Climate System II

(Winter 2023/2024)

10th lecture:

Permafrost

(characterization, occurrence, past and future changes, permafrost carbon pools)

Gerrit Lohmann, Martin Werner

Tuesday, 10:15-11:45

https://paleodyn.uni-bremen.de/study/climate2023_24.html

Permafrost in the climate system

[https://www.eskp.de/klimawandel/kohlenstofffreisetzung-aus-sibirischen-permafrostboeden-935527/

What is permafrost?

- permanently frozen ground
  - *temperature of the ground remains under zero degrees Celsius for at least two consecutive years*
- material: rock, sediment or soil
  - *can contain varying quantities of ice*
- can reach far down into Earth
  - *North-East Siberia: up to 1.7km*

[https://www.awi.de/en/focus/permafrost/permafrost-an-introduction.html

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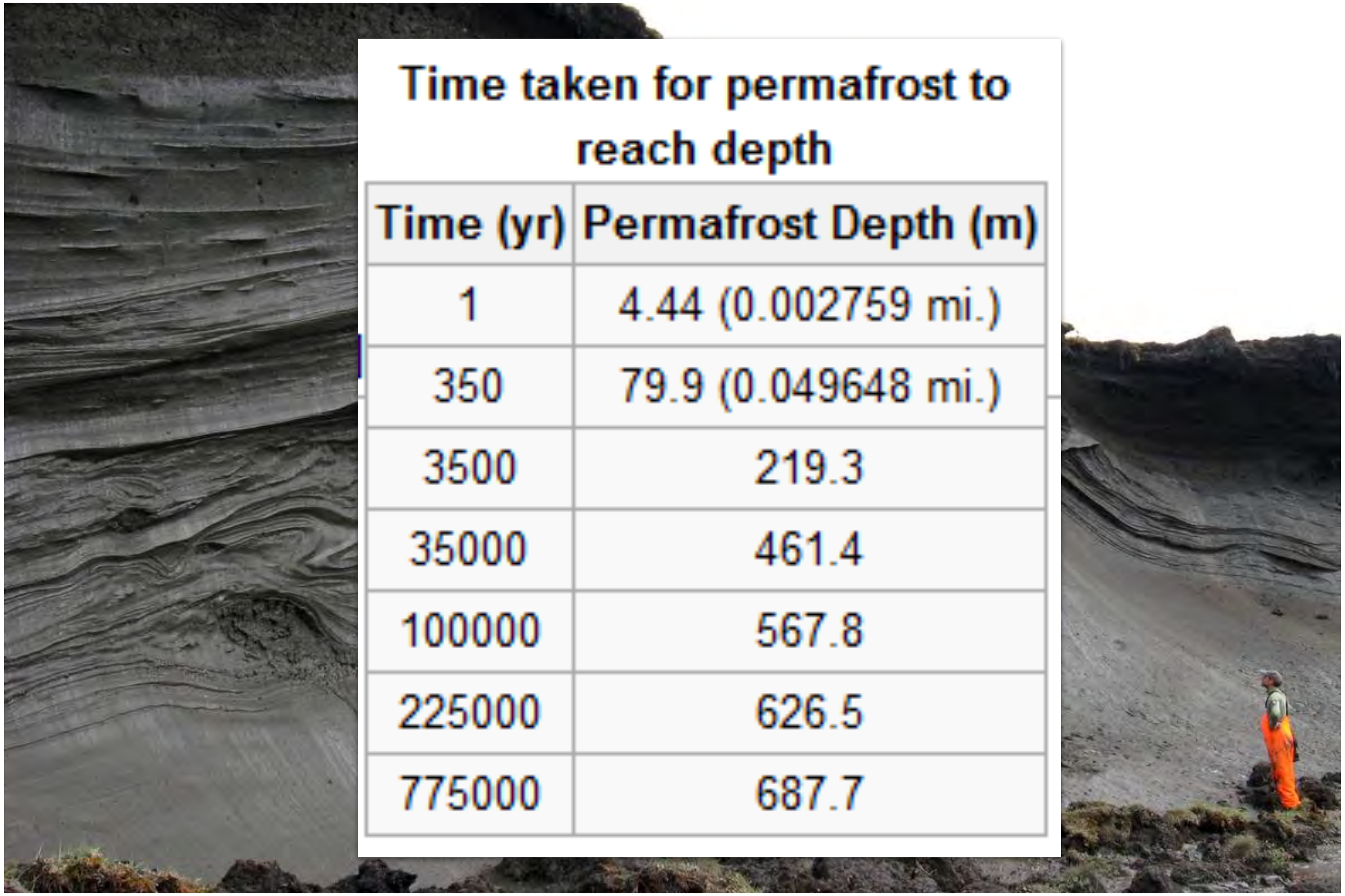

Time taken for permafrost to reach depth

Time (yr)	Permafrost Depth (m)
1	4.44 (0.002759 mi.)
350	79.9 (0.049648 mi.)
3500	219.3
35000	461.4
100000	567.8
225000	626.5
775000	687.7

[https://www.awi.de/en/focus/permafrost/permafrost-an-introduction.html

[https://faculty.washington.edu/tswanson/ESS/315/Student%20PP%20Presentations/ESS315-Permafrost.ppt

