Geoscience Frontiers xxx (2017) 1–13

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

China University of Geosciences (Beijing)

Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf

Research paper

Early Holocene climate signals from stable isotope composition of ice wedges in the Chara Basin, northern Transbaikalia, Russia

Yurij K. Vasil'chuk [a,*], Alla C. Vasil'chuk [a], Julia V. Stanilovskaya [b]

[a] Geography and Geology Departments, Lomonosov Moscow State University, Moscow, Russia
[b] Sergeev Environmental Geoscience Institute of the Russian Academy of Sciences, Russia

A R T I C L E I N F O

Article history:
Received 3 October 2016
Received in revised form
4 April 2017
Accepted 28 April 2017
Available online xxx
Handling Editor: Wenjiao Xiao

Keywords:
Holocene
Ice wedge
Stable isotopes
Southern permafrost areas
Northern Transbaikalia

A B S T R A C T

Stable isotope composition of syngenetic and epigenetic ice wedges, radiocarbon age, and pollen spectra of the surrounding deposits were studied during long term investigations at the "Belyi Klyuch" site on the first (6–8 m height) terrace of the Chara River (720 m.a.s.l.) in northern Transbaikalia to assess climatic conditions during ice-wedge formation. It was revealed that Holocene ice wedges had been formed from 10 to 7.5 ka ^{14}C BP. The isotope composition (δ^{18}O, δ^2H) of relict ice wedges is the lightest and amounts −23‰ and −185‰, correspondingly. The isotopic compositions of ice lenses from sandy loam above ice wedges are −15.7‰ and −133‰; of small ice wedge in peat and sand are −15.3‰ and −117.9‰, accordingly.

Interpretation of the ice wedge isotope composition has yielded that mean winter temperatures during cold stages of Holocene optimum were lower than today, during warm stages they were close to modern ones. During the coldest stages of Holocene optimum the total annual freezing index varied from −5100 to −5700 °C degree days, i.e. 300–600 °C degree days colder than during extremely severe modern winters. The total annual thawing index varied from 1300 to 1800 °C degree days, which was slightly higher than modern ones.

1. Introduction

Ice wedges can be a valuable source of proxy information on past climates (Vasil'chuk, 1992, 2013). The stable-isotope signature (δ^{18}O and δ^2H) of syngenetic ice wedges is an important indicator in long-time-scale paleoclimatic reconstructions according to the empirical linear relationship between mean winter and mean January air temperature and the isotopic composition of wedge ice (Vasil'chuk, 1992) as the snow melt water is the main source for ice-wedge formation. The isotopic signature of winter precipitation is transferred to ice wedges. As the winter precipitation originates from the air mass, it provides a site-specific signature of the ambient air temperature, stored within ice wedges at the site. This means that a major shift in the isotopic composition of different elementally ice veins could reflect the paleotemperature fluctuation. The linear relationship between mean winter temperatures and the isotopic composition of ice wedges permits quantitative reconstruction of paleotemperature during the ice-wedge growth.

Patterned ground and ice wedges are widespread within the Chara Basin in northern Transbaikalia (57°N and 118°E) especially within sediments of the first terrace of the Chara River (Lopatin, 1967). Sediments of the first terrace are medium and coarse sands, often interbedded with gravel and pebbles. It is supposed that ice wedges in pebbles and gravels may form only in extremely severe winter conditions (Black, 1965). Ice wedges in the Chara River valley are valuable as analogues of ice wedges formed in severe conditions in gravel sediments.

Age of ice wedges assessed indirectly by their location in the first terrace sediments in river valley. This led to the erroneous opinion, that ice wedges are Late Pleistocene relict, as buried wedge ice in the northern part of the Udokan Range at the height of 900–1000 m was dated at least to the Late Pleistocene (Romanovsky et al., 1988), which is significantly more severe than Holocene. It was assumed that the conditions for the ice-wedge formation were significantly more severe than modern and Holocene ones based on their formation in gravel sediment. We obtained data that are redefining the age of ice wedges and clarifying the temperature conditions of their formation. The main objective of the study is to get Holocene paleotemperature signal from ice wedges in the first terrace of the Chara River.

