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PALEOGEOGRAPHY

Radiocarbon Age and Stable Oxygen Isotopes in Holocene Ice Wedges on the Coast of Baydarata Bay: Reconstruction of the January Paleotemperature

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Abstract—For the first time, AMS radiocarbon dating was used to date microinclusions of organic material extracted directly from Holocene syngenetic ice wedges in the Noprthern European part of Russia, on the coast of Baydarata Bay near the village of Yarynskaya, 500 m south of the mouth of the Ngarka-Tambyakha River (68°51′20.27″ N, 66°52′6.51″ E). Dated ice wedges formed about 6.4, 5.0, and 1.9 ka BP. According to isotope oxygen data, the average January air paleotemperature in the Middle and Late Holocene on the coast of Baydarata Bay was calculated. It is shown that the average January air temperature during this period here varied from about −20 to −25°C. However, during milder winters it could have been about −18°C.

Keywords: ice wedges, Holocene, AMS radiocarbon dating, stable oxygen isotopes, January paleotemperature, coast of Baydarata Bay

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In the western sector of the Russian cryolithozone, very few ice wedges have been studied in detail, although they could serve as a source of reliable paleogeographic and isotopic-paleotemperature data [1–5]. In this regard, new radiocarbon dating and isotope data on Holocene ice wedges on the coast of Baydarata Bay obtained using accelerator mass spectrometry (AMS) for the first time for the Northern European part of Russia are of great relevance.

The main purpose of this work is to establish the formation time of Holocene syngenetic ice wedges that have been exposed on the coast of Baydarata Bay near the village of Yarynskaya, 500 m to the southeast from the mouth of the Ngarka-Tambyakha River (68°51′20.27″ N, 66°52′6.51″ E) and to establish the approximate mean January (mean February) paleotemperature during this period using oxygen isotope data. To solve this problem, the age of Holocene ice wedges in the Northern European part of Russia was determined for the first time based on organic microinclusions represented by organic dust (deposited soil and biogenic aerosols, organic dust-like particles from organic microinclusions extracted from ice wedges), using accelerator mass spectrometry (AMS), and the isotope-oxygen composition of six ice wedges was studied in detail.

The studied section of the first sea-shore terrace (absolute height 4–9 m) is located along a narrow section of the Ural coast of Baydarata Bay, 500 m to the southeast from the mouth of the Ngarka-Tambyakha River (68°51′20.27″ N, 66°52′6.51″ E).

The western coast of Baydarata Bay is characterized by a subarctic climate. The warmest month is July (the average monthly air temperature is +8.3°C), and the coldest one is February (–20.6°C) [6]. The thickness of permafrost ranges from 8 to 25 m or more [7]. The geocryological section represents an alternation of permafrost rocks with cooled ones [8]. Based on the GTNP database [9], the average annual temperature of permafrost in the study area at a depth of zero fluctuations ranges from –4.8°C to –3.7°C. On the southwestern coast of Baydarata Bay, frost cracking and ice wedges are widely developed.

Ice samples were collected from ice wedges along the vertical profile every 10 cm using Makita DDF481rte 18B and Bosch GSR 36 VE-2-LI drills with steel ice crowns with a diameter of 51 mm. Radio-

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Fig. 1. Holocene ice wedges in laida deposits on the western coast of Baydarata Bay, at the mouth of the Ngarka-Tambyakha River.

carbon dating of ice samples and organic microinclusions extracted directly from ice wedges was carried out at the Radiocarbon Laboratory of the Institute of Geography, Russian Academy of Sciences, and the Center for Applied Isotope Research, University of Georgia (United States). Measurements of the oxygen and hydrogen isotopic compositions in ice were performed on a Picarro L 2130-i laser infrared spectrometer at the Center for X-ray Diffraction Studies at the Research Park of St. Petersburg State University (XRD Center SPbU). The following international standards were used: V-SMOW-2, GISP, SLAP, USGS-45, and USGS-46. The measurement errors were ±0.02‰ for $\delta^{18}O$ and ±0.3‰ for δ^2H. In total, 63 samples of ice wedges were analyzed.

