Fossil Organic Matter in Arctic Permafrost

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Introduction

- Since 1998, northeast Siberian permafrost sequences have been analyzed as frozen paleoenvironmental archives of the last about 200,000 years in the context of the joint Russian-German science cooperation “SYSTEM LAPTEV SEA”. Organic matter (OM) properties were used as an important paleo proxy.
- This study summarizes regional datasets on the quality and quantity of fossil OM in permafrost sequences of NE Siberia, in order to show the permafrost carbon pool heterogeneity related to paleoenvironmental dynamics, and the improved estimation of permafrost organic carbon stocks.
- OM distribution in the upper permafrost zone up to 100 m depth in the Northeastern Siberian Arctic indicates considerable variability of OM between different stratigraphical units, between the same stratigraphical unit at different study sites, and even within stratigraphic units at the same site.

Study sites

Western Laptev Sea:
(1) Cape Mamontov Klyk

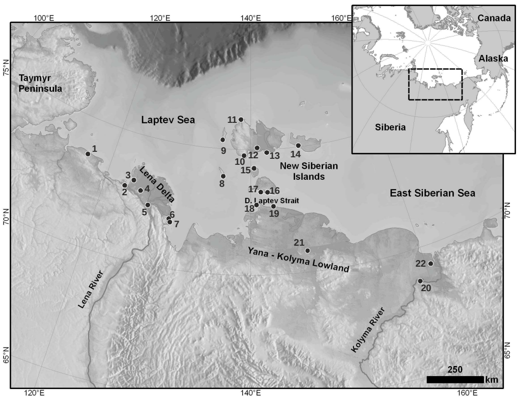
Lena Delta:
(2) Turakh Sise Island, (3) Ebe Sise Island (Nagym), (4) Khardang Island, (5) Kurungnakh Sise Island

Central Laptev Sea:
(6) Bykovsky Peninsula, (7) Muostakh Island

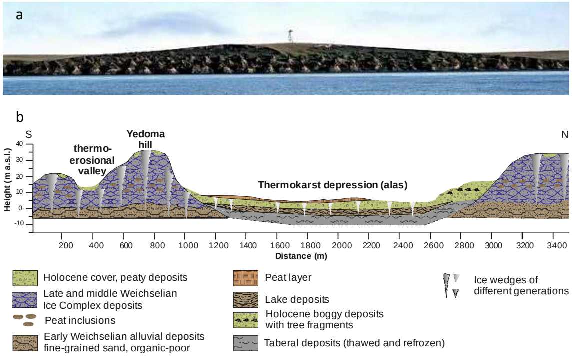
New Siberian Archipelago:
(8) Stolbovoy Island, (9) Bel’kovsky Island, (10) Kotel’ny Island (Cape Anisii), (11) Kotel’ny Island (Khomurganakh River), (12) Bunge Land (low terrace), (13) Bunge Land (high terrace), (14) Novaya Sibir Island, (15) Maly Lyakhovsky Island

Dmitry Laptev Strait:
(16) Bol’shoy Lyakhovsky Island (Vankina river mouth), (17) Bol’shoy Lyakhovsky Island (Zimov’e river mouth), (18) Cape Svyatoy Nos, (19) Oyogos Yar coast

Indigirka-Kolyma lowland:
(20) Kytalyk (Berelekh R.), (21) Pokhodsk (Kolyma Delta) (23) Duvanny Yar (Lower Kolyma R.).



Study sites of permafrost archives in NE Siberia with data sets of fossil OM



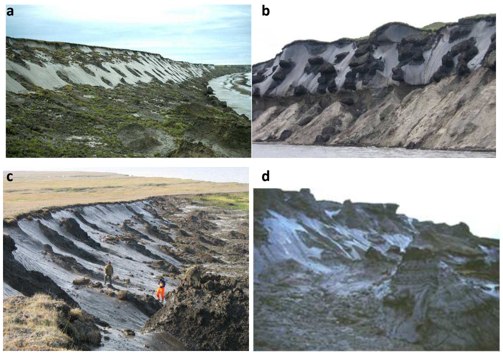
Exemplary costal cross section of permafrost sequences at the Mamontovy Khayata site (Bykovsky Peninsula, site no 6); a –Yedoma costal segment; b – Generalized stratigrafic scheme.

Methods

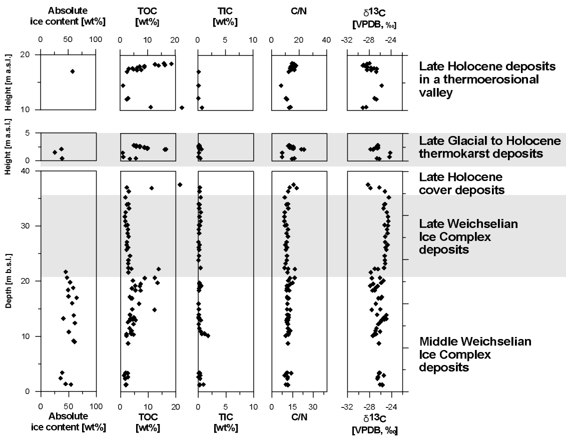
Ice content – gravimetrically measured
→ Ice-rich (>50 %), ice-bearing (25-50 %), ice-poor (< 25%)
→ Syncryogenic formation, thawing & refreezing (taberite)
→ Total mass balance calculation, bulk density estimation

