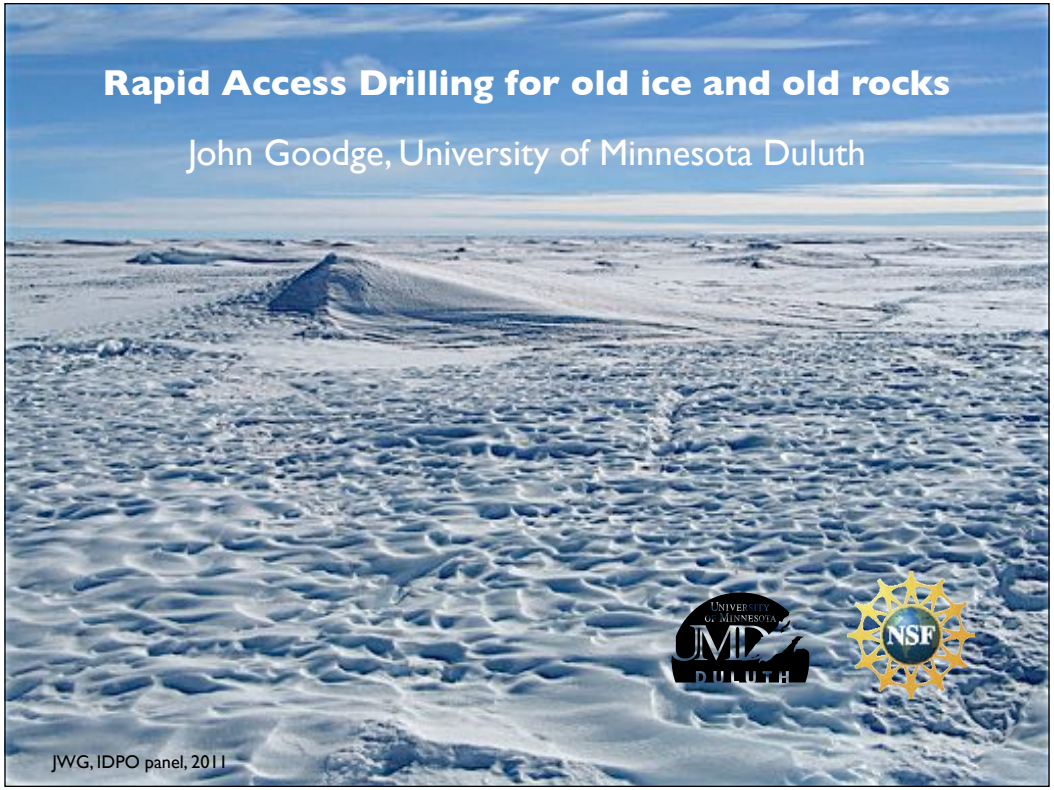
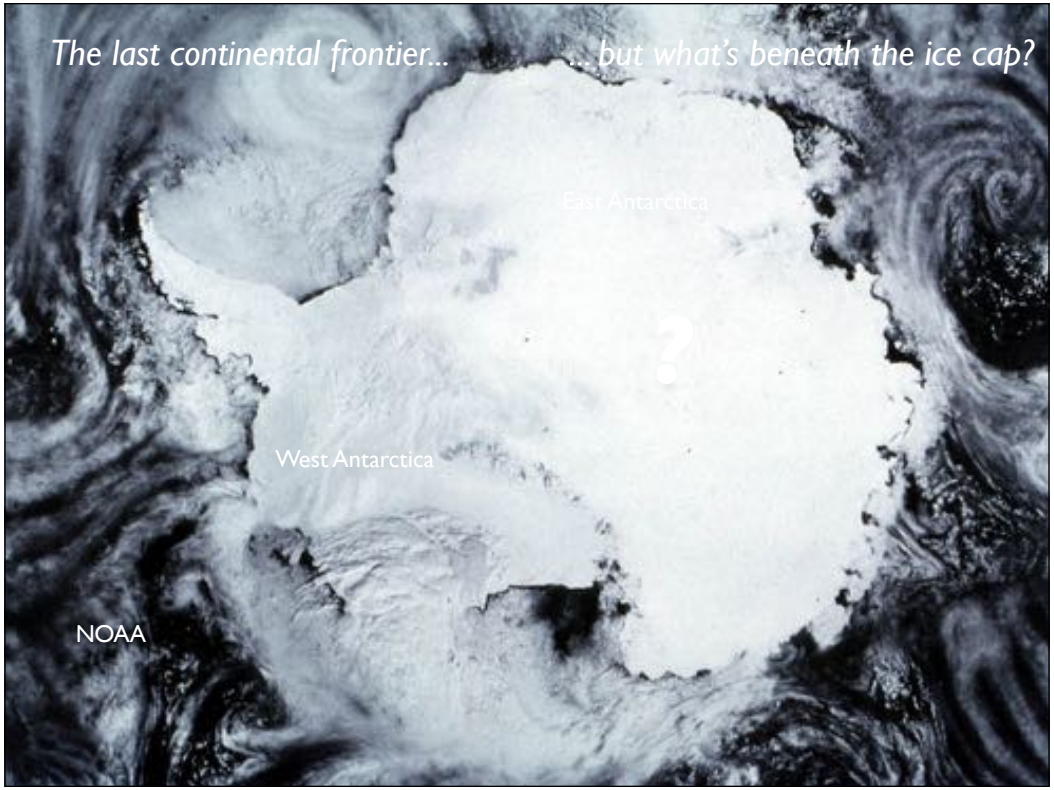
