Stable-Isotope Signals of Paleo-Winter Temperatures in Permafrost Ice Wedges of Central Yakutia, Northeastern Siberia

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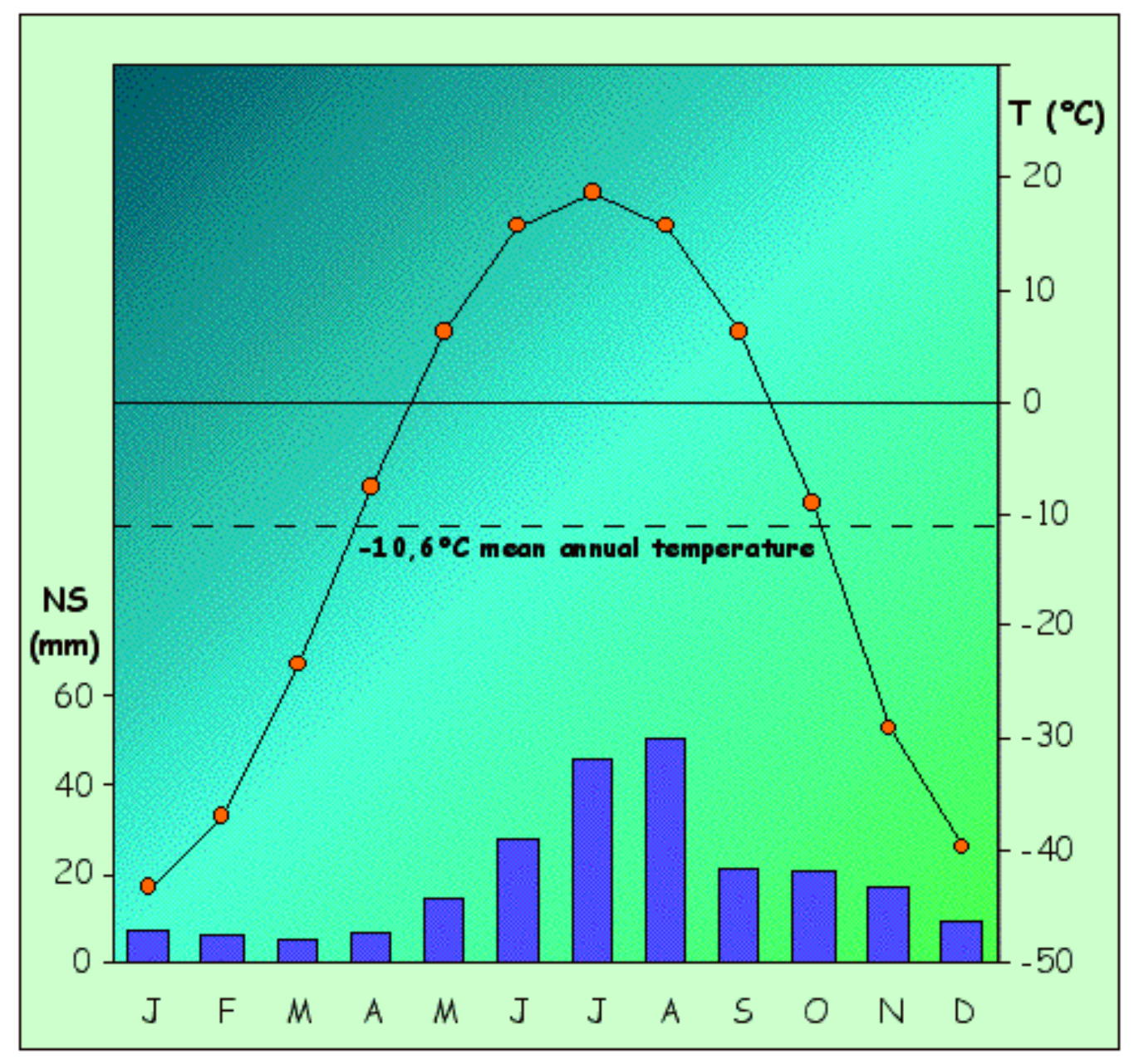
Introduction

Yakutia in northeast Siberia represents a region of extended permafrost landscapes. The extreme continental setting gave rise to the development of deep-reaching permafrost up to 400 m thick in Central Yakutia. The region is rarely influenced by maritime air masses. The strong continental climate is responsible for annual temperature differences of nearly 60°C with absolute extreme values of -64°C in winter and +39°C in summer. The mean annual precipitation amounts to around 200 mm.

