



C11E-0718: What controlled the distribution of Laurentide eskers?

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The Problem

Numerical ice sheet models have been used to explain landform patterns [1] and landform patterns have been used to test numerical ice sheet models [2]. Neither approach is robust unless underlying assumptions are consistent with the landform record. Eskers are the casts of ice-walled channels and are a common landform within the footprint of the last Laurentide Ice Sheet (LIS). Most Laurentide eskers formed in subglacial to low englacial ice tunnels [3], a condition that likely favoured their preservation. However, there is considerable debate over a) whether they formed gradually from astronomically-forced meltwater flows [1, 2] or rapidly from glacial lake or surge-related outburst floods [4, 5], b) whether they formed in segments time-transgressively [1, 2] or synchronously along their length [3, 4, 5], and c) whether their distribution is mainly controlled by bed deformability [6], bed permeability and groundwater flow [2, 7], sediment supply [8] or climate/water supply [3]. It is imperative that these debates be resolved so that the underlying assumptions of numerical models are robust. Here we approach the problem from first principles, asking first what basic conditions are required for esker formation and what controls these conditions, then assessing the evidence for each of these controls 1) at the scale of the LIS and 2) in southern Alberta where eskers are relatively small.

Esker-forming conditions (first principles)	Main controls
An ice tunnel plumbing system	Substrate character, meltwater flux (climate), ice character* (temperature and structure)
A sediment supply that is appropriate (quantity & type) for esker-building	Substrate character (antecedent bedrock/sediment distribution, glacial processes)
A water supply adequate for gravel transport	Climate, geothermal heat flux*, ice dynamics*