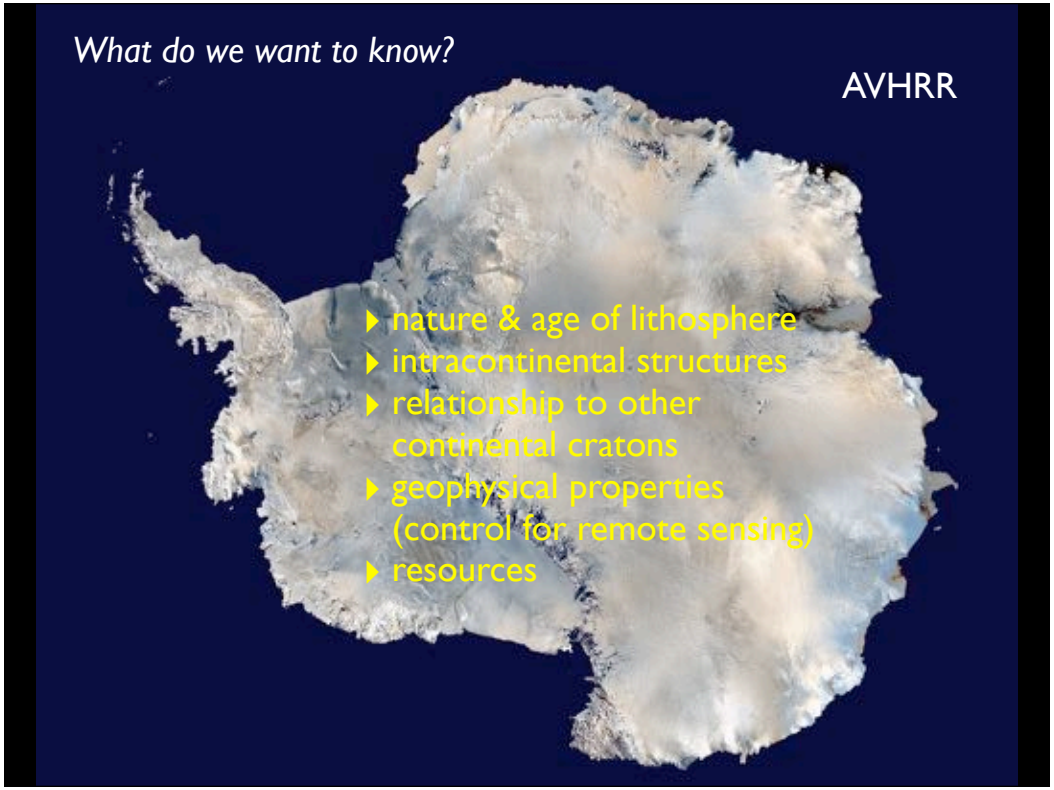
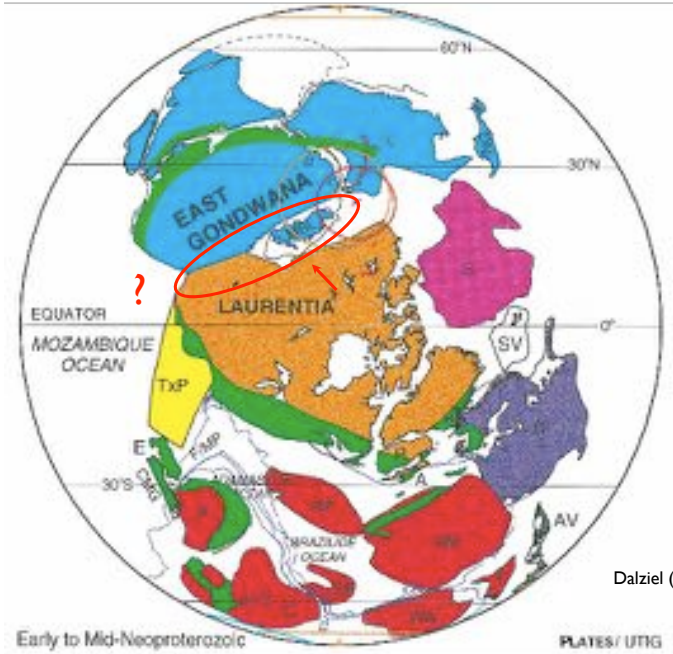