Due to a thin snow cover, the ground is completely frozen in winter. Frost cracks, which open during winter, are filled with snow melt in spring. If no kinetic fractionation processes accompany the melting and re-freezing of snow within the frost cracks and if no mixing with surface waters takes place, the isotopic composition in the stored ice veins of permafrost yields a palaeoclimatic signal of winter temperature.

Over hundreds or thousands of years formed, the ice wedges are an useful climate archive in the periglacial and even temporally glaciated region along the southwestern edge of the Verkhoyanks Mountains.



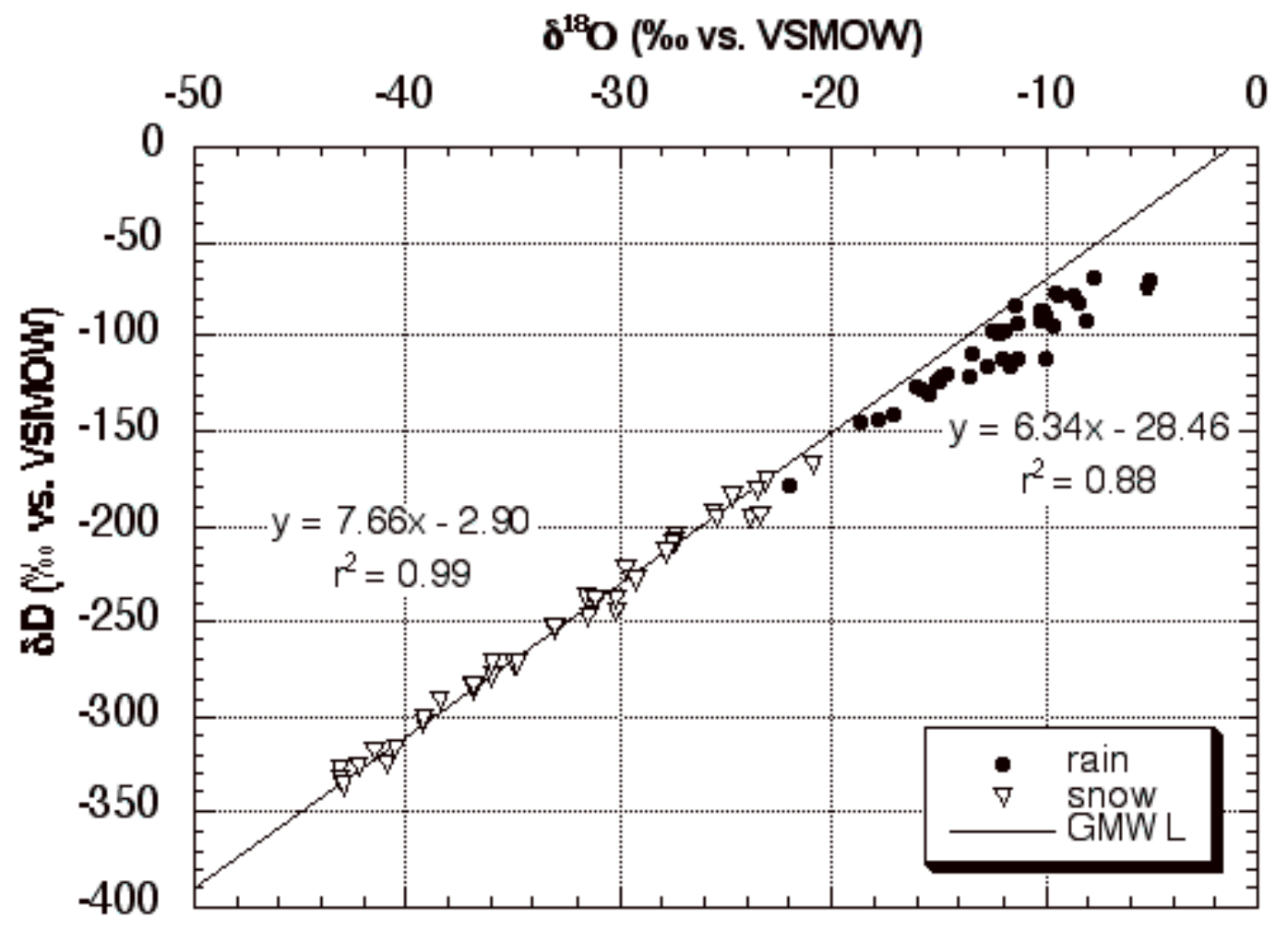
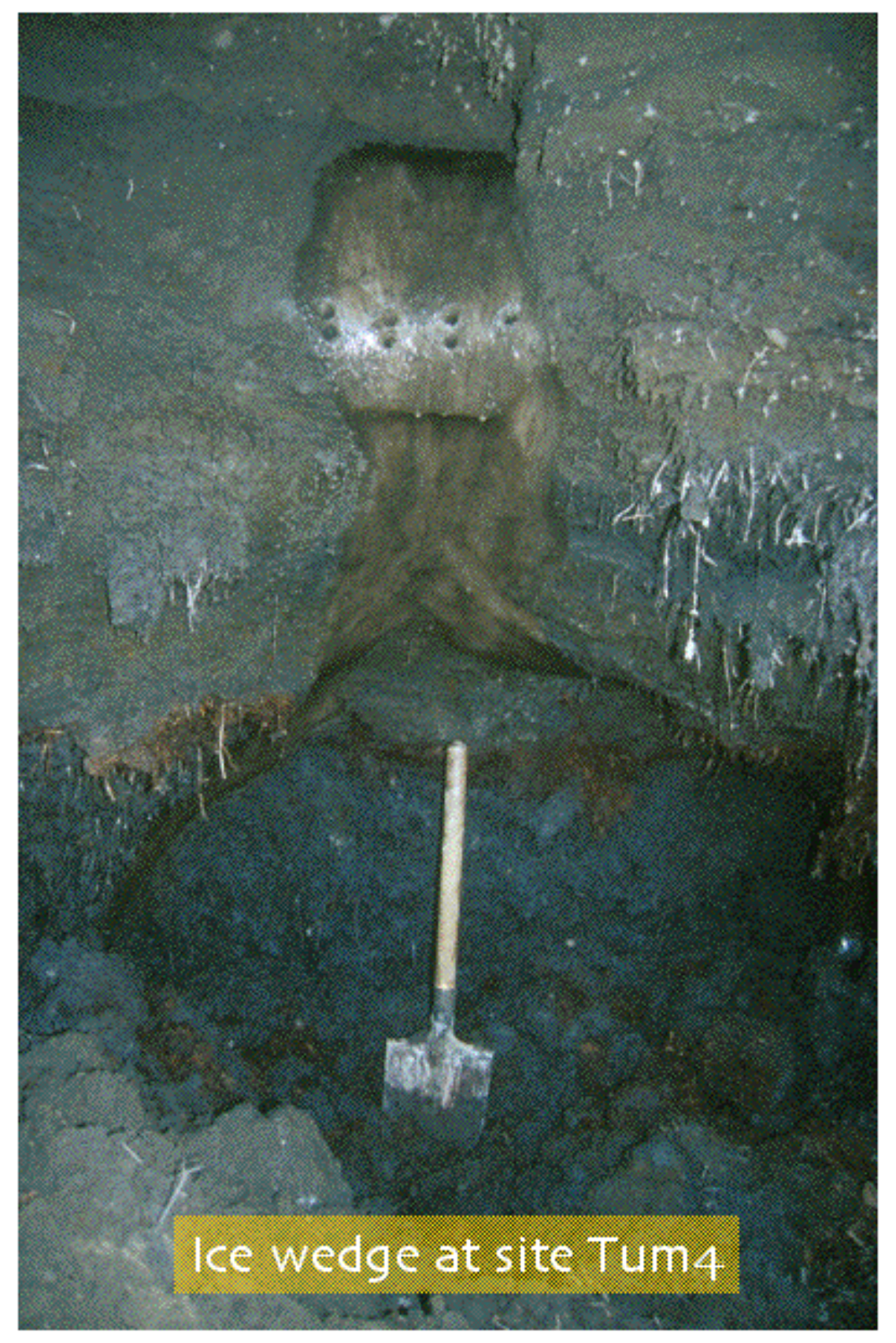


Fig. 1: Mean monthly temperature and precipitation for Yakutsk over a ten-year period (left) and isotopic composition of annual precipitation in Yakutsk for 1997/98 (above).


