Radiometric dating of ancient glacial ice using ^{81}Kr – a progress report

Christo Buizert, V. Petrenko, R. Purtschert, Z. T. Lu, D. Baggenstos, T. Bauska, J. Lee, T. Kuhl, J. Severinghaus and E. Brook

Oregon State University OSU

VSP UCAR Visiting Scientist Programs

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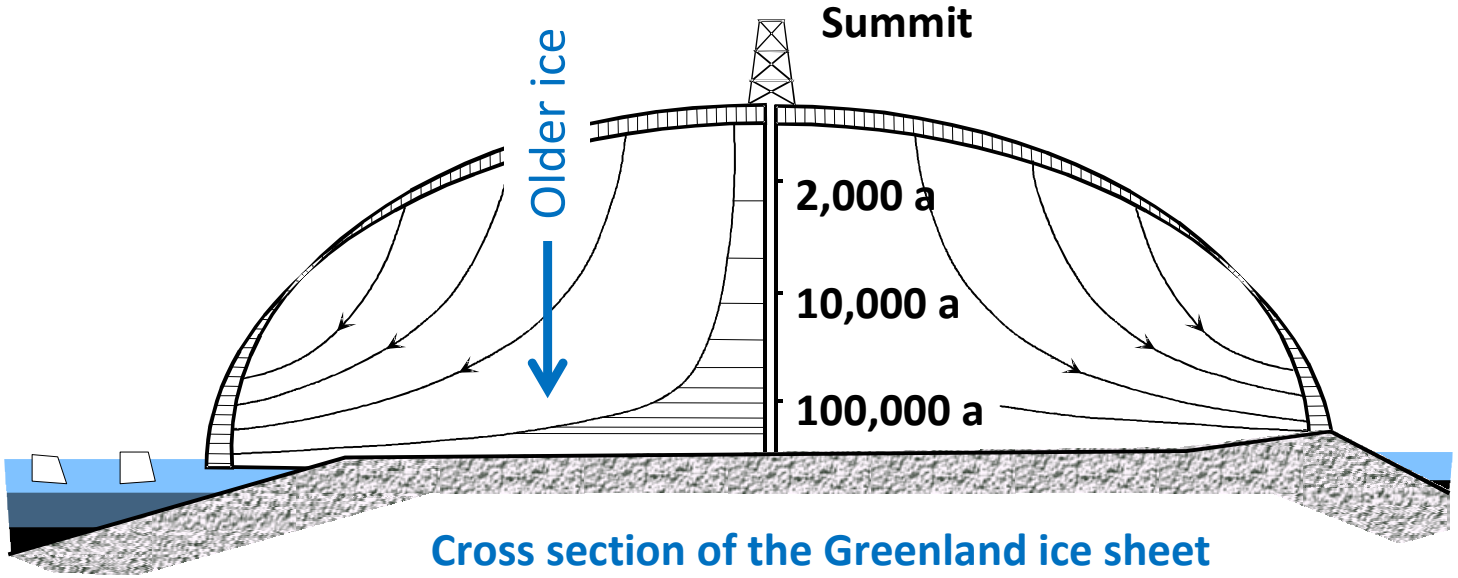
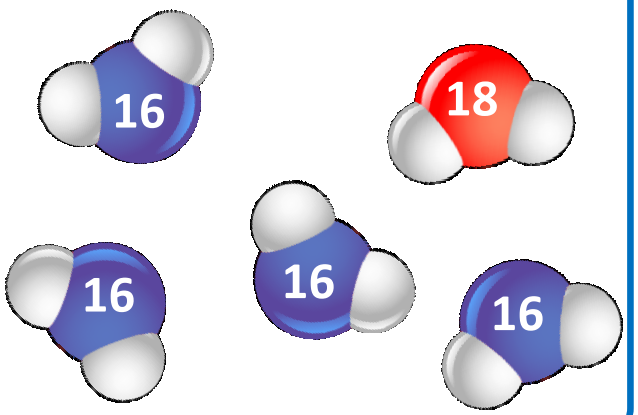
Contents of this presentation

Ice coring

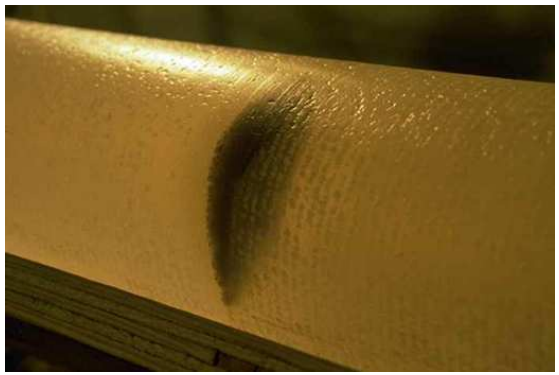


Cross section of the Greenland ice sheet

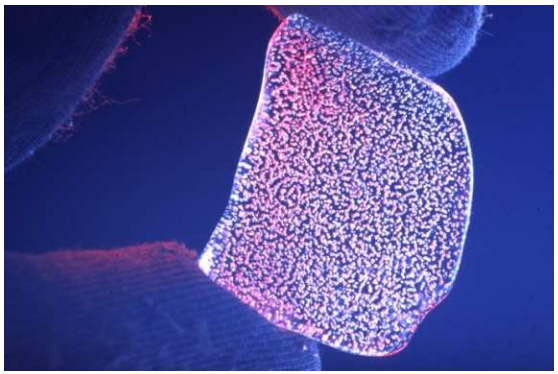
ICE (WATER)