Rapid Access Drilling for old ice and old rocks
John Goodge, University of Minnesota Duluth
JWG, IDPO panel, 2011


The last continental frontier...
... but what's beneath the ice cap?
East Antarctica
?
West Antarctica
NOAA

... it's probably complex ...


What do we want to know?
AVHRR
nature & age of lithosphere
intracontinental structures
relationship to other continental cratons
geophysical properties (control for remote sensing)
resources

East Antarctica & supercontinents

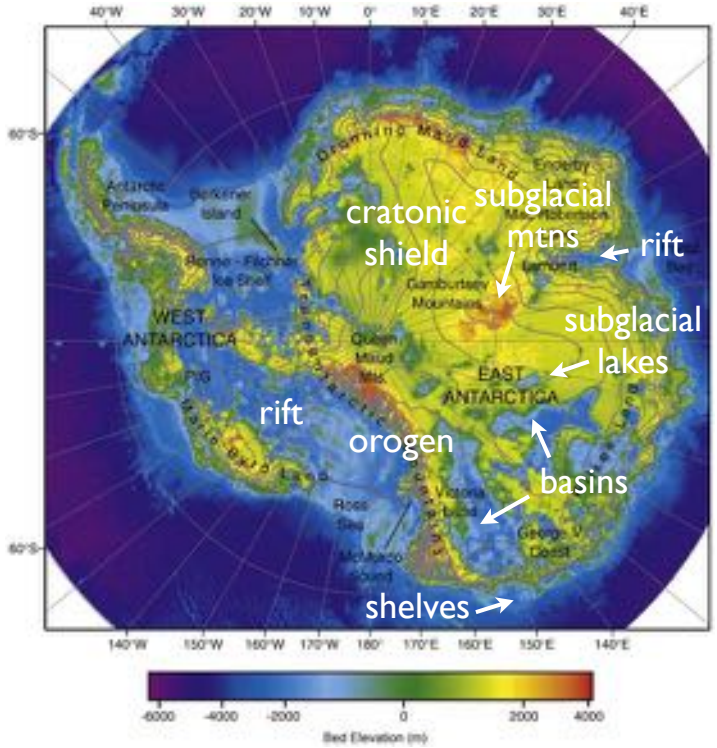


- long-lived association with other cratons (since >1 byr)
- what did supercontinents look like?
- when formed? breakup? how?
- how related to emergence of life?

