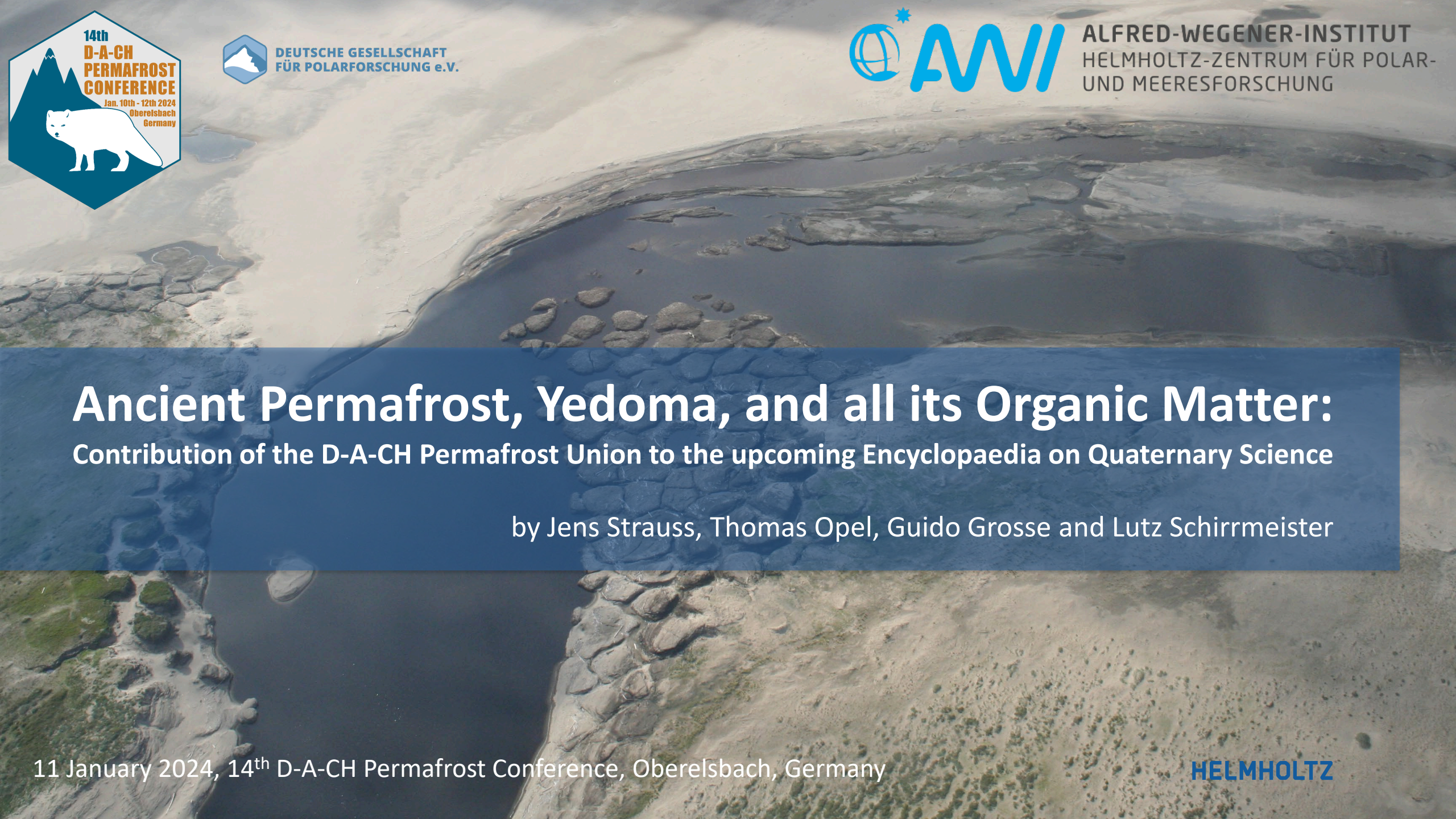


Ancient Permafrost, Yedoma, and all its Organic Matter:

Contribution of the D-A-CH Permafrost Union to the upcoming Encyclopaedia on Quaternary Science

by Jens Strauss, Thomas Opel, Guido Grosse and Lutz Schirrmeister

11 January 2024, 14th D-A-CH Permafrost Conference, Oberelsbach, Germany

HELMHOLTZ

Introduction

- In late 2024/2025 there is a 3rd volume of the Encyclopaedia of Quaternary Science planned

- Besides various topics on Quaternary Science there are 24 chapters on ‘Permafrost and Periglacial Features’, and three of those are led by authors from the D-A-CH Permafrost Community.

Permafrost and Periglacial Features (coordinated by J. Murton)
01800. Introduction
01801. Permafrost
01802. Active-layer processes
01803. Paraglacial geomorphology
01804. Slope deposits and forms
01805. Frost mounds: active and relict forms
01806. Patterned ground
01807. Talus slopes
01808. Thermokarst topography
01809. Ice wedges and related features
01810. Cryoturbation structures
01811. Blockfields (felsenmeer)
01812. Block/rock streams
01813. Rock weathering
01814. Rock glaciers and protalus forms
01815. Periglacial fluvial sediments and forms
01816. Permafrost and glacier interactions
01817. Yedoma: Late Pleistocene ice-rich syngenetic permafrost of Beringia
01818. Past permafrost and ancient permafrost
01819. Periglacial aeolian and niveo-aeolian features
01820. Dry valleys
01821. Bedrock disturbances
01822. Nivation features, cryoplanation terraces and cryopediments
01823. Organic matter storage and vulnerability in the permafrost domain
01824. Cryogenic cave calcites

AWI

HELMHOLTZ

Ancient + past permafrost

- **Relict permafrost**
  Permafrost **not in equilibrium** with modern climate → relict of past colder climate (includes submarine permafrost)