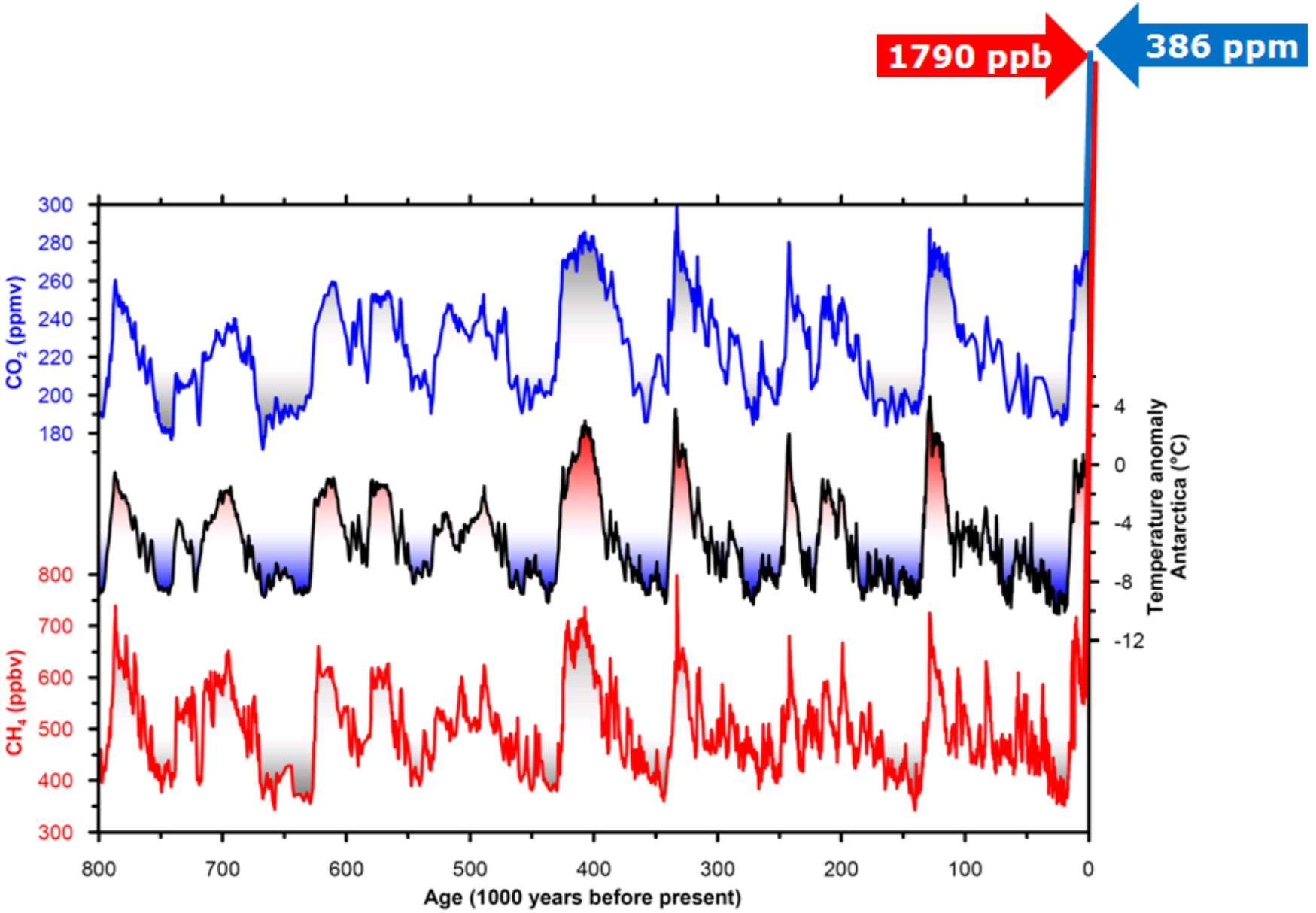
CHEMICALS / DUST



GAS BUBBLES



Reconstructing climate back in time



Dating of ice cores

A combination of dating techniques is commonly used

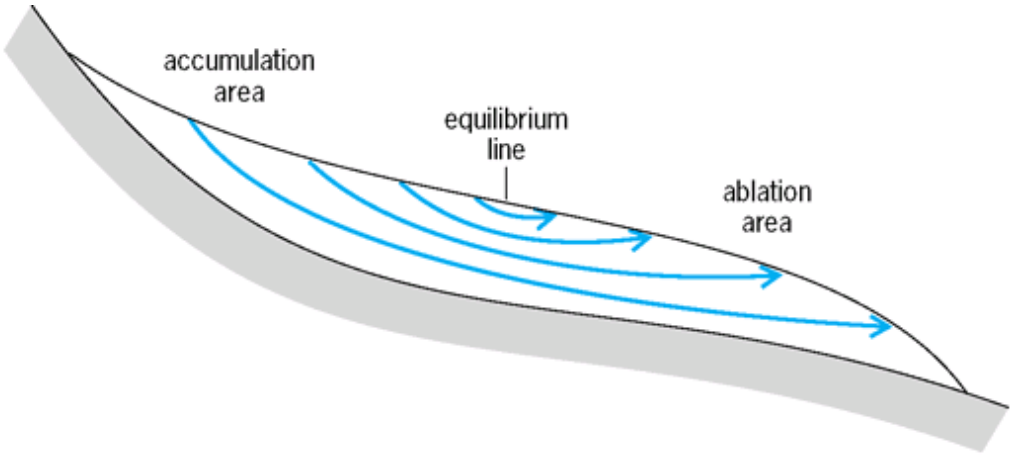
- Annual layer counting
- Ice flow modeling
- Orbital tuning (e.g. using insolation + $\delta O_2/N_2$)
- Fixed tie points (e.g. volcanic deposits)
- Stratigraphic matching to other (ice core) records

Absolute dating tools exist, but are inprecise

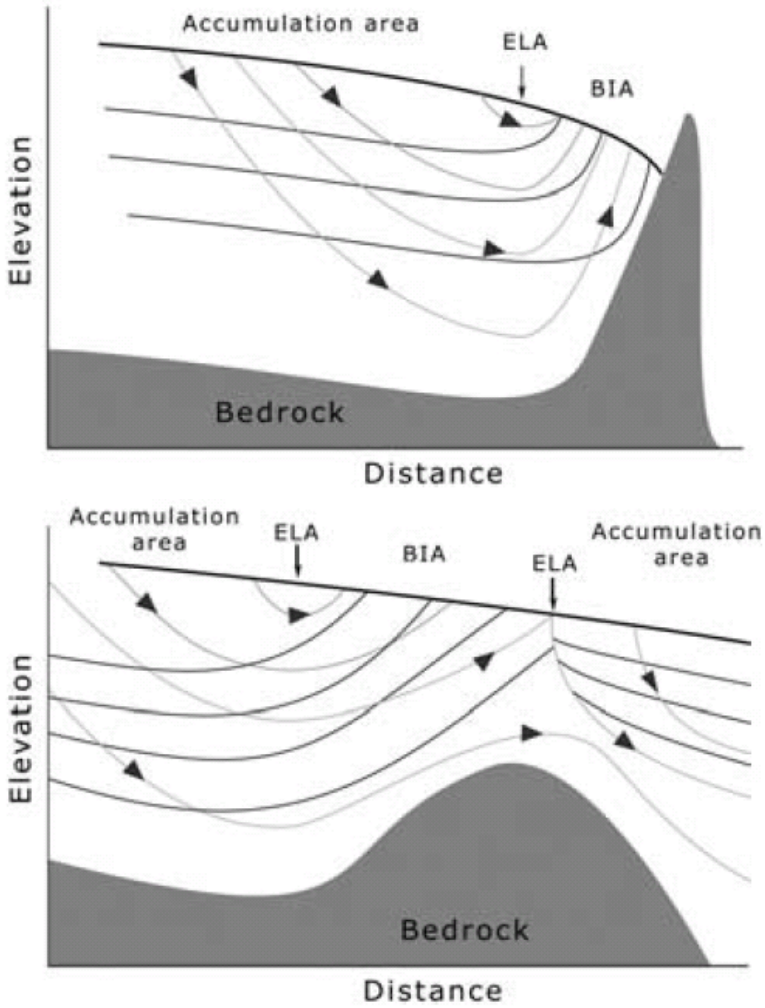
- Radiocarbon dating of CO_2 (suffers from cosmogenic ^{14}C production in ice)
- $\delta^{40}Ar/^{36}Ar$ dating [Bender et al. 2008]
- Recoil accumulation U-series [Aciego et al. 2011]

The poor man's ice core

Margin site



Blue Ice Area



Dating of BIA ice

A combination of techniques is used

- Stratigraphical matching to other (ice core) records (gases, water isotopes)
- Radar isochrones

Radiometric dating methods:

- Radiocarbon dating of CO_2 (suffers from in situ ^{14}C production)
- Radiocarbon dating of organic material [Jenk et al. 2007]
- Tephra layers /meteorite dating [e.g. Dunbar et al. 2008]

