Understanding High Latitude Landscape Development in the Presence of Non-Erosive Glacial Ice

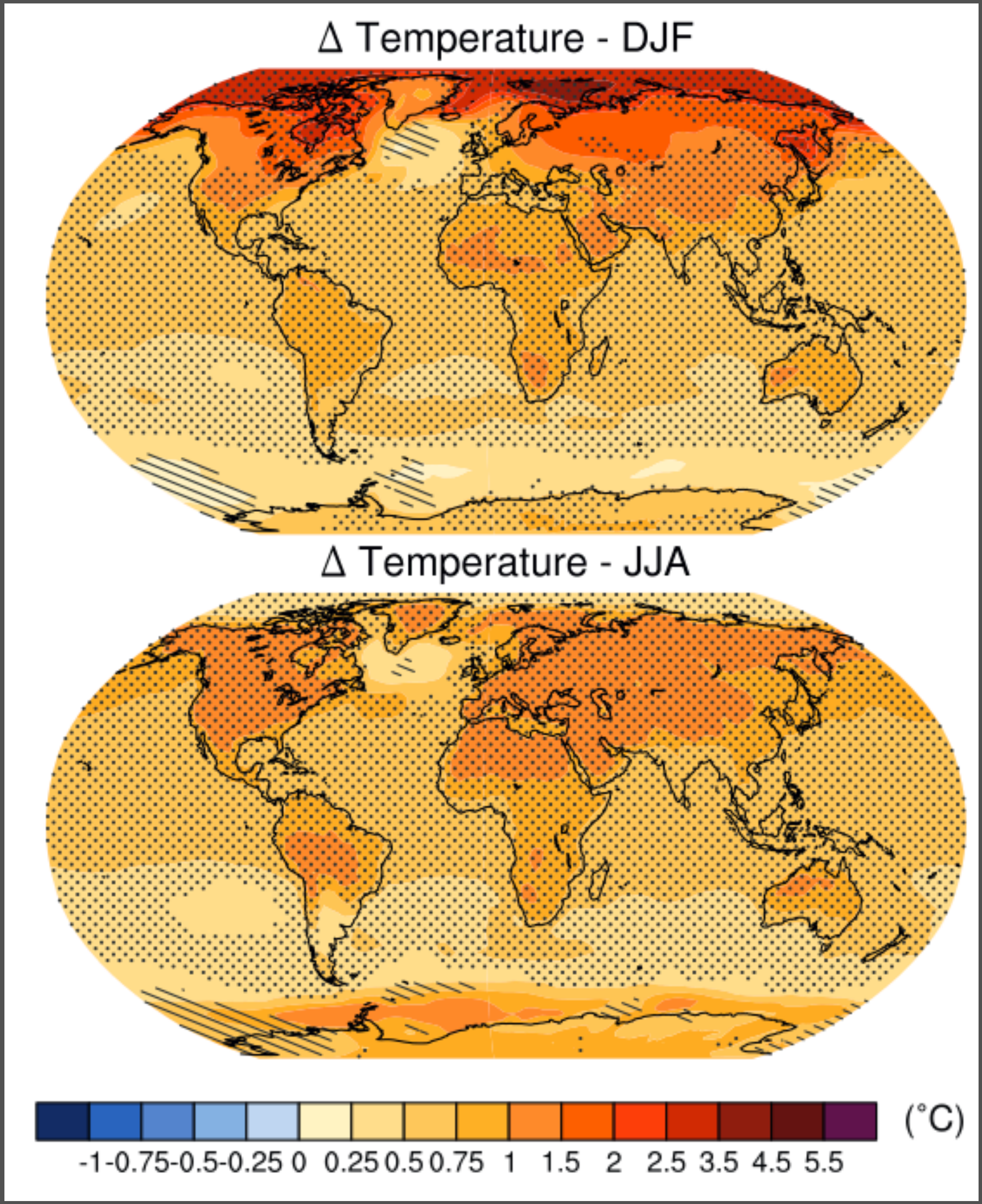
Lee Corbett

RSENR Dissertation Proposal

July 1, 2015

The high latitudes are warming...

Projected surface air temperature change for years 2016-2035, relative to years 1986-2005



2013 IPCC Report

...forcing Arctic nations to make choices about land management...

Greenland explores Arctic mineral riches amid fears for pristine region

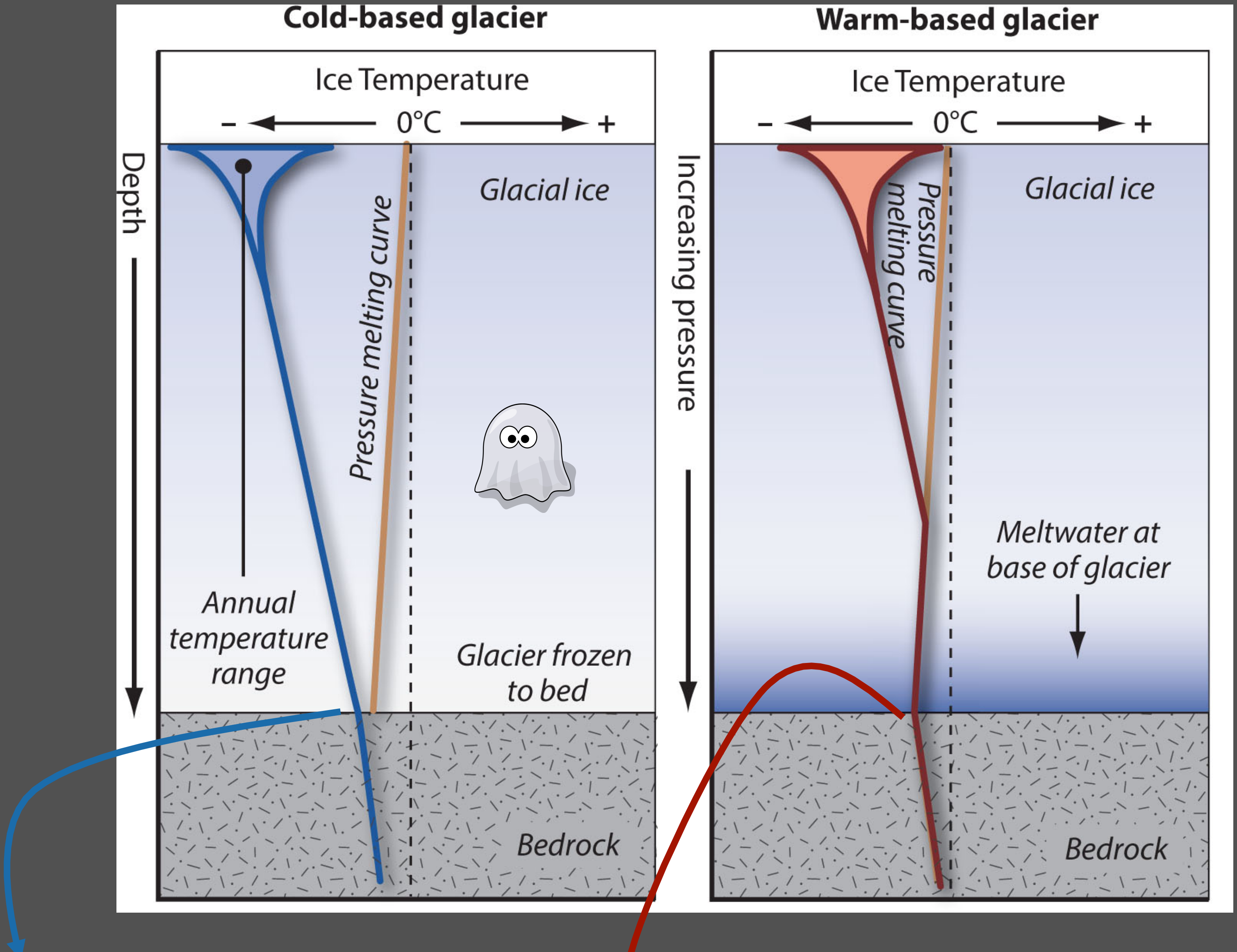
London Mining's £1.5bn iron ore mine and new oil drilling licences for BP and Shell spark concern for environment

Greenland iron ore mine gets green light

The Isua project will comprises of a mine, processing plant and 105km concentrate pipeline which connects the plant to a deepwater port capable of year round loading of 250,000t ships. Image from London Mining corporate video.

...hence, we need a better understanding of how high-latitude landscapes work.

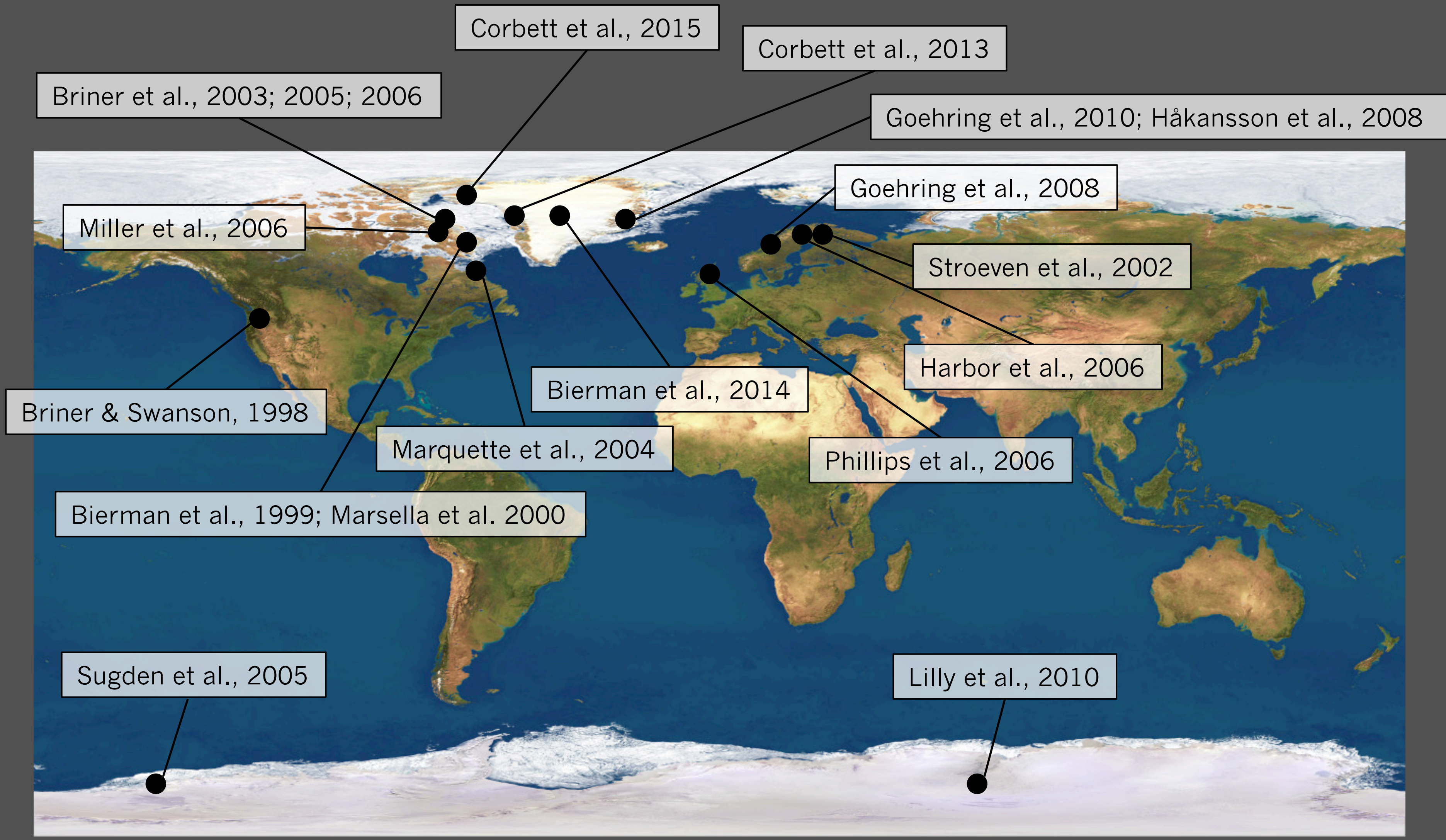
But, we have a problem:



NO liquid water present
No erosion can occur

Liquid water is present
Erosion by abrasion
Erosion by plucking/quarrying

Cold-based ice is widespread in the high latitudes...