* Corresponding author.
E-mail address: vasilch_geo@mail.ru (Y.K. Vasil'chuk).
Peer-review under responsibility of China University of Geosciences (Beijing).

http://dx.doi.org/10.1016/j.gsf.2017.04.008

Ice wedges can be a valuable source of proxy information on past climates (Vasil'chuk and Vasul'chuk, 1995; Vasil'chuk et al., 2000; Opel et al., 2011; Yang and Jin, 2011; Yang et al., 2013, 2016). The main objective of the study is to get Holocene paleotemperature signal from ice wedges in the first terrace of the Chara River.

2. Study area

The study area is located in the southern part of Siberian Platform within the Chara Basin (708–740 m.a.s.l., Fig. 1). The eastern part of the basin is limited by the Udokan Ridge (2515 m.a.s.l.), the west part by the Kodar Ridge (3073 m.a.s.l.). Chara Basin has a length of up to 125 km; maximum width in the middle part is 35 km. The slopes and bottom of the basin are occupied by numerous mountain ridges, alluvial fans, river terraces; some part of the territory is swamped. The main landscapes are marshy meadows, dwarf birch, pine forests and mountain taiga.

The climate is continental with a winter temperature inversion and the predominance of western (regional) atmospheric transport. Heterogeneous distribution of meteorological elements within the basin is caused by the imbricate location of the ridges.

The observations carried out for more than 70 years at the meteorological station of Old Chara village. Meteorological data allow allocating a period of relative cooling (1939–1960) and a period of relative warming (1960–2004) (Weather of Russia…, http://meteo.infospace.ru). The average air temperature for 1959–2015 in Chara Basin was −7.6 °C, minimum (−9.8 °C) was recorded in 1969, the maximum (−3.6 °C) in 2004 (Fig. 2). Average winter temperature for 1939–1960 was −21 °C and the average January temperature was −34 °C (Climate reference book…, 1966), the average January temperature for 1960–2004 was −33 °C. We emphasize that the annual freezing index for 1939–1960 was 4438 °C degree days. It is lower by 100–130 °C degree days than for 1960–2004. The annual thawing index is 1633 °C degree days (Weather of Russia…, http://meteo.infospace.ru).

Annual amplitude of the air temperature is 92 °C: absolute minimum is −57 °C; the absolute maximum is +35 °C. Period with negative mean monthly temperature lasts 7–8 months. Daily amplitude is 27–37 °C, which is associated with intense sun exposure during daytime and the intensive radiance of the surface at night. The absolute minimum recorded in July in the Chara village is −2 °C. Sharp daily fluctuations with significant temperature decreases at night lead to occasional freezing events in July (Plyukhin, 1990).

The precipitation increased from 220 mm (1973) to 450 mm (1989), and to 420 mm (1993) has been observed. Average precipitation during last 50 yr is 340 mm. The duration of snow cover in the basin averages 176 days, and average snow depth varies from 15 to 20 cm, its maximum height according to the Chara meteorological station is 30 cm, the minimum is 6 cm. Wind transport is negligible, which is favorable for the ubiquitous uniform cooling of different elements of the relief (Nekrasov and Zabolotnik, 1967). The warming effect of snow is very high, so cooling during dry winters and following cracking are very intensive. Temperature gradient in snow is 1.5°/cm or more (Kolomyts, 1966). Due to the friability and high heat insulating ability of the snow cover the active layer is completely frozen by February; by this time of winter, obviously, the most active frost cracking occurs.

Seasonal thawing on the terraces and flood plain begins in early May and ends in October. Active layer depth varies from 0.5 to 3.5 m (Zabolotnik and Klimovsky, 1966). The minimum depth of thawing (up to 1 m) has been recorded the treeless marshy areas or in areas with sparse larch forest, therefore, these sites are the most favorable for the development and preservation of ice wedges.

