



Geology datasets of North America for use with ice sheet models

Evan J. Gowan¹, Lu Niu¹, Gregor Knorr¹, and Gerrit Lohmann¹

¹Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

Correspondence: Evan J. Gowan (evan.gowan@awi.de)

Abstract.

The ice-substrate interface is an important boundary condition for ice sheet modelling. The substrate affects the ice sheet by allowing sliding through sediment deformation and accommodating the storage and drainage of subglacial water. We present three datasets with different geological parameters for the region that was covered by the ice sheets in North America, including Greenland and Iceland. The first dataset includes the distribution surficial sediments, which is separated into continuous, discontinuous and predominantly rock categories. The second dataset includes sediment grain size properties, which is divided into three classes: clay, silt and sand, based on the dominant grain size of the glacial sediments. The third dataset is the generalized bedrock geology. We demonstrate the utility of these datasets for governing ice sheet dynamics by using an ice sheet model with a simulation that extends through the last glacial cycle. Changes in ice thickness by up to 40% relative to a reference simulation happened when the shear friction angle was reduced to account for a weaker substrate. These datasets provide a basis to improve the basal boundary conditions in ice sheet models.

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15 1 Introduction

Temperate ice sheets, such as the Laurentide and Eurasian ice sheets behaved differently depending on whether or not the substrate was covered by thick, continuous unconsolidated sediments (Clark and Walder, 1994). These sediments provided a potential pathway for subglacial water storage and drainage. Areas where crystalline bedrock is predominant at the surface tend to have eskers, indicating that subglacial water drained via large tunnel systems (Clark and Walder, 1994). The subglacial drainage where the surface is covered by continuous, unconsolidated sediments tends to be via linked channel systems (Carlson et al., 2007). The main cause of these different drainage regimes is likely related to the roughness of the bed (*i.e.* in areas with sediment cover, the surface is smoothed by the glacier, while in areas with bedrock outcrops will be more irregular). Sediment deformation in areas with continuous cover is also hypothesized to play a prominent role in the motion of glaciers (Boulton et al., 2001; Evans et al., 2006), possibly also including decoupling with the underlying, non-deforming surfaces (Kjær et al.,



2006). When sediments become water saturated, they become mechanically weaker than the overlying ice. If this happens, it causes a decoupling from the underlying bed and allows the ice to flow faster than with ice deformation alone. Whether or not this mechanism could have been spatially and temporally pervasive is still open to debate (Piotrowski et al., 2004; Iverson and Zoet, 2015).

- 5 In North America, there was a distinct difference in ice sheet behavior between the sparsely covered Canadian Shield and the sediment covered sedimentary basins at the southern and western fringes, and Hudson Bay and the Foxe Basins in the center and north. The most striking imprint of this in the geomorphological record is the reduced number of ice streams on much of the Canadian Shield, while areas covered with continuous sediments have many (Margold et al., 2015). The presence or absence influenced the distribution of ribbed moraine, drumlins and eskers on the Canadian Shield (Aylsworth and Shilts, 10 1989). Retreat of the Laurentide Ice Sheet after the Last Glacial Maximum (LGM) also slowed when the ice sheet became confined to the Canadian Shield (Dyke, 2004). During the advance of the ice sheet prior to the LGM, the margin remained close to the Canadian Shield boundary until the ice sheet reached a threshold that allowed to advance onto the surrounding plains (Dyke et al., 2002). The part of the ice sheet that covered the plains had a low profile relative to the Canadian Shield, which has been attributed to this contrast in basal conditions (Fisher et al., 1985; Licciardi et al., 1998; Gowan et al., 2016).
- 15 Observations of the dynamics in modern glaciers, for instance in Svalbard, are strongly governed by whether or not they lay on sedimentary or crystalline bedrock (*e.g.* Jiskoot et al., 2000). Areas underlain by sedimentary bedrock are more likely to a thick, fine grained till that is easier to deform when subjected to water saturated conditions.

Having realistic basal conditions is essential in numerical ice sheet modelling. Many ice sheet modelling studies of the Laurentide Ice Sheet (Calov et al., 2002; Tarasov and Peltier, 2004; Gregoire et al., 2012; Abe-Ouchi et al., 2013) used the global 20 sediment thickness map (Laske and Masters, 1997), which was designed for seismology applications rather than surficial processes. This dataset reflects the thickness of Phanerozoic sedimentary rocks that have not undergone significant metamorphism. This map does not reflect the actual distribution of unconsolidated sediments, as many regions of the Canadian Shield do have continuous sediment cover (Aylsworth and Shilts, 1989), and there are regions of discontinuous unconsolidated sediment cover where there is sedimentary bedrock (Fulton, 1995; Soller and Garrity, 2018). This dataset also misses Precambrian sedimentary 25 basins that are overlain by unconsolidated sediments that were modified by ice sheets (Cofaigh et al., 2013). The direct impacts on ice sheet dynamics may only depend on the uppermost few meters of unconsolidated sediment (Boulton et al., 2001; Iverson and Zoet, 2015), so this map may not be representative of the sediment properties that affected the ice sheet. More recently, Stokes et al. (2012) and Tarasov et al. (2012) used a more complete parameterization with additional data from the surficial materials map by Fulton (1995). They use a parameter from 0 (no sediments) to 1 (pervasive sediments). Previous modelling 30 studies did not directly account for variability in the grain size or other properties of the sediments.

In order to gain flexibility in parameterizing sediment parameters for ice sheet modelling, we present three datasets. These data come from existing surficial geological maps when possible, and inferred from other studies where coverage is not complete. (i) The *Sediment distribution dataset* contains information on the distribution of sediment cover, whether continuous, veneer, or dominantly bedrock. (ii) The *sediment grain size dataset* contains information on the average grain size of the sediments. This is based on common geological descriptions of sandy, silty and clay rich diamiction and glacial sediments. (iii)



The *bedrock geology dataset* contains the generalized bedrock type, including distinctions between sedimentary, igneous and metamorphic rocks. These data can be used in a variety of ways, such as by changing the mechanical strength and frictional resistance of the sediment (such as the shear friction angle), effects of hydrology (porosity and permeability of the sediments or rock, type of drainage), roughness of the bed, and the erodibility of substrate.

In order to be usable in ice sheet models, it is necessary to have a continuous dataset. Since existing geological map datasets are discontinuous, due to the presence of post-glacial sediments and water bodies, we had to fill in these gaps. These datasets include supplementary information from geophysical surveys and coring studies to compliment existing maps. We also made an inference on grain size properties in the vast regions without information by using geological maps.

2 Description of datasets

2.1 Overview and construction

With this dataset, the goal is to represent the subglacial sediment properties for the most recent glaciation, the late Wisconsin glaciation in North America, for use in paleo-ice sheet modelling and reconstruction. The late Wisconsin extended between about 31 000 and 34 000 yr BP (years before present) to about 7000 yr BP (Dyke et al., 2002). For ice sheet modelling, using the modern day distribution and composition of glacial sediments is likely sufficient to use as a boundary condition for the most recent glacial period, though further back in time, this assumption may not be valid (Clark and Pollard, 1998). There are great uncertainties in many of the boundary conditions used in ice sheet modelling, such as uncertainties in past atmospheric and ocean conditions, but sediment cover likely does not change that greatly in a single glaciation (Piotrowski et al., 2001), so we do not feel this is a major setback for the use of this dataset. We want to emphasize that the categories chosen for this dataset are simplified from some of the original data sources in order to make it easier for ice sheet modellers to manipulate a limited range of parameters, rather than match specific geological observations that may only be applicable very small regions. The lack of sediment grain size information over much of Canada also precludes a large range of geological parameters. When ice sheet modelling, it is necessary to have continuous boundary conditions over the whole domain. In areas without geological information, it is necessary to make inferences on the properties based on alternative sources of information, such as bedrock geology maps.

The three datasets are largely based on existing surficial and bedrock geology maps (Table 1). Wherever possible, we used the most up-to-date regional scale (*i.e.* >1:500,000 scale) maps, in order to make it possible to construct the entire dataset in a reasonable amount of time. For the sediment distribution data, where there was overlapping with the map by Fulton (1995), we favoured the more recent dataset. The first step was to import the existing shapefiles of the maps (or digitizing paper maps if not available), and break up the units into the classification schemes that we are using. This involved removing any water bodies and post-glacial sediment units from the maps, and simplifying glacial that had a more complex scheme than we use. The resulting datasets have gaps. To fill in the gaps, we expanded the polygons in a way to favour the dominant unit in the region, or to extend the trend of elongated units. The datasets were edited using ArcGIS and QGIS.



There are many areas where late Wisconsin till is buried by glacio-fluvial and Holocene non-glacial sediments, so the nature or existence of glacial sediments is uncertain. This is also true for previously glaciated areas under lakes and the oceans and places currently covered in glaciers, ice caps and the Greenland Ice Sheet. In these regions, we tried to find published sediment cores, sedimentary sections, and geophysical data that can be used to estimate the the properties of the sediments (Table 2).

5 We incorporate sediment data from areas outside of the late Wisconsin limit, as in an ice sheet simulation, the exact margin of the ice sheet is unlikely to match the geologically constrained limit, and could become more expansive. For areas south of the Laurentide Ice Sheet limit, there is glacial sediment from more extensive, older glaciations. These data were taken from the US quadrangle maps (Table 1). In other areas such as Alaska and offshore regions, we take the properties from non-glacial sediments and inferences from bedrock geology maps.

10 In the creation of the dataset, existing shapefile compilations were used if available, which have variable resolution. To simplify the datasets when the originals were high resolution, we used bend simplify tool in the ARCGIS Cartography/generalization Toolbox, with a tolerance of 5 km, and minimum area of 25 km² (25000000 m²). This is visually similar to the generalization that was used in the surficial materials map by Fulton (1995). Any polygon that had a total area that was less than 2.25 km² (2250000 m²) was merged to the polygon that had the largest shared border to further simplify the dataset.

15 2.2 Sediment distribution dataset

The map of glacial sediment distribution is shown on Figure 1. Data sources for this dataset are shown in Table 1. By "glacial sediment" we are referring to sediment that is produced as a direct result of glacial action. In a generic sense, it is synonymous with diamiction or till, an unsorted sediment with grain size ranging from clay to boulder. When possible, we try to determine the distribution of glacial sediments in extensive areas covered by post-glacial cover and water bodies (see Table 2). A detailed explanation for the distribution units, which is based on the scheme found on the Surficial Materials of Canada map by Fulton (1995) is as follows:

25 **Rock:** Bedrock outcrops are predominant (>75% of the surface area is exposed bedrock (Fulton, 1995)) and extensive glacial sediment deposits are rare. We include "regolith" areas in the northern Canadian archipelago, which were not pervasively affected by late Wisconsin glaciation (even if the upper layer was not well consolidated) and therefore do not produce glacial sediment deposits.

30 **Veneer:** Many maps seem to have a different definition on what "veneer" means. In general, it means that glacial sediment deposit are discontinuous (can be zero thickness), but the area covered in glacial sediment exceeds that of exposed rock. The topography of the underlying bedrock is usually visible in these areas. In most maps, these areas have "thin" cover, with thin being defined as anything between less than one meter to as much as ten meters. Commonly, the cutoff is set to be 2-3 meters, although some maps (*e.g.* the Surficial Materials map of Canada by Fulton (1995)) do not explicitly state a value. A recommended thickness value setting for veneer areas should be less than three meters to conform to the most common description of "veneer" provided in maps used in this dataset, though even a thin layer of glacial sediment might affect the dynamics of an ice sheet (Evans et al., 2006).