- **Ancient permafrost**

  Permafrost that has persisted at a locality since the Pleistocene or earlier and is still present

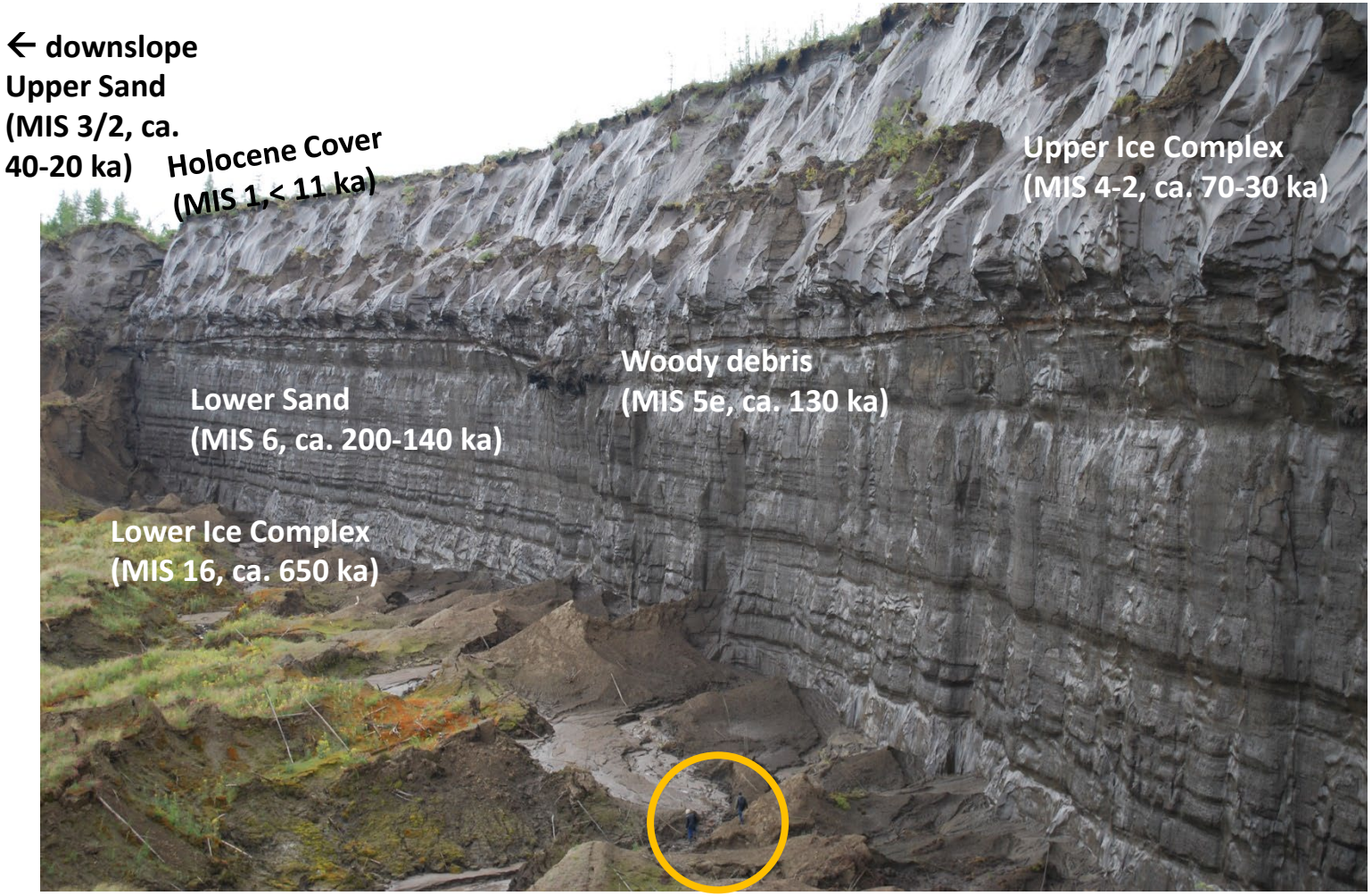
  - Antarctica: ca. 15 Ma
  - Klondike (Yukon/Canada): ca. 740 ka
    Batagay (East Siberia): ca. 650 ka

- **Past Permafrost**
  Permafrost of late Pleistocene (i.e. > Marine Isotope Stage (MIS) 2) or older origin that no longer exists at a particular locality