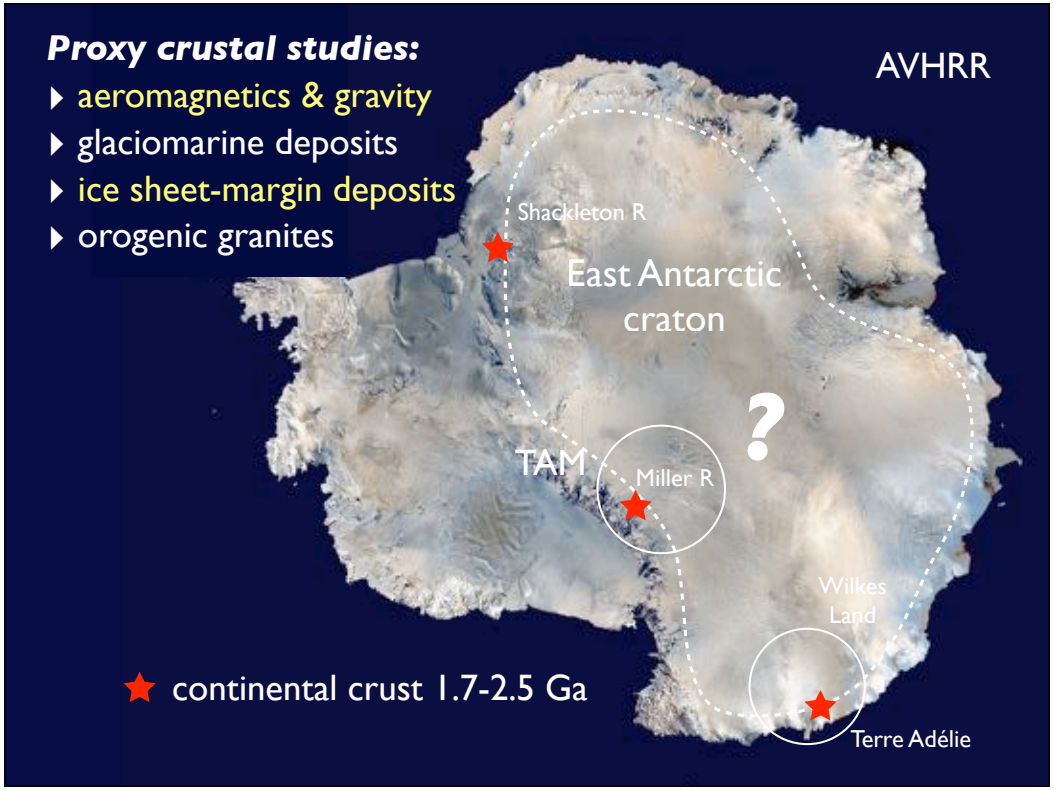
Dalziel (*GSA Bulletin*, 1997)

Sub-ice topography

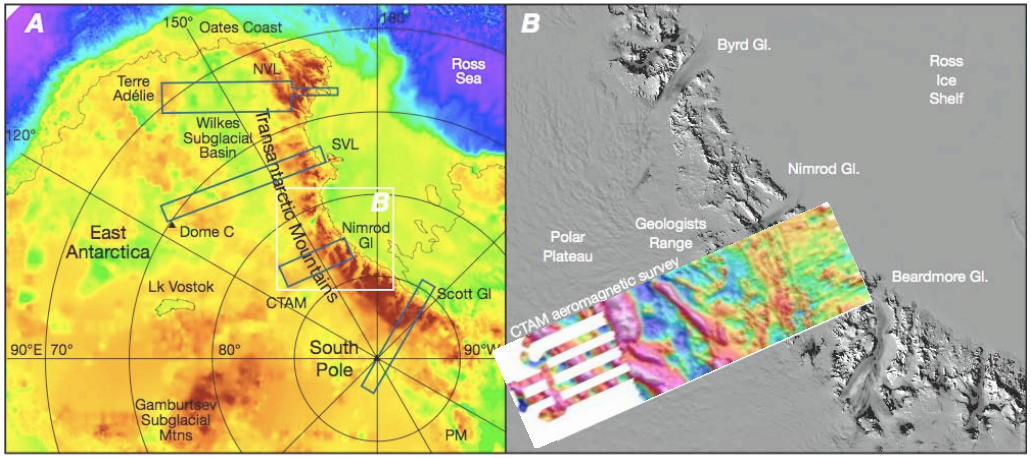
- what tectonic features?
- setting of subglacial lakes?
- what condition of ice bed?
- where/how did ice sheet grow?



