Investigating the role of subglacial geology on ice sheet dynamics

Evan Gowan, Lu Niu, Gregor Knorr, Gerrit Lohmann, and Sebastian Hinck

Alfred Wegener Institute, Bremerhaven Germany

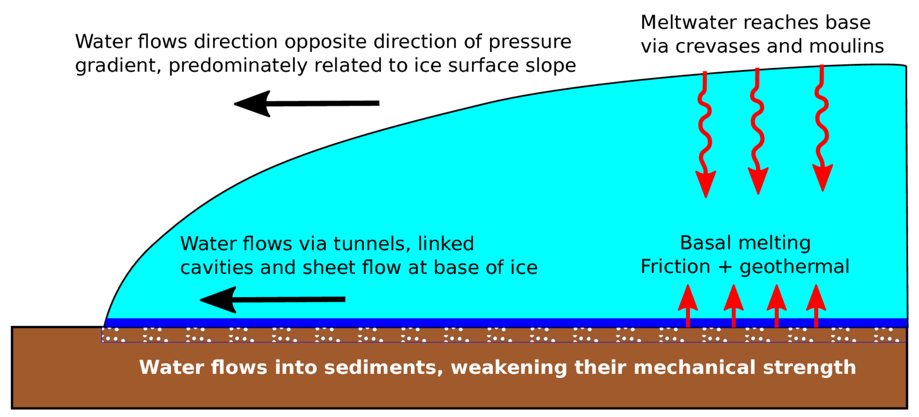
Basal conditions: the key to ice flow

Greenland and West Antarctica are experiencing a disproportionate increases in temperature due to global warming. There are already observations that this is coinciding with increased velocity of ice streams in these ice sheets.

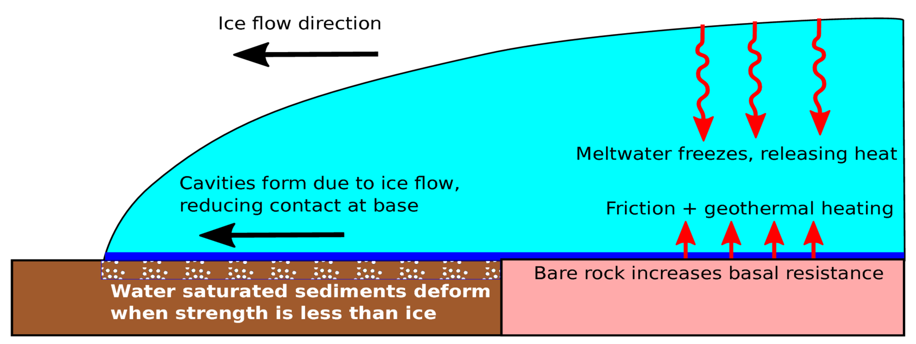
The flow of large ice sheet masses is dependent on the conditions at the base. Direct observations of the base of ice sheets are extremely limited. Due to this, is is instructive to look at how past ice sheets behaved during periods of rapid warming.

In order to investigate ice sheet basal conditions, we use the Parallel Ice Sheet Model (PISM; Bueler and Brown, 2009). This next generation ice sheet model allows for the modeling of ice sheet dynamics by coupling the shallow ice approximation in regions with low velocity, and the shallow shelf approximation in places where sliding occurs. We are developing a model that includes spatial changing basal hydrological and geological conditions that can also work on glacial time scales.

Ice Sheet Hydrology



Ice Sheet Dynamics



Effects of Geology on Ice Sheet Dynamics

By default, PISM includes a basal model that assumes that there is a thick layer of sediments underneath the ice sheet. When these sediments become saturated, they become mechanically weaker than the overlying ice and will deform. The main control for this is a Coulomb friction criteria:

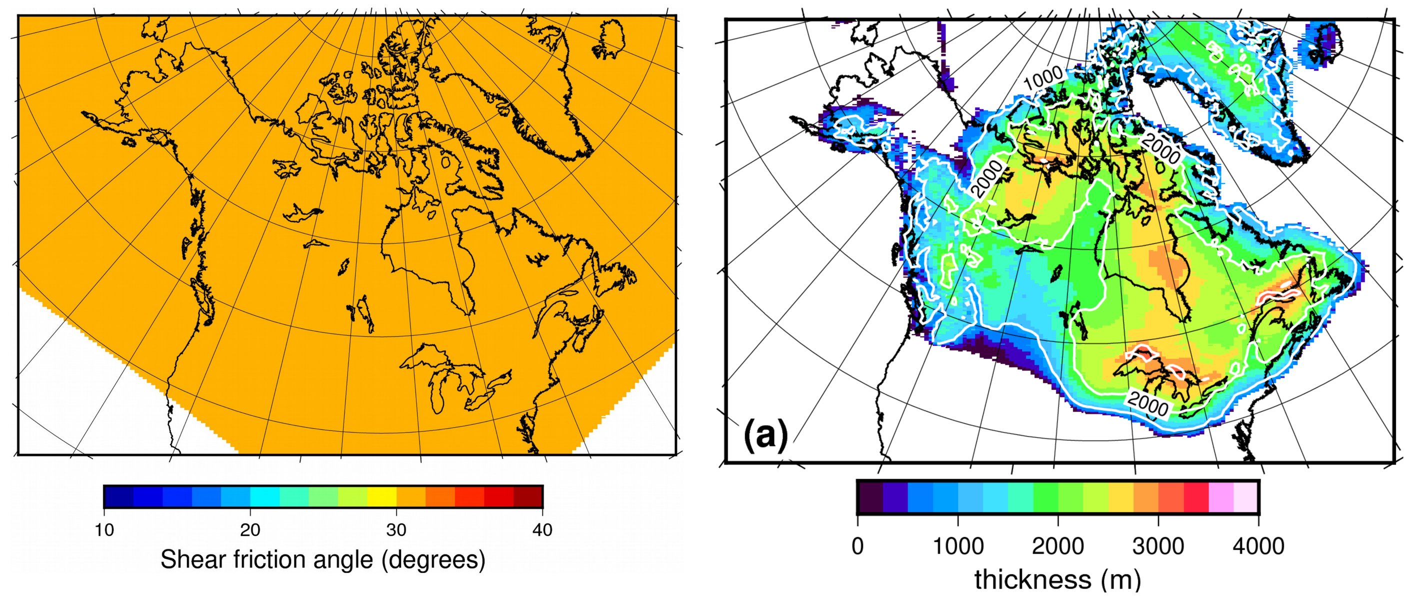
$$\tau_c = N \tan(\phi)$$

Where τ_c is the yield stress, **N** is the effective pressure at the base if the ice sheet and ϕ is the shear friction angle of the sediments. A lower ϕ will make the base weaker.