Blanket: These regions are defined as regionally continuous glacial sediment. As with the "vener" classification, it is not always clear what thickness or distribution is used as a threshold for defining "blanket". If values are given, the threshold is usually greater than three meters. In areas with a blanket of sediment, generally the underlying bedrock topography is not obvious. Glacial sediment units that are described as "hummocky" are included in this definition. These glacial sediments formed during stagnation of the ice sheet, and are commonly found on elevated regions in western Canada (Eyles et al., 1999). The thickness can vary from a few meters to more than 25 meters, but it is assumed here that these deposits are at least three meters and can be put into the blanket definition.

2.3 Sediment grain size dataset

The map of generalized grain size of glacial sediments is shown on Figure 3. To simplify the classification, we only have three main classification types, based on the dominant grain size of the sediments. This classification scheme is based on the Surficial Materials in the Conterminous United States map (Soller and Reheis, 2004), and we attempted to unify this scheme with maps and data in Canada. Glacial sediments tend to be very poorly sorted, so these values should be assessed as being an average composition. A glacial sediment, diamiction or till (the later has a definitive glacial origin) is an unsorted material with grain size ranging from clay to boulder, but the average grain size can vary depending on the local source material. As an example, in the map by Soller and Reheis (2004), clay rich glacial sediment exists in areas around the Great Lakes, where source material was derived from lake sediments, and sandy glacial sediment exists in mountainous regions where there are extensive rock outcrops.

clay: Glacial sediment has a large clay component (>50%).

silt: intermediate of clay and sand dominant composition. This unit includes any description called "loamy till", which is a soil with an average grain size between sand and silt.

sand: Sand rich till, with the possible presence of abundant coarser grained (pebble to boulder sized) material, with only minor clay component and more sand than silt.

Many maps do not give specific classifications of the grain size of glacial sediments. The United States quadrangle maps (Table 1), which cover most areas south of about 54° north (except in the Cordillera), fortunately do have this information. The lack of information north of this is likely due to accessibility issues, where there are few extensive geology/soil/engineering surveys that would serve as the basis for such a map. As a result, the sediment type for many of these regions was derived from bedrock geology maps. In general, glacial sediments in North America have a composition that similar to the underlying bedrock (Fulton, 1989), so we assume that the grain size should be related to the bedrock geology. Our approach for classifying grain size from geology maps is as follows:

silt: fine grained clastic sedimentary rocks (shale, carbonates); mafic igneous rocks; undivided igneous rocks; low grade metamorphic rocks (*e.g.* greenschist)

sand: course grained clastic sedimentary rocks (sandstone, conglomerate); felsic igneous rocks; high grade metamorphic rocks (*e.g.* gneiss)



2.4 Bedrock geology dataset

This dataset is a simplification of the Geologic Map of North America (Reed et al., 2004; Garrity and Soller, 2009). For the area covered by the Greenland Ice Sheet, we use the map by Dawes (2009). The rocks were divided into the following groups:

5 **Sedimentary:** All units described as being sedimentary.

Felsic plutonic: All rocks explicitly described as felsic igneous (*e.g.* granite), charnockite, units described as being "felsic and intermediate" and units that were undivided mafic and felsic rocks.

Felsic volcanic: Same as felsic plutonic, but explicitly described as volcanic (*e.g.* rhyolite)

10 **Mafic plutonic:** All rocks explicitly described as mafic igneous (*e.g.* gabbro), units described as being "intermediate" and "intermediate and intermediate", alkaline, and units that were undivided mafic and felsic rocks.

Felsic volcanic: Same as plutonic, but explicitly described as volcanic (*e.g.* basalt), also includes volcanic deposits that are described as having interlayered sedimentary layers

low grade metamorphic: Marble, plus units described as being "undivided crystalline rocks"

high grade metamorphic: Units that are highly metamorphosed *i.e.* gneiss

15 The map has few units that can be confidently placed in the low grade metamorphic class, because most of these units are grouped with their non-metamorphosed source rock class. Therefore it should be assumed that many of the areas with igneous and sedimentary rocks have undergone some level of metamorphism, particularly on the Canadian Shield. We placed the "undivided unit" in the low grade category, as these most of these areas are in the continental shelf where no geophysical surveys or sampling has taken place. The description given in the original dataset indicates that these rocks likely contain some
20 amount of metamorphism. It can be assumed that these rocks along the Atlantic coast were probably subjected to some amount of metamorphism during the opening of the Atlantic Ocean, or in the case of Hudson Bay are likely part of the Precambrian Shield.

2.5 Caveats

In this compilation, we tried to incorporate the most recent information on surficial geology that was available. Unfortunately,
25 there are places where, due to discrepancies between adjacent maps, there are visible seams. This is especially evident at the Yukon-Alaska border and the British Columbia - Washington border. Obviously, these areas will be in need of revision when new mapping information becomes available. There are also discrepancies in interpretation and classification between maps. A good example is the dataset we used for Manitoba (Matile and Keller, 2006), which had only two classes for distribution (blanket and rock). The corresponding map by Fulton (1995) divides the regions that are classified as "rock" into veneer and
30 rock. Since our intention is to use the most up-to-date information, we use the dataset by Matile and Keller (2006), but with the caveat that this also causes a seam with the adjacent regions in northern Ontario and Saskatchewan that has a broader classification scheme.



3 Usage in ice sheet models

3.1 Parameters

Some general properties of sediment grain size types are shown on Table 3. Most of these properties are described in more detail in Cuffey and Paterson (2010). These properties are only given in a qualitative manner because there have been relatively few in-situ or laboratory measurements of these properties over a range of composition (Iverson and Zoet, 2015). Measured permeability values were reported to be between 10^{13} – 10^{16} m² (Cuffey and Paterson, 2010). It is recommended that when modelling the behavior of ice sheets, that a range of values be explored.

The effect of sediment distribution on ice sheet models is less well known. The patchiness of sediments may result in "sticky spots", primarily though bedrock knobs that resist the flow of ice (Alley, 1993). The lack of sediment in an otherwise sediment covered region may increase resistance to flow as well (Stokes et al., 2007). The influence later process is likely controlled by the availability of subglacial water. All of the thickness categories made in this dataset are derived from existing geological maps. Because of inconsistencies in classification between maps, and vast regions where there are few direct observations, it is not possible to give a detailed quantitative estimates of distribution or thickness. These exact values of the percentage of surface cover, and sediment thickness can be set as a variable in ice sheet models.

The geological map can be used for determining the erosive properties of the rocks, the source material of glacial sediment (as we did for the grain size dataset), and drainage of water under the ice. For the later case, the transition from Precambrian rock and sedimentary rock has been used to explain the relative absence of eskers south of the Canadian Shield by accommodating the basal meltwater (Grasby and Chen, 2005). Modelling of the effect of bedrock on subglacial water routing has been done by Carlson et al. (2007).

3.2 Example of usage of datasets in an ice sheet model

To show the utility of the dataset, we incorporate the information for use with the ice sheet model PISM 1.0 (Bueler and Brown, 2009; PISM authors, 2017), with the addition of an index forcing scheme described in (Niu et al., 2017). In PISM, the basal sediments influence ice sheet dynamics by assuming they deform as a Mohr-Coulomb plastic material (Tulaczyk et al., 2000). The relationship that governs the relationship between the material and the yield stress, τ_c , is:

$$\tau_c = c_o + N \tan(\phi) \quad (1)$$

The sediment parameters include the apparent cohesion, c_o , and the shear friction angle, ϕ . The cohesion is generally regarded as insignificant (Cuffey and Paterson, 2010) and set to zero in most ice sheet simulations (Bueler and Brown, 2009). The shear friction angle is the angle that a material will fracture given a normal stress above its yield strength. This is the primary factor used to tune the basal sediment strength in PISM. In situ and laboratory experimental values of ϕ for glacial sediments have a large range, between 18° and 40° (Cuffey and Paterson, 2010). The parameter N is the difference between the normal stress from the load of the ice sheet and the water pressure in the sediments. In PISM, this factor is generally high



enough that the sediments will not deform unless they are saturated. In our simulations, $N = 0.01$ when saturated. For the tests of these datasets, we only adjust ϕ .

The results shown below are for an ice sheet model that is run for the entire last glacial cycle, the past 122 000 years. A time slice at 21 000 yr BP is chosen to display the effect of changing the sediment friction angle, as this was when the North American ice sheets were near their maximum extent (Dyke, 2004). Niu et al. (2017) provide a full description of the parameters related to other boundary conditions. The shear friction angle used in their study was a constant 30° , so to show the effects of changes in basal geological parameters, this value is lowered. The results given below are just to show the effects of changing the basal properties, we make no recommendation of what the values should be. Ultimately, the model used in PISM is dependent on having enough water produced to saturate the sediment layer (Bueler and Brown, 2009). If the water production is too low (*i.e.* the basal temperature of the ice is below pressure melting point), changing the shear friction angle will have no effect on the simulation. Therefore, in the cases shown in this section, the largest changes occur in places where there is significant ice flow, or are connected to ocean basins. Efforts to combine the effects of these datasets with ice sheet hydrology and ice dynamics are ongoing, and show that this model substantially underestimates that amount of water that should be available at the base (Gowan et al., 2018).

The basal conditions model in PISM is based on the assumption that the entire base of the ice sheet is covered in potentially deformable sediments, the strength of which is controlled by the sediment shear friction angle. A lower angle will weaken the ice-bed interface, and therefore encourage sliding. The philosophy of the choice of shear friction angle in these examples is as follows. Areas with continuous sediment cover should be weak, since sediment deformation will be the dominant factor in sliding. The angle in sediment covered areas are lowered from the reference value to accommodate this. For the grain size data, finer grained sediments will be weaker than coarse grained sediments, so the angle in areas with finer sediments are lowered from the reference value. For the geology dataset, we expect that areas underlain with sedimentary and mafic volcanic rocks will be more prone to erosional effects, and therefore more likely to produce unconsolidated sediments, and should therefore be weaker. The angle in these areas are reduced from the reference to simulate this effect.

3.2.1 Impact of sediment distribution

The basal boundary condition in PISM has an assumption that continuous sediment cover is over the entire domain (Bueler and Brown, 2009). In order to simulate the differences in sediment distribution, the shear friction angle is changed depending on the coverage. For continuous areas, it is set to $\phi = 10^\circ$ (weak, deformable bed), for discontinuous areas it is set to $\phi = 20^\circ$, and for dominantly rock it is set to $\phi = 30^\circ$ (strong, undeformable bed). Using these values, most of the Canadian Shield has a shear friction angle of 20° , while areas underlain by Phanerozoic sedimentary rocks have values of 10° . The impact of this is that there are reductions of ice along the east coast of Canada, the Cordillera, the Great Lakes region, and western Arctic Archipelago and Greenland by up to 40% (Figure 4). There is also an increase in ice thickness in the area east of the Cordillera (5-10% greater), south of the Great Lakes and in Hudson Strait. The lower resistance to flow likely leads the ice sheet to flow further south of the Great Lakes relative to the default simulation. The lack of change in the Canadian Shield, despite decreasing the shear friction angle, is most likely due to the lack of meltwater production to cause a reduction in basal strength.



5 3.2.2 Impact of sediment grain size

To test the effects of sediment grain size type, the input map from Figure 2 was converted to a shear friction angle input by setting clay to $\phi = 10^\circ$, silt to $\phi = 20^\circ$ and sand to $\phi = 30^\circ$. This simulates the fact that clay rich sediments are mechanically weaker, even though an angle of $\phi = 10^\circ$ is below the low end of measurements of real till (Cuffey and Paterson, 2010). The difference in ice thickness at 21 000 yr BP is shown on Figure 5. In this case, most of the Canadian Shield, Greenland and parts of Cordillera have a shear friction angle of 30° , some areas south of the Great Lakes are 10° , while the rest is 20° . The end result at 21 000 yr BP is that there is less change in the simulation compared to the reference. There is a slight reduction in ice thickness in the Cordillera (10-20%) and east coast of Canada (5-10%). South of the Great Lakes, where there is clay rich till with an angle of 10° , the ice sheet goes further south than the reference simulation.