Motivation
^{81}Kr radiometric dating of ice

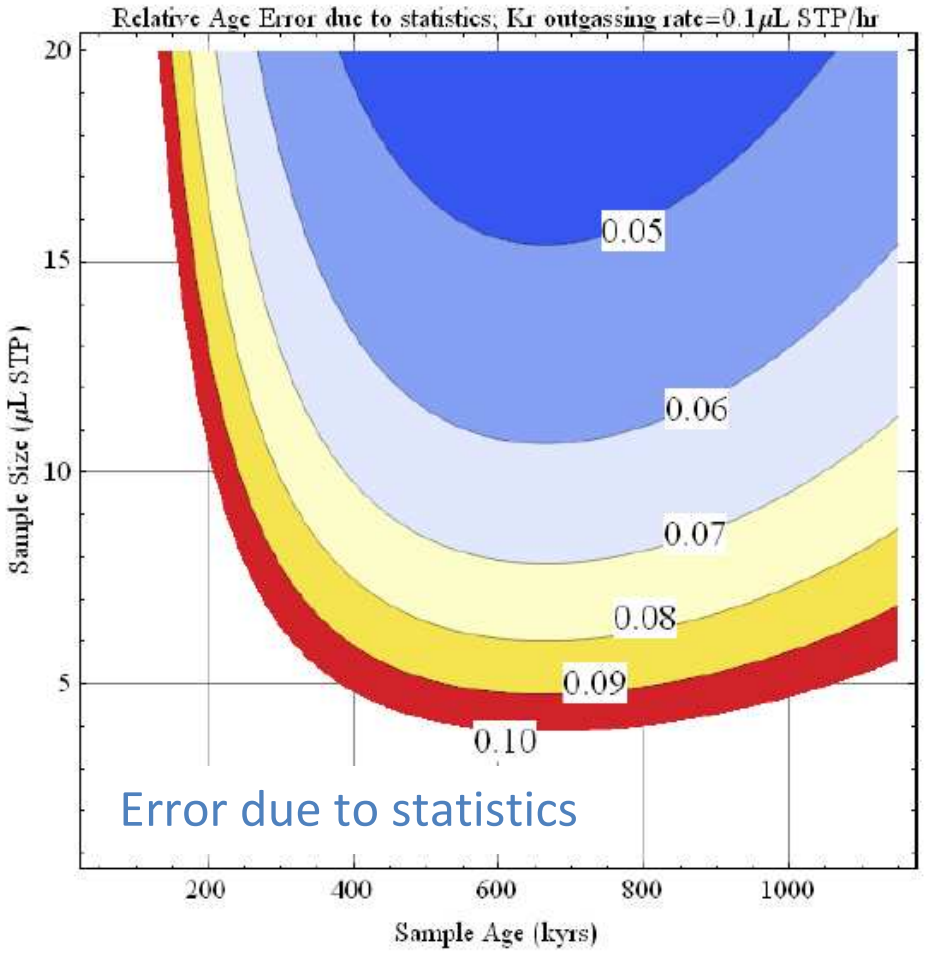
Advantages of ^{81}Kr radiometric dating of ice:

(1) All polar ice contains air bubbles, → widely applicable.
(2) No need for incidental particle inclusions (e.g. tephra)
(3) Does not require a continuous or undisturbed ice stratigraphy
(4) No in situ cosmogenic ^{81}Kr production in ice
(5) Absolute age estimate.

Disadvantage:

(1) SAMPLE SIZE → 100 kg equals 14 m of 4" core. No problem at BIAs!

Motivation
^{81}Kr radiometric dating of ice



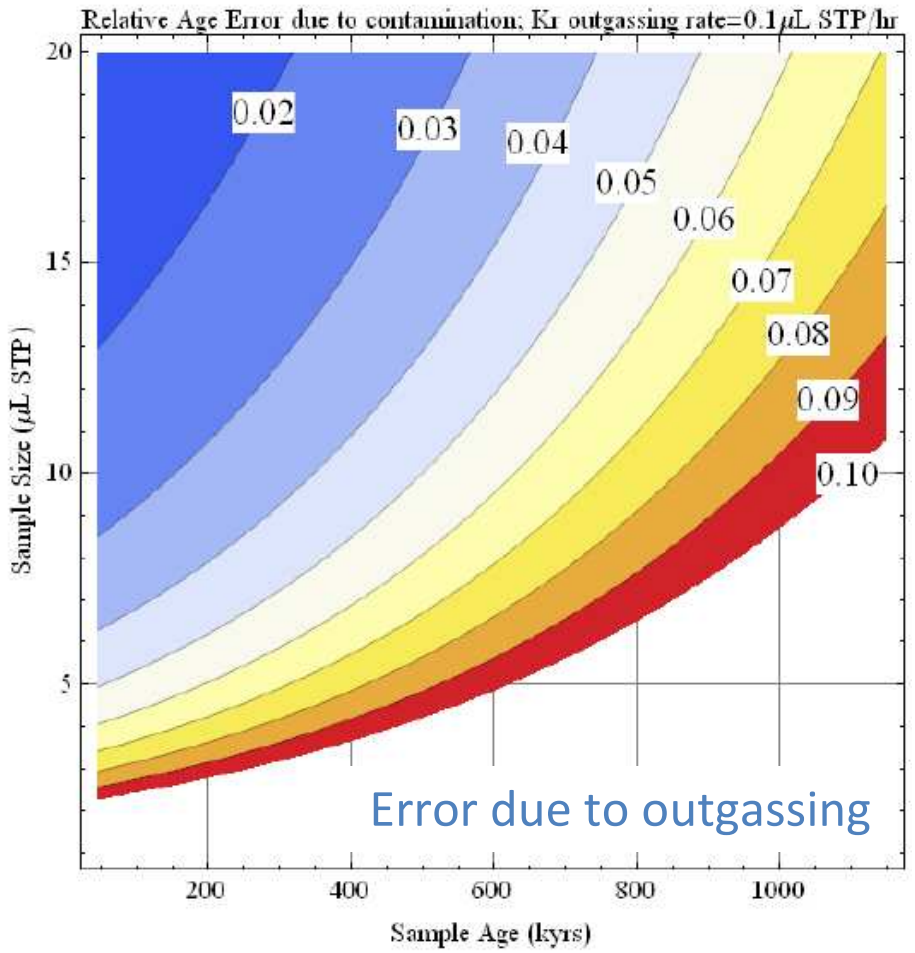
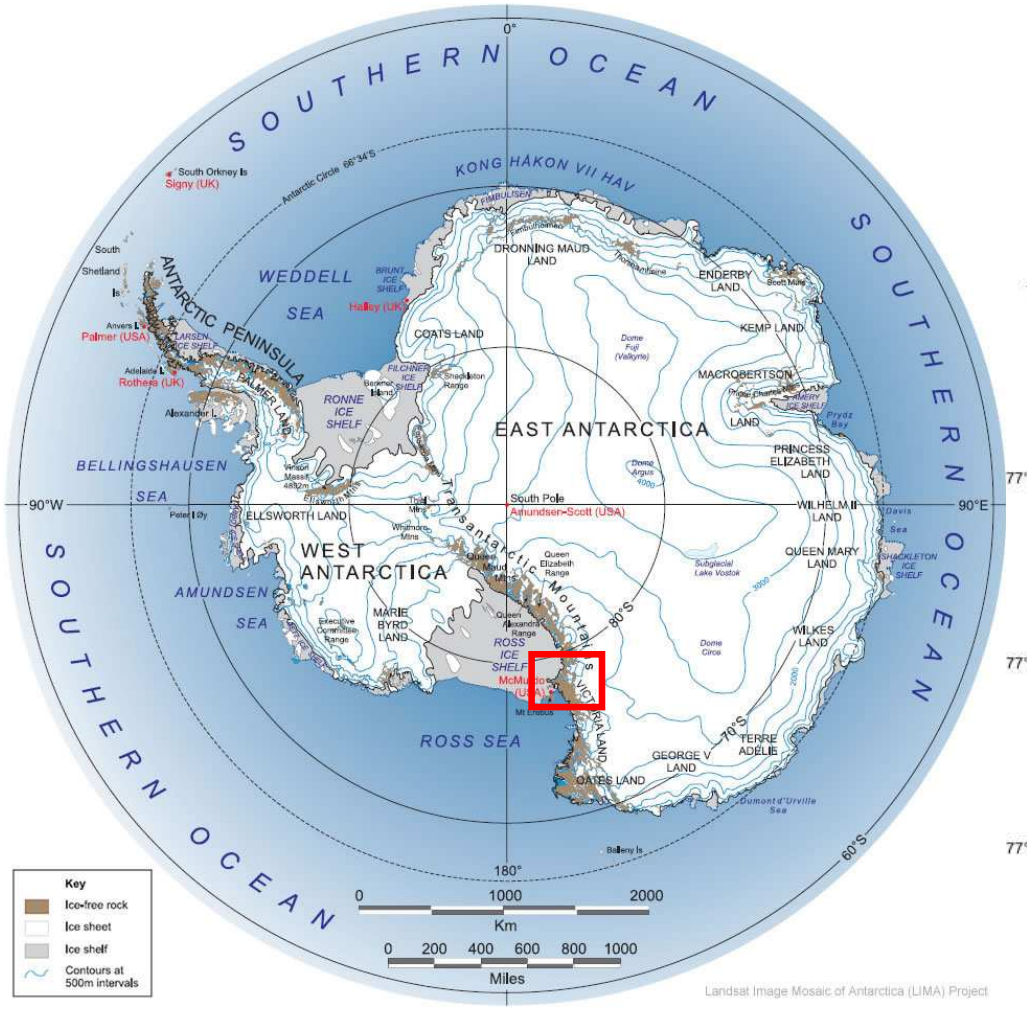