* Not addressed on this poster

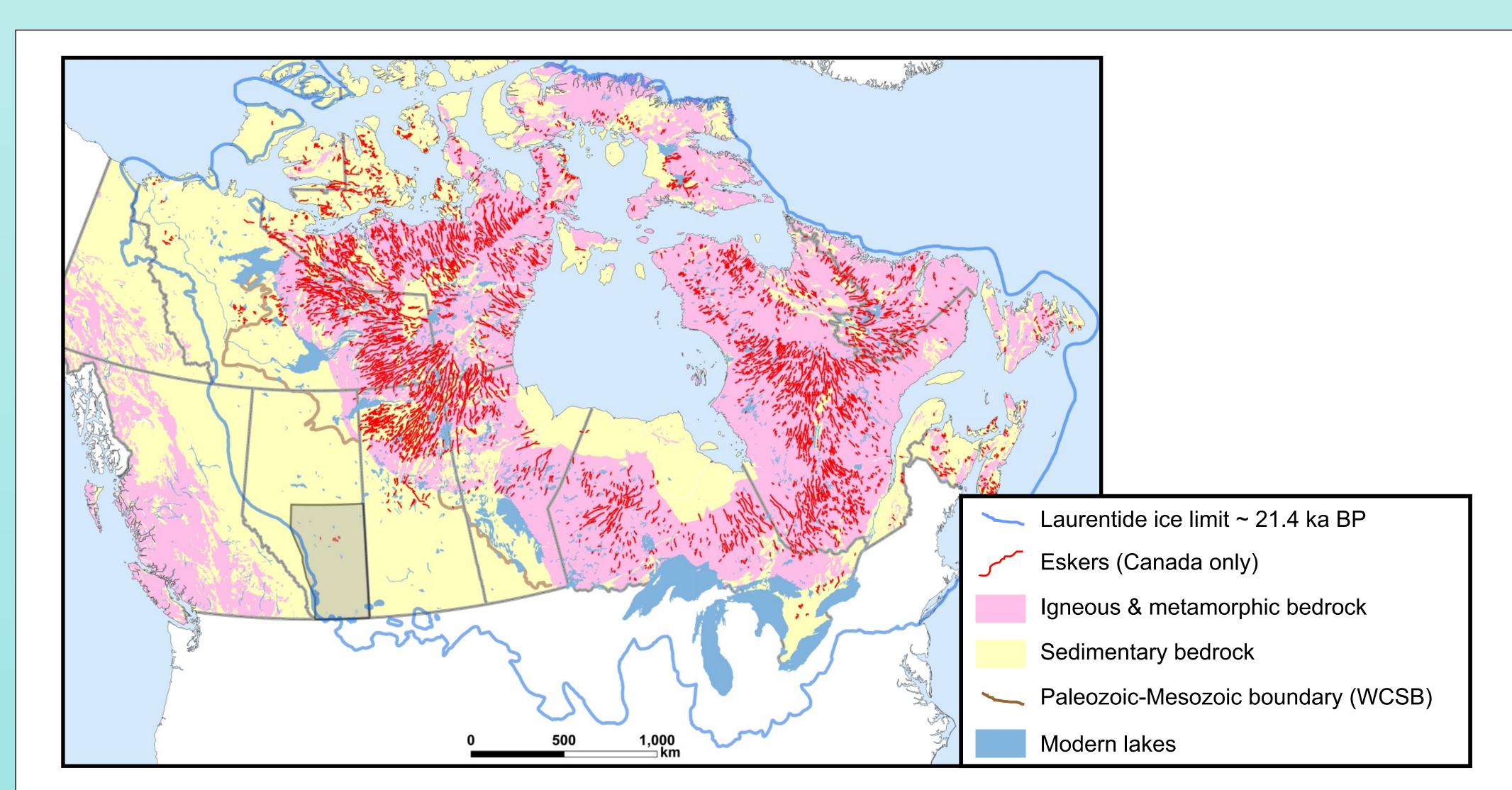


Figure 1: Over igneous and metamorphic bedrock of the Canadian Shield eskers are relatively long and ubiquitous; they are shorter and less common over sedimentary bedrock. Assuming that glaciers overriding sedimentary bedrock necessarily produce deforming beds, this distribution has been attributed to the preferential development of canals over soft beds, and R-channels over rigid substrates [6]. However, over the Western Canadian Sedimentary Basin (WCSB) eskers are present over Mesozoic clastics (relatively impermeable) and rare over Paleozoic carbonates (more permeable). Thus, R-channel location has been attributed to bed permeability [7]. Ice limit from [9], eskers from [10], and bedrock from [11]. Grey box delimits southern Alberta study (Figs 4, 5).

