Ice-wedge based permafrost chronologies and stable-water isotope records from Arctic Siberia

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1 Permafrost and fossil ice-wedge polygons

In permafrost regions, decreasing winter air temperatures in winter promote thermal contraction of the organo-ground and frost cracking Snow, ice wedges and spring meltwater 5.1 in the cracks to form vertical ice vents that may grow into syngentic ice wedges after numerous freeze-thaw cycles (Figure 2). Physical self-organization leads to the typical pattern of polygonal tundra with ice-wedges below the rims and sedimentary centers.

Ice wedges are thought to be the most common ground ice type in permafrost and serve as paleoclimate archives to be studied by means of stable-water isotopes. The isotopic compositions of each single ice wedge is linked to winter snow, and, therefore, indicative of the climate condition during the corresponding cold season. The δ18O and δD of wedge ice (in ‰ vs. VSMOW) are related to the condensation temperature of the precipitation and interpreted as mean winter air temperature proxy at the study site. The δD (δD = 8D) is indicative for the evaporation conditions (i.e. relative humidity, sea surface temperature) in the moisture source region.

2 Study area, dating and local stratigraphy

Mid- and late Pleistocene tundra-steppe environments of western Beringia are preserved and described as Ice Complex (IC) deposits. Those are differentiated in four IC generations as recognized at the coasts of the Dmitry Laptev Strait, on Boley Bay Lyakhovsky Island and partly on the Oyogos mainland coast (Figures 3 and 4).

Direct dating of ice wedges, in particular for the pre-Holocene challenges as there is (a) only a little particulate organic material for radiocarbon dating preserved in ice wedge, and (b) the ages are often close to the age limit of radiocarbon dating. New promising dating tools are in development and compare radiocarbon dating of air-bubble CO2 and dissolved organic carbon from ground ice as well as cosmogenic 39Cl/Cl dating for mid- to late Pleistocene ground ice. Most often syngentic ice wedges are stratigraphically attributed to the embedding frozen sediments with known geochronological information from radiocarbon, luminescence and radiocarbon disequilibrium (14C/12C) dates.

3 Exemplarily Holocene wedge-ice stable water isotope records

The internal stratification of syngentic ice wedges is best seen along horizontal transects (Figure 5). Ice wedge growth overtimes in width and height captures changes in isotopic composition of winter precipitation. 8D/18O cross plots are commonly used to assess the paleoclimatic significance by comparison with the Global Meteoric Water Line (GMWL, 8δD = 8δ18O + 10, Craig 1961). Radiocarbon dates of ice enclosed organic matter provide age control and may enable the development off time series (Meyer et al. 2015).

Slope and intercept values are used to assess the deviation from the GMWL or LMRWL as result of secondary fractionation processes after precipitation of snow (in the snow cover by sublimation or hoar frost development), during melting and refreezing and during ice-sediment exchange.

Dexcess may indicate significant changes in moisture sources such as Atlantic vs. Pacific vs. regional (e.g. polynya) and/or sea and humidity conditions in the moisture source regions.

Further reading: EGU2016-3892, CL1.07, X3.41

Opel et al. 2011.
Opel et al. 2009.
Meyer et al. 2015.
Craig 1961.
References

Meyer et al. 2015.
Paleoclimate implications

If comparing ice-wedge data from both coasts of the Dmitry Laptev Strait those records of the same stratigraphic unit reveal the similar paleoclimatic information. Interstadial periods of the late Pleistocene show (MS7a, MS5a-b, MS3) mean values from -33 to -30 ‰ for 8δD and from -260 to 240 ‰ for 8δ18O (Figure 6). The Last Glacial Maximum (MS2) reveals coldest winter conditions as mirrored by mean values of -37 ‰ for 8δD and -290 ‰ for 8δ18O. Warmest winter conditions are obvious in Holocene (MS1) records by mean values of more than -25 ‰ for 8δD and more than -140 ‰ for 8δ18O. More recent approaches, (b) the construction of high-quality time-series for certain time slices (e.g. Holocene), (c) the calibration of 8D to local temperatures and (d) an improved interpretation of δD.

Ongoing research in ice-wedge based paleoclimatology deals with (a) the further development of dating approaches, (b) the construction of high-quality time-series for certain time slices (e.g. Holocene), (c) the calibration of 8D to local temperatures and (d) an improved interpretation of δD.

References

Operation of synoptic and regional studies of the northern Russian Arctic, Akoovu, 37, 17-37.
Meyer, L., et al. 2015. Late Holocene stable isotope based winter temperature records from ice-wedges in the Northeast Siberian Arctic.
Hall X3 on Friday, 22 Apr 2016, 17:30-19:00.

Further reading:

Figure 2. Schematic cut-away of ice-wedge polygons (R. Mitchell/Inkworks for U.S. Fish and Wildlife Service)

Figure 3. Study region in eastern Siberia (2012).

Figure 4. Dating and stratigraphy of Holocene wedge ice from Dmitry Laptev Strait (Meyer et al. 2002; Wetterich et al. in press; Meyer et al. 2002).

Figure 5. Holocene wedge-ice stable water isotope data from coastal exposure (Oyogos mainland coast (Opel et al. 2011).