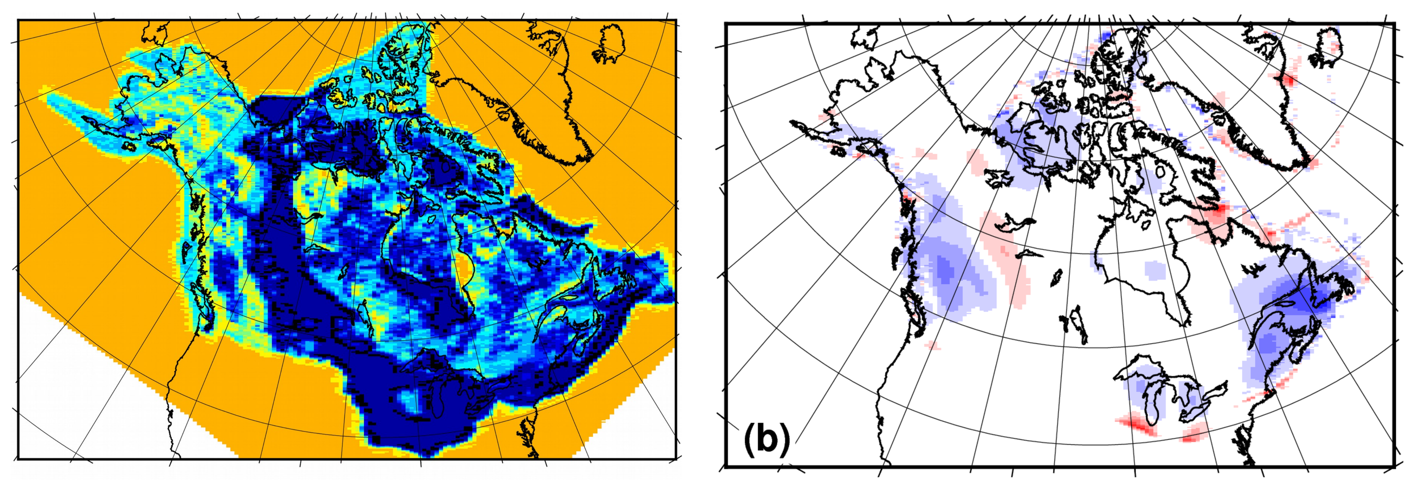
As an initial test for changing basal conditions, we use an ice sheet simulation of the last glacial cycle, based on a simulation found in Niu et al (in review). We adjust the shear friction angle depending on the basal condition (i.e. "rock" is stronger than "blanket", "sand is stronger than "clay"). The plots to the right show the changes in ice thickness at 20,000 years before present if the shear friction angle is changed to account for sediment composition and distribution.

We are currently working on a model that also incorporates changes sediment distribution and hydrology.