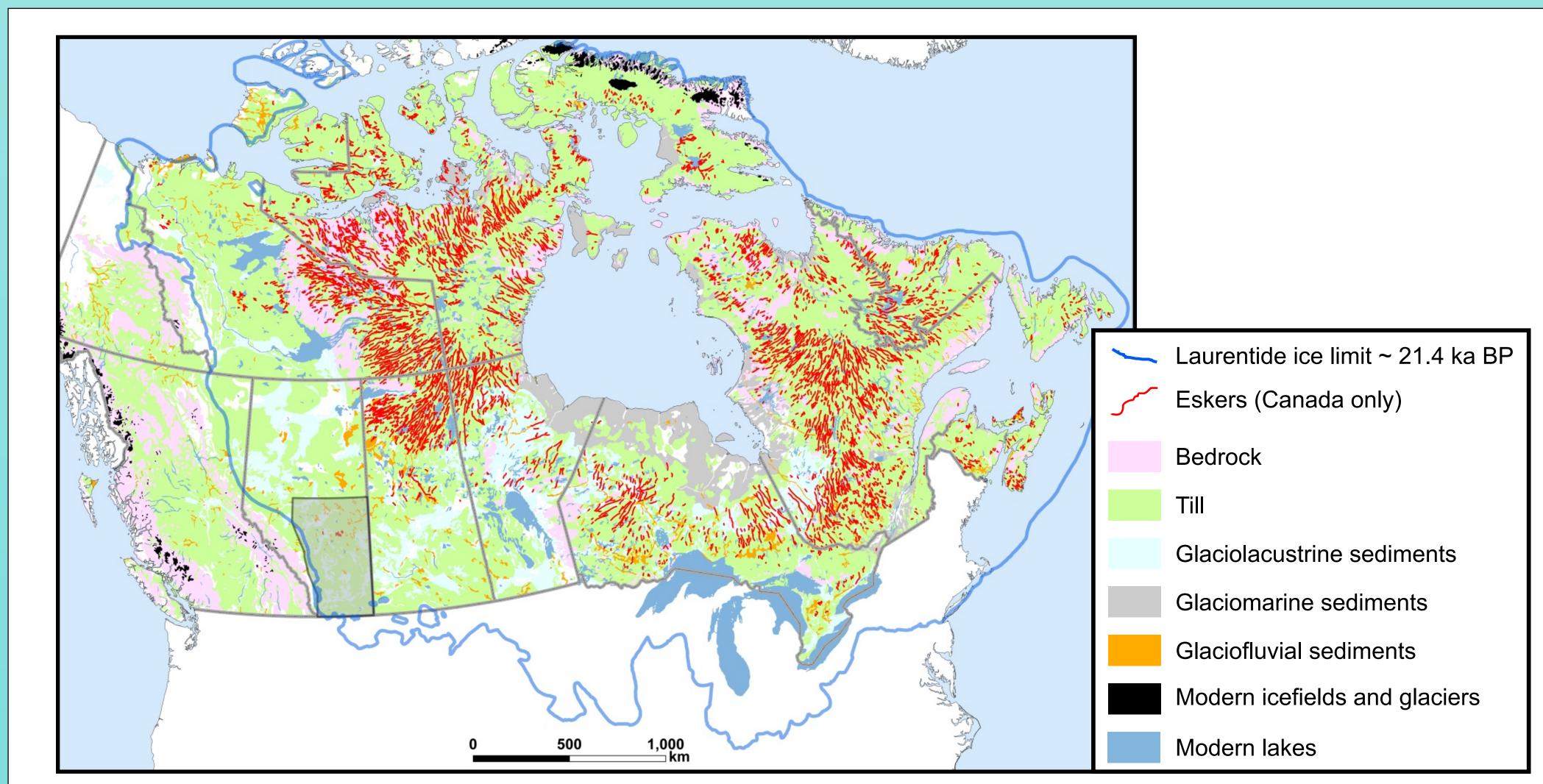


Figure 2: Laurentide eskers are composed of sediment eroded mainly from glacial drift [12]. Coarse tills overlying metamorphic and igneous bedrock of the Canadian Shield are excellent suppliers of esker-forming sediment. Eskers are rare or small in driftless Shield areas [8] and areas of fine-grained drift, highlighting the importance of sediment supply on esker distribution. Ice limit from [9], eskers and surficial material from [10]. Grey box delimits southern Alberta study (Figs 4, 5).