3.2.3 Impact of bedrock geology

The effects of bedrock geology are shown on Figure 6. For this simulation, we adjusted the shear friction angle downwards for geological types that are more likely erode to produce deformable sediments. Sedimentary rocks are given an angle of $\phi = 10^\circ$, to indicate their relative weakness. Low grade metamorphic rocks (which includes areas where the geology is uncertain), are given an angle of $\phi = 20^\circ$. Volcanic rocks are assigned a value of $\phi = 25^\circ$, as they should be more likely to be erodible than plutonic rocks. Plutonic rocks and high grade metamorphic rocks retain the default value of $\phi = 30^\circ$. The results show a decrease in ice thickness in the Cordillera, Canadian Archipelago, eastern Canada and northeastern Greenland by up to about 30%. These areas are largely underlain by sedimentary rocks. As with the other simulations, south of the Great Lakes region, the ice sheet goes further south than the reference simulation.

4 Conclusions

We have presented three datasets that present different types of geological data, including sediment distribution, grain size, and bedrock geology. These datasets are intended for use in ice sheet models, where the geological parameters will have impacts on ice sheet dynamics and hydrology. We demonstrated that changing the basal conditions in an ice sheet model on the basis of these datasets do impact the thickness of the ice. With these datasets, we hope that improvements can be made to ice sheet models to incorporate this geological data and gain a better understanding of basal conditions.

5 Data availability

Gowan, E.J., Niu, L., Knorr, G., and Lohmann, G., 2018. Geology datasets of North America for use with ice sheet models, link to datafiles. *PANGAEA*, <https://doi.pangaea.de/10.1594/PANGAEA.895889>



Author contributions. EJG compiled the datasets and was the main author of the text. LN designed the ice sheet model simulation. All authors contributed to the text and design of the study.

Competing interests. There are no competing interests.

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References

- 15 Abe-Ouchi, A., Saito, F., Kawamura, K., Raymo, M. E., Okuno, J., Takahashi, K., and Blatter, H.: Insolation-driven 100,000-year glacial cycles and hysteresis of ice-sheet volume, *Nature*, 500, 190–193, 2013.
- Alley, R. B.: In search of ice-stream sticky spots, *Journal of Glaciology*, 39, 447–454, <https://doi.org/10.3189/S0022143000016336>, 1993.
- Aylsworth, J. M. and Shilts, W. W.: Bedforms of the Keewatin ice sheet, Canada, *Sedimentary Geology*, 62, 407–428, [https://doi.org/10.1016/0037-0738\(89\)90129-2](https://doi.org/10.1016/0037-0738(89)90129-2), 1989.
- 20 Batchelor, C. L., Dowdeswell, J. A., and Pietras, J. T.: Seismic stratigraphy, sedimentary architecture and palaeo-glaciology of the Mackenzie Trough: evidence for two Quaternary ice advances and limited fan development on the western Canadian Beaufort Sea margin, *Quaternary Science Reviews*, 65, 73–87, <https://doi.org/10.1016/j.quascirev.2013.01.021>, 2013.
- Booth, D. B.: Glaciofluvial infilling and scour of the Puget Lowland, Washington, during ice-sheet glaciation, *Geology*, 22, 695–698, [https://doi.org/10.1130/0091-7613\(1994\)022<0695:GIASOT>2.3.CO;2](https://doi.org/10.1130/0091-7613(1994)022<0695:GIASOT>2.3.CO;2), 1994.
- 25 Borns, N. R., Gadd, P. L., Martineau, G., Chauvin, L., Fulton, R. J., Chapman, W. F., Wagner, W. P., Grant, D. R., and Martin, G.: Quaternary geologic map of the Quebec 4 degrees x 6 degrees quadrangle, United States and Canada, USGS Numbered Series IMAP 1420(NL-19), U.S. Geological Survey, scale 1:1,000,000, 1987.
- Bouchard, M. A.: Subglacial landforms and deposits in central and northern Quebec, Canada, with emphasis on Rogen moraines, *Sedimentary Geology*, 62, 293–308, [https://doi.org/10.1016/0037-0738\(89\)90120-6](https://doi.org/10.1016/0037-0738(89)90120-6), 1989.
- 30 Boulton, G. S., Dobbie, K. E., and Zatsepin, S.: Sediment deformation beneath glaciers and its coupling to the subglacial hydraulic system, *Quaternary International*, 86, 3–28, [https://doi.org/10.1016/S1040-6182\(01\)00048-9](https://doi.org/10.1016/S1040-6182(01)00048-9), 2001.
- Bueller, E. and Brown, J.: Shallow shelf approximation as a "sliding law" in a thermodynamically-coupled ice sheet model, *J. Geophys. Res.*, 114, <https://doi.org/10.1029/2008JF001179>, 2009.
- Calov, R., Ganopolski, A., Petoukhov, V., Claussen, M., and Greve, R.: Large-scale instabilities of the Laurentide ice sheet simulated in a fully coupled climate-system model, *Geophysical Research Letters*, 29, 2002.
- 35 Carlson, A. E., Jenson, J. W., and Clark, P. U.: Modeling the subglacial hydrology of the James Lobe of the Laurentide Ice Sheet, *Quaternary Science Reviews*, 26, 1384–1397, <https://doi.org/10.1016/j.quascirev.2007.02.002>, 2007.
- Christoffersen, P., Tulaczyk, S., Wattrus, N. J., Peterson, J., Quintana-Krupinski, N., Clark, C. D., and Sjunneskog, C.: Large subglacial lake beneath the Laurentide Ice Sheet inferred from sedimentary sequences, *Geology*, 36, 563–566, <https://doi.org/10.1130/G24628A.1>, 2008.
- Clague, J. J.: Quaternary geology of the Canadian Cordillera, in: *Quaternary Geology of Canada and Greenland*, edited by Fulton, R. J., no. 1
- 5 in *Geology of Canada*, chap. 1, pp. 17–96, Geological Survey of Canada, 1989.
- Clague, J. J., Fulton, R. J., and Ryder, J. M.: Surficial geology, Vancouver Island and adjacent mainland, British Columbia, map, scale 1:1,000,000, 1982.
- Clark, P. U. and Pollard, D.: Origin of the middle Pleistocene transition by ice sheet erosion of regolith, *Paleoceanography and Paleoclimatology*, 13, 1–9, 1998.
- 10 Clark, P. U. and Walder, J. S.: Subglacial drainage, eskers, and deforming beds beneath the Laurentide and Eurasian ice sheets, *Geological Society of America Bulletin*, 106, 304–314, [https://doi.org/10.1130/0016-7606\(1994\)106<0304:SDEADB>2.3.CO;2](https://doi.org/10.1130/0016-7606(1994)106<0304:SDEADB>2.3.CO;2), 1994.
- Cofaigh, C. Ó., Stokes, C. R., Lian, O. B., Clark, C. D., and Tulaczyk, S.: Formation of mega-scale glacial lineations on the Dubawnt Lake Ice Stream bed: 2. Sedimentology and stratigraphy, *Quaternary Science Reviews*, 77, 210–227, 2013.



- Corbett, L. B., Bierman, P. R., Lasher, G. E., and Rood, D. H.: Landscape chronology and glacial history in Thule, northwest Greenland,
15 Quaternary Science Reviews, 109, 57–67, <https://doi.org/10.1016/j.quascirev.2014.11.019>, 2015.
- Cuffey, K. M. and Paterson, W. S. B.: The physics of glaciers, Elsevier, 2010.
- Dawes, P. R.: The bedrock geology under the Inland Ice: the next major challenge for Greenland mapping, Geological Survey of Denmark
and Greenland Bulletin, 17, 2009.
- Denne, J. E., Luza, K. V., Richmond, G. M., Jensen, K. M., Fishman, W. D., and Wermund, E. G.: Quaternary Geologic Map of the Wichita
20 4° x 6° Quadrangle, United States, USGS Numbered Series I-1420 (NJ-14), U.S. Geological Survey, scale 1:1 000 000, 1993.
- Dowdeswell, J. A., Evans, J., and Cofaigh, C. Ó.: Submarine landforms and shallow acoustic stratigraphy of a 400
km-long fjord-shelf-slope transect, Kangerlussuaq margin, East Greenland, Quaternary Science Reviews, 29, 3359–3369,
<https://doi.org/10.1016/j.quascirev.2010.06.006>, 2010.
- Duchesne, M. J., Pinet, N., Bédard, K., St-Onge, G., Lajeunesse, P., Campbell, D. C., and Bolduc, A.: Role of the bedrock topography
25 in the Quaternary filling of a giant estuarine basin: the Lower St. Lawrence Estuary, Eastern Canada, Basin Research, 22, 933–951,
<https://doi.org/10.1111/j.1365-2117.2009.00457.x>, 2010.
- Duk-Rodkin, A. and Hughes, O. L.: Surficial Geology, Upper Ramparts River, District of Mackenzie, Northwest Territories, Map 1783A,
Geological Survey of Canada, scale 1:250 000, 1993.
- Dyke, A. S.: An outline of North American deglaciation with emphasis on central and northern Canada, in: Quaternary Glaciations—Extent
30 and Chronology - Part II: North America, edited by Ehlers, J., Gibbard, P. L., and Hughes, P. D., Developments in Quaternary Science,
pp. 373–424, Elsevier, [https://doi.org/10.1016/S1571-0866\(04\)80209-4](https://doi.org/10.1016/S1571-0866(04)80209-4), 2004.
- Dyke, A. S., Andrews, J. T., Clark, P. U., England, J. H., Miller, G. H., Shaw, J., and Villette, J. J.: The Laurentide and Innuitian ice sheets
during the Last Glacial Maximum, Quaternary Science Reviews, 21, 9–31, [https://doi.org/10.1016/S0277-3791\(01\)00095-6](https://doi.org/10.1016/S0277-3791(01)00095-6), 2002.
- Evans, D. J. A., Phillips, E. R., Hiemstra, J. F., and Auton, C. A.: Subglacial till: formation, sedimentary characteristics and classification,
35 Earth-Science Reviews, 78, 115–176, <https://doi.org/10.1016/j.earscirev.2006.04.001>, 2006.
- Eyles, N., Boyce, J. I., and Barendregt, R. W.: Hummocky moraine: sedimentary record of stagnant Laurentide Ice Sheet lobes resting on
soft beds, Sedimentary Geology, 123, 163–174, [https://doi.org/10.1016/S0037-0738\(98\)00129-8](https://doi.org/10.1016/S0037-0738(98)00129-8), 1999.
- Eyles, N., Moreno, L. A., and Sookhan, S.: Ice streams of the Late Wisconsin Cordilleran Ice Sheet in western North America, Quaternary
Science Reviews, 179, 87–122, <https://doi.org/10.1016/j.quascirev.2017.10.027>, 2018.
- Farrand, W. R., Mickelson, D. M., and ande J. E. Goebel, W. R. C.: Quaternary geologic map of the Lake Superior 4 degrees x 6 degrees
5 quadrangle, United States and Canada, USGS Numbered Series IMAF 1420(NL-16), U.S. Geological Survey, scale 1:1 000 000, 1984.
- Fisher, D., Reeh, N., and Langley, K.: Objective reconstructions of the Late Wisconsinan Laurentide Ice Sheet and the significance of
deformable beds, Géographie Physique et Quaternaire, 39, 229–238, 1985.
- Freire, F., Gyllencreutz, R., Greenwood, S. L., Mayer, L., Egilsson, A., Thorsteinsson, T., and Jakobsson, M.: High resolution mapping of
offshore and onshore glaciogenic features in metamorphic bedrock terrain, Melville Bay, northwestern Greenland, Geomorphology, 250,
10 29–40, <https://doi.org/10.1016/j.geomorph.2015.08.011>, 2015.
- Fullerton, D. S., Cowan, W. R., Sevon, W. D., Goldthwait, R. P., Farrand, W. R., Muller, E. H., Behling, R. E., and Stravers, J. A.: Quaternary
geologic map of the Lake Erie 4 degrees x 6 degrees quadrangle, United States and Canada, USGS Numbered Series IMAF 1420(NK-17),
U.S. Geological Survey, scale 1:1,000,000, 1991.