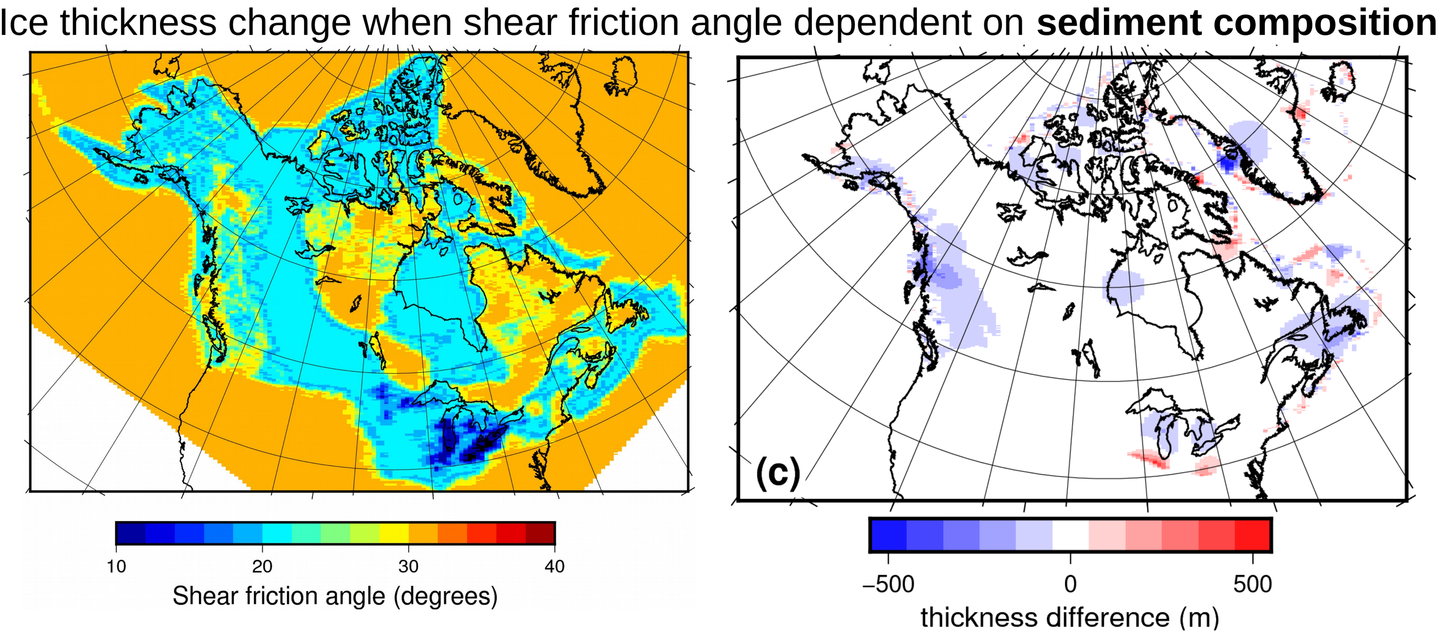
Default - constant shear friction angle



Ice thickness change when shear friction angle dependent on **sediment distribution**