Holocene ice wedges (IW) are exposed on the laida coast of Baydarata Bay in an outcrop of up to 1–1.5 m high. In the laida area studied, a polygonal and convex-polygonal network is developed. The shape of the polygons is isometric, and their dimensions vary from 40 × 25 m to 7 × 10 m, reaching 30 m in diameter. Holocene ice wedges from the thickness of lacustrine loams overlain by peat of 0.3–0.6 m thick were sampled. The peat is horizontally layered with fine sand layers with massive, rarely basal cryostructure. Peat is underlain by gray silty loam with a layered lenticular cryostructure. Ice wedges of 1.2–1.5 m wide lie at a depth of 0.5–0.6 m (Fig. 1); six ice wedges of 0.5–1 m are exposed. The composition of soil inclusions in the ice varies from heavy loam to clay, with microinclusions of organic matter. Sampling was carried out on a grid along the entire exposed part of ice wedges.

Ice wedges are ultra-fresh, and the total mineralization of veins measured in the field using a TDS meter is in the range from 16.5 to 36.9 mg/L.

The *isotopic oxygen composition* in the studied ice wedges differs noticeably (Fig. 2, Table 1). The highest average $\delta^{18}O$ values (–12.51‰) were obtained in IW-5, and the lowest ones (–18.40‰), in IW-8. The difference was 5.89‰. The $\delta^{18}O$ values in ice wedges with clearly visible inclusions of gray clay soil are somewhat heavier, from –11.30‰ in IW-1 to –13.73‰ in IW-6 and up to –12.17‰ in IW-5. The most mineralized ice wedges with the total amounts of particles dissolved in water of 29.4 and 36.9 mg/L are also the most isotopically heavy. The $\delta^{18}O$ values in them are –11.30 and –12.49‰, which indicates either an admixture of water in the seasonally thawed layer in the veins or microadmixtures of marine aerosols in ice wedges. It should be noted that such high values have never been recorded for the previously studied Holocene ice wedges in adjacent areas and the newly obtained extremely high isotopic data require further study.

The δ^2H–$\delta^{18}O$ ratio in the Holocene ice wedges on the coast of Baydarata Bay (Fig. 3) is close to the Global Meteoric Water Line (GMWL) and is described by the equation $\delta^2H = 7.5\delta^{18}O + 2.1$. The δ^2H–$\delta^{18}O$ ratio in the previously studied Holocene ice wedges near the Vorkuta town $\delta^2H = 7.68\delta^{18}O + 6.55$ [3], on the Yamal and Gydan peninsulas $\delta^2H = 7.4\delta^{18}O - 0.3$ [4], in modern sediments in Amderma $\delta^2H = 7.62\delta^{18}O + 6.86$ and Salekhard $\delta^2H = 7.66\delta^{18}O + 1.21$ [3] are also close to GMWL.

Radiocarbon dating of microinclusions of organic matter, extracted directly from three Holocene syngenetic ice wedges, was conducted using accelerator mass spectrometry (AMS). The dating of the wedges correlates to their formation approximately 6.4, 5.0, and 1.9 cal ka BP (Table 2).

