists of the All-Union Aerogeological Trust in many regions of the Ydanskii Peninsula and Yamal. In cross sections at the mouth of the Mongatalyang'yakha R. and near Mys Sablera they are characterized by absolute C¹⁴ dates which suggest that a similar history of development in the Karginskii period is usually typical of the entire Yamal-Ydanskii province and even, probably, the Taimyr region.

It is interesting to compare the results obtained with data from oxygen isotope determinations according to foraminifers and ice of glaciers, dated Karginskii. As examples, we will look (Fig. 2) at comparatively secure dates according to C¹⁴ of a fragment of columns P-6304-8 and P-6304-9 from the Caribbean core [24], and also oxygen isotope diagrams of glacial columns of Camp Century in Greenland [34] and the Vostok Station in the Antarctic [19]. Without detailing their interpretation, we note the most essential circumstance for us. In all four diagrams (and in the surprising majority of deepsea columns from other regions of the Earth [17]) the content of δ¹⁸O in depth intervals dated from 30 (and even from 70) to 10 thousand years ago, indicates drier climate conditions: ocean water in these periods was isotopically heavier than Holocene (and modern)
water, and the snow (ice) is substantially lighter.* Results of our determinations agree as a whole with these data.

In conclusion, we note that the presence of underformed thick syngenetetic multiple vein ice in deposits of the Karginskii and older periods in the immediate vicinity of the surface oblige us, as we have already noted [29], to have serious doubts about the possibility of the ice cap of the Yamal and Gyanskii Peninsulas in any of its modifications at the very end of the Late Pleistocene. Because of its weight or during movement, the ice should have changed the initial appearance and bedding conditions of the veins, this has not been discovered in any of the northern regions of Western Siberia, as many years of studying vein ice by ourselves and our colleagues have shown. In the surprising majority there are not even individual signs of ice deformations from pressure above, nor traces of contortions even in the deposits enclosing them.

The third of the discussed problems, concerning the thickness of permafrost rocks in the Sartan stage of the Late Quaternary, came under debate recently after the appearance of a work by Baulin et al. [4]. A permafrost series thickness of 700 m or more is shown on the map of permafrost rocks of the USSR at the end of the Late Pleistocene for the Yamal-Gyanskii province. If the debate were on the thickness of the soil series with subzero temperatures, including slightly frozen cryopegs, this would not cause problems. But since the authors speak of the bedding depth of the base of the permafrost rocks, these figures seem overstated. If we accepted the considerations outlined below on the development of paleocryogenic conditions of the Holocene during the period of its "optimum", we cannot understand why almost 200-300 m of frozen rocks at the bottom disappeared after the Sartan period. At present in Yamal even under the oldest geomorphological conditions the thickness of the frozen series is 300-350 m, and on the Gyanskii Peninsula it reaches 500 m in the extreme east. We emphasize that there are no grounds for assuming such substantial degradation in the Holocene, as done in [4], considering that the cryological conditions in the Yamal-Gyanskii province on the surface in this period was relatively stable or varied somewhat toward warming. Based on the modern ratio of thicknesses of permafrost rocks in this part of Western Siberia [26,27], it is more logical to assume that the thickness of the permafrost rock series after the Sartan within ancient geomorphological levels was stable or increased very insignificantly, whereas within young levels it continued to grow extensively. The position of the base of frozen series at the end of the Sartan stage was probably substantially different. The thickness of the series of permafrost rocks within most of Yamal and the Gyanskii Peninsula at that time obviously did not exceed 300-350 m.

The fourth problem in the paleocryopedology of Western Siberia is also knotty. Followers usually tend to assume unequivocally that the Holocene "optimum" was the time of the greatest warming during the last 100 thousand years, which led to deep thawing of permafrost rocks from the south to 67°N and to substantial moderation of the geocryological circumstances north of this latitude [4,15]. However, in 1964 Popov [23] stated his doubt as to the validity of such models.

*Formulas for recalculating the isotope content in paleotemperature descriptions of foraminifers and for ice are different. For foraminifers, a simplified formula is presented in [17]: \( T^° = 16.9\% - 4.0(\delta^{18}O_{\text{for}} - \delta^{18}O_{\text{OM}}) \). For glaciers, we usually use the equation of Dansgaard [33]: \( \delta^{18}O = 0.695\% \), where \( \delta^{18}O_{\text{for}} \) and \( \delta^{18}O_{\text{OM}} \) are respectively the deviations of the oxygen isotope content in foraminifers and ocean water from the Chicago standard "Pi-di-bêlemonite", and \( \delta^{18}O \) is the deviation from the SMOW ocean water standard.
and described the "optimum" as the time of increased continental climate, having shown by example of polygonal vein peat massive in the lower reaches of the Ob R. that during the "optimum" multiple vein ice could have developed even near the Arctic Circle. This was later supported by Danilov and Polyakova [14] based on analysis of materials on the central part of the Tazovskii Peninsula. The materials presented may let us deplete the number of statements about the possibly somewhat different climate in the period of the "optimum" than is usually considered, following the analogies with the "optimum" of southern Siberian or East Europe.