  - Klondike (Yukon/Canada): 3 Ma, Alaska: 2 Ma, Siberia: not well dated

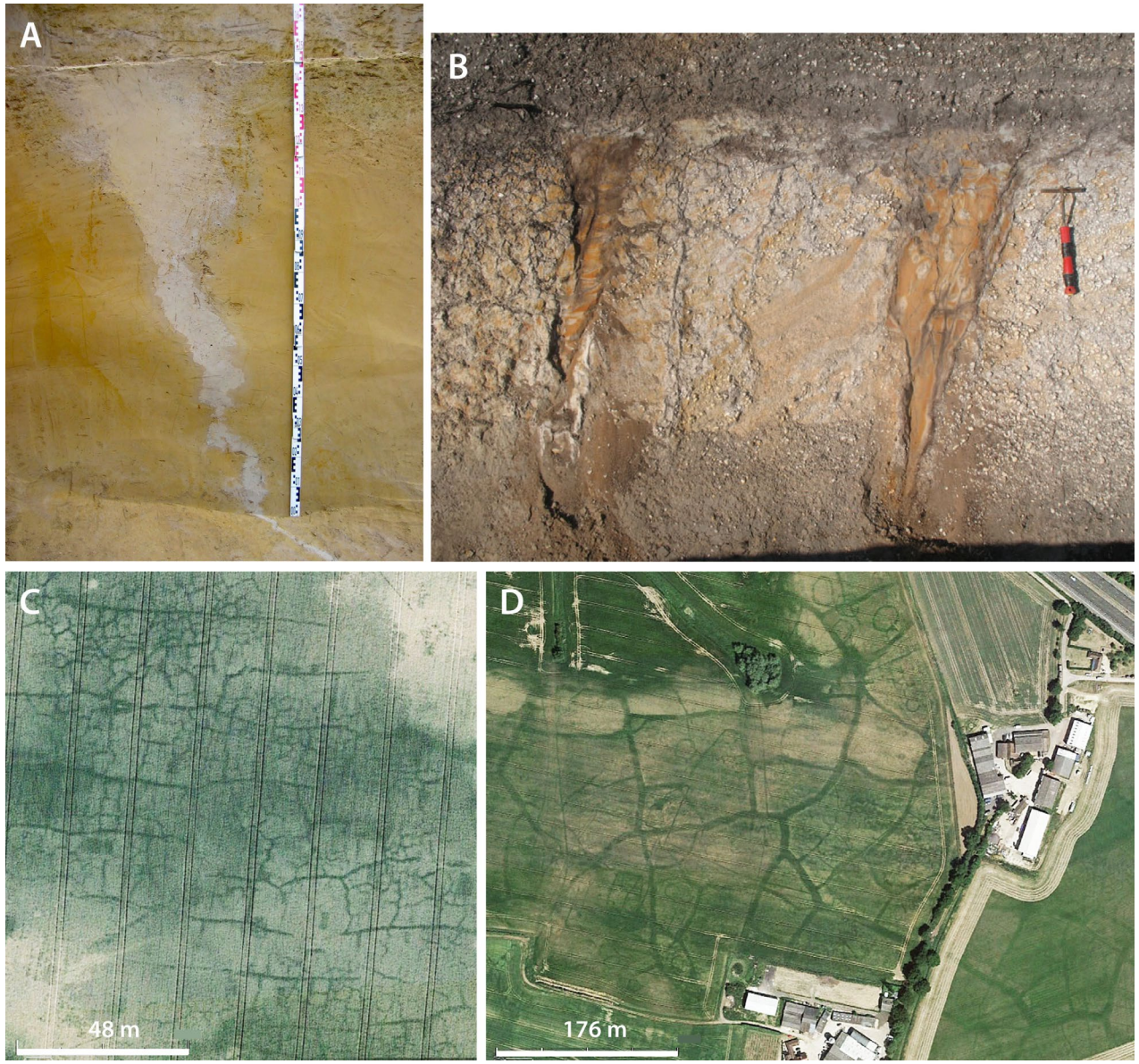
Ancient + past permafrost

Batagay Megaslump in East Siberia – a prime example of ancient permafrost and past permafrost dynamics in response to climate variations



- Permafrost degradation in Late Glacial
- Ice-rich/ ice poor permafrost formation from MIS 4 to MIS 2
- Permafrost degradation in MIS 5e (Eemian)
- Ice-poor permafrost formation in MIS 6
- Permafrost degradation at some time between MIS 16 and 6
- Ice-rich permafrost formation in MIS 16

Past permafrost



Indications of past (Last glacial period) permafrost in Europe

View of sedimentary structures and landforms indicative of past permafrost.
A - ice wedge pseudomorph in Last Glacial loess, Curgies, France; the scale is 1.6 m (photo J.L. Locht);
B - sand wedges in alluvial sand and gravel, Salaunes, France; the tool is 0.38 m long;
C - subdivided orthogonal polygons, Dziewa, Poland (Google Earth);
D - large mixed polygons, Great Milton, UK (Google Earth). Compiled by Pascal Bertran

