Quality and Distribution of Frozen Organic Matter (Old, Deep, Fossil Carbon) in Siberian Permafrost

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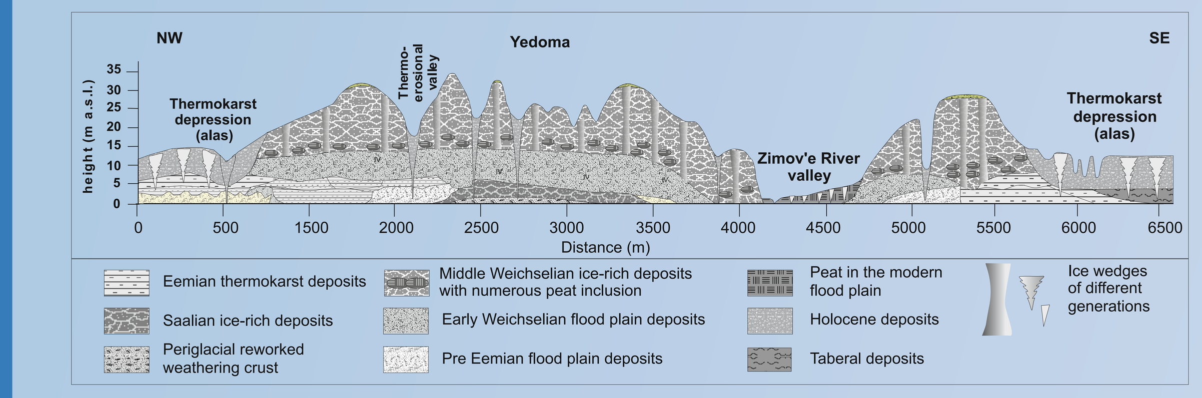
Introduction

- Since 1998, northeast Siberian permafrost sequences have been analyzed as frozen paleoenvironmental archives of the last ~200,000 years (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:
  - → to show the permafrost carbon pool heterogeneity related to paleoenvironmental dynamics, and
  - → to improved estimations 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 same stratigraphical units at different study sites, and even within stratigraphic units at the same site.



Scheme of stratigraphical units from Bolshoy Lyakhovsky Island (site 17), Dmitry Laptev Strait

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)

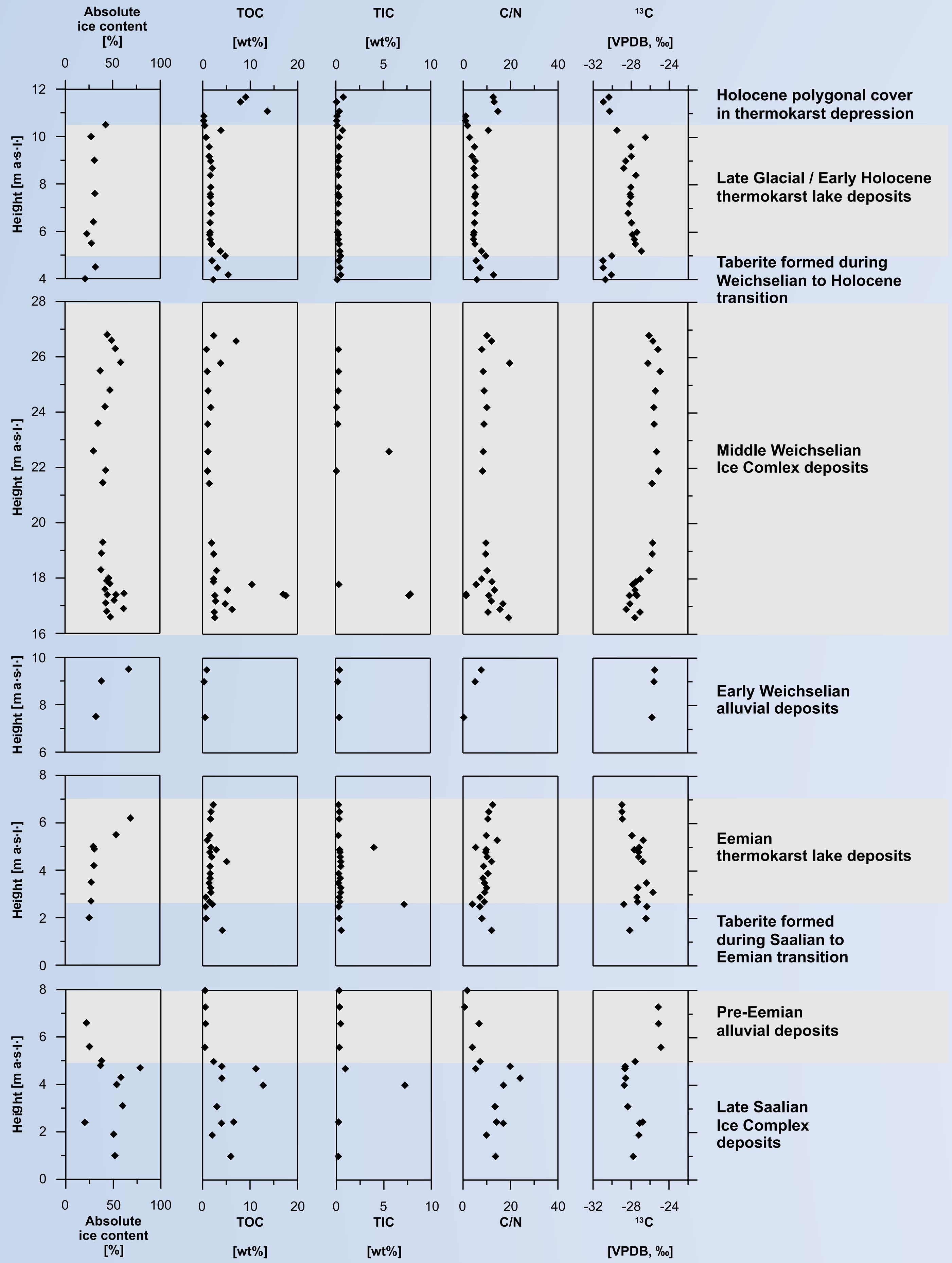
TOC → Variations in OM accumulation and degradation
TOC/TN → Decomposition degree, microbial activities
→ Low ratios: strongly decomposed;
high ratios: less decomposed
TC-TOC → TIC; inorganic carbon (e.g. fossil shells)