Jamieson et al. (*EPSL*, 2010)


Proxy crustal studies:
aeromagnetics & gravity
glaciomarine deposits
ice sheet-margin deposits
orogenic granites
AVHRR
Shackleton R
East Antarctic craton
?
TAM
Miller R
Wilkes Land
continental crust 1.7-2.5 Ga
Terre Adélie

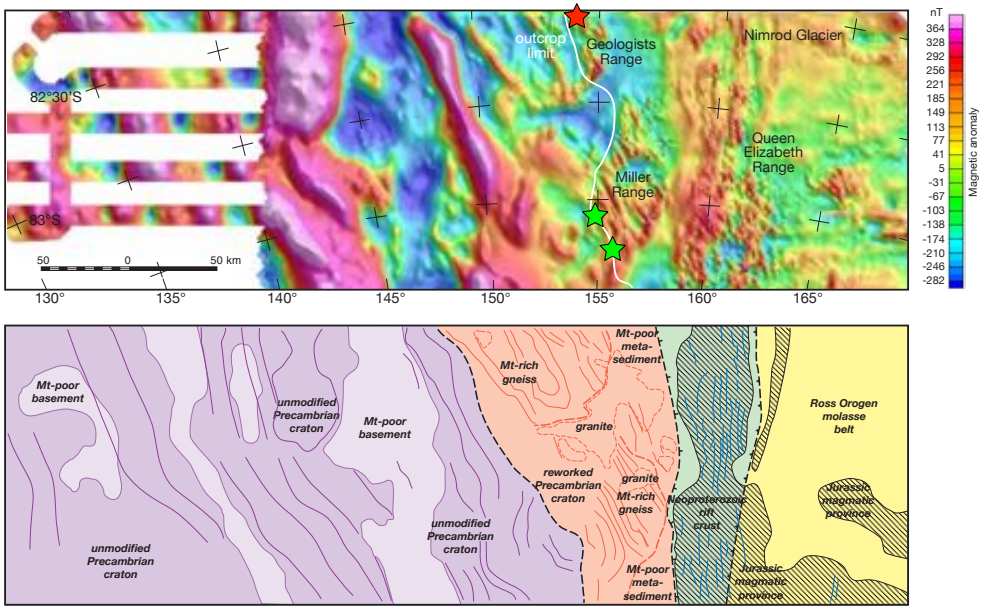
Sub-ice aeromagnetic mapping (2003-04)



Goodge & Finn (*JGR*, 2010)

Source of high-amplitude mag anomalies?

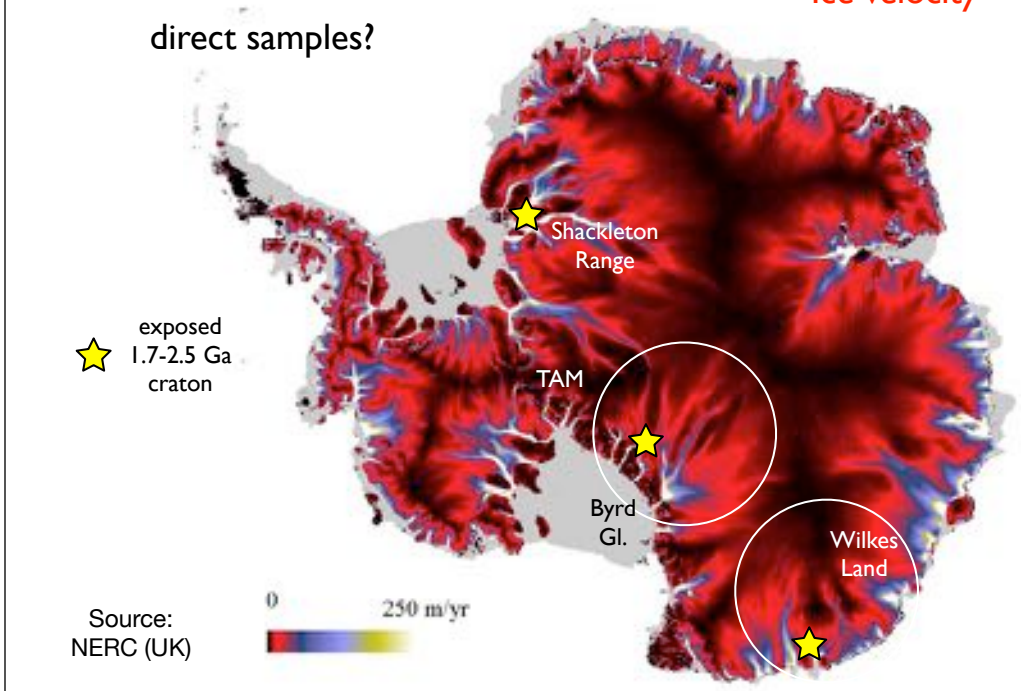
★ 1.1 Ga orthogneisses ★ 1.4 Ga rapakivi granites