- Fullerton, D. S., Sevon, W. D., Muller, E. H., Judson, S., Black, R. F., Wagner, P. W., Hartshorn, J. H., Chapman, W. F., and Cowan, W. D.:
15 Quaternary geologic map of the Hudson River 4 degree x 6 degree quadrangle, United States and Canada, USGS Numbered Series IMAP
1420(NL-18), U.S. Geological Survey, scale 1:1,000,000, 1992.
- Fullerton, D. S., Gadd, N. R., Veillette, J. J., Wagner, P. W., and Chapman, W. F.: Quaternary geologic map of the Ottawa 4 degrees x 6
degrees quadrangle, United States and Canada, USGS Numbered Series IMAP 1420(NK-18), U.S. Geological Survey, scale 1:1,000,000,
1993.
- 20 Fullerton, D. S., Bluemle, J. P., Clayton, L., Steece, F. V., Tipton, M. J., Bretz, R., and Goebel, J. E.: Quaternary geologic map of the Dakotas
4 degrees x 6 degrees quadrangle, United States, USGS Numbered Series I-1420(NL-14), U.S. Geological Survey, scale 1:1,000,000,
1995.
- Fullerton, D. S., Ringrose, S. M., Clayton, L., Schreiner, B. T., and Goebel, J. E.: Quaternary geologic map of the Winnipeg 4 degrees x
6 degrees quadrangle, United States and Canada, USGS Numbered Series I-1420(NM-14), U.S. Geological Survey, scale 1:1,000,000,
25 2000.
- Fullerton, D. S., Colton, R. B., Bush, C. A., and Straub, A. W.: Map showing spatial and temporal relations of mountain and continental
glaciations on the northern plains, primarily in northern Montana and northwestern North Dakota, Scientific Investigations Map 2843,
United States Geological Survey, 1 map, 2004.
- Fullerton, D. S., Christiansen, E. A., Schreiner, B. T., Colton, R. B., and Clayton, L.: Quaternary Geologic Map of the Regina 4 Degrees x
30 6 Degrees Quadrangle, United States and Canada, USGS Numbered Series I-1420(NM-13), U.S. Geological Survey, scale 1:1,000,000,
2007.
- Fullerton, D. S., Colton, R. B., and Bush, C. A.: Quaternary geologic map of the Glasgow $1 \times 2^\circ$ quadrangle, Montana, Open-File Report
2012-1217, U.S. Geological Survey, scale 1:250,000, 2012.
- Fullerton, D. S., Colton, R. B., and Bush, C. A.: Quaternary geologic map of the Shelby $1 \times 2^\circ$ quadrangle, Montana, Open-File Report
35 2012-1170, U.S. Geological Survey, scale 1:250,000, 2013.
- Fullerton, D. S., Colton, R. B., and Bush, C. A.: Quaternary geologic map of the Wolf Point $1 \times 2^\circ$ quadrangle, Montana and North Dakota,
Open-File Report 2016-1142, U.S. Geological Survey, <https://doi.org/10.3133/ofr20161142>, scale 1:250,000, 2016.
- Fulton, R. J.: Quaternary Geology of Canada and Greenland, vol. 1 of *Geology of Canada, no. 1*, Geological Survey of Canada, Ottawa,
Canada, <https://doi.org/10.4095/127905>, 5 sheets, 1989.
- Fulton, R. J.: Surficial materials of Canada, Map 1880A, Geological Survey of Canada, <https://doi.org/10.4095/205040>, scale 1:5 000 000,
5 1995.
- Funder, S.: Quaternary Geology of the Ice-Free areas and Adjacent Shelves of Greenland, in: Quaternary Geology of Canada and Greenland,
edited by Fulton, R. J., 1, chap. 13, pp. 743–792, Geological Survey of Canada, 1989.
- Funder, S. and Klüver, B. G.: Quaternary Map of Greenland Scoresby Sund, Map Sheet 12, The Geological Survey of Greenland, scale
1,500,000, 1988.
- 10 Garrity, C. P. and Soller, D. R.: Database of the Geologic Map of North America; adapted from the map by J.C. Reed, Jr. and others (2005),
U.S. Geological Survey Data Series 424, U.S. Geological Survey, <https://pubs.usgs.gov/ds/424/>, 2009.
- Geological Survey of Canada: Surficial geology of Canada, Map Canadian Geoscience Map 195 (preliminary, surficial data model v. 2.0
conversion of Map 1880A), Geological Survey of Canada, <https://doi.org/10.4095/295462>, scale 1:5 000 000, 2014.



- Goebel, J. E., Mickelson, D. M., Farrand, W. R., Clayton, L., Knox, J. C., Cahow, A., C.Hobbs, H., and Walton Jr., M. S.: Quaternary geologic
15 map of the Minneapolis 4 degrees x 6 degrees quadrangle, United States, USGS Numbered Series I-1420(NL-15), U.S. Geological Survey,
scale 1:1,000,000, 1983.
- Government of Newfoundland and Labrador: Geoscience atlas, Tech. rep., Geological Survey Division of the Department of Natural Re-
sources, version: 3, Build: 1, Build Date: October 22, 2013, 2013.
- Gowan, E., Niu, L., Knorr, G., Lohmann, G., and Hinck, S.: Investigating the role of subglacial geology on ice sheet dynamics, EGU General
20 Assembly 2018, abstract EGU2018-7212 (scientific conference - presentation), 2018.
- Gowan, E. J., Tregoning, P., Purcell, A., Montillet, J.-P., and McClusky, S.: A model of the western Laurentide Ice Sheet, using observations
of glacial isostatic adjustment, *Quaternary Science Reviews*, 139, 1–16, <https://doi.org/doi:10.1016/j.quascirev.2016.03.003>, 2016.
- Grasby, S. E. and Chen, Z.: Subglacial recharge into the Western Canada Sedimentary Basin – Impact of Pleistocene glaciation on basin
hydrodynamics, *Geological Society of America Bulletin*, 117, 500–514, <https://doi.org/10.1130/B25571.1>, 2005.
- 25 Gray, H. H., Bleuer, N. K., Linebacker, J. A., Swadley, W. C., Richmond, G. M., Miller, R. A., Goldthwait, R. P., and Ward, R. A.: Qua-
ternary geologic map of the Louisville 4 degree x 6 degree quadrangle, United States, USGS Numbered Series IMAP 1420(NJ-16), U.S.
Geological Survey, scale 1:1 000 000, 1991.
- Gray, J. T. and Lauriol, B.: Dynamics of the late Wisconsin ice sheet in the Ungava Peninsula interpreted from geomorphological evidence,
Arctic and Alpine Research, pp. 289–310, <https://doi.org/10.2307/1551019>, 1985.
- 30 Gregoire, L. J., Payne, A. J., and Valdes, P. J.: Deglacial rapid sea level rises caused by ice-sheet saddle collapses, *Nature*, 487, 219–222,
<https://doi.org/10.1038/nature11257>, 2012.
- Gustafson, D. J.: A Geophysical Investigation of Dewatering Structures in Western Lake Superior, Master’s thesis, University of Minnesota,
2012.
- Håkansson, L., Alexanderson, H., Hjort, C., Möller, P., Briner, J. P., Aldahan, A., and Possnert, G.: Late Pleistocene glacial history of Jameson
35 Land, central East Greenland, derived from cosmogenic ¹⁰Be and ²⁶Al exposure dating, *Boreas*, 38, 244–260, 2009.
- Hallberg, G. R., Lineback, J. A., Mickelson, D. M., Knox, J. C., Goebel, J. E., Hobbs, H. C., Whitfield, J. W., Ward, R. A., Boellstorff, J. D.,
Swinehart, J. B., and Dreeszen, V. H.: Quaternary Geologic Map of the Des Moines 4 Degrees x 6 Degrees Quadrangle, United States,
USGS Numbered Series I-1420(NK-15), U.S. Geological Survey, scale 1:1,000,000, 1994.
- Harrison, J. C., St-Onge, M. R., Petrov, O. V., Strelnikov, S. I., Lopatin, B. G., Wilson, F. H., Tella, S., Paul, D., Lynds, T., Shokalsky, S. P.,
Hults, C. K., Bergman, S., Jepsen, H. F., and Solli, A.: Geological map of the Arctic, scale 1:5,000,000, 2011.
- Hartshorn, W. B., Thompson, W. F., Chapman, R. F., Black, G., Richmond, M., Grant, D. R., Fullerton, D. S., and Martin, G.: Quaternary
5 geologic map of the Boston 4 degrees x 6 degrees quadrangle, United States and Canada, USGS Numbered Series IMAP 1420(NK-19),
U.S. Geological Survey, scale 1:1,000,000, 1991.
- Henriksen, N., Higgins, A., Kalsbeek, F., and Pulvertaft, T. C. R.: Greenland from Archaean to Quaternary, *Geological Survey of Denmark
and Greenland Bulletin*, 18, 126, 2009.
- Hjort, C., Ingólfsson, Ó., and Norðdahl, H.: Late Quaternary geology and glacial history of Hornstrandir, northwest Iceland: a reconnaissance
10 study, *Jökull*, 35, e29, 1985.
- Howard, A. D., Behling, R. E., Wheeler, W. H., Daniels, R. B., Swadley, W., Richmond, G. M., Goldthwait, R. P., Sevon, W. D., and Miller,
R. A.: Quaternary geologic map of the Blue Ridge 4 degrees x 6 degrees quadrangle, United States, USGS Numbered Series IMAP
1420(NJ-17), U.S. Geological Survey, scale 1:1,000,000, 1991.



