# INTERPRETATION OF METEORIC $^{10}$BE IN MARGINAL ICE-BOUND SEDIMENT OF THE GREENLAND ICE SHEET, WEST GREENLAND

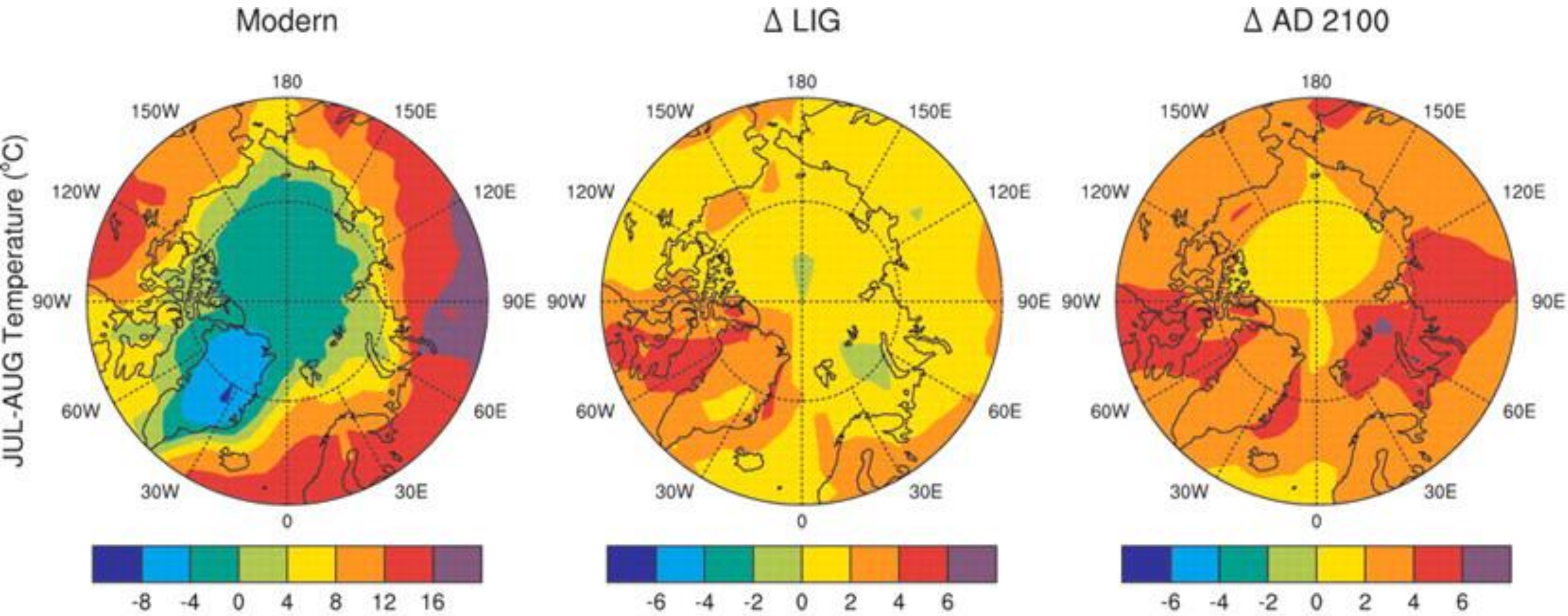
**Joseph Graly**

Thesis Defense

# Outline of Presentation

- Project Motivation and Concept
- Glaciological Background
- Meteoric $^{10}$Be and Atmospheric Processes
- Meteoric $^{10}$Be in Soils
- West Greenland Results
- Interpretation of Greenland Glacial History
- Conclusions

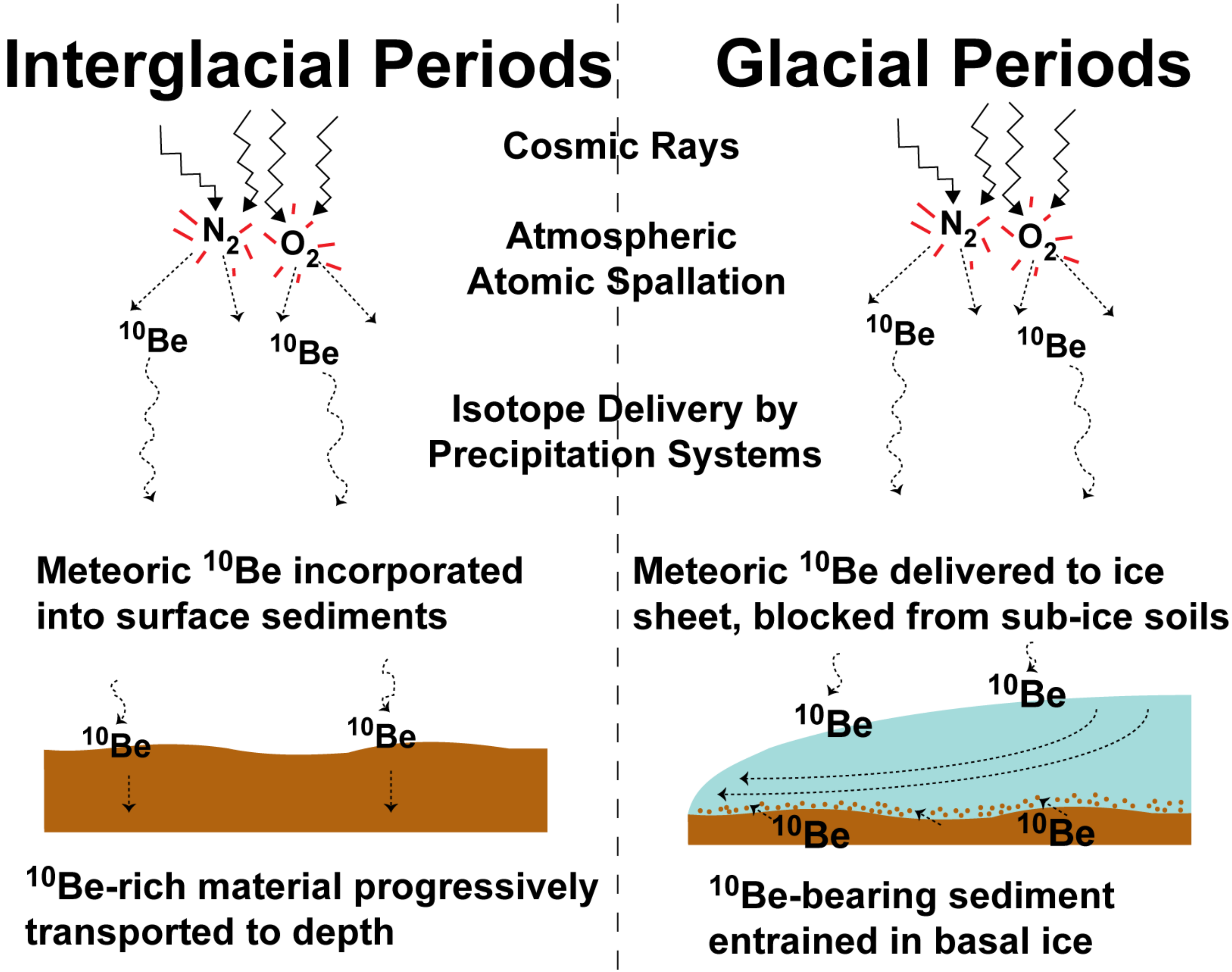
# Past Performance Predicts Future Results?

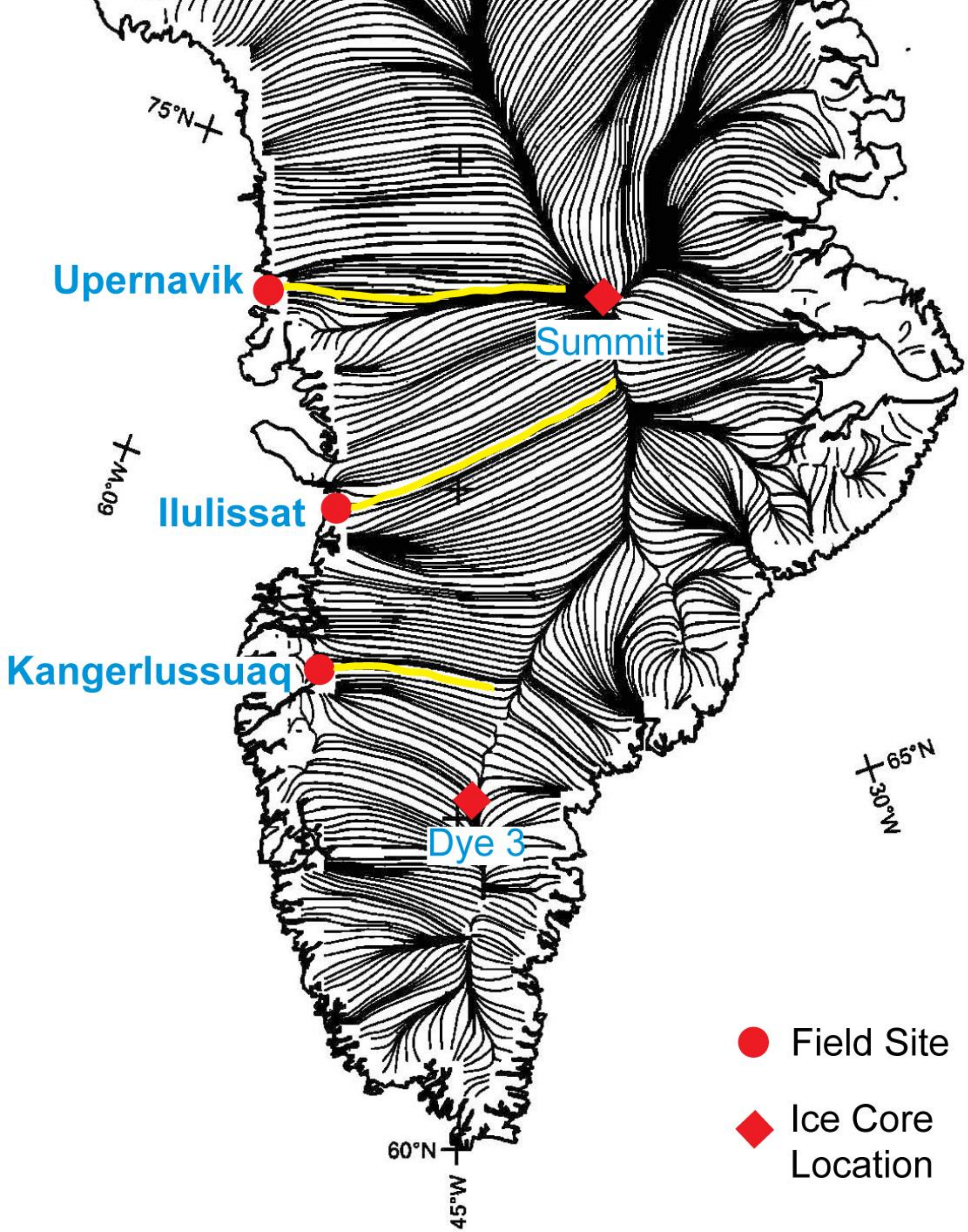



**Climate models for the Arctic for the present, last interglacial period (116-130 ka before present) and 2100** (form Overpeck et. al., 2006)

**The temperatures modelled for Greenland are similar in the last Interglacial period and 2100**

# Meteoric $^{10}$Be as a Tracer

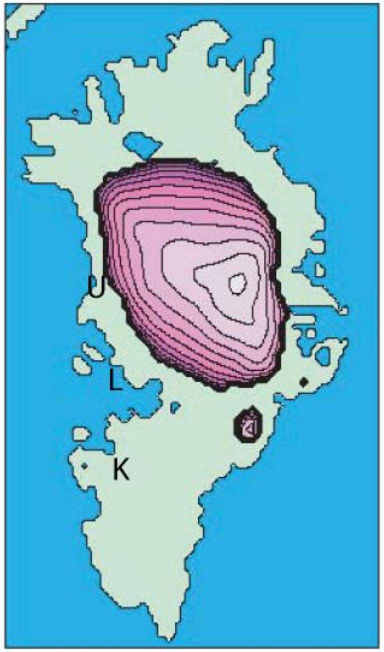




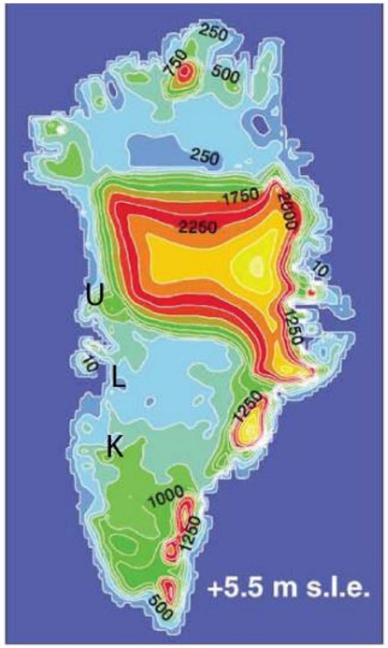

**Map of Greenland showing modern glacier flowlines**
(from Zwally and others, 2001)

**Locations of our three western Greenland field sites and central Greenland ice cores are shown**

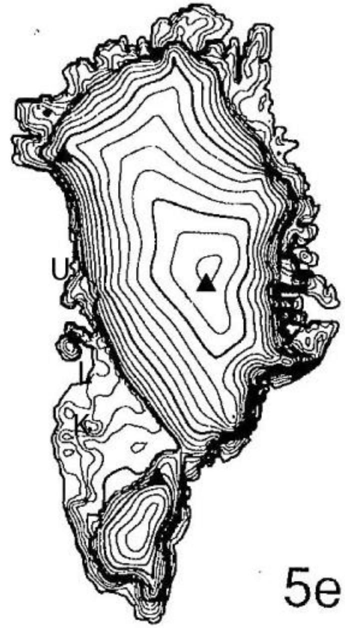
**The yellow lines indicate plausible source areas for rock and sediment delivered to the western Greenland sites**



