Book of Abstracts

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High-resolution stable isotope records reflect January air paleotemperature of 49-22 ka cal BP in Central Yakutia (applying AMS radiocarbon dated of Ice Wedges of the Batagay Yedoma)

Yu.K.Vasil'chuk, J.Yu.Vasil'chuk, N. A. Budantseva, A.C. Vasil'chuk
Lomonosov Moscow State University, Moscow, Russia, e-mail: vasilch_geo@mail.ru

Batagay megaslump exposed the greatest geocryological formation known in the world in the north of Central Yakutia in the upper reaches of Yana River (67°34'49"N, 134°46'19"E). A vertical wall of 70 to 100 m exposes the yedoma with thick syngenetic ice wedges, underlying by older horizontally layered frozen sediments with narrow ice wedges. This outcrop began to be studied relatively recently but some interesting results have been obtained [Murton et al., 2017; Vasil'chuk et al., 2017, 2019; Ashastina et al., 2017; Opel et al., 2019 et al.]. To study the paleochronology and paleoclimate of the Batagay area, complex studies including radiocarbon dating (as well as AMC dating of micro-organic inclusions in ice wedges) and stable isotope studies were carried out by authors.

Radiocarbon age measurements. AMS radiocarbon dating was carried out in the Laboratory of Radiocarbon Dating and Electronic microscopy of the Institute of Geography of the Russian Academy of Sciences (obtaining counting material) and the Center for Isotope Research of the University of Georgia in the USA (direct measurement on an accelerator mass spectrometer).

Stable isotope measurements. The isotope composition of oxygen and hydrogen in the ice were made in the mode of constant helium flux (CF-IRMS) on a Delta-V mass spectrometer using a gas-bench complex, at the isotope laboratory of the Geography Department, Lomonosov Moscow State University (MSU). The calibration was made with OxCal software [Bronk Ramsey, 2009] using IntCal 20.

Stable isotope and air temperature relationship. To establish the $\delta^{18}O$ and air temperature relationship we compared winter and January air temperature and the $\delta^{18}O$ values of modern ice wedges (or veinlets) in different regions of the Eurasian permafrost area [Vasil'chuk, 1991]. These relationships are expressed in the following simplified regression equations: $t_{mJ} = 1.5\delta^{18}O_{iw}$ (± 3°C) where t_{mJ} - mean January air temperature; $\delta^{18}O_{iw}$ is oxygen isotope composition of ice-wedge ice.

Detailed isotope-oxygen and deuterium diagrams obtained from ice wedges [Vasil'chuk et al., 2020], allowed to suggest the very severe winter conditions prevailed in the Verkhoyansk region of Central Yakutia in the Late Pleistocene. The chronological reference of these diagrams was based on the dating of the yedoma sediments. But presence of reworking organic material in the yedoma that lead to aging of radiocarbon dates is a rule [Vasil'chuk, Vasil'chuk, 2017], so several ^{14}C age inversions are also found among the dates obtained from micro-inclusions of organic matter from the Batagay sediments.

Chronostratigraphy. The three ice wedges profiles (IW-3, IW-5 and IW-7) were sampled to cover the entire exposed permafrost and ice wedge sequence at in spatial context. 7 AMS ^{14}C dates from 34396 to 27156 cal BP were obtained from micro-inclusions of organic matter extracted from IW-3. However, not all dates can be considered as a valid. Using the previously developed strategy for selecting valid dates in yedoma [Vasil'chuk, Vasil'chuk, 2017], the most reliable dates are 27156 cal BP from a depth of 6.7 m and 30886 cal BP from a depth of 10 m.