Ice wedge at site Tum2


Ice wedge at site Tum4

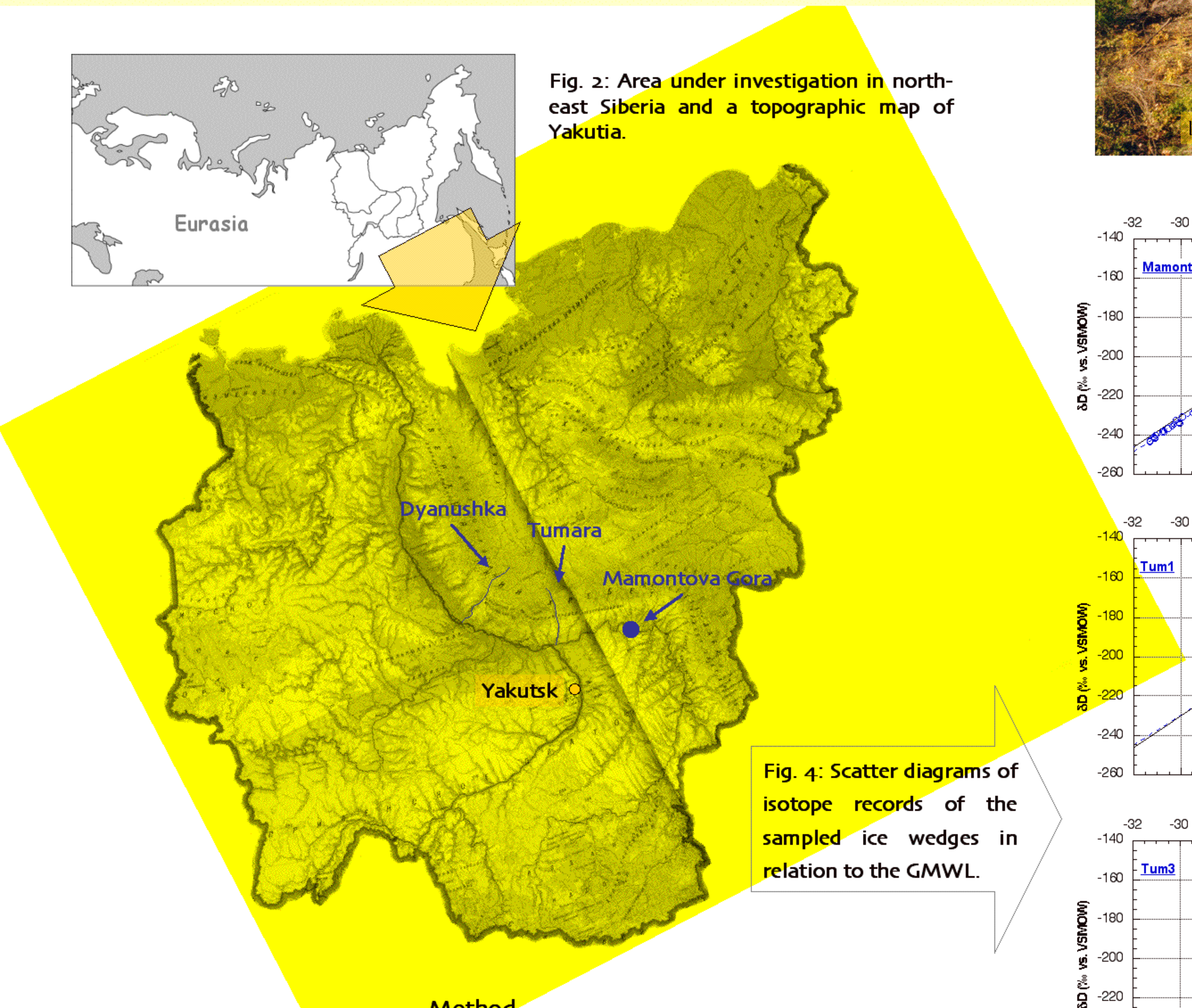


Fig. 2: Area under investigation in northeast Siberia and a topographic map of Yakutia.