- Hutchinson, D. R., Lewis, C. F., and Hund, G. E.: Regional stratigraphic framework of surficial sediments and bedrock beneath Lake Ontario, *Géographie physique et Quaternaire*, 47, 337–352, 1993.
- Ingólfsson, Ó.: Late Weichselian glacial geology of the lower Borgarfjörður region, western Iceland: a preliminary report, *Arctic*, pp. 210–213, 1985.
- Iverson, N. R. and Zoet, L. K.: Experiments on the dynamics and sedimentary products of glacier slip, *Geomorphology*, 244, 121–134, <https://doi.org/10.1016/j.geomorph.2015.03.027>, 2015.
- 20 Jackson, G. D.: Geology, Belcher Islands, Nunavut, Open File 4923, Geological Survey of Canada, <https://doi.org/10.4095/292434>, scale 1:125,000, 2012.
- Jiskoot, H., Murray, T., and Boyle, P.: Controls on the distribution of surge-type glaciers in Svalbard, *Journal of Glaciology*, 46, 412–422, <https://doi.org/10.3189/172756500781833115>, 2000.
- Josenhans, H. and Lehman, S.: Late glacial stratigraphy and history of the Gulf of St. Lawrence, Canada, *Canadian Journal of Earth Sciences*, 25 36, 1327–1345, <https://doi.org/10.1139/e99-030>, 1999.
- Josenhans, H. W. and Zevenhuizen, J.: Dynamics of the Laurentide ice sheet in Hudson Bay, Canada, *Marine Geology*, 92, 1–26, [https://doi.org/10.1016/0025-3227\(90\)90024-E](https://doi.org/10.1016/0025-3227(90)90024-E), 1990.
- Karlstrom, T. N. V.: Surficial geology of Alaska, USGS Numbered Series IMAF 357, U.S. Geological Survey, scale 1:584,000, 1964.
- Karrow, P. F.: Quaternary Geology of the Great Lakes Subregion, in: *Quaternary Geology of Canada and Greenland*, edited by Fulton, R. J., 30 1, chap. 4, pp. 326–350, Geological Survey of Canada, 1989.
- King, E. L.: Quaternary unconsolidated sediment thickness on the Grand Banks of Newfoundland and northeast Newfoundland Shelf; a GIS database, Open File 7513, Geological Survey of Canada, <https://doi.org/10.4095/295113>, scale 1:500 000, 2014.
- Kjær, K. H., Larsen, E., van der Meer, J., Ingólfsson, Ó., Krüger, J., Benediktsson, Í. Ö., Knudsen, C. G., and Schomacker, A.: Subglacial decoupling at the sediment/bedrock interface: a new mechanism for rapid flowing ice, *Quaternary Science Reviews*, 25, 2704–2712, 35 <https://doi.org/10.1016/j.quascirev.2006.06.010>, 2006.
- Klassen, R.: Quaternary geology of the Southern Canadian Interior Plains, chap. 2, pp. 138–166, Geological Survey of Canada, 1989.
- Kovanen, D. J. and Slaymaker, O.: Glacial imprints of the Okanogan Lobe, southern margin of the Cordilleran Ice Sheet, *Journal of Quaternary Science*, 19, 547–565, <https://doi.org/10.1002/jqs.855>, 2004.
- Kullessa, B., Hubbard, A. L., Booth, A. D., Bougamont, M., Dow, C. F., Doyle, S. H., Christoffersen, P., Lindbäck, K., Pettersson, R., Fitzpatrick, A. A., et al.: Seismic evidence for complex sedimentary control of Greenland Ice Sheet flow, *Science advances*, 3, e1603 071, <https://doi.org/10.1126/sciadv.1603071>, 2017.
- 5 Larsen, N. K., Kjær, K. H., Funder, S., Möller, P., van der Meer, J. J., Schomacker, A., Linge, H., and Darby, D. A.: Late Quaternary glaciation history of northernmost Greenland—Evidence of shelf-based ice, *Quaternary Science Reviews*, 29, 3399–3414, 2010.
- Laske, G. and Masters, G.: A Global Digital Map of Sediment Thickness, *EOS Transactions*, 78, F483, 1997.
- Lewis, C. F. M., Cameron, G. D. M., King, E. L., Todd, B. J., and Blasco, S. M.: Structural contour, isopach and feature maps of Quaternary sediments in western Lake Ontario, Report INFO-0555, Atomic Energy Control Board, 1995.
- 10 Licciardi, J., Clark, P., Jenson, J., and Macayeal, D.: Deglaciation of a soft-bedded Laurentide Ice Sheet, *Quaternary Science Reviews*, 17, 427–448, [https://doi.org/10.1016/S0277-3791\(97\)00044-9](https://doi.org/10.1016/S0277-3791(97)00044-9), 1998.
- Lineback, J. A., Dell, C. I., and Gross, D. L.: Glacial and postglacial sediments in Lakes Superior and Michigan, *Geological Society of America Bulletin*, 90, 781–791, [https://doi.org/10.1130/0016-7606\(1979\)90<781:GAPSIL>2.0.CO;2](https://doi.org/10.1130/0016-7606(1979)90<781:GAPSIL>2.0.CO;2), 1979.



- Lineback, J. A., Bleuer, N. K., Mickelson, D. M., Farrand, W. R., and Goldthwait, R. P.: Quaternary geologic map of the Chicago 4 degrees
15 x 6 degrees quadrangle, United States, USGS Numbered Series IMAP 1420(NK-16), U.S. Geological Survey, scale 1:1 000 000, 1983.
- Lipovsky, P. S. and Bond, J. D.: Yukon digital surficial geology compilation, digital release 1, 08-Apr-2014, Yukon Geological Survey, 2014.
- Loring, D. H. and Nota, D. J. G.: Morphology and sediments of the Gulf of St. Lawrence, Bulletin of the Fisheries Research Board of Canada
182, Fisheries Research Board of Canada, 1973.
- MacLean, B.: Marine geology of Hudson Strait and Ungava Bay, Eastern Arctic Canada: Late Quaternary sediments, depositional en-
20 vironments, and late glacial-deglacial history derived from marine and terrestrial studies, Geological Survey of Canada Bulletin 566,
<https://doi.org/10.4095/212180>, 2001.
- MacLean, B., Blasco, S., Bennett, R., England, J., Rainey, W., Hughes-Clarke, J., and Beaudoin, J.: Ice keel seabed features in marine
channels of the central Canadian Arctic Archipelago: evidence for former ice streams and iceberg scouring, Quaternary Science Reviews,
29, 2280–2301, <https://doi.org/10.1016/j.quascirev.2010.05.032>, 2010.
- 25 MacLean, B., Blasco, S., Bennett, R., Lakeman, T., Hughes-Clarke, J., Kuus, P., and Patton, E.: New marine evidence
for a Late Wisconsinan ice stream in Amundsen Gulf, Arctic Canada, Quaternary Science Reviews, 114, 149–166,
<https://doi.org/10.1016/j.quascirev.2015.02.003>, 2015.
- Margold, M., Stokes, C. R., and Clark, C. D.: Ice streams in the Laurentide Ice Sheet: Identification, characteristics and comparison to
modern ice sheets, Earth-Science Reviews, 143, 117–146, 2015.
- 30 Massey, N. W. D., MacIntyre, D. G., Desjardins, P. J., and Cooney, R. T.: Digital map of British Columbia: whole province, GeoFile 2005-1,
B.C. Ministry of Energy and Mines, scale 1:1,000,000, 2005.
- Matile, G. L. D. and Keller, G. R.: Surficial Geology Compilation Map Series, Tech. rep., Manitoba Science, Technology, Energy and Mines,
Manitoba Geological Survey, <http://geoapp2.gov.mb.ca/website/surficialgeo/viewer.htm>, scale 1:1,000,000, 2006.
- McMartin, I., Dredge, L. A., Ford, K. L., and Kjarsgaard, I. M.: Till composition, provenance and stratigraphy beneath the Keewatin Ice
35 Divide, Schultz Lake area (NTS 66A), mainland Nunavut, Open File 5312, Geological Survey of Canada, 2006.
- Morlighem, M., Williams, C., Rignot, E., An, L., Arndt, J. E., Bamber, J. L., Catania, G., Chauché, N., Dowdeswell, J. A., Dorschel, B.,
et al.: BedMachine v3: Complete bed topography and ocean bathymetry mapping of Greenland from multibeam echo sounding combined
with mass conservation, Geophysical research letters, 44, <https://doi.org/10.1002/2017GL074954>, 2017.
- Niessen, F., Matthiessen, J., and Stein, R.: Sedimentary environment and glacial history of the Northwest Passage (Canadian Arctic
Archipelago) reconstructed from high-resolution acoustic data, Polarforschung, 79, 65–80, 2010.
- Niu, L., Lohmann, G., Hinck, S., and Gowan, E. J.: Sensitivity of atmospheric forcing on Northern Hemisphere ice sheets during the last
glacial-interglacial cycle using outputs from PMIP3, Climate of the Past Discussion, <https://doi.org/10.5194/cp-2017-105>, in review, 2017.
- 5 Ontario Geological Survey: Quaternary Geology of Ontario, Tech. Rep. Dataset 14, scale 1:1 000 000, digital map, 1997.
- Ontario Geological Survey: Surficial geology of southern Ontario, Miscellaneous Release Data 128, revised 2010, 2003.
- Piotrowski, J. A., Mickelson, D. M., Tulaczyk, S., Krzyszkowski, D., and Junge, F. W.: Were deforming subglacial beds beneath past ice
sheets really widespread?, Quaternary International, 86, 139–150, [https://doi.org/10.1016/S1040-6182\(01\)00056-8](https://doi.org/10.1016/S1040-6182(01)00056-8), 2001.
- Piotrowski, J. A., Larsen, N. K., and Junge, F. W.: Reflections on soft subglacial beds as a mosaic of deforming and stable spots, Quaternary
10 Science Reviews, 23, 993–1000, <https://doi.org/10.1016/j.quascirev.2004.01.006>, 2004.
- Piper, D. J. W., Mudie, P. J., Fader, G. B., Josenhans, H. W., MacLean, B., and Vilks, G.: Quaternary geology of the southwestern Canadian
Shield, in: Geology of the Continental Margin of Eastern Canada, edited by Keen, M. J. and Williams, G. L., Geology of Canada Series
2, chap. 10, pp. 475–607, Geological Survey of Canada, 1990.



- PISM authors: PISM, a Parallel Ice Sheet Model, <http://www.pism-docs.org>, 2017.
- 15 Plouffe, A.: Quaternary geology of the Fort Fraser and Manson River map areas, central British Columbia, Bulletin 554, Geological Survey of Canada, <https://doi.org/10.4095/211641>, scale 1:250,000, 2000.
- Prest, V. K.: Surficial Deposits of Prince Edward Island, Map 1366A, Geological Survey of Canada, <https://doi.org/10.4095/108971>, scale 1:126,720, 1973.
- Principato, S. M., Jennings, A. E., Kristjánisdóttir, G. B., and Andrews, J. T.: Glacial-marine or subglacial origin of diamicton units from the southwest and north Iceland shelf: implications for the glacial history of Iceland, *Journal of Sedimentary Research*, 75, 968–983, <https://doi.org/10.2110/jsr.2005.073>, 2005.
- 20 Rampton, V. N.: Quaternary geology of the Tuktoyaktuk coastlands, Northwest Territories, Memoir 423, Energy, Mines and Resources Canada, 1988.
- Reed, J. C., Wheeler, J. O., and Tucholke, B. E.: Geologic Map of North America: Decade of North American Geology, Map 001, Geological Society of America, scale 1:5 00 000, 2004.
- 25 Sado, E. V., Fullerton, D. S., Baker, C. L., and Farrand, W. R.: Quaternary Geologic Map of the Sudbury 4 Degrees × 6 Degrees Quadrangle, United States and Canada, USGS Numbered Series IMAF 1420(NL-17), U.S. Geological Survey, scale 1:1 000 000, 1993.
- Sado, E. V., Fullerton, D. S., and Farrand, W. R.: Quaternary Geologic Map of the Lake Nipigon 4 Degrees x 6 Degrees Quadrangle, United States and Canada, USGS Numbered Series IMAF 1420(NM-16), U.S. Geological Survey, scale 1:1 000 000, 1994.
- 30 Sado, E. V., Fullerton, D. S., Goebel, J. E., and Ringrose, S. M.: Quaternary Geologic Map of the Lake of the Woods 4 Degrees x 6 Degrees Quadrangle, United States and Canada, USGS Numbered Series I-1420(NM-15), U.S. Geological Survey, scale 1:1 000 000, 1995.
- Scholz, C. A.: Late and Post-glacial Lacustrine Sediment Distribution in western Lake Superior From Seismic Reflection Profiles, in: Thirtieth Annual Institute On Lake Superior Geology, pp. 61–62, Wausau, Wi United States, 1984.
- Schreiner, B. T.: Quaternary geology of the Precambrian Shield, Saskatchewan, Report 221, Saskatchewan Energy and Mines, Saskatchewan Geological Survey, scale: 1:1,000,00, 1984.
- 35 Soller, D. R. and Garrity, C. P.: Quaternary sediment thickness and bedrock topography of the glaciated United States east of the Rocky Mountains, Scientific Investigations Map 3392, U.S. Geological Survey, <https://doi.org/10.3133/sim3392>, scale 1:5,000,000, 2018.
- Soller, D. R. and Reheis, M. C.: Surficial Materials in the Conterminous United States, U.S. Geological Survey Open File Report OFR-03-275, U.S. Geological Survey, <https://pubs.er.usgs.gov/publication/ofr2003275>, scale 1:5,000,000, 2004.
- Soller, D. R., Reheis, M. C., Garrity, C. P., and Van Sistine, D. R.: Map Database for Surficial Materials in the Conterminous United States, U.S. Geological Survey Data Series 425, U.S. Geological Survey, <http://pubs.usgs.gov/ds/425>, scale 1:5,000,000, 2009.
- 5 St-Onge, M. R., Van Gool, J. A., Garde, A. A., and Scott, D. J.: Correlation of Archaean and Palaeoproterozoic units between northeastern Canada and western Greenland: constraining the pre-collisional upper plate accretionary history of the Trans-Hudson orogen, Geological Society, London, Special Publications, 318, 193–235, <https://doi.org/10.1144/SP318.7>, 2009.
- Stea, R. R., Conley, H., and Brown, Y.: Surficial geology of the province of Nova Scotia, 92-3, scale 1:500 000, 1992.
- Stokes, C. R., Clark, C. D., Lian, O. B., and Tulaczyk, S.: Ice stream sticky spots: a review of their identification and influence beneath contemporary and palaeo-ice streams, *Earth-Science Reviews*, 81, 217–249, <https://doi.org/10.1016/j.earscirev.2007.01.002>, 2007.
- 10 Stokes, C. R., Tarasov, L., and Dyke, A. S.: Dynamics of the North American Ice Sheet Complex during its inception and build-up to the Last Glacial Maximum, *Quaternary Science Reviews*, 50, 86–104, <https://doi.org/10.1016/j.quascirev.2012.07.009>, 2012.
- Sugden, D.: Landscapes of glacial erosion in Greenland and their relationship to ice, topographic and bedrock conditions, 1974.