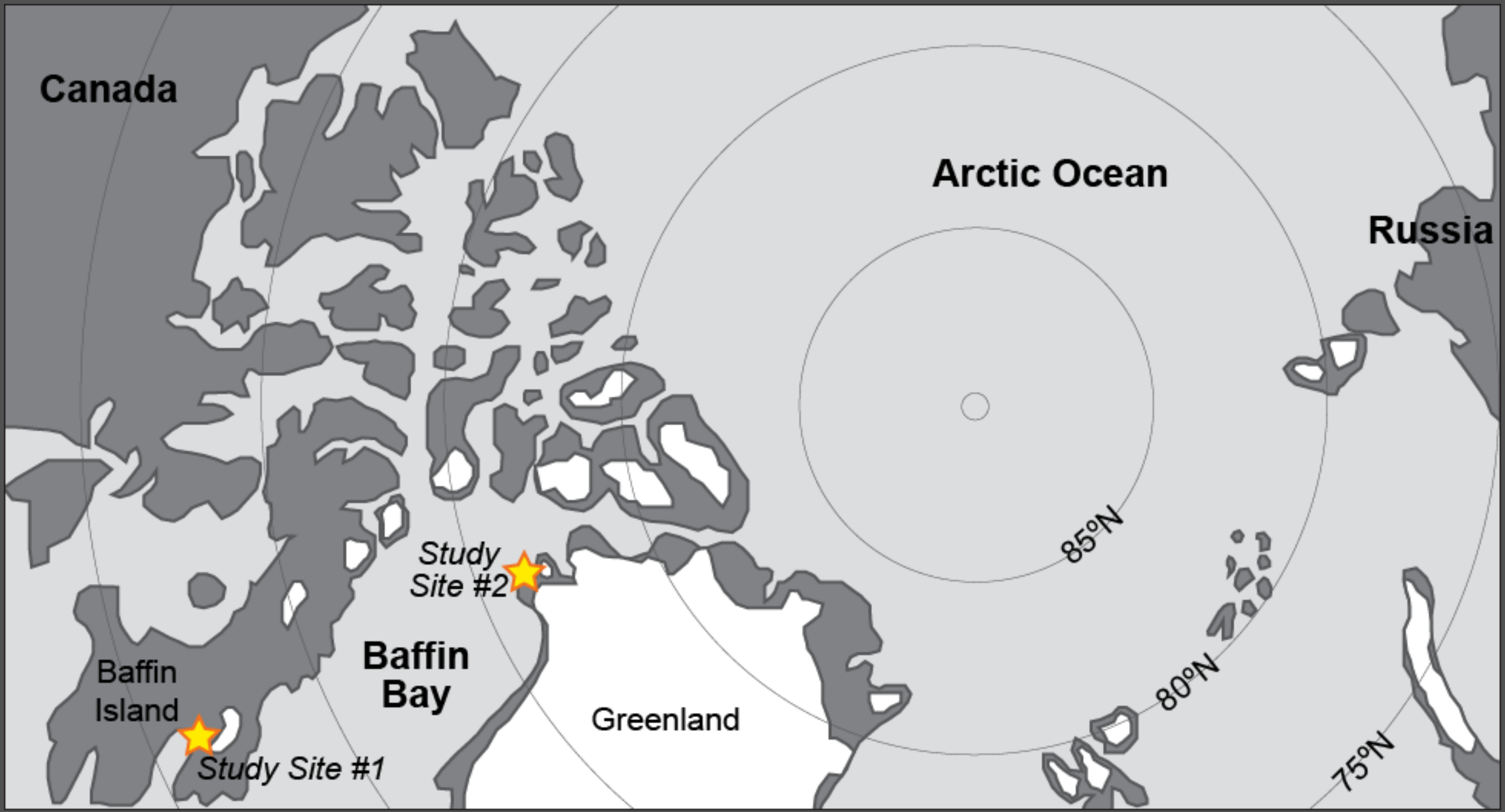


The Problem

Cold-based glaciers perform little erosion and therefore leave behind little evidence of their presence.

So how do we know if a landscape was covered by cold-based glaciers?

Project Goals



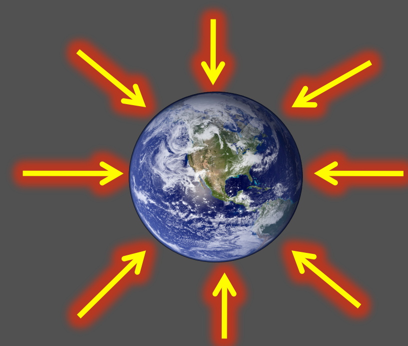
1. Understand the **history** of these high-latitude landscapes
2. Understand cold-based ice **processes** and improve the **methods** for studying cold-based ice landscapes

Tools: In situ Cosmogenic ^{10}Be & ^{26}Al

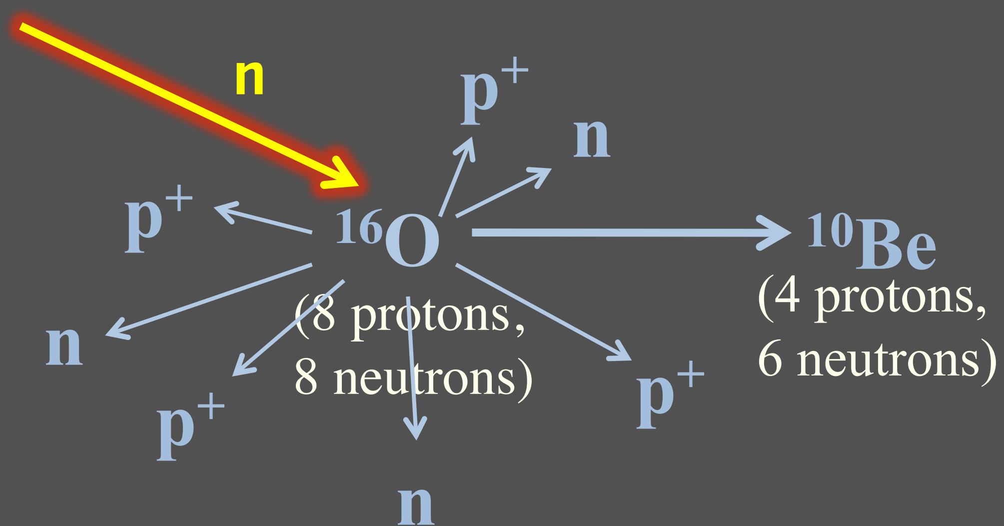
- *"In situ"*: produced within the mineral structure (quartz)
- "Cosmogenic": from cosmic rays
- "^{10}Be": rare, radioactive isotope of Be; $t_{1/2} = 1.36$ Ma
- "^{26}Al": rare, radioactive isotope of Al; $t_{1/2} = 0.71$ Ma

Formation of Cosmogenic Nuclides

Earth is bombarded by high-energy cosmic rays



...causing the formation of ^{10}Be in quartz (SiO_2)



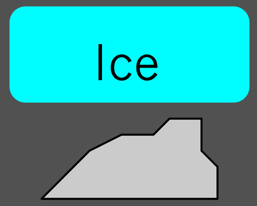
^{10}Be is produced only on the surface of a rock

^{10}Be is produced at about 4 atoms per gram of quartz per year

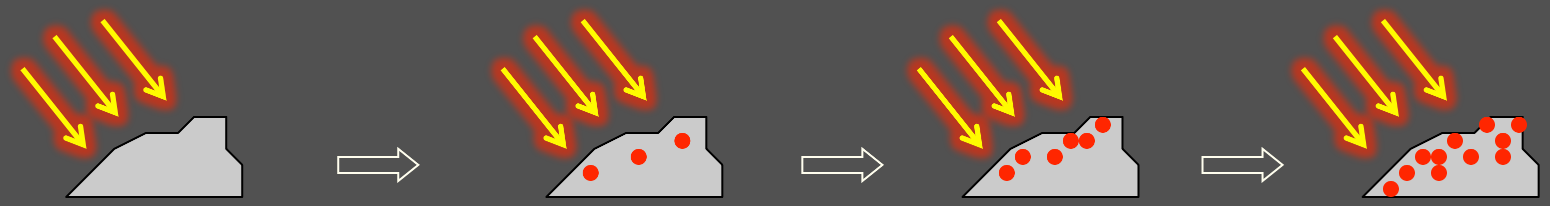
^{10}Be is radioactive and has a half-life of 1.36 million years

"Cosmogenic Dating"

Glacial period: Bedrock is **shielded**



Interglacial period: Bedrock is **exposed**

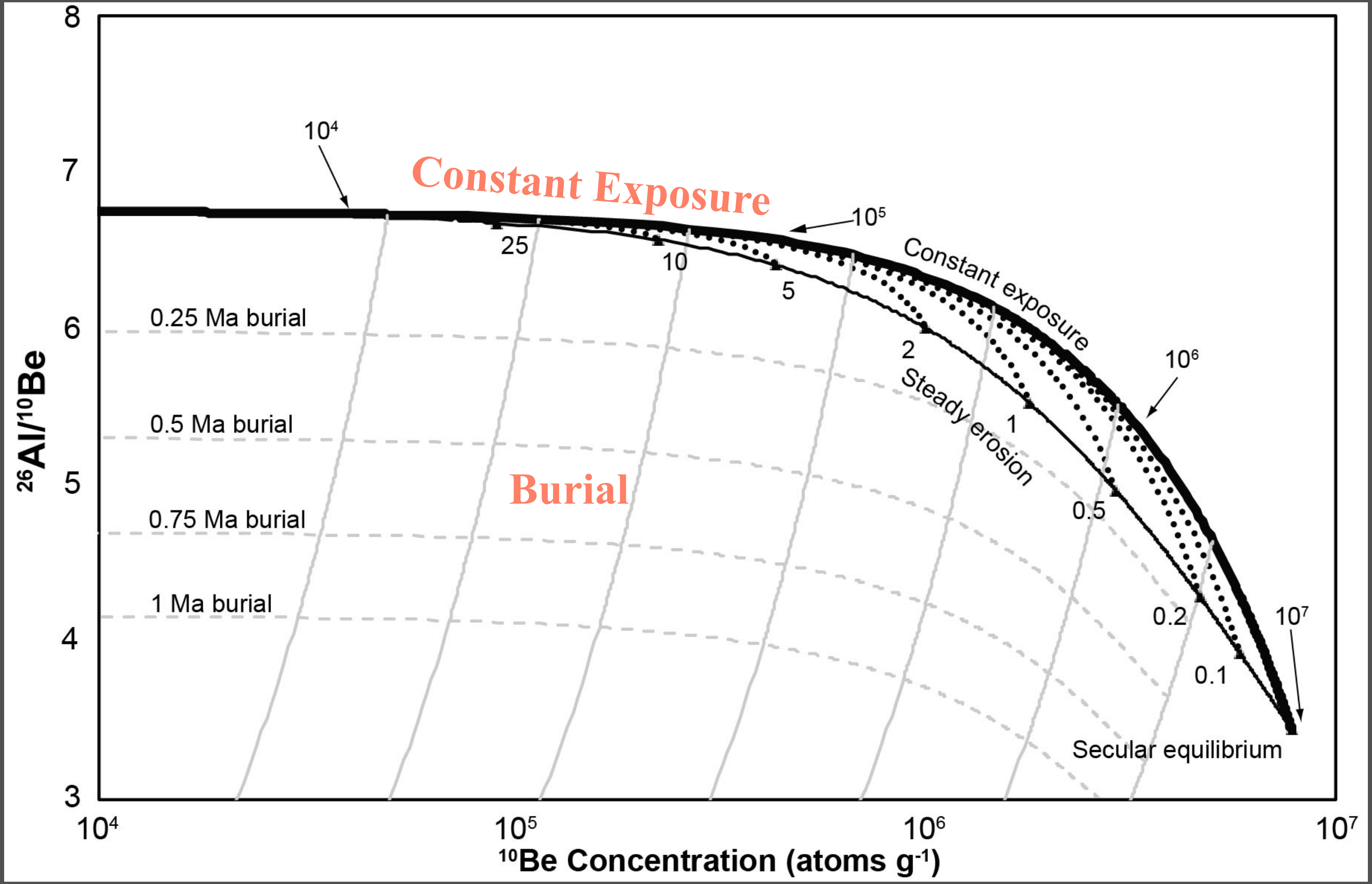


Assumption: Zero **inheritance**
(i.e. no ^{10}Be leftover from previous periods of exposure)

The Two-Isotope Approach

^{10}Be
Production Rate: ~4 atoms g^{-1} yr^{-1}
Half-life: 1.36 million yr

^{26}Al
Production Rate: ~26 atoms g^{-1} yr^{-1}
Half-life: 0.71 million yr



1.) How old are the landscapes preserved in Baffin Island and Thule?

2.) Is subglacial erosion homogeneous or heterogeneous?

3.) Are glacial sediments (till) recycled over numerous glacial/interglacial cycles?

4.) What is the lifecycle of these high-latitude landscapes, especially the relative portions of exposure and burial?