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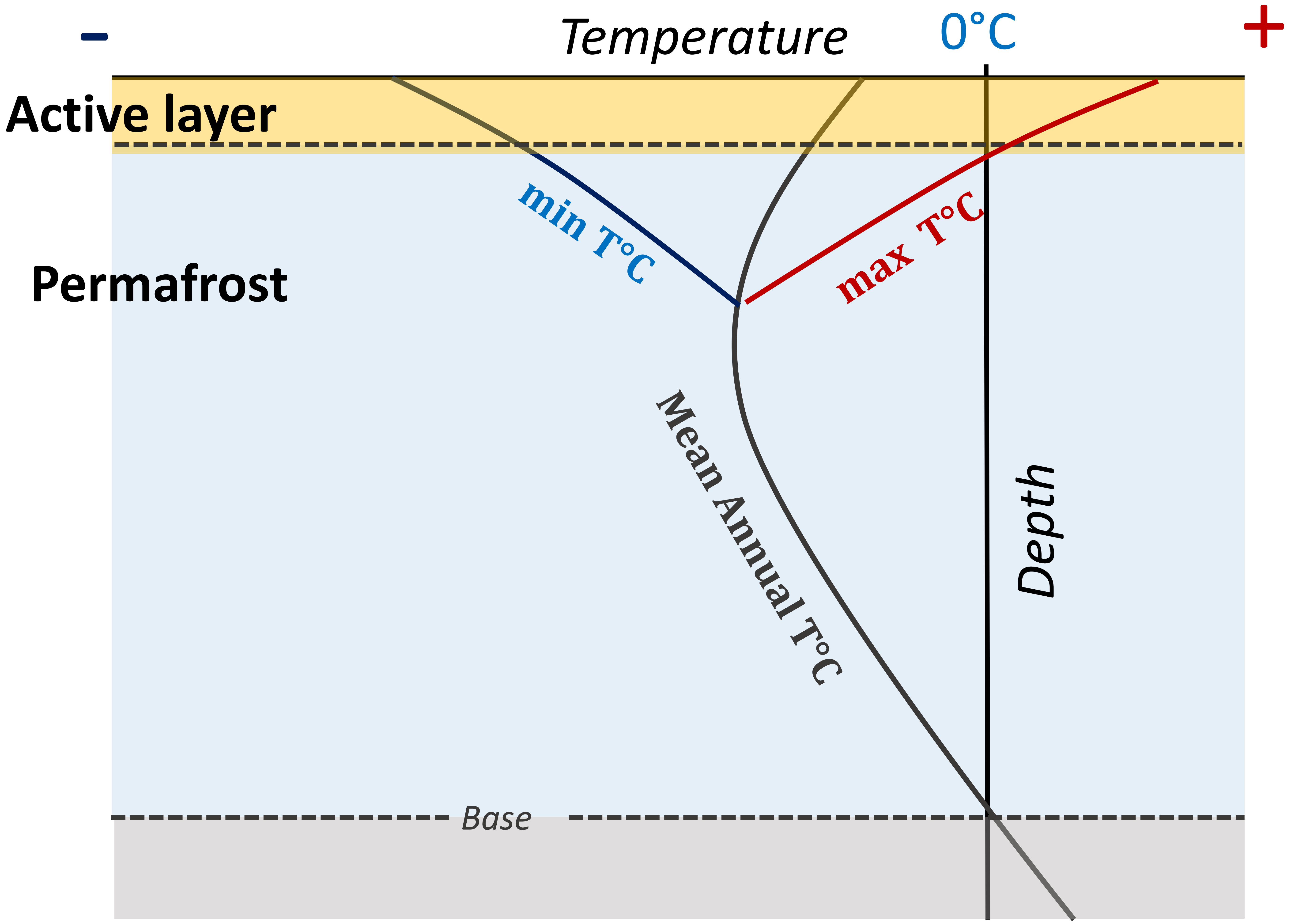
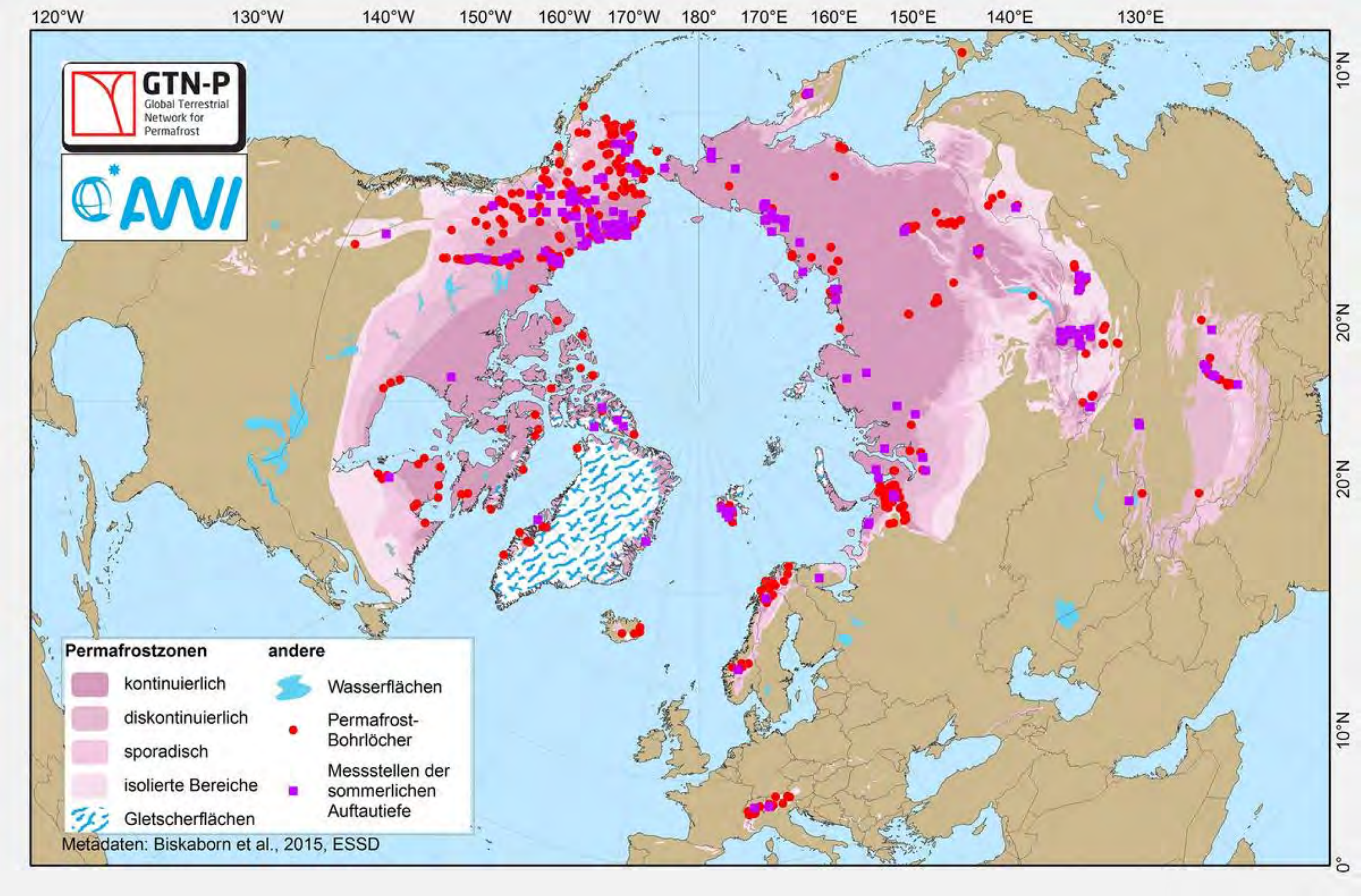
- can be recognised by typical patterning of their surface formed by repeated deep freezing in winter
- often, there is an active layer of soil above the permafrost (15-100cm), which is thawing in summer



[https://hal.science/hal-03866147v1/file/Magnin_et_al.Permafrost_presentation_HAL.pdf]

Where can we find permafrost in the Arctic?