- Swinehart, J. B., Dreeszen, V. H., Richmond, G. M., Tipton, M. J., Bretz, R., Steece, F. V., Hallberg, G. R., and Goebel, J. E.: Quaternary
15 Geologic Map of the Platte River 4 Degrees x 6 Degrees Quadrangle, United States, USGS Numbered Series I-1420(NK-14), U.S.
Geological Survey, scale 1:1 000 000, 1994.
- Tarasov, L. and Peltier, W.: A geophysically constrained large ensemble analysis of the deglacial history of the North American ice-sheet
complex, *Quaternary Science Reviews*, 23, 359–388, <https://doi.org/10.1016/j.quascirev.2003.08.004>, 2004.
- Tarasov, L., Dyke, A. S., Neal, R. M., and Peltier, W.: A data-calibrated distribution of deglacial chronologies for the North American ice
20 complex from glaciological modeling, *Earth and Planetary Science Letters*, 315–316, 30–40, <https://doi.org/10.1016/j.epsl.2011.09.010>,
2012.
- Teller, J. T. and Fenton, M. M.: Late Wisconsinan glacial stratigraphy and history of southeastern Manitoba, *Canadian Journal of Earth
Sciences*, 17, 19–35, <https://doi.org/10.1139/e80-002>, 1980.
- Thériault, R., Beauséjour, S., and Tremblay, A.: Geological map of Quebec, QERPUB - Publication du M.E.R. DV2012-07, Ministère des
25 Ressources naturelles, Québec, scale 1:2,000,000, 2012.
- Thorleifson, L. H., Wyatt, P. H., Shilts, W., and Nielsen, E.: Hudson Bay lowland Quaternary stratigraphy: evidence for early Wisconsinan
glaciation centered in Quebec, in: *The Last Interglacial–Glacial Transition in North America*, edited by Clark, P. U. and Lea, P. D., vol.
270 of *Special Paper*, pp. 207–221, Geological Society of America, <https://doi.org/10.1130/SPE270-p207>, 1992.
- Todd, B., Lewis, C., Nielsen, E., Thorleifson, L., Bezys, R., and Weber, W.: Lake Winnipeg: geological setting and sediment seismostratig-
30 raphy, *Journal of Paleolimnology*, 19, 215–243, <https://doi.org/10.1023/A:1007997024412>, 1998.
- Todd, B. J. and Shaw, J.: Laurentide Ice Sheet dynamics in the Bay of Fundy, Canada, revealed through multibeam sonar mapping of glacial
landsystems, *Quaternary Science Reviews*, 58, 83–103, <https://doi.org/10.1016/j.quascirev.2012.10.016>, 2012.
- Todd, B. J., Fader, G. B., Courtney, R. C., and Pickrill, R. A.: Quaternary geology and surficial sediment processes, Browns Bank, Scotian
Shelf, based on multibeam bathymetry, *Marine Geology*, 162, 165–214, [https://doi.org/10.1016/S0025-3227\(99\)00092-4](https://doi.org/10.1016/S0025-3227(99)00092-4), 1999.
- 35 Tulaczyk, S., Kamb, W. B., and Engelhardt, H. F.: Basal mechanics of Ice Stream B, West Antarctica: 2. Undrained plastic bed model, *Journal
of Geophysical Research: Solid Earth*, 105, 483–494, <https://doi.org/10.1029/1999JB900328>, 2000.
- Uchupi, E. and Bolmer, S.: Geologic evolution of the Gulf of Maine region, *Earth-Science Reviews*, 91, 27–76,
<https://doi.org/10.1016/j.earscirev.2008.09.002>, 2008.
- Voges, A.: International Quaternary Map of Europe, Map IQaME2500, Bundesanstalt für Geowissenschaften und Rohstoffe, scale
1:2,500,000, 1995.
- Walter, F., Chaput, J., and Lüthi, M. P.: Thick sediments beneath Greenland’s ablation zone and their potential role in future ice sheet
5 dynamics, *Geology*, 42, 487–490, <https://doi.org/10.1130/G35492.1>, 2014.
- Weidick, A. and Christoffersen, M.: Quaternary Map of Greenland Søndre Strømfjord – Nūgssuaq, Map Sheet 3, The Geological Survey of
Greenland, scale 1,500,000, 1974.
- Weidick, A. and Christoffersen, M.: Quaternary Map of Greenland Frederikshåbs Isblink – Søndre Strømfjord, Map Sheet 2, The Geological
Survey of Greenland, scale 1,500,000, 1978.
- Weidick, A. and Klüver, B. G.: Quaternary Map of Greenland SydgrønSund, Map Sheet 1, The Geological Survey of Greenland, scale
580 1,500,000, 1987.
- Wessel, P., Smith, W. H., Scharroo, R., Luis, J., and Wobbe, F.: Generic mapping tools: improved version released, *Eos, Transactions
American Geophysical Union*, 94, 409–410, <https://doi.org/10.1002/2013EO450001>, 2013.



- Wheeler, J. O., Hoffman, P. F., Card, K. D., Davidson, A., Sanford, B. V., Okulitch, A. V., and Roest, W. R.: Geological Map of Canada, Map 1860A, Geological Survey of Canada, <https://doi.org/10.4095/208175>, scale 1:5 000 000, 1996.
- 585 Whitfield, J. W., Ward, R. A., Denne, J. E., Holbrook, D. F., Bush, W. V., Lineback, J. A., Luza, K. V., Jensen, K. M., and Fishman, W. D.: Quaternary geologic map of the Ozark Plateau 4° x 6° quadrangle, United States, USGS Numbered Series IMAF 1420(NJ-15), U.S. Geological Survey, scale 1:1,000,000, 1993.
- Wilson, F. H., Hulst, C. P., Mull, C. G., and Karl, S. M.: Geologic map of Alaska, Scientific Investigations Map 3340, United States Geological Survey, <https://doi.org/10.3133/sim3340>, pamphlet 196, scale 1:1,584,000, 2015.
- 590 Yukon Geological Survey: Yukon Digital Bedrock Geology, Tech. rep., http://www.geology.gov.yk.ca/update_yukon_bedrock_geology_map.html, accessed: September 2, 2016, 2016.

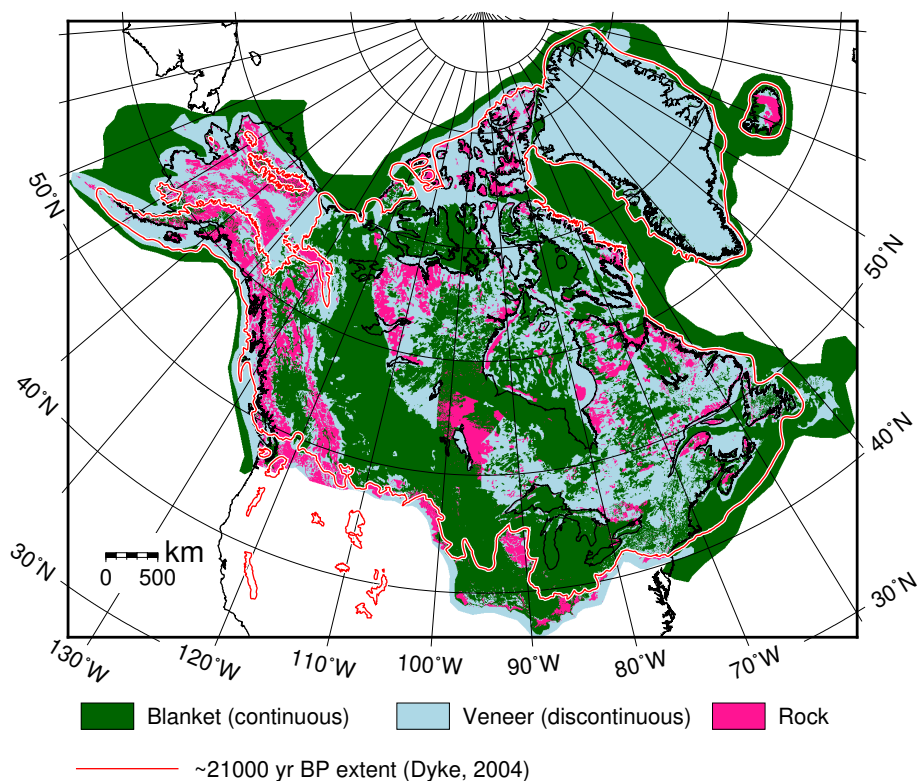


Figure 1. Sediment distribution. The red line is the glacial limits during the Last Glacial Maximum, 21 000 yr BP (thousands of years ago). Blanket regions are where unconsolidated sediments form a continuous surface, veneer regions have variable amounts of rock outcrops and discontinuous sediment cover, while rock areas have little or no sediment cover.