Summary ancient + past permafrost

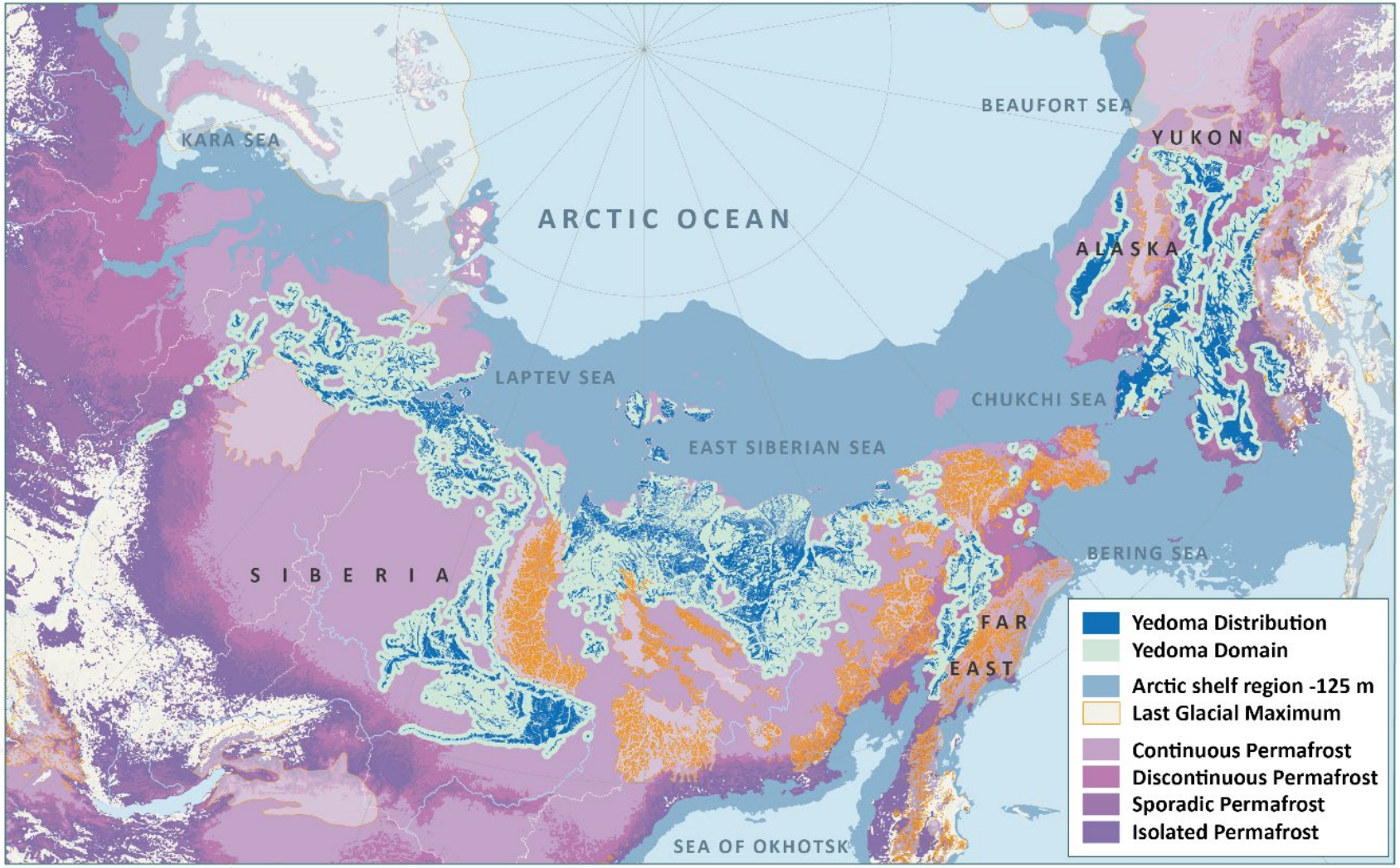
- Ancient and past permafrost are **valuable paleoclimate archives** and can inform about the **response of permafrost to climate variations**, i.e. about permafrost formation, stability or degradation

- Ancient and past permafrost can be used to derive **climatic thresholds for long-term large-scale permafrost dynamics**, considering
  - **Seasonality** of temperature and precipitation
  - **Continentality** (distance to oceanic moisture and vast ice sheets)
  - Local **vegetation** cover, **hydrology**, and **disturbances**

- **Ancient permafrost may survive interglacials** warmer (MIS5e) or longer (MIS 11) than the Holocene and may provide insights into the future of permafrost under anthropogenic warming conditions