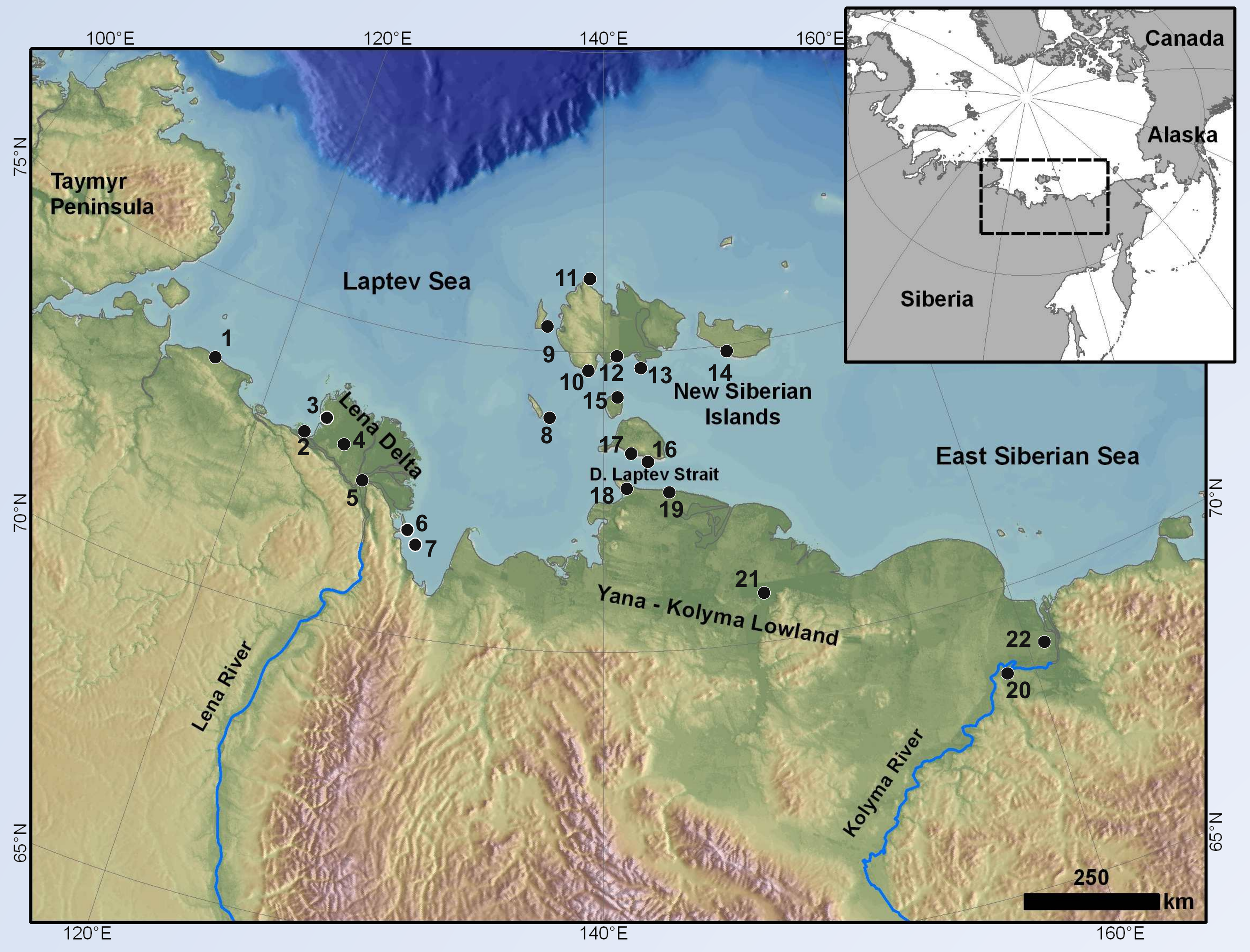
$\delta^{13}C$ (TOC) - Finnigan DELTA S mass spectrometer