Thus, one can calculate the rate of vertical growth of ice wedge IW3: 3.3 m of ice accumulated in about 3.7 ka, i.e. the rate of accumulation was about 1 m per 1 ka years. Consequently, the fragment of IW3 with vertical thickness of 5.5 m was accumulated over a period of about 5 ka – from 30.9 to 25.9 cal ka BP.3 AMS ^{14}C dates in the range from 49232 to 44724 cal BP were obtained from micro-inclusions of organic matter extracted from IW-5. However, the sample dated to 49232 cal BP from a depth of 14.8 m is most likely contaminated with ancient organic matter, so the more reliable dates are 47541 cal BP from a depth of 17 m and 44724 cal BP from a depth of 12.55 m. Thus, the rate of vertical accumulation of IW5 ice wedge was about 1.3 m per 1 ka years. Consequently, the studied fragment of IW5 with vertical thickness near to 8 m accumulated over a period of about 6 ka – from 47.5 to 41.5 cal ka BP.

3 AMS ^{14}C dates in the range from 52.2 to 45.8 ka cal BP were obtained from micro inclusions of organic matter extracted from IW-7. However, the uppermost sample from a depth of 2.4 m, dated to 52286 cal BP, is most likely contaminated with ancient organic matter, so the more reliable dates are 45844 cal BP from a depth of 7 m and 47908 cal BP from a depth of 12.8 m. Thus, the rate of vertical accumulation of ice IW7 is quite high and exceeded 2.5 m per 1 ka years. Consequently, the studied fragment of IW7 with vertical thickness of about 12 m accumulated over a period of about 5 ka – from 47.9 to 42.9 cal ka BP.

The overlap in sampling positions of the three profiles (Fig. 1, 2) and the modelled age-height relation allows for deducing a stacked record that differentiates into three chronostratigraphic and ice wedge units:

IW-3: MIS 2, Yedoma IC (27.1 to 30.8 cal ka BP), IW-5: MIS 3, Yedoma IC (44.7 to 47.5 cal ka BP), IW-7: MIS 3, Yedoma IC (45.8 to 47.9 cal ka BP).

Stable isotope ratio. Ice wedges from three sections on Batagay outcrop were sampled for stable oxygen ($\delta^{18}O$) and hydrogen (δ^2H) isotopes; the first section (IW-3) was located in the left wall at the mouth of a ravine, the second section (IW-5) and the third section (IW-7) in the southwestern part of the Batagay megaslump. Ice screws were used to drill transects across the exposed ice, keeping a distance of 0.1-0.2 m between the drill-holes.

Table. The range and mean values of $\delta^{18}O$ and δ^2H in the ice wedges from Batagay yedoma

Number of samples	$\delta^{18}O$, ‰			δ^2H, ‰		
	Min	Mean	Max	Min	Mean	Max
IW3.Depth 5-10 m (315-320 m asl.)						
38	–34.83	–34.36	–32.47	–272.6	–266.3	–255.6
IW5. Depth 9-17 m (273.9-266 m asl.)						
53	–35.15	–34.12	–32.36	–273.5	–264.5	–238.1
IW7. Depth 1-12.8 m (239-227.2 m asl.)						
79	–35.36	–34.33	–32.98	–276.0	–265.2	–248.9

Mean values of $\delta^{18}O$ in the ice wedges from three sections varies in a narrow range from –34.36 to –34.12 ‰, and δ^2H values from –266.3 to –264.5 ‰. Based on detailed isotope data (170 samples), the average January temperature of the Late Pleistocene was calculated from 25 to 30 cal. ka BP and from 42 to 49 cal ka BP for the Batagay section and for a number of supporting sections, in the north-west of Yakutia. It was shown that the lowest average

January air temperature in this period was in the Batagay region (-51°C, average january temperature is -45°C), while in areas located 500-600 km to the north, it was 4-5°C higher 25 to 30 cal ka BP and 5-7°C higher from 42 to 49 cal ka BP. These severe winter climate conditions are explained by the existence by stable Yakutia anticyclone in the Late Pleistocene (from 25 to 49 cal ka BP), which still exists at present. The work was supported by the Russian Scientific Foundation (grant No. 19-17-00126 – field studies) and Russian Foundation for Basic Research (grant No. 18-05-60272 "Arctic" -radiocarbon and stable isotope composition).

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