Yedoma permafrost

Distribution of Yedoma

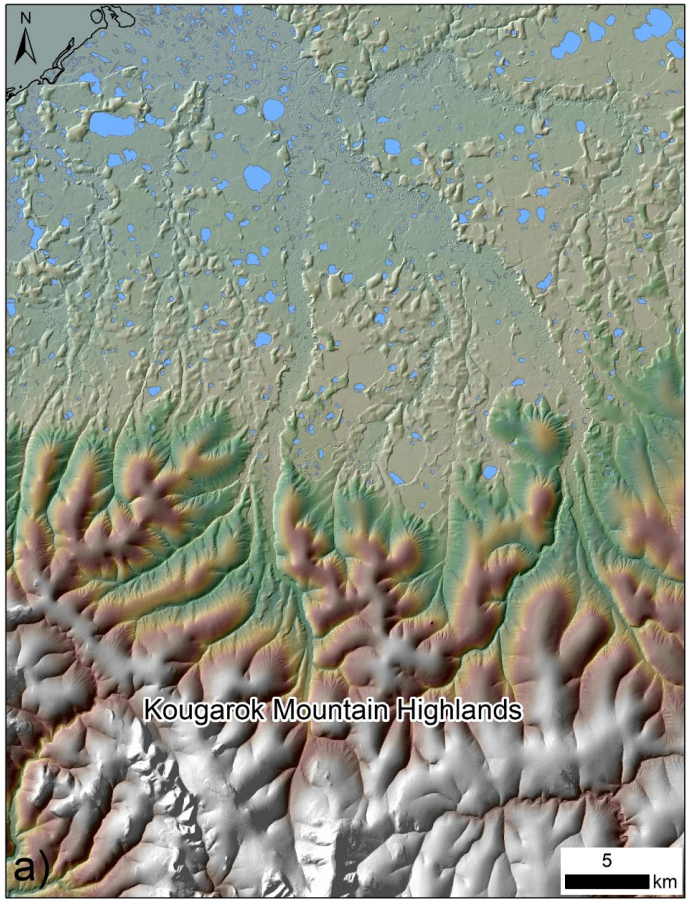


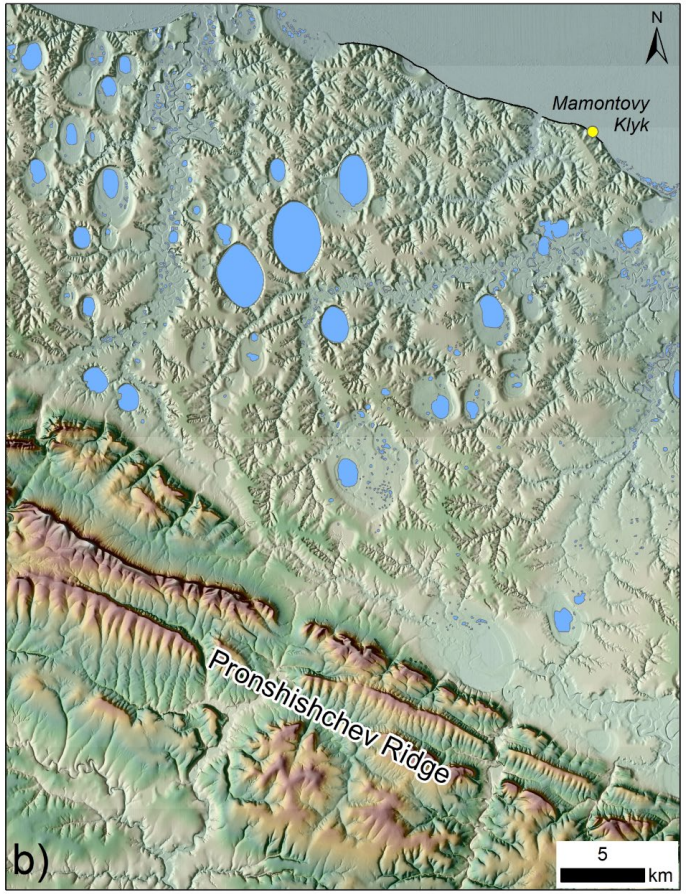
Distribution of Yedoma Ice Complex deposits and the Yedoma Domain in the Siberian and North American Arctic and Subarctic

Yedoma – 3 levels of meaning

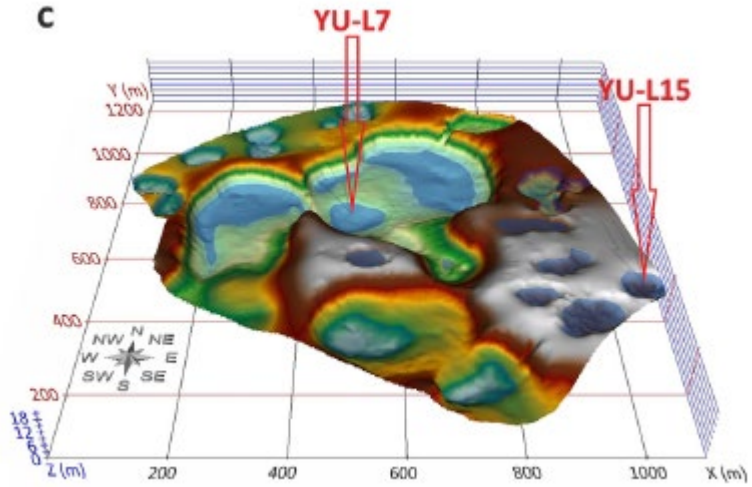
1st: Yedoma surface

- in the geomorphic sense, describing hills separated by thermokarst depressions





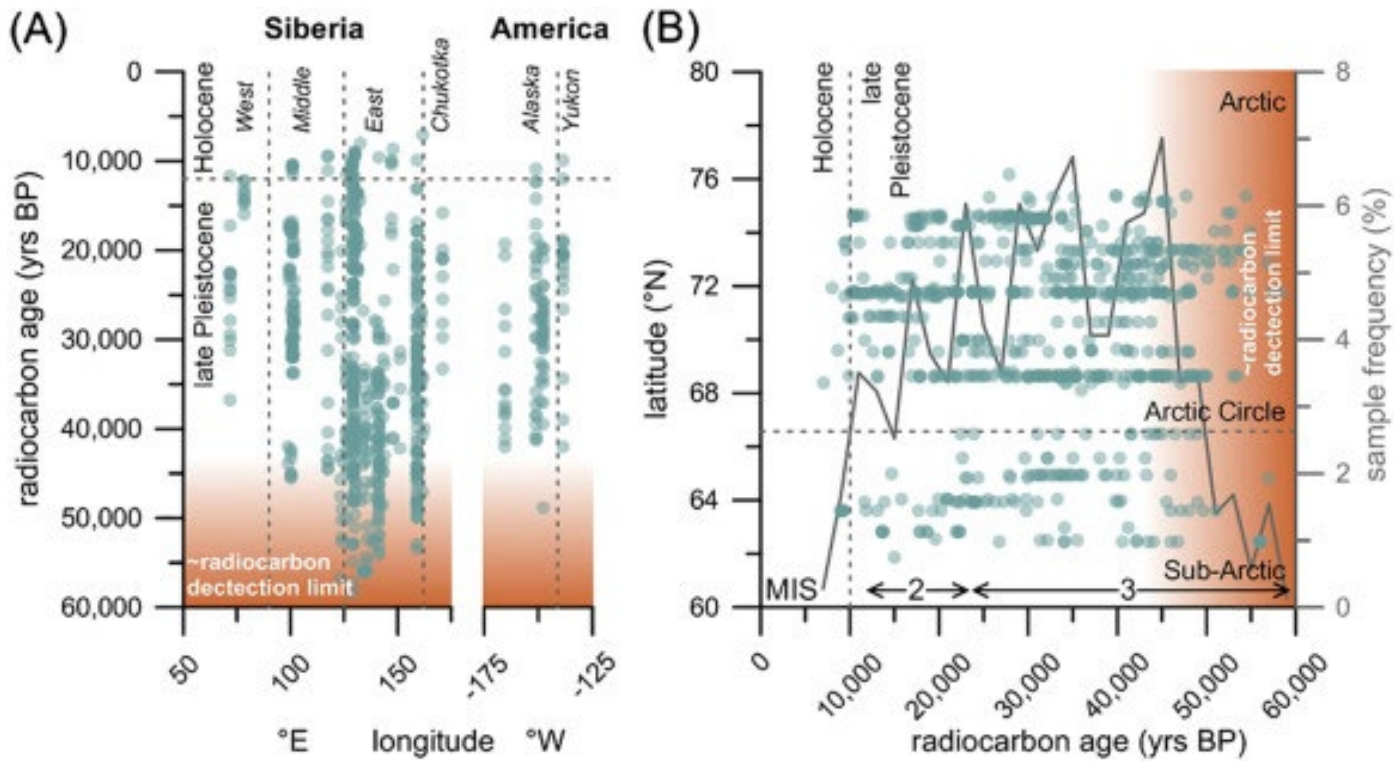
Schirrmeister et al., draft for Encyclopedia



