Measuring in situ ^{26}Al and ^{10}Be in Post-Glacial Sand Reveals Limited Erosion by Quebec-Labrador Ice Dome

Peyton Cavnar

Thesis Defense, May 2024

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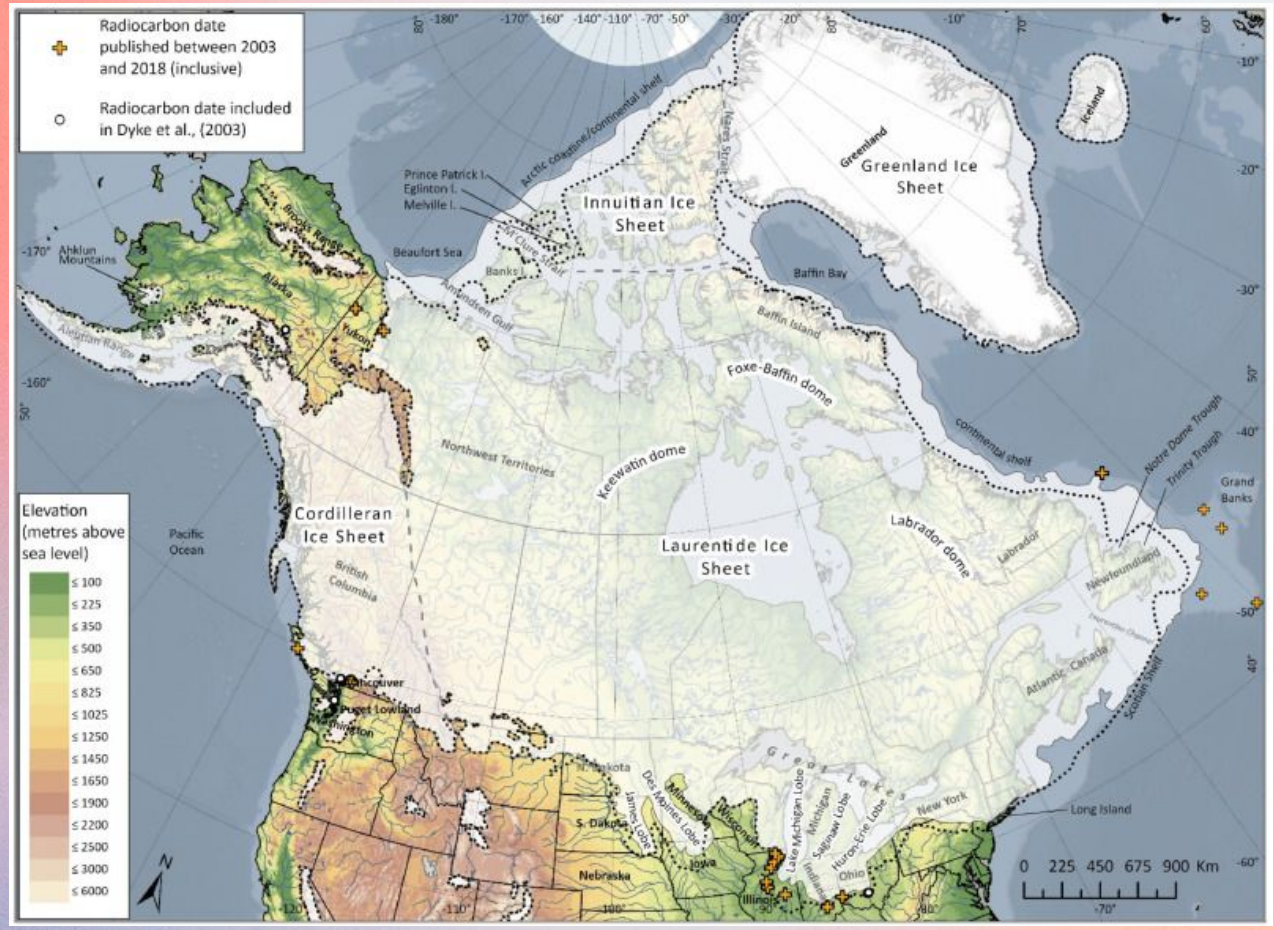
01. Introduction



Credit: Dalton et al., 2020

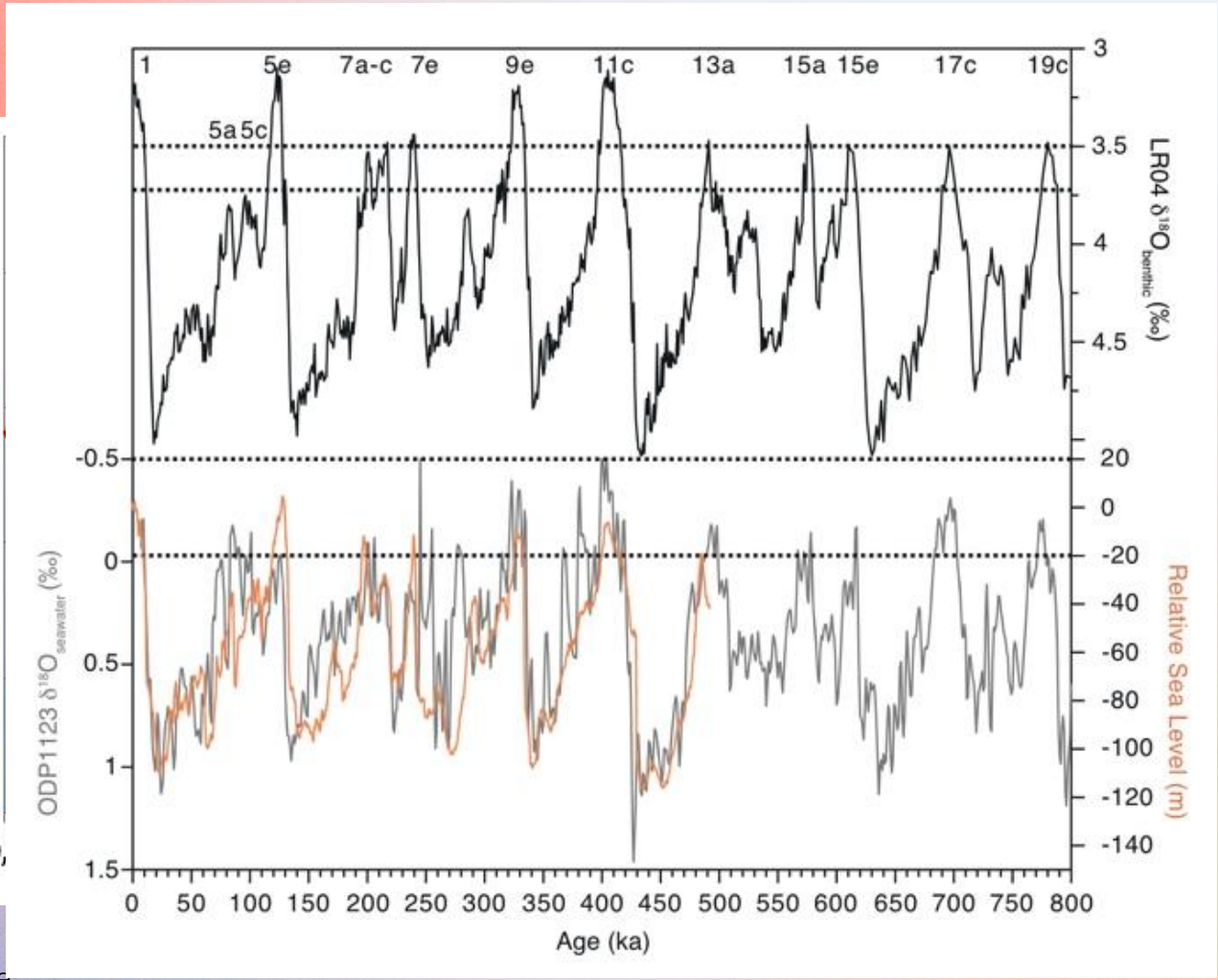


Figure credit: Steven Earle

Credit: Past Interglacials Working Group of PAGES (2016)