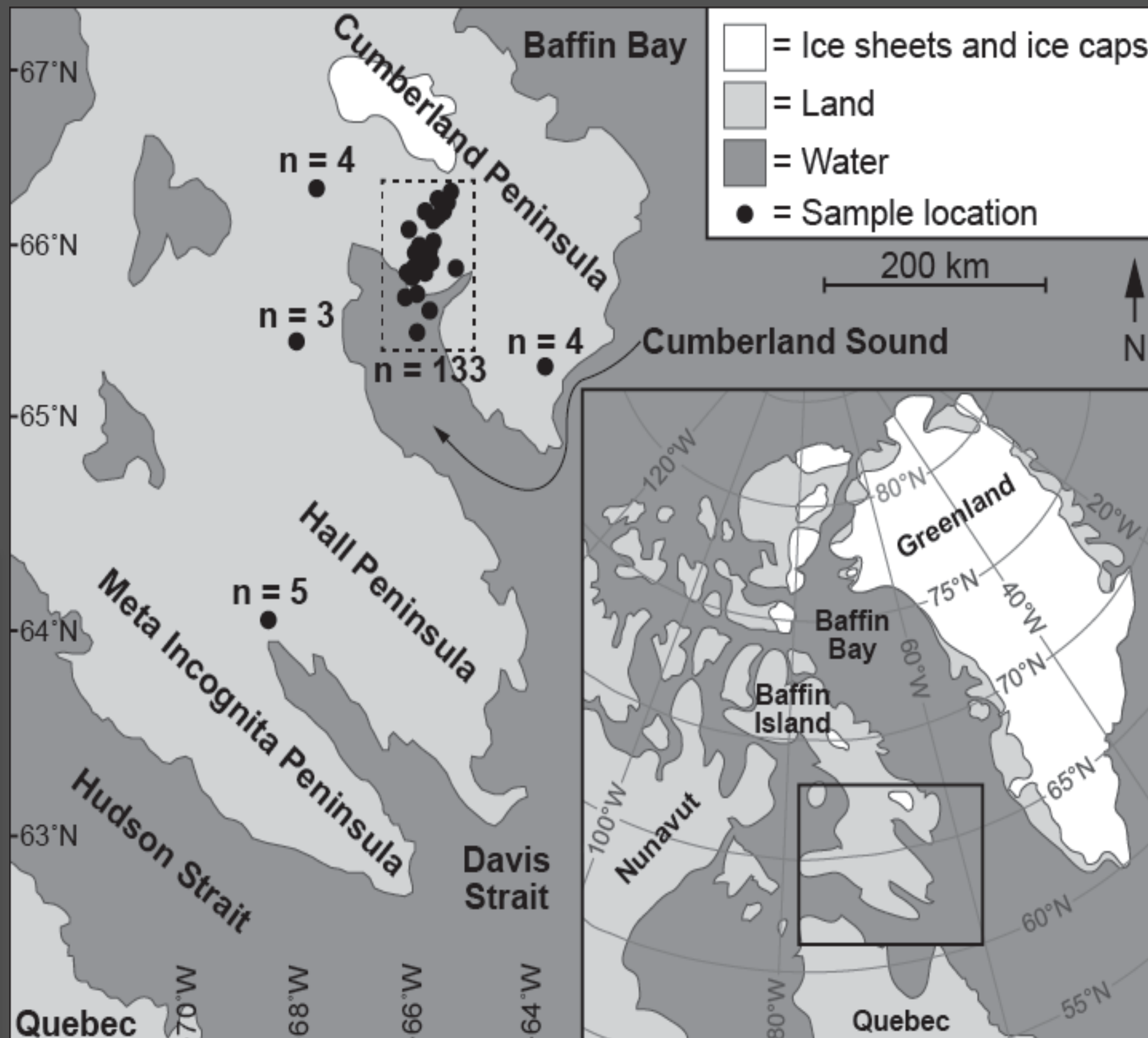
5.) What new techniques and approaches can I develop to more effectively extract valuable climatic information from these complex landscapes?


Baffin Island, Canada

The Data Set

149 samples
(144 $^{26}Al/^{10}Be$)
Collected 1992-1995

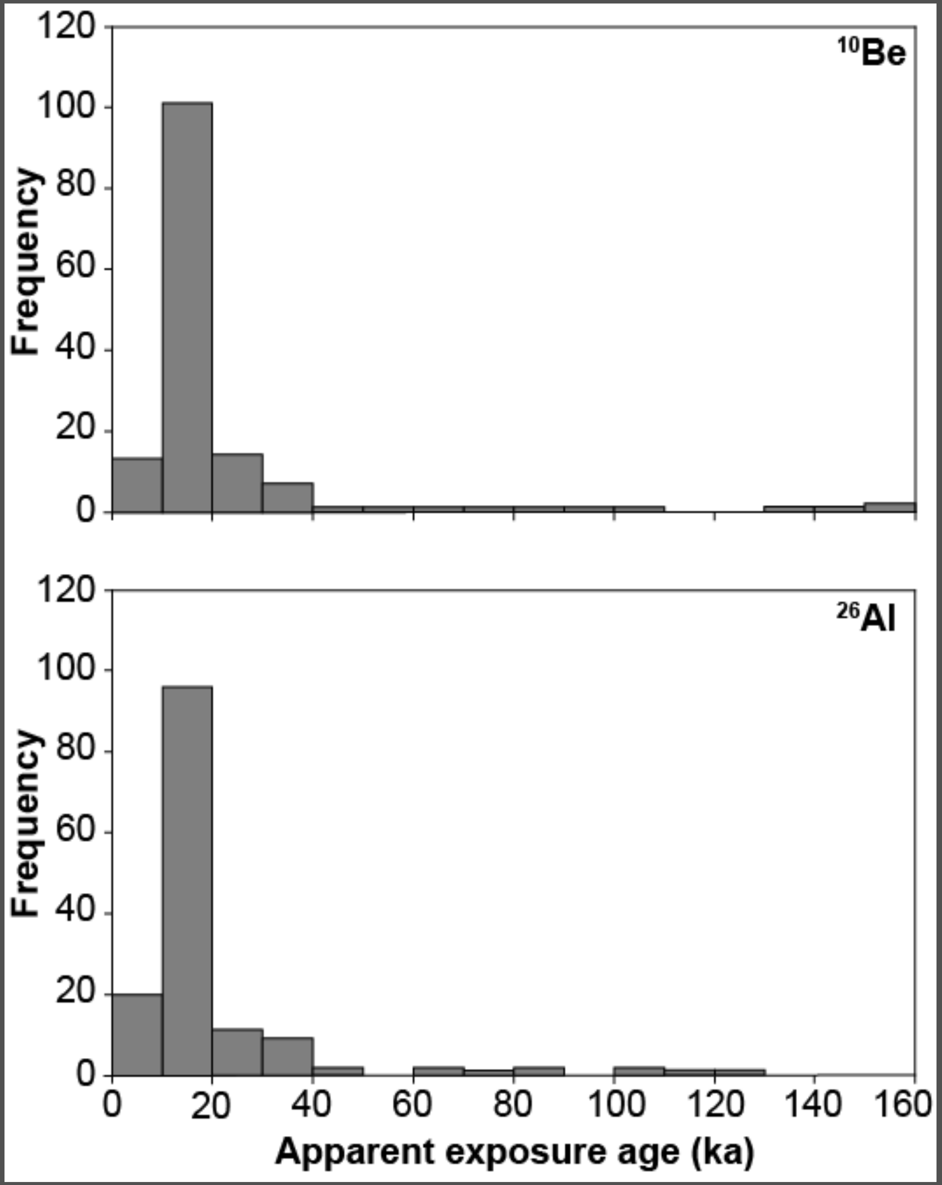
Bedrock & boulders
(65 bedrock)
(84 boulders)



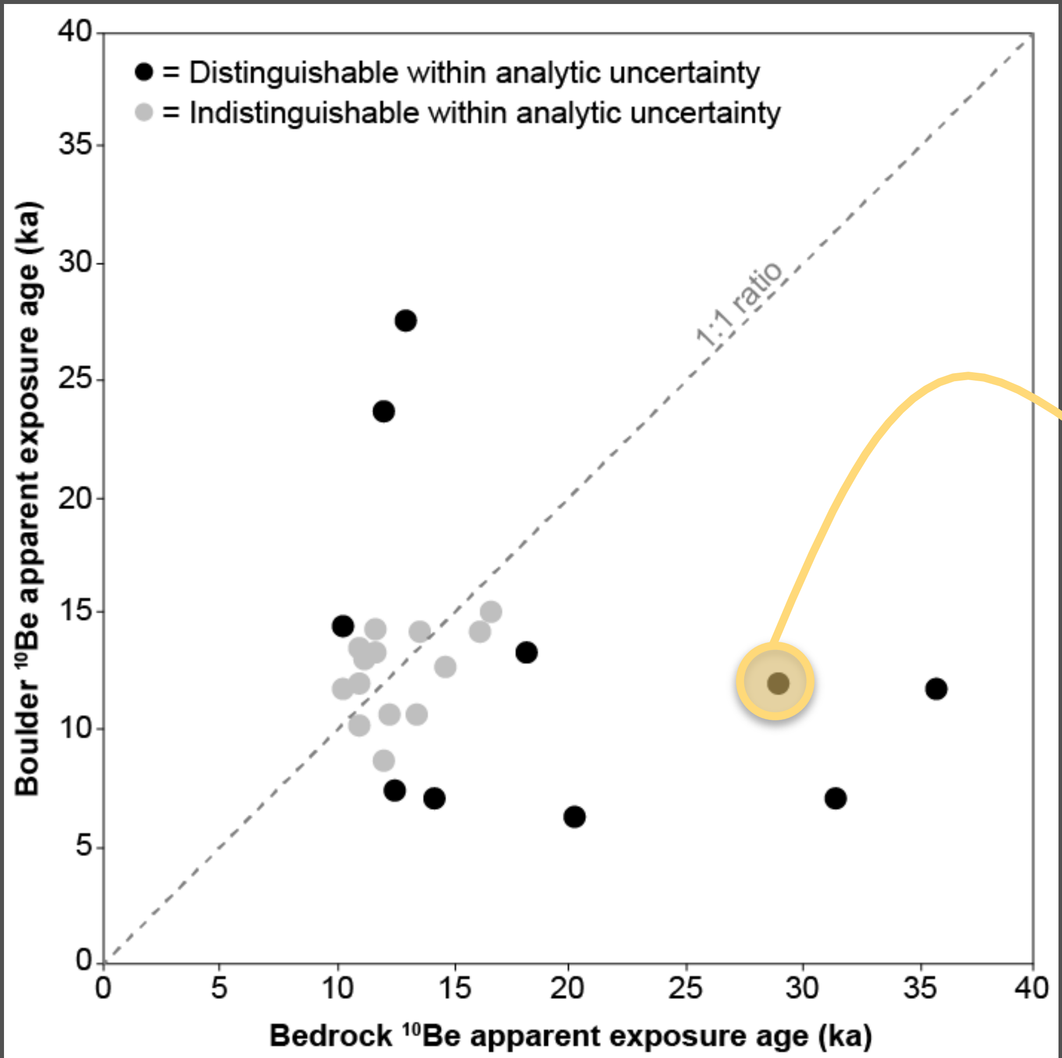
Apparent Exposure Ages

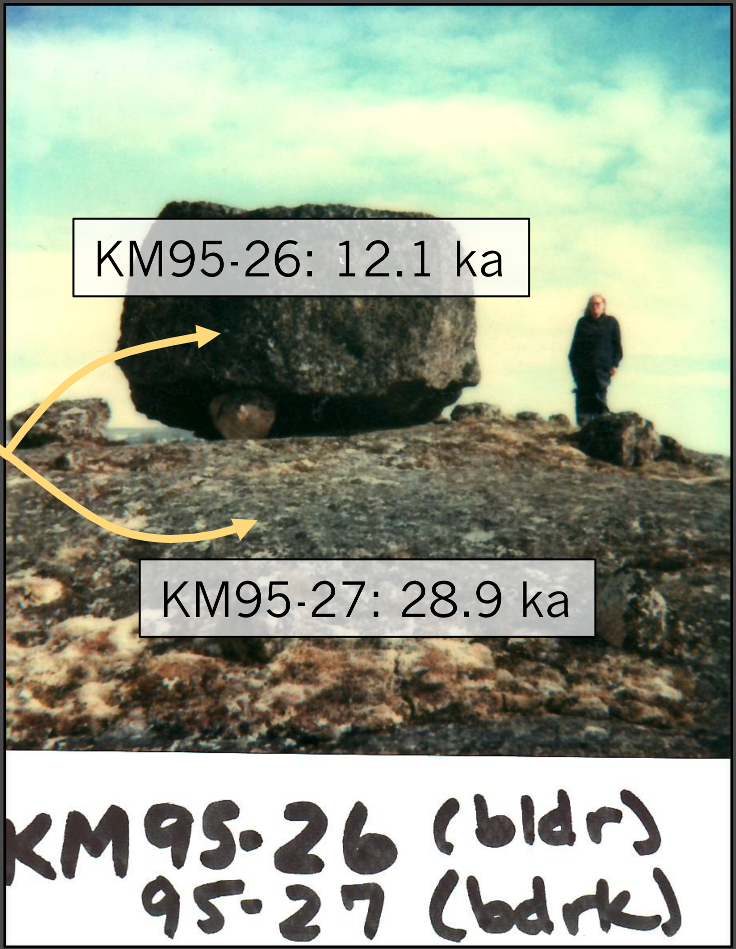
^{10}Be apparent exposure ages:
6.3-160 ka (n = 146)

^{26}Al apparent exposure ages:
4.3-124 ka (n = 147)