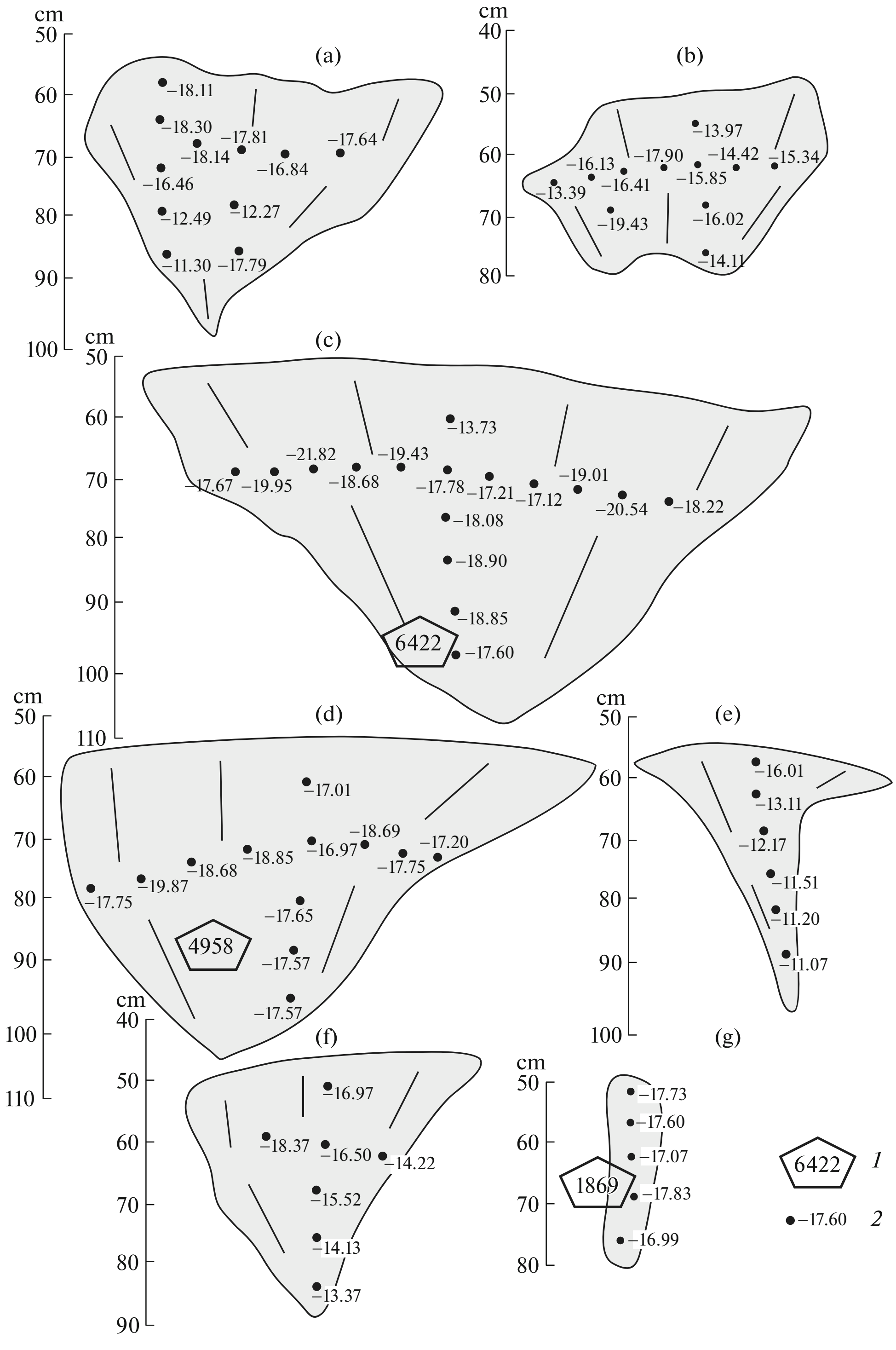

Fig. 2. The $\delta^{18}O$ values in Holocene ice wedges and in mixed segregated ice and ice wedges with inclusions of gray loam soil on the western coast of Baydarata Bay, at the mouth of the Ngarka-Tambyakha River: (a) IW-1; (b) IW-2; (c) IW-3; (d) IW-4; (e) IW-6; (f) IW-7. (*1*) AMS radiocarbon age cal. BP; (*2*) $\delta^{18}O$ value.

The reconstruction of the approximate mean January (mean February) air temperature in different periods of the Holocene was made on the basis of isotopic data. A comparison of the oxygen isotopic composition of the Holocene ice wedges (in which the $\delta^{18}O$ values vary mainly from −21.8 to −13.73%) and modern ice wedges (the age of which, as a rule, does not exceed 100 years) shows a close range of variations in values.

