Old Organic Matter in Siberian Permafrost Deposits and its Degradation Features

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Introduction

During the late Quaternary, a large pool of organic matter (OM) accumulated in the arctic permafrost zone. Because of the potential re-introduction into the biogeochemical cycle from degrading permafrost, the OC inventory of ice-rich permafrost deposits and its degradation features are relevant to current concerns about the effects of global warming.

The objectives of this paper are (1) to deduce the quality and quantity of OM stored in the studied sediments and (2) to infer the paleoenvironmental conditions of the source biota. Therefore, standard sedimentological and a molecular marker (biomarker) approach are applied.

Methods

The study site is located on the west coast of the Buor Khaya Peninsula (N 71.6°, E 132.2°, Fig. 1), Yakutia (Russia). In Table 1 the used methods are summarized.

Table 1. Applied methods

Parameter	Analyses and methods
Radiocarbon age	AMS ^{14}C
Grain size	Diffraction Particle Size Analyzer
Bulk density	Gas pycnometer
OM characteristics (TOC, C/N, $\delta^{13}C$)	Element analyses Mass -spectrometry
Isotope signature of ground ice ($\delta^{18}O$, $\delta^{2}H$)	Mass -spectrometry
Biomarkers (brGDGT, archaeol, *n*-alkanes)	HPLC-MS GC-MS
Hydrobiochemistry (Acetate)	Ion chromatography