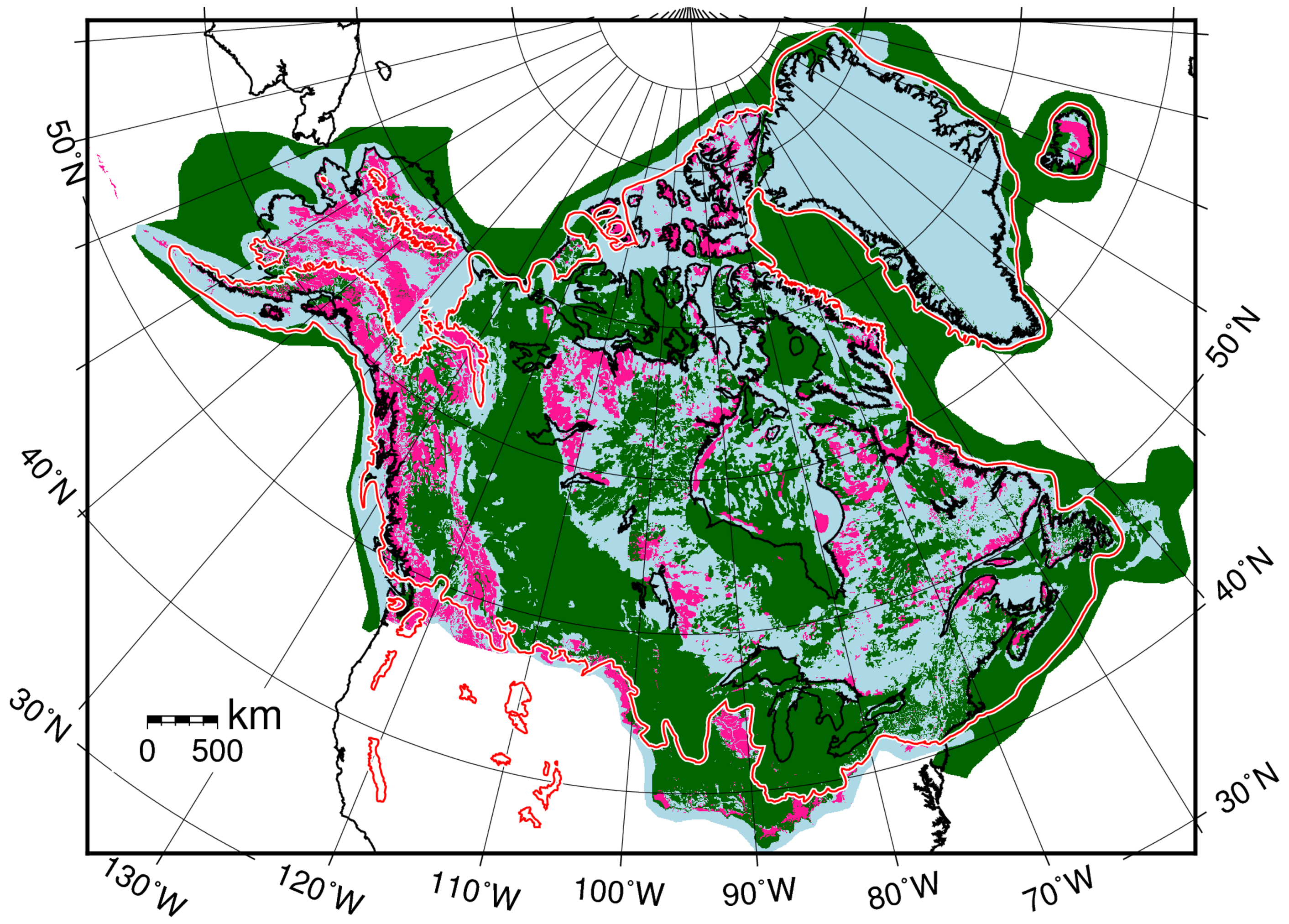


Ice thickness change when shear friction angle dependent on **sediment composition**