Method

Ice wedges have been sampled in vertical and horizontal transects, using an ice screw or chain saw. The isotopic composition was measured with a Finnigan MAT Delta-S mass spectrometer. The results are presented as permil difference to the standard: "Vienna Standard Mean Ocean Water". They are displayed in $\delta^{18}O$-δD scatter diagrams, related to the Global Meteoric Water Line (GMWL). This line delineates the temperature-dependent isotope composition of fresh natural waters, defined as $\delta D = 8\ \delta^{18}O + 10$ ‰ SMOW (Craig 1961). Datapoints along the GMWL reflect the ambient temperature conditions during precipitation. The lighter the isotopic composition of wedge ice, the colder was the precipitation and vice versa.

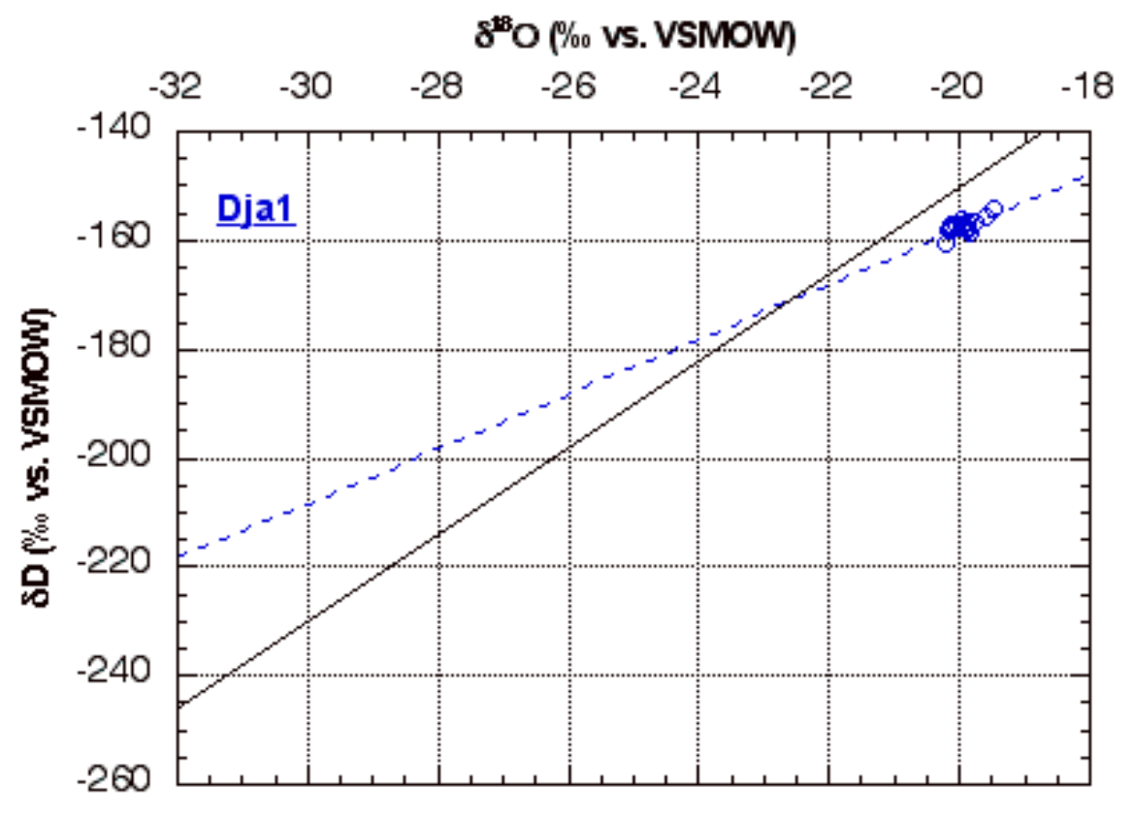


Fig. 3: Scatter diagram of ground ice affected by kinetic fractionation processes.