The mean annual soils temperature (as measured in 1964) was relatively high and ranging from −2 °C under a canopy of larch woodlands to positive values of 1–2 °C on dry sand and in the dry open field (Gavrilova, 1967). Similar range was determined by our measurements in 2007–2014. Contrast of permafrost conditions, even within a single element of the relief, is very noticeable; the average soil temperature can vary by 2 °C and more. This contrast is even more emphasized, for example, with Upper Chara thermal chloride-sulphate-sodium spring with a temperature of 41 °C in April to 50.5 °C in the northern part of the Chara Basin near Arbakalir Lake in May (Nekrasov and Golovanova, 1966).

The spatial distribution of permafrost in Chara region varies from sporadic to continuous. Taliks locate within the Chara Sandy Desert on the left bank of the Chara River and under the beds of large rivers (Chara, Nizhniy Ingamakit, Sredniy Sakukan and others). The Chara Basin is surrounded by mountains where the relief changes from smooth and rounded to typical alpine with present-day glaciation. Numerous permafrost features are present, including kurums,

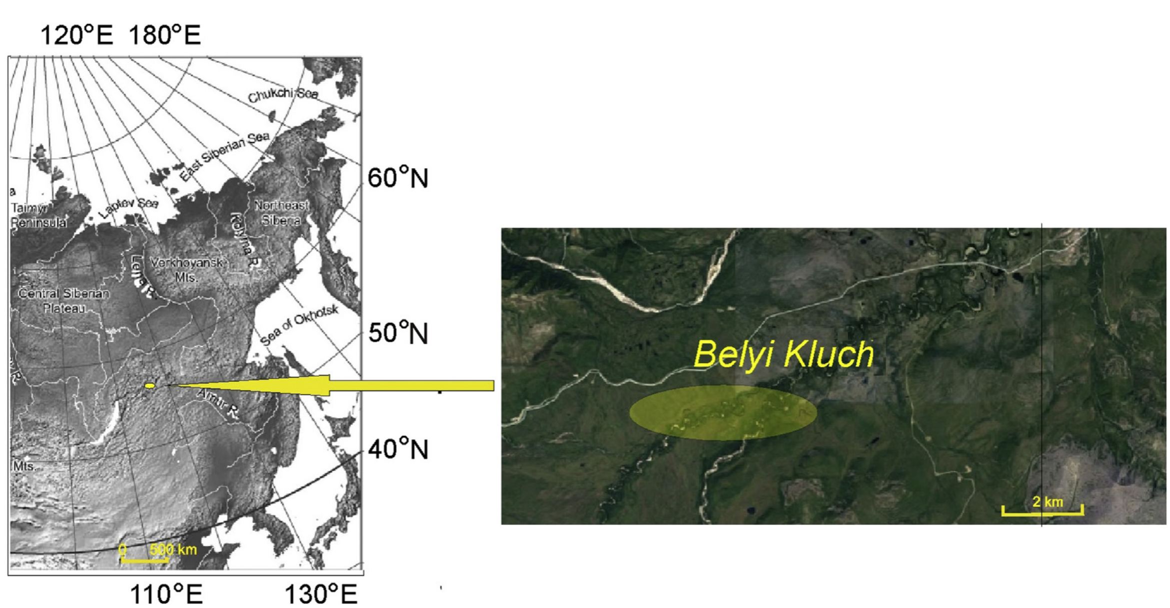

Figure 1. Location of the study site along the Transbaikalia.

Please cite this article in press as: Vasil'chuk, Y.K., et al., Early Holocene climate signals from stable isotope composition of ice wedges in the Chara Basin, northern Transbaikalia, Russia, Geoscience Frontiers (2017), http://dx.doi.org/10.1016/j.gsf.2017.04.008