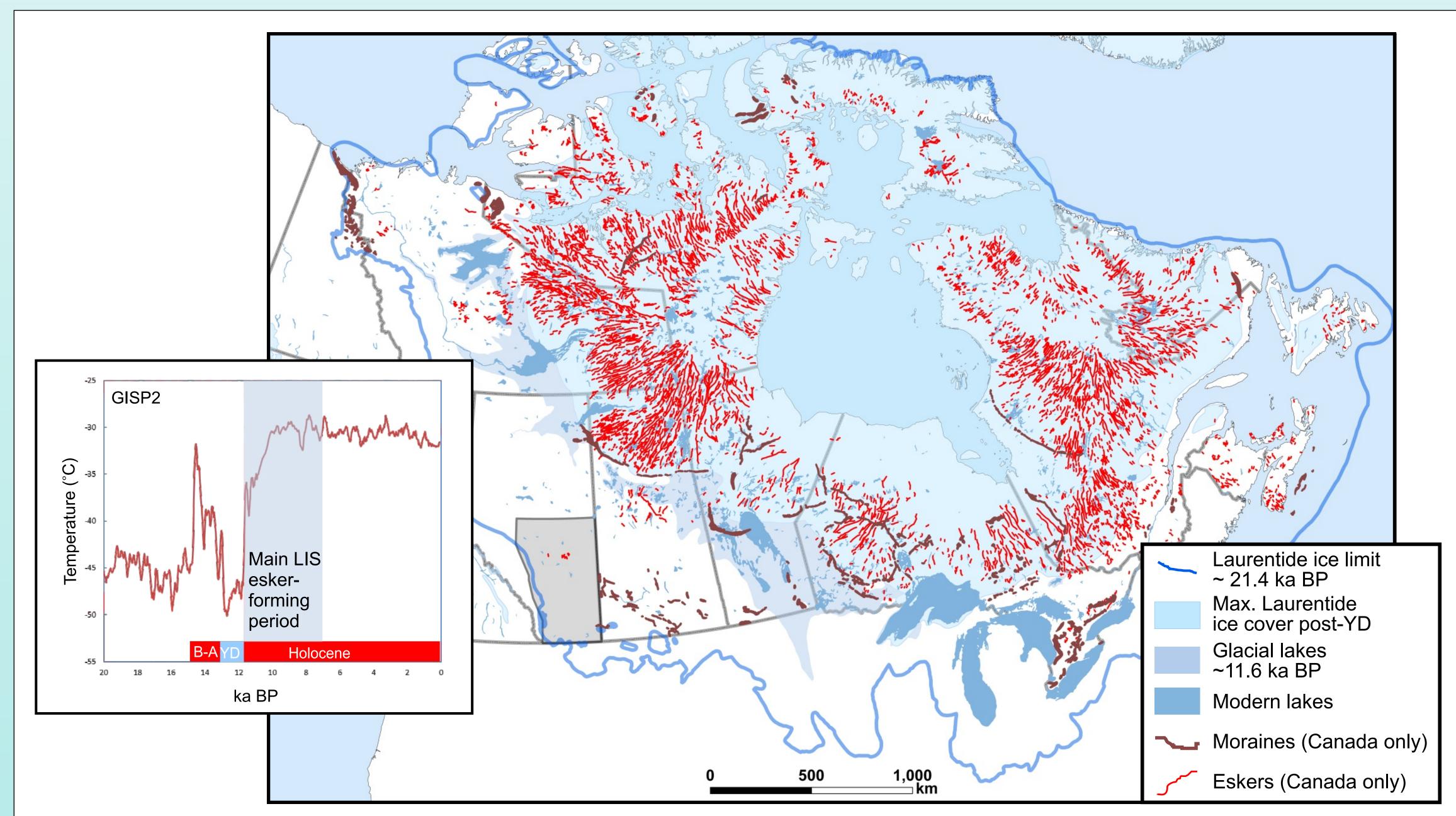
