ISSN 1028-334X, Doklady Earth Sciences, 2010, Vol. 433, Part 1, pp. 985–990. © Pleiades Publishing, Ltd., 2010.
Original Russian Text © A.C. Vasil'chuk, Yu.K. Vasil'chuk, 2010, published in Doklady Akademii Nauk, 2010, Vol. 433, No. 3, pp. 397–402.

GEOGRAPHY

Local Pollen Spectra As a New Criterion for Nonglacial Origin of Massive Ice

A. C. Vasil'chuk and Yu. K. Vasil'chuk

Presented by Academician N.S. Kasimov December 10, 2009

Received December 14, 2009

DOI: 10.1134/S1028334X10070305

The stratal ice deposits represent one of the most dangerous cryogenic phenomena, which influences the economic activity in areas with permafrost development. This is particularly true in connection with intense development of Arctic areas, which required extensive studies of stratal ice deposits and their genesis. Such studies were conducted in the Shpindler Cape area [1], on the southern coast of the Baidaratskaya Estuary [2], near the Marresale [3] and Kharasavei [4] settlements, in the western Yamal Peninsula, in the Bovanenkovo [5] area, in the Yuribei River valley [6], in the Neito Lake area [7] in the central part of the Yamal Peninsula, and in the Erkutayakh River valley [8].

Genetic interpretation of all these ice deposits is uncertain despite the relatively high degree of knowledge about them, repeated visits to them, the cryostratigraphic descriptions, and substantially comprehensive analytical studies [9]. Moreover, the same structural and compositional features are frequently interpreted in different ways [10]. As a whole, all the interpretation variants are limited to the following dilemma: this is either intrastratal or buried glacial ice.

The purpose of this work is to demonstrate new possibilities of palynological analysis, primarily using local components of pollen spectra for clarifying the genesis of stratal ice, which allow the ice of buried glaciers to be discerned from all other types of stratal ice since local pollen and spores cannot accumulate in glaciers of Arctic domes.

The long-term palynological studies of ground deposit-forming ice made it possible to define several characteristic features of their spectra. In short, these characteristic feature may be formulated in the following way: (1) pollen and spores are present in practically all varieties of deposit-forming ground ice and their concentration ranges within limits of 50 to 1500 specimens per 1 kg of ice or in 1 l of thawed water; (2) most stratal ice deposits contain spectra with the composition close to that of subfossil tundra pollen spectra with the dominant dwarf birch and Ericaceae pollen and Bryales spores; (3) stratal ice deposits frequently contain pre-Quaternary palynomorphs of Cenozoic, Mesozoic, and Paleozoic ages reworked from older sediments; (4) most of the studied stratal ice deposits enclose pollen of aquatic plants such as *Potamogeton, Sparganium, Typha* as well as Equisetales spores and remains of freshwater diatoms and Chlorophycaceae algae.

In order to define palynological features of nonglacial genesis of ice deposits, we studied the composition of pollen spectra from snow cover and Arctic ice and discerned the pollen spectra properties that would indicate a glacial origin of ice. The pollen spectra from Arctic ice domes differ substantially in their structure and composition from their counterparts in ice of different natures.

For reliable recognition of ground ice genesis, or to be more exact, its glacial or nonglacial origin, it is reasonable, in our opinion, to consider primarily pollen spectra from Arctic glaciers, which can serve as analogues of ice with a known glacial origin. It seems also to be of significance to discriminate elements of the pollen spectra from ice and snow of glacial Arctic caps, which should either certainly occur in ground ice of the buried glacial type or be missing from ground ice of nonglacial origin.