01. Introduction

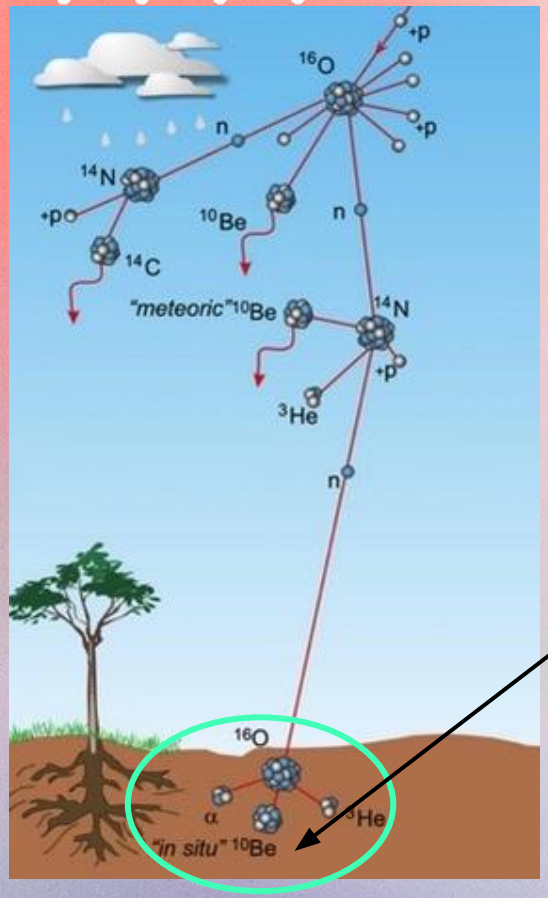


Figure Credit: Blackenburg & Willenbring, 2014

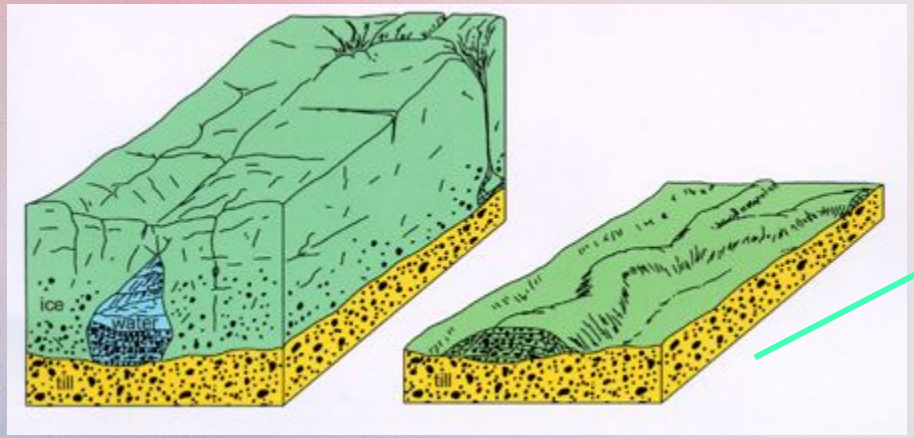
$^{26}Al/^{10}Be$

- Rare forms of isotopes
- Spallation > muonogenic production at surface
- ^{10}Be half life ~ 1.36 My
- ^{26}Al half life~ ~730 ky

01. Introduction

- $^{26}Al/^{10}Be$ production ratio ~7.3±0.3 at high latitudes
- “Depressed” ratio -> burial ~ 3.5-4.5