Ulrich et al. et al, 2021

2nd: Yedoma Suite

- in the stratigraphic sense; radiocarbon dates suggest that much of the Yedoma sequences are formed during the MIS 4 to 2 stages

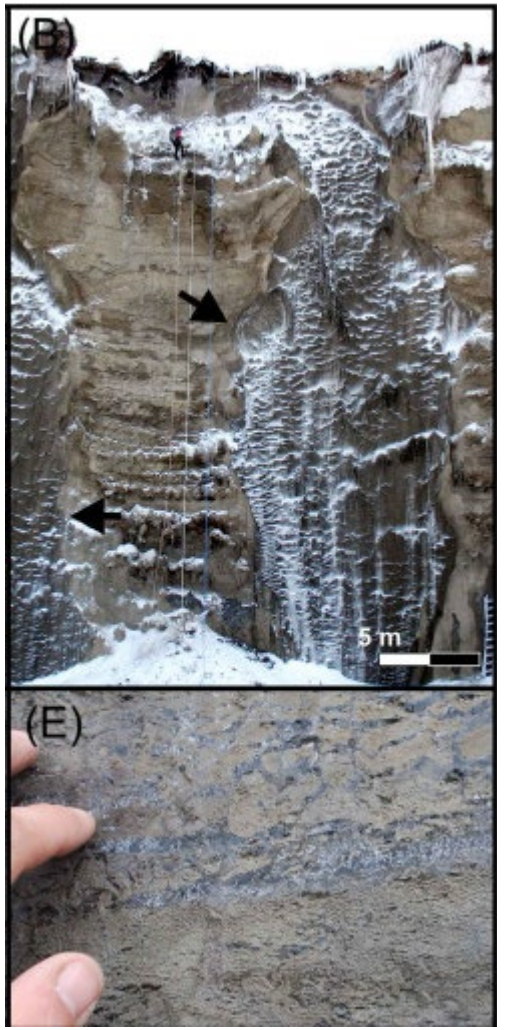


Strauss et al. 2017

3rd: Yedoma Ice Complex

- in the cryolithological sense, implying a special kind of frozen sediment widely distributed in Beringia.

- Encompassing distinctive ice-rich silt and silty sand penetrated by **large ice wedges**, resulting from sedimentation and syngenetic freezing and driven by certain climatic and environmental conditions during the late Pleistocene.



Strauss et al. 2017

Summary Yedoma

- Yedoma is a special type of periglacial or cryogenic facies typical of cold stages of late Pleistocene Beringia, and is important as an archive, for engineering issues but also the global climate

- Yedoma favored by a cold, dry climate that promoted intense periglacial weathering, transport, and accumulation of fine-grained deposits, resulting in syngenetic permafrost growth during the late Pleistocene.

- Paleoenvironmental reconstructions indicate the presence of cryoxeric steppe-tundra vegetation communities.

Permafrost Carbon

Organic matter storage and vulnerability in the permafrost domain

Jens Strauss[a], Matthias Fuchs[b], Gustaf Hugelius[c,d], Frederieke Miesner[a], Ingmar Nitze[a], Sophie Opfergelt[e], Edward Schuur[f], Claire Treat[a], Merritt Turetsky[b], Yuanhe Yang[g], and Guido Grosse[a,h], [a] Permafrost Research Section, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany; [b] Renewable and Sustainable Energy Institute, Department of Ecology and Evolutionary Biology, University of Colorado Boulder, Boulder, USA; [c] Department of Physical Geography, Stockholm University, Stockholm, Sweden; [d] Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden; [e] Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium; [f] Center for Ecosystem Science and Society, Northern Arizona University, Flagstaff, AZ, United States; [g] State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing, China and [h] Institute of Geosciences, University of Potsdam, Potsdam, Germany

Abstract

This chapter synthesizes information about the storage and vulnerability of organic matter in permafrost. The permafrost region is rapidly warming, leading to degradation and release of carbon. Permafrost holds a vast amount of organic carbon (~1460–1600 gigatons (Gt = 10^9 $t = 10^{12}$ kg) on land, and in total more than 4300 Gt (including organic carbon in subsea permafrost), making the permafrost domain the Earth's largest terrestrial carbon pool. The thawing of permafrost also affects ecosystem types and greenhouse gas emissions. Projections suggest that by 2100, the Arctic could release between 55 and 232 Gt of CO_2-equivalent, highlighting the potential to release carbon in amounts similar to that from industrial nations. While the possibility of a sudden release of greenhouse gases is not confirmed, permafrost destabilization increases the likelihood of the Arctic becoming a continuous carbon source, crucial to be included in climate mitigation considerations.