The structure of pollen spectra from Arctic glaciers is primarily determined by circulation of air masses over them. Bourgeois [11] analyzed the composition of pollen and spores in the snow cover and ice caps in the Canadian and Russian Arctic regions: the Devon, Agassiz, Komsomolets, Penny, and other caps. It turned out that >95% of pollen and spores were transported over long distances; i.e., they are elements of long-range transportation. They include a group of such exotic long-distance transported pollen characterizing thermophilic plants and a group of regional

*Moscow State University,
Moscow, 119991 Russia
e-mail: vasilch@geol.msu.ru*

Correlation between occurrences of some components in pollen spectra from polar ice caps and stratal ice of Arctic Canada and Russia regions

Local components of pollen spectra	Massive ice					Ice of polar ice caps					
	Gyda River mouth [9]	Bovanenkovo [5]	Upper reaches of the Yuribei River (Yamal Peninsula) [9]	Lower reaches of the Yuribei River (Yamal Peninsula) [9]	Mackenzie River mouth [14]	Akademii Nauk Ice Cap, Komsomolets Island [11]	IGAN Glacier, Polar Urals [13]	Devon Ice Cap [11]	Agassiz Ice Cap [11]	Quviagivaa Ice Cap [11]	Penny Ice Cap [11]
Pollen of thermophilic arboreal forms. Acer, Fraxinus, Quercus, and Ulmus, Populus, Tilia, Abies	Not detected	Not detected	Not detected	Not detected	Not detected	+	+	++	++	Not detected	+
Rubus pollen	+	+	+	+	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Pollen of aquatic plants (*Potamogeton*, *Sparganium*)	+	+	+	+	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Ericaceae pollen	+	+	+	+	Not detected	Not detected	Not detected	Not detected	+	Not detected	+
Bryales spores	+++	++	++	++	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Equisetales spores	Not detected	++	++	+	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Reworked	Not detected	++	++	++	+++	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Diatom algae	+	+	+	+	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Chlorophycaceae	+	+	+	+	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected

Note: Content: (+) 0.1–10%, (++) 10–20%, (+++) >20% of the total quantity of counted grains.

pollen belonging to representatives of the northern taiga and tundra [12].

The occurrence of exotic thermophilic pollen in ice pollen spectra without indications of erosion and reworking in the water medium implies a glacial origin of the ice deposit. It was established that the content of recent exotic pollen in subfossil tundra pollen spectra is less than one pollen grain per thousand of counted grains [12].

In pollen spectra from ice and snow cover of polar glaciers, Ericaceae pollen is extremely rare: its quantity averages two grains per thousand of counted grains with their maximal concentration being 1–2%. On the contrary, it is a common or even dominant component in tundra pollen spectra [12]. Therefore, the notable concentration of Ericaceae pollen in pollen spectra may indicate a nonglacial origin of ice.

Bryales spores represent an additional important indicator. They are missing in pollen spectra from Arctic ice caps [11, 12] and were never found even in the Polar Urals: no Bryales spores and larch pollen were found in ice and snow cover of the IGAN and Olenii glaciers of the Polar Urals [13], although these plants occur in the surrounding phytocoenoses. The pollen spectra from the snow patch near the Polyarnyi Settlement (Polar Urals) contain insignificant quantities (1–3%) of Poaceae and Cyperaceae pollen and Polypodiaceae spores, which are missing from pollen spectra characterizing ice in a nearby small hanging-cirque glacier [12]. Its pollen spectra demonstrate a more notable content of *Pinus silvestris* (26–36%), *P. sibirica* (9–16%), and *Betula* sect. *Nanae* (8–11%) pollen and *Sphagnum* spores (18–26%) as compared with their counterparts from the snow patch. The concentration of Ericaceae pollen in ice does not exceed 1%. No Bryales and Equisetales spores are found in pollen spectra from both snow and ice [12].