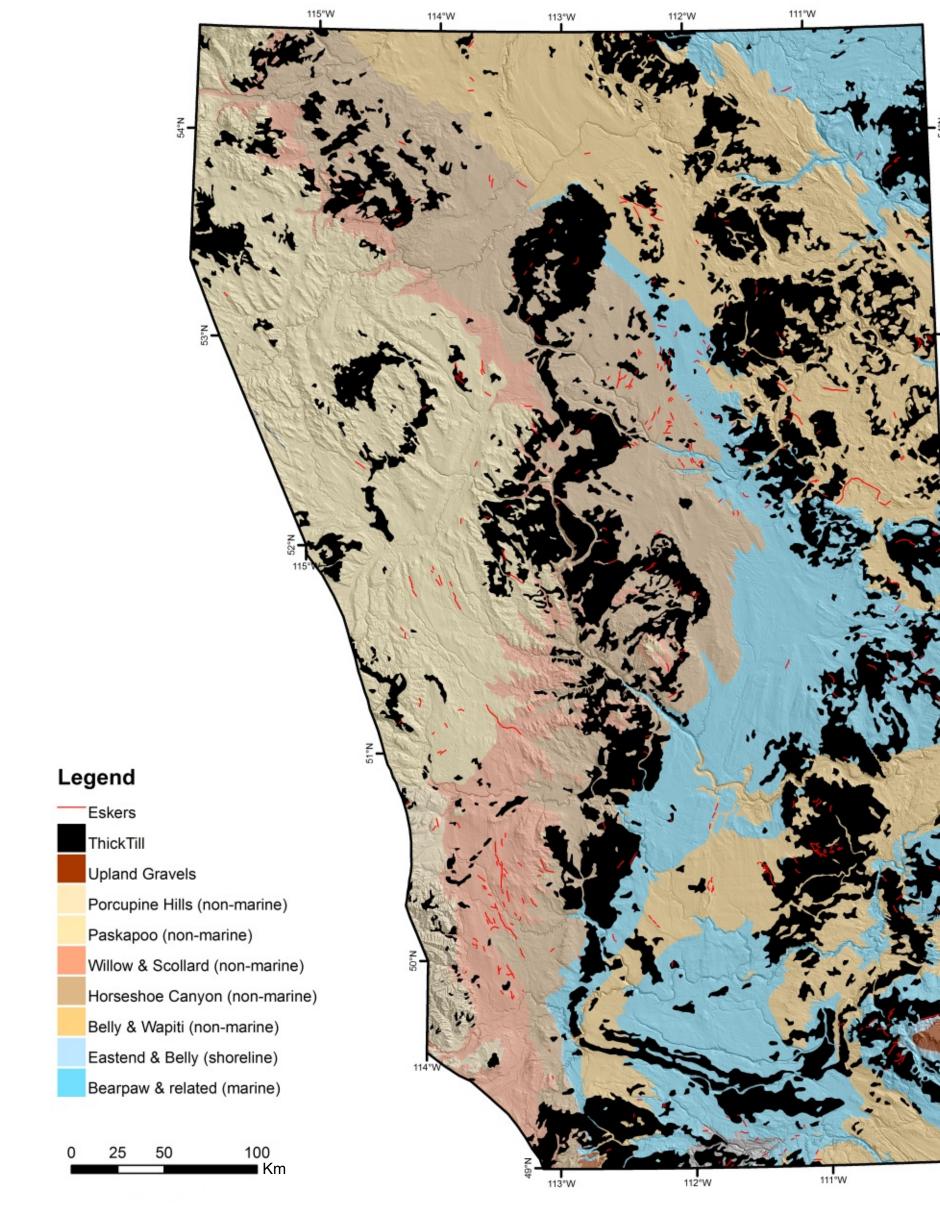