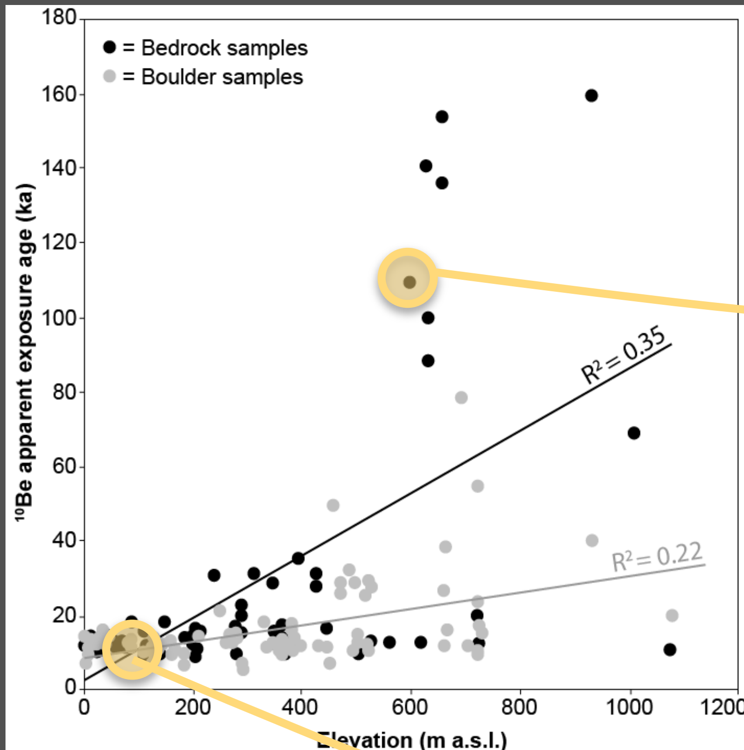


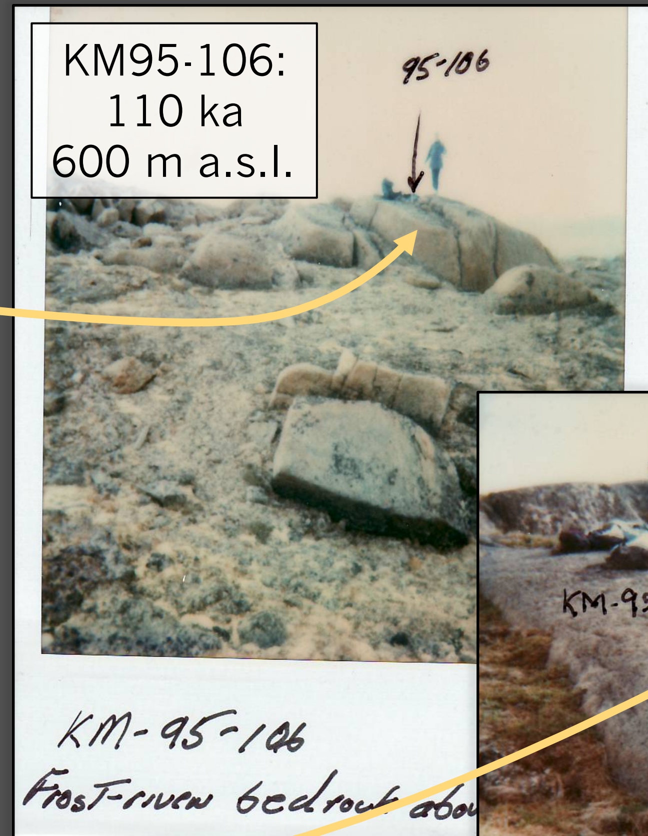
Trends: Bedrock Ages > Boulder Ages



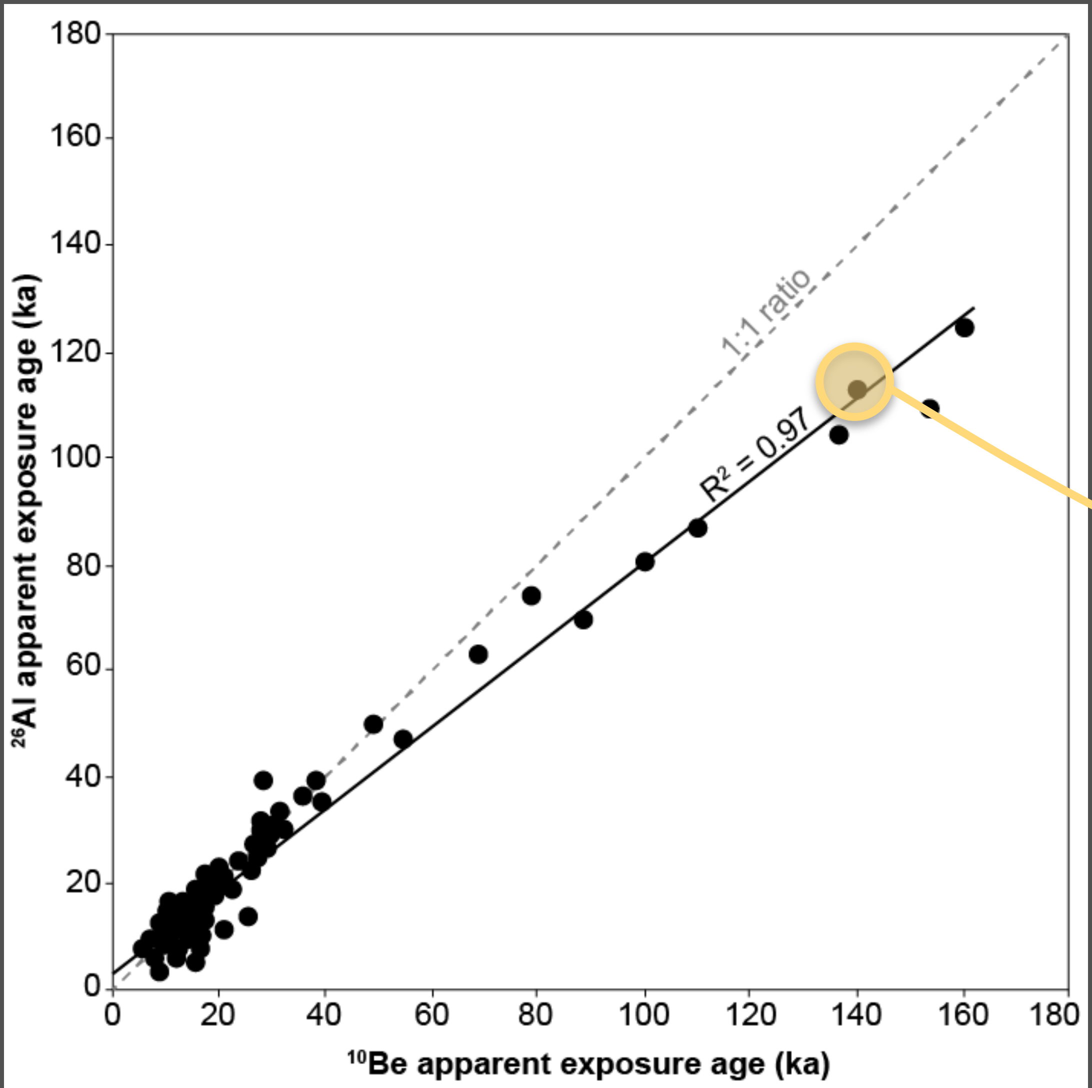


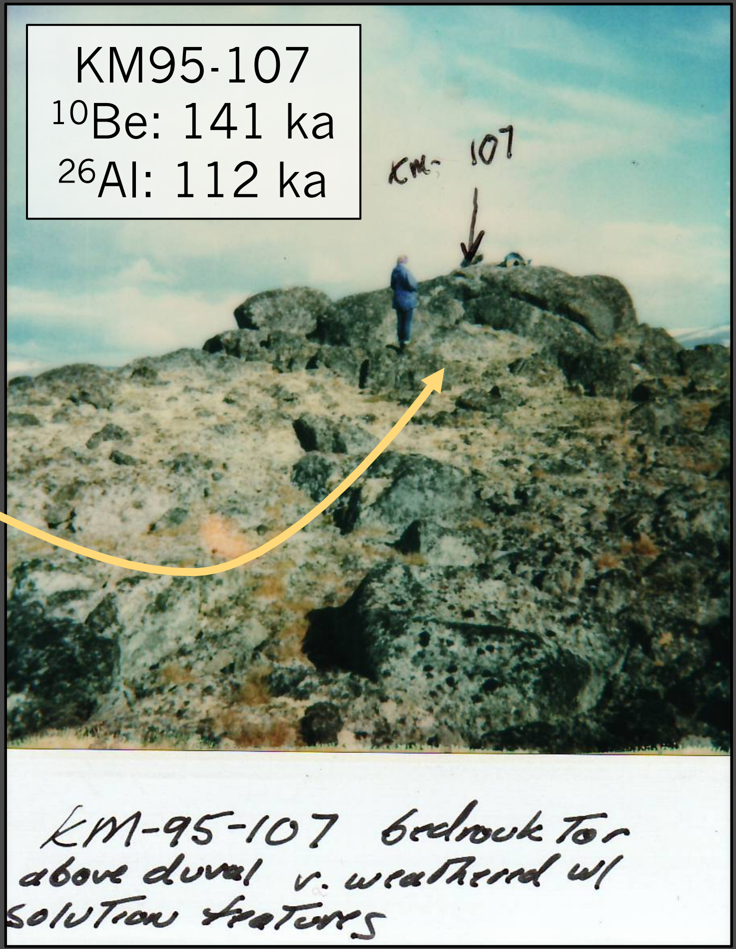
Trends: Ages Increase with Elevation



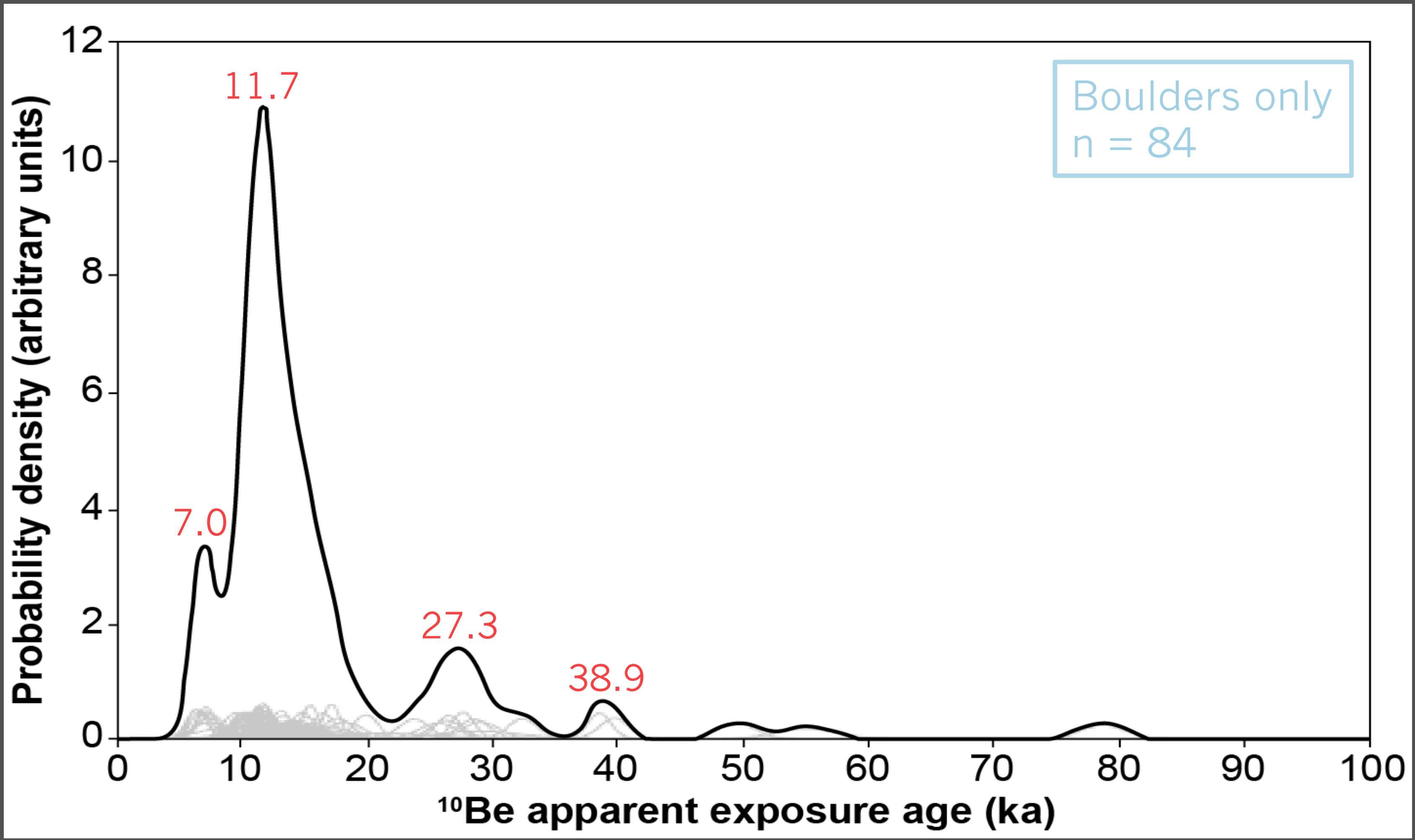


Trends: ^{10}Be Ages > ^{26}Al Ages

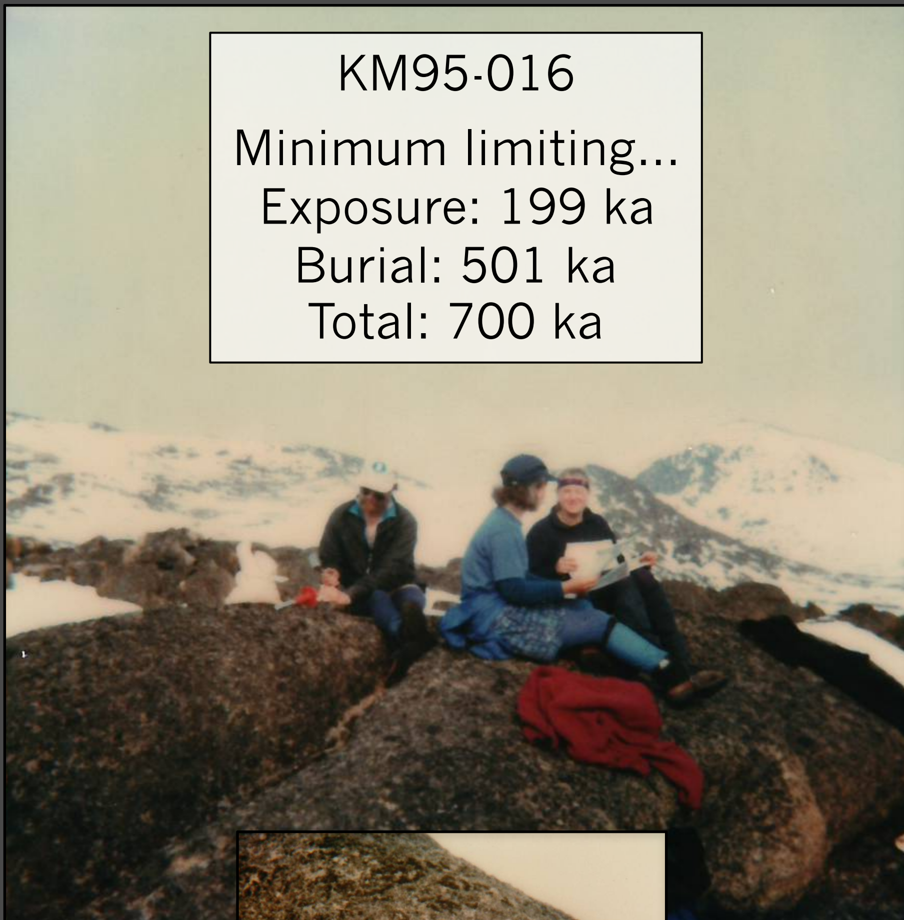




Trends: Multi-Modal Age Distributions



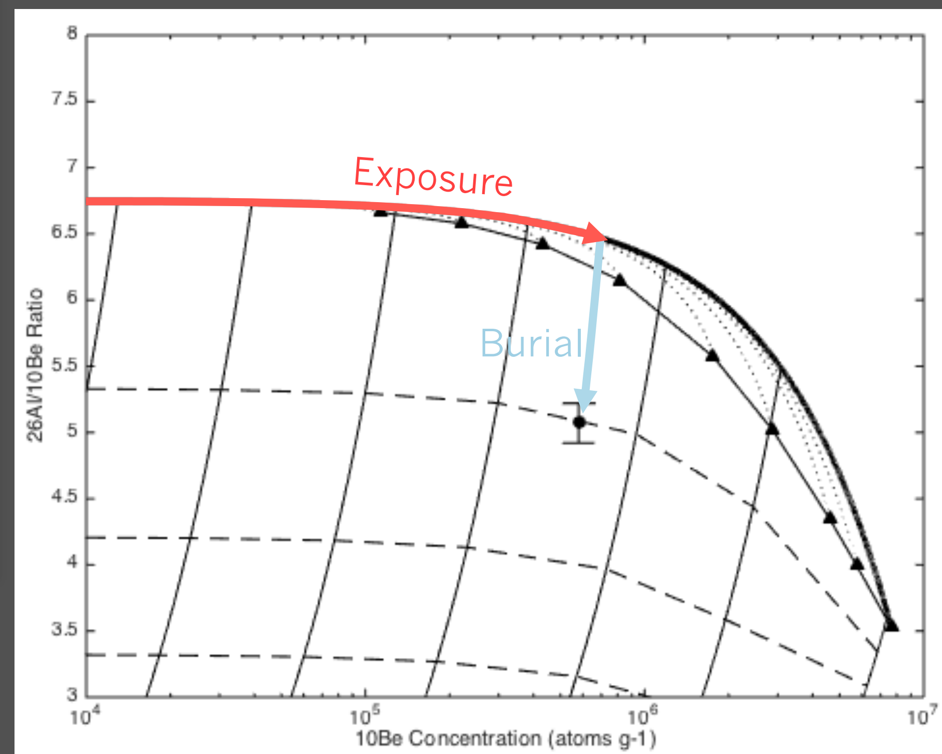
Exposure/Burial Modeling