Pollen of aquatic *Potamogeton, Sparganium*, and *Typha* are extremely rare [11]. According to our estimates, their abundance is less than one grain per thousand of counted grains [12]. Consequently, the occurrence of pollen belonging to aquatic plants, which is mostly transported by water, may be considered as

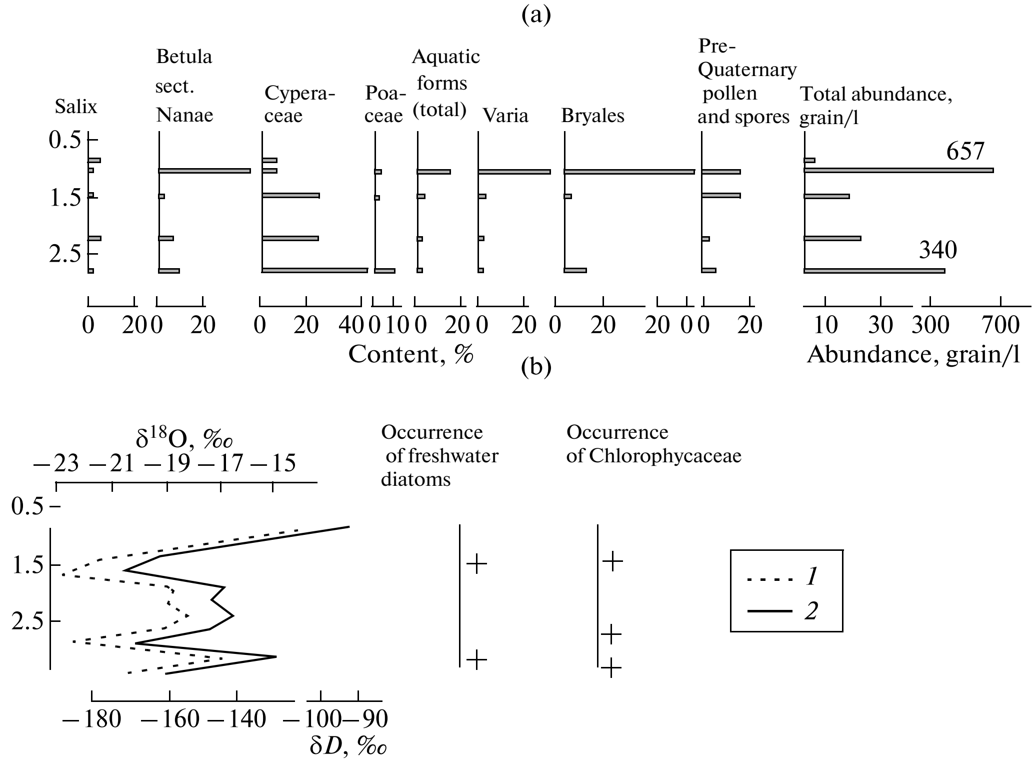

Fig. 1. Pollen spectra: (a) stratal ice deposit 4 in the third terrace of the Bovanenkovo gas condensate field and (b) isotopic composition of ice in the same samples. Isotopic curves demonstrate the distribution of $\delta^{18}O$ (*1*) and δD (*2*).

indicating a nonglacial origin of ice. Equisetaceae spores, which are missing from glacier pollen spectra, may also serve as such an indicator: in pollen spectra of the tundra zone, their content averages 1–4%.

The low content of pollen and spores of aquatic plants in ice and snow cover of glaciers is explained by their morphological properties: they have practically no adaptive means for air transportation; instead, they adapted well to transport in water.

Thus, it should be noted that ice and snow cover are practically barren of some components characteristic of the tundra pollen spectra (Table 1). These are pollen of *Rubus* and aquatic plants, which is poorly suitable for air transportation, as well as Equisetales and Bryales pollen and spores. The content of Ericaceae pollen in ice covering glaciers is substantially lower as compared with that in the tundra pollen spectra. The pollen spectra from glaciers are characterized by the dominant role of pollen transported long distances belonging to both arboreal and herbaceous plants, such as *Acer, Fraxinus, Quercus, Ulmus, Populus, Abies,* and *Juniperus.*

In the tundra pollen spectra, pollen spectra from snow patches, river and sea ice included, exotic thermophilic arboreal pollen is extremely rare among forms transported long distances: approximately one per thousand of the counted grains.

The palynological study of several different types of stratal ice deposits observed in Yamal sections made it possible to verify the above-mentioned features and clarify their origin.