TC, TN, TOC - CNS analyzer (Elementar Vario EL III)
TOC → Variations in OM accumulation and degradation
TOC/TN → Decomposition degree, microbial activities
→ Low ratios: strongly decomposed;
high ratios: less decomposed
TC-TOC → TIC; inorganic carbon (e.g. fossil shells)

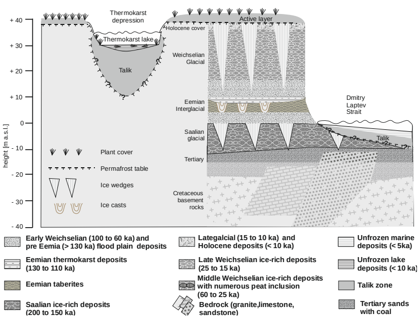
$\delta^{13}C$ (TOC) - Finnigan DELTA S mass spectrometer
→ OM origin (marine, terrestrial: subaerial/aquatic)
→ Composition of plant material
→ Isotopic fractionation during carbon metabolism
→ Decomposition degree (low $\delta^{13}C$ less, high $\delta^{13}C$ strong)



Exposure examples from different study sites: a - Cape Mamontov Klyk (1) Western Laptev Sea, b – Kurungnakh Island (5) Lena delta, c - Oyogos Yar coast (19) Dmitry Laptev Strait, d - Stolbovoy Island (8) New Siberian Archipelago



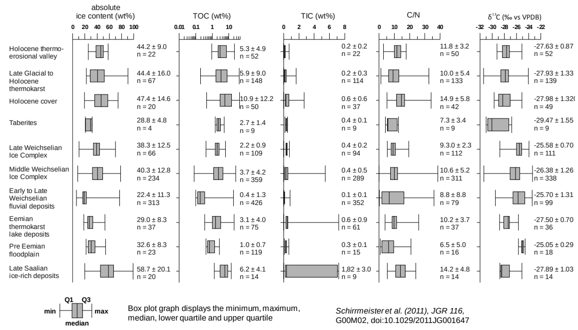
Compilation of ice content and OM signatures at the Mamontovy Khayata site showing the heterogeneity permafrost profiles according to stratigraphic units



General scheme of the stratigraphical segments of the permafrost zone, and several components of arctic periglacial landscapes

Stratigraphical Units	Ice Content [wt%]	Bulk Density [g cm^{-3}],	Total organic carbon [wt%],	Carbon inventory [kg C m^{-3}]	SD
Holocene thermo-erosional valley	44.2 ± 9.0	0.781	5.3 ± 4.9	**41.42**	40.87
Holocene thermokarst	44.4 ± 16.0	0.775	6.9 ± 9.0	**53.51**	77.22
Holocene cover	47.4 ± 14.5	0.686	10.9 ± 12.9	**74.73**	96.26
Taberites	28.8 ± 4.8	1.242	2.7 ± 1.4	**33.55**	17.82
Late Weichselian Ice Complex	38.3 ± 12.5	0.958	2.2 ± 0.9	**21.08**	11.92
Middle Weichselian Ice Complex	40.5 ± 12.8	0.892	3.7 ± 4.1	**33.23**	40.07
Early to Middle Weichselian fluvial deposits	22.4 ± 11.3	1.434	0.5 ± 1.4	**7.17**	18.72
Eemian lake deposits	29 ± 8.3	1.236	3.2 ± 4.2	**39.57**	50.10
Pre Eemian floodplain	32.6 ± 8.3	1.129	1.0 ± 0.8	**11.29**	8.28
Saalian Ice Complex	58.7 ±20.1	0.347	5.3 ± 4.3	**18.41**	34.93

Carbon inventory estimates



Stratigraphical classification of permafrost deposits by organic matter signatures

Conclusion

- Carbon contents, OM qualities and decomposition degrees are highly variable and connected to changing palaeo-environmental conditions
  - Interglacial & interstadial periods: High TOC contents, high C/N, low $\delta^{13}C$ -> less-decomposed OM accumulated under wet, anaerobic soil conditions
  - Glacial & stadial periods: Less variable, low TOC, low C/N, high $\delta^{13}C$ values indicating stable environments with reduced bioproductivity and stronger OM decomposition under dryer, aerobic soil conditions.
- OM release to the ocean, to lakes and rivers and to the atmosphere due to permafrost degradation (e.g. thermokarst, thermal erosions, coastal erosion) and microbial decomposition
- The landscape average is likely about 30 % lower than previously published permafrost carbon inventories.
- Still large uncertainties in carbon estimations/calculations
  - Detailed mapping of permafrost deposits especially of Ice Complex (Yedoma-type) and thermokarst deposits (Alas-type), their distribution and thickness are essential and in progress
  - Analyses of OM available for decomposition are necessary