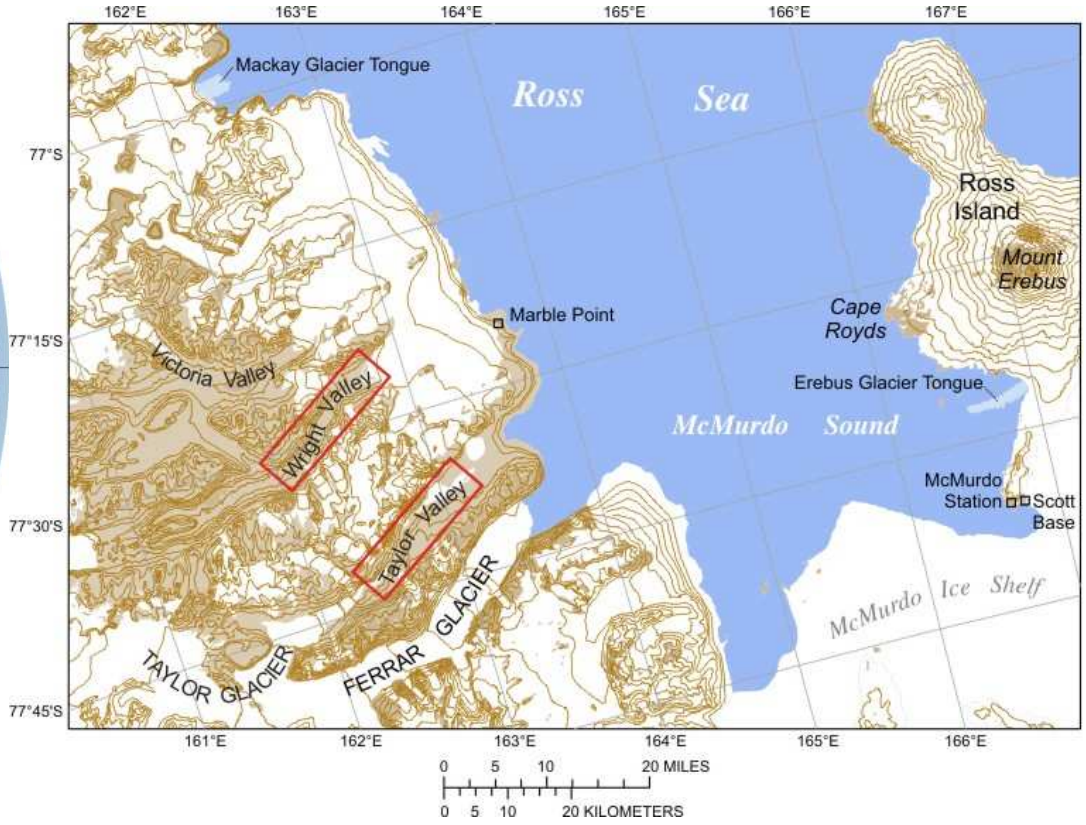
Figure by Zheng-Tian Lu; 4 hour measurement