In the Bovanenkovo gas condensate field, stratal ice is widespread in the form of beds, laccoliths, stocks, and lenses. The palynologically studied ice bed is characterized by a significantly variable isotopic composition (Fig. 1). In the upper 0.2–0.8 m, $\delta^{18}O$ and δD vary from −12.49 to −22.75‰ and from −91.7 to −171.9‰, respectively [5]. Stratal ice demonstrates pollen spectra close to their typical tundra counterparts. They are characterized by the dominant role of *Betula* sect. *Nanae* and *Carex* pollen and Bryales spores (7–36%) accompanied by common pollen of aquatic plants, primarily *Sparangium* (3–4%), Ericaceae (2–3%), and single *Rubus* grains. Ice pollen spectra include also reworked pre-Quaternary pollen and spores (2–9%), as well as freshwater diatoms and Chlorophycaceae algae. They are barren of exotic arboreal pollen; even *Pinus* pollen, particularly characteristic of the snow cover and Holocene ice in Arctic glaciers, occurs as single grains.

The concentration of pollen and spores in some layers is as high as 300–1300 grain/l, which is atypical of Arctic glaciers. Ice also encloses diatoms from the *Pinnularia* genus and Chllorophycaceae algae from the *Pediastrum* genus. The results of the conducted

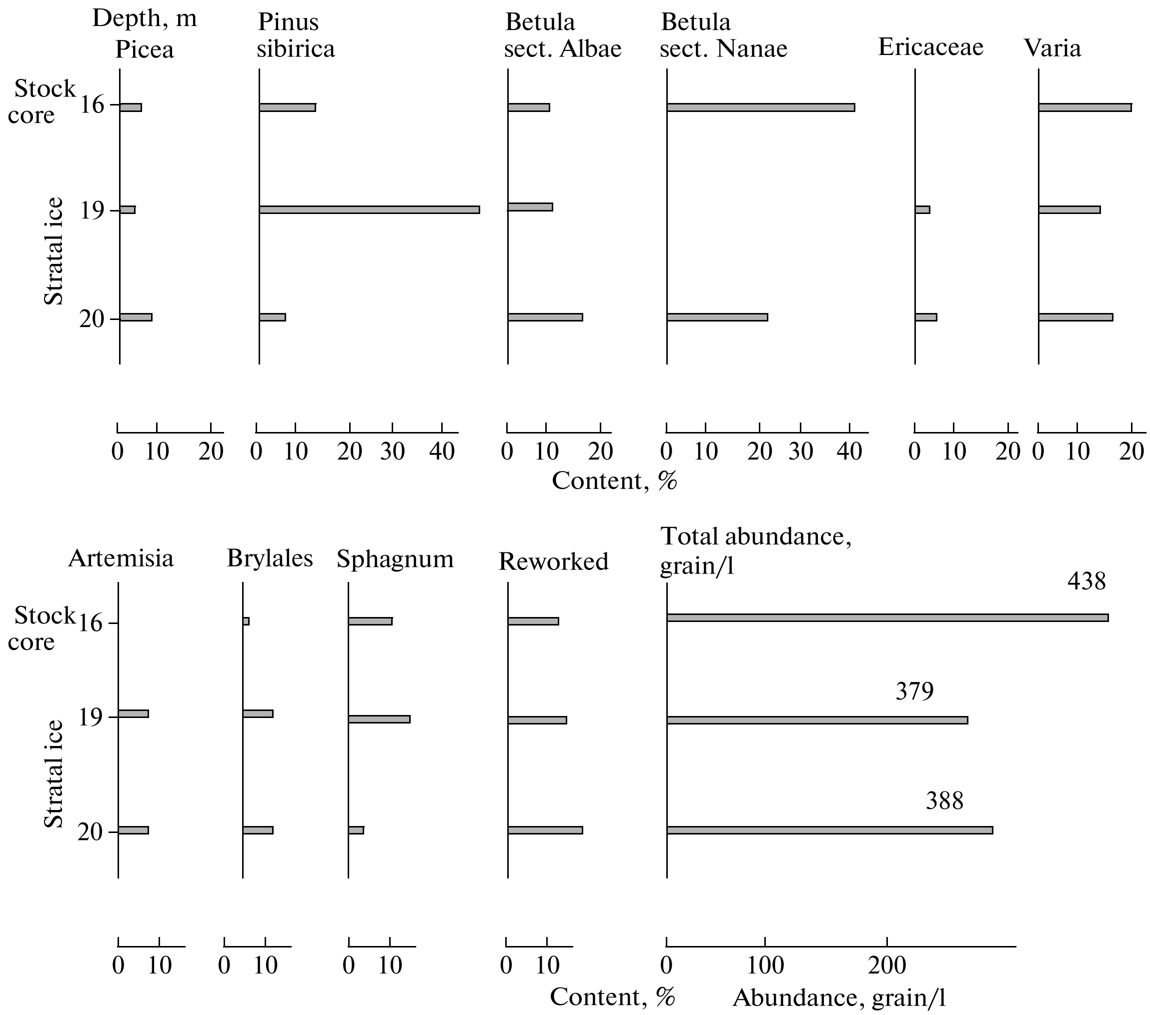

Fig. 2. Pollen spectra from the stratal ice deposit in the lower courses of the Yuribei River (Yamal Peninsula).

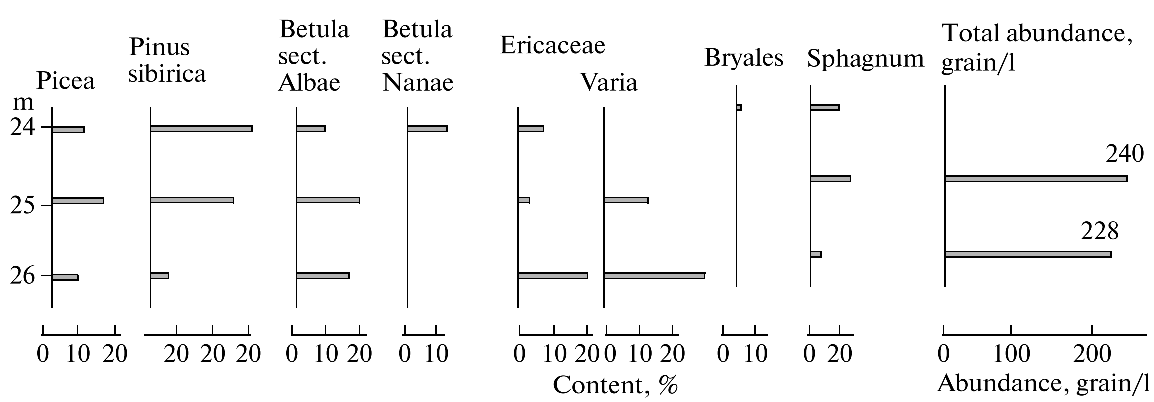

Fig. 3. Pollen spectra from the stratal ice deposit in the upper courses of the Yuribei River (Yamal Peninsula).

study indicate that this ice deposit cannot be of glacial or iceberg origin.

The stratal ice deposit studied in the lower reaches of the Yuribei River in the Yamal Peninsula [6, 9] is located at a depth of 15 m within a sequence of dark gray loams representing an element of the Kazantsevo plain relict section (Fig. 2). The central part of the sequence is occupied by an ice body 3 and 2.5 m wide in its lower and upper parts, respectively. The contact between this body and the hosting sediments is marked