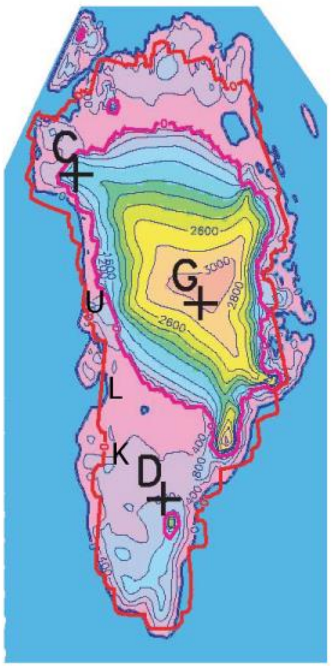
Cuffey and Marshell, 2000



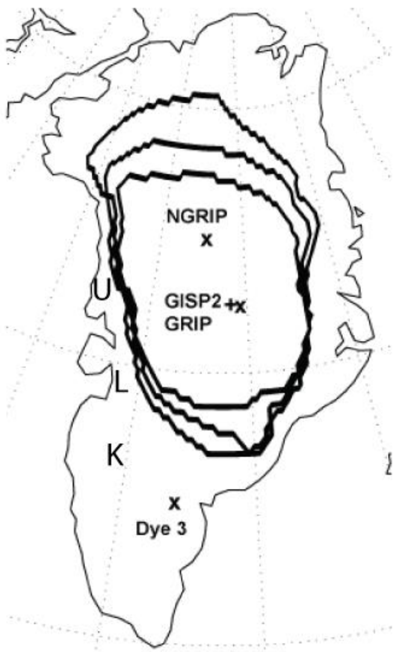
Huybrechts, 2002



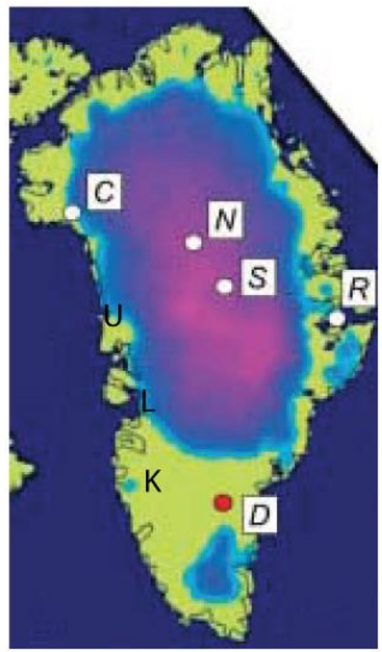
Letreguilly et al., 1991



Tarasov and Peltier, 2003



Lehomme et al., 2005

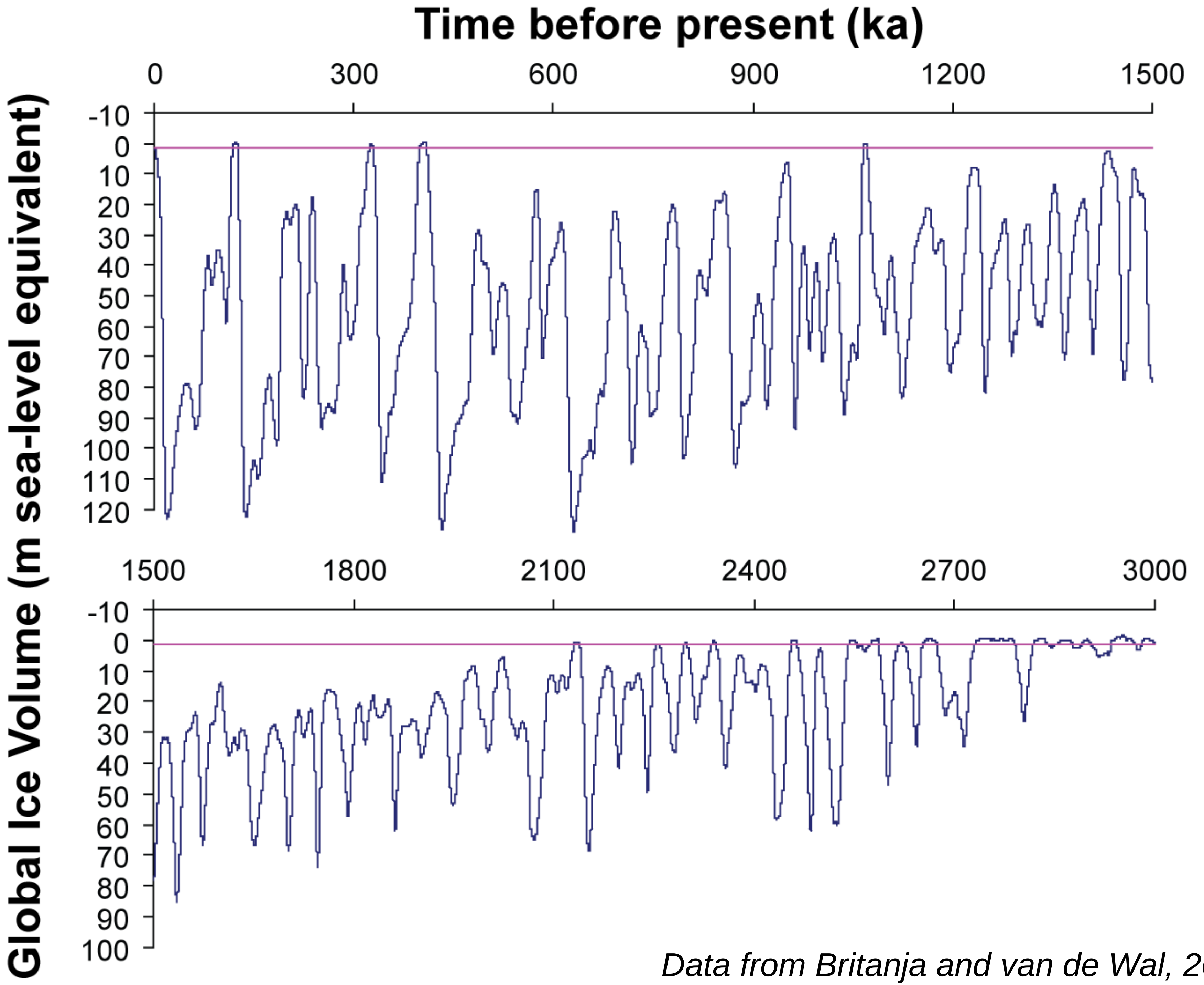


Otto-Bliesner et al., 2006

**Six models of Eemian ice sheet retreat from the published literature.**

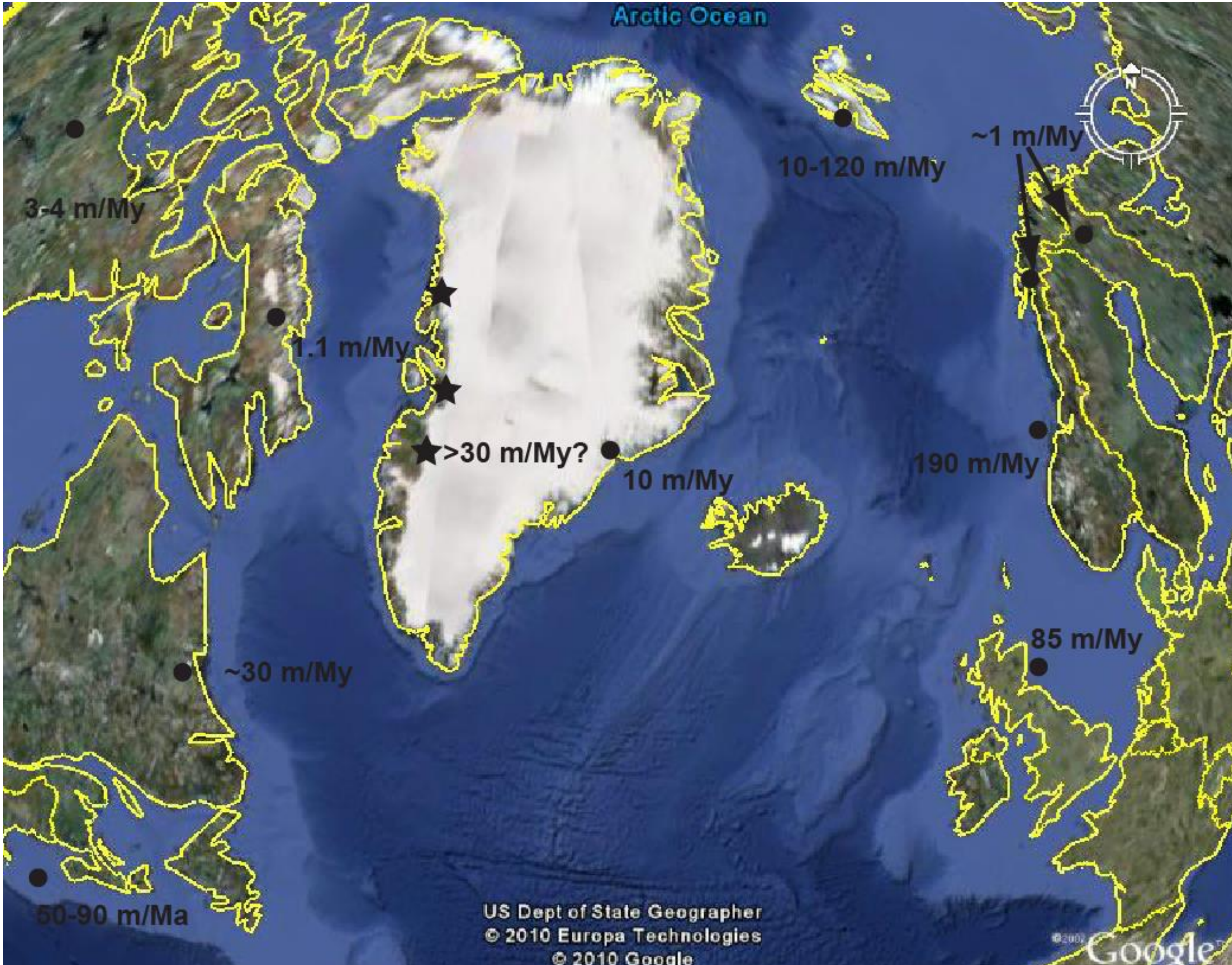
**Approximate locations of our field sites at Kangerlussuaq (K), Ilulissat (L), and Upernavik (U) are marked.**