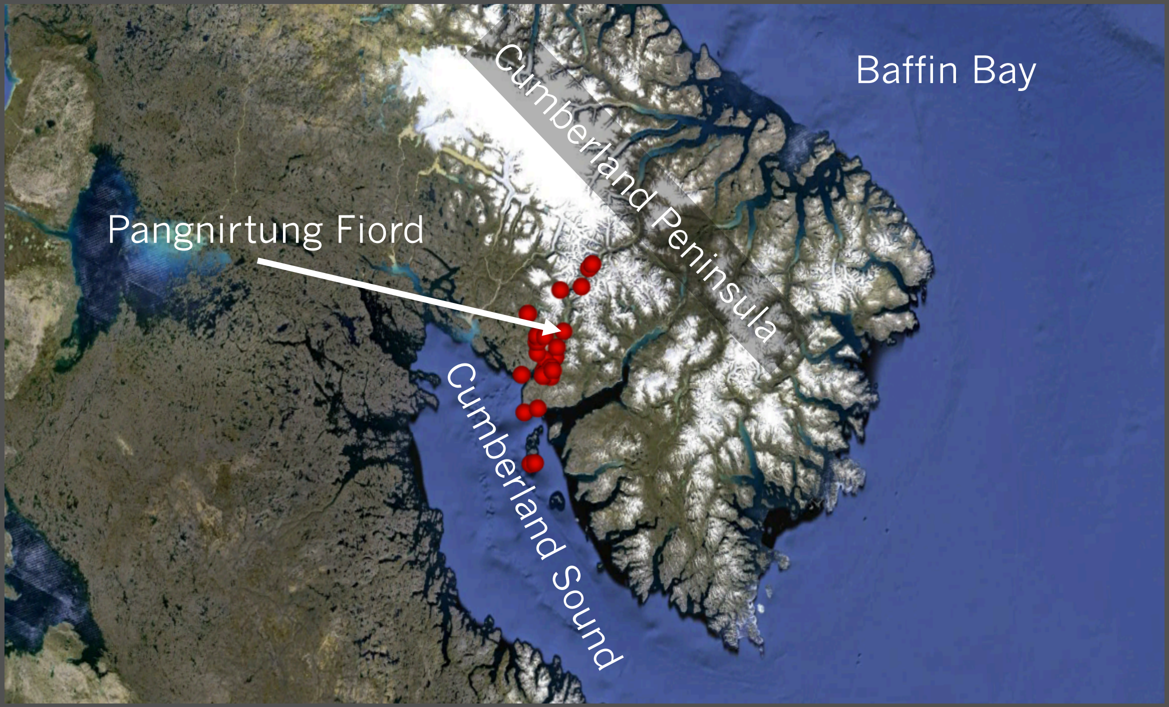
KM95-016

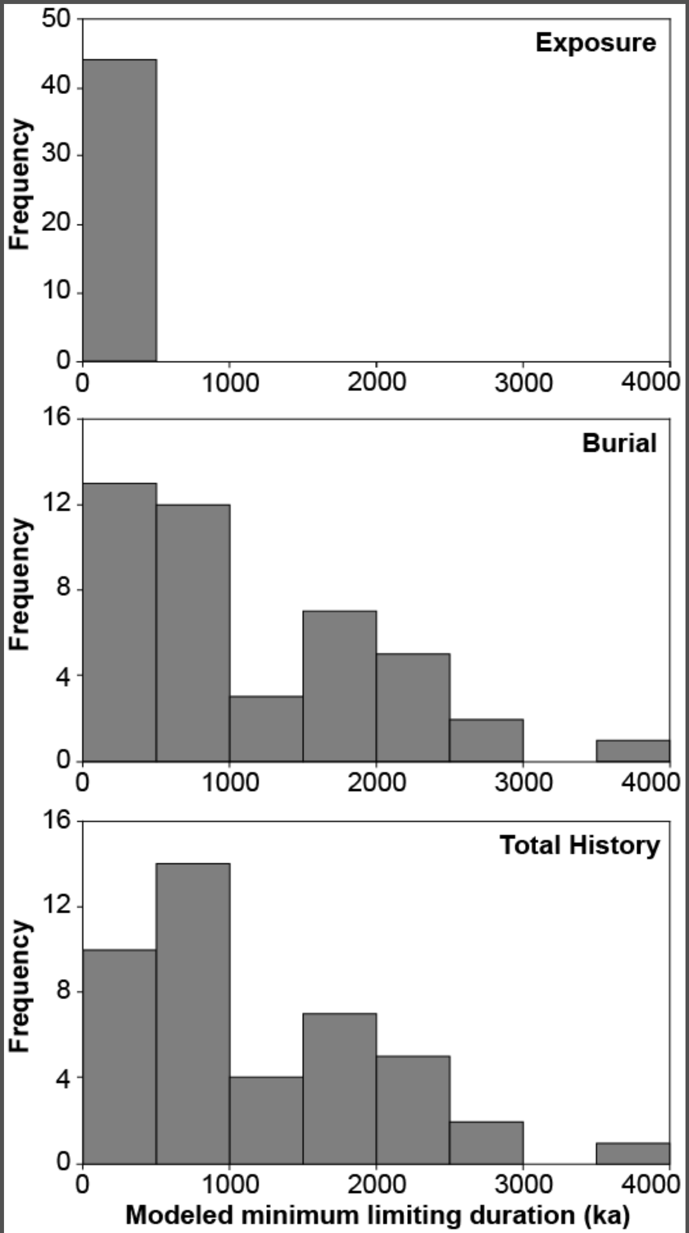
Minimum limiting...
Exposure: 199 ka
Burial: 501 ka
Total: 700 ka

Solving for the simplest path:
One period of exposure
followed by one period of burial



Exposure/Burial Modeling





Minimum-limiting exposure durations: 4.8-213 ka

Minimum-limiting burial durations: 135-3691 ka

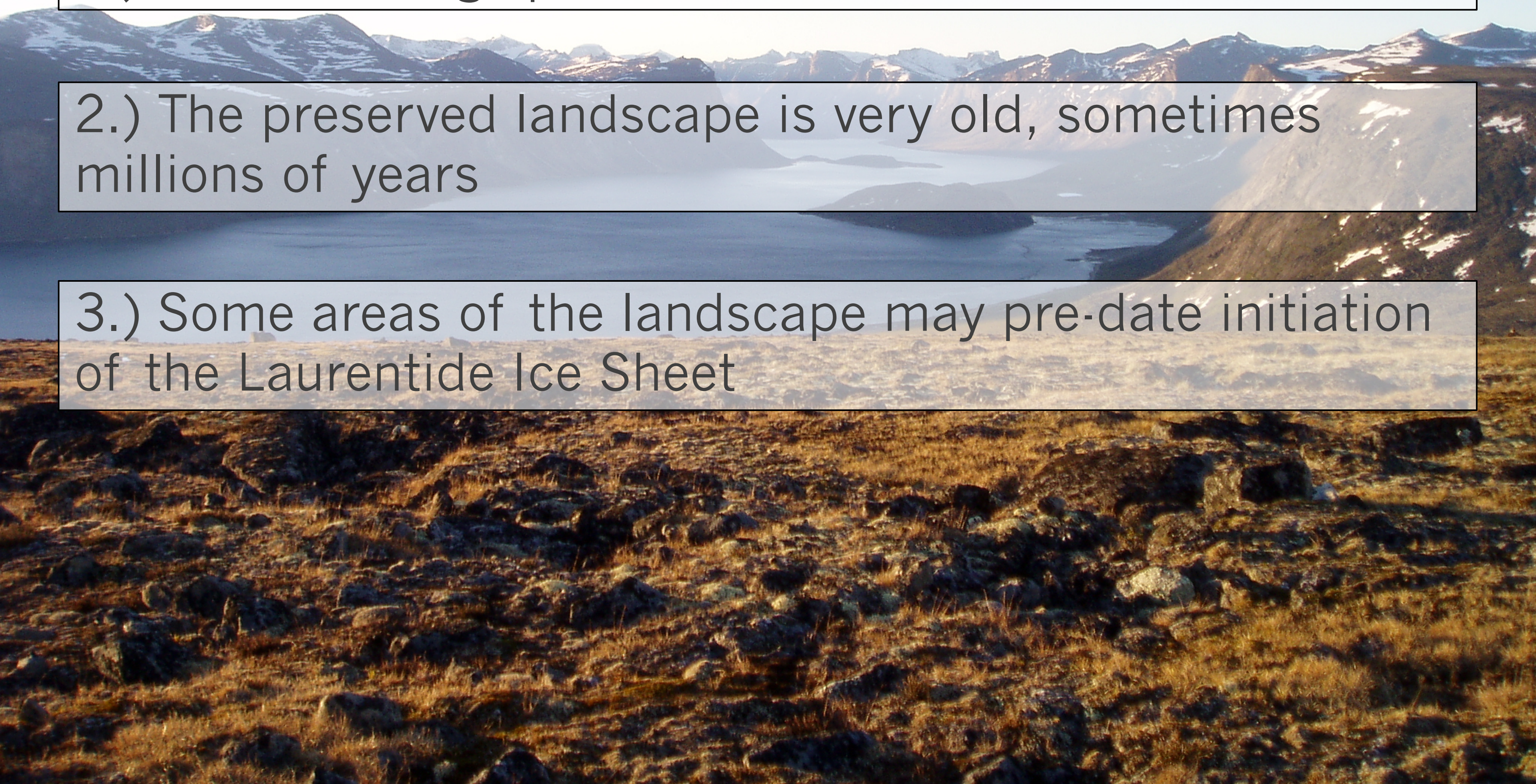
} Minimum-limiting total histories: 189-3768 ka