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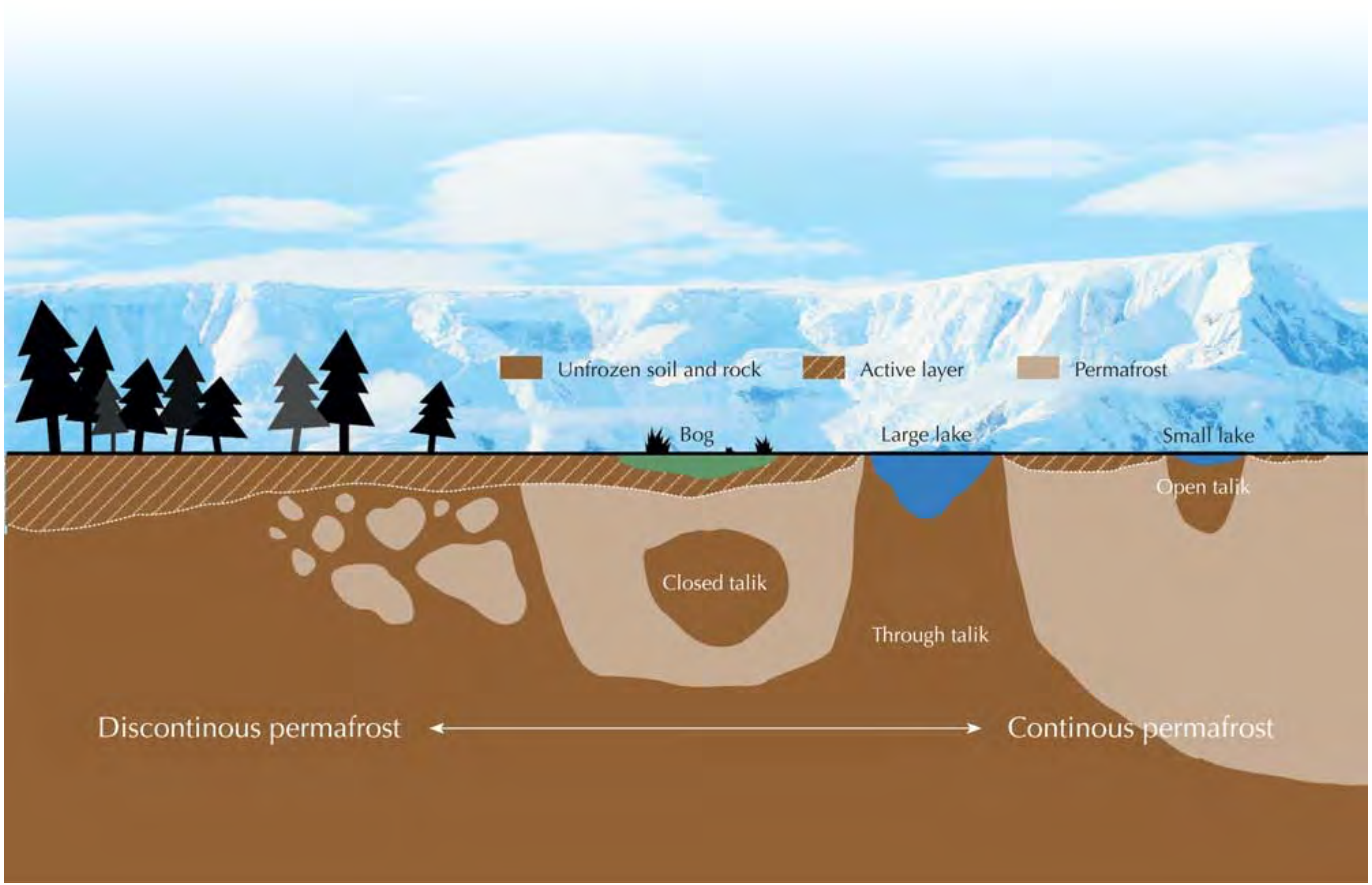
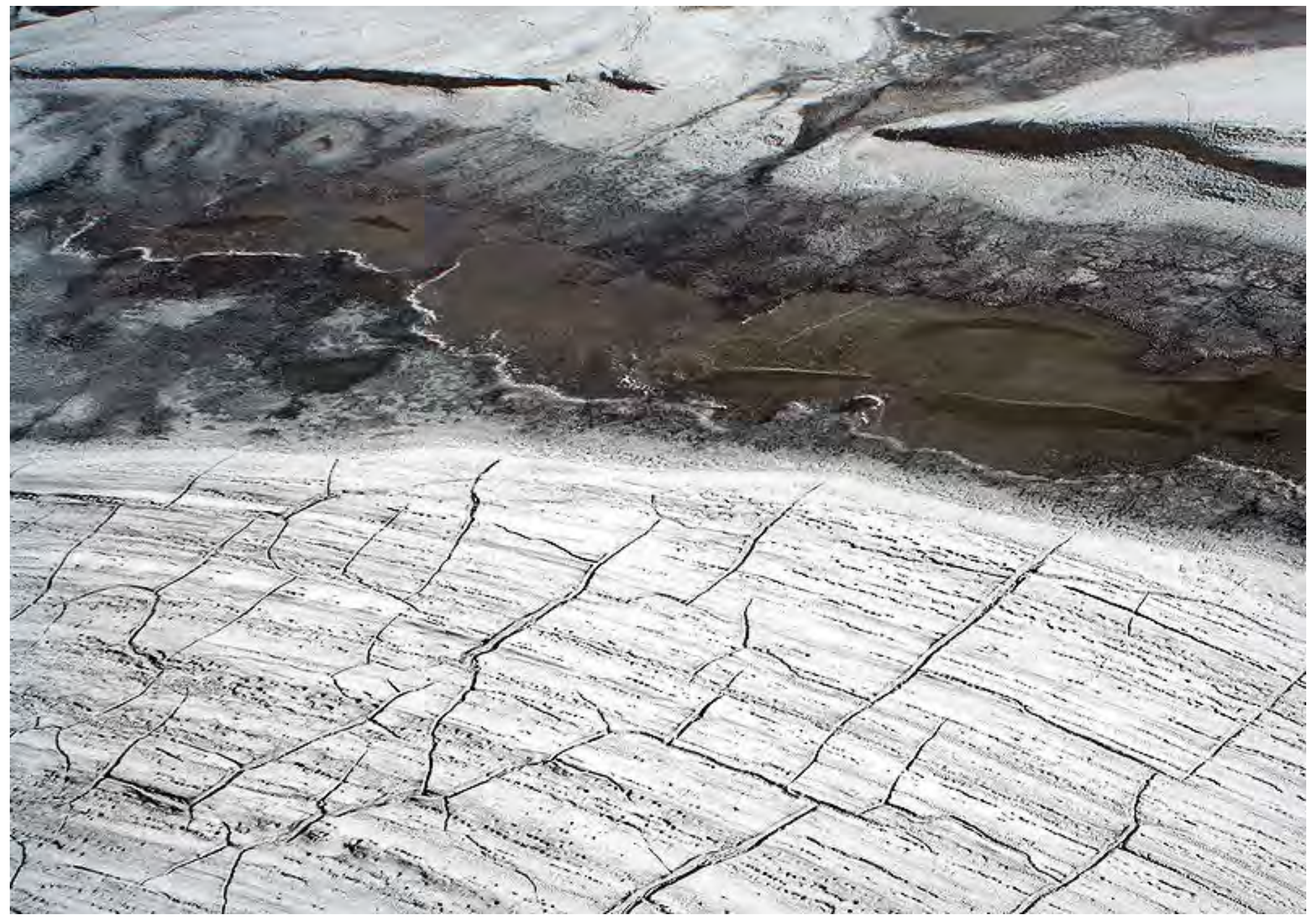


[https://www.scienceinschool.org/article/2012/permafrost/]

Permafrost ground patterns and landscapes



[https://faculty.washington.edu/tswanson/ESS/315/Student PP Presentations/ESS315-Permafrost.ppt]

Changes of Arctic permafrost since the LGM

Since the last glacial maximum the Arctic has changed from a surface ice dominated regime …

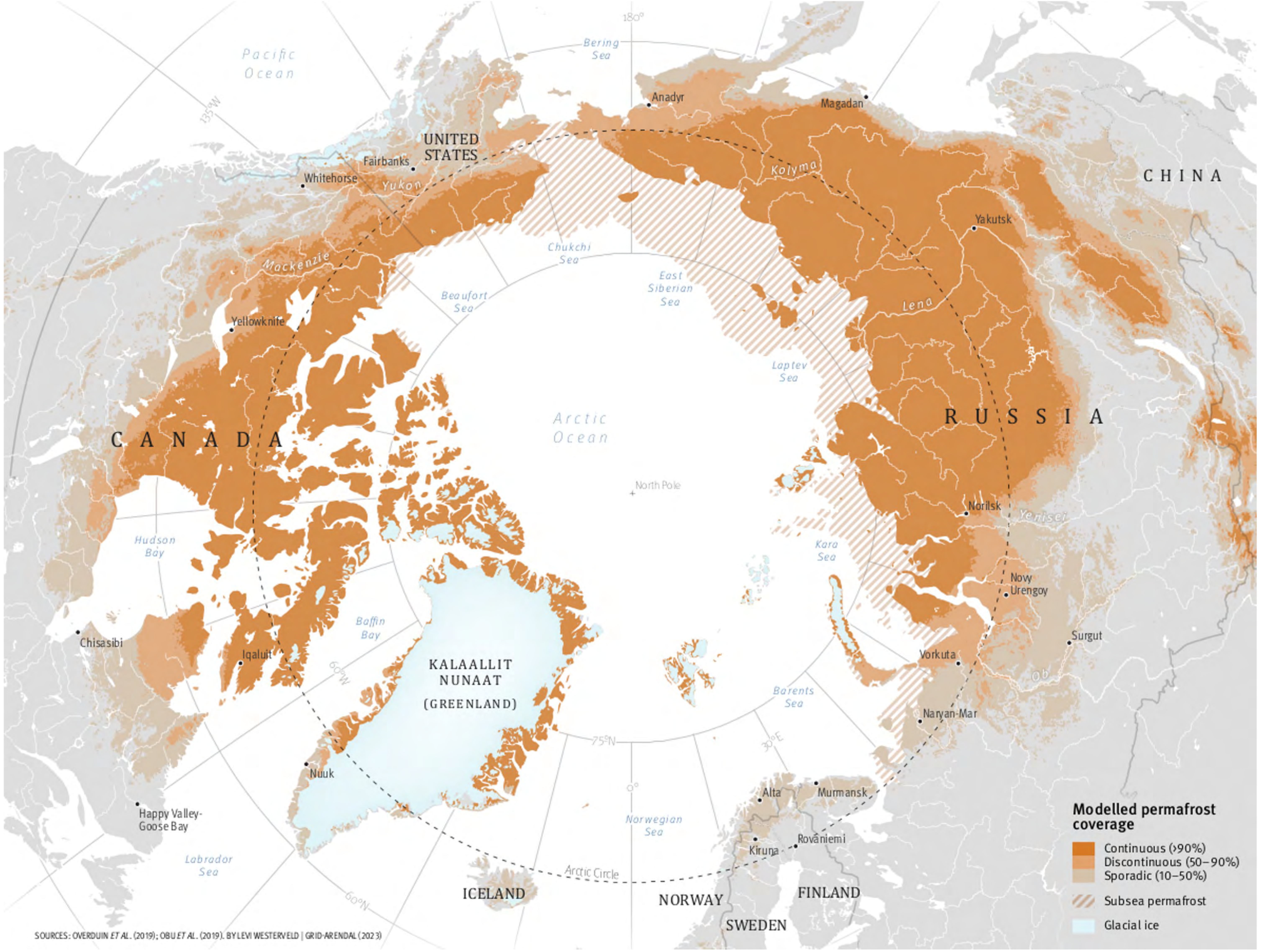
[plot by G. Mollenhauer & M. Langer, Netherlands Polar Programme and AWI Collaborative workshop, 11/2023]