**Models agree on substantial retreat at southern latitudes and more moderate retreat at northern latitudes**



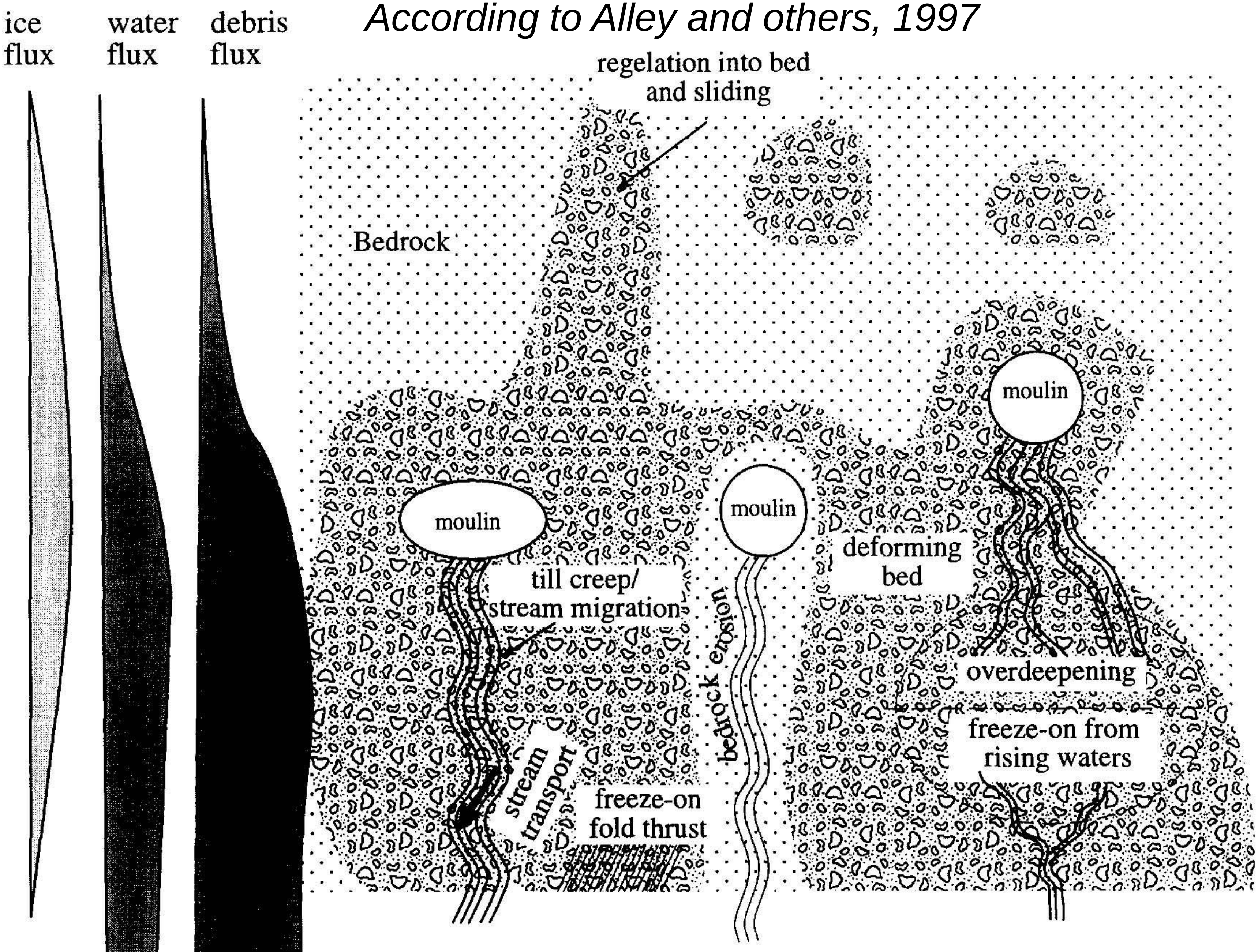

*Data from Britanja and van de Wal, 2008*

# North Atlantic Glacial Erosion Rates



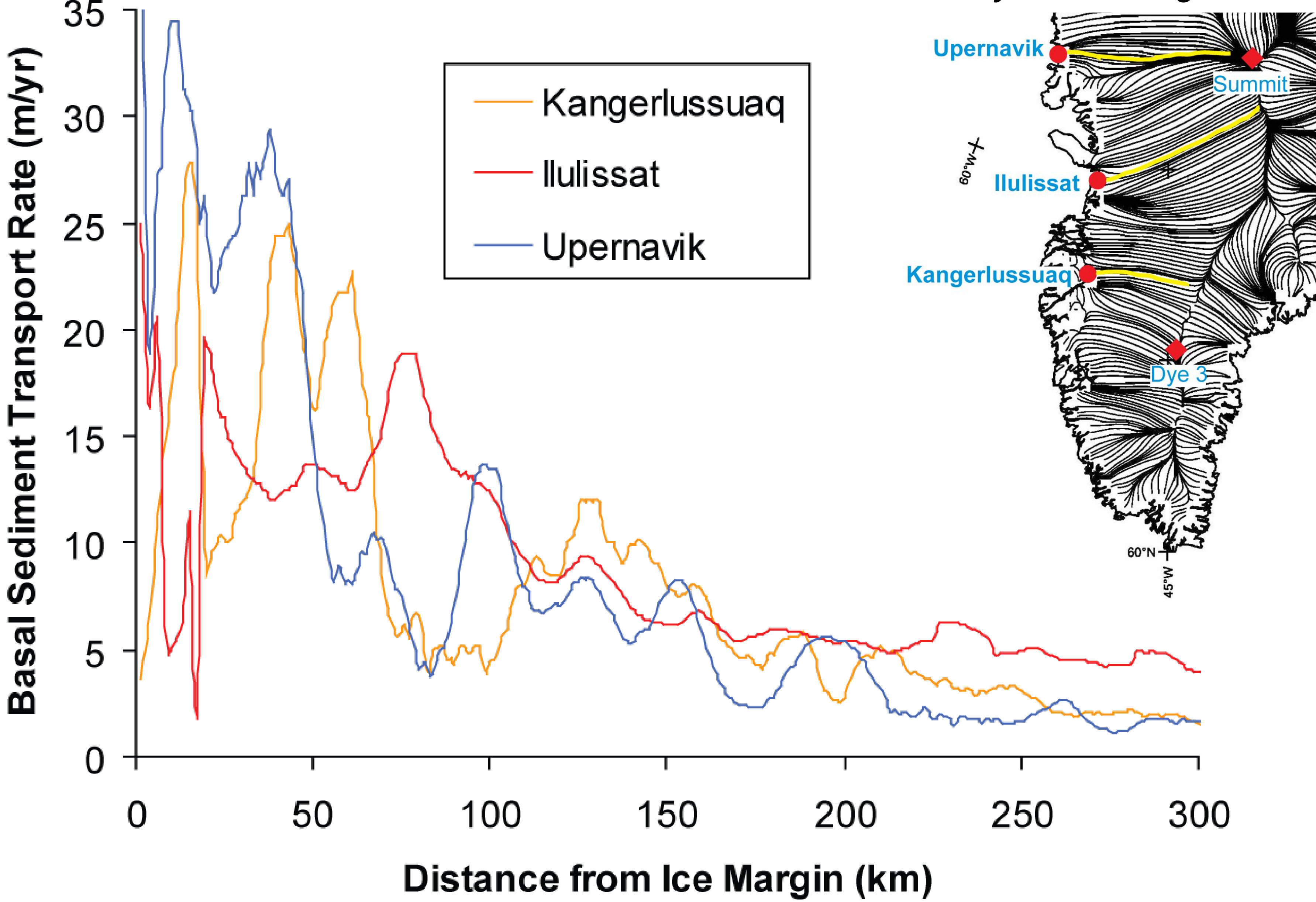
# Typical Subglacial Processes

*According to Alley and others, 1997*



# Modern Sediment Transport Rate

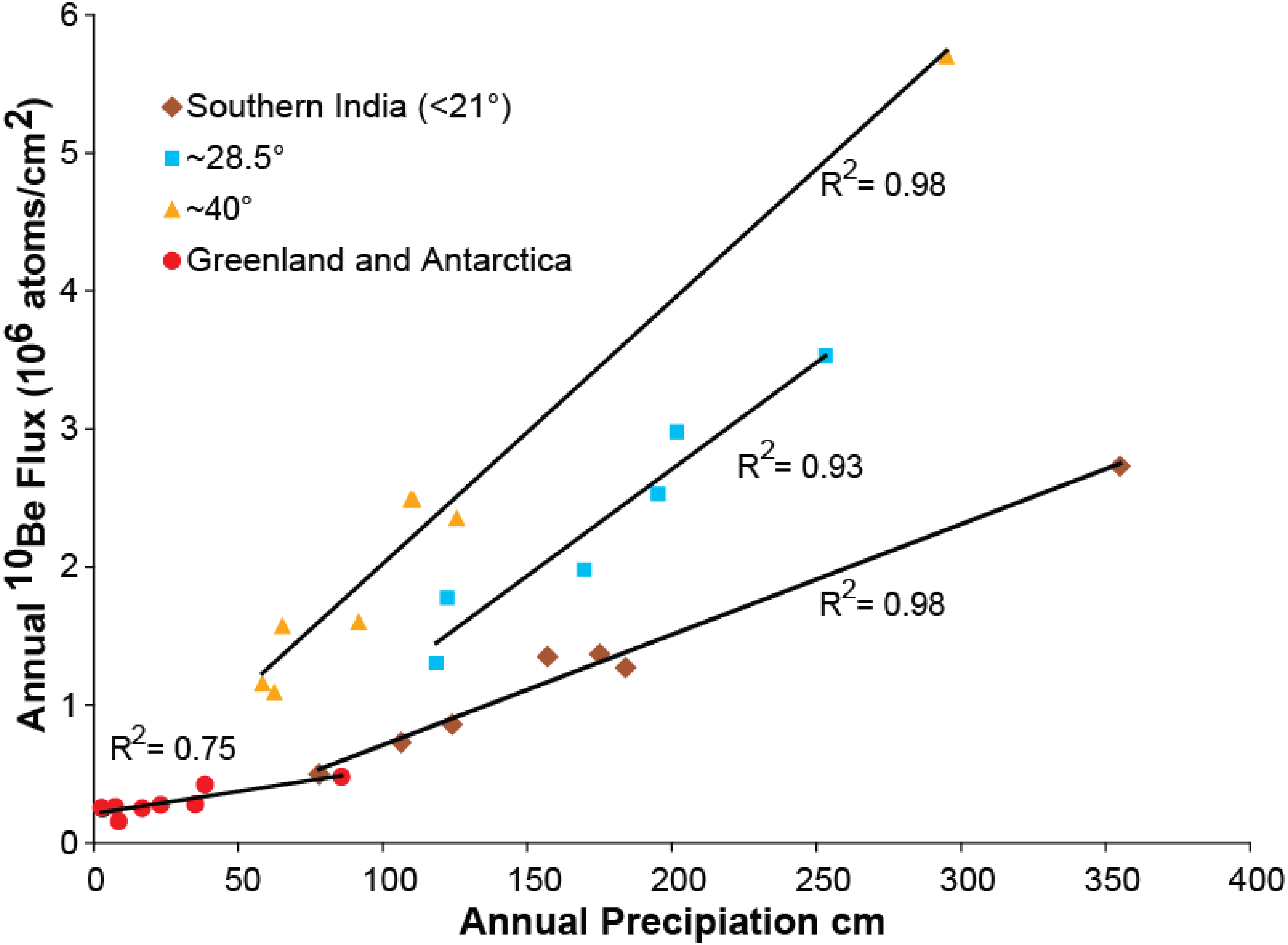
*Based on a model by W.L. Wang*



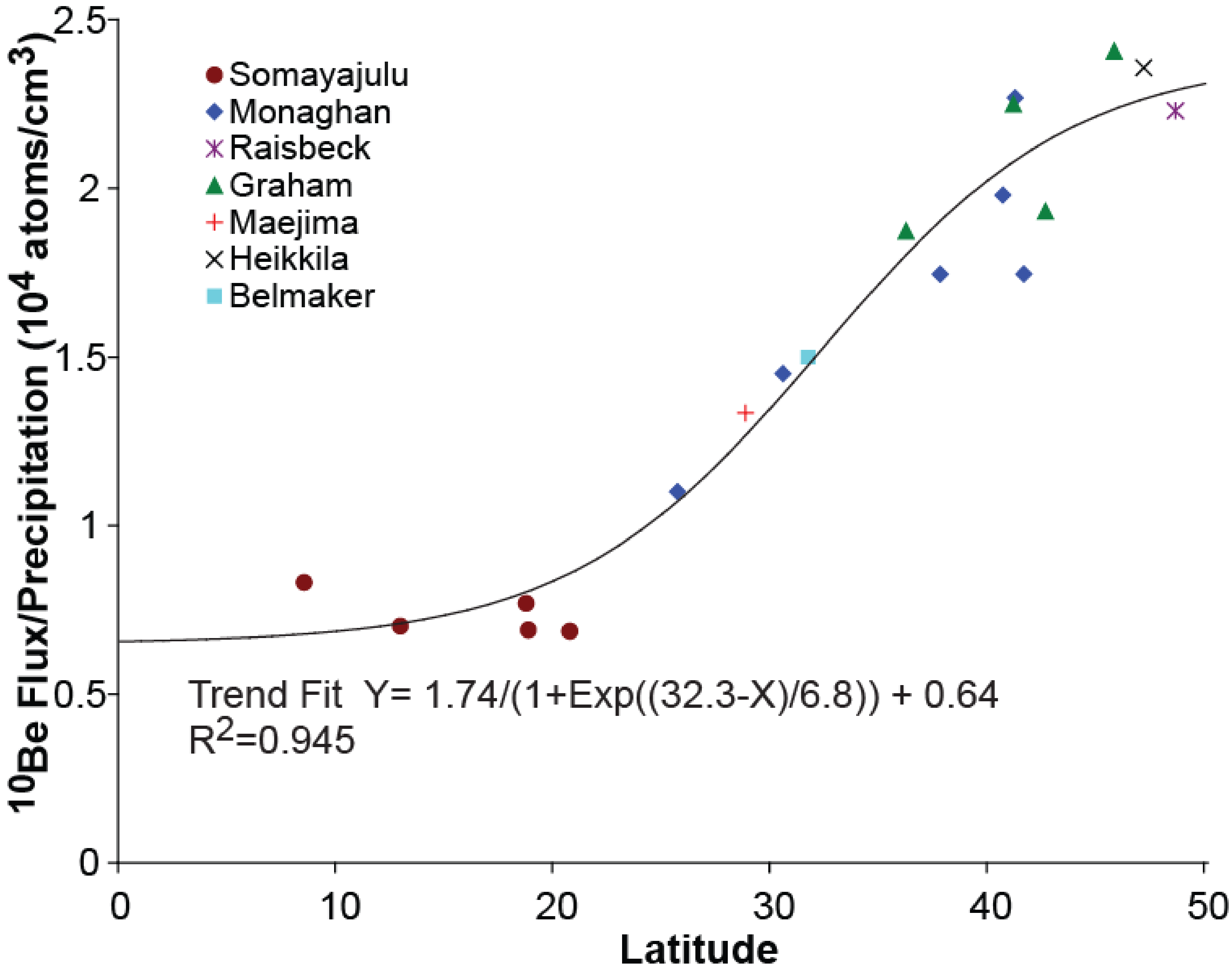
# Meteoric $^{10}$Be and Atmospheric Processes

- What controls the distribution of meteoric $^{10}$Be in Earth's atmosphere?
- Can the long-term meteoric $^{10}$Be deposition rate be predicted at a given site?

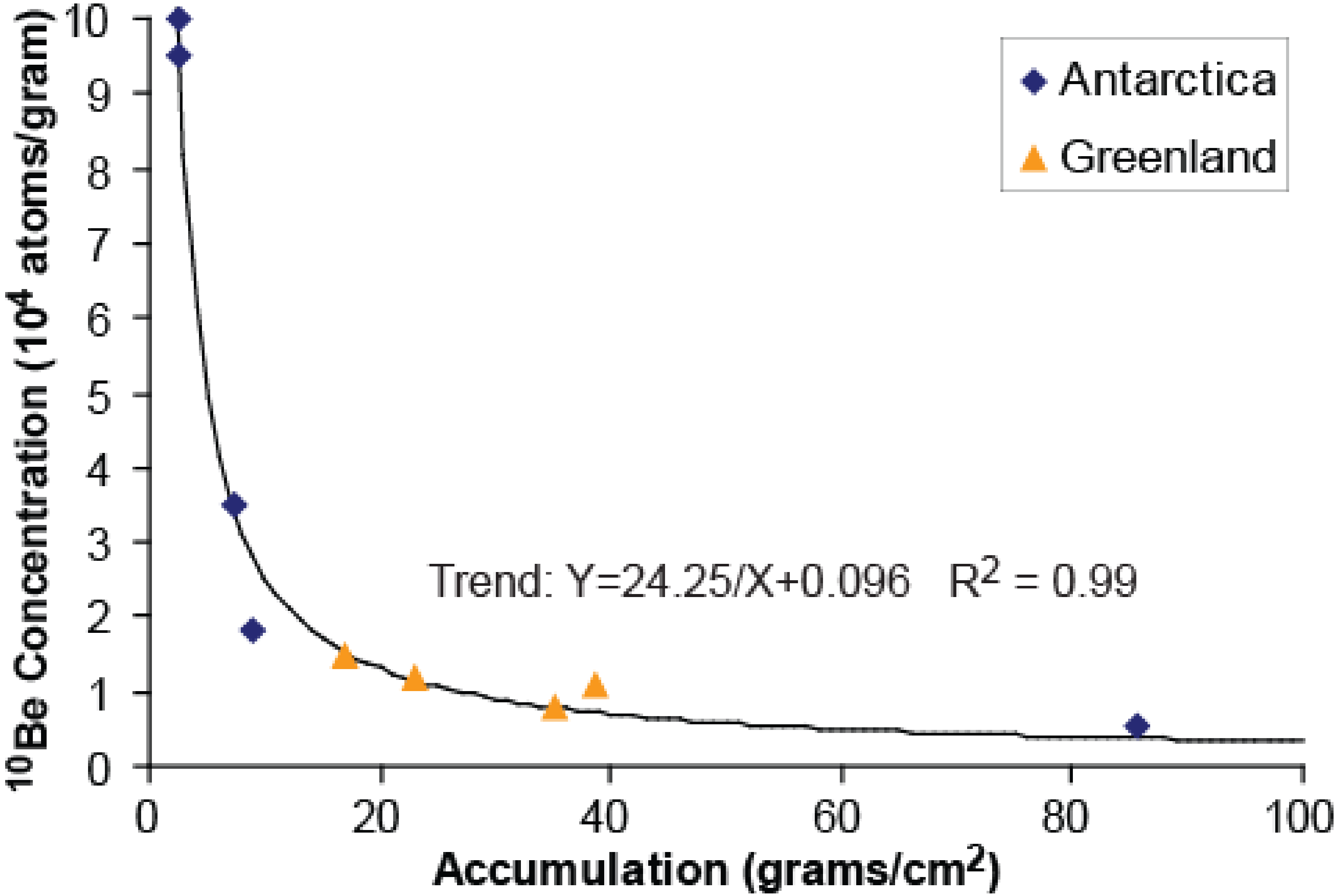
# Meteoric $^{10}Be$ deposition predicted by precipitation



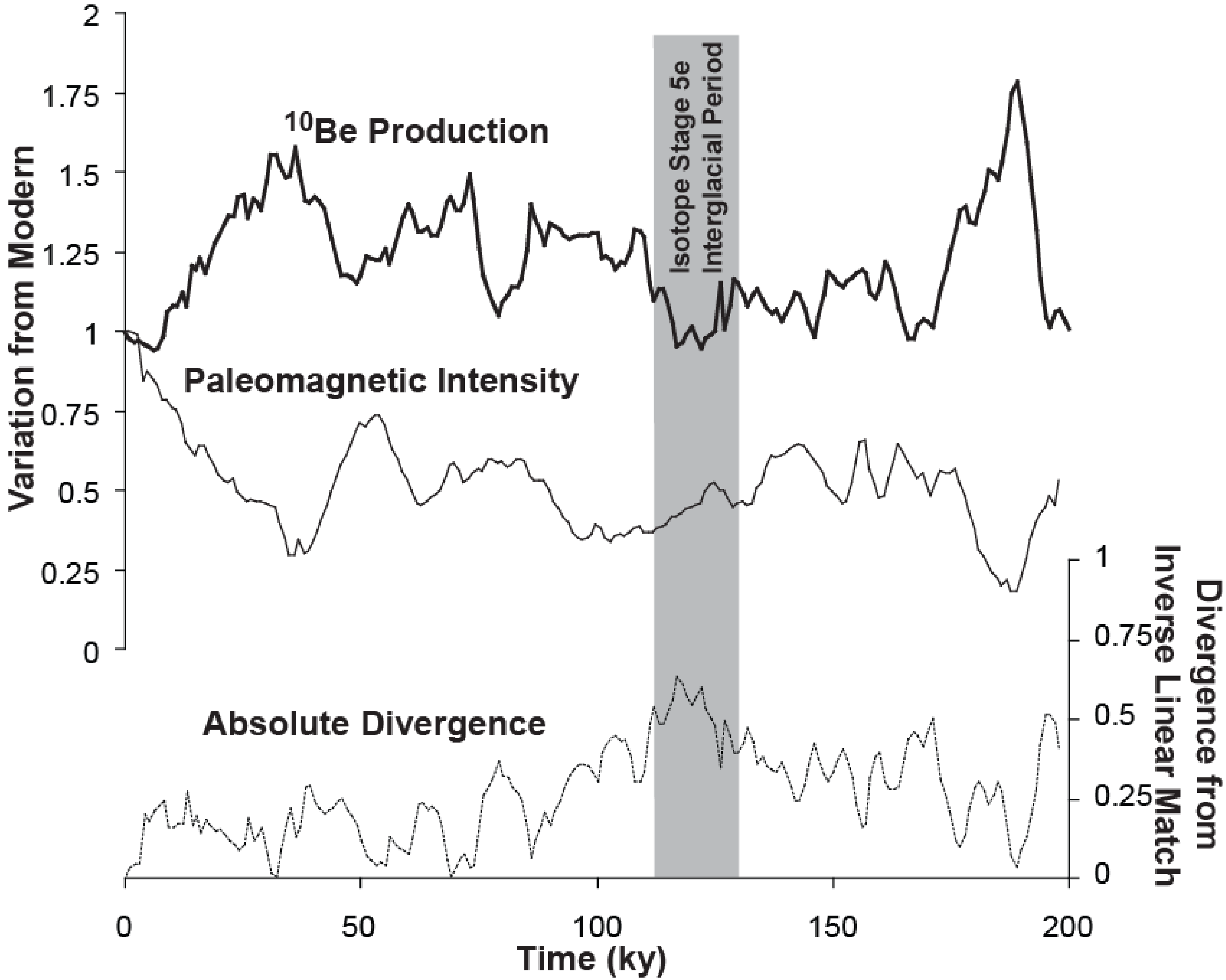
# Meteoric $^{10}$Be deposition predicted by latitude



# Meteoric $^{10}$Be deposition in Polar Regions



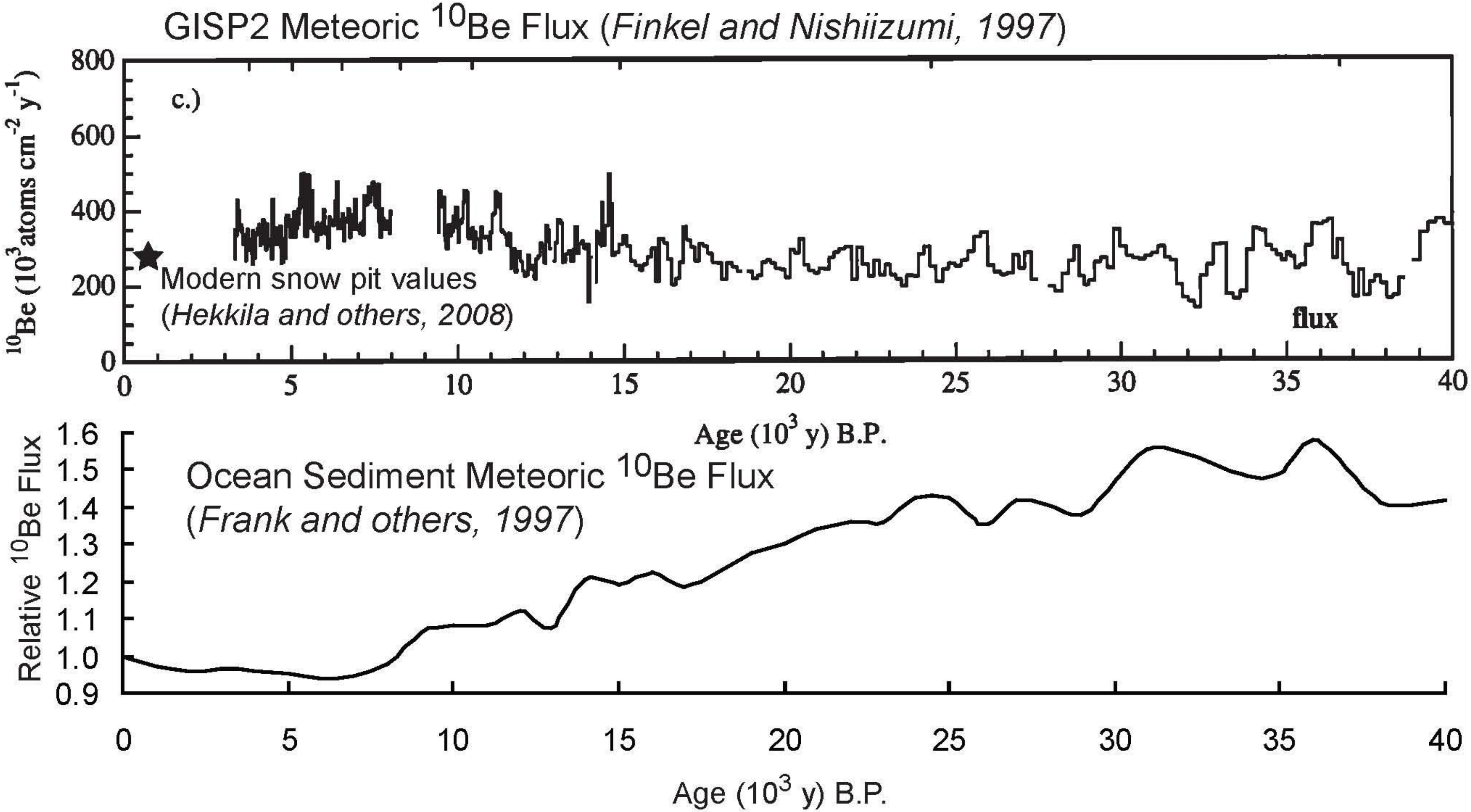
# Long-term Record: Marine Sediment



# Long-term Record: Soils

| First Author | Location | Surface Age (ka) | $^{10}Be$ Inventory (atoms/cm$^2$) | Inherited Inventory (atoms/cm$^2$) | Minimum Long-term Deposition Rate (atoms·cm$^{-2}$·yr$^{-1}$) | Modern Deposition Rate (atoms·cm$^{-2}$·yr$^{-1}$) | Percent Difference (Long-term vs. Modern) |
|---|---|---|---|---|---|---|---|
| Reusser | Waipaoa, New Zealand | 17.9 | $4.02 \cdot 10^{10}$ | $9.90 \cdot 10^{9}$ | $1.70 \cdot 10^{6}$ | $2.09 \cdot 10^{6}$ | -18.5% |
| Harden | Western Iowa | 13.0 | $3.04 \cdot 10^{10}$ | $1.30 \cdot 10^{10}$ | $1.34 \cdot 10^{6}$ | $1.68 \cdot 10^{6}$ | -20.3% |
| Balco | Minnesota | 15.0 | $2.70 \cdot 10^{10}$ | $7.29 \cdot 10^{9}$ | $1.32 \cdot 10^{6}$ | $1.64 \cdot 10^{6}$ | -19.7% |
| Maejima | Kikai Island, Japan | 80 | $3.40 \cdot 10^{11}$ | $1.85 \cdot 10^{10}$ | $4.10 \cdot 10^{6}$ | $2.88 \cdot 10^{6}$ | 42.4% |
| Elgi | Swiss Alps | 3.55 | $1.47 \cdot 10^{10}$ | 0 | $4.15 \cdot 10^{6}$ | $4.49 \cdot 10^{6}$ | -7.5% |