Goodge & Finn (*JGR*, 2010)

Ice-sheet margin deposits

direct samples?



Large glacial clasts

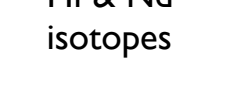
- petrology
- geochemistry
- metamorphic P-T
- geochronology
- isotope geochemistry


Turret Nunatak
TNQ

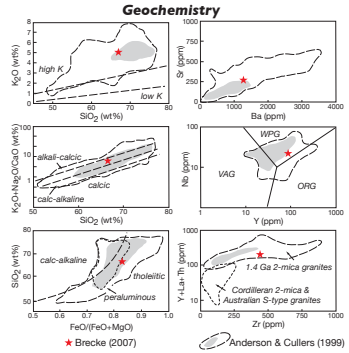
TNQ matches to Laurentia

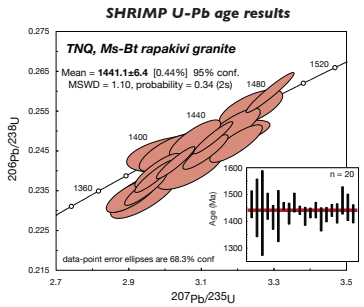
2-mica, A-type rapakivi granite

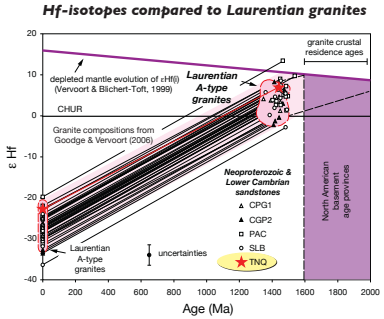
- texture
- mineralogy
- geochemistry
- U-Pb age
- Hf & Nd isotopes

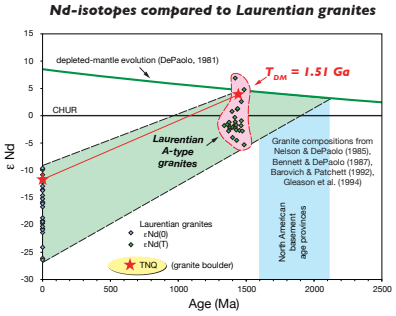


Goodge et al. (*Science*, 2008)