Changes of Arctic permafrost since the LGM

… to a ground ice dominated regime …

… and will potentially evolve into a largely ice free regime in the long term future.

This goes along with large carbon pools that are created, depleted, mobilized and relocated.



[plot by G. Mollenhauer & M. Langer, Netherlands Polar Programme and AWI Collaborative workshop, 11/2023]

Permafrost thawing processes

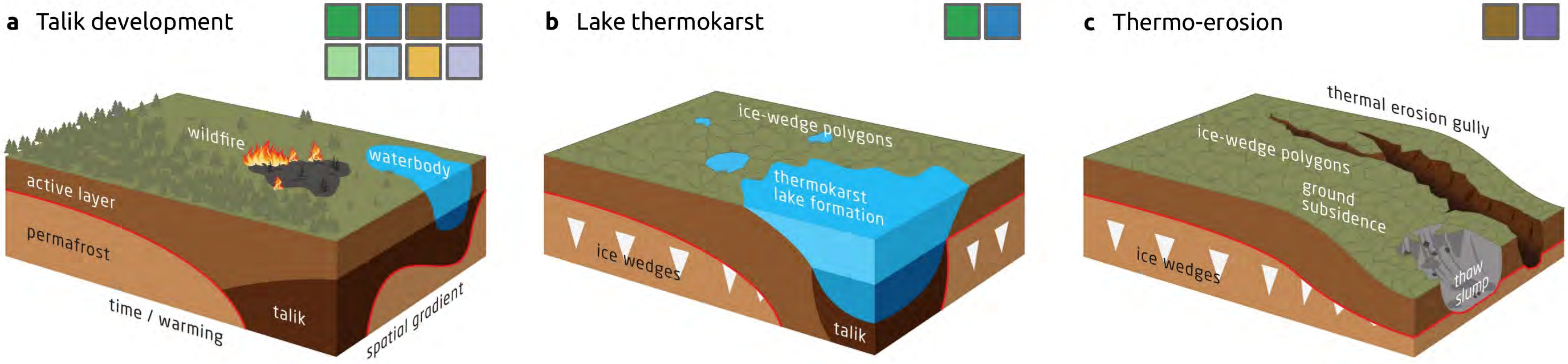
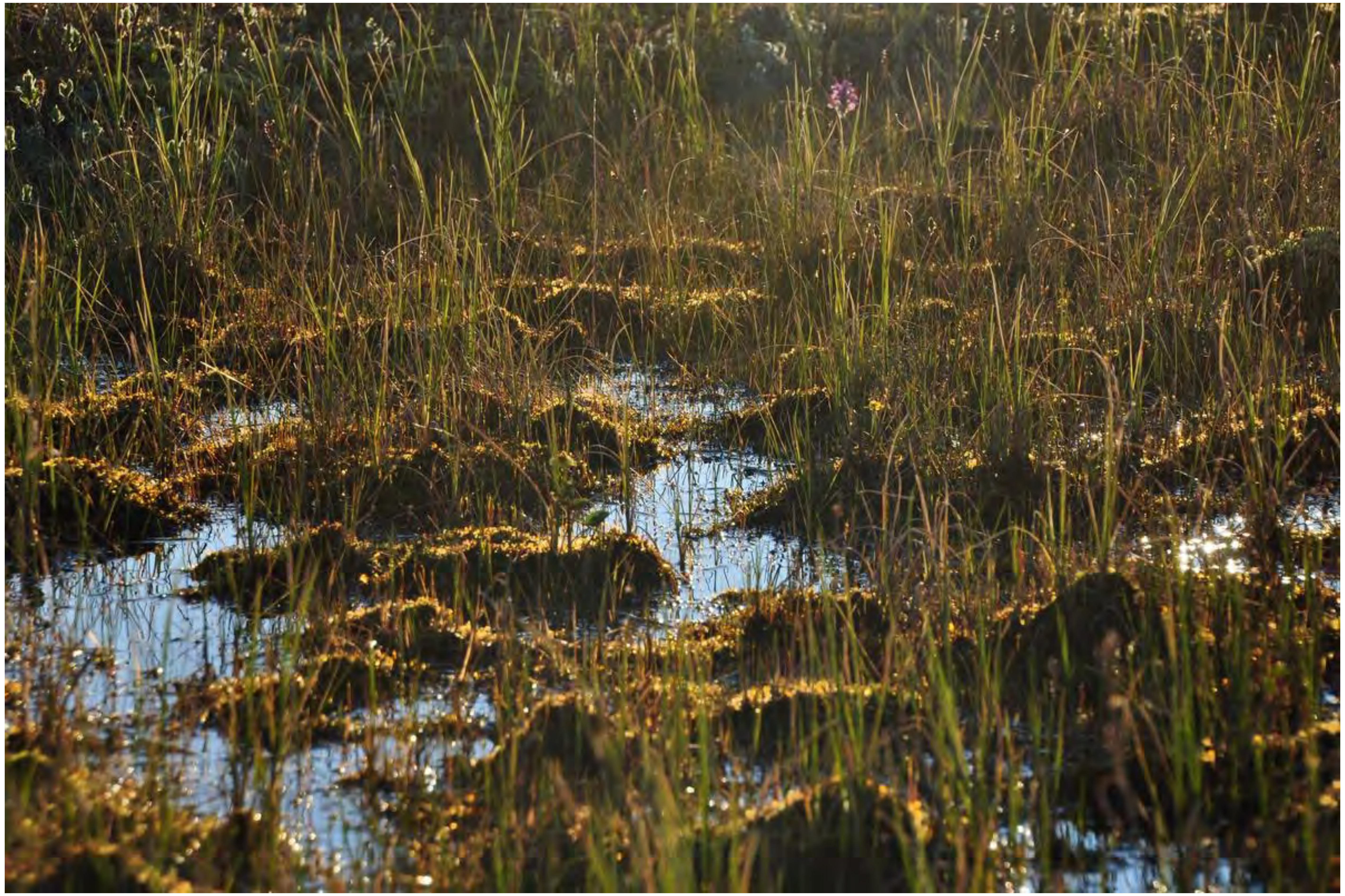


Fig. 3. a-c: Illustrations of local-scale processes driving permafrost thaw. The colored squares indicate the sub-regions in Fig. 2 where these processes predominantly occur. a: Taliks (perennially unfrozen ground surrounded by permafrost) can form due to surface disturbances (wildfires, thermokarst lakes) or climatic extremes and accelerate the transition from a permafrost-underlain into a permafrost-free landscape. b: Thermokarst lakes are abundant and actively forming in ice-rich lowlands by expanding laterally through shore erosion and into depth by forming a sub-lake talik. c: Thermo-erosion landforms are most abundant in ice-rich upland regions, where they form by the interactions between running water, melting ground ice, and sediment erosion.