# Long-term Record: Greenland Ice Sheet

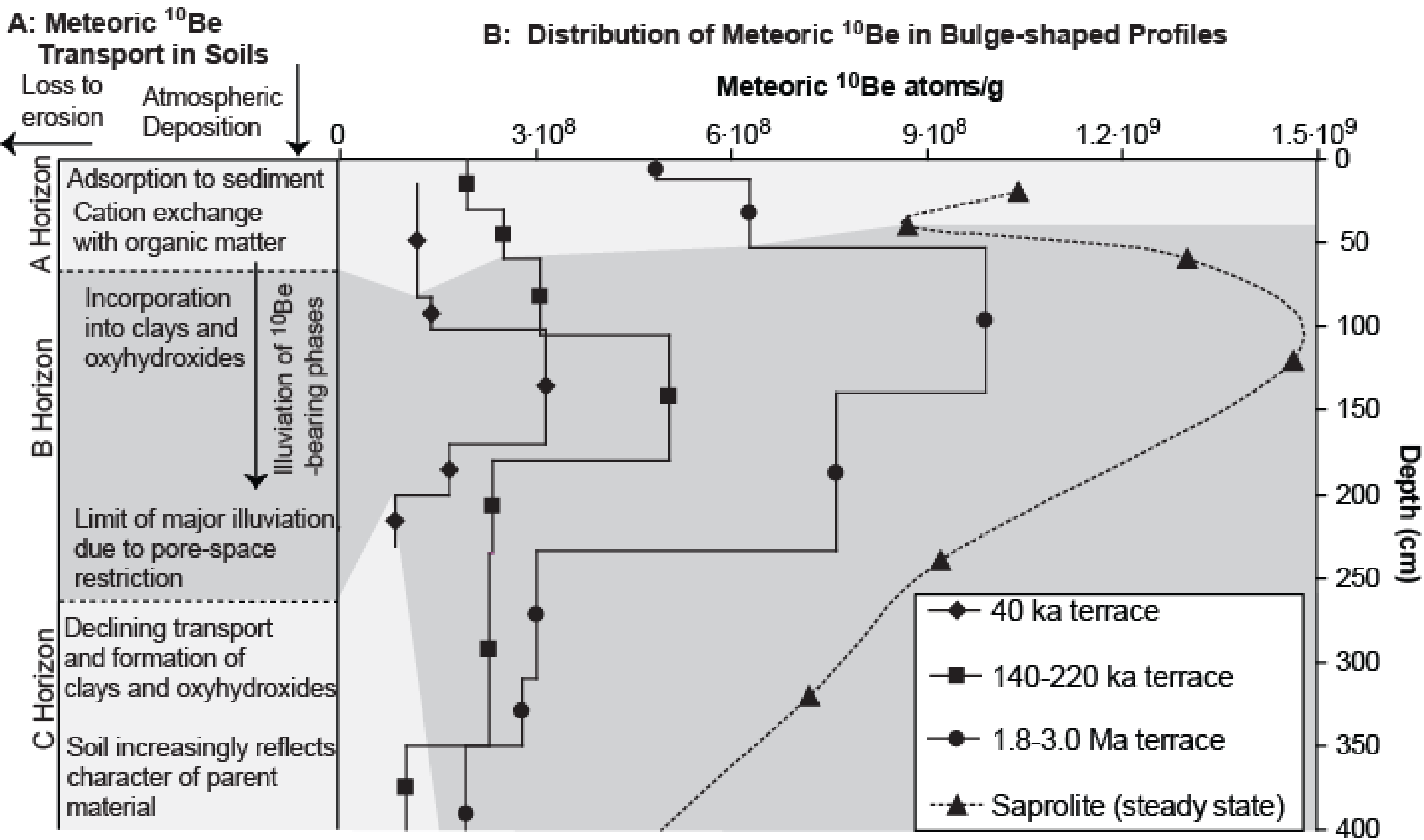


# Meteoric $^{10}$Be in Soils

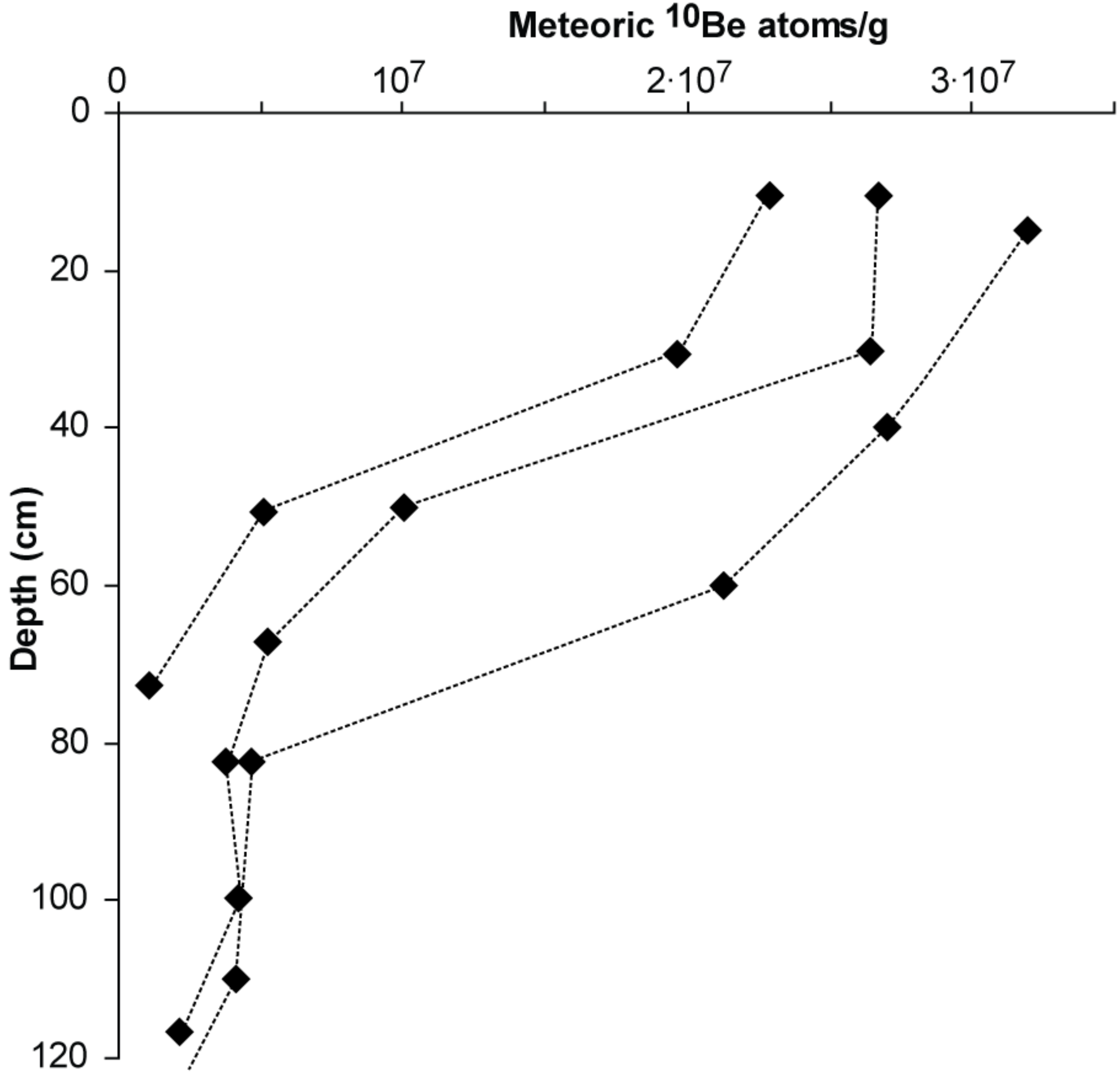
- How is meteoric $^{10}$Be typically distributed in soils?
- Can the effects of erosion of meteoric $^{10}$Be bearing sediment be modeled from a typical depth distribution?

# Existing work on meteoric $^{10}Be$ in soils

# Typical Distribution with Depth



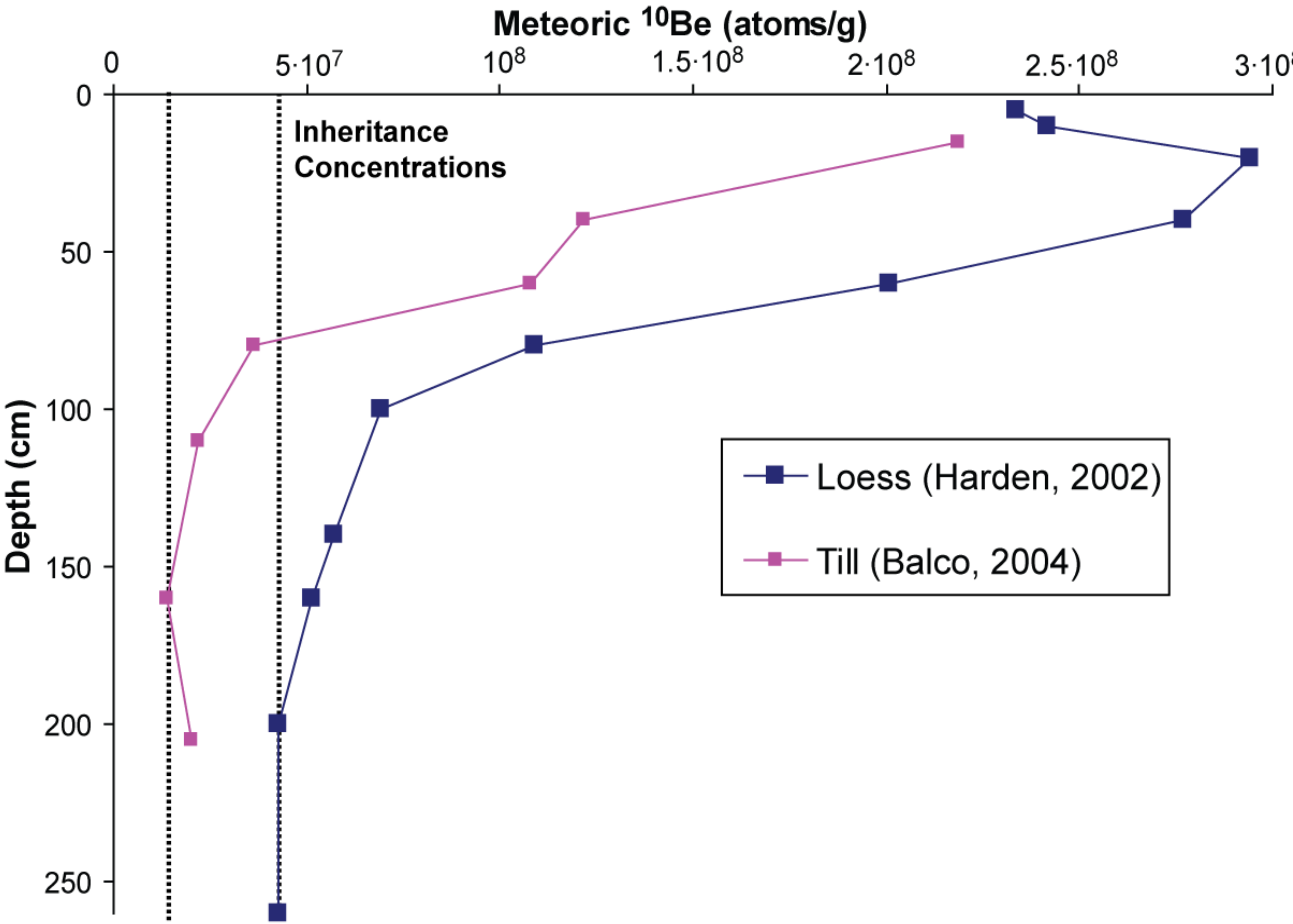
# Declining Profile Shapes: Eroding Hillslopes



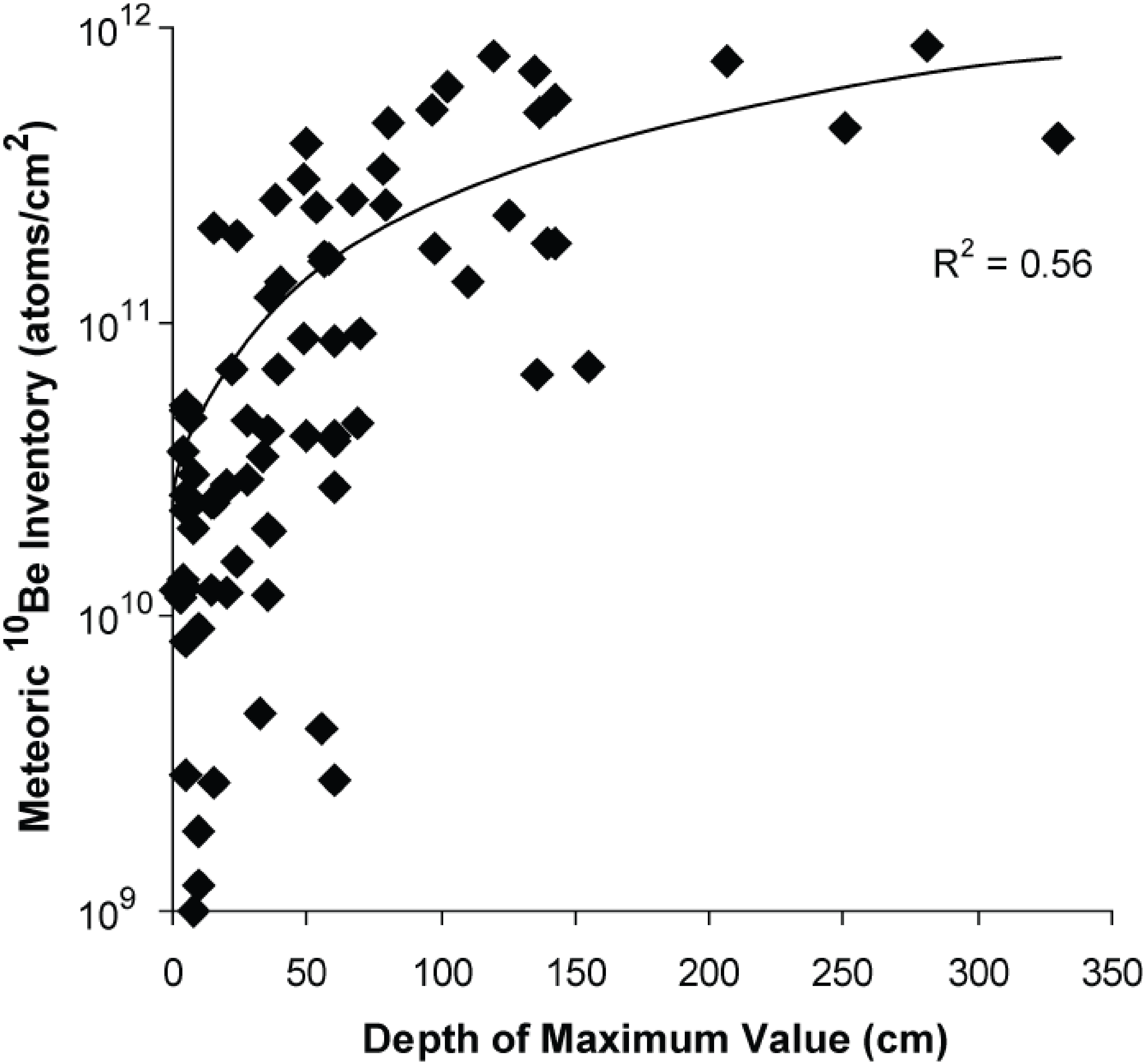

Profiles from Contra Costa, California

*McKean et al, 1993*

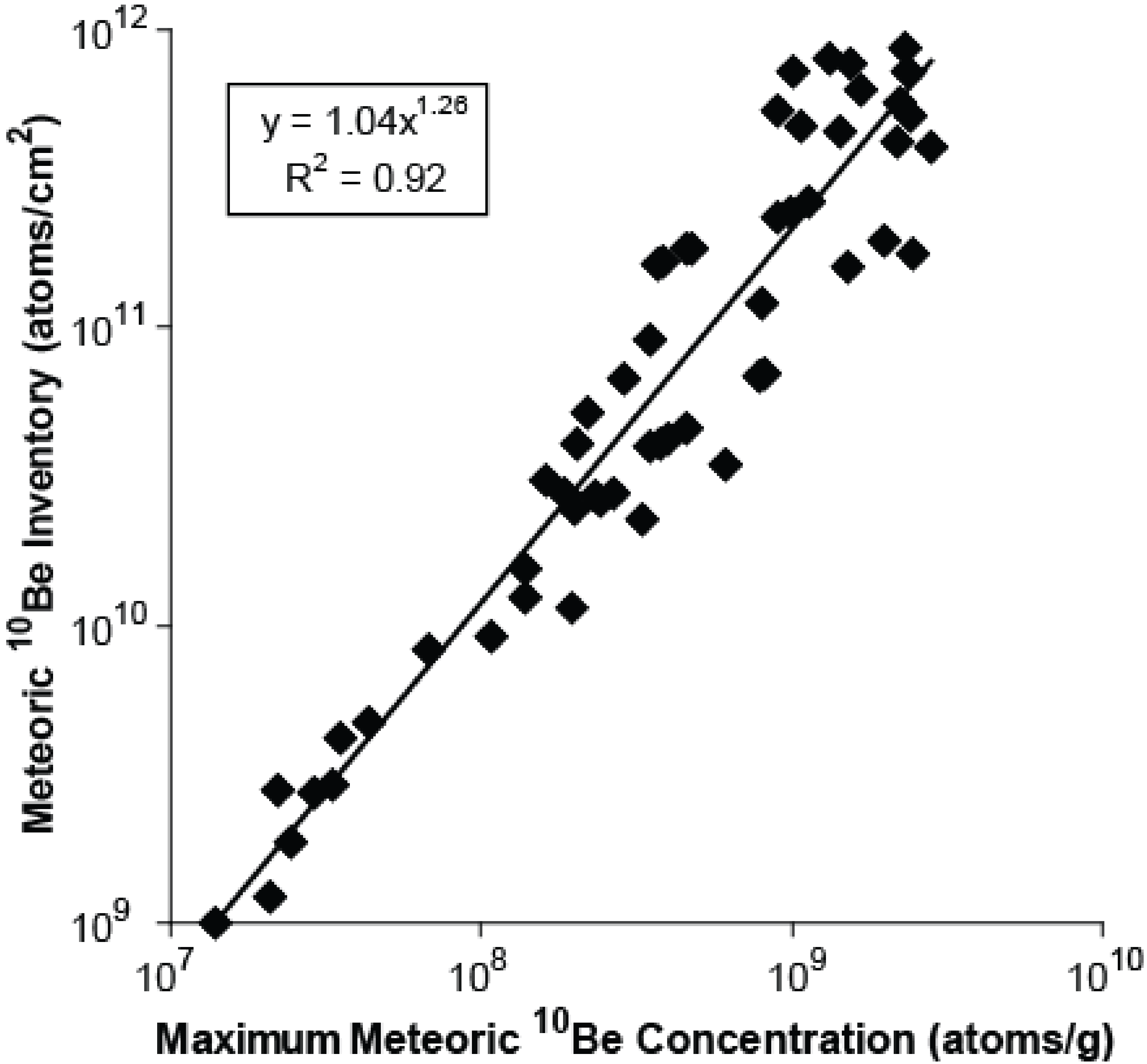
# Declining Profile Shapes: Young Surfaces