Figure 3: Inspection of current Laurentide Ice Sheet (LIS) reconstructions reveals that the majority of Laurentide eskers formed post-Younger Dryas (YD), a time of rapid temperature increase and melting (grey shading on graph). Under such conditions the LIS would have developed numerous melt ponds on its surface, much like the Greenland Ice Sheet (GrIS) today. Drainage of many of these melt ponds to the bed, and sediment entrainment and transport in ice tunnels at the bed likely favoured the post-Younger Dryas production of a dense esker network. Ice limits, ice cover and glacial lakes from [9], moraines and eskers from [10], and GISP2 data from [13]. B-A, Bolling-Allerod. Grey box on map delimits southern Alberta study (Figs 4, 5).

More than 380 eskers (most relatively small) have been mapped in southern Alberta. We use a chi-square analysis in conjunction with a Bonferroni z-statistic [14] to estimate if eskers occur more, or less, often in any substrate type based on weighted area. The Bonferroni adjustments are necessary when simultaneously estimating multiple substrate types; they resulted in more appropriate confidence intervals. All analyses are significant at 90% confidence.



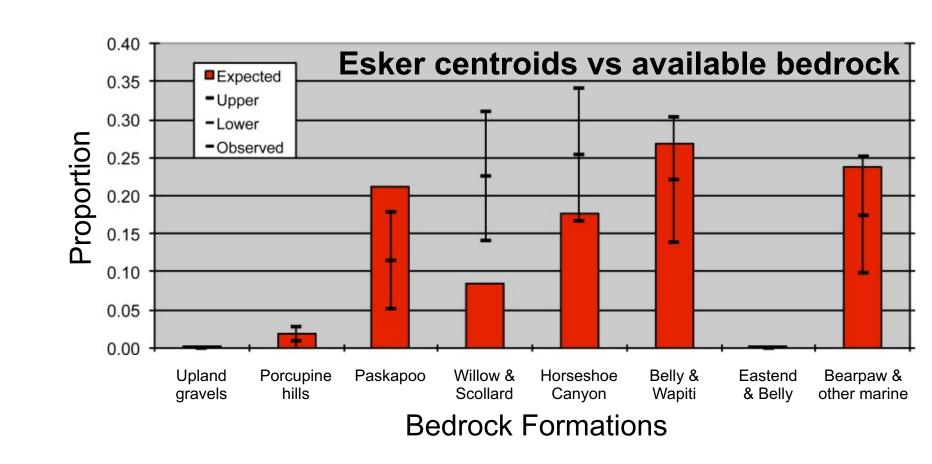
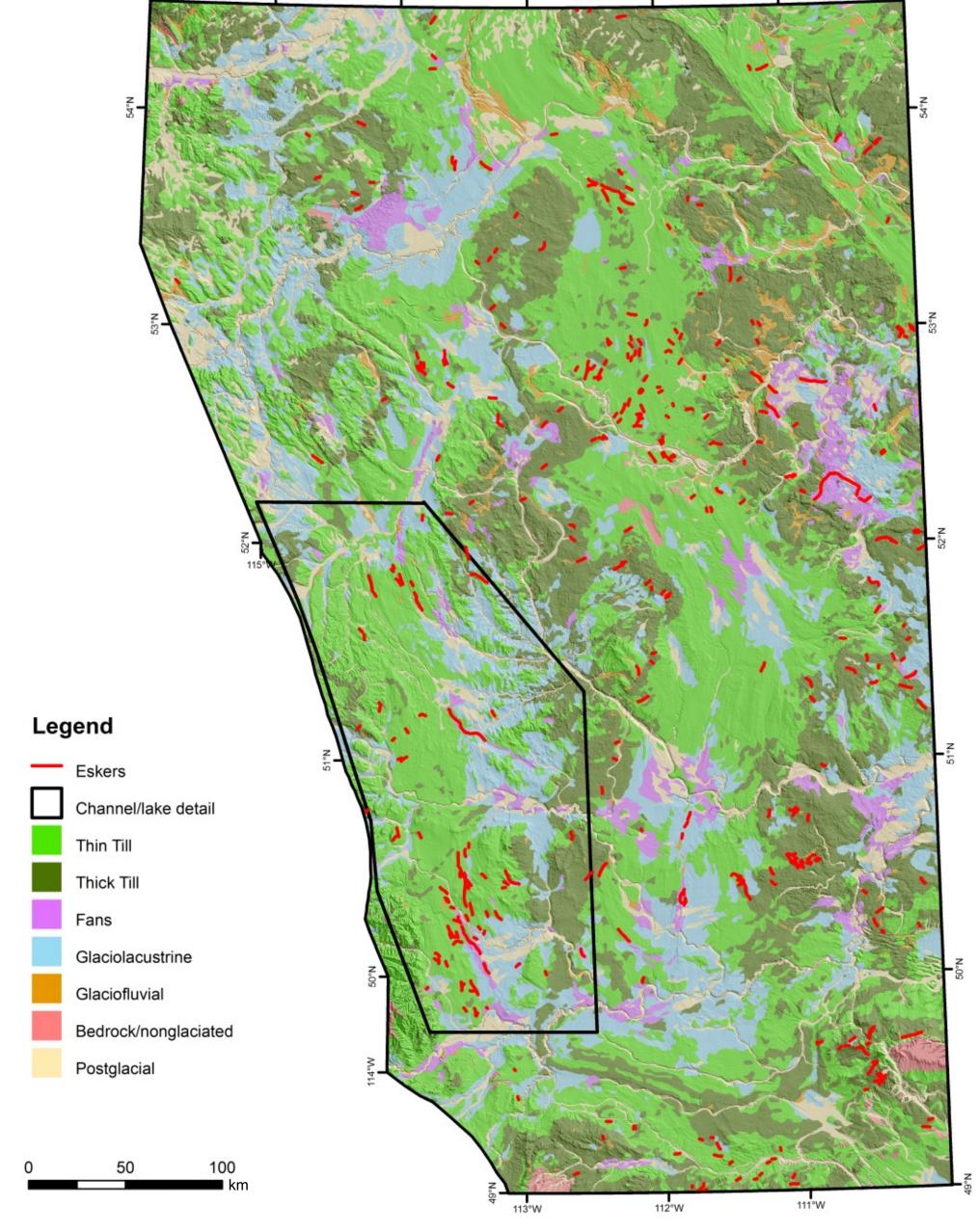