Preliminary Baffin Conclusions

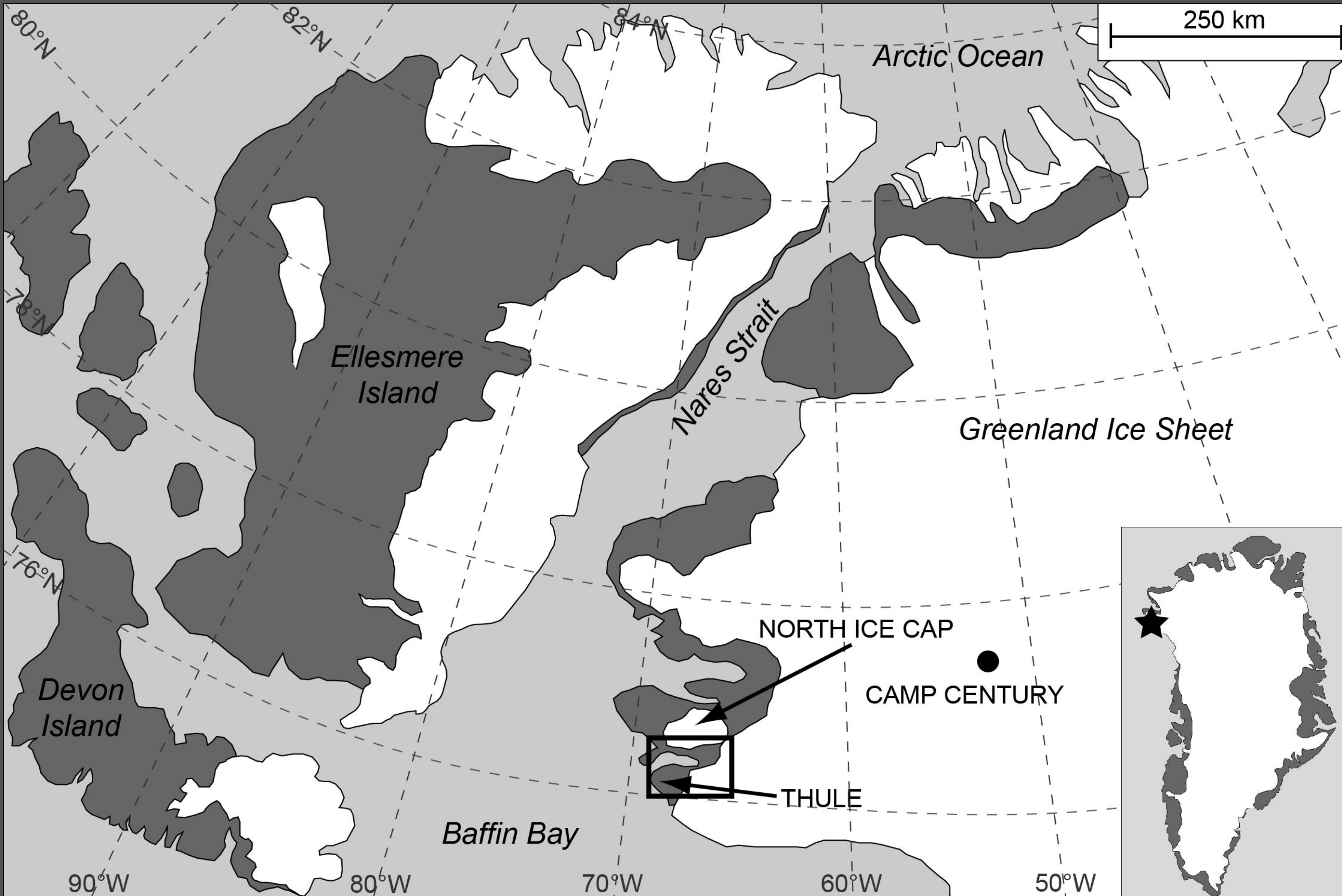
1.) Numerous age patterns indicate cold-based ice

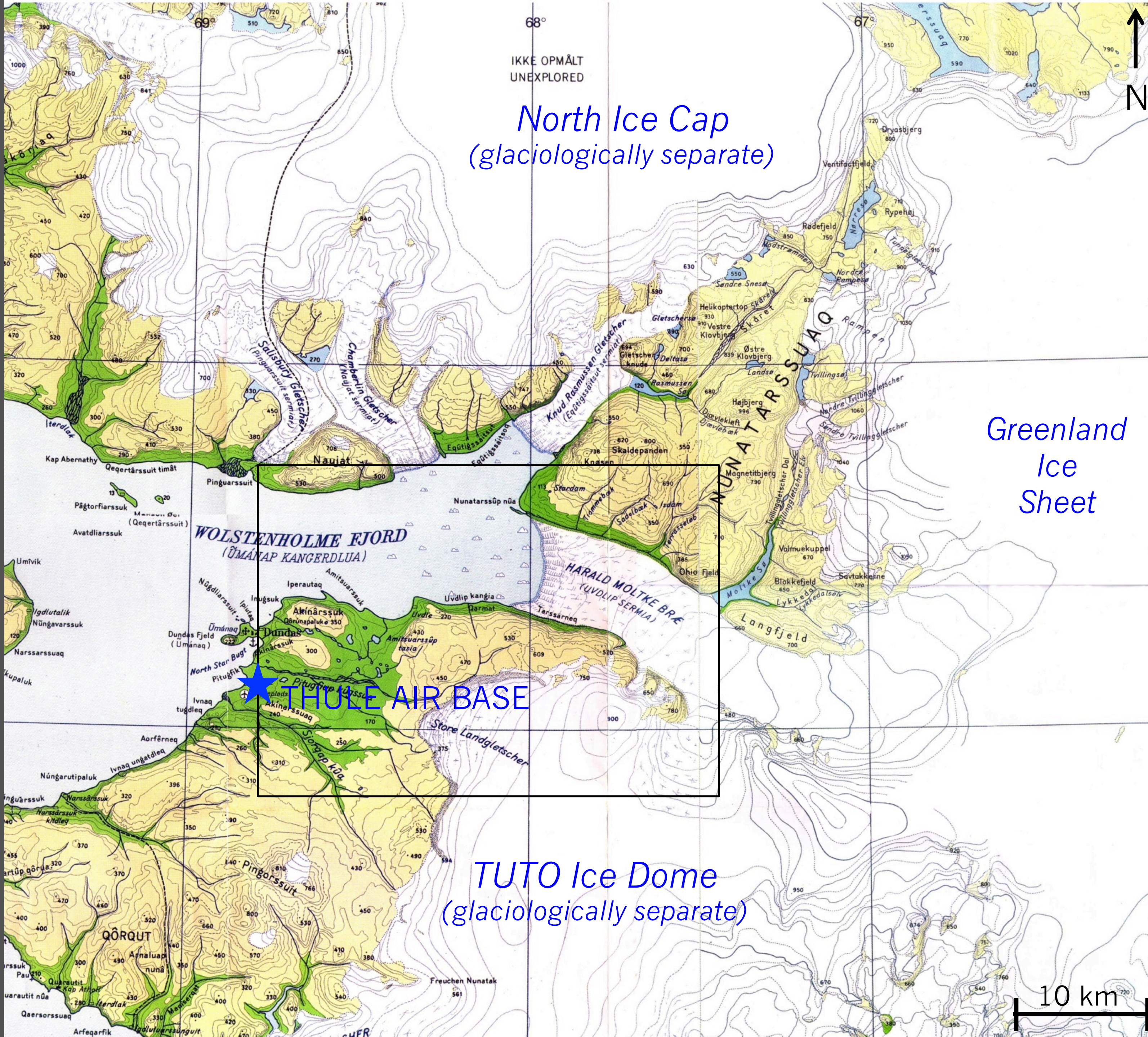
2.) The preserved landscape is very old, sometimes millions of years

3.) Some areas of the landscape may pre-date initiation of the Laurentide Ice Sheet

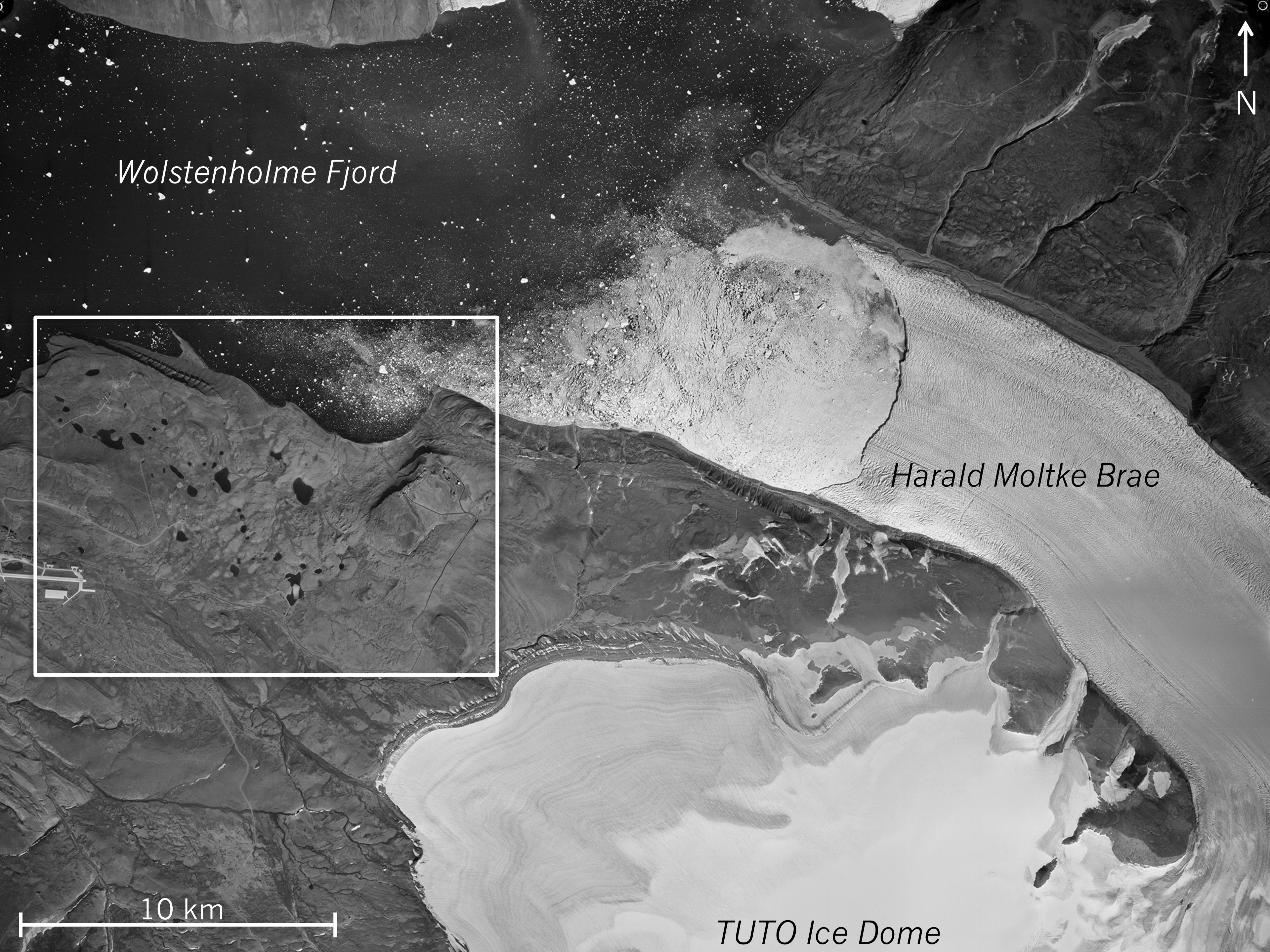


Thule, Northwest Greenland

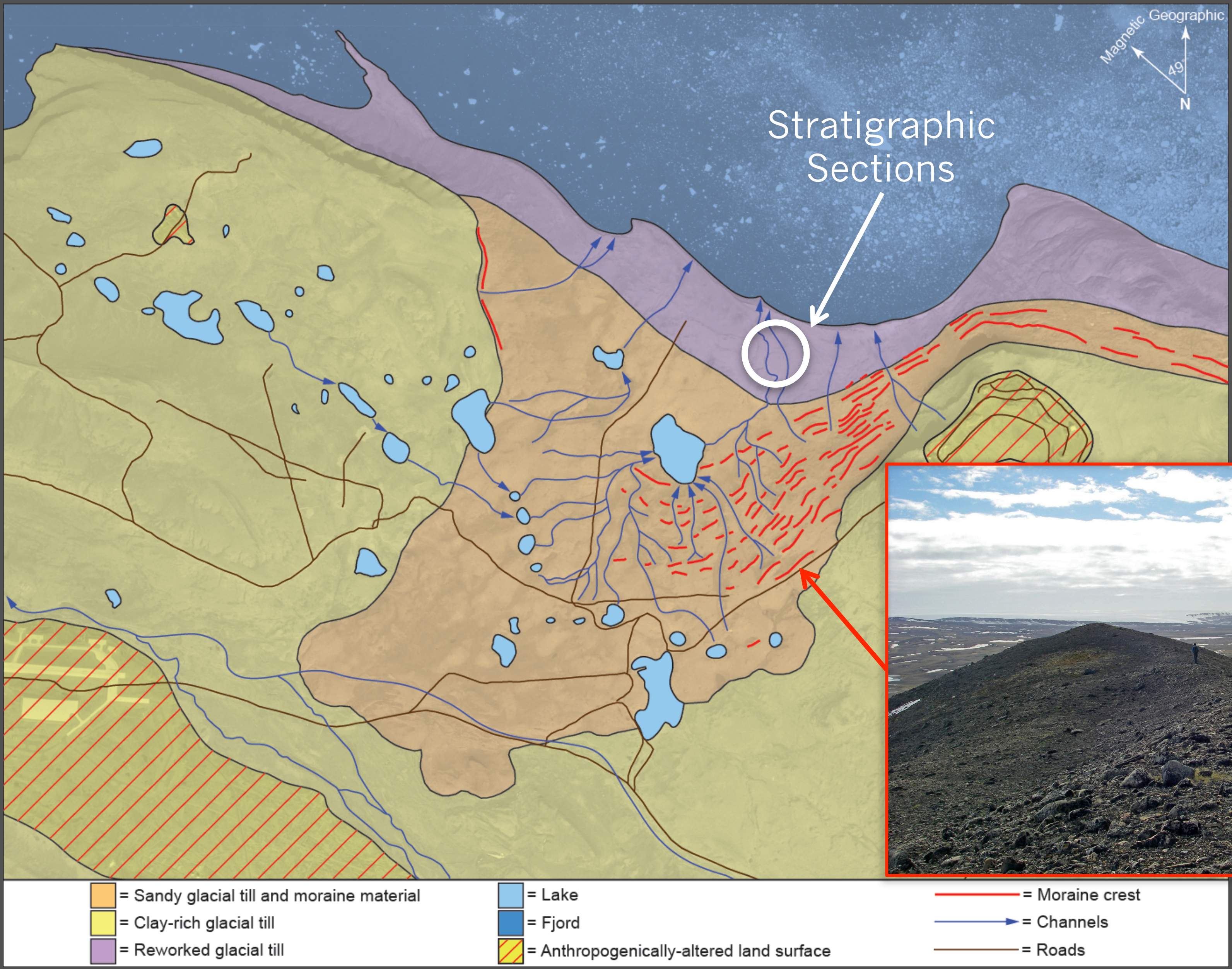

250 km
80°N
82°N
84°N
78°N
76°N
Arctic Ocean
Ellesmere Island
Nares Strait
Greenland Ice Sheet
Devon Island
NORTH ICE CAP
CAMP CENTURY
THULE
Baffin Bay
90°W
80°W
70°W
60°W
50°W