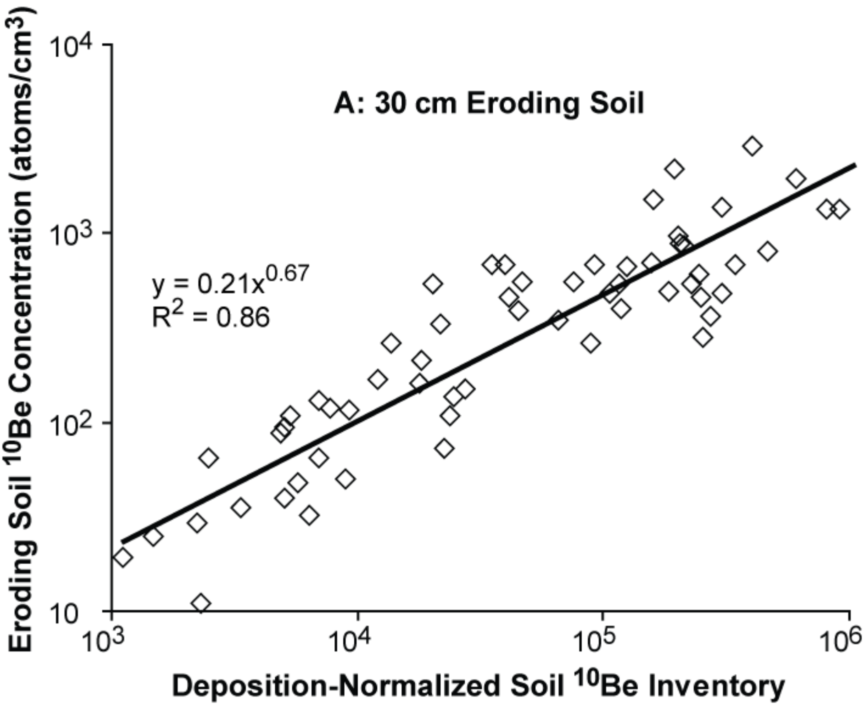
# Development of max accumulation zone

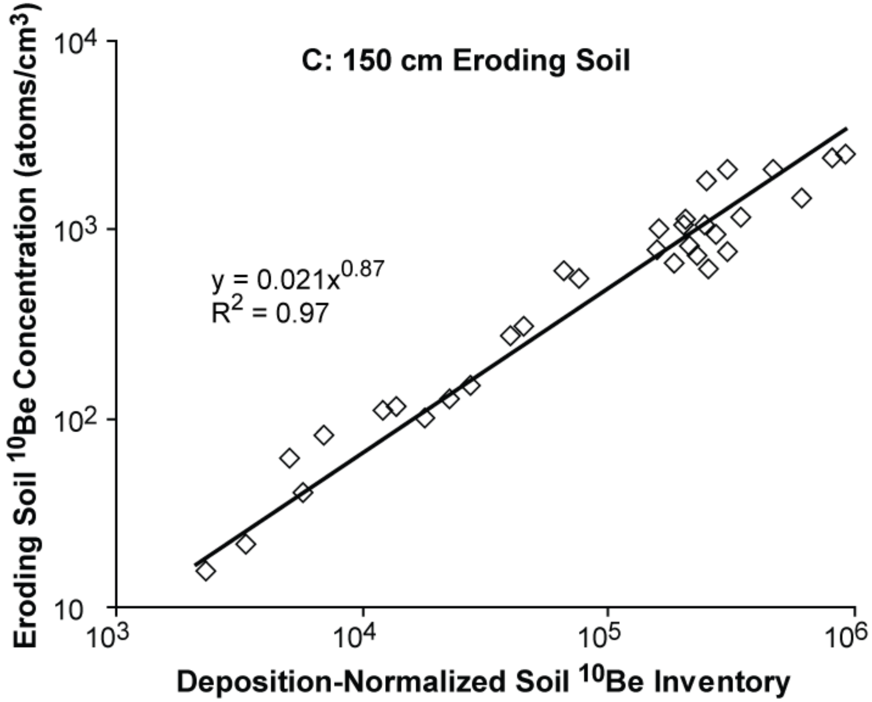


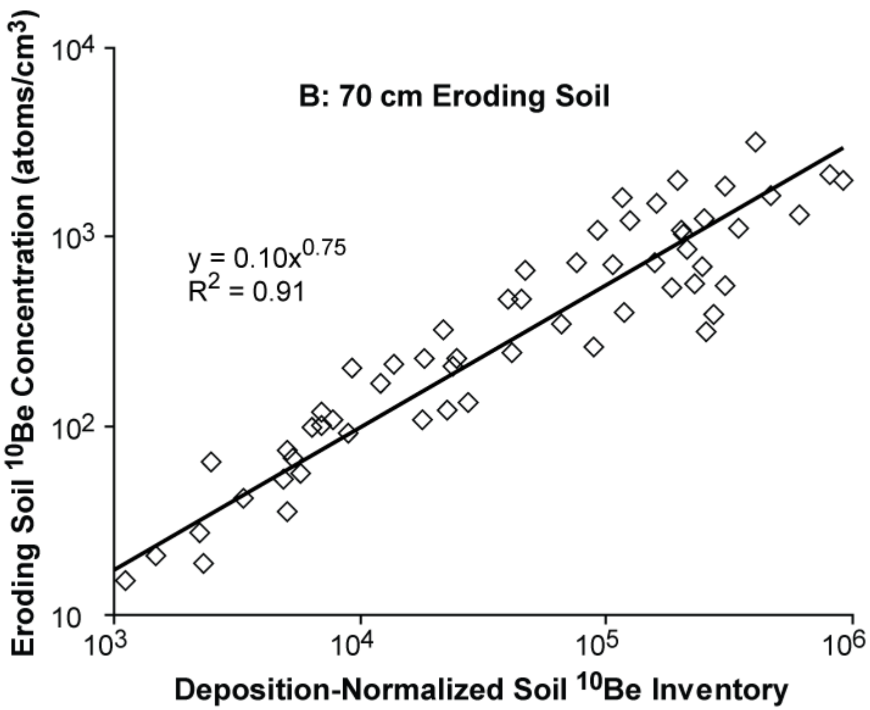
# Maximum predictive of total inventory



# Topsoil Meteoric $^{10}Be$ Concentration Predictive of Total Inventory



# West Greenland Results and Interpretation

- Which sites were sampled and what meteoric $^{10}$Be measurements were made?
- What can be inferred about the erosion and interglacial exposure of West Greenland?