Figure Credit: North Dakota Mineral Resources



01. Introduction

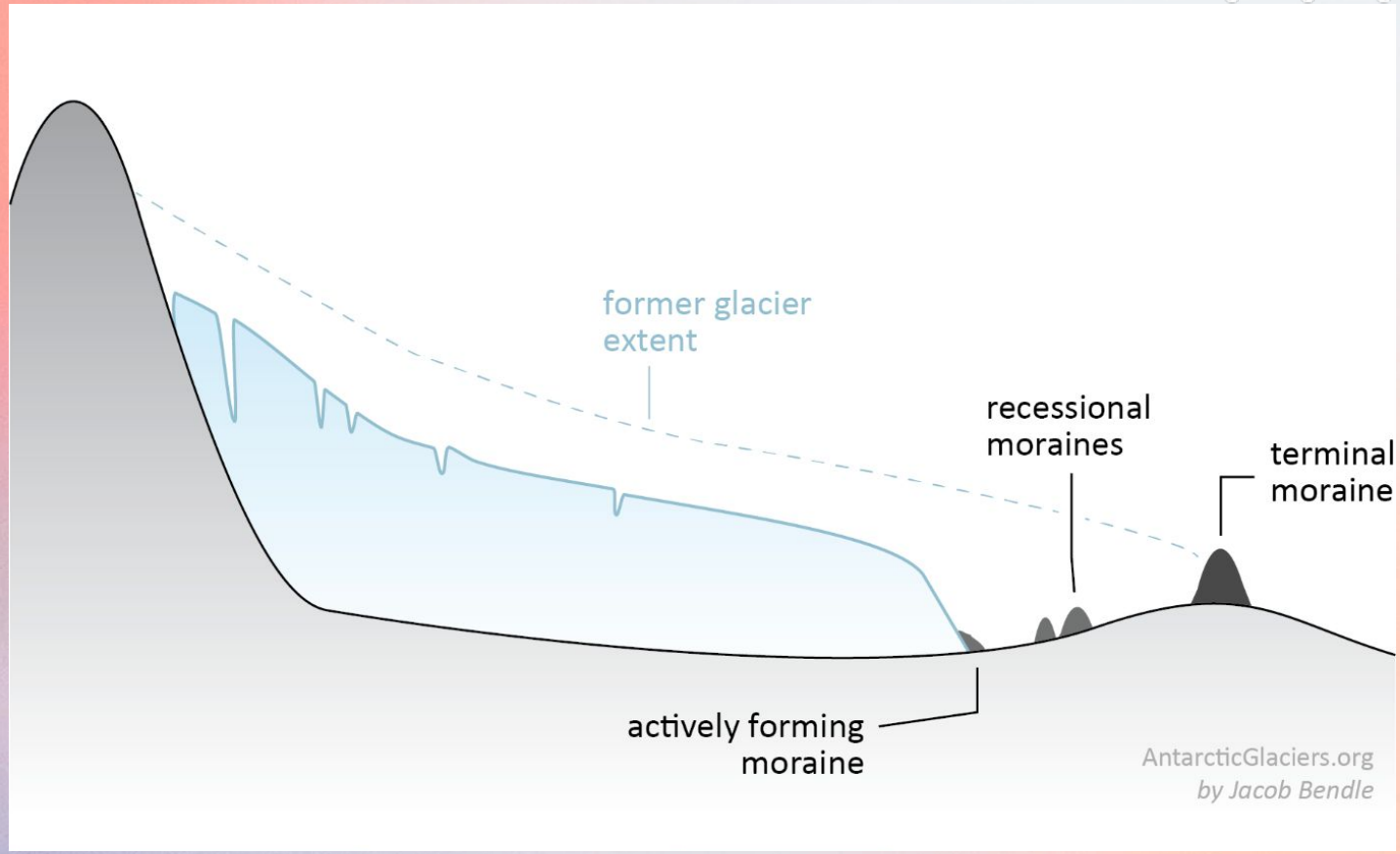


Figure Credit: Bendle 2020 https://www.antarcticglaciers.org

02. Motivation

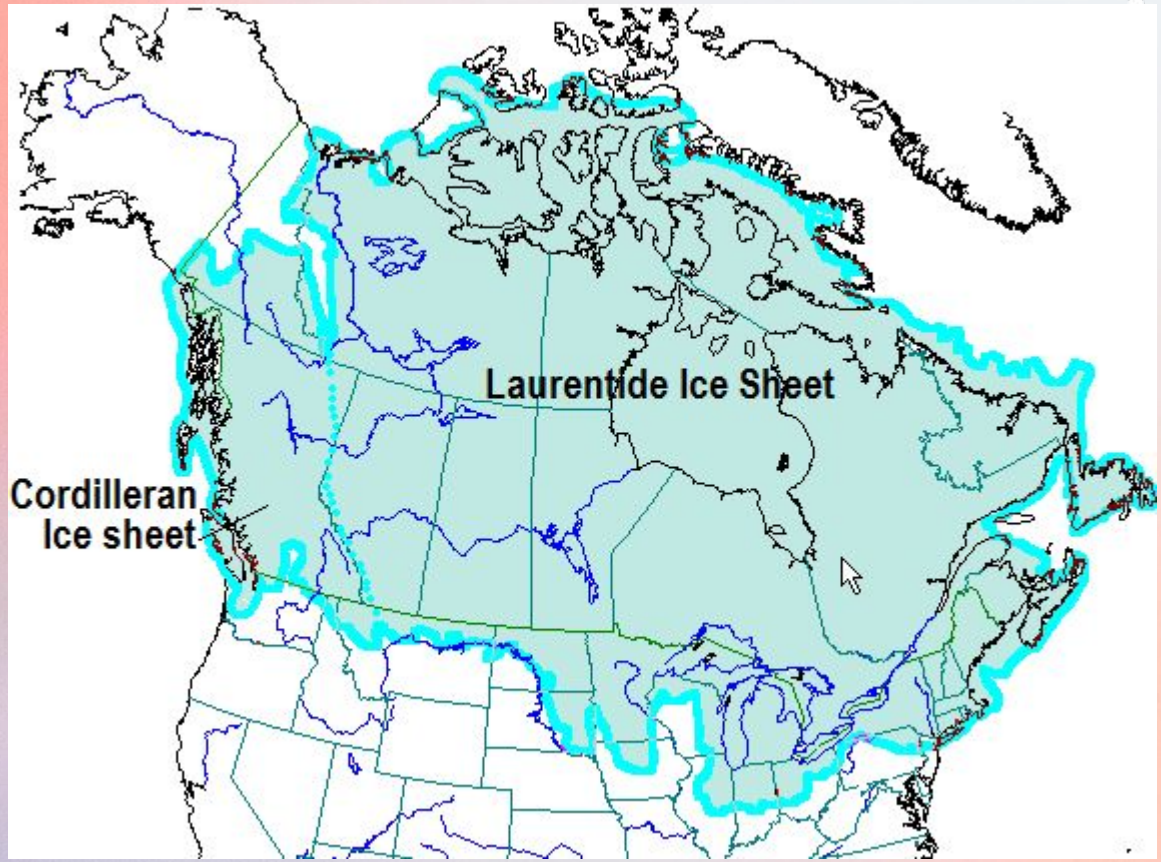


Figure credit: Steven Earle and NOAA

02. Motivation

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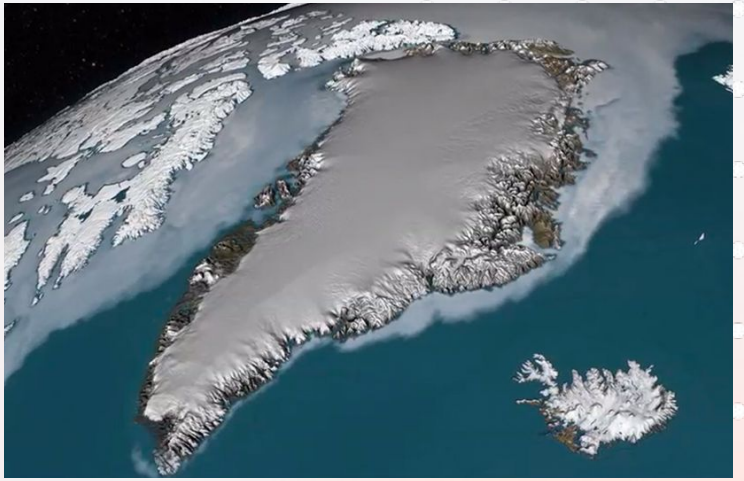

-150 billion tons yr^{-1}

-270 billion tons yr^{-1}

Photo credits: NASA

03. Background: Sediment Sourcing

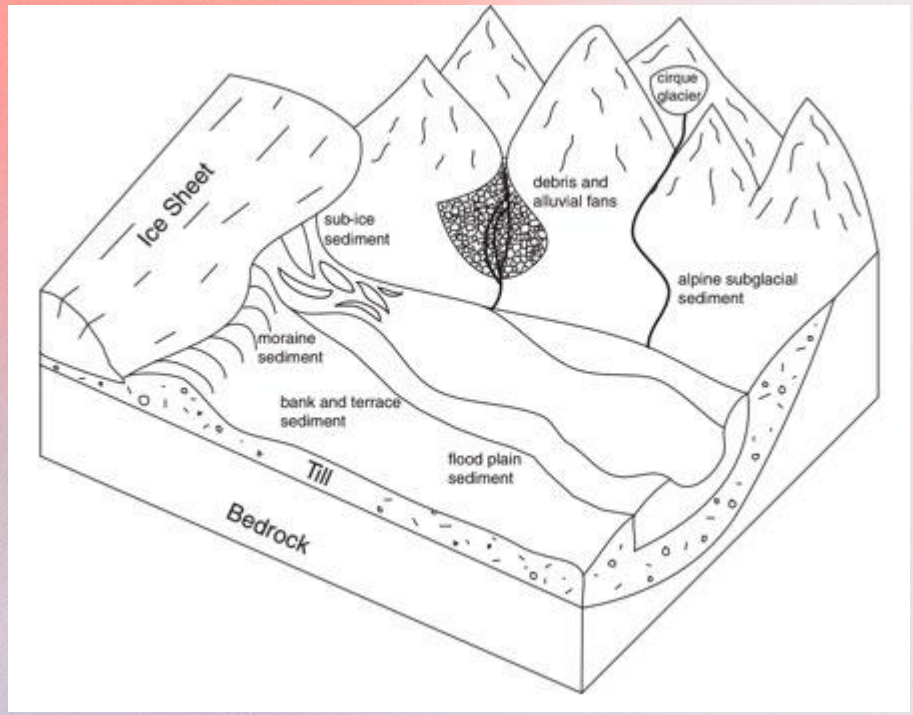

Figure Credit: Nelson et al., 2014

- the majority of sediment on glacial and paraglacial landscapes in Greenland comes from the under glacier opposed to the adjacent deglaciated areas (Nelson et al., 2014)
- In some paraglacial landscapes
    - Both modern and deglacial river sediments are all sourced primarily from the rapid erosion of steep river cutbacks that expose glacial deposits (Balco et al., 2005)

03. Background: Erosivity of Ice Sheets

- Paradise moraine system have unusually high concentrations of ^{10}Be
- 4 out of 6 samples inaccurately dating the moraine as being older than a margin further east
- Boulder recycling and nuclide inheritance