Kinetic fractionation processes

At site Dja1, kinetic fractionation processes affected the frost crack entering water. We assume, that lake water was the source of wedge ice, subjected to extensive evaporation during summer. That is the reason why the isotopic composition displayed under the GMWL with a low slope und suggests a relatively warm signal.


Ice complex at Mamontova Gora


Ice wedges at site Tum3

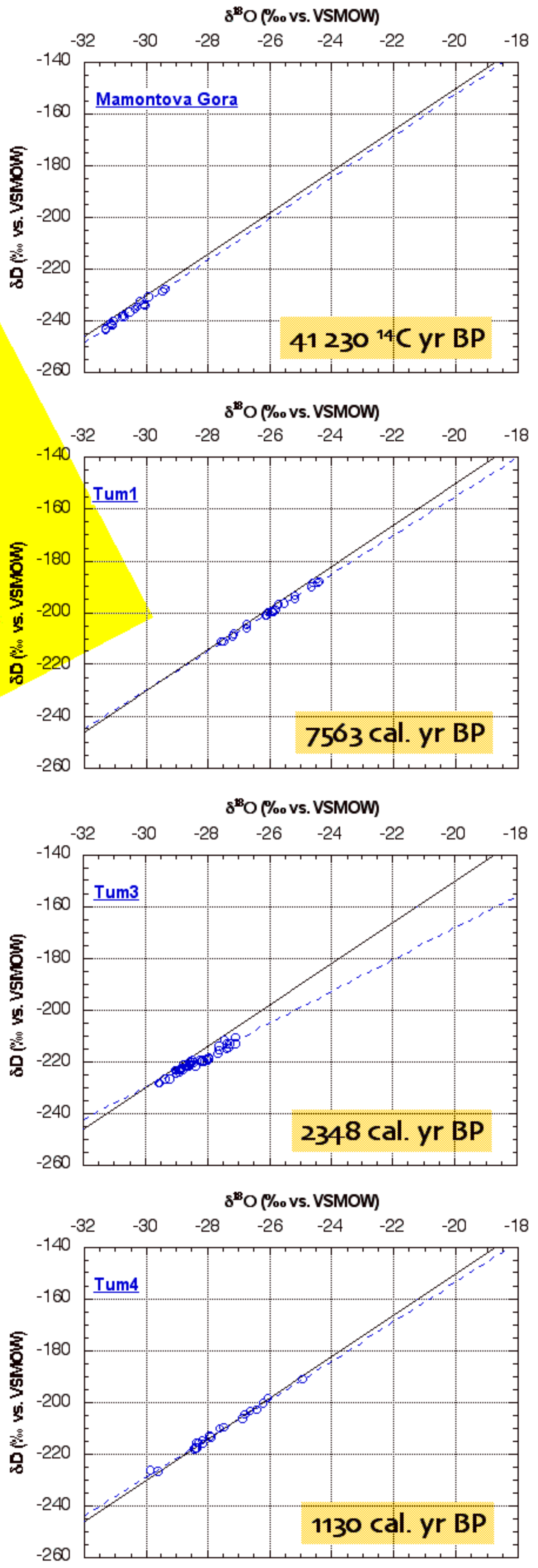


Fig. 4: Scatter diagrams of isotope records of the sampled ice wedges in relation to the GMWL.

Palaeoclimatic Signals

The sampled ice wedges reflect the development of winter conditions during the last 40 000 years. Site Mamontova Gora represents a Pleistocene ice complex with the "coldest" isotope signature. The early Holocene showed a winter climate optimum, as indicated by the isotopic composition of wedge ice site Tum1. The late Holocene, in turn, was characterised by a deterioration of winter conditions in Central Yakutia, indicated by again "lighter" isotopic composition of sites Tum3 and Tum4. Using the relationship between the isotope signal in recent ice veins and present climate data, an estimation of winter palaeotemperatures is possible.

Fig. 5: Relationship between isotopic composition of recent wedge ice and modern climate in northeast Siberia (Meyer, unpublished).