Table 1. The measurement results of the $\delta^{18}O$ values in samples from ice wedges near the village of Yarynskaya at the mouth of the Igarka-Tambyakha River

Number of samples	$\delta^{18}O$, ‰			Number of samples	$\delta^{18}O$, ‰		
	min	mean	max		min	mean	max
IW-1				IW-5			
11	−18.30	−16.10	−11.30	6	−16.01	−12.51	−11.07
IW-2				IW-6			
11	−19.43	−15.72	−13.39	7	−18.37	−15.95	−13.73
IW-3				IW-7			
16	−21.82	−18.40	−13.73	5	−17.83	−17.44	−16.99
IW-4							
12	−19.87	−17.96	−16.97				

Table 2. Results of radiocarbon dating of samples of ice wedges near the village of Yarynskaya at the mouth of the Ngarka-Tambyakha River*

Field number of sample	Depth, m	$IGAN_{AMS}$	AMS ^{14}C dates, years ago (1σ)	Calibrated age, years, probability 95.4%	
				age range	median
Yary-29 (IW-3)	1.04	10443	5640 ± 20	6489–6320	6422
Yary-45 (IW-4)	0.94	10444	4400 ± 20	5042–4873	4958
Yary- 69 (IW-7)	0.73	10445	1945 ± 20	1939–1821	1869

*The age was calibrated using the IntCal20 curve [14] and Oxcal version 4.4.4 software [15]. The age of organic matter (cal yr BP) from ice wedges was calibrated until 1950.

The $\delta^{18}O$ value in ice veinlets at the mouth of the Ngarka-Tambyakha River varies from –21.82 to −14.11‰ [1]. The previously obtained $\delta^{18}O$ value in the ice veinlet in the Amderma village area is –15.2‰ [10]. Two $\delta^{18}O$ values in ice veinlets in the peat at Cape Shpindler are –13.1‰ and –16.9‰ [11]. The $\delta^{18}O$ value of –16.0‰ was obtained for a ice veinlets in the Vorkuta area [3]. According to the data for 1965 recorded at the Vorkuta, Amderma, and Ust-Kara weather stations, the current average winter air temperature for the period from November to March in the study area varied from –14 to –18°C [12]. In the study area, a direct correlation was noted between the average winter (from –14 to –18°C) and the average January (from –20 to –25° C) air temperatures and the $\delta^{18}O$ parameter of modern ice wedge sprouts (from –13 to –19‰) with a deviation of ±2–3°C.

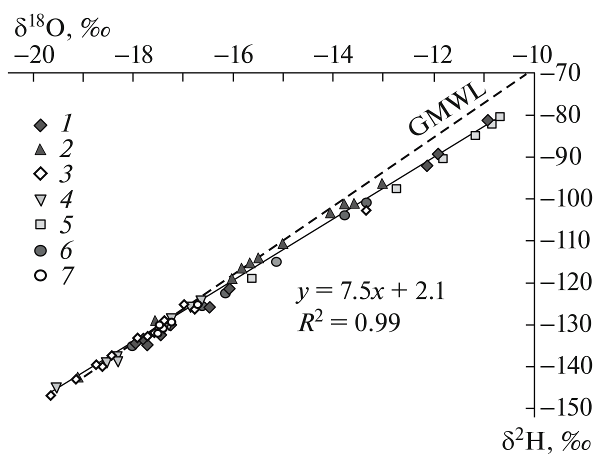

Fig. 3. The δ^2H–$\delta^{18}O$ ratio in Holocene ice wedges along the coast of Baydarata Bay. (*1*) IW-1; (*2*) IW-2; (*3*) IW-3; (*4*) IW-4; (*5*) IW-5; (*6*) IW-6; (*7*) IW-7.

Applying the approximate dependence of the oxygen isotopic composition of ice wedges on the average January air temperatures proposed by Yu.K. Vasil'chuk [13], one can conclude that the variations in the average January air temperature during the formation of ice wedges in the study area were approximately in the range from –20 to –25°C. However, during milder winters, the average January air temperature could have been about –18°C.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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