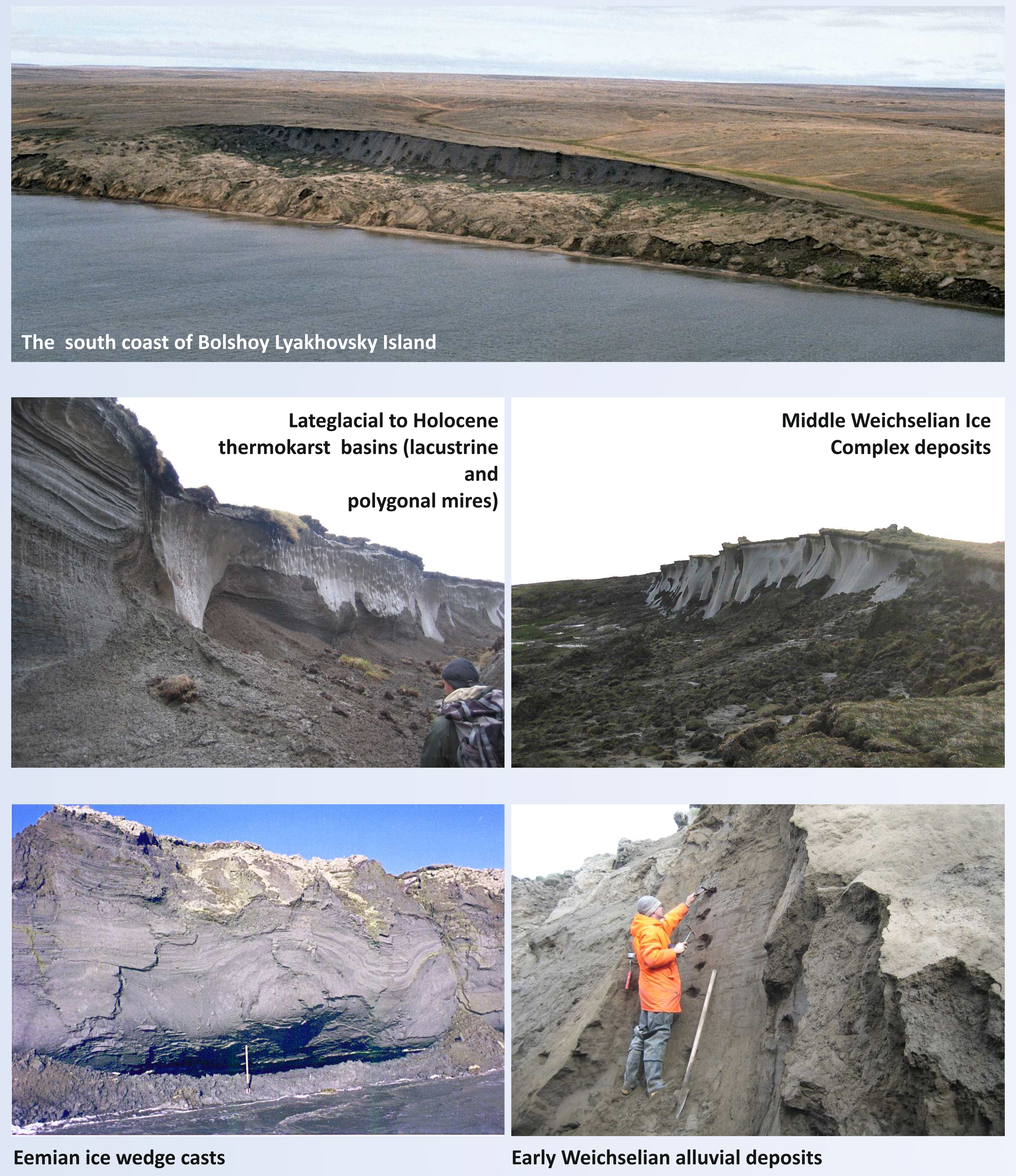
→ OM origin (marine, terrestrial; subaerial/aquatic)
→ Composition of plant material
→ Isotopic fractionation during carbon metabolism
→ Decomposition degree (low $\delta^{13}C$ less, high $\delta^{13}C$ strong)