10 kg of ice gives ~ 1 µL STP Kr

Uncertainty in ^{40}Ar method is 180 ka or 11%, whichever is greater

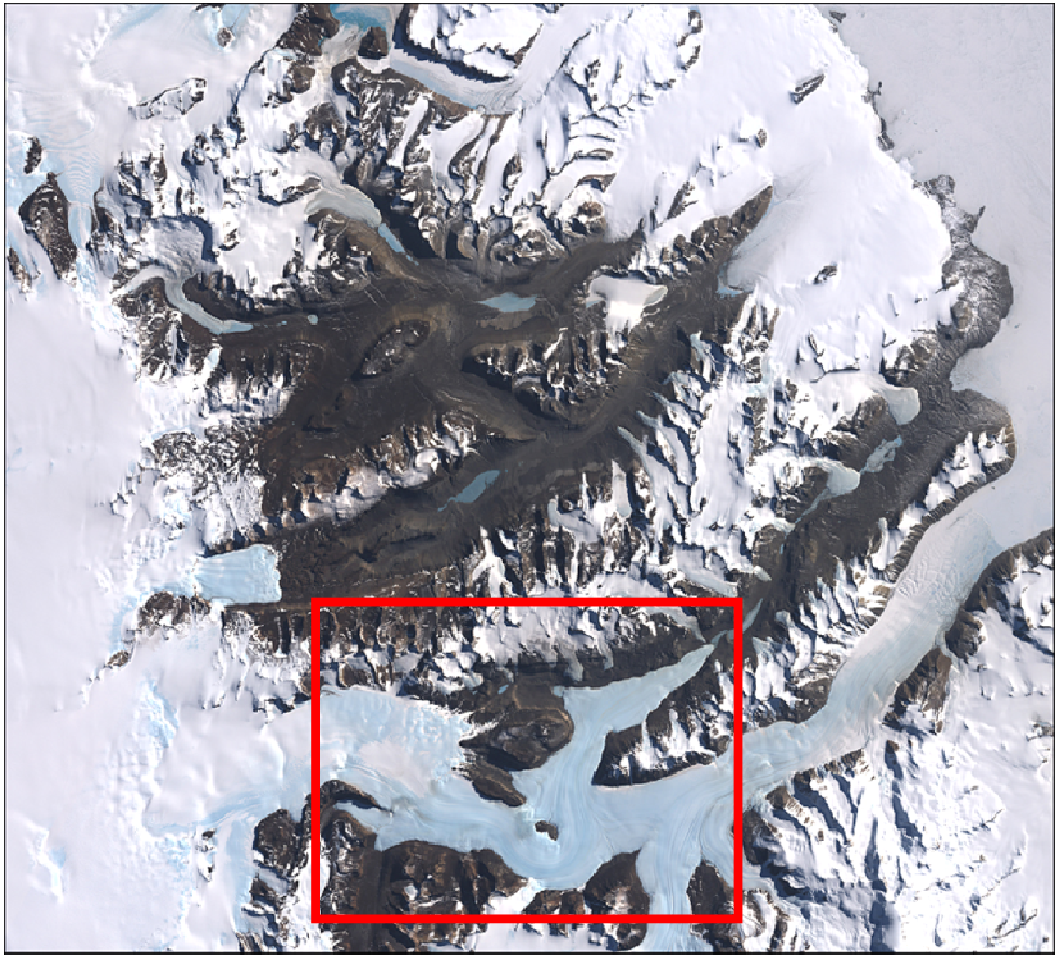
Taylor Glacier
Geographic location

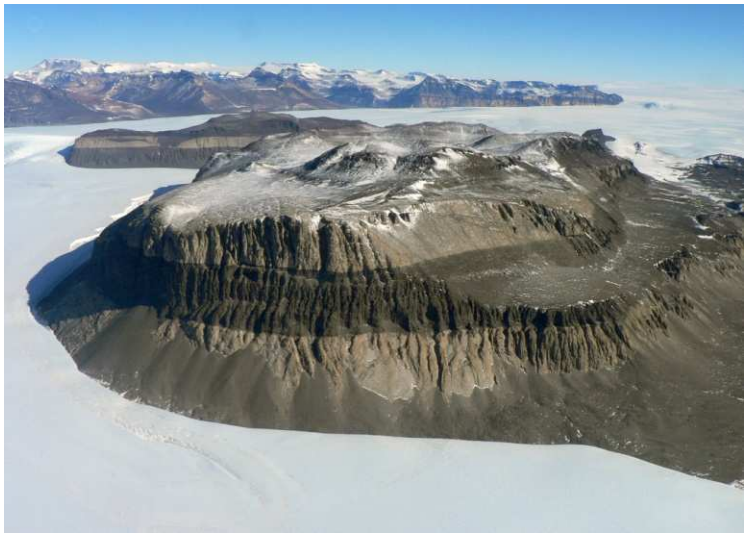




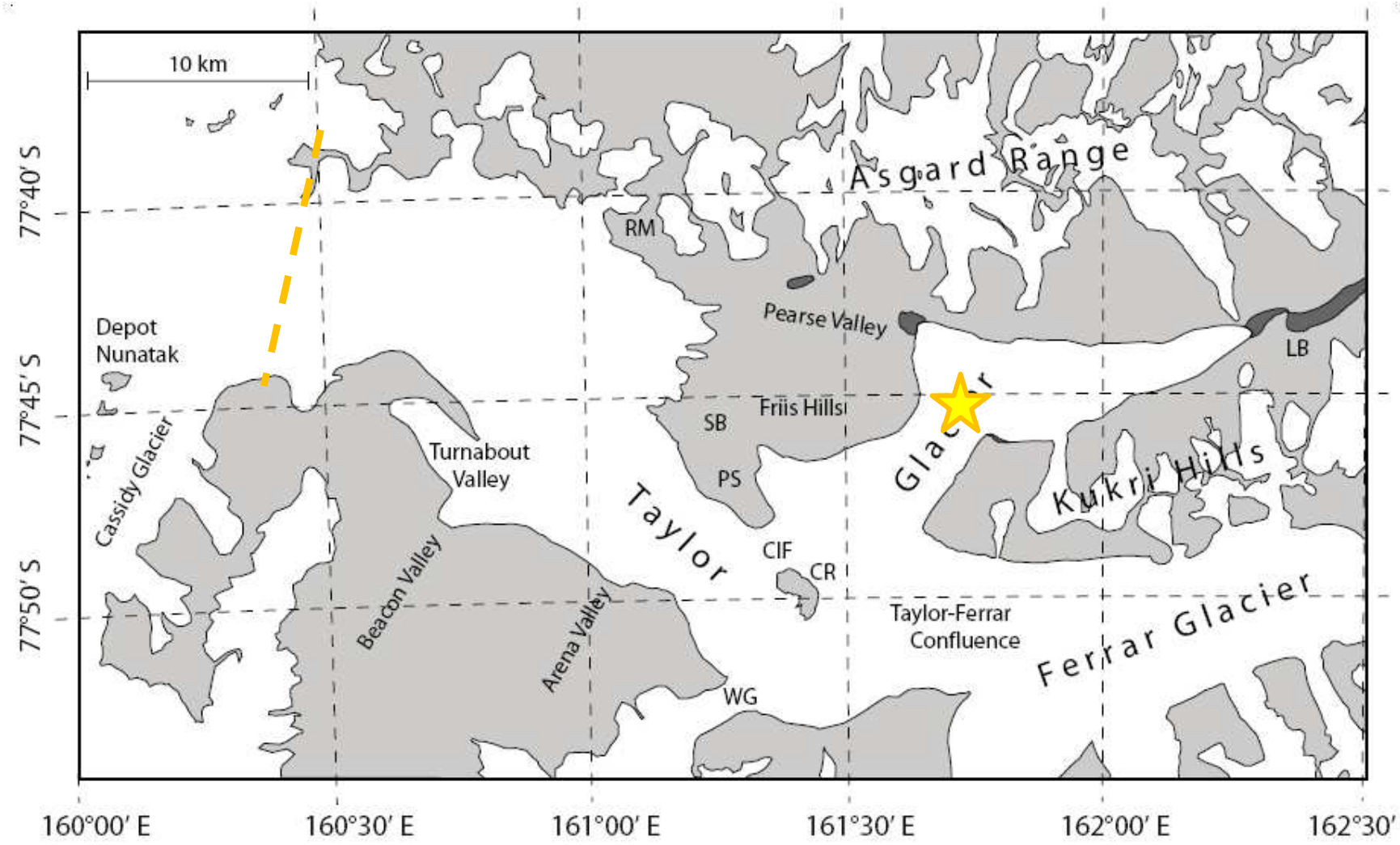
Taylor Glacier

McMurdo Dry Valleys