# Kangerlussuaq: Isunnguata Sermia Glacier

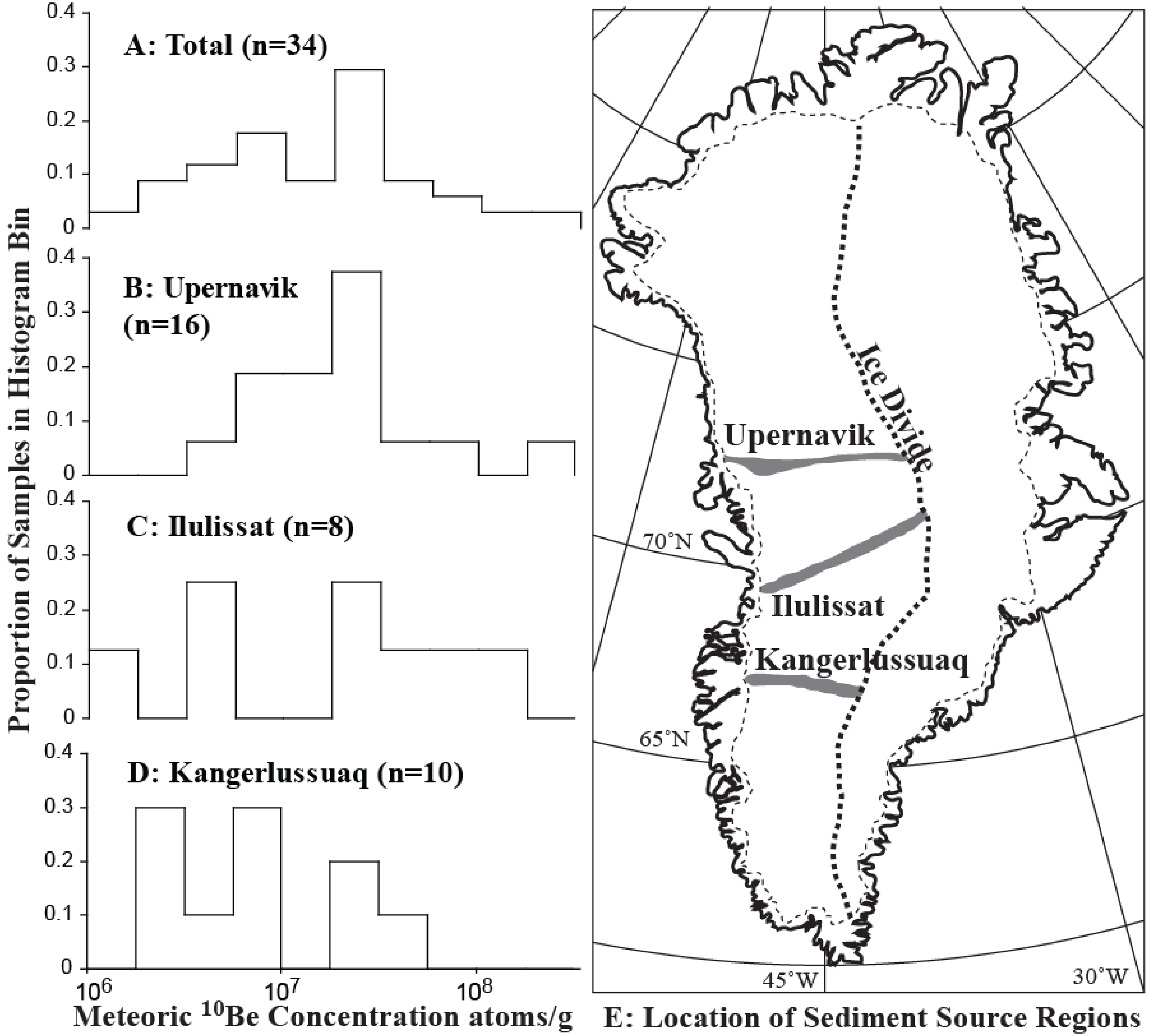
# Kangerlussuaq:  Dead Ice Zone

# Ilulissat:  Sermeq Avannarleq Glacier

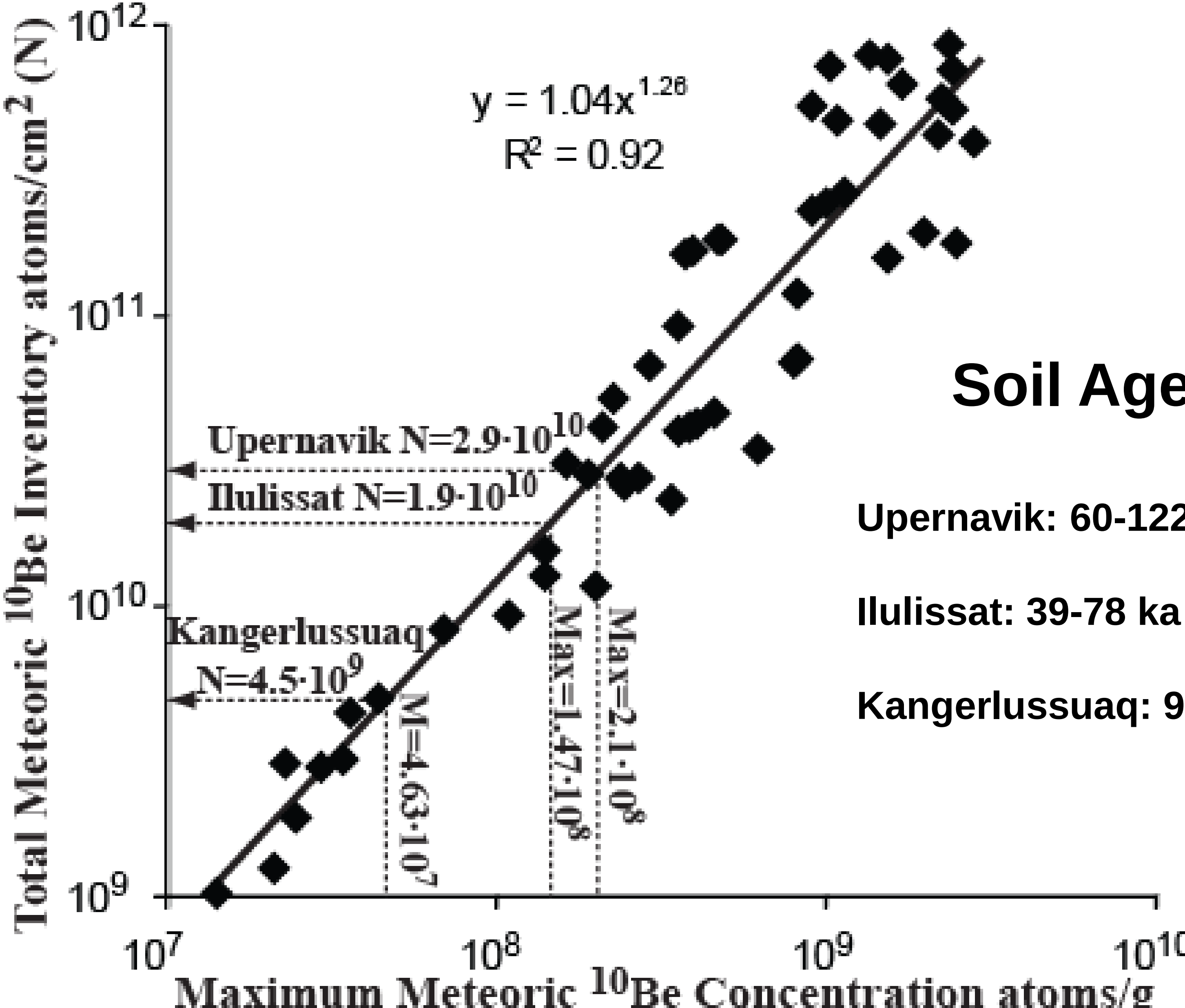
# Upernavik: Transect


# Upernavik: Nunatak

# West Greenland Meteoric $^{10}$Be Results



# Estimate of Meteoric $^{10}Be$ Inventory



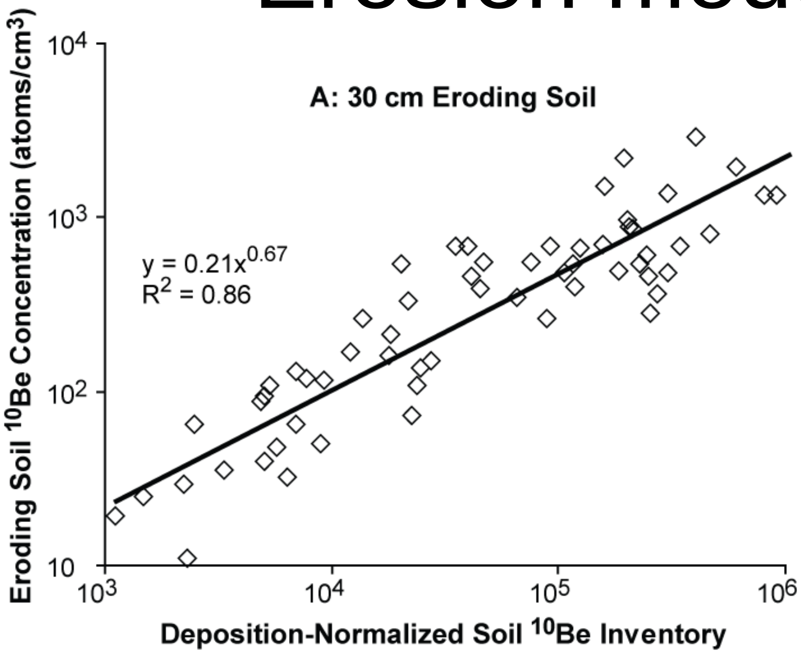

## Soil Ages

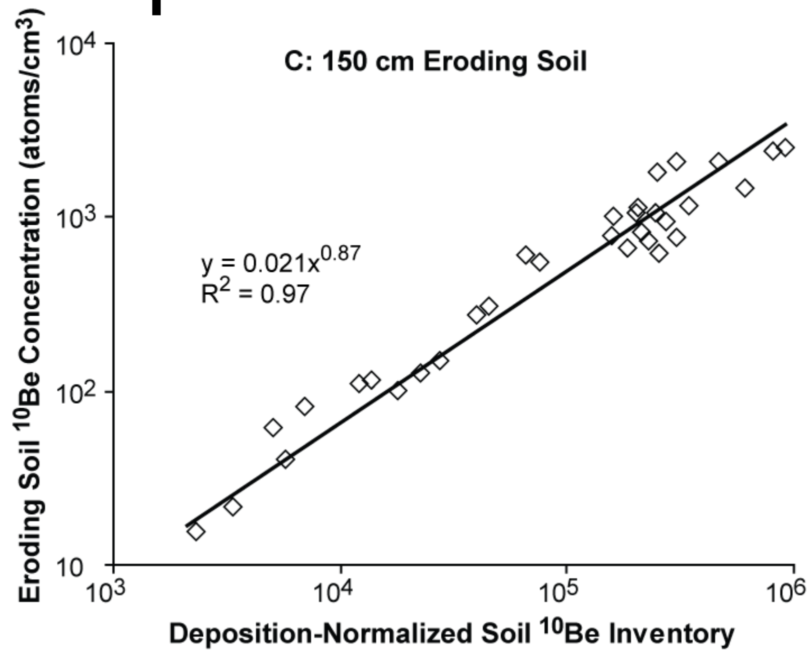
**Upernavik: 60-122 ka**

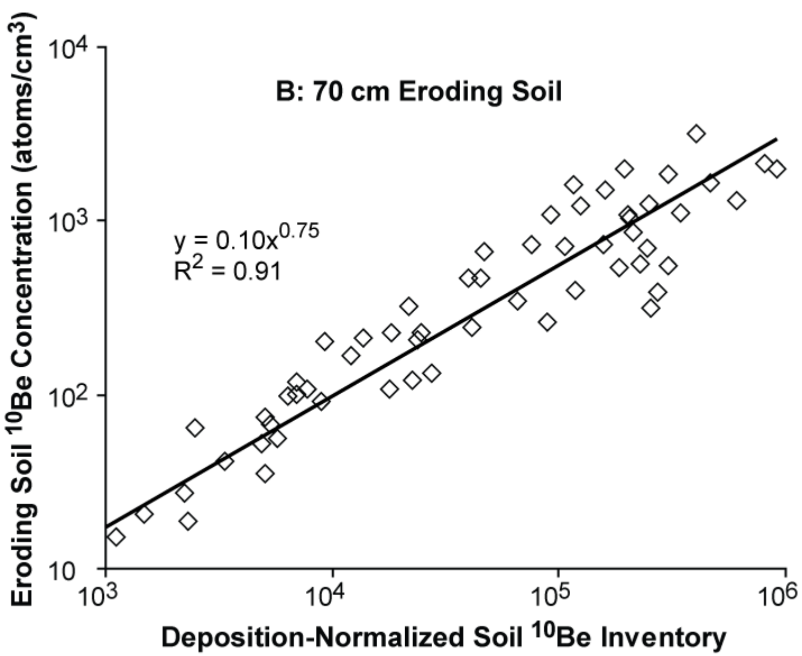
**Ilulissat: 39-78 ka**

**Kangerlussuaq: 9-18 ka**

# Erosion model: Top 150 cm




**Pre-Glacial Inventory:**

$N=q(1-E\cdot\alpha\cdot(N/q)^{\beta})/(\lambda(1-e^{-\lambda t}))$

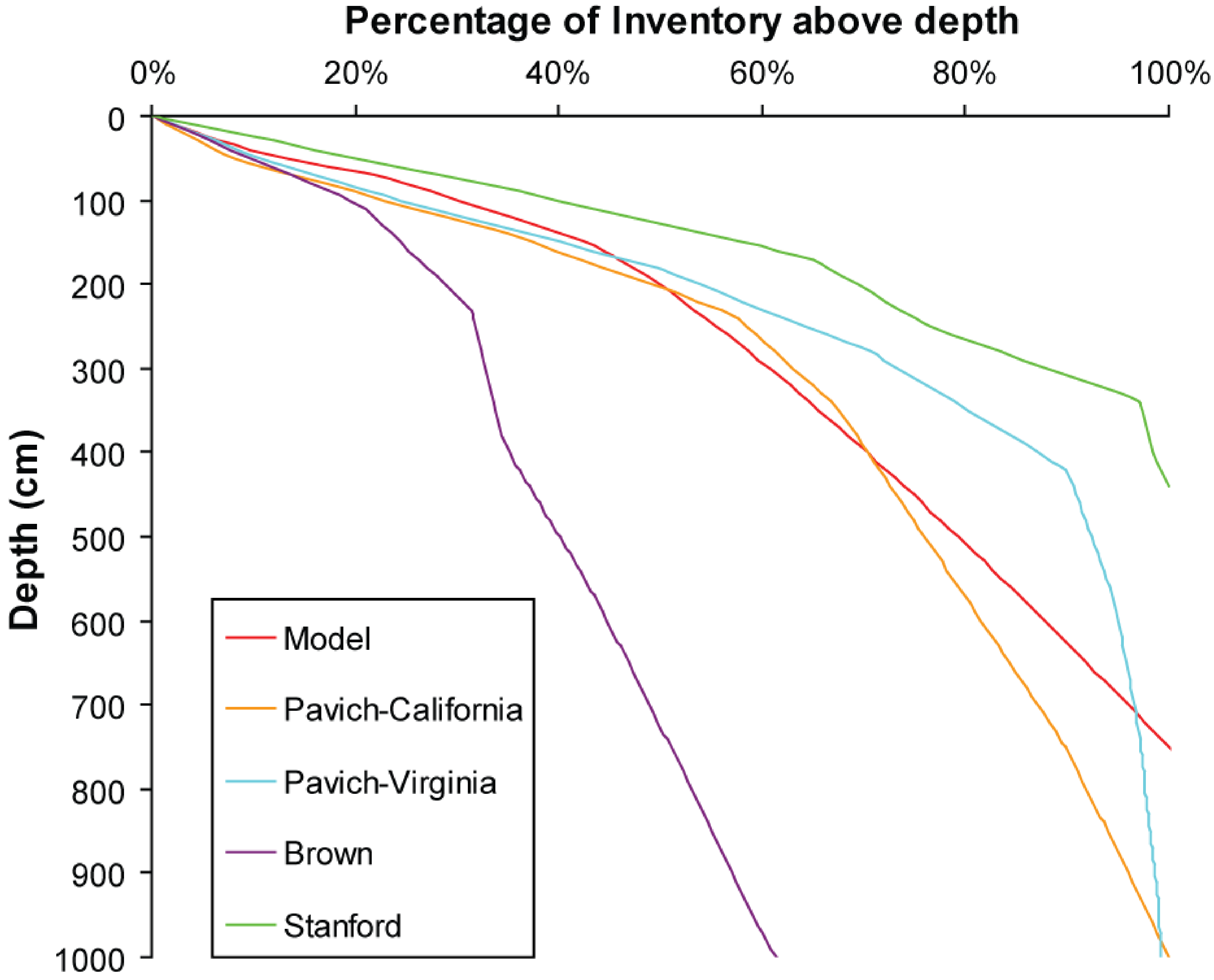
**Interglacial Inventory:**

$N=(q/\lambda)(1-e^{-\lambda t})$

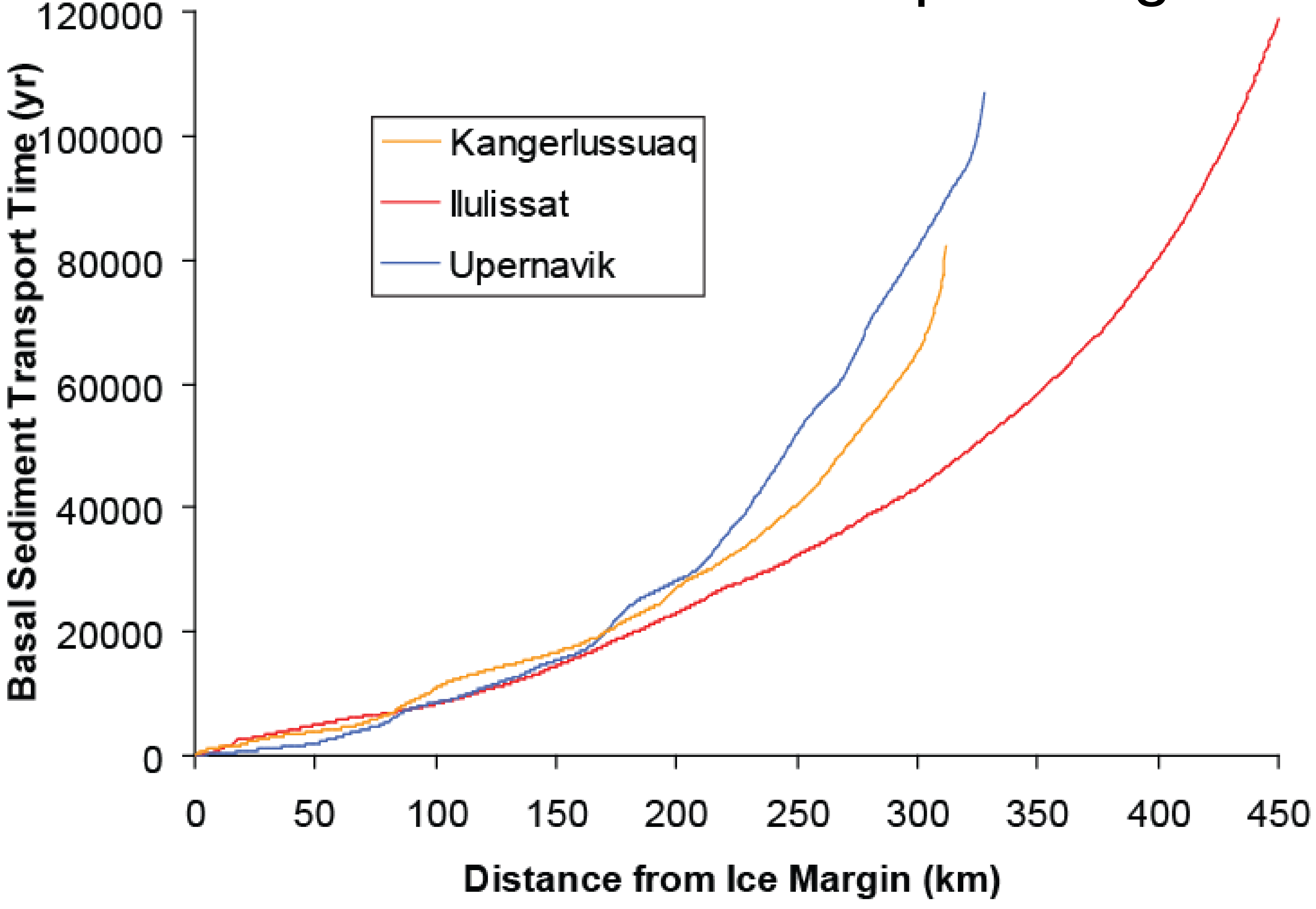
**Inventory Lost to Glacial Erosion:**

$N_L=z\cdot q\cdot\alpha\cdot(N/q)^{\beta}$

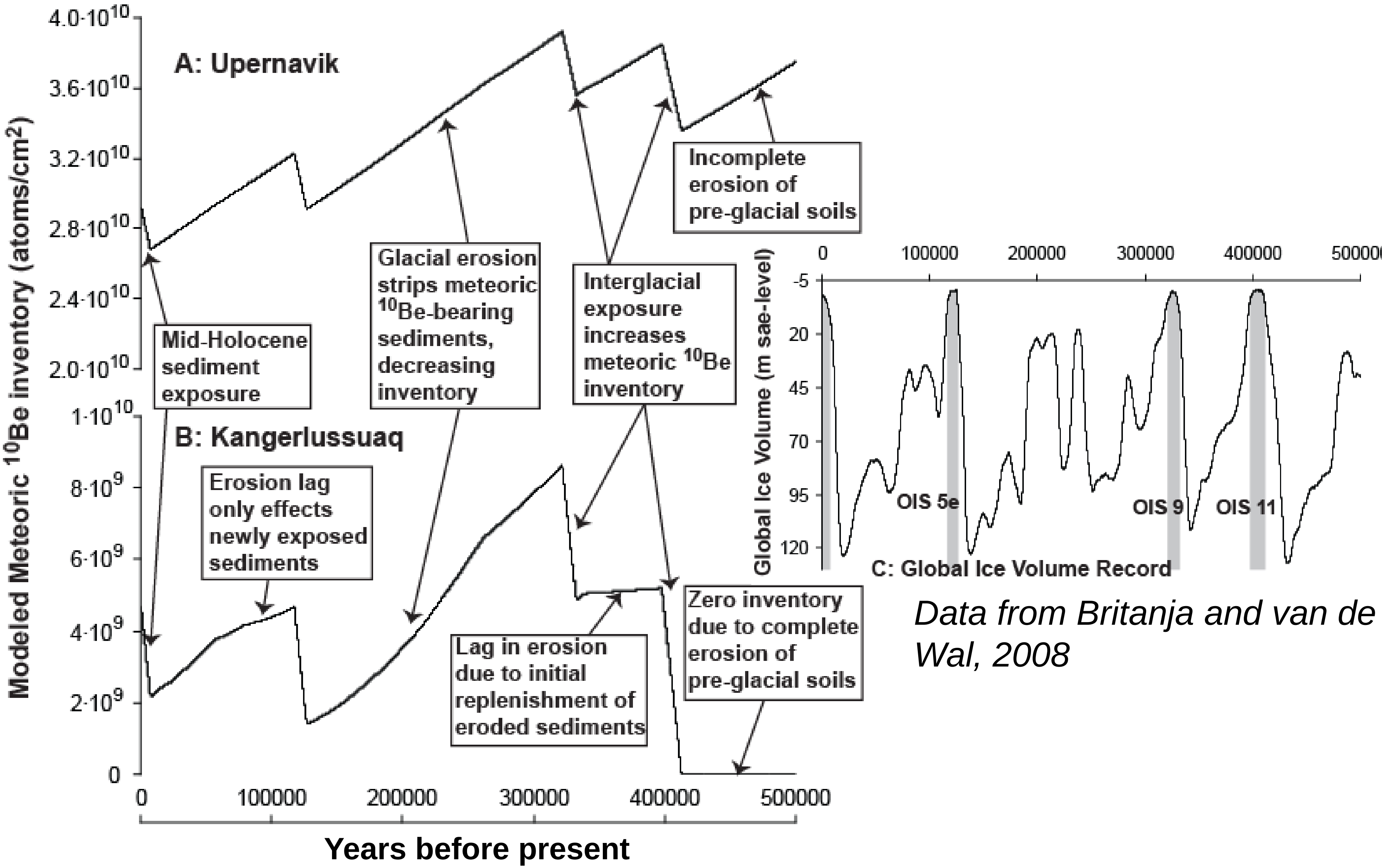
# Erosion Model: Deep Erosion



# Glacial Sediment Transport Lag

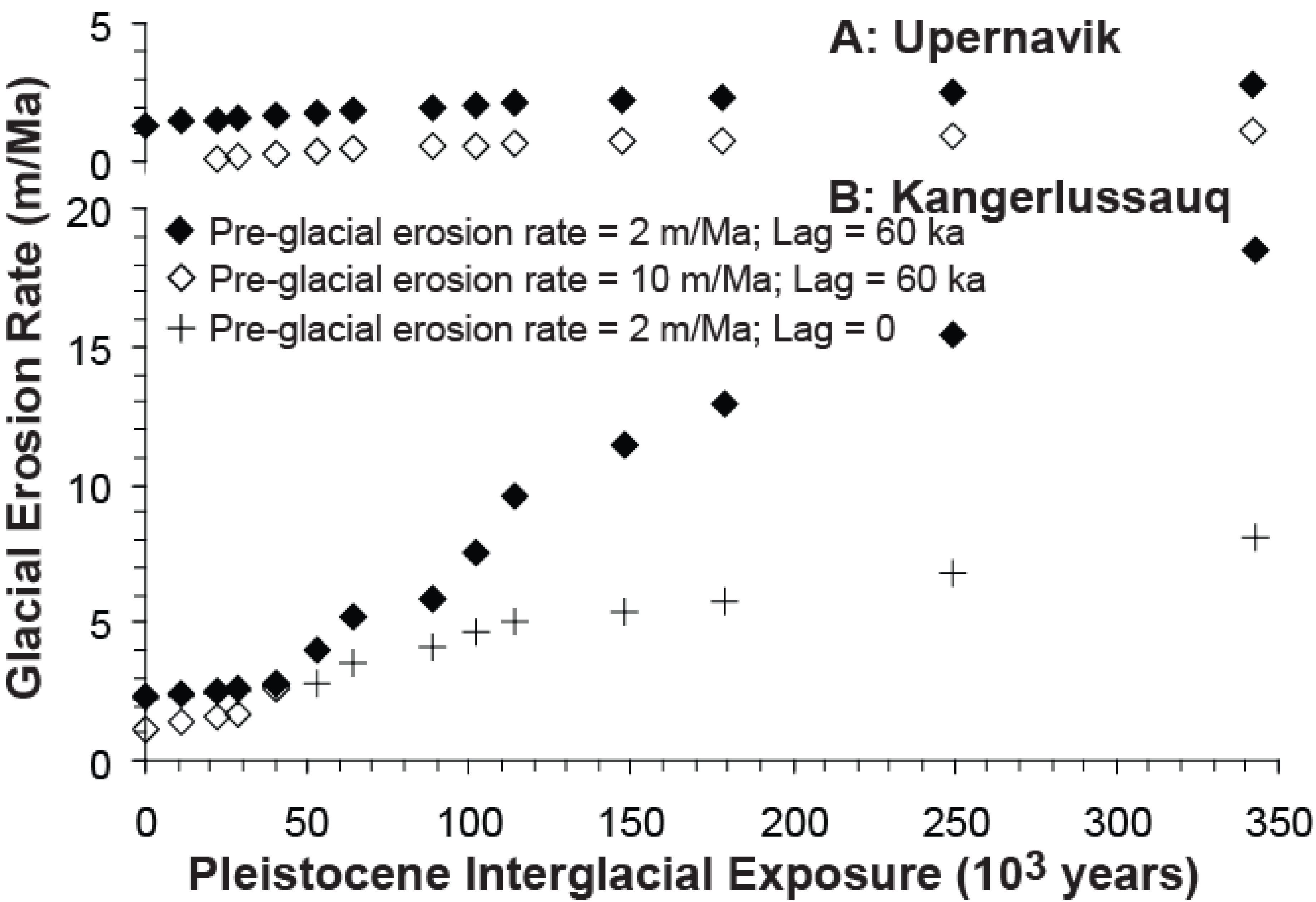