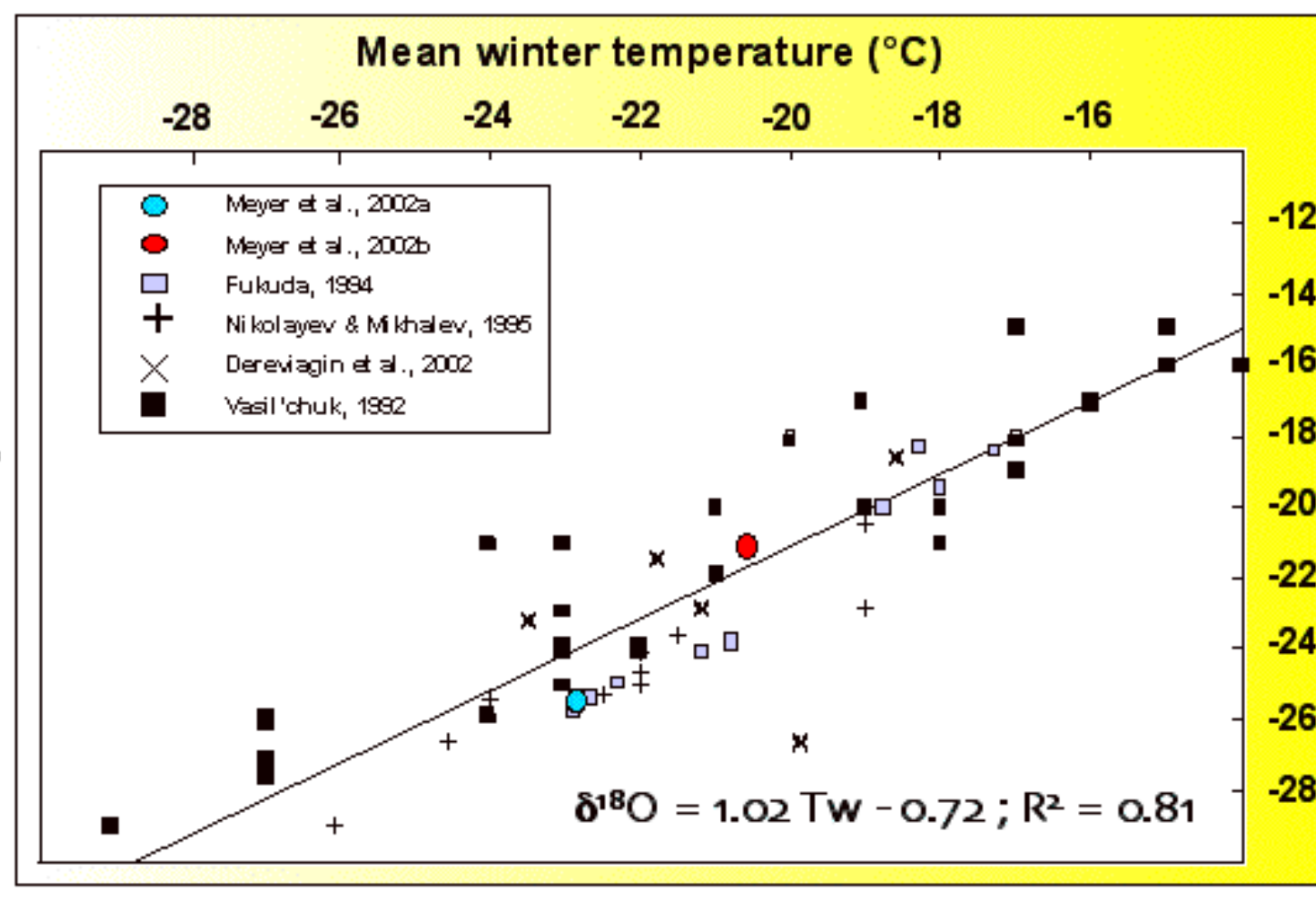
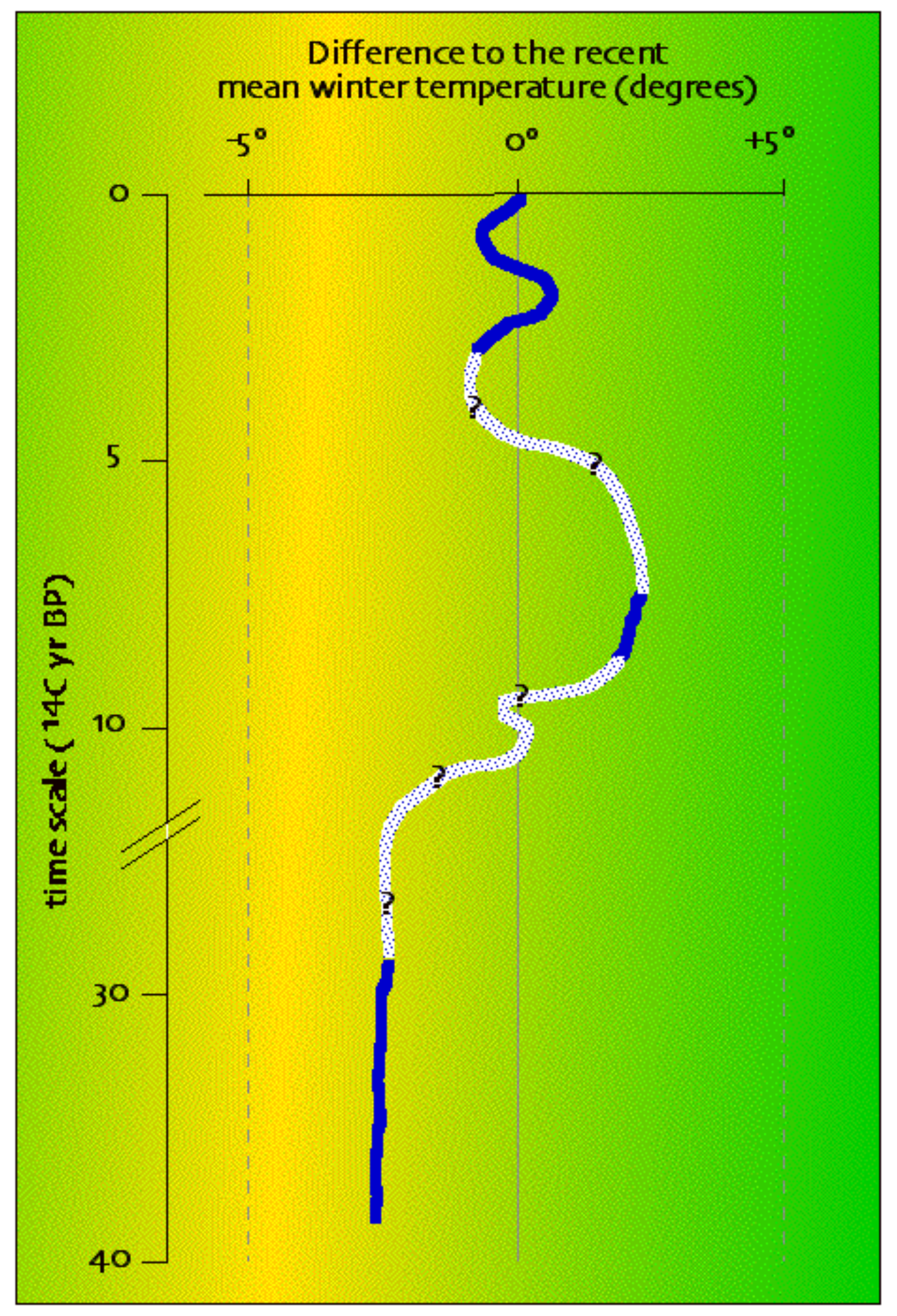


Fig. 6: Preliminary estimation of palaeotemperatures. The dotted line marks the assumed trend according to other proxies, such as pollen records.



Conclusions and Outlook

- ice wedges are useful paleoclimate archives in periglacial regions with no glacier ice
- feeding by winter precipitation, wedge ice reflects the winter conditions of the time of its formation, if kinetic fractionation processes can be excluded
- ice wedges in Central Yakutia showing severe and cold winters during the middle Weichelian period, followed by an early Holocene optimum and late Holocene climate deterioration
- further sampling is necessary to verify and widen the database of isotopic records from this innercontinental region for comparing with adjacent areas