[Figure produced by J. Nitzbon et al., 2023]

Consequences of permafrost thawing

- permafrost contains high amounts of organic materials (OC: organic carbon)
- warming leads to increased microbe activities
- by such decomposition processes, high amounts of CO_2 and CH_4 might have been released / will be released
  - *exact amount for past & future is still debated*
- thawing also leads to changes in the surface structure and albedo
  - *liquid waters are darker than ice, will take up more heat and increase the waring effect*
- thawing consequences have a „positive feedback“ to further thawing
  - *quantifying all effects is complicated and a strong focus of current research*



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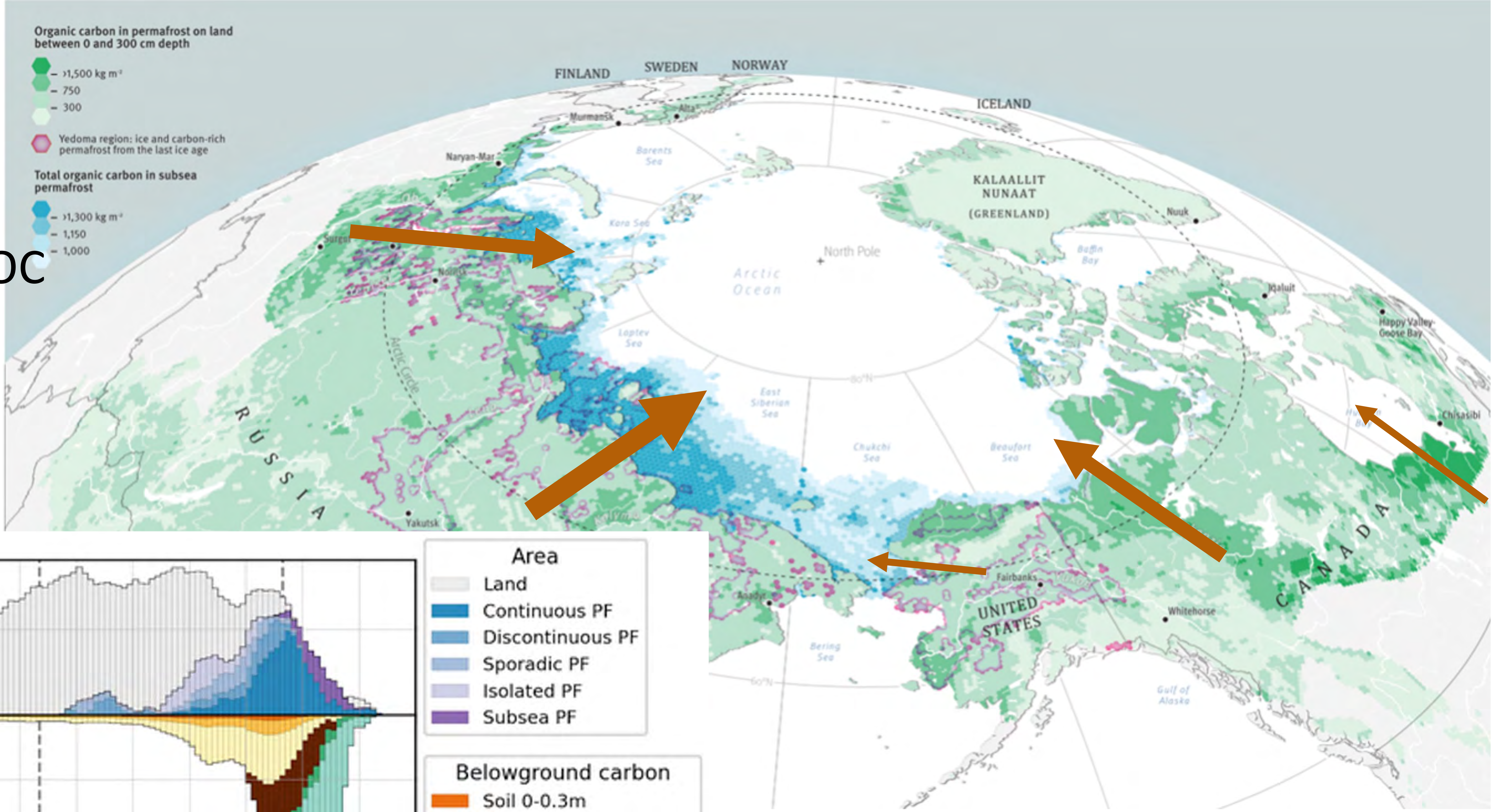
Mobilization of the permafrost carbon pools

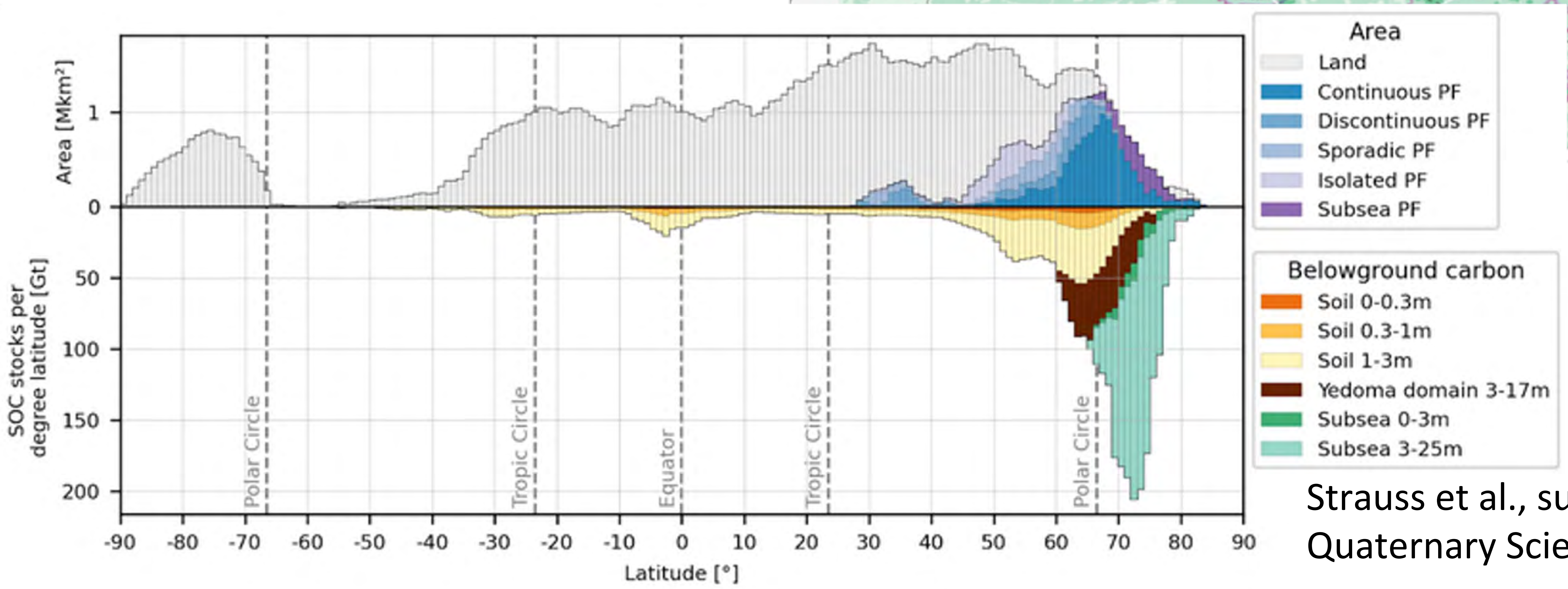
Permafrost stores in total:
2700 - 6600 Pg OC

- Terrestrial PF: 1200-1600 Pg OC
- Subsea PF: 1500–5000 Pg OC

compared to:

- *atmosphere: ca. 830 Pg C*





Strauss et al., submitted for the Encyclopedia of Quaternary Science, 3rd Edition (2024)

[plot by G. Mollenhauer & M. Langer, Netherlands Polar Programme and AWI Collaborative workshop, 11/2023]