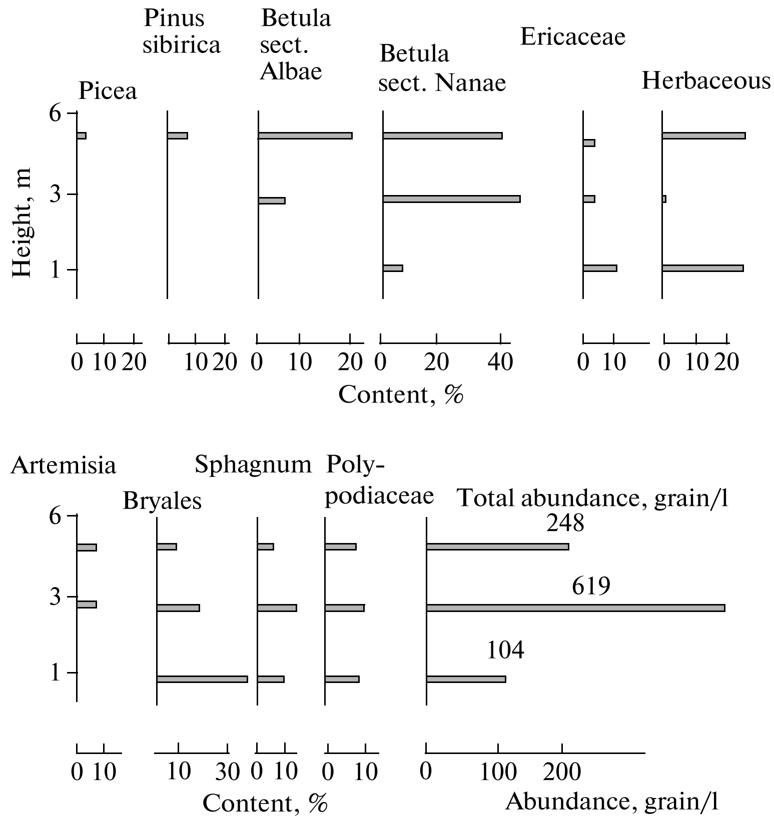

Fig. 4. Pollen spectra from the stratal ice deposit in the Gyda River mouth.

by a member of alternating ice (beds up to 0.5 m thick) and loam (0.2–0.3 m thick) with bed inclines parallel to the lateral surface of the body.

No exotic pollen of thermophilic arboreal plants is found in deposit-forming ice in the lower reaches of the Yuribei River. Reworked pre-Quaternary pollen and spores constitute 10–17%. Pollen of aquatic plants is recorded in one of the samples from the horizontal ice bed (2.5%). The content of Ericaceae pollen is 2–5% and that of Bryales varies from 2 to 12%. Equisetales spores occur at a level of 1–2%. The pollen spectra include also diatoms and Chlorophycaceae remains. Consequently, judging from all the features, this ice deposit cannot be of glacial origin.

In the upper reaches of the Yuribei River, stratal ice bodies were described in loams of the fifth terrace at depths of 21–22 m [10, 13] (Fig. 3). In this area, ice of two types is observable. The central part of the outcrop exhibits a pear-shaped ice body with a member of alternating ice and loam (up to 3.0–3.5 m wide and approximately 3 m high) surrounded with deformed host sediments. Its lateral left contact with near-vertical layers of host sediments is marked by a bed of horizontally bedded ice up to 2.5 m wide and approximately 3 m high.

No exotic pollen of thermophilic arboreal plants is found in deposit-forming ice in the lower reaches of the Yuribei River as well. Coniferous pollen is abundant with that of *Picea* and *Pinus sibirica* constituting 11–17 and 8–31%, respectively. The content of pre-Quaternary reworked pollen and spores is as high as 2–4%. The pollen spectra include also *Rubus* and Ericaceae pollen. Pollen of aquatic plants was found in two lower samples (1–3%). Ericaceae pollen compose 5–32%. Equisetales and Bryales spores occur as single grains. The pollen spectra from this ice deposit demonstrate features indicating its nonglacial origin.

Four levels with lenticular ice bodies 0.3–0.4 m thick and 6–8 m long are recorded in the section of the low terrace in the Gyda River mouth [9]. In addition to ice bodies, the section also encloses syngenetic ice-wedge ice. The pollen spectra extracted from ice [9, 12] reflect variations in the composition of Arctic and Hypoarctic tundra vegetation (Fig. 4) and indicate the nonglacial nature of stratal ice deposits exposed near the Gyda Settlement.