Basal properties in areas glaciated in North America

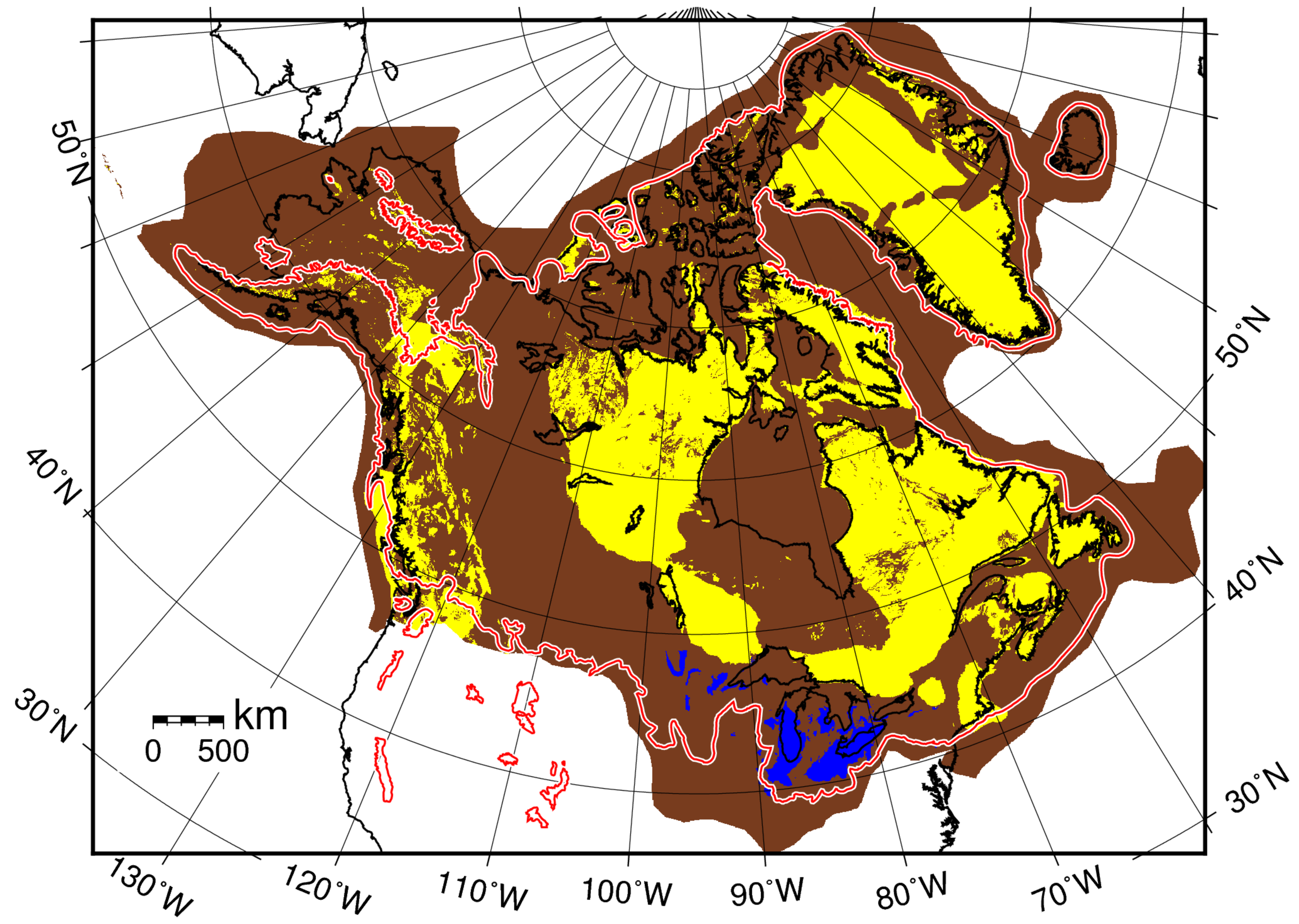
Basal sediment distribution



Blanket (continuous) Veneer (discontinuous) Rock

~21000 yr BP extent (Dyke 2004)