Analysis of materials in the literature and also obtained in the process of our many years of research, unequivocally testify to the fact that the universal thawing in the Holocene "optimum" did not occur even in the southern part of the modern cryolithozone of Western Siberia. It is curious that far from all these materials are completely new. In 1959 Lavrushin [20] described a thick shallow ice deposit of pre-Holocene age to the south of the Arctic Circle in the region of the village of Yanov Stan. This along could place doubts as to the validity of the viewpoint of the universal thawing of frozen rocks south of 67°N during the "optimum". Doubts of this type were heard in the works of Belopukhova [5] and Shpolyanskaya [30], and now there are many examples testifying to the preservation of the permafrost state of masses situated in the southern half of the cryolithozone. This is a stratified deposit near the mouth of the Kureika on the Enisei, described by Grigor'ev and Karpov [12] and by Solomatín [25], and buried ice penetrated by thick syngenetic veins in the series of the second terrace of the Messoyakhki R., studied by Danilov [13], and syngenetic Late Pleistocene veins noted near the village of Novyi Port by Novikov, and near the mouth of the Vanuito R. on the southern coast of the Ob bay by Dan'ko and Stremyakov [16], and many others [8,9,10]. All this lets us consider that roughly between 67 and 65°N in the territory of Western Siberia during the Holocene "optimum" permafrost rocks degraded far from completely; preserved there was the distribution of frozen rocks, interrupted on the surface, and in many regions they predominated [8,9,10].

No less interesting is the problem of what occurred north of 67°N within the territories of Yamal and the Gyanskii Peninsula. Did the Cryological circumstances there moderate? At that time in that territory syngenetic frozen series formed within floodplains, laidas, and in cross sections of slope deposits [3,8,27]. According to our data [8], in cross sections of frozen peat bogs during the Holocene "optimum" syngenetic multiple vein ice formed extensively to 66°N. Convincing proof of this are spore-pollen spectra (analysis by palynologists Petrova and Serova) from the ice veins themselves and the results of their comparison with spectral from deposits enclosing the veins. It turned out that 94 of the 125 productive analyzed samples (more than 300 samples were analyzed) contain more than 50% pollen of woody species. Such data force us to assume that most of the ice of the Holocene veins were formed at the same time as the increased "forestation" of Yamal and the Gyanskii Peninsula, i.e., in the period of the Holocene "optimum": 9.0-4.5 thousand years ago.

Reconstructed according to results of broad study of cross sections, the history of development of polygonal vein complexes at the mouth of the Tamehi R. and in the Messoyakhka R. Valley showed that veins in these areas began to form in the "optimum" [11,28]. Often even C14 dates confirm the facts of the extensive growth of multiple vein ice in the Holocene "optimum". Thus, most of the ice in veins bedded in the peat on the Shuchchi'ya R. formed from 7.7 to 6.1 thousand years ago, and the vein in the peat at the village of Yaptik Sale formed 8.9-4.5 thousand years ago [8].

We have presented new data here, connected with the use of oxygen isotope analysis. It was noted above that the age of epigenetic veins in the upper part
of the cross section near the village of Seyakha are dated 9.3–8.7 thousand years ago. The content of \(^{18}O\) in them was 19.4–20.3 parts per thousand, i.e., 1–2 parts per thousand isotopically lighter than modern; expressed as temperatures this difference can be estimated at 1–3°C lower than modern (we should also mention winter and early spring palaeotemperatures). It is curious that the oxygen isotope composition of multiple vein ice in the series of terrace I near the village of Kharasavel, which probably formed in the "pre-optimal" period of the Holocene (according to a date 9560 ± 130 years ago (G-2651) from peat horizontally bedded over the head vein), turned out to be equal to 14–15.9 parts per thousand, which is 2.5–4 parts per thousand heavier than modern ice. This suggests temperatures of the winter and early spring period of the "pre-optimal" stage by at least 3–6°C exceeding modern. Unfortunately, we still do not have other reliably dated diagrams of the oxygen isotope composition of Holocene age. However, available material lets us make two essential conclusions. First, the oxygen isotope composition differs from modern and from the Holocene by its significantly lower content of stable isotopes of \(^{18}O\), which agrees well with data from oxygen isotope determinations of ice in Greenland and the Antarctic (Fig. 2). Second, during the Holocene the oxygen isotope composition changed substantially; in some periods it was isotopically much lighter (at least at the beginning of the "optimum"), and in others heavier (in the "pre-optimal" stage 10–9 thousand years ago) than ice of modern syngentic veins. Subsequent work will let us more exhaustively discuss this phenomenon and use it in solving problems of palaeocryology.

REFERENCES

1. The Anthropogene of Taimyr [in Russian], Moscow, 1982.

30 March 1983