The palynological characteristic of deposit-forming ice in the Mackenzie River delta near Taktakoyak in northwestern Canada [14] differs from that obtained for pollen spectra from stratal ice of the Yamal Peninsula. The pollen spectra from the stratal ice deposit in the Mackenzie River delta are characterized by very high concentrations of pre-Quaternary pollen and spores. They are yellowish brown in color, owing to which they are readily recognizable. The Quaternary pollen in ice is represented by single *Pinus* and *Picea* grains. This ice deposit is most likely of glacial origin.

Thus, the obtained data indicate that pollen spectra from deposit-forming ice of nonglacial origin are characterized by the following features: (1) lack of in situ exotic pollen belonging to thermophilic genera *Acer, Fraxinus, Quercus, Ulmus, Populus, Tilia*, and *Abies*; (2) occurrence of pollen of *Rubus*, aquatic plants, Bryales and Equisetales spores; (3) occurrence of reworked pollen and spores.

For discriminating between different types among stratal ice deposits based on palynological features, additional studies are needed to obtain statistically significant regularities. It seems that clear evidence for the ice nature (glacial/nonglacial) may be derived from the palynological analysis.

ACKNOWLEDGMENTS

This work was partly supported by the Russian Foundation for Basic Research (project nos. 08-05-01068 and 07-05-01100) and the Federal Agency of Science and Innovations (state contract 02.740.11.0337).

REFERENCES

1. Ó. Ingólfsson and H. Lokrantz, Permafrost Periglac. Proc. **14**, 199–215 (2003).
2. N. G. Belova, V. I. Solomatin, and F. A. Romanenko, in *Proc. of the 9th Intern. Conf. on Permafrost* (Inst. Northern Eng. Univ. Alaska, Fairbanks, 2008), vol. 1, pp. 107–112.
3. V. N. Gataullin, in *Proc. of hte Intern. Symp. on Geocriological Studies in Arctic Regions, Yamburg, 1989* (Tyumen, 1990), No. 1, pp. 3–11.
4. F. A. Kaplyanskaya, *Bedded Ices of Cryolitozone* (Inst. Merzlotovedeniya SO AN SSSR, Yakutsk, 1982), pp. 71–80 [in Russian].
5. Yu. K. Vasil'chuk, A. K. Vasil'chuk, N. A. Budantseva, et al., Dokl. Akad. Nauk **428**, 675–681 (2009) [Dokl. Earth Sci. **428**, 1326 (2009)].
6. Yu. K. Vasil'chuk, *Engineering Surveys in Building,* Collected vol. of PNIIIS (PNIIS, Moscow, 1980), Ser. 1, No. 2, p. 17 [in Russian].
7. G. I. Dubikov, *Compound and Cryogenic Structure of Frozen Thickness of Western Siberia* (Geos, Moscow, 2002) [in Russian].
8. V. I. Astakhov, *Beginning of Quaternary Geology*, The School-Book (S.-Peterb. Gos. Univ., St. Petersburg, 2008) [in Russian].
9. Yu. K. Vasil'chuk, *Oxygen Isotopic Composition of Ground Ices* (Otdel Teor. problem RAN, MGU, PNIIS, Moscow, 1992) [in Russian].
10. A. C. Vasil'chuk and Yu. K. Vasil'chuk, *Inzhenernaya Geologiya,* No. 1, 24–38 (2010).
11. J. C. Bourgeois, Rev. Palaeobot. Palynol. **108**, 17–36 (2000).
12. A. C. Vasil'chuk, *Palynology and Chronology of Polygonal Wire Complexes in Russia Cryolithozone* (Mosk. Gos. Univ., Moscow, 2007) [in Russian].
13. T. G. Surova, Mater. Glyatsiol. Issled. **45**, 130–136 (1982).
14. K. Fujino and S. Sato, *Charakteristics of the Massive Ground Ice Body in the Western Canadian Arctic Related to Paleoclimatology (1984–1985)* (Inst. Low Temperature Sci.; Hokkaido Univ., Hokkaido, 1986,) pp. 9–36.