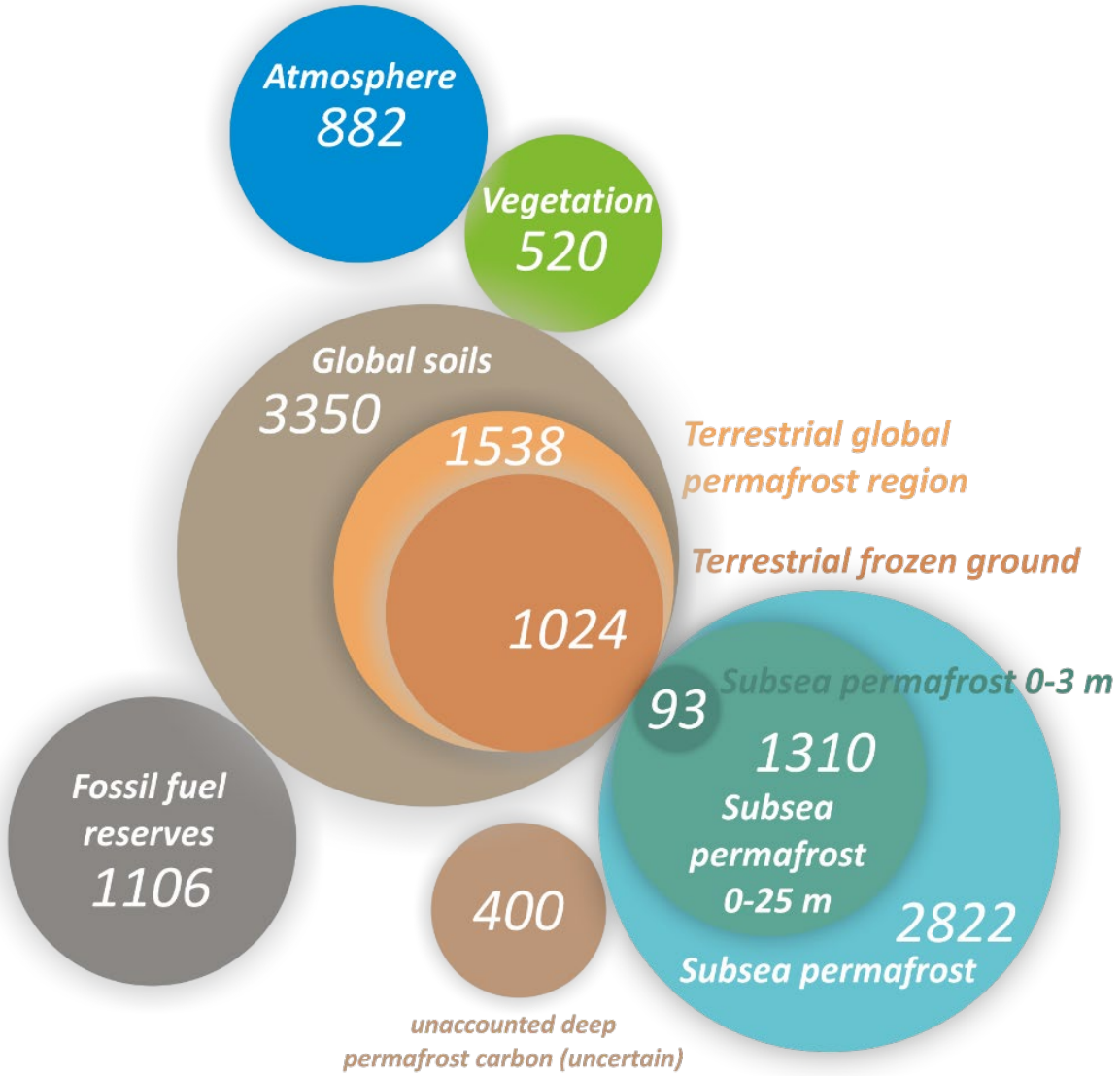
Keywords Arctic warming; Carbon stocks; Emissions; Greenhouses gases; Permafrost; Thaw; Thermokarst

Key points

- The permafrost domain is the largest terrestrial carbon pool on Earth.
- Permafrost thaw has a carbon release potential in the same order of magnitude as that from large industrial nations.
- Permafrost carbon release is dominated by CO_2, but will involve increasing amounts of CH_4 with time.
- The vast majority of the permafrost carbon pool is located in the northern high latitudes where the temperature increase is significantly higher (up to 4-times) than the global average.