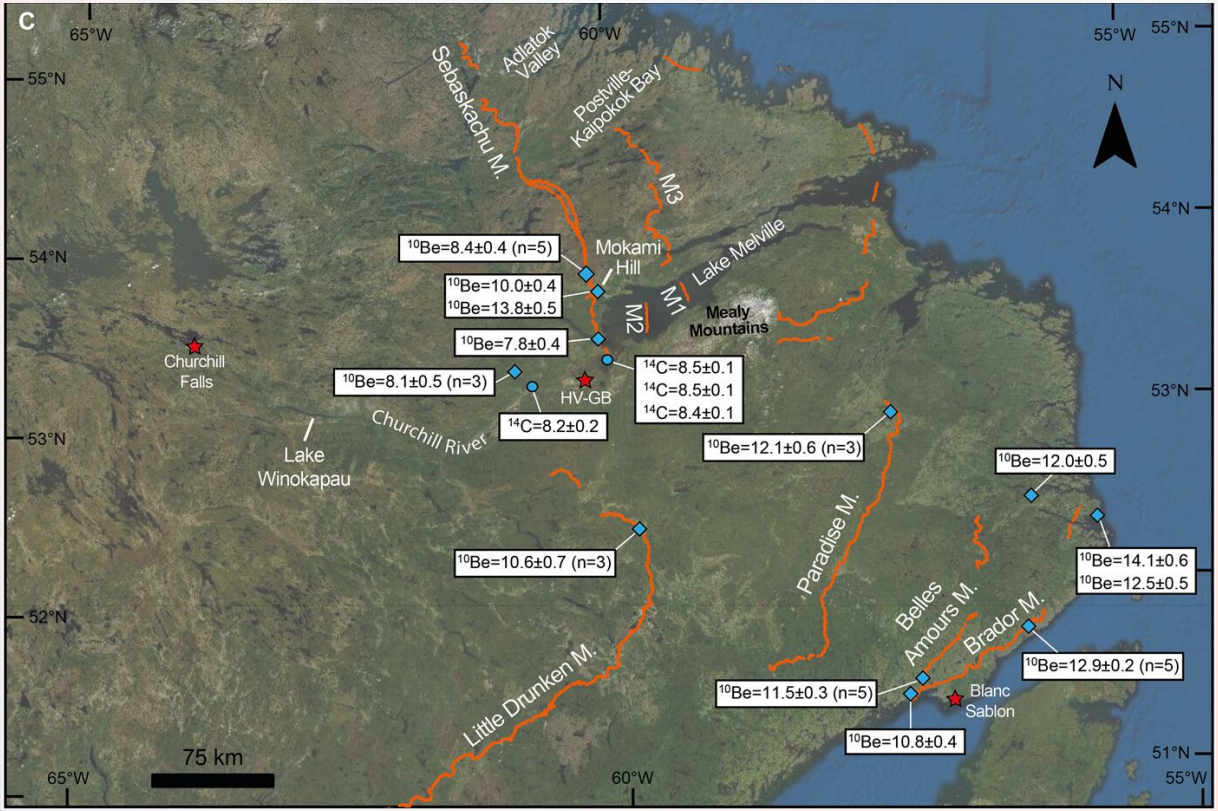

Figure Credit: Couette et al., 2023

03. Background: Ice Rafted Debris

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Laurentide Ice Sheet persistence during Pleistocene interglacials

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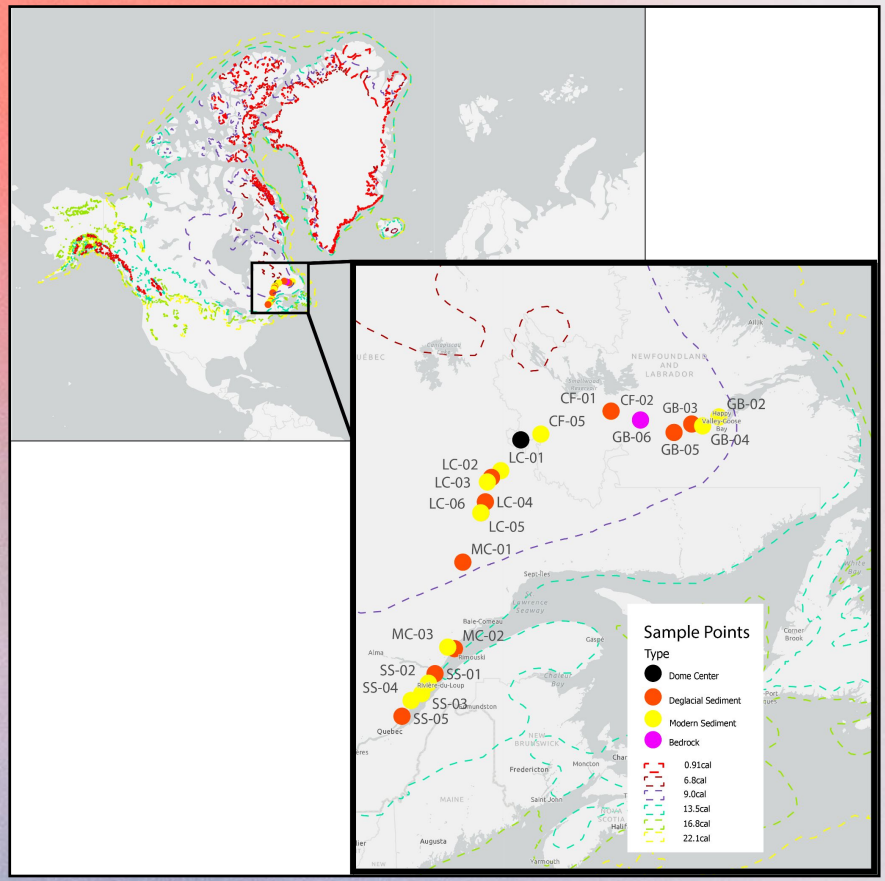
04. Goals/ Guiding Questions

- Is there evidence for deep erosion by the LIS during the LGM (i.e., near-zero nuclide concentrations) and what does this suggest about its basal thermal conditions?

- Do different sources of sediment have different cosmogenic nuclides concentrations and $^{26}Al/^{10}Be$ ratios?

- Do depressed $^{26}Al/^{10}Be$ ratios in terrestrial sediments support LeBlanc et al.'s (2023) inference from marine sediments that the LIS rarely deglaciated during the last million years?