# Development of Modern $^{10}Be$ Inventory

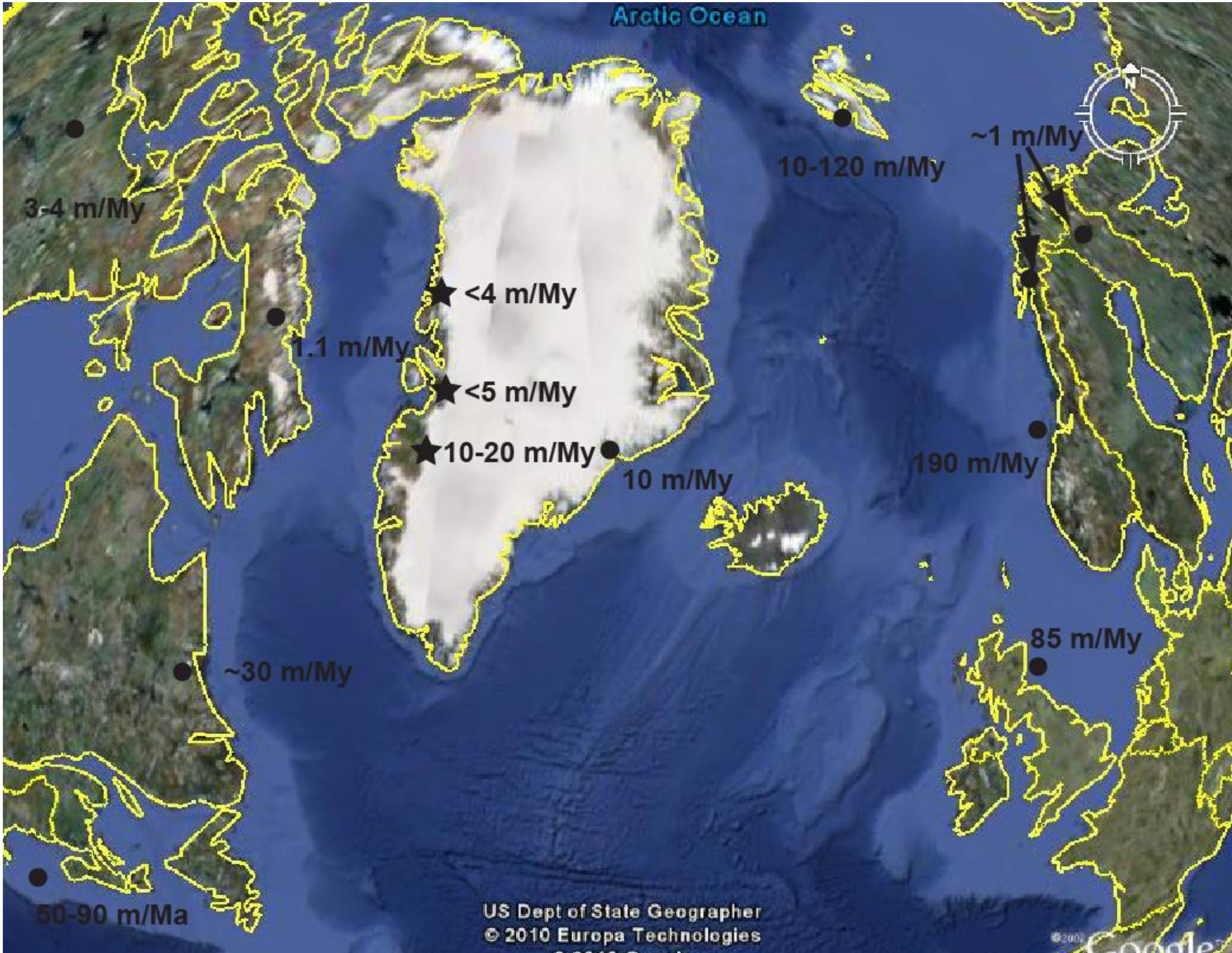



*Data from Britanja and van de Wal, 2008*

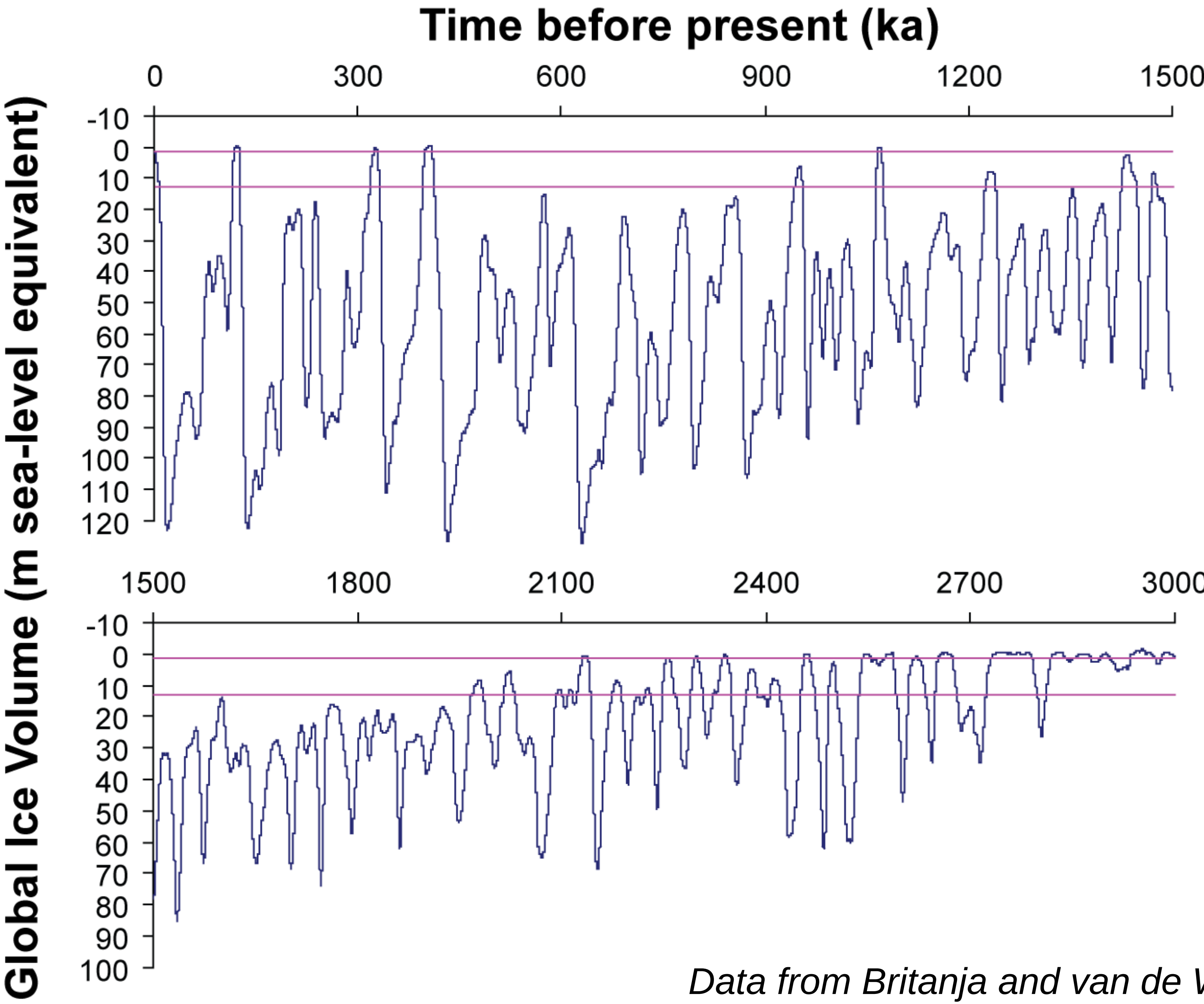
# Valid Erosion Exposure Interpretations



# Glacial Erosion Rates Reconsidered



# Interglacial Exposure Reconsidered




*Data from Britanja and van de Wal, 2008*

# Conclusions

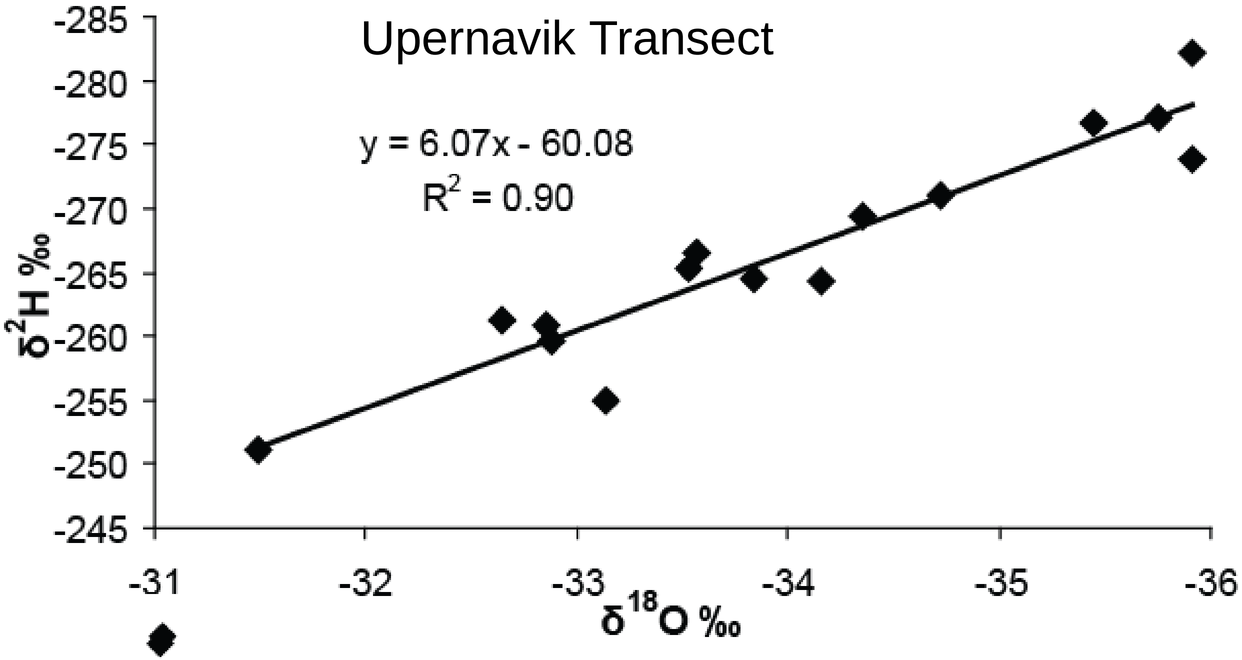
- Long-term meteoric $^{10}Be$ deposition rate is moderately predictable from precipitation and latitude
- Meteoric $^{10}Be$ depth distribution is moderately predictable from total soil meteoric $^{10}Be$ inventory
- Pre-Quaternary regolith under Greenland’s Main Dome has not completely eroded, with glacial erosion rates < 5 m/My
- Greenland’s Southern Dome has experienced substantial interglacial exposure

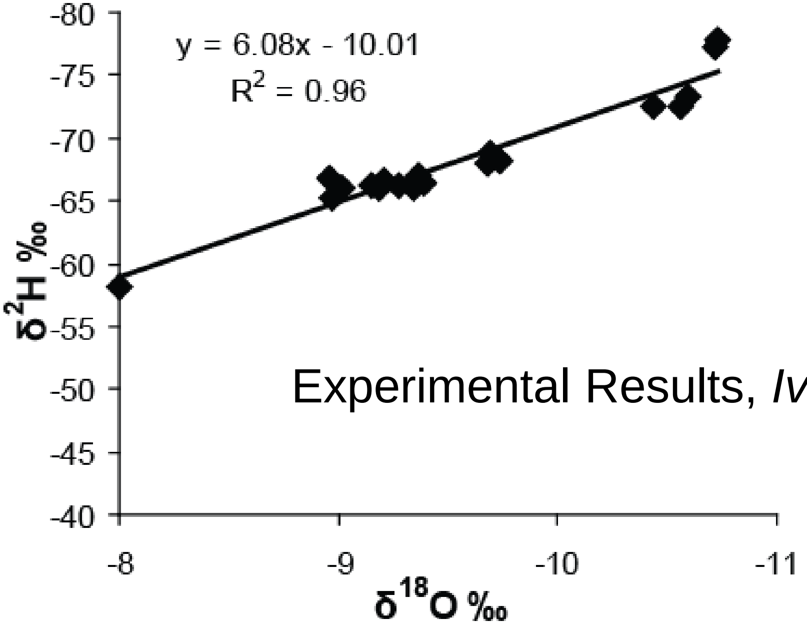
# Acknowledgements


- National Science Foundation
- CH2M HILL Polar Services (Kangerlussuaq)
- Lawrence Livermore National Laboratory
- Greenland Cosmochronology Project Team
- Fellow geology grad students, family, and friends