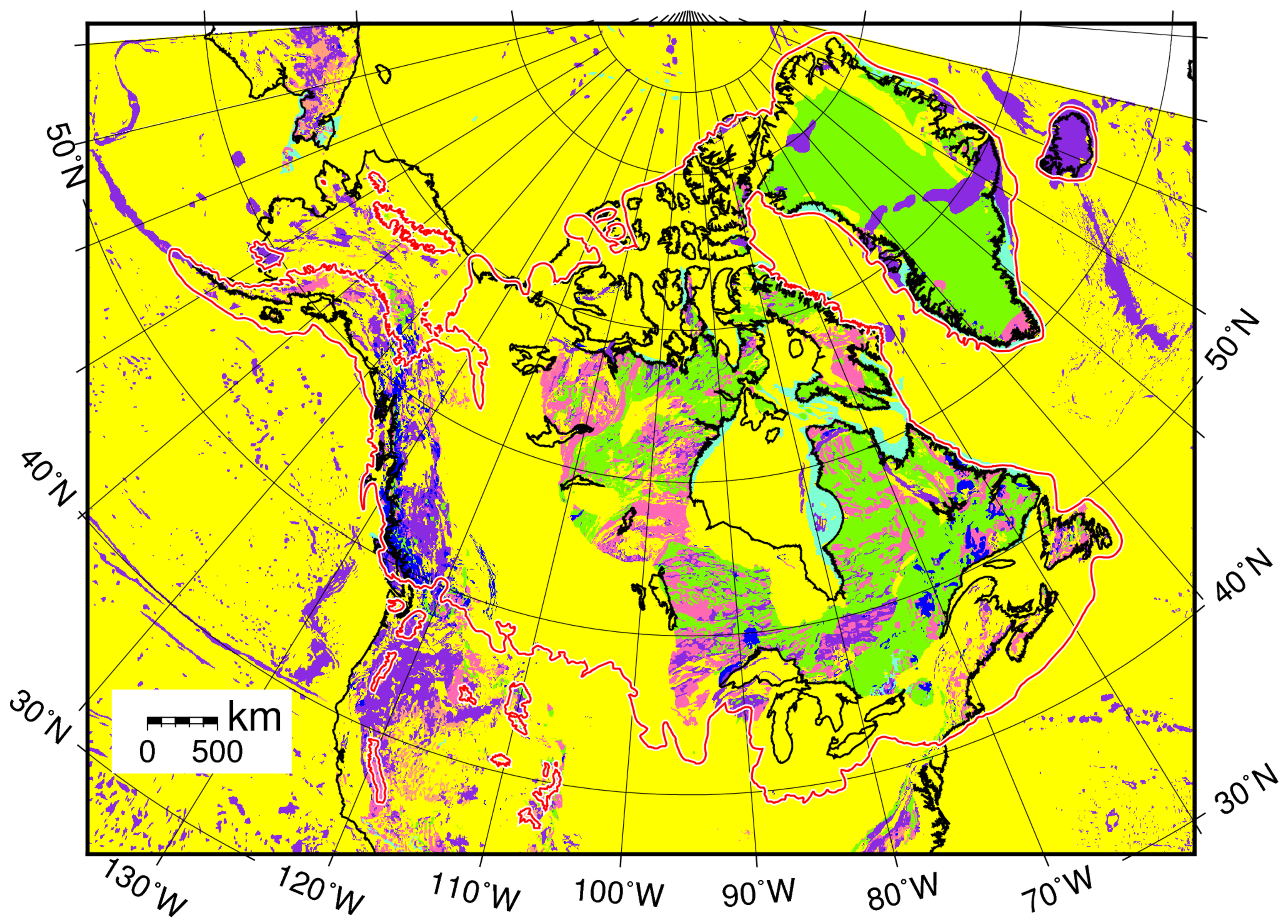
Basal sediment composition



Clay Silt Sand

~21000 yr BP extent (Dyke 2004)

Bedrock geology



Sedimentary Mafic plutonic Mafic volcanic

Felsic plutonic Felsic volcanic

Low grade metamorphic High grade metamorphic

~21000 yr BP extent (Dyke 2004)

The Laurentide ice sheet had notable differences in behavior depending on whether the dynamic part of the ice sheet laid on the "hard bedded" Canadian Shield, or the "soft bedded" sedimentary basins at the southern and western peripheries and Hudson Bay. In the "soft bedded" regions, the ice sheet profile was lower, and there were numerous ice streams, possibly aided by sediment deformation. In "hard bedded" regions, the hydrological regime was dramatically different, as water escaped the subsuface through vast esker systems. Bedrock type may also affect hydrological conditions, with porous rocks able to absorb meltwater. We present three datasets that will be used for modeling the basal conditions of the North American ice sheets.

- Basal sediment distribution: A qualitative assessment of the fraction of the base that is covered by sediment. The source datasets have varied definitions, but "**blanket**" means continuous coverage, "**veneer**" means the nature of the underlying bedrock is visible (< 3 m of sediment) and "**rock**" means that bedrock outcrops dominate the landscape.
- Basal sediment composition: Glacial sediment or till is an unsorted material with grain sizes between clay and boulder. The dominant grain size is influenced by the source material. Areas underlain by crystaline rocks tend to have a coarser fabric (**sand**), while till derived from proglacial lakes tend to be more clay rich (**clay**). Sediment derived from Phanerozoic sedimentary rocks tend to have an intermediate composition (**silt**). In areas without existing maps, the composition is inferred from the bedrock geology.
- Bedrock geology: This dataset is largely a simplified version of the Geologic Map of North America (Reed et al 2004). Sedimentary and volcanic rocks may have higher porosity and are better able to absorb water. These rocks also may be more prone to erosion than plutonic and high grade metamorphic rocks.

References:

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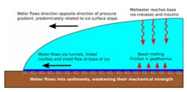

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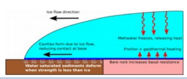

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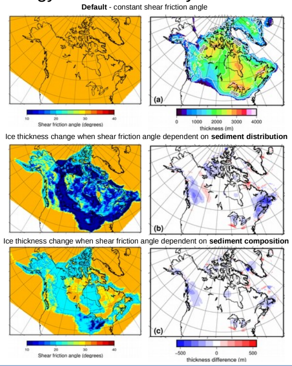

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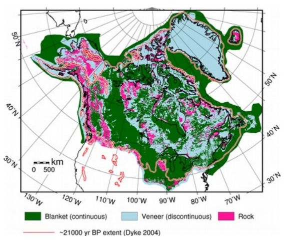

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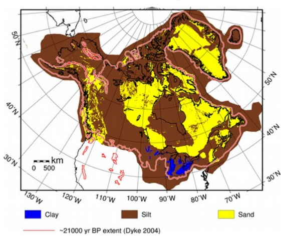
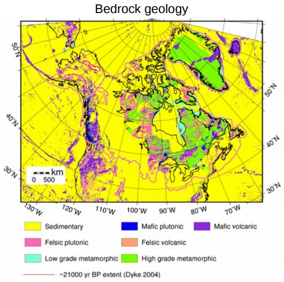


Bedrock geology



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