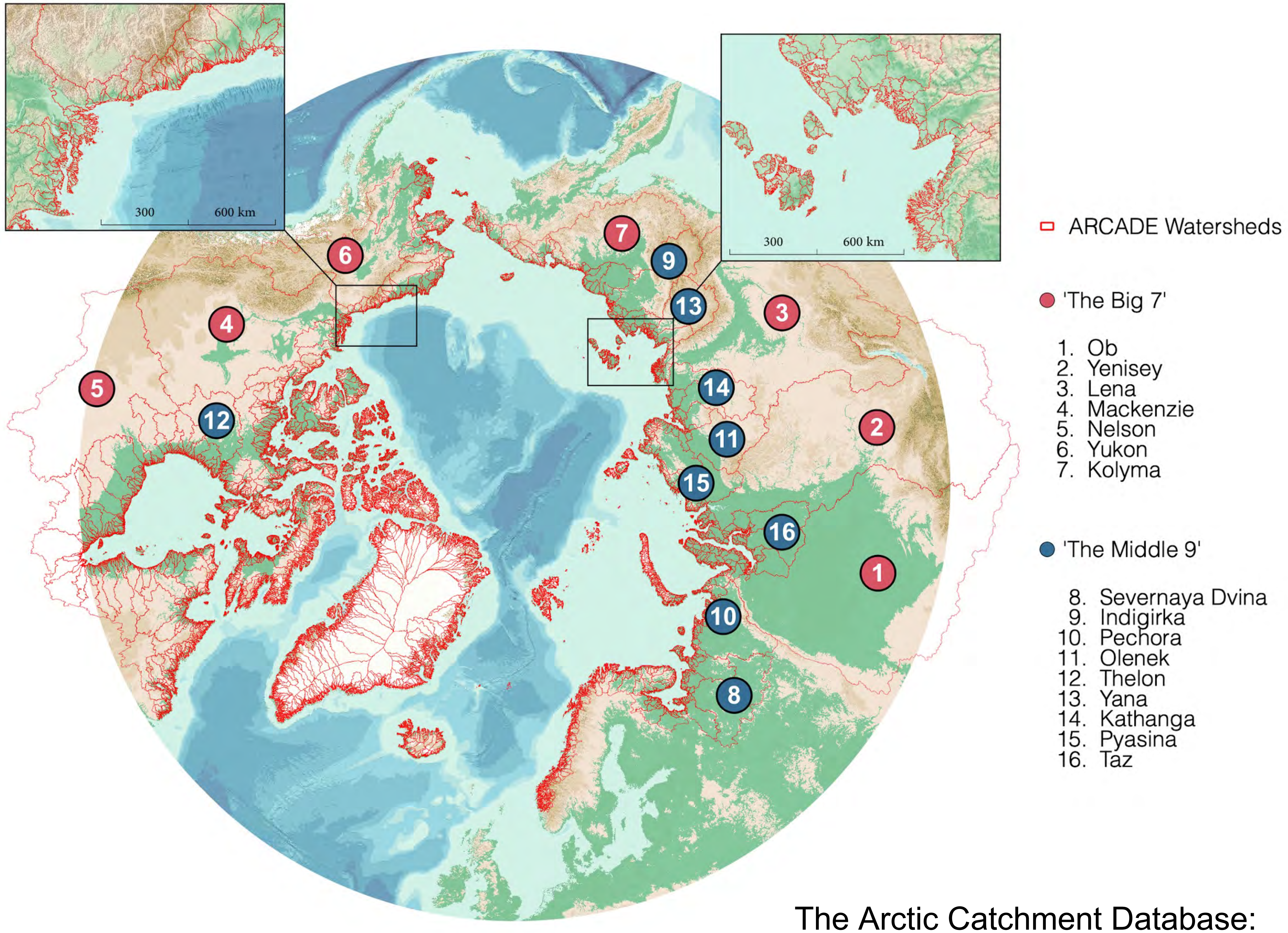
How does permafrost carbon reach the ocean?

Coastal erosion:

- direkt supply to the ocean
- intensifying over the last decades

Riverine transport:

- catchment sizes are highly variable
- catchment feature different rates of warming, permafrost thaw, and OC mobilization
- OC remineralization during transport is highly variable



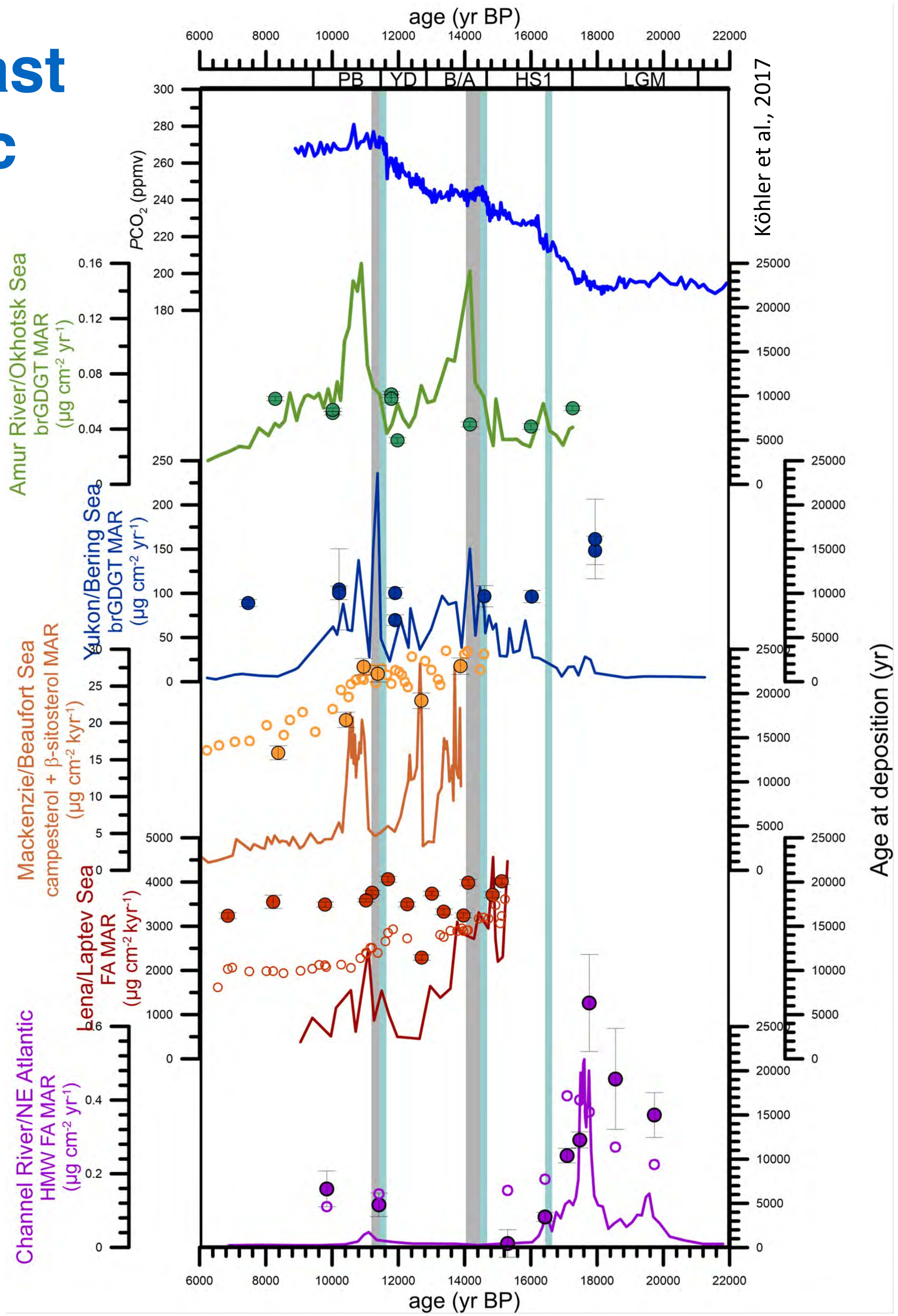
The Arctic Catchment Database: ARCADE, Speetjens et al., 2023