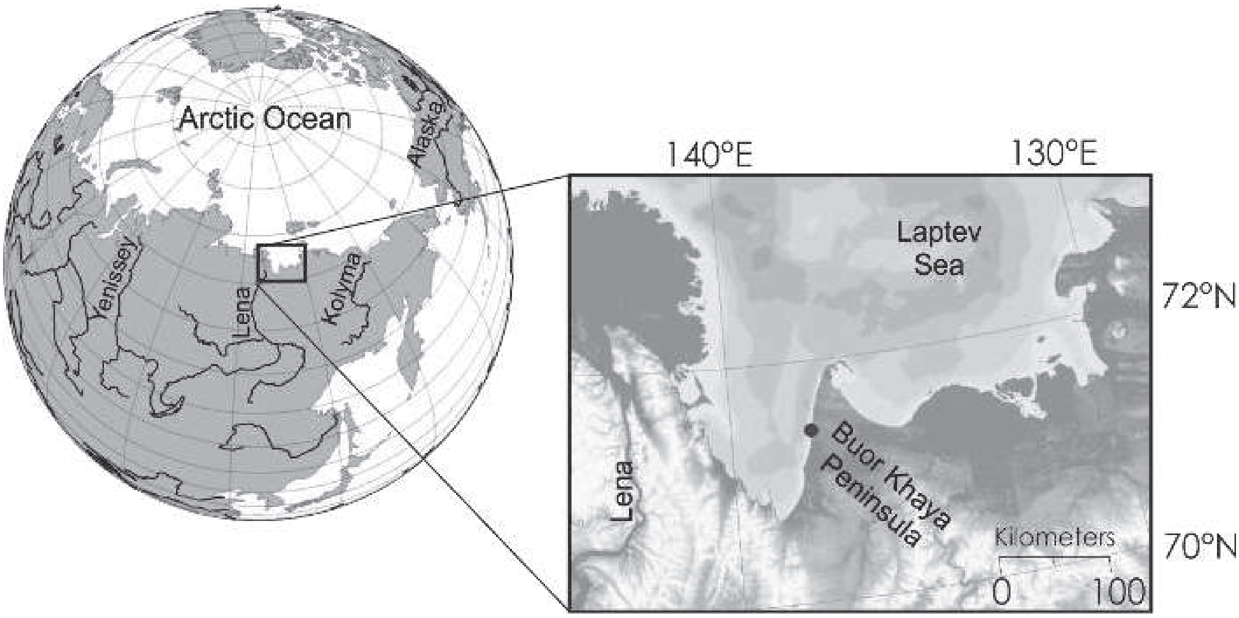

Figure 1. Location of the Buor Khaya Peninsula and the study site

Results and Discussion

Stratigraphically, two sediment units are distinguished. The first unit is composed of late Pleistocene ice-rich permafrost (Yedoma). The second unit consists of Holocene thermokarst deposits. The mean bulk density is ca. 1 $10^3 kg/m^3$. The average total organic carbon (TOC) content is 2.4 wt% for Yedoma, 2.8 wt% for thermokarst deposits. The OM is low degraded (mean C/N 10) for mineral sediments. Hence, the deposits accumulated at relatively fast rates and the OM underwent a short time of decomposition before it was incorporated into permafrost. The volumetric organic carbon contents of the Yedoma and thermokarst deposits are 13 ± 11 kg/m^3 and 22 ± 11 kg/m^3, respectively. This quantity is inside the range of comparable deposits studied by Schirrmeister et al. [*2011*]. $\delta^{13}C$ reveal a terrestrial signal dominated by C3 plants (mean -26.5 ‰).

Ground ice $\delta^{18}O$ and $\delta^{2}H$, average ratios of about -32.46 to 19.59 ‰ and -241.80 to -155.93 ‰, respectively reveal cold temperatures during its formation especially for Yedoma deposits. Ground ice in thermokarst deposits indicate warmer conditions (-20.91 to -18.13 ‰ for $\delta^{18}O$ and -162.16 to -148.56‰ for $\delta^{2}H$) compared to Yedoma, but at the lower part Yedoma reflects a remarkably warm isotope signal of –-22.26 to – -20.44 ‰.

Using branched bacterial glycerol dialkyl glycerol tetraethers (brGDGT) as fossil biomarker according to Wejers et al., [*2007*], estimations of absolute temperatures are possible. Negative brGDGT temperatures reveal feasible results for permafrost. A contradictory fact is that Holocene thermokarst deposits reveals the lowest brGDGT temperatures (-7 °C thermokarst deposits average).

Originating from methanotrophic microorganisms, archaeal lipids like archaeol can be used as a proxy for methanotroph communities. The concentration suggests a response of archaeal communities to temperature and humidity changes in the past [*Pancost et al. 2011*]. The higher archaeol content in the thermokarst deposits (156.76 ng/g sediment) indicates larger archaeal communities, which is related to a drier and warmer climate.

The *n*-alkane proxies (compound preference index (CPI) and average chain length (ACL)) reveal a low microbial degradation (mean CPI 11) and as source higher (vascular) land plants (mean ACL 28). The source proxy for waxy hydrocarbons (P_{wax}) shows values >0.7, which is interpreted as a high input of higher land plants.

The occurrence of acetate >1 mg/l, which is an ideal substrate for microorganisms, indicates minor degradation in the permafrost and that the sediments were frozen very quickly.

Conclusions

OM parameters such as the total amount of organic carbon and the C/N ratio and acetate concentrations indicate labile carbon. The studied deposits contain a significant carbon pool of 13 ± 11 kg/m³ (Yedoma) and 22 ± 11 kg/m³ (thermokarst). Moreover, biomarker *n*-alkane proxies reveal a higher land plant source signal and a minor degradation state of the OM.

Stable water isotopes of ground ice and archaeol concentration reveal cold climate during the late Pleistocene and a comparatively warmer temperature during the Holocene. The biomarker temperature is a promising tool and could be a supplement to the temperature signals inferred from water isotopes, but our data illustrates that the absolute GDGT temperature interpretation is not appropriate for the studied deeper sediments.

References

Pancost, R.D., E.L. McClymont, E.M. Bringham, Z. Roberts, D.J. Charman, E.R.C. Hornibrook, A. Blundell, F.M. Chambers, K.L.H. Lim, R.P. Evershed, 2011. Archeol as a methanogen biomarker in ombrotrophic bogs. Organic Geochemistry, 42, 1279-1287

Schirrmeister, L., Grosse, G., Wetterich, S., Overduin, P.P., Strauss, J., Schuur, E.A.G., Hubberten, H.-W., 2011. Fossil organic matter characteristics in permafrost sequences of the Northeast Siberian Arctic. Journal of Geophysical Research – Biogeosciences, 116, G00M02.

Weijers, J. W. H., S. Schouten, J. C. v. d. Donker, Ellen C. Hopmans, J. S. S. Damste, 2007. Environmental controls on bacterial tetraether membrane lipid distribution in soils. Geochimica et Cosmochimica Acta, 71, 703-713.