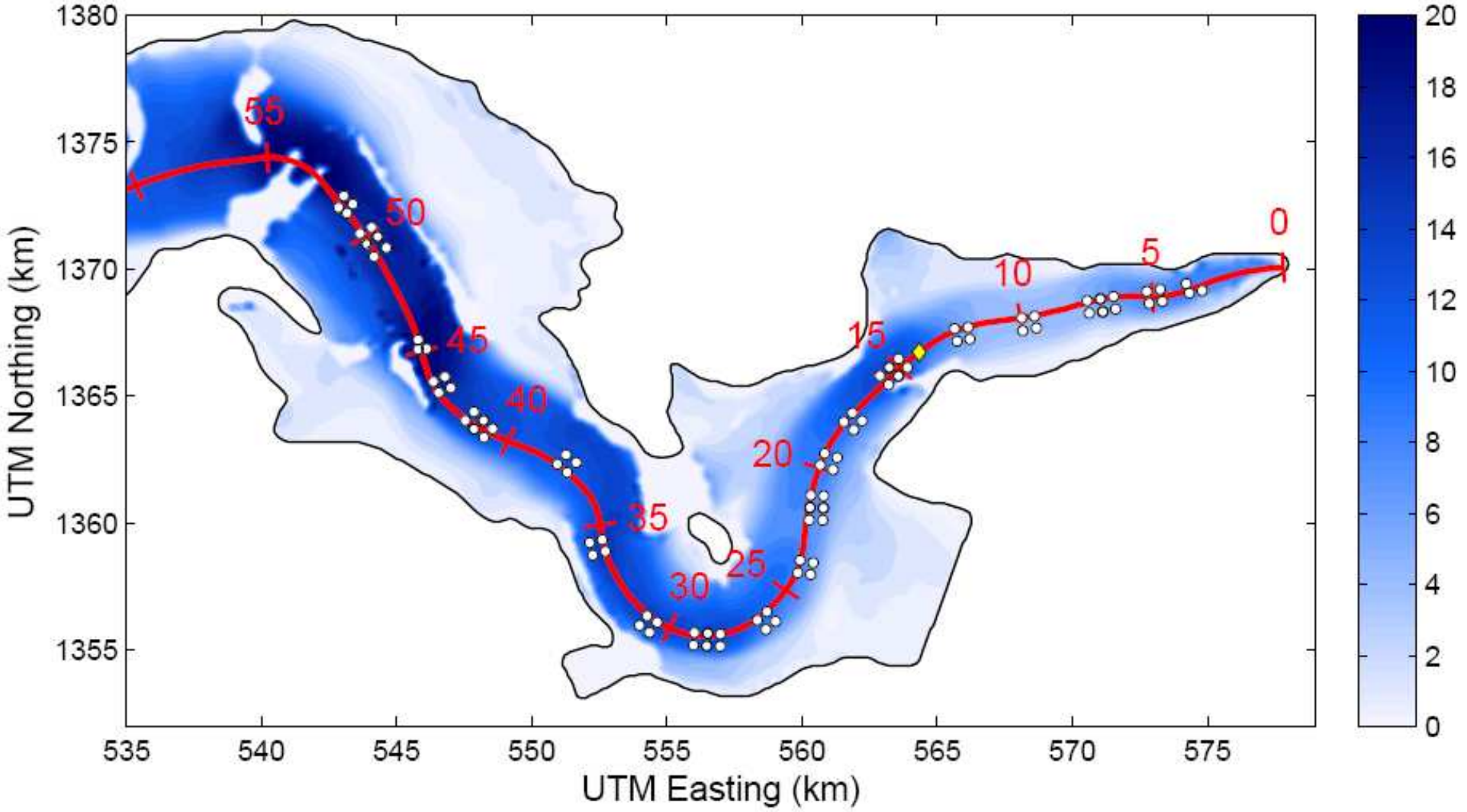




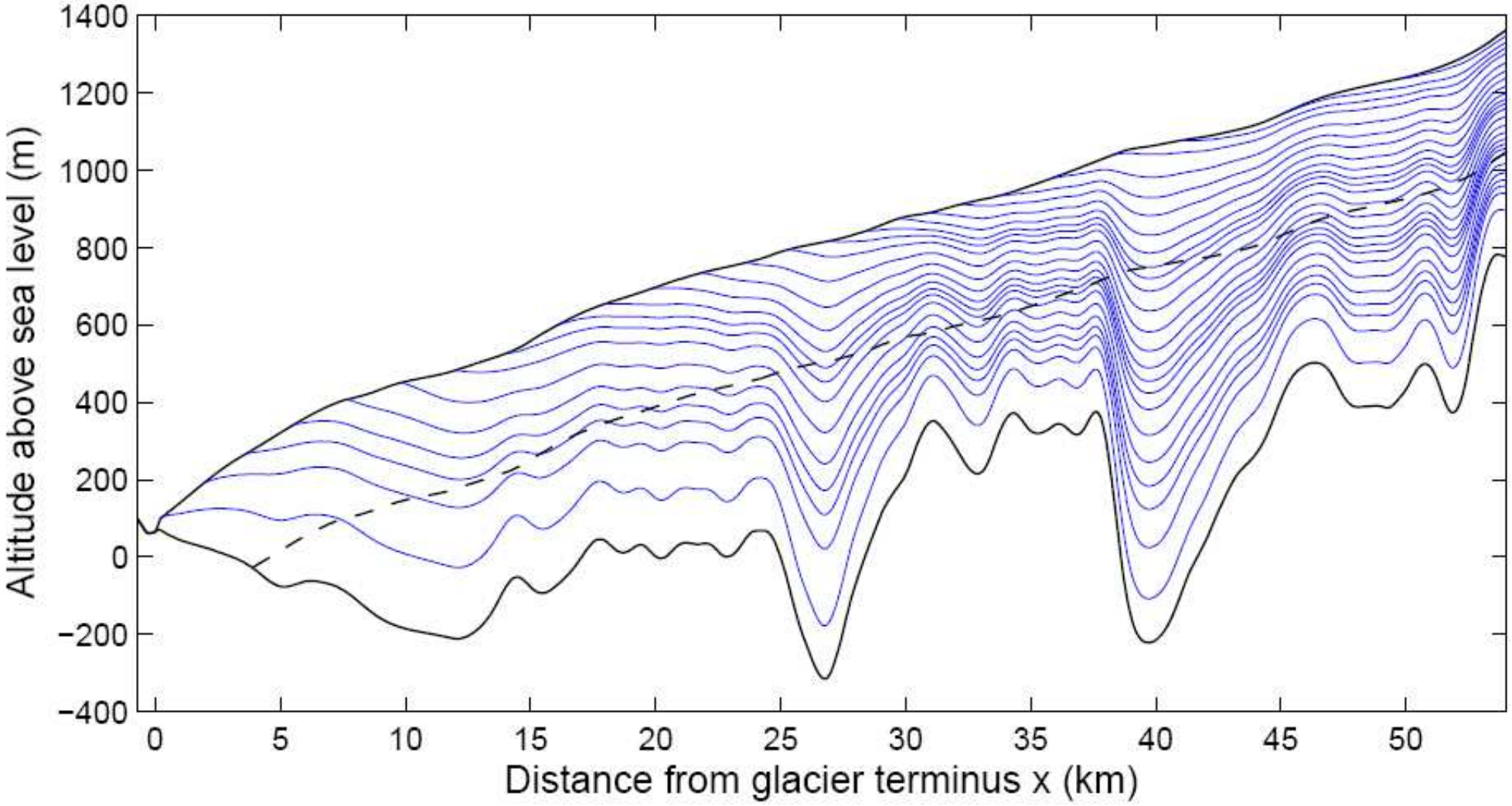
Taylor Glacier geometry



Taylor Glacier flow

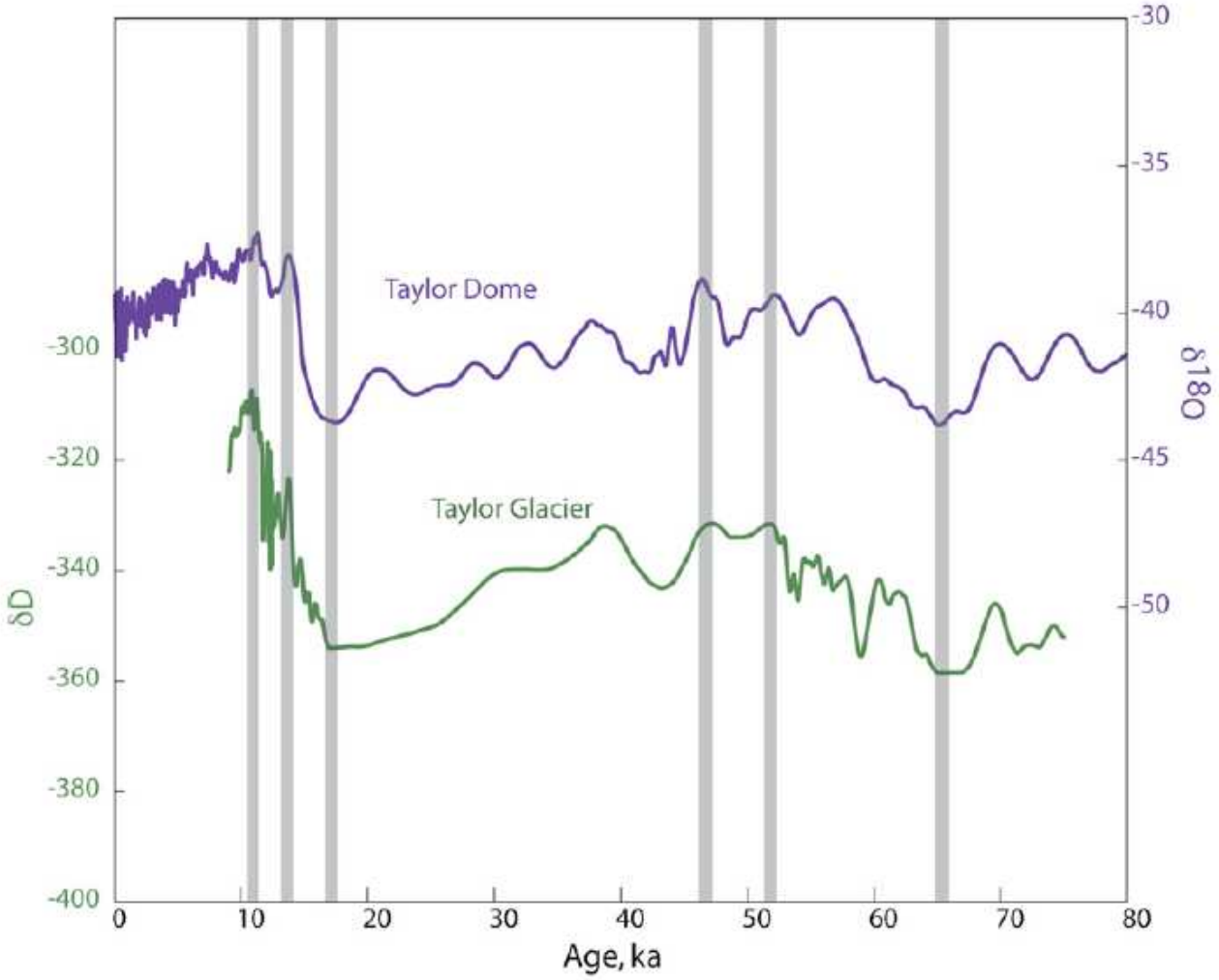


Taylor Glacier flow lines



Dating of Taylor Glacier Ice using Water isotopes

Stratigraphic matching of water stable isotopes to the Taylor Dome ice core record