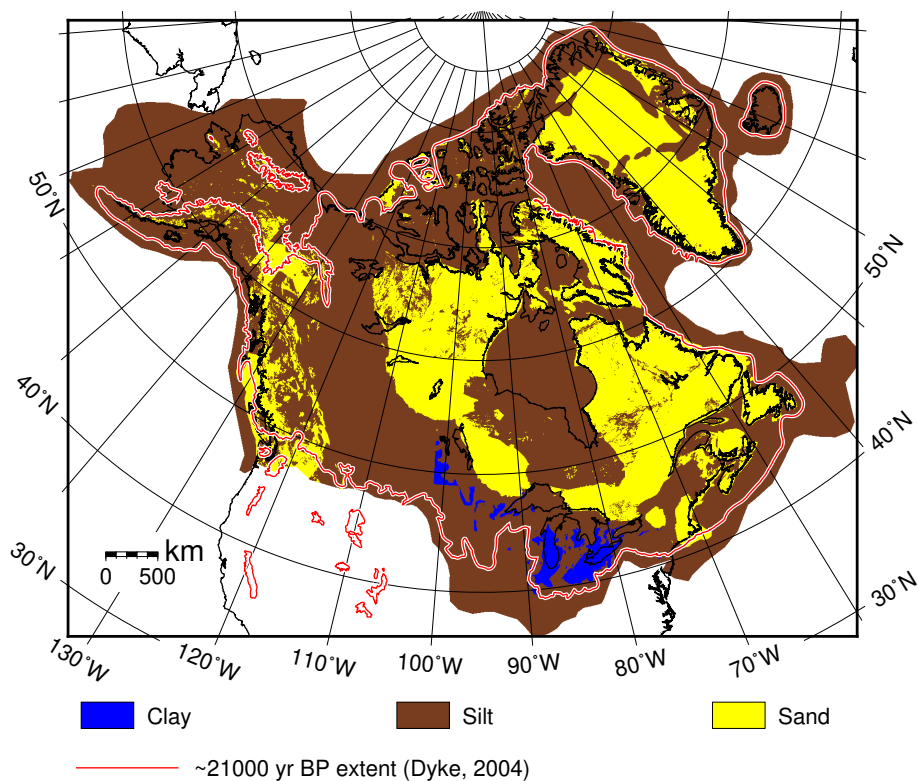


Figure 2. Sediment grain size. The red line is the glacial limits during the Last Glacial Maximum, 21 000 yr BP (Dyke, 2004). The types of sediment include clay (dominantly fine grained sediment), silt (an average composition between sand and clay), and sand (dominantly coarse grained sediments).

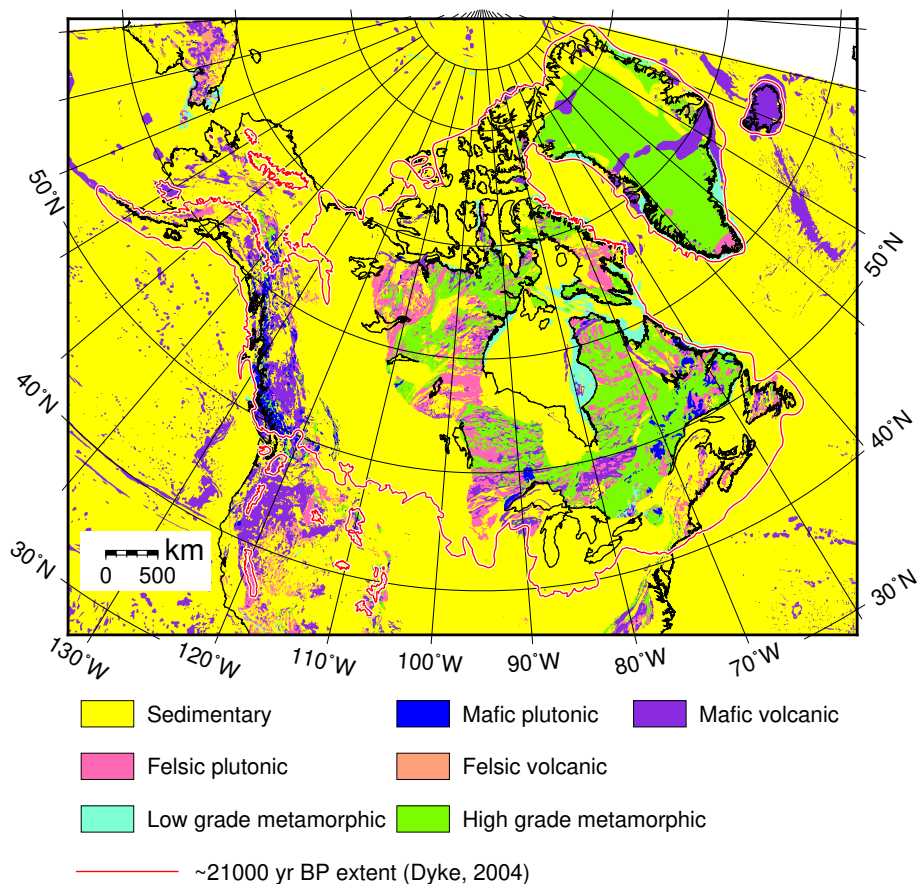


Figure 3. Generalized geology. The red line is the glacial limits during the Last Glacial Maximum, 21 000 yr BP (Dyke, 2004). The rock types are divided into sedimentary, felsic and mafic, volcanic and plutonic, and metamorphic categories.

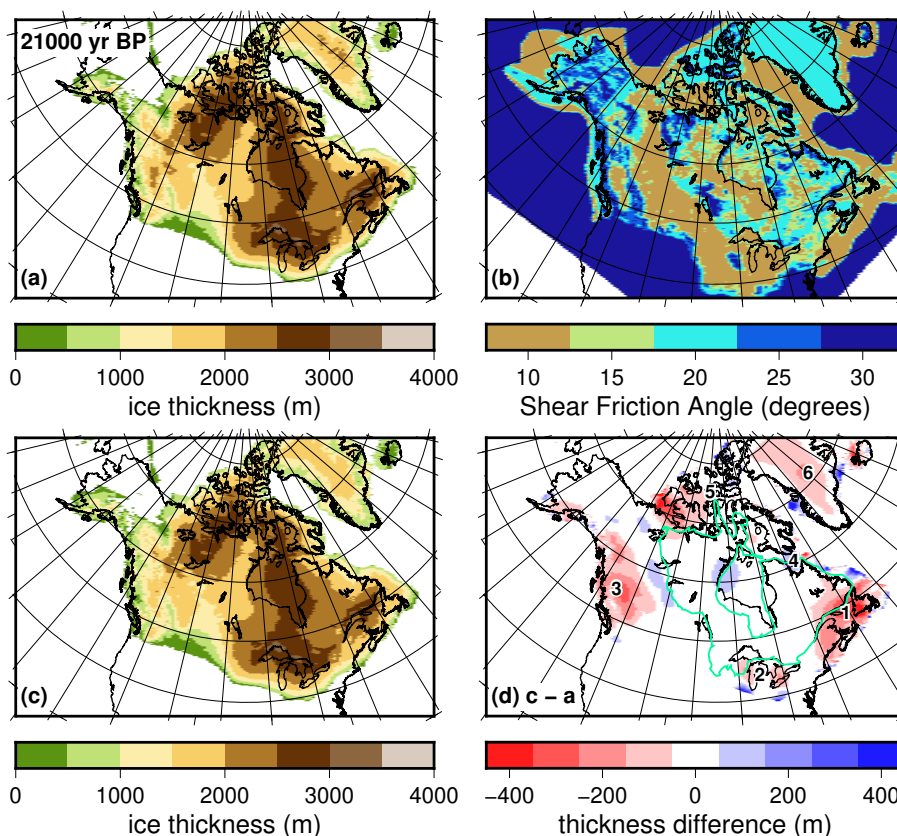


Figure 4. Impact of the distribution of sediments on the simulation of North American ice sheets. (a) Thickness of the ice sheets at 21 000 yr BP (after about 101 000 years of simulation) with the default shear friction angle, $\phi = 30^\circ$. (b) Shear friction angle adjusted downwards for sediment cover. (c) Ice thickness at 21 000 yr BP using the shear friction angle shown in (b). (d) Difference in ice thickness between (a) and (c). The numbers in (d) represent areas mentioned in the text: (1) Eastern Canada, (2) Great Lakes, (3) Cordillera (4) Hudson Strait (5) Arctic Archipelago (6) Greenland. The green outline shows the exposed limit of the Canadian Shield.

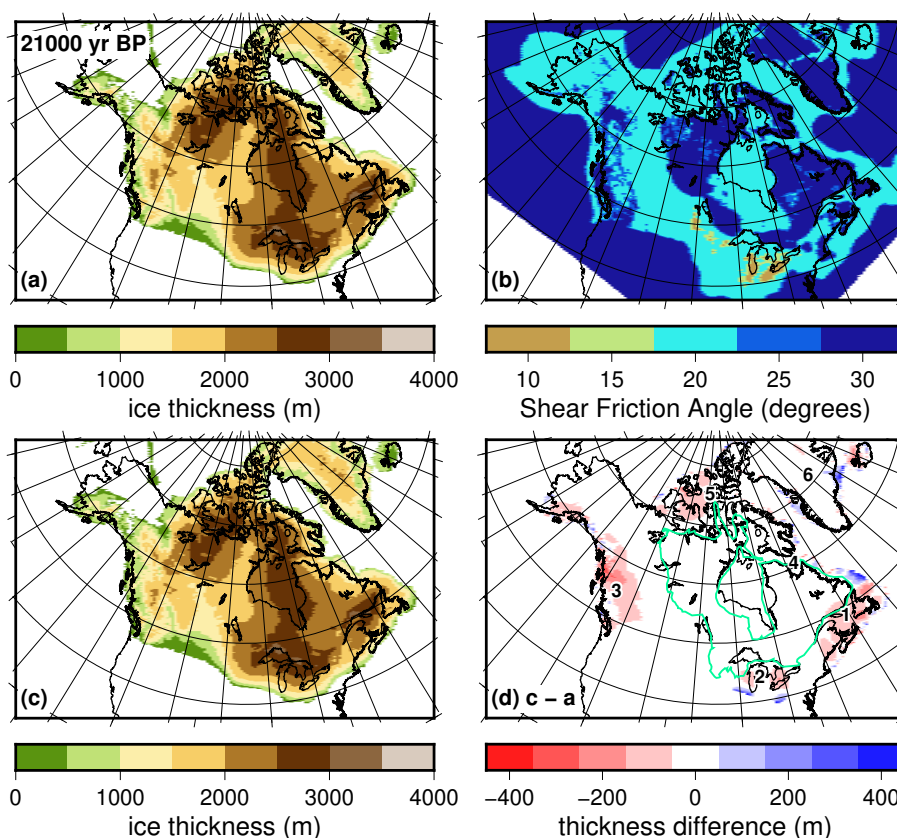


Figure 5. Impact of the grain size of sediments on the simulation of North American ice sheets. (a) Thickness of the ice sheets at 21 000 yr BP (after about 101 000 years of simulation) with the default shear friction angle, $\phi = 30^\circ$. (b) Shear friction angle adjusted downwards for finer grained sediments. (c) Ice thickness at 21 000 yr BP using the shear friction angle shown in (b). (d) Difference in ice thickness between (a) and (c). The numbers in (d) represent areas mentioned in the text: (1) Eastern Canada, (2) Great Lakes, (3) Cordillera (4) Hudson Strait (5) Arctic Archipelago (6) Greenland. The green outline shows the exposed limit of the Canadian Shield.