05. Field Methods

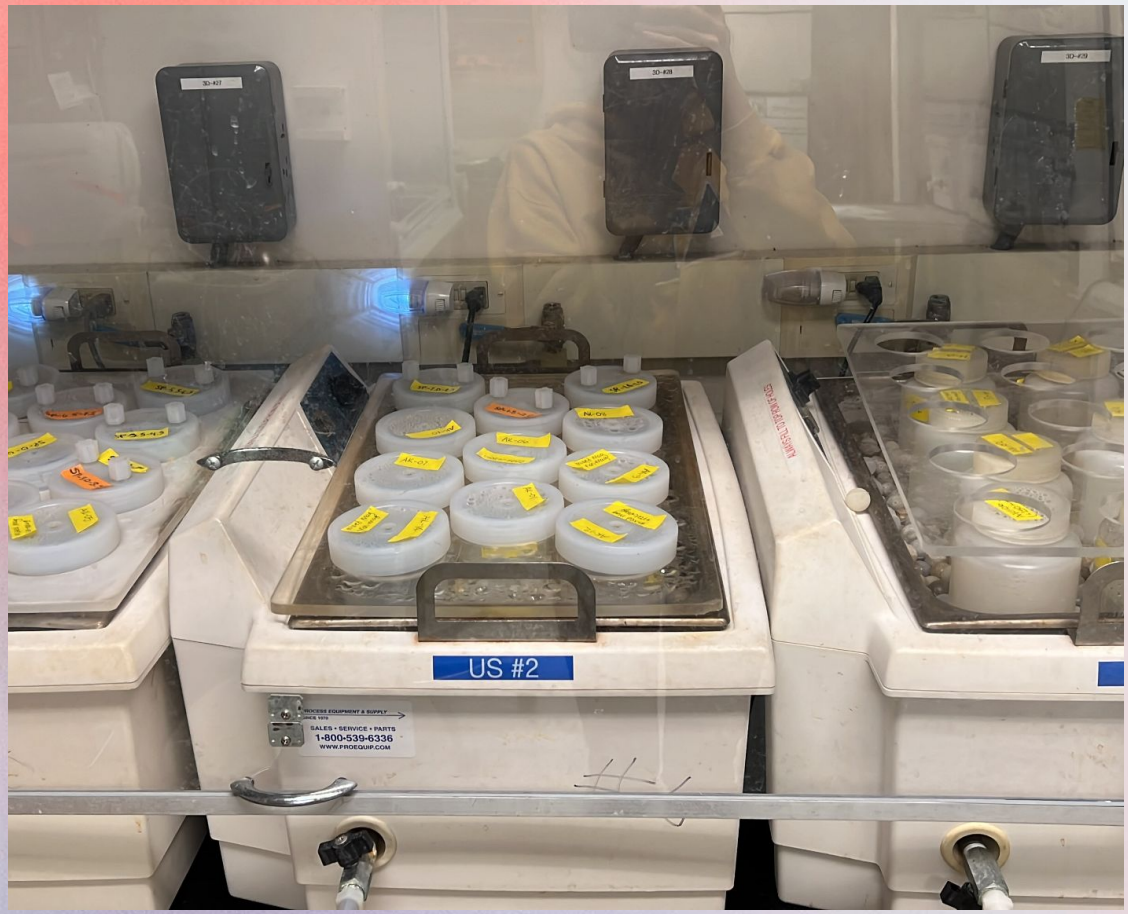


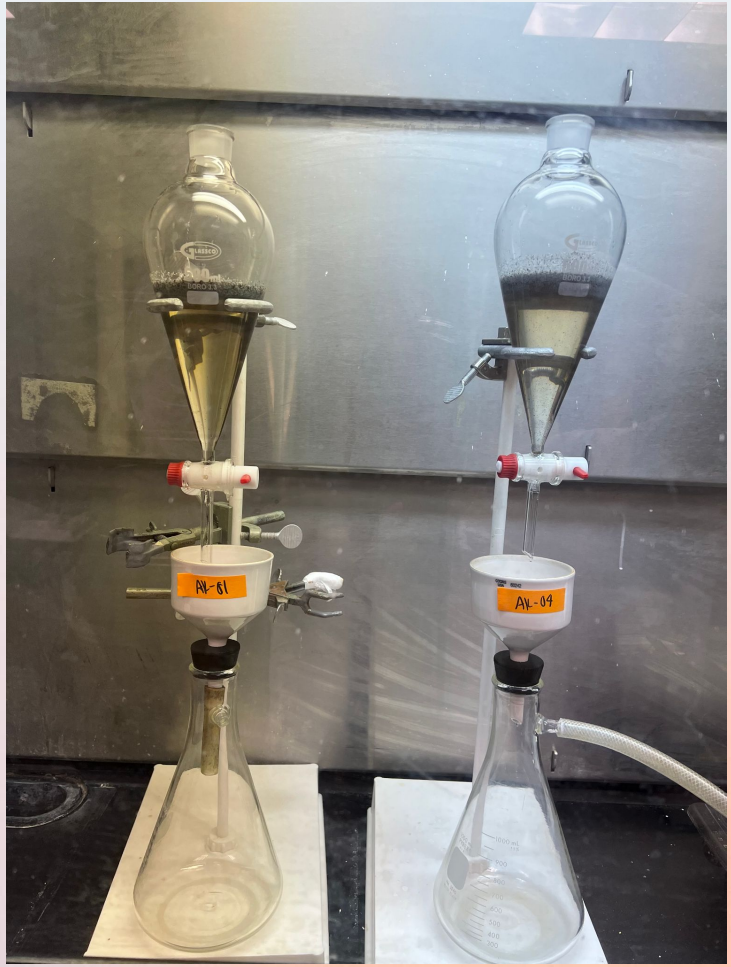
- Modern (n=10) river sediment and deglacial sediment (n=11)
- Bedrock samples (n=2)
- ~500 g of sand
- Trans-Labrador Highway