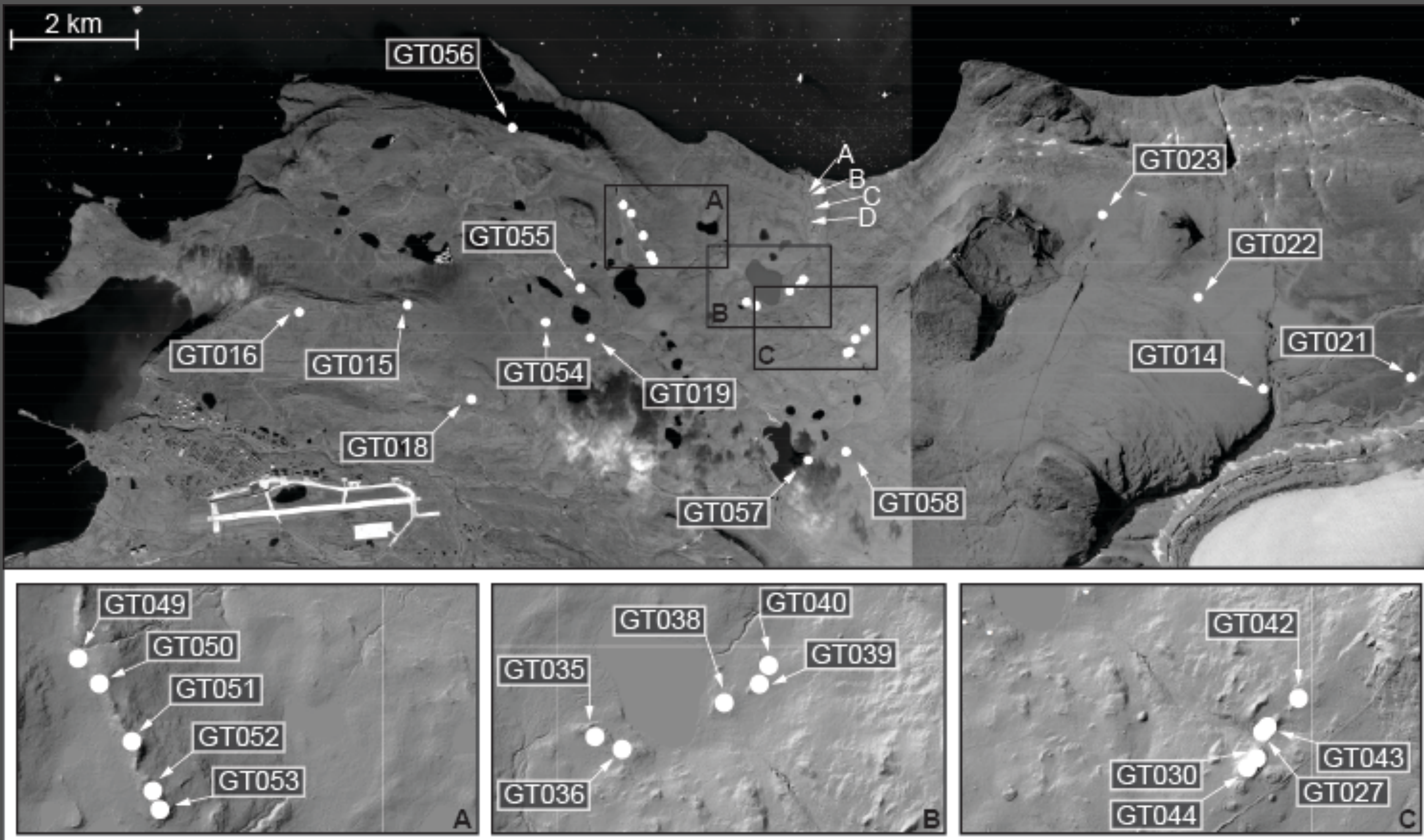
N
IKKE OPMÅLT
UNEXPLORED
North Ice Cap
(glaciologically separate)
Greenland
Ice
Sheet
NUNATARSSUAQ
WOLSTENHOLME FJORD
(ŪMÁNAP KANGERDLUA)
HARALD MOLTKE BRÆ
(UVDLIP SERMIA)
Salisbury Gletscher
Chamberlin Gletscher
Knud Rasmussen Gletscher
Store Landgletscher
Naujat
Dundas
THULE AIR BASE
TUTO Ice Dome
(glaciologically separate)
Langfjeld
Pingorssuit
QÔRQUT
Freuchen Nunatak
10 km


N
Wolstenholme Fjord
Harald Moltke Brae
TUTO Ice Dome
10 km

Mapping

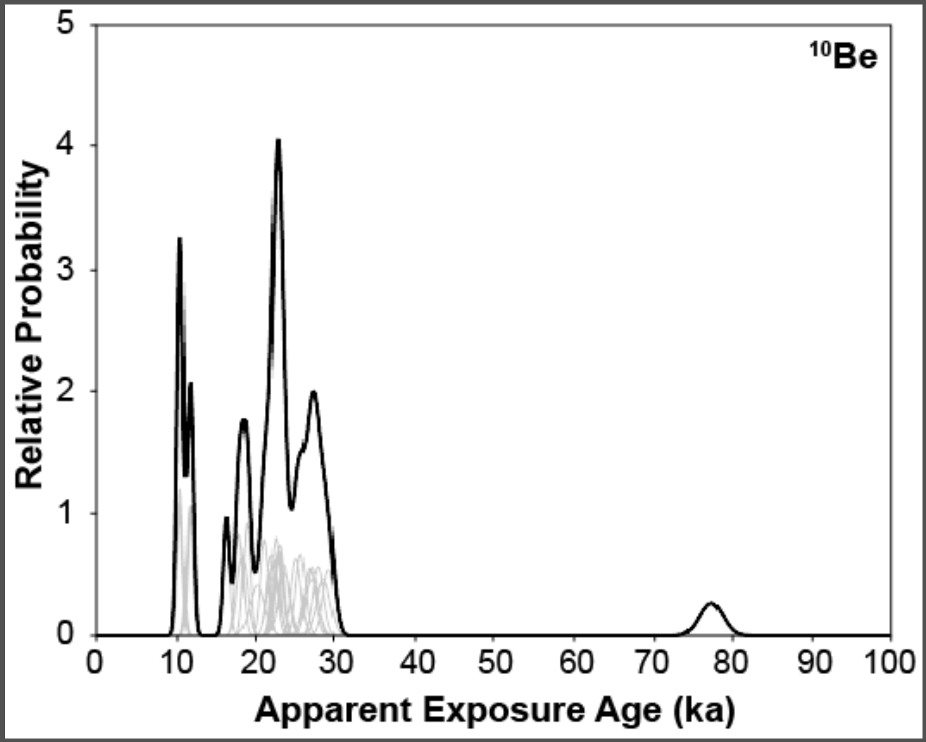

Geographic
Magnetic
49°
N
Stratigraphic Sections
= Sandy glacial till and moraine material
= Clay-rich glacial till
= Reworked glacial till
= Lake
= Fjord
= Anthropogenically-altered land surface
= Moraine crest
= Channels
= Roads

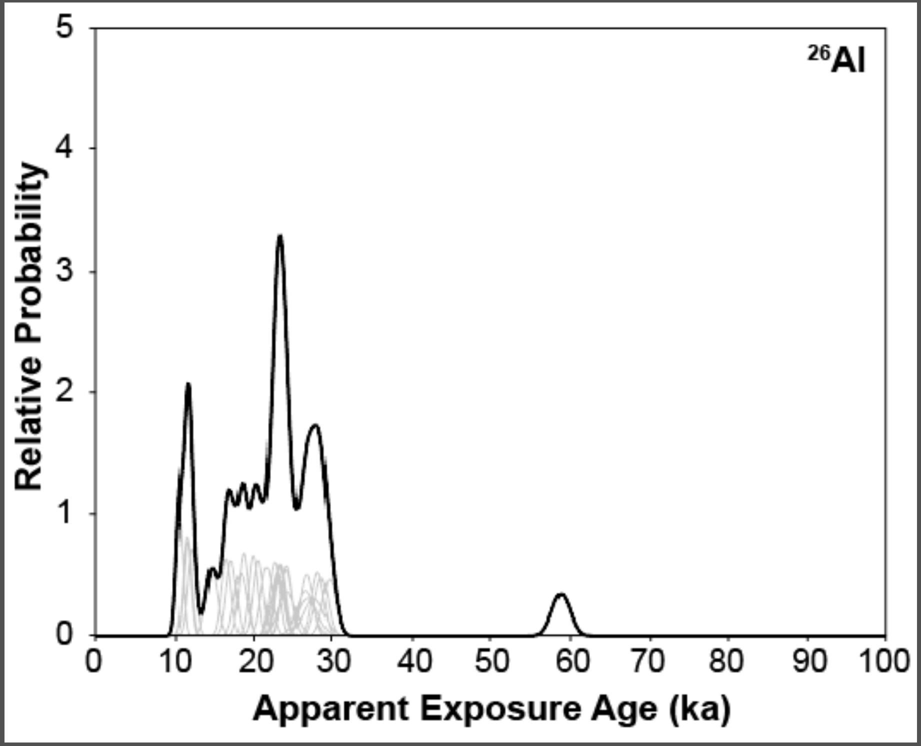
Analysis of Cosmogenic ^{10}Be and ^{26}Al



(n = 28 glacially-deposited boulders)