Reference

Schirrmeister, L., G. Grosse, S. Wetterich, P. P. Overduin, J. Strauss, E. A. G. Schuur, and H.-W. Hubberten (2011), Fossil organic matter characteristics in permafrost deposits of the northeast Siberian Arctic, J. Geophys. Res. 116, G00M02, doi:10.1029/2011JG001647



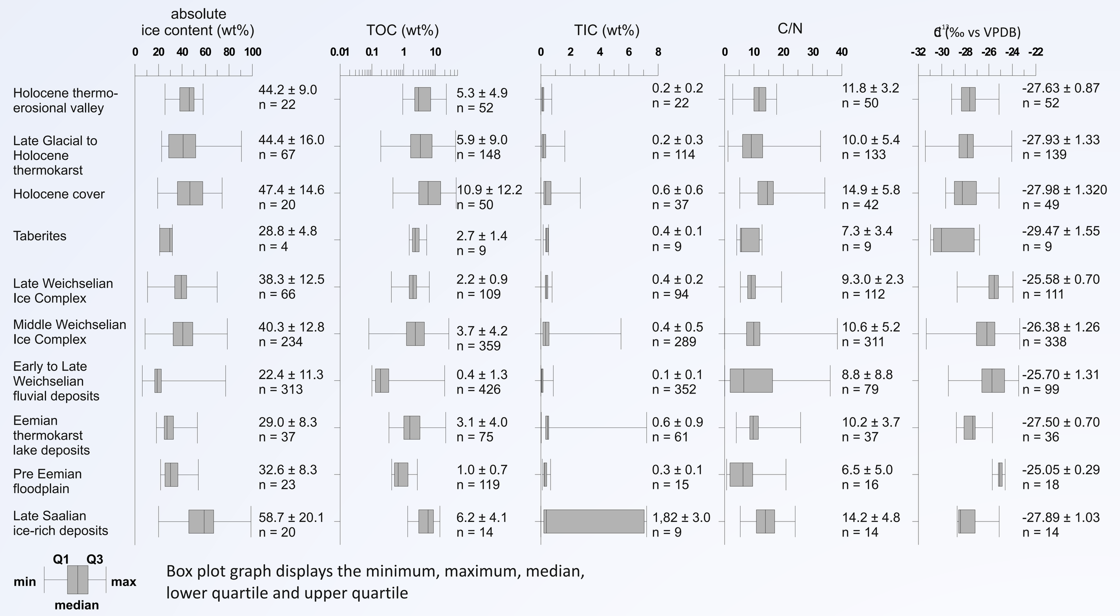




Studied section of different stratigraphical units from Bolshoy Lyakhovsky Island (site 16), Dmitry Laptev Strait