Field Photos

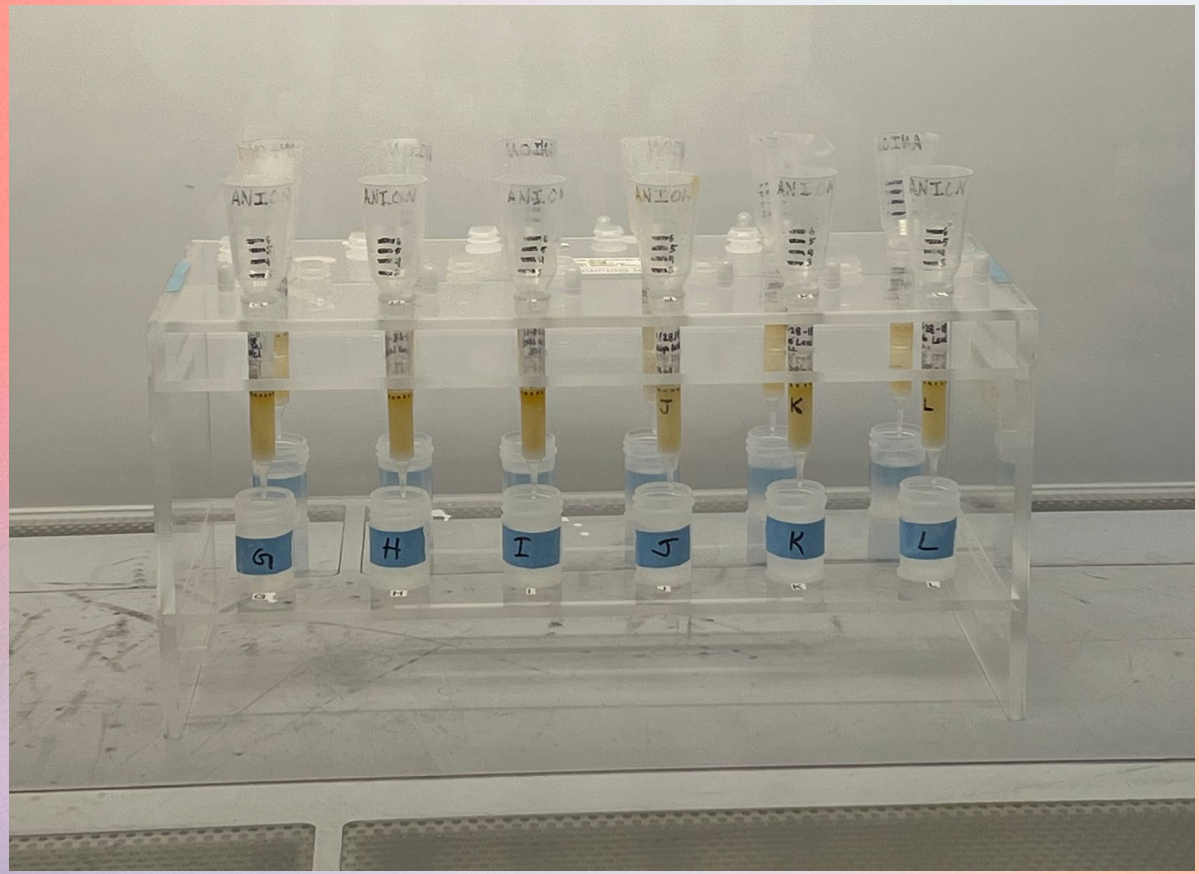

QUICKSILVER

05. Laboratory Methods


US #2
SALES • SERVICE • PARTS
1-800-539-6336
WWW.PROEQUIP.COM


AL-61
AL-09

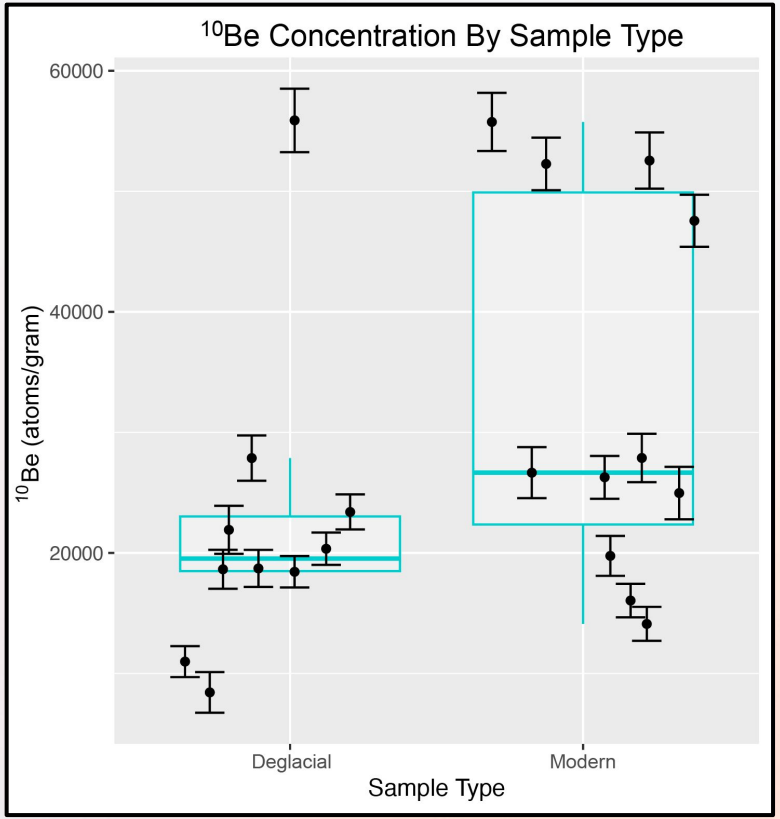

DANGER
CAUTION
PLENUM WASHDOWN


G
H
I
J
K
L

06. Results

Measured ^{26}Al and ^{10}Be

- ^{10}Be ranged from $8.42 \pm 1.68 * 10^3$ to $55.9 \pm 2.63 * 10^3$ atoms g^{-1}
  - Mean=$3.01 * 10^4$,median=$2.41 * 10^4$ atoms g^{-1}
- Measured concentrations of ^{26}Al ranged from $2.78 \pm 2.65 * 10^4$ to $59.0 \pm 2.9 * 10^4$ atoms g^{-1} with a
  - Mean=$19.9 * 10^4$, median=$15.7 * 10^4$
- Measured ratios of $^{26}Al/^{10}Be$ ranged from 1.73±1.66 to 8.44 ±4.19
  - Mean=6.49, median=6.47
- Single bedrock sample (GB-06) had a ^{10}Be concentration of $73.3 \pm 3.90 * 10^3$ atoms g^{-1} and a ^{26}Al concentration of 59.0 $\pm 2.90 * 10^4$ atoms g^{-1},
  - $^{26}Al/^{10}Be$ ratio of 8.05±0.58
- No statistically significant difference between ^{10}Be concentrations for modern and deglacial sediment (p=0.11)