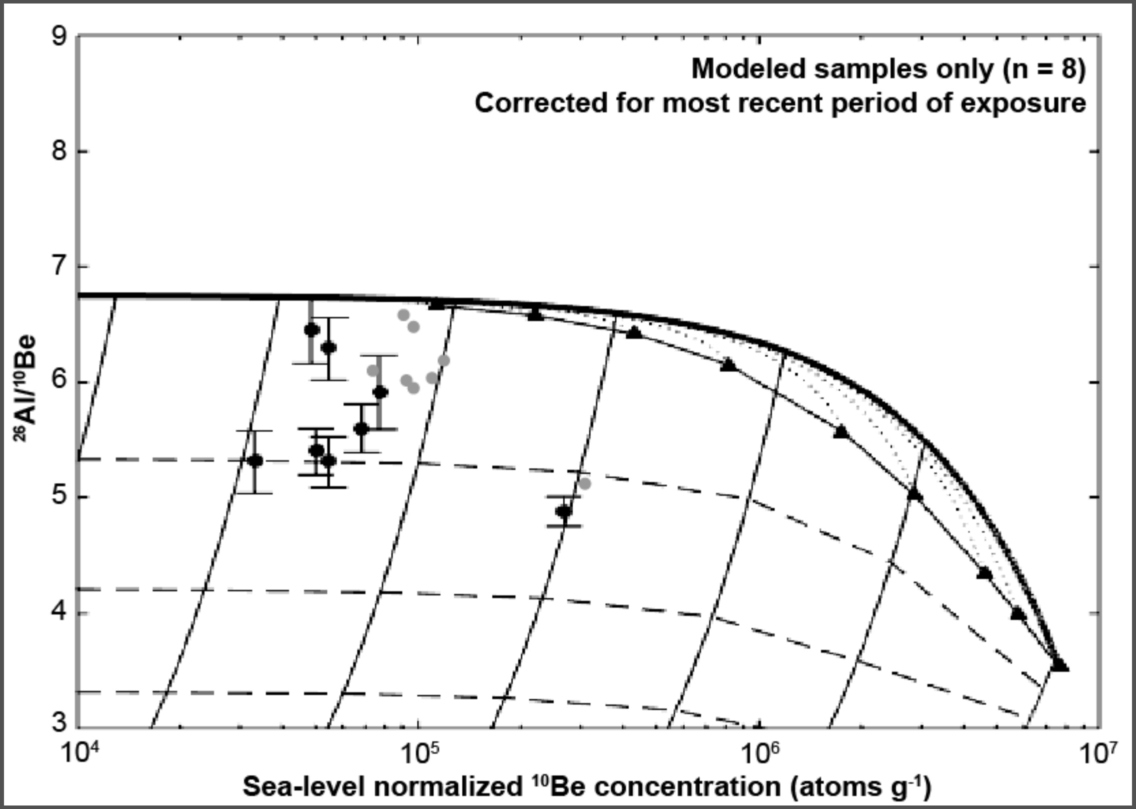
Single-Isotope Data



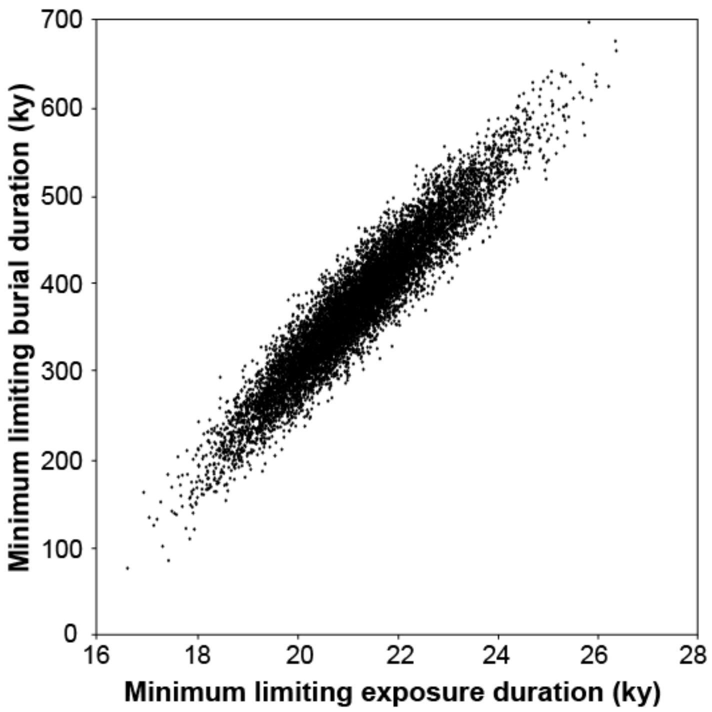


Two-Isotope Data

Two-isotope analysis:
Sample histories up to 700,000 yr!

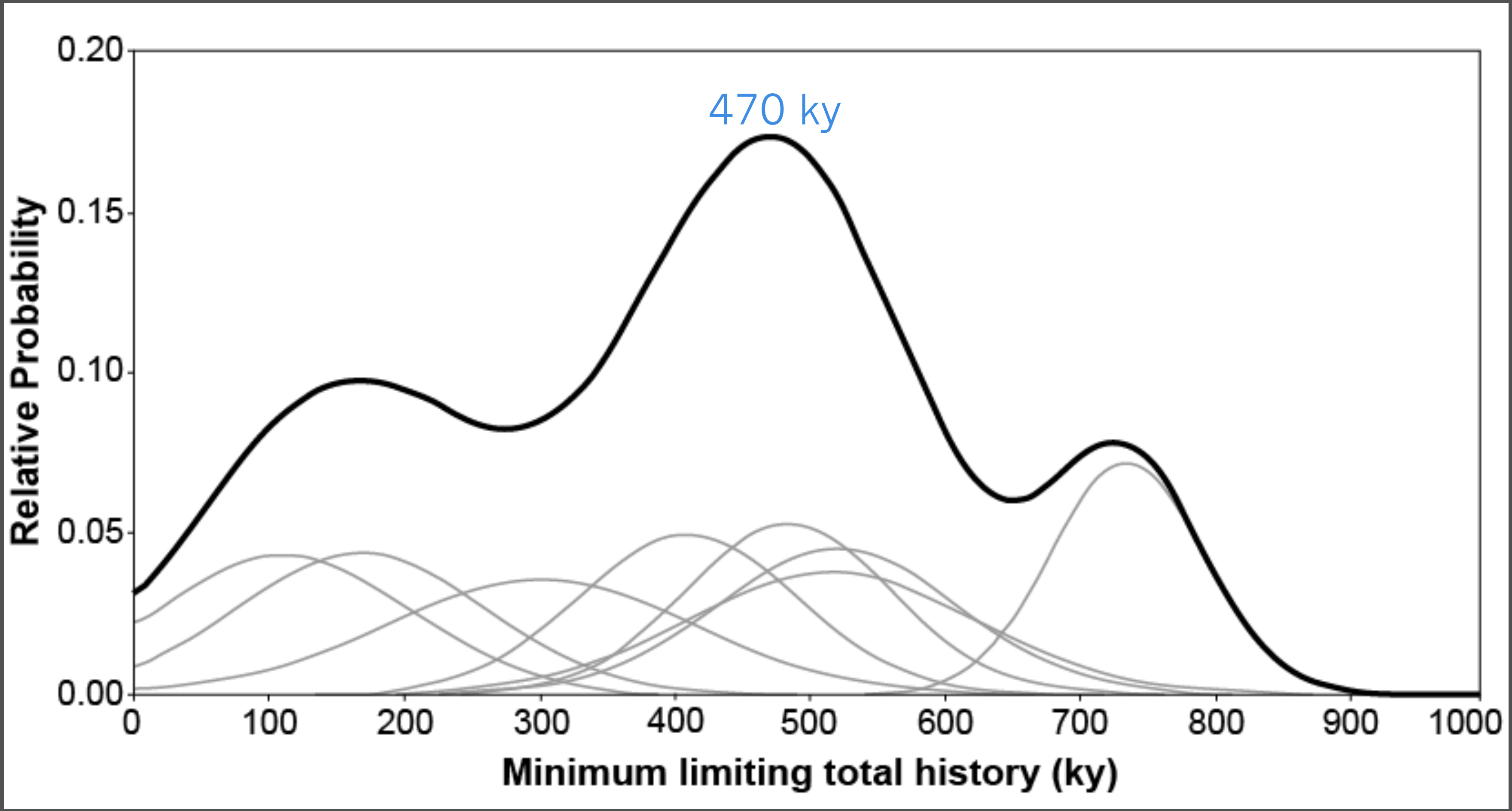


Uncertainty analysis with
Monte Carlo simulations:



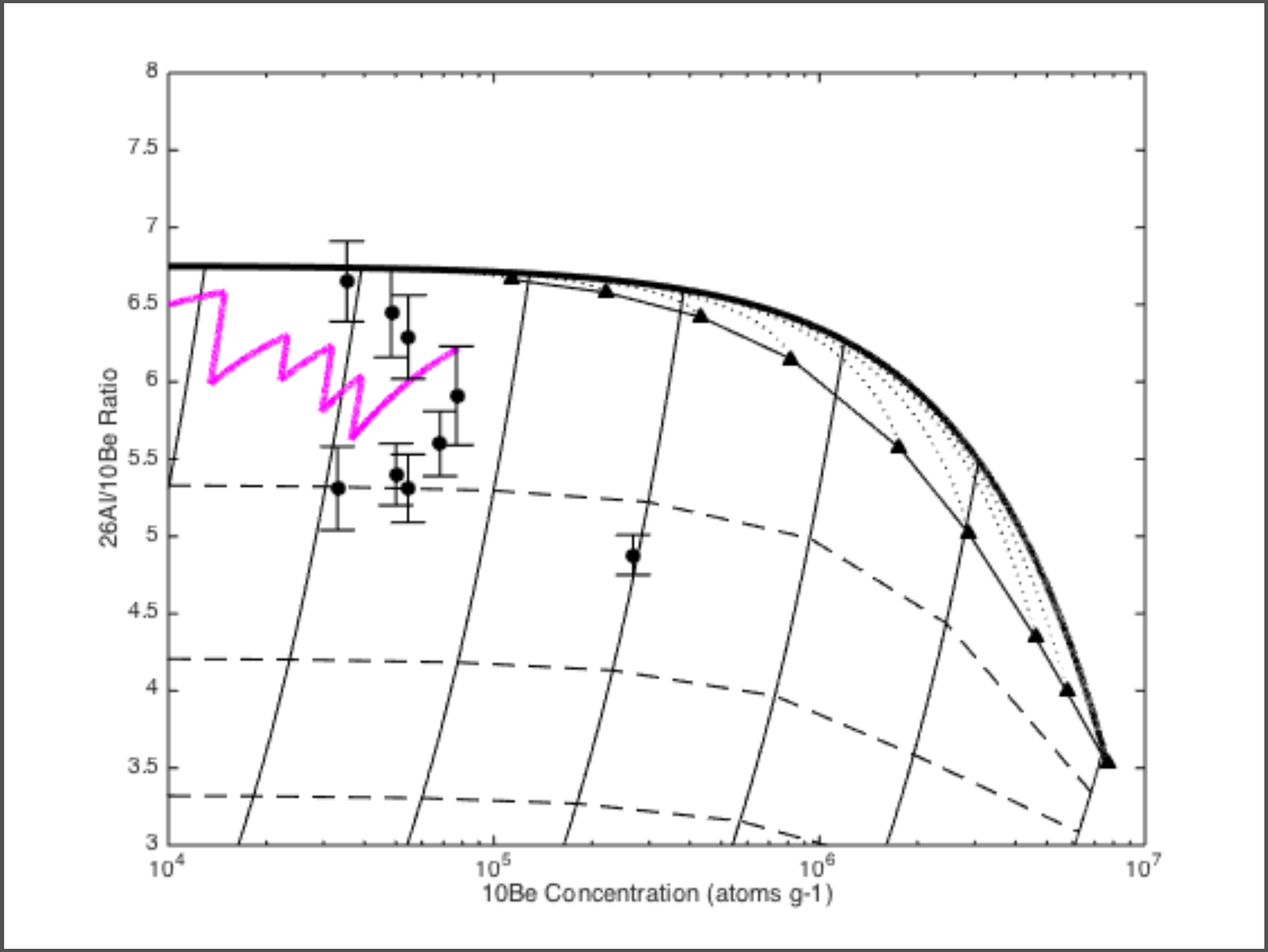
Total History

Probability distributions of preserved total (minimum limiting) surface histories:



Possible Scenarios (?)

Numerical modeling of possible exposure/burial histories:



Preliminary Thule Conclusions

1.) Initial deglaciation of the landscape occurred ~11 ka

2.) Outlet glaciers re-advanced <10 ka (coincident with the 8.2ka Event?)

3.) Basal thermal conditions are heterogeneous, at least partly cold-based

4.) Certain surfaces have been preserved for long durations (hundreds of thousands of years) subglacially

5.) Sediments (till) have been recycled over numerous glacial/interglacial periods

The Big Picture

Subglacial erosion processes are heterogeneous over both space and time

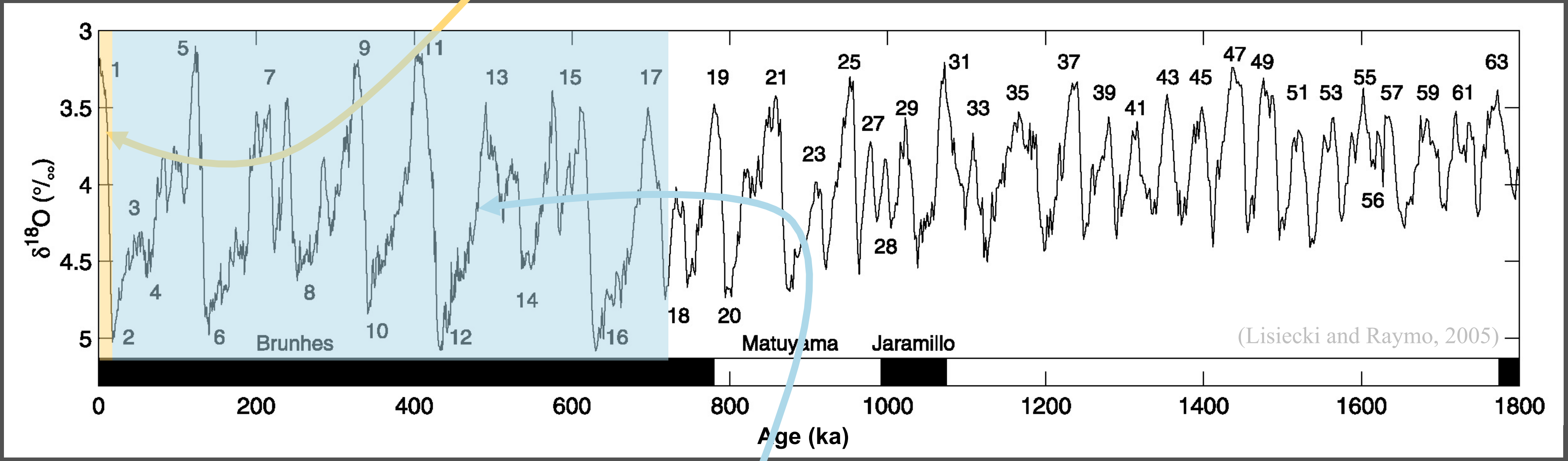
Cold-based ice can preserve surfaces subglacially, yielding ancient, relict landscapes

New techniques are needed to understand these complex surfaces

Cold-Based Ice:
An (Information) Resource Opportunity?

Record preserved on a warm-based ice landscape

Interglacial



Glacial

Record preserved on a cold-based ice landscape
(Baffin study; median total history ~700 ka)