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

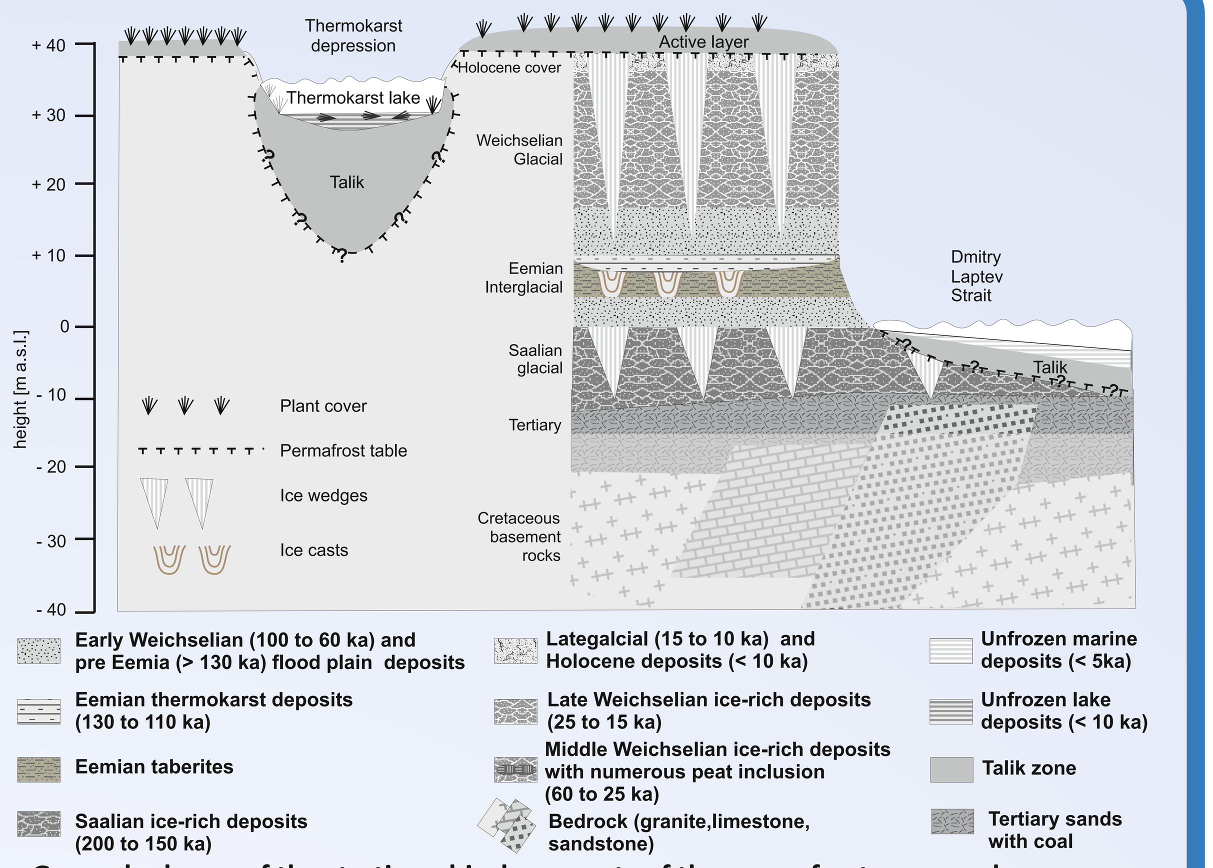
Western Laptev Sea:
(1) Cape Mamontov Klyk
Lena Delta:
(2) Turakh Sise Island, (3) Ebe Sise Island (Nagym), (4) Khardang Island, (5) Kurungnakh Sise Island
Central Laptev Sea:
(6) Bykovsky Peninsula, (7) Muostakh Island
New Siberian Archipelago:
(8) Stolbovoy Island, (9) Bel'kovsky Island, (10) Kotel'ny 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) Duvanny Yar (Lower Kolyma R.).
(21) Kytalyk (Berelekh R.), (22) Pokhodsk (Kolyma Delta)



Stratigraphical classification of permafrost deposits by organic matter signatures, Schirrmeister et al. (2011)

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



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

Conclusion

- Carbon contents, OM qualities and decomposition degrees are highly variable and connected to changing paleoenvironmental 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 → stable environments with reduced bioproductivity and stronger OM decomposition under dryer, aerobic soil conditions.
- OM release to the ocean, lakes, rivers and the atmosphere due to permafrost degradation (e.g. thermokarst, thermal erosion, 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 for OM pool estimation.
  - → Measurements and estimations on OM available for decomposition are necessary.