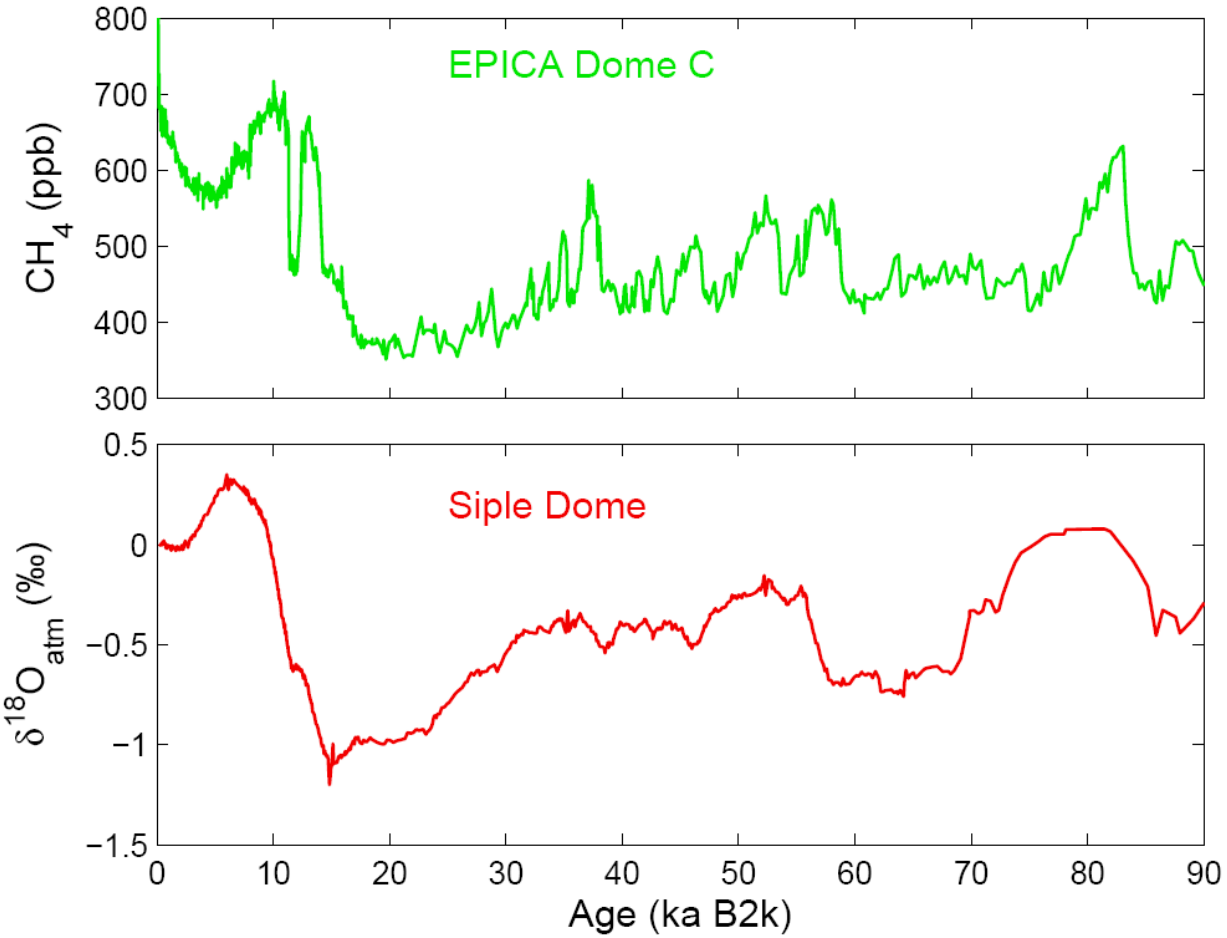
[Aciego et al. Quat. Res. 2007]

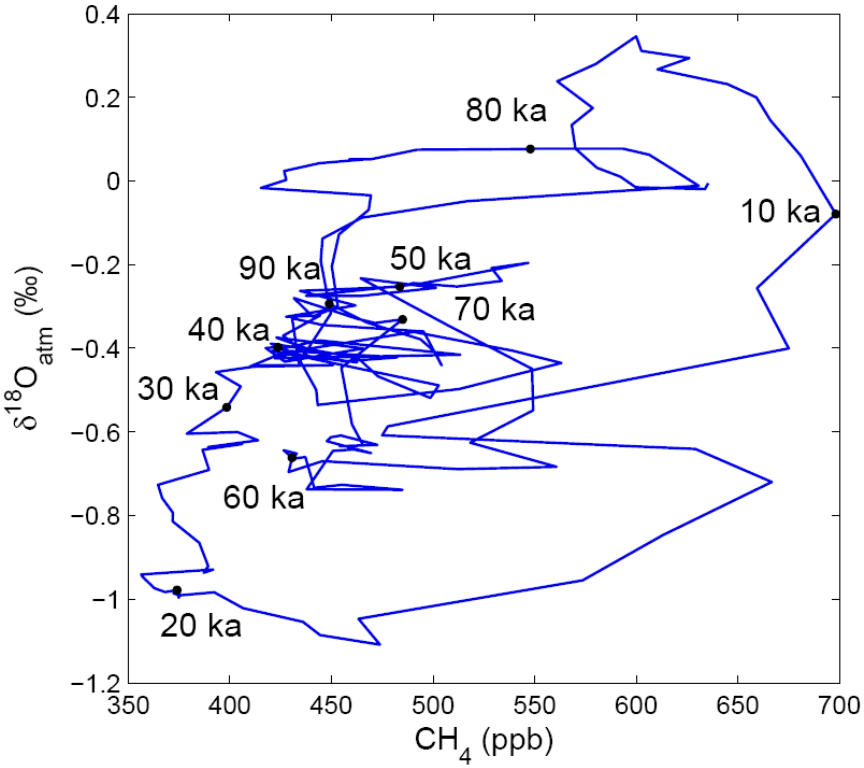
Dating of Taylor Glacier Ice CH_4 and $\delta^{18}O$-O_2

CH_4 changed rapidly in the atmosphere

$\delta^{18}O_{atm}$ (= $\delta^{18}O$ in O_2; the Dole effect) changes gradually

The combination of the two often provides a good age constraint.