Figure 4: This map and graph show the relationship between eskers and the bedrock formations [15] they overlie in southern Alberta. Bedrock formations underlying thick (> 3 m) drift are masked and not included in the analysis. If bedrock permeability controlled esker distribution [cf.7], then bedrock aquifers (Paskapoo, Willow, Scollard, Horeshoe Canyon Fm.) should have fewer eskers than expected (results are conflicting) and bedrock aquitards (Bearpaw and other marine) should have more eskers than expected (results do not support this).



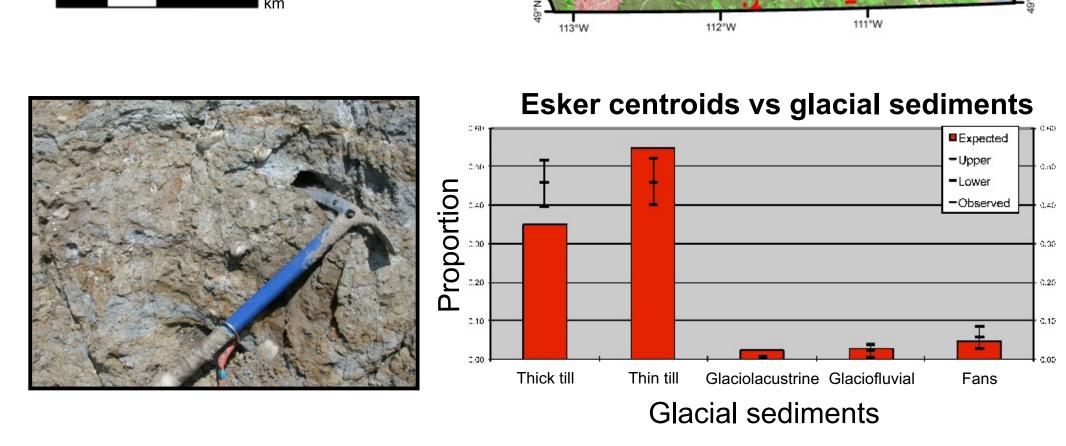
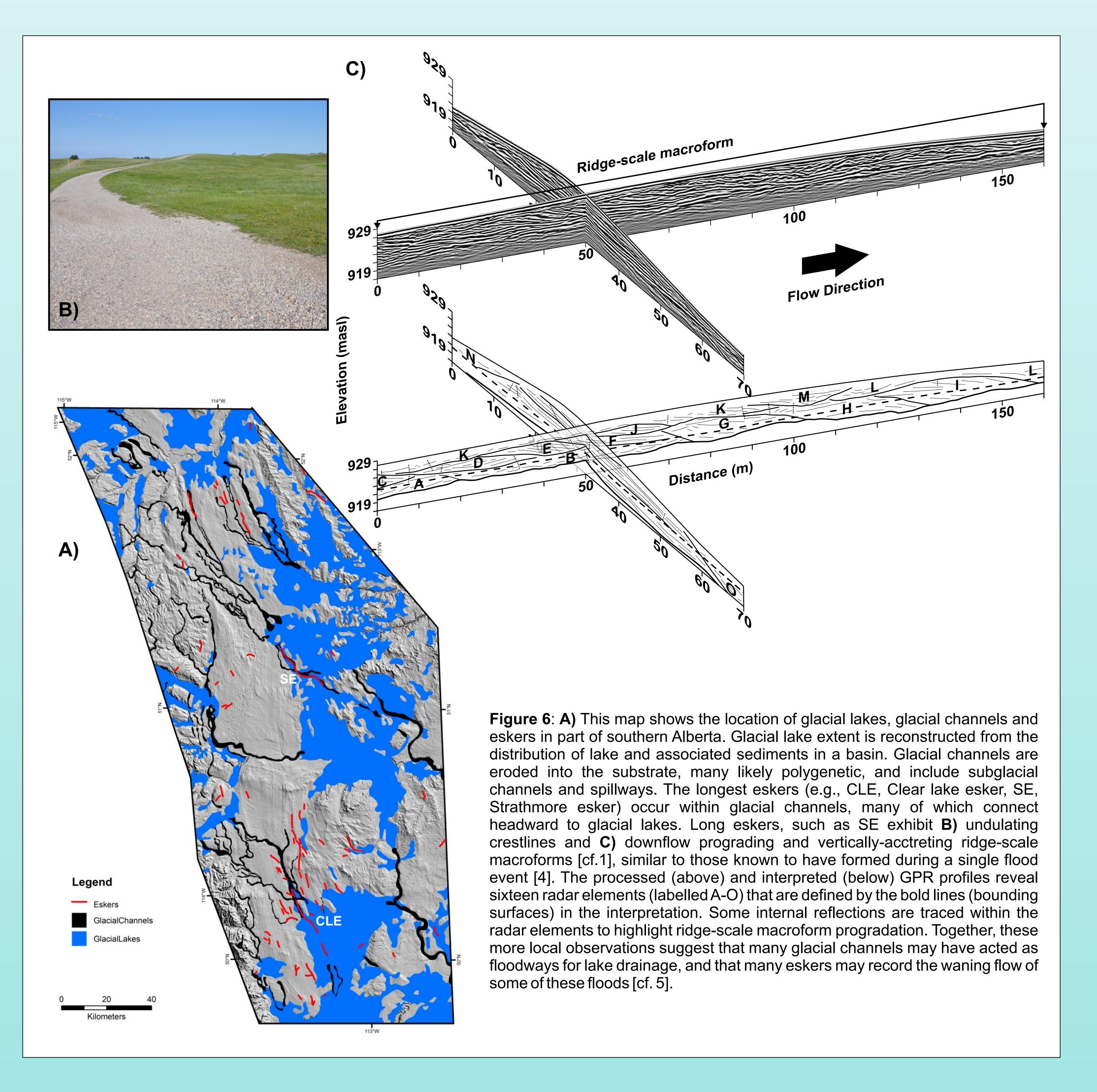


Figure 5: This map and graph show the relationship between eskers and surficial glacial sediments [16] in southern Alberta. The clast-poor, clayey tills in the area (photo) have been inferred to be deformable [17]. If deformable beds precluded R-channel formation [cf.6], then thick till should have fewer eskers than expected. This is not the case. Thick till may have acted as an aquiclude favouring R-channel formation [cf.7]. The small size of eskers on clast-poor, clayey tills suggests esker distribution is sediment supply limited in southern Alberta. Black box on map delimits Figure 6A.



Conclusions

Controls at the ice sheet scale

It is difficult to tease out whether climate or substrate was the dominant control on esker distribution at the ice sheet scale because of the spatial coincidence of Shield terrain (impermeable rocks; coarse tills) and the footprint of the LIS post-Younger Dryas. Over Shield terrain it is plausible that subglacial ice tunnels preferentially formed over impermeable beds as theory suggests, yet is equally plausible that as climate warmed (post-YD) increased melt rates favoured formation of surface melt ponds that drained through subglacial ice tunnels aiding dense esker network formation. Eskers may be forming today under the GrIS in association with melt pond drainage. Clast-rich drift was also critical in providing an adequate local supply of sand and gravel for esker building on the Shield.