[plot by G. Mollenhauer & M. Langer, Netherlands Polar Programme and AWI Collaborative workshop, 11/2023]

Land-ocean organic matter transport during past periods of rapid climate warming in the Arctic

- Massive release of terrigenous organic matter to the ocean during last deglaciation
- Evidence from multiple locations across the (Arctic
- Short-term maxima, ±coeval with periods of rapid sea-level rise
- Impact on atmospheric CO2 may be large – **depending on fate of terrigenous OM**

Winterfeld et al., 2018, Meyer et al., 2019, Wu et al., 2020, 2022, Nicolas.et al., in prep., Alves, in review



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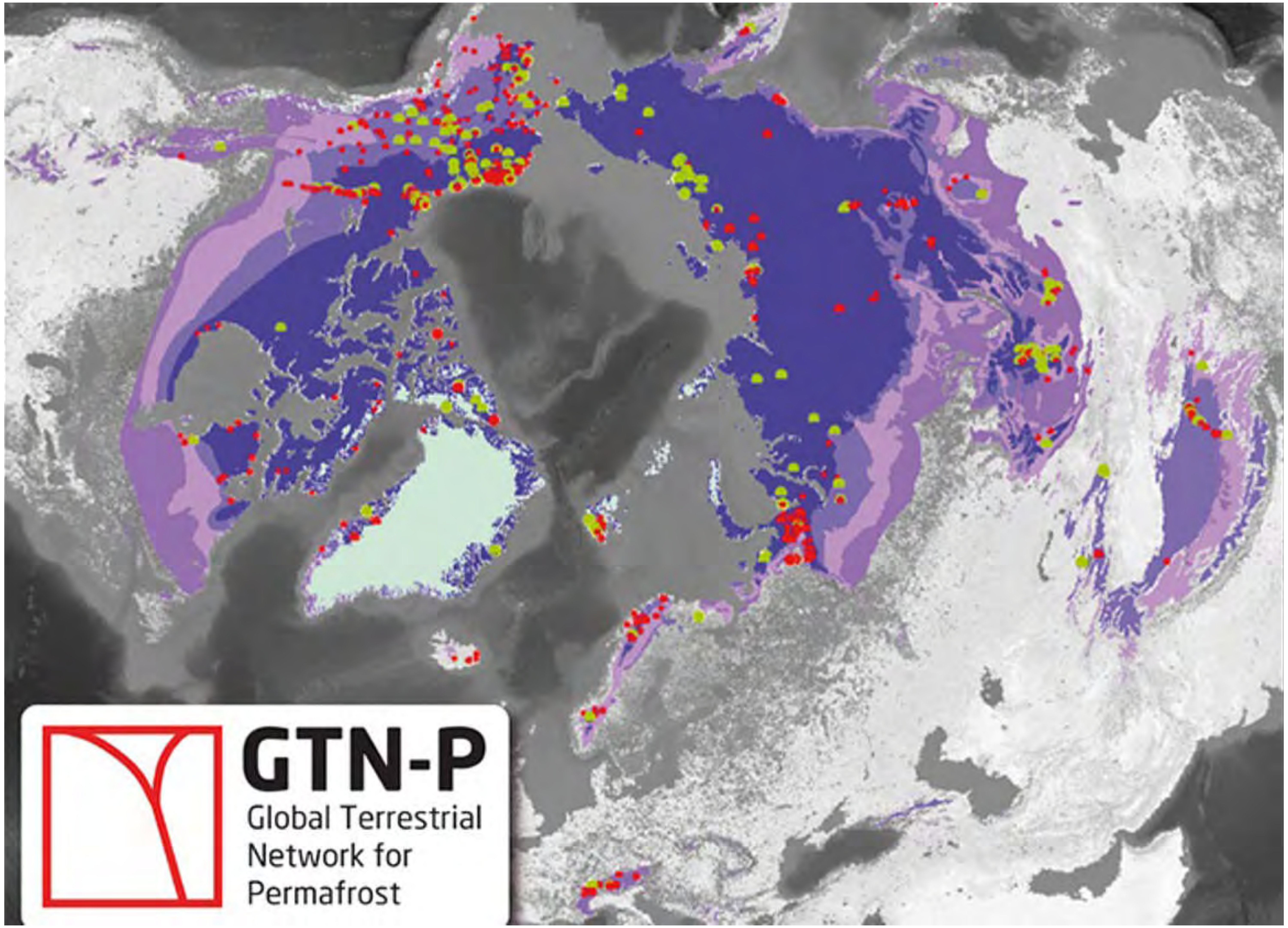
Future climate change: How fast is permafrost thawing?

- climate warming leads to warming of permafrost areas
  - *polar amplification leads to even stronger warming in high northern latitudes*
- permafrost areas are already warming since several decades
  - *between 2007 and 2016: approx. 0.3°C warming*
- warming is directly measured in more than 150 boreholes in permafrost regions



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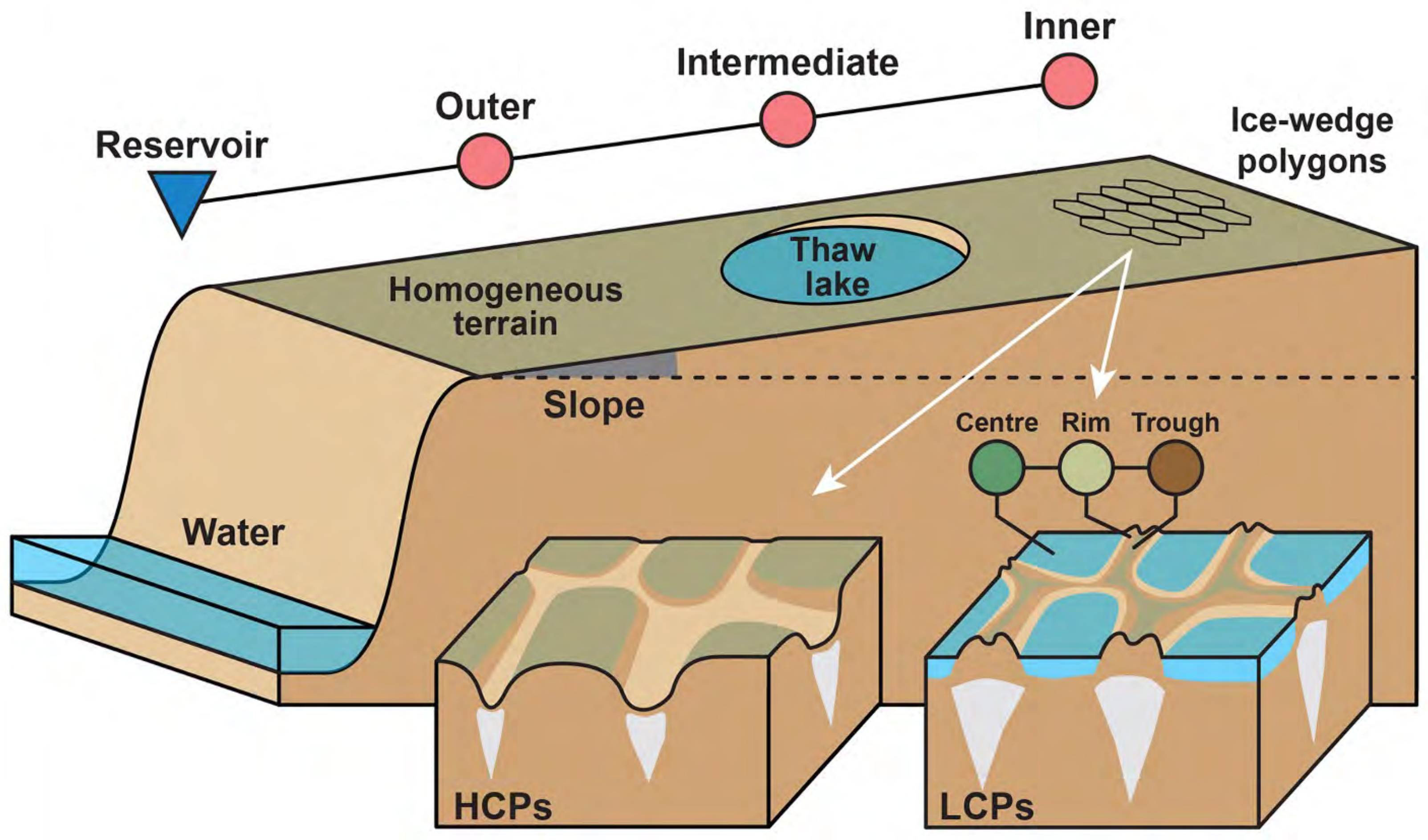
Modelling permafrost thawing and hydrological transport mechanisms