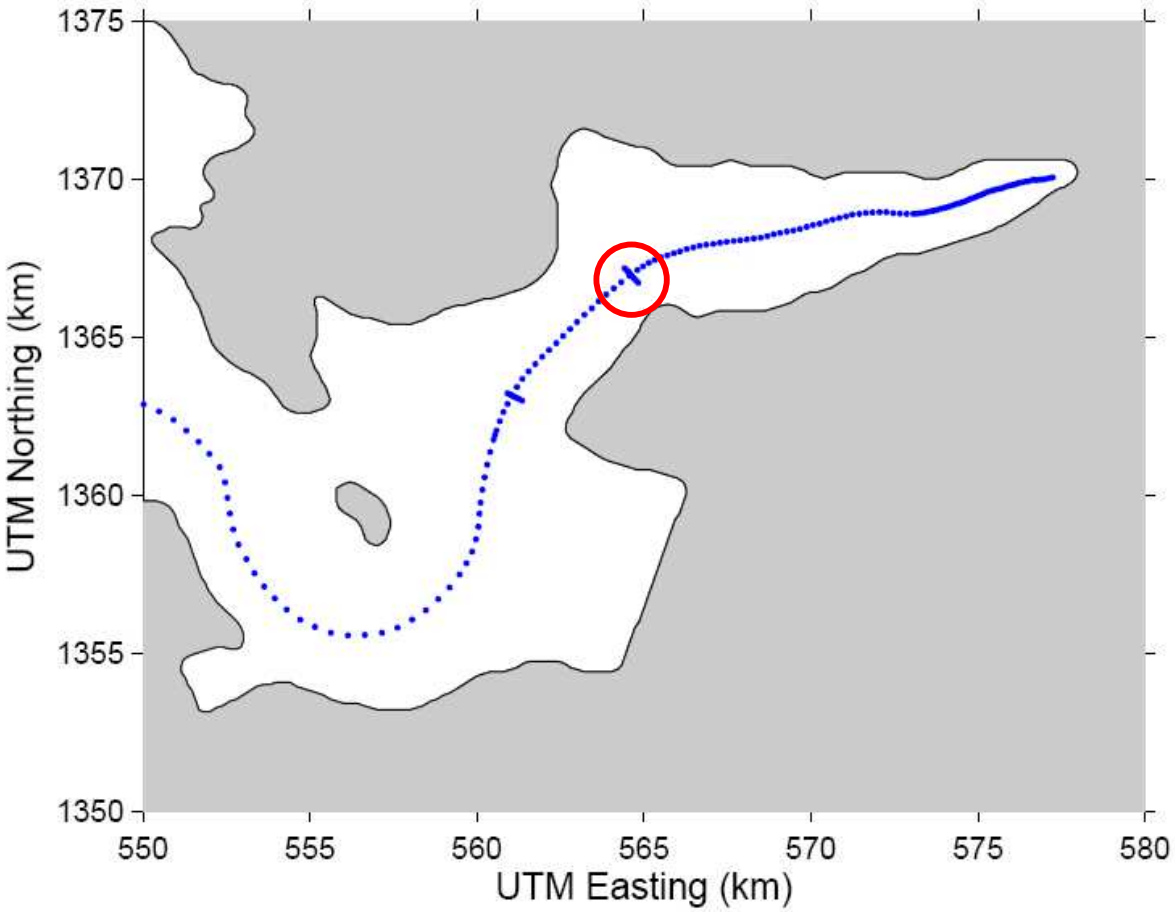
Checklist

Taylor Glacier offers:

- Large quantities of well dated ice
- Large volume melting setup for $^{14}CH_4$ analysis

Dating of Taylor Glacier Ice

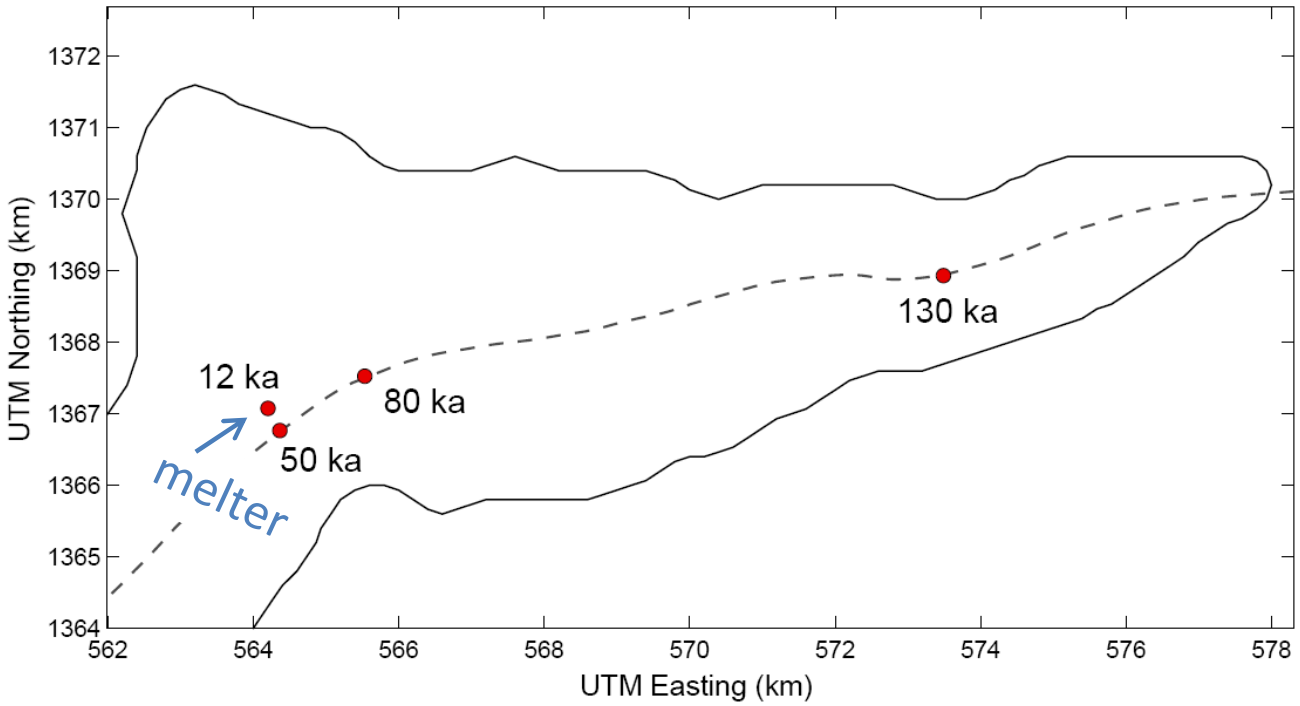
Dating of Taylor Glacier ice using gas stratigraphic matching is PhD work of Daniel Baggenstos (Scripps)
Longitudinal profile and several transects



Sample overview

2011-2012 Field season:

- Four ice samples: approx. 12, 50, 80 and 130 ka
- One atmospheric control sample to check contamination (^{85}Kr).
- 12 ka sample is too young for reliable dating; serves as a check on in situ production in ice.
- Possibility putative 130 ka sample is from T_1 rather than T_2



Drilling ice samples

Top ~5 m of the ice is cracked due to diurnal / seasonal temperature cycle.

Samples are obtained from a single ice core, 5-15 m depth.

Large diameter (24 cm) ice drill (ICDS, Univ. Wisconsin-Madison).

Each sample ~ 350 kg of ice (30 µL Kr)

Sample transportation

Samples needed to be transported over distances up to 10 km
Special ”Ice core burrito” was developed for transport behind skidoo
Drilling and transport done in shade of Kukri Hills

Sample transportation pt 2: meltwater

Oldest sample (Termination II) drilled between two meltwater streams

Air extraction in large volume Melter

Ice core is loaded in large volume melter setup
The sample is melted under vacuum
Air is re-circulated for 30 minutes for equilibration
Air is collected in 35 L flasks (electropolished stainless steel).

[Petrenko et al. J. Glaciol. 2008]

Summary & Conclusions

Radiometric dating of old ice:

- ^{81}Kr is a promising technique for dating ancient ice
- Currently applicability is limited by sample size
- BIAs provide large amounts of accessible ancient ice; dating of BIA ice is challenging.

This pilot study:

- We sampled well-dated Taylor Glacier blue ice
- Four 350 kg samples with ages 10, 50, 80 and 130 ka obtained
- We have one atmospheric control sample
- Samples currently with Roland, analysis underway