Controls in southern Alberta

Substrate control (permeability or deformability) on plumbing style is ambiguous in southern Alberta. Thick till may have acted as an aquiclude favouring subglacial ice tunnel operation, but esker formation is also sediment supply limited. Thus, esker distribution is a minimum map of LIS subglacial ice tunnel location in this region. The association of large eskers with ridge-scale macroforms, glacial channels and glacial lakes suggests that these eskers may record deposition during the waning stages of floods that occurred as one lake basin decanted into another.

Implications for the underlying assumptions of numerical models

- Esker formation can be related to episodic (flood) flows from glacial lakes (supra-, en- or sub-glacial, or ice-marginal). Thus, esker distribution likely reflects abundant water availability (surface melt and ice-dammed lakes), as well as substrate control on plumbing style.
- Esker formation is sediment supply limited; consequently an esker map is a minimum map of subglacial ice tunnel location beneath paleo-ice sheets.

References

[1] Hooke, R. LeB., Fastook, J. 2007. Thermal conditions at the bed of the Laurentide ice sheet in Maine during deglaciation: implications for esker formation. Journal of Glaciology, 53(183): 646-658.

[2] Boulton, G.S., Hagdorn, M., Maillot, P.B., Zatsepin, S. 2009. Drainage beneath ice sheets: groundwater-channel coupling, and the origin of esker systems from former ice sheets. Quaternary Science Reviews, 28: 621-638.

[3] Brennand, T.A. 2000. Deglacial meltwater drainage and glaciodynamics: inferences from Laurentide eskers, Canada. Geomorphology, 32: 263-293.

[4] Burke, M.J., Woodward, J., Russell, A.J., Fleisher, P.J., Bailey, P.K. 2010. The sedimentary architecture of outburst flood eskers: a comparison of ground-penetrating radar data from Bering Glacier, Alaska and Skeidararjokull, Iceland. GSA Bulletin, 122 (9/10): 1637-1645.

[5] Fleisher, P.J., Bailey, P.K., Natel, E.M., Russell, A.J. 2010. Subglacial hydraulic scouring and deposition during surge-related outburst floods, Bering Glacier, Alaska. Quaternmary Science Reviews, 29: 2261-2270. [6] Clark, P.U., Walder, J.S. 1994. Subglacial drainage, eskers, and deforming beds beneath the Laurentide and Eurasian ice sheets. Geological Society of America, Bulletin, 106: 304-314. [7] Grasby, S.E., Chen, Z. 2005. Subglacial recharge into the Western Canadian Basin - impact of Pleistocene glaciation on basin hydrodynamics. Geological Society of America, Bulletin, 117: 500-514. [8] Shilts, W.W., Aylsworth, J.M., Kaszycki, C.A., Klassen, R.A. 1987. Canadian Shield. In: Graf, W.L. ed., Geomorphic Systems of North America. Geol. Soc. Am., Centennial Spec. 2: 119-161. [9] Dvke, A.S., Moore, A., Robertson, L. 2003. Deglaciation of North America. Geological Survey of Canada Open File 1574.

10] Fulton, R.J. compiler 1995. Surficial materials of Canada, Geological Survey of Canada, Map 1880A, scale 1:5 000 000.
11] Wheeler, J.O., Hoffman, P.F., Card, K.D., Davidson, A., Sanford, B.V., Okulitch, A.V., Roest, W.R. (Comp.) 1997. Geological Map of Canada, Geological Survey of Canada, Map D1860A.

[12] Rampton, V.N. 2000. Large-scale effects of subglacial meltwater flow, the southern Slave Province, Northwest Territories, Canada. Canadian Journal of Earth Sciences, 37: 81-93.
[13] Alley, R.B. 2004. GISP2 Ice Core Temperature and Accumulation Data. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2004-013. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.
[14] Neu, C.W. Byers, C.R., Peek, J.M. 1974. Journal of Wildlife Management, 38 (3): 541-545.
[15] Hamilton, W.N., Price, M.C., and Langenberg, C.W. (compilier), 1999; Geological Map of Alberta, Alberta Geological Survey, Alberta Energy and Utilities Board, Map No. 236, scale 1:1,000,000.

[16] Shetsen, I. 1987. Quaternary geology, southern Alberta. Alberta Research Council Map 1:500 000.
[17] Evans, J.A., Clark, C.D., Rea, B.R. 2008. Landform and sediment imprints of fast glacier flow in the southwest Laurentide Ice Sheet. Journal of Quaternary Science, 23(3): 249-272.