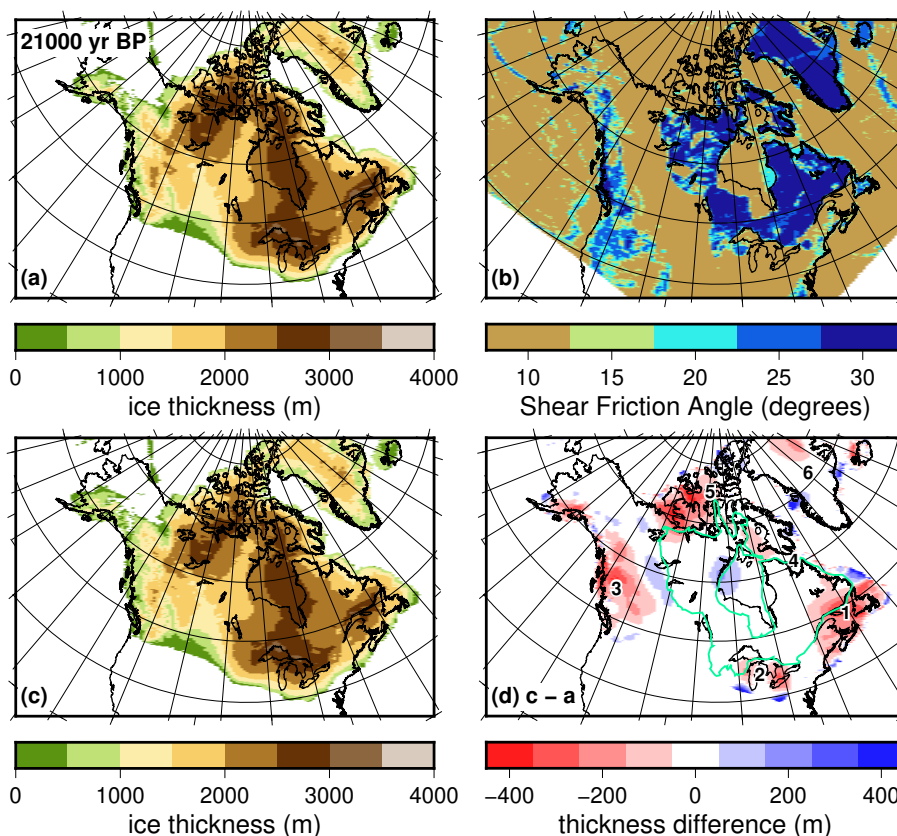


Figure 6. Impact of the geology on the simulation of North American ice sheets. (a) Thickness of the ice sheets at 21 000 yr BP (after about 101 000 years of simulation) with the default shear friction angle, $\phi = 30^\circ$. (b) Shear friction angle adjusted downwards sediments and volcanic rocks. (c) Ice thickness at 21 000 yr BP using the shear friction angle shown in (b). (d) Difference in ice thickness between (a) and (c). The numbers in (d) represent areas mentioned in the text: (1) Eastern Canada, (2) Great Lakes, (3) Cordillera (4) Hudson Strait (5) Arctic Archipelago (6) Greenland. The green outline shows the exposed limit of the Canadian Shield.

**Table 1.** Maps used for the creation of the distribution and grain size dataset

Map region	dataset used	reference
Canada	distribution	Fulton (1995); Geological Survey of Canada (2014)
Canada	grain size	Wheeler et al. (1996)
Continental United States west of the Rocky Mountains	distribution	Soller and Garrity (2018)
Ottawa Quadrangle	distribution, grain size	Fullerton et al. (1993)
Quebec Quadrangle	distribution, grain size	Borns et al. (1987)
Boston Quadrangle	distribution, grain size	Hartshorn et al. (1991)
Hudson River Quadrangle	distribution, grain size	Fullerton et al. (1992)
Sudbury Quadrangle	distribution, grain size	Sado et al. (1993)
Lake Erie Quadrangle	distribution, grain size	Fullerton et al. (1991)
Blue Ridge Quadrangle	distribution, grain size	Howard et al. (1991)
Lake Nipigon Quadrangle	distribution, grain size	Sado et al. (1994)
Lake Superior Quadrangle	distribution, grain size	Farrand et al. (1984)
Chicago Quadrangle	distribution, grain size	Lineback et al. (1983)
Louisville Quadrangle	distribution, grain size	Gray et al. (1991)
Lake of the Woods Quadrangle	distribution, grain size	Sado et al. (1995)
Minneapolis Quadrangle	distribution, grain size	Goebel et al. (1983)
Des Moines Quadrangle	distribution, grain size	Hallberg et al. (1994)
Ozark Plateau Quadrangle	distribution, grain size	Whitfield et al. (1993)
Winnipeg Quadrangle	distribution, grain size	Fullerton et al. (2000)
Dakotas Quadrangle	distribution, grain size	Fullerton et al. (1995)
Platte River Quadrangle	distribution, grain size	Swinehart et al. (1994)
Wichita Quadrangle	distribution, grain size	Denne et al. (1993)
Regina Quadrangle	distribution, grain size	Fullerton et al. (2007)
Montana	distribution, grain size	Fullerton et al. (2004, 2012, 2013, 2016)
Southern Cordillera Ice Sheet	distribution, grain size	Soller et al. (2009)
Nova Scotia	grain size	Stea et al. (1992)
Prince Edward Island	grain size	Prest (1973)
New Brunswick	grain size	Rampton (1988)
Newfoundland and Labrador	distribution, grain size	Government of Newfoundland and Labrador (2013)
Quebec	grain size	Thériault et al. (2012)
Northern Ontario	distribution, grain size	Ontario Geological Survey (1997)
Southern Ontario	distribution, grain size	Ontario Geological Survey (2003)
Manitoba	distribution, grain size	Matile and Keller (2006)

**Table 1.** Continued

Map region	dataset used	reference
Northern Saskatchewan	distribution, grain size	Schreiner (1984)
Alberta	grain size	Wheeler et al. (1996)
British Columbia	grain size	Massey et al. (2005)
Southwestern British Columbia	grain size	Clague et al. (1982)
Cordillera Ice Sheet	distribution	Eyles et al. (2018)
Yukon	distribution, grain size	Lipovsky and Bond (2014)
Yukon	grain size	Yukon Geological Survey (2016)
Alaska	distribution	Karlstrom (1964)
Alaska	grain size	Wilson et al. (2015)
Mainland Northwest Territories, Nunavut, and Baffin Island	grain size	Harrison et al. (2011)
Offshore Newfoundland and Grand Banks	distribution	King (2014)
Hudson Strait	distribution, grain size	MacLean (2001)
Gulf of St. Laurence	distribution, grain size	Loring and Nota (1973); Josenhans and Lehman (1999)
Labrador Shelf	distribution	Piper et al. (1990)
Southwestern Greenland	distribution	Weidick and Christoffersen (1974, 1978); Weidick and Klüver (1987)
Central eastern Greenland	distribution	Funder and Klüver (1988)
Southeastern Greenland and Iceland	distribution	Voges (1995)
Greenland	distribution	Sugden (1974)
Greenland and Iceland	grain size	Reed et al. (2004)
Greenland Ice Sheet	grain size	Dawes (2009)

**Table 2.** Supplementary resources used for the creation of the distribution and grain size dataset

Region	dataset used	notes	reference
Okanogan Lobe (southern Cordillera Ice Sheet)	distribution	Sediment cover is a veneer	Kovanen and Slaymaker (2004)
Puget Sound (southern Cordillera Ice Sheet)	distribution	The Puget Lobe overrode a thick sequence of proglacial sediments	Booth (1994)
Northern and Central Quebec	distribution, grain size	Dominantly sandy tills except in regions with sedimentary rocks	Bouchard (1989)
Ungava Peninsula, Quebec	distribution, grain size	Thick layers of coarse grained diamiction	Gray and Lauriol (1985)
Hudson Bay Lowlands, Ontario	grain size	Glacial sediments contain roughly equal amounts of clay, silt and sand	Thorleifson et al. (1992)
Southeastern Manitoba	grain size	Grain size of glacial sediments underneath Lake Agassiz deposits is dependent on the source region, but on average is silt	Teller and Fenton (1980)
Lake Winnipeg, Manitoba	distribution	Glacial sediments are discontinuous under the entire lake, except where there are end moraines.	Todd et al. (1998)
Alberta Interior Plains	grain size	Glacial sediments have a relatively uniform composition that is roughly equal parts clay, silt and sand.	Klassen (1989)
British Columbia	grain size	Glacial sediments generally have similar composition as underlying bedrock, though more coarse at higher elevations	Clague (1989)
British Columbia interior	grain size	Glacial sediments are silt or sand rich	Plouffe (2000)
Mainland Northwest Territories and Nunavut	grain size	Glacial sediments generally have grain size reflective of bedrock geology	McMartin et al. (2006)
Western Northwest Territories	grain size	Areas overlying the Western Canadian Sedimentary Basin have an unsorted mixture of sand silt and clay	<i>e.g.</i> Duk-Rodkin and Hughes (1993)
Hudson Bay	distribution	Multibeam data collected from Hudson Bay, which was ultimately used in Fulton (1995)	Josenhans and Zevenhuizen (1990)
Eastern Hudson Bay	distribution, grain size	Betcher Islands are relatively barren of unconsolidated sediments, bedrock is Proterozoic sedimentary and volcanic rocks	Jackson (2012)
St. Laurence estuary	distribution	Thick accumulations of glacial sediments only occur where there are bedrock troughs	Duchesne et al. (2010)
Offshore Nova Scotia	distribution	Seismic and multibeam data indicates significant glacial sediment accumulation	Todd et al. (1999); Todd and Shaw (2012)
Gulf of Maine	distribution, grain size	There is a thick succession of fine grained sediments, near Cape Cod it is more sandy	Uchupi and Bolmer (2008)

**Table 2.** Continued

Region	dataset used	notes	reference
Northern Northwest Passage, Arctic Canada	distribution	Multibeam data indicates limited cover by glacial sediments	Niessen et al. (2010)
Gulf of Boothia	distribution	Multibeam data indicates of continuous layer of sediments	MacLean et al. (2010)
Coronation and Amundsen gulfs	distribution	Sediment veneer in the Coronation Gulf and inner Amundsen Gulf, thicker in the outer Amundsen Gulf	MacLean et al. (2015)
Western Lake Superior	distribution	Seismic data indicates that glacial sediment units are not continuous	Scholz (1984)
Western Lake Superior near Thunder Bay	distribution, grain size	Thick glacial sediment units that were interpreted to be fine grained	Gustafson (2012)
Lake Superior and Lake Michigan	distribution, grain size	Thick sediment cover with composition that reflects local geology for Lake Superior, and high clay content for Lake Michigan	Lineback et al. (1979)
Lake Ontario	distribution	The core of Lake Ontario has thick glacial sediment cover, but on the margins it is thin and discontinuous	Hutchinson et al. (1993); Lewis et al. (1995)
Lake Erie	distribution, grain size	Erie Lobe sediments are clay rich due to reworking of lake sediments	Karrow (1989)
Eastern Great Slave Lake	distribution	Glacial sediments are thick in some areas, but is not continuous	Christoffersen et al. (2008)
Beaufort Sea	distribution	Seismic data indicates thick sediment cover	Batchelor et al. (2013)
Greenland	distribution	Thick glacial sediment cover generally only exists in fjords and high plateaus	Funder (1989)
Greenland	distribution	Sediment cover in areas described by Sugden (1974) generally completely covers the bedrock	Corbett et al. (2015); Larsen et al. (2010); Håkansson et al. (2009)
Offshore Greenland	distribution	areas with scoured bedrock visible from multibeam and seismic data have limited sediment cover, and smooth topography is more continuous	Funder (1989); Morlighem et al. (2017); Freire et al. (2015); Dowdeswell et al. (2010)

**Table 2.** Continued

Region	dataset used	notes	reference
Greenland Ice Sheet	distribution	Seismic evidence indicates the presence of sediments under the ice sheet	Walter et al. (2014); Kulesa et al. (2017)
Greenland Ice Sheet	distribution, grain size	Most of Greenland is underlain by Archean and Paleoproterozoic cratons, which are composed largely of high grade metamorphic and plutonic rocks, and likely has similar characteristics as the Canadian Shield.	St-Onge et al. (2009); Henriksen et al. (2009)
Offshore Iceland	distribution, grain size	Seismic surveys indicate thick sediment cover with relatively fine grain size	Principato et al. (2005)
Western Iceland	grain size	Older glacial sediments have been described as being silt rich and sandy-silt	Hjort et al. (1985); Ingólfsson (1985)

Table 3. General properties of sediments relating to composition and texture

Material	Grain Size (mm)	Shear Friction Angle	Cohesion	Permeability	Dilation
clay	<0.005	<20	>10 kPa	low	appreciable
silt	0.05-0.005	<30	<10 kPa	variable	variable
sand	>0.05	>30	negligible	high	none