# Thanks for Listening… Any Questions?

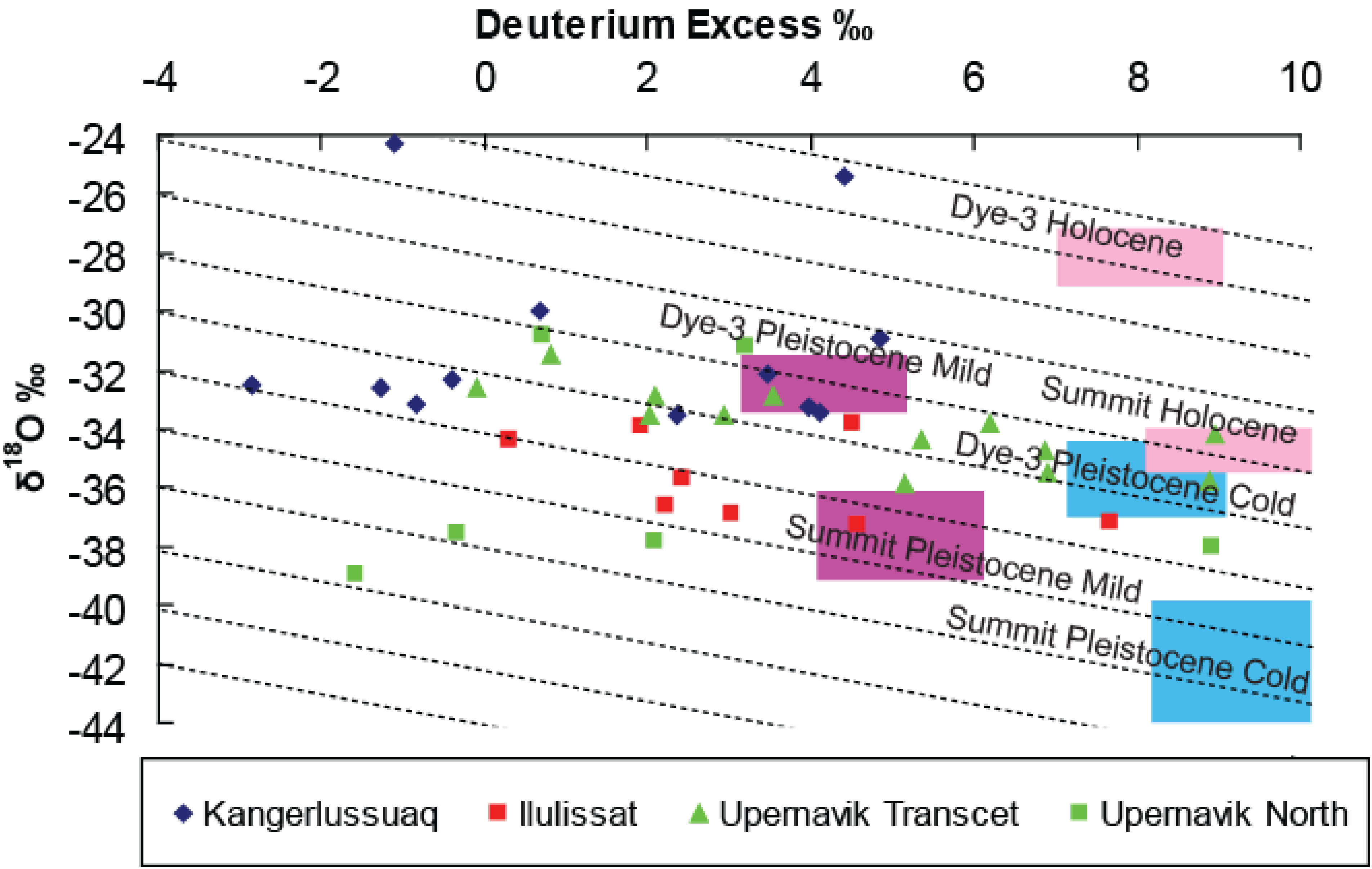
# West Greenland Stable Isotope Results



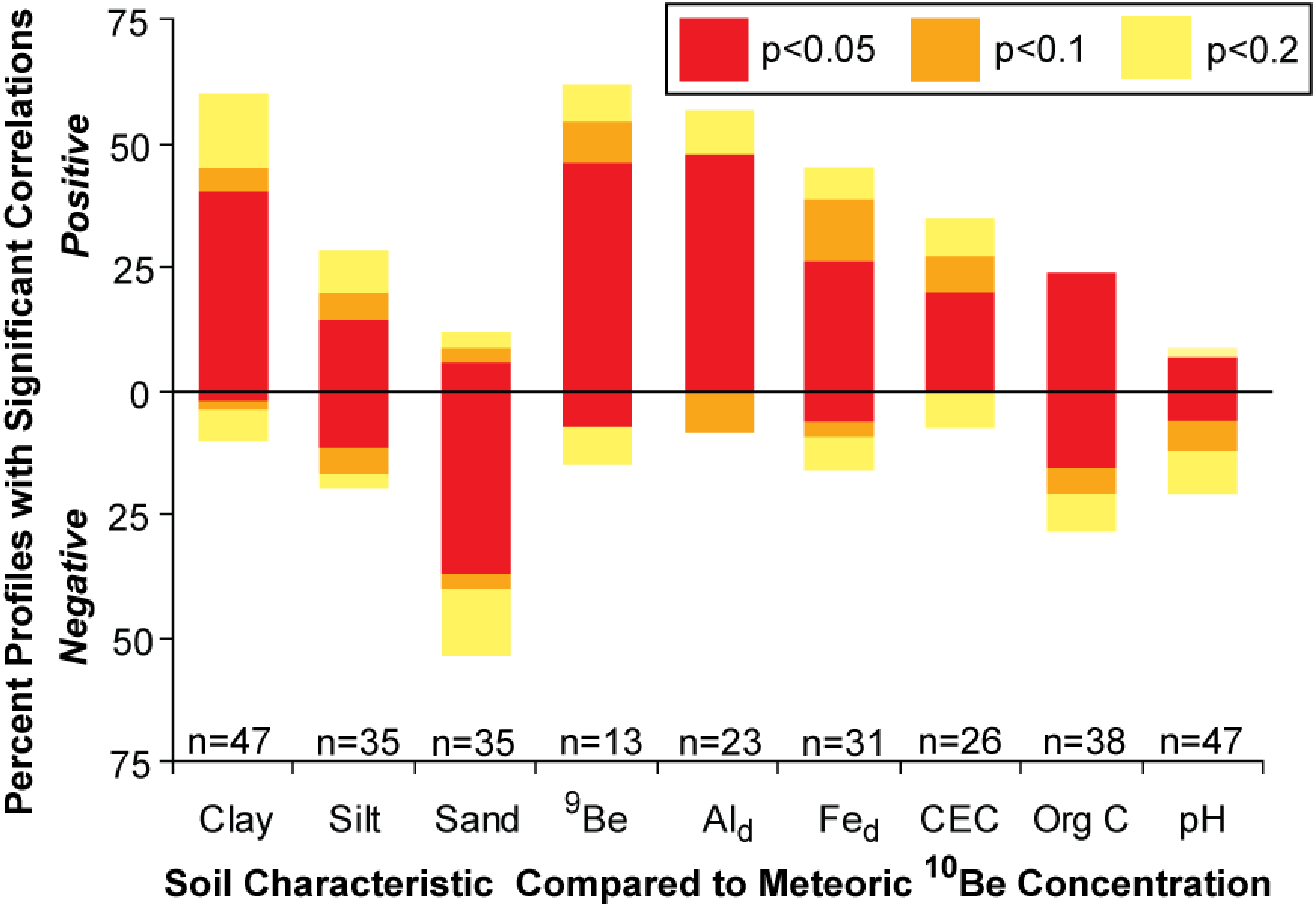




Experimental Results, *Iverson and Souchez, 1996*

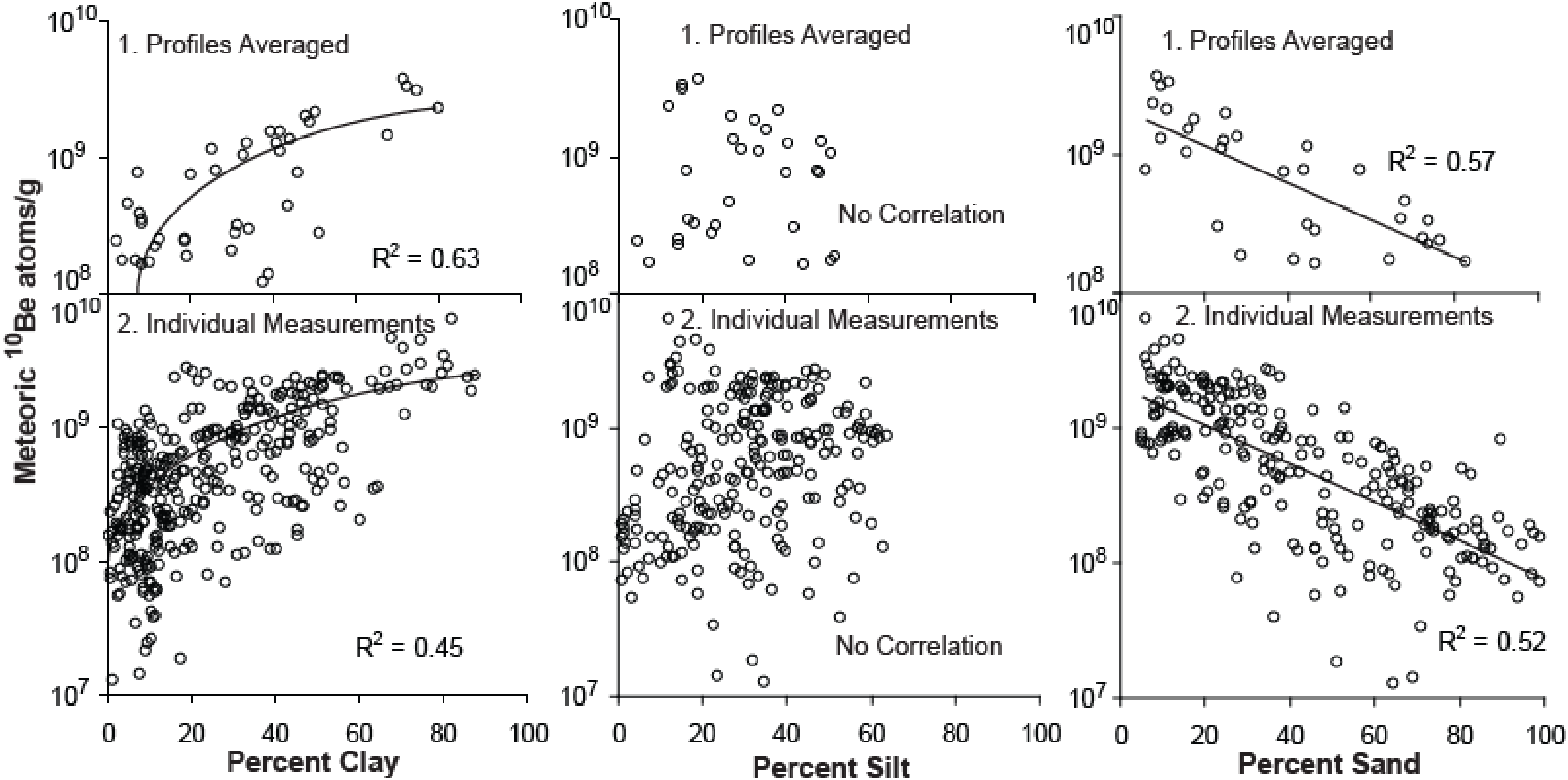
# West Greenland Stable Isotope Results



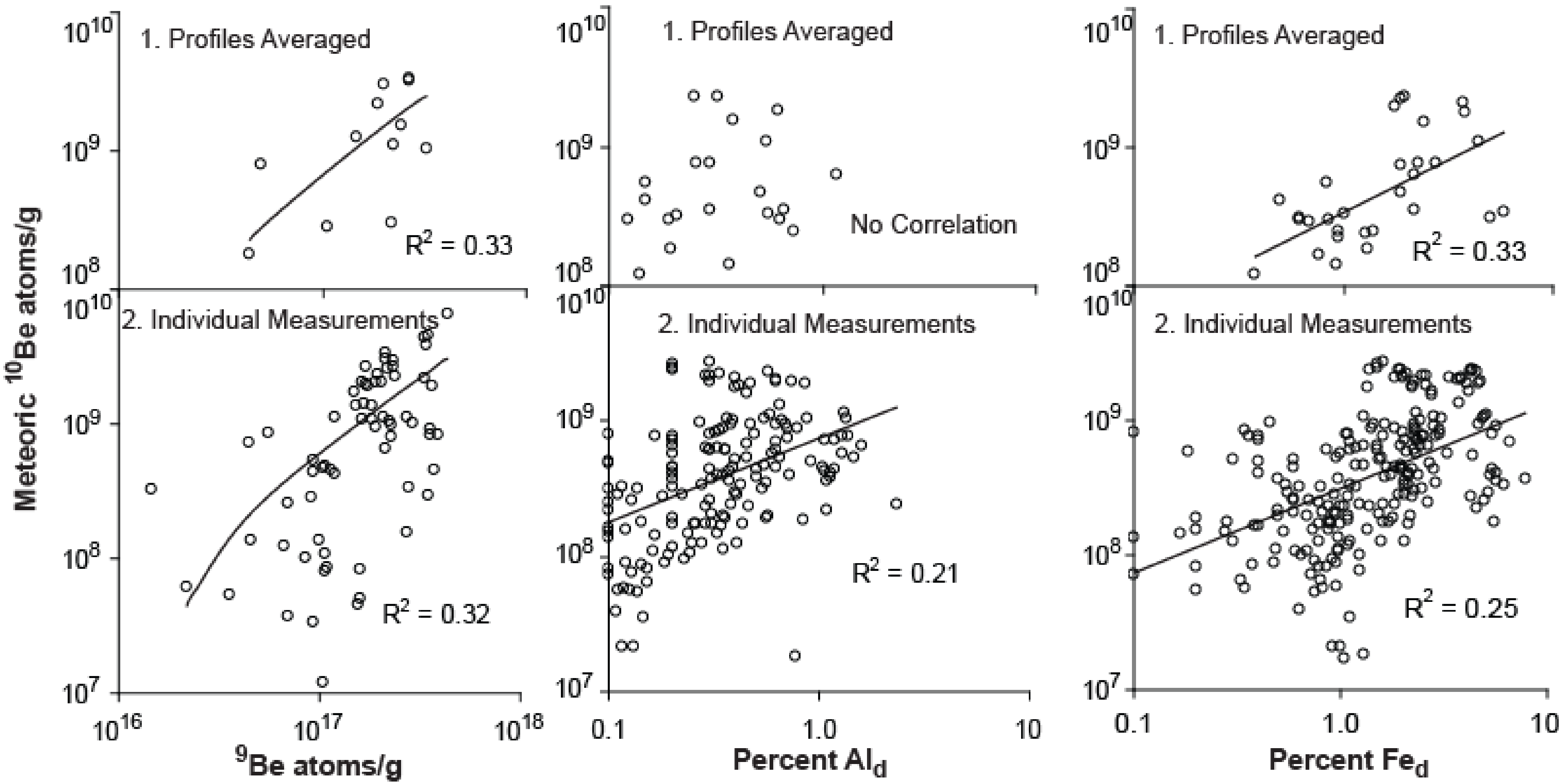
# Distribution Controlled by Soil Properties?



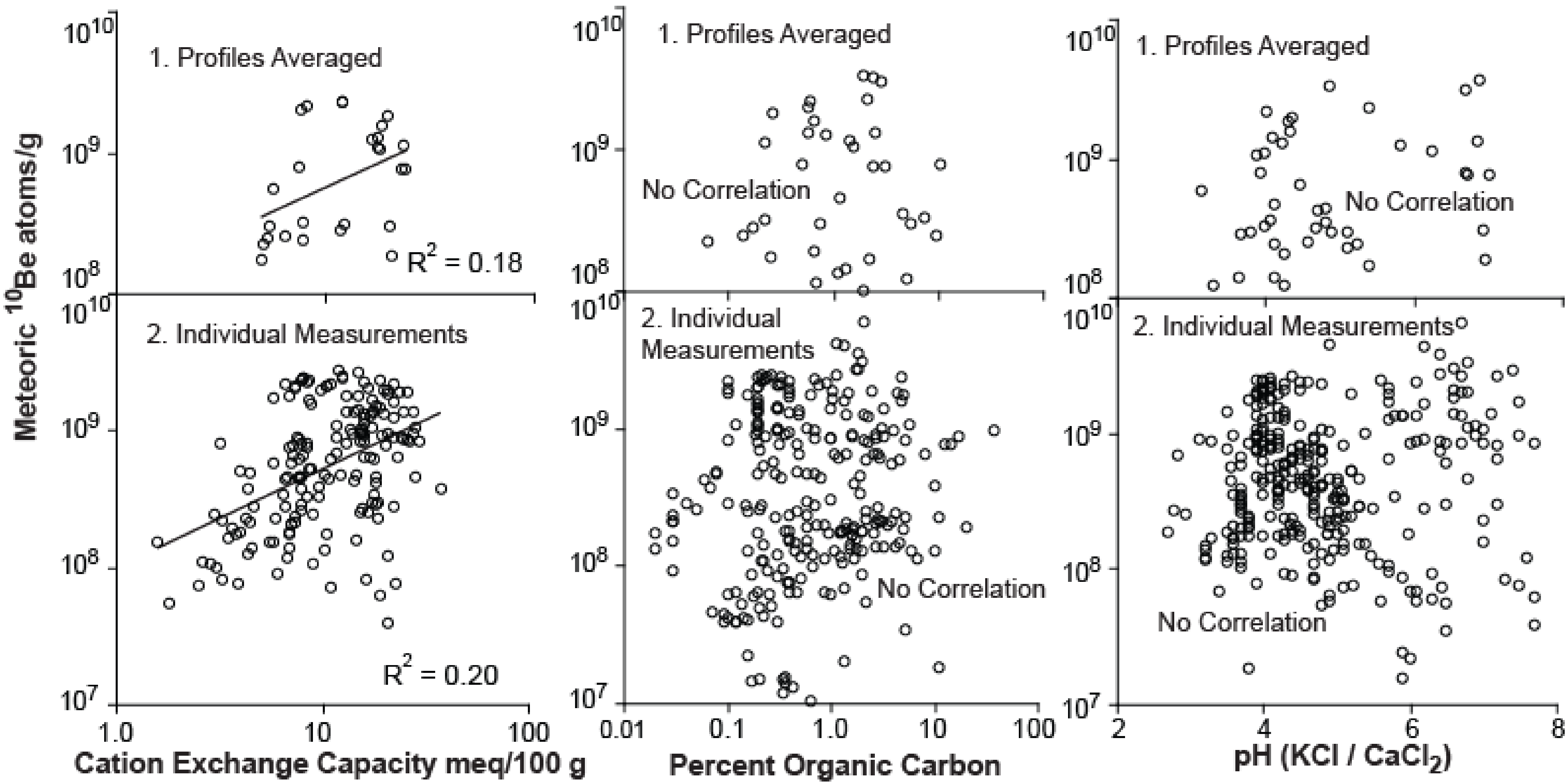
# Grain Size Effect



# Comparable Mobile Cations



# CEC, Organic Carbon, and pH



# Meteoric $^{10}Be$ deposition predicted by latitude