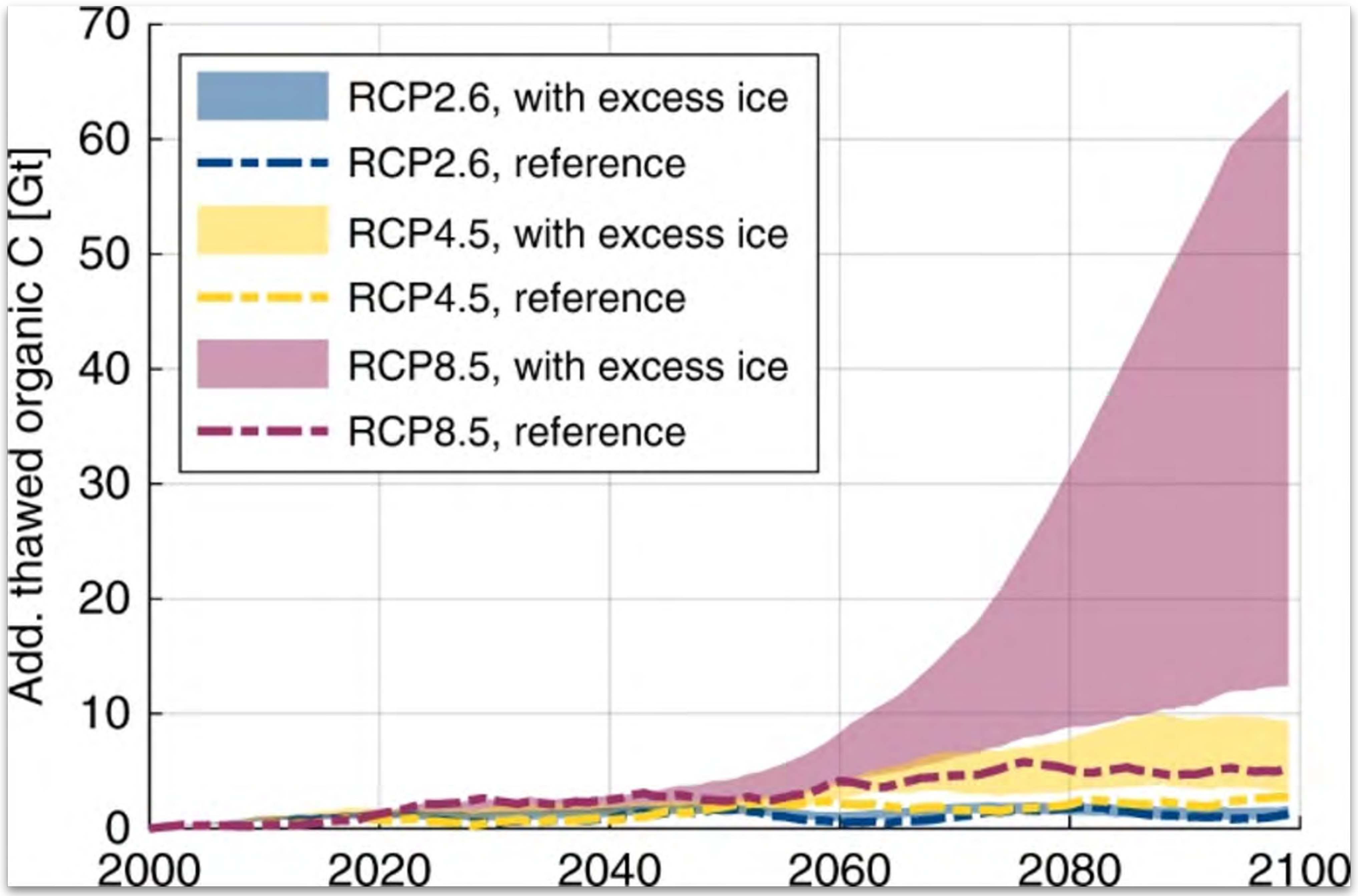
Hydrological networks in permafrost environments evolve highly dynamic with changing climate conditions.

Permafrost thaw is accompanied by rapid thaw and erosion processes. → controlling OC release and pathways.

→ Demands sophisticated thermo-hydrological modeling schemes.



Nitzbon et al. (2021). Effects of multi-scale heterogeneity on the simulated evolution of ice-rich permafrost lowlands under a warming climate. The Cryosphere, 15(3), 1399-1422.



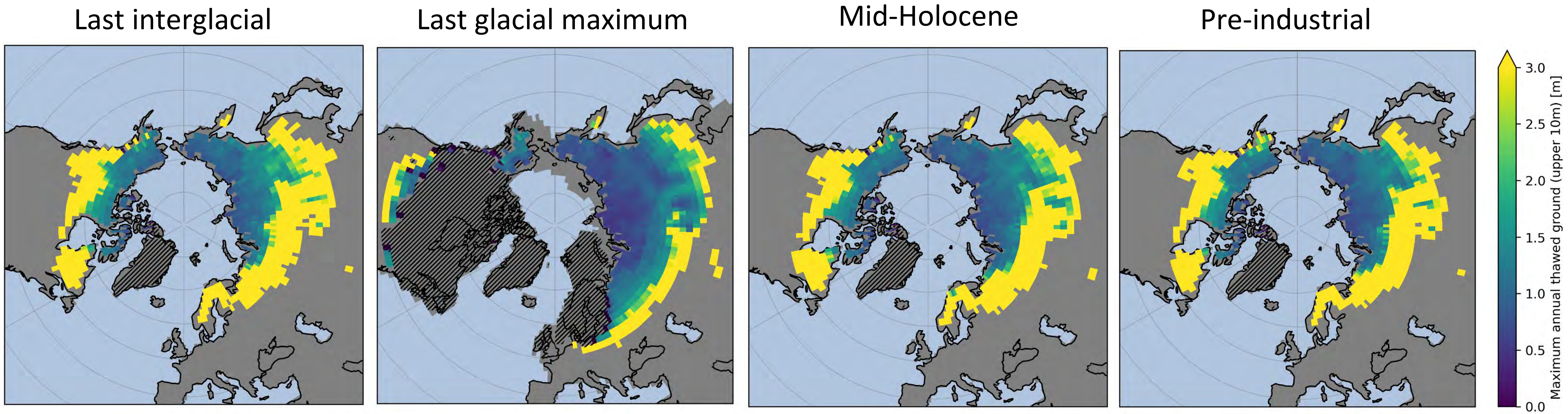
The impact of rapid thaw processes on the release of OC using CryoGrid with laterally coupled tiles.

[plot by G. Mollenhauer & M. Langer, Netherlands Polar Programme and AWI Collaborative workshop, 11/2023]

Modeling the temporal evolution of permafrost

From time slices to transient simulations of glacial-interglacial permafrost evolution.

→ Fast and bias corrected paleo-climate-permafrost models must be developed
→ Combination of different climate models complexity to cover different time spans / estimations of large ensembles
→ Use of combination of downscaling and local offline information to improve data -- model integration



Time slice simulations using CryoGridLite coupled to AWI-ESM (Nitzbon et al. 2023, in preparation)

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End of lecture.

Slides available at:

https://paleodyn.uni-bremen.de/study/climate2023_24.html