Strauss et al., Encyclopedia, accepted

Carbon quantity

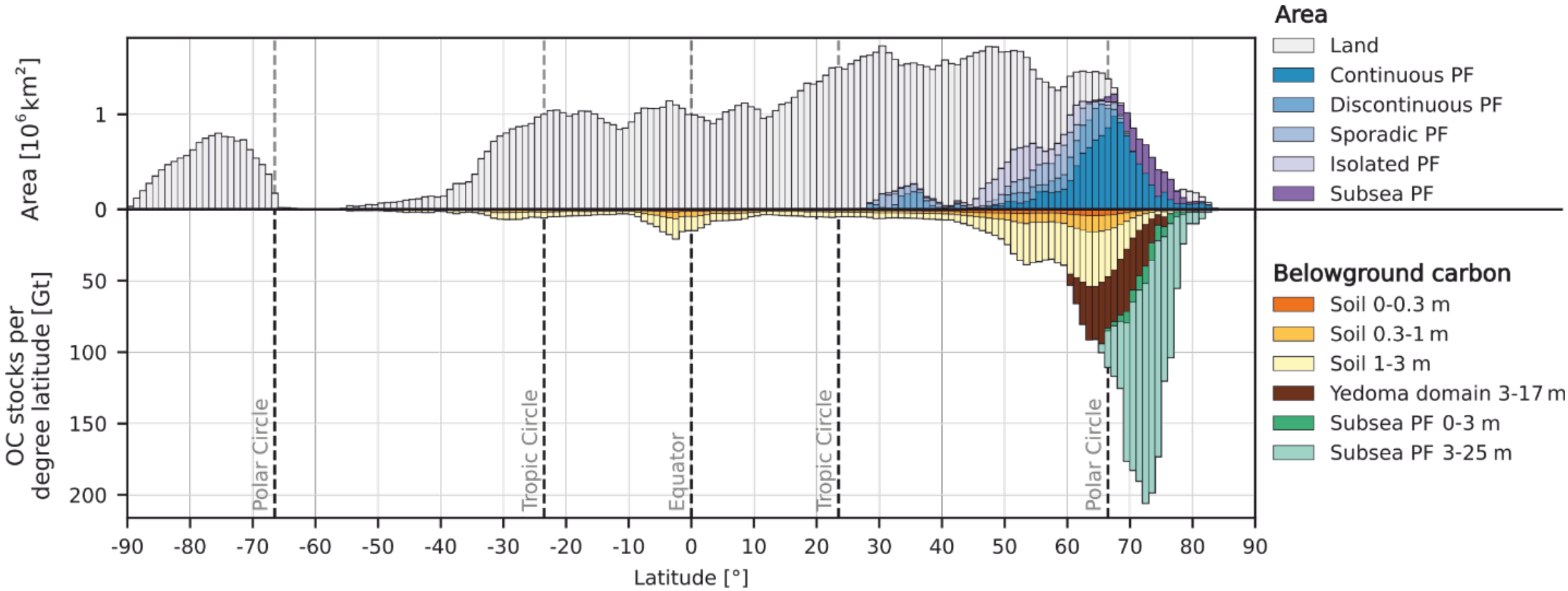


Terrestrial carbon stocks and atmospheric carbon in relation to the carbon stored in the permafrost region, in gigatons (Gt)

Strauss et al., Encyclopedia, accepted

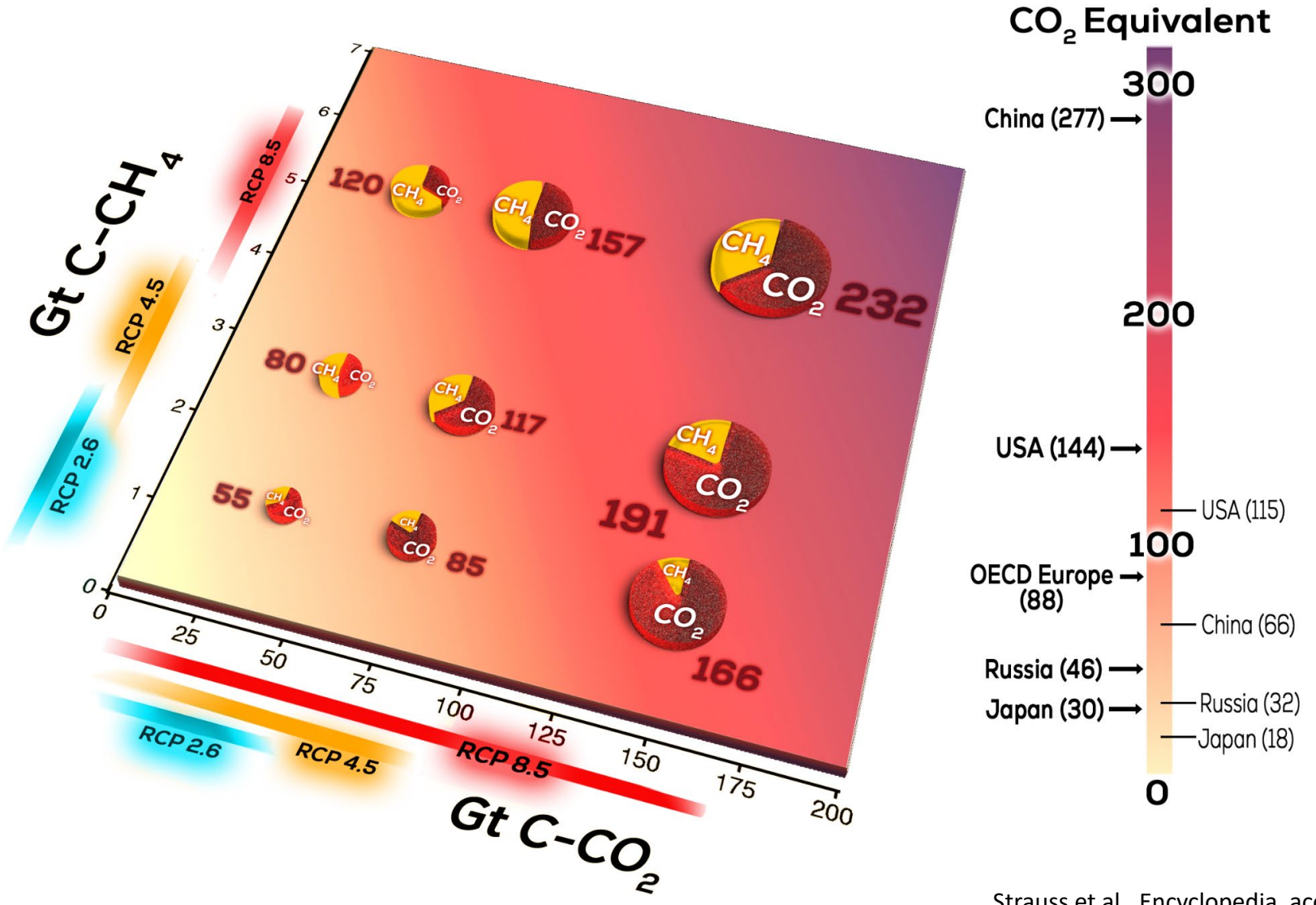
Latitudinal Carbon Distribution

Latitudinal distribution of belowground organic carbon (OC) in relation to land mass and permafrost coverage



Strauss et al., Encyclopedia, accepted

Permafrost Carbon Risk Assesment



Strauss et al., Encyclopedia, accepted

Carbon summary

- The permafrost domain is the largest terrestrial carbon pool on Earth.
- Permafrost thaw has a carbon release potential in the same order of magnitude as that from large industrial nations.
- Permafrost carbon release is dominated by CO_2, but will involve increasing amounts of CH_4 with time.

Thank you