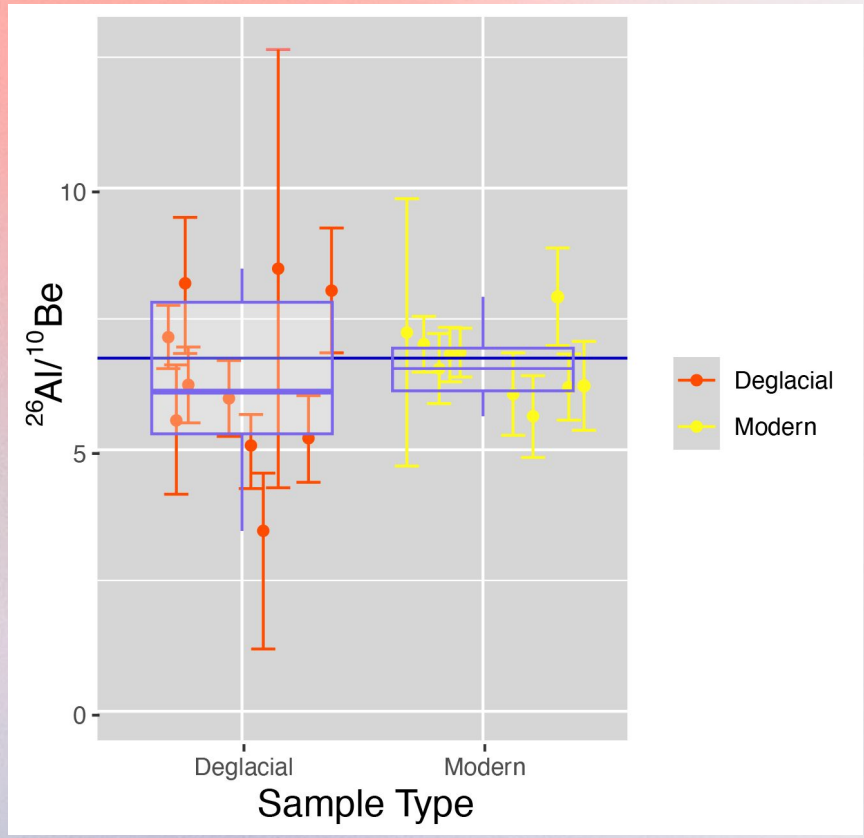


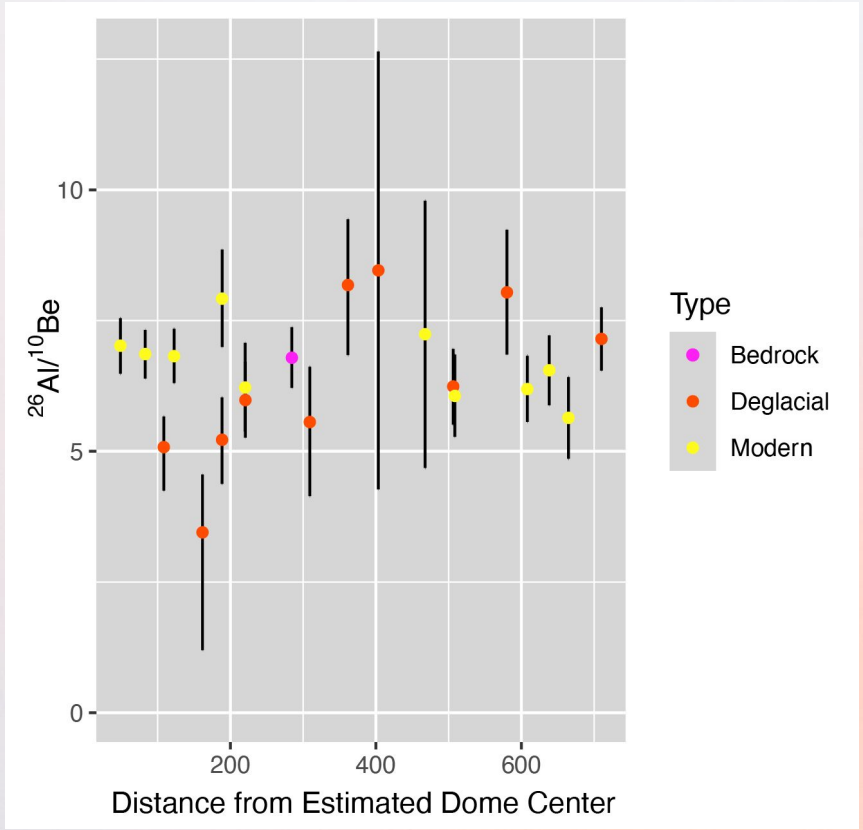
06. Results

Holocene Exposure Corrected Data

- ~19% (mean) of ^{10}Be in deglacial samples produced by exposure during the Holocene
- ~22% (mean) of ^{26}Al in deglacial samples produced by exposure during the Holocene
- Significant difference between mean deglacial and modern sediment nuclide concentrations (^{10}Be: p=0.020, 26Al: p=0.036)
- GB-06 corrected ^{10}Be concentration: $2.47*10^{4}$ atoms g^{-1}
- GB-06 corrected ^{26}Al concentration: $1.68*10^{5}$ atoms g^{-1}
- Deglaciated around 7.6 ka, meaning ~3.2 ka of surface exposure equivalent of inherited nuclides

06. Results


10
5
0
$^{26}Al/^{10}Be$
Deglacial
Modern
Sample Type
Deglacial
Modern


10
5
0
$^{26}Al/^{10}Be$
200
400
600
Distance from Estimated Dome Center
Type
Bedrock
Deglacial
Modern

07. Discussion

Limited Erosion by Quebec-Labrador Ice

- Despite being buried for ~60-105 ka by the LIS during the last glacial period, nuclide concentrations have not been reset by erosion to zero
- Ullman et al.'s (2016) CL3 transect showing ^{10}Be inheritance in boulders only 1.09 km from GB-06
    - 12 boulders excluded as outliers, 5 from Couette et al., 2023
- Rounded bedrock outcrops indicate warm-based, highly erosive ice at some point
- Exposure likely during MIS5e *at least*
- Marshall-Clarke model shows isolated pockets in Quebec-Labrador were cold based during the LGM

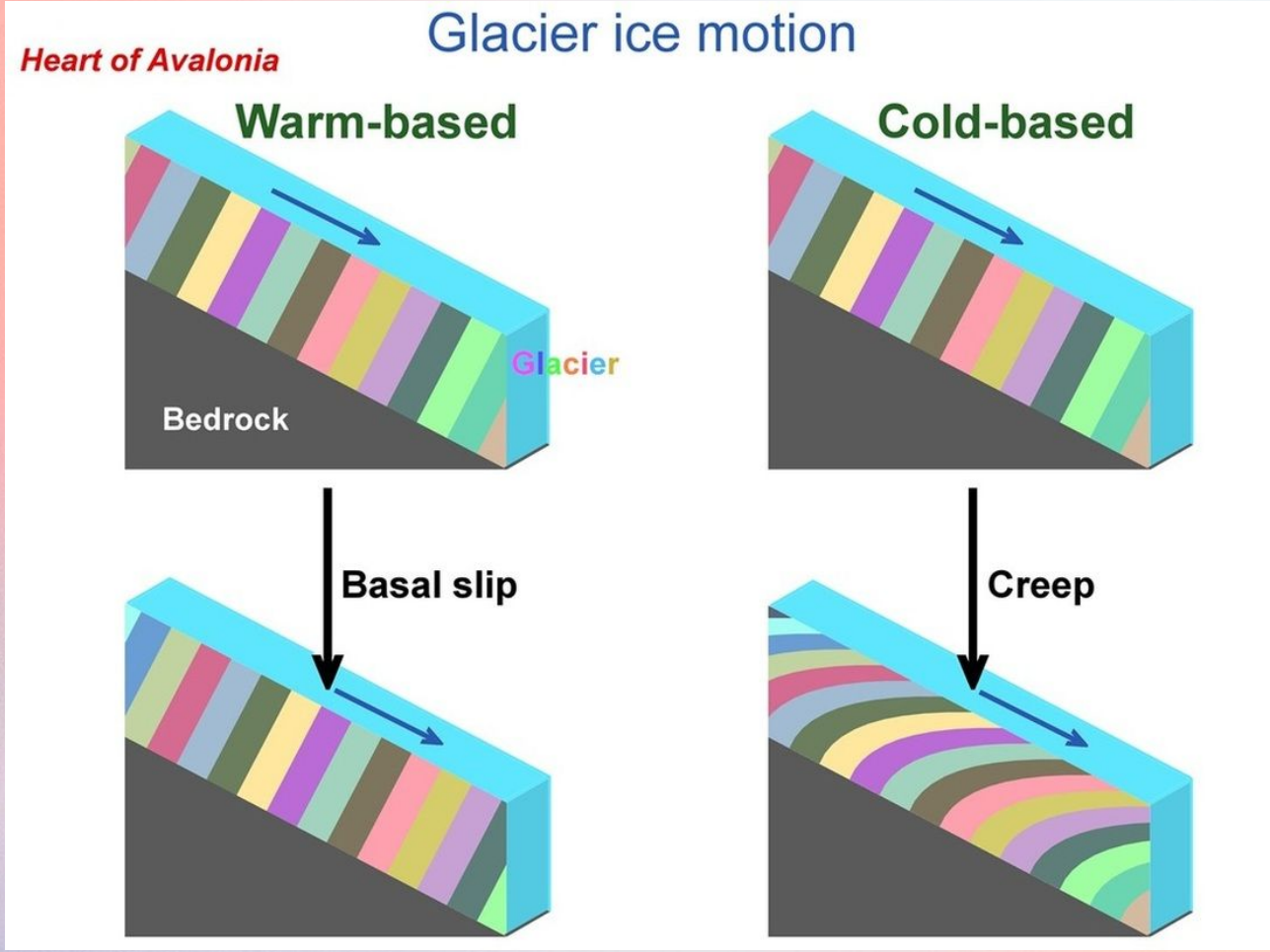


Figure Credit:
https://www.heartofavalonia.org

07. Discussion

Limited Erosion by Quebec-Labrador Ice

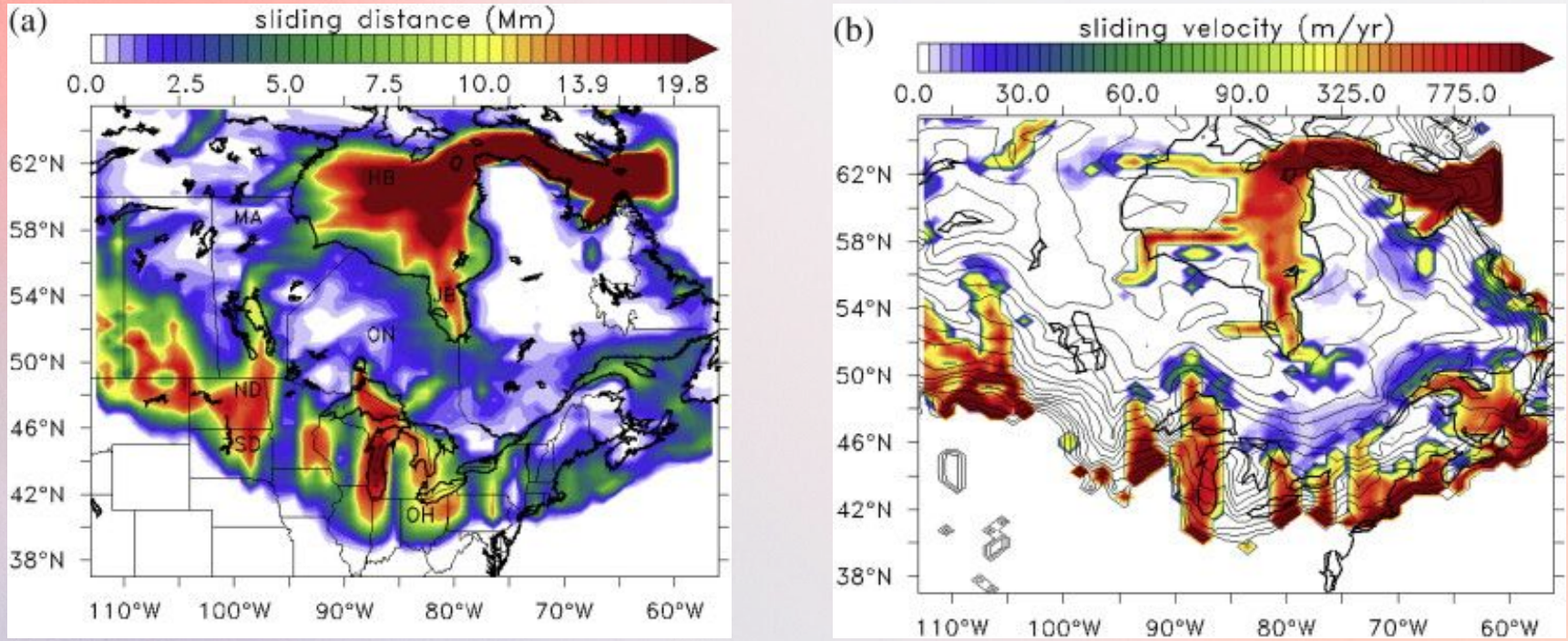
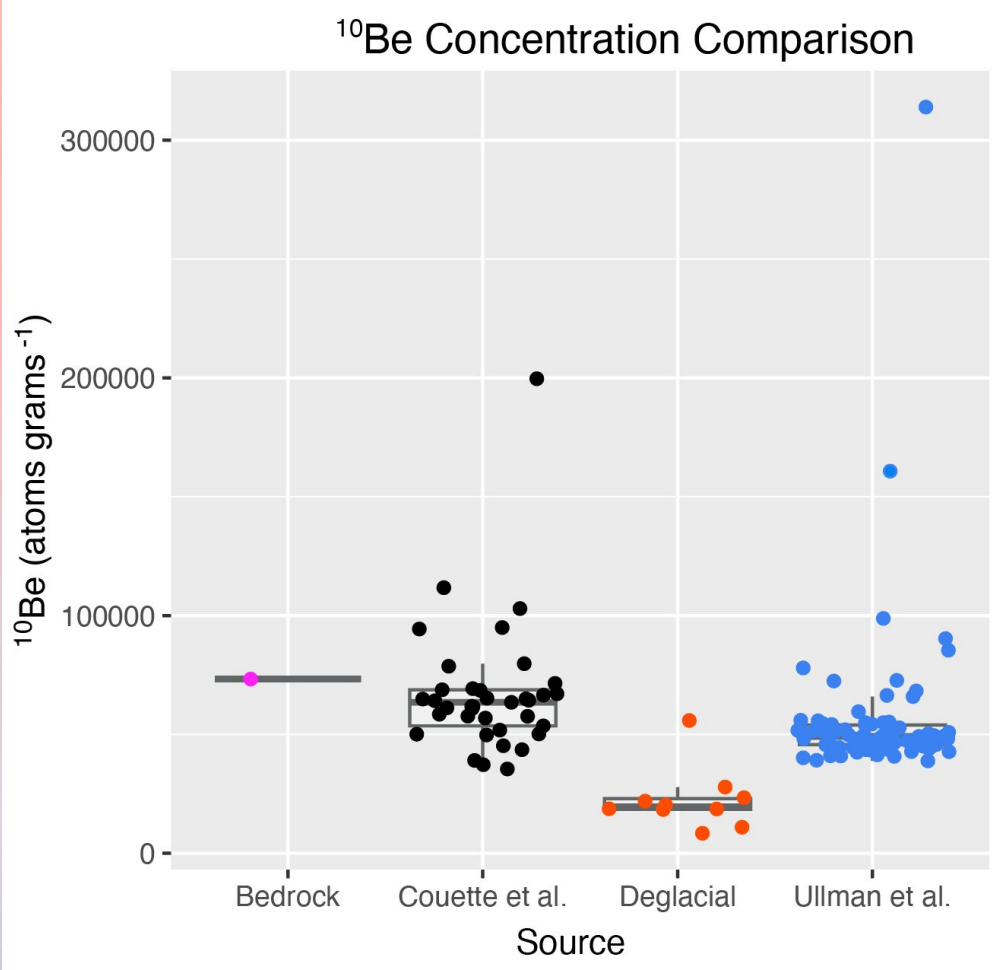


Figure Credit: Melanson et al., 2013


^{10}Be Concentration Comparison
^{10}Be (atoms grams^{-1})
300000
200000
100000
0
Bedrock
Couette et al.
Deglacial
Ullman et al.
Source

07. Discussion

Ice Dome was Not Persistent During Pleistocene Interglacials

- $^{26}Al/^{10}Be$ ratios from our deglacial samples are not depressed enough to indicate burial over multiple Pleistocene interglacials

- Means of our deglacial sample $^{26}Al/^{10}Be$ ratios are significantly different than LeBlanc et al.'s (2023) IRD ratios (wilcoxon rank-sum, p=0.00084)

- Deglacial sample $^{26}Al/^{10}Be$ ratios are statistically inseparable from the production ratio of 7.3 ±0.3 (1σ) (alpha=0.05; p=0.l8) while the IRD is not (p<0.0000001)

- Both IRD and deglacial samples support minimal Quebec-Labrador Erosion

08. Reflections

- Bedrock sampling
- Missing field season
- Community engagement

“Uncertainty is inevitable on the frontiers of knowledge.”

— Joel Achenbach

Figure Credits

Berger, A., Crucifix, M., Hodell, D. A., Mangili, C., McManus, J. F., Otto-Bliesner, B. L., Pol, K., Raynaud, D., Skinner, L. C., Tzedakis, P. C., Wolff, E. W., Yin, Q., Abe-Ouchi, A., Barbante, C., Brovkin, V., Cacho, I., Capron, É., Ferretti, P., Ganopolski, A., . . . Riveiros, N. V. (2016). Interglacials of the last 800,000 years. *Reviews of Geophysics*, *54*(1), 162–219. https://doi.org/10.1002/2015rg000482

Change, N. G. C. (n.d.). *Ice Sheets | NASA Global Climate Change*. Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/vital-signs/ice-sheets/?intent=121

Earle, S., & Earle, S. (2015, September 1). *16.1 Glacial Periods in Earth's History*. Pressbooks. https://opentextbc.ca/geology/chapter/16-1-glacial-periods-in-earths-history/

Eskers in North Dakota. (n.d.). Department of Mineral Resources, North Dakota. https://www.dmr.nd.gov/dmr/ndgs/eskers

Heart of Avalonia. (n.d.). Heart of Avalonia. https://www.heartofavalonia.org/