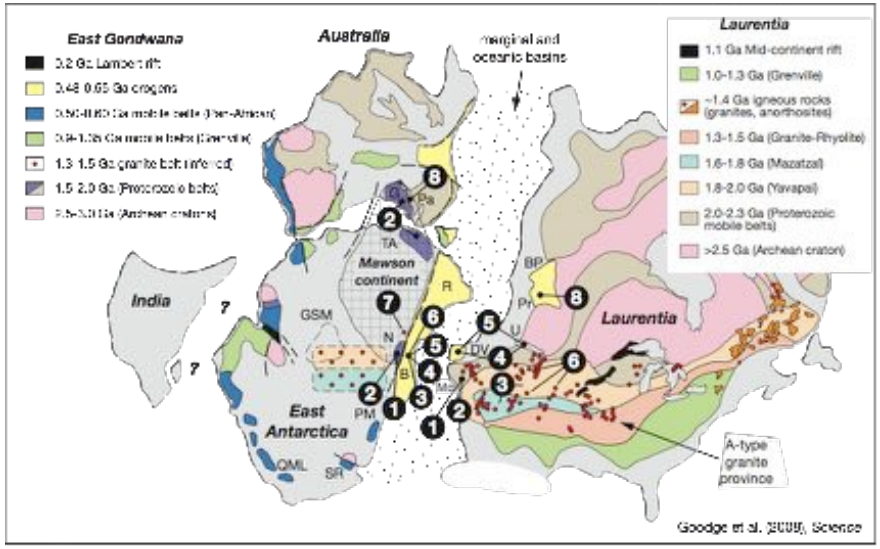






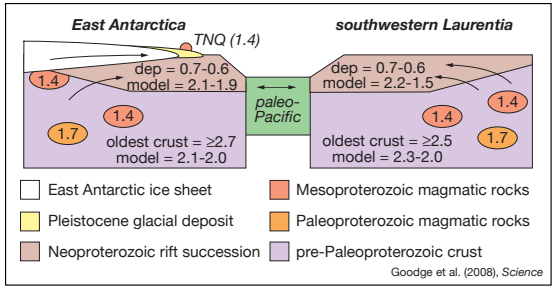


SWEAT model of central Rodinia



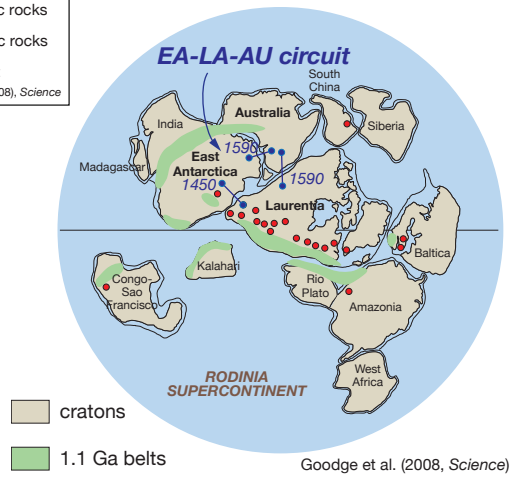
1. Nd-isotope basement model ages
2. ~1.7 Ga orogenesis & magmatism
3. 1.8–1.4 Ga detrital zircon provenance
4. Nd-isotope signature in rift-margin sediment
5. ~0.7 Ga rift-margin sedimentation
6. ~1.4 Ga Laurentian Hf-isotope signature
7. glacial clast of ~1.4 Ga rapakivi A-type granite
8. sediment with Gawler age & Hf signature

SWEAT model of central Rodinia



8 different crustal signatures,
TNQ is the linch-pin

cratonic nucleus of Rodinia,
assembled & extant by
at least ~1.4 Ga



Goodge et al. (2008, *Science*)

Glacial evidence of Proterozoic magmatic province

- multiple clasts
- proximal source
- familiar ages:

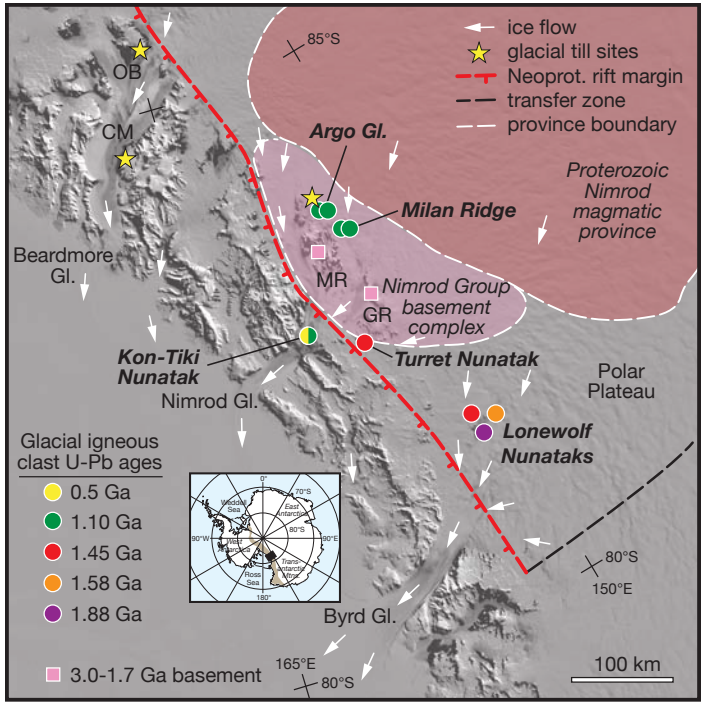
1.1 Ga
(Grenville Province, TX)

1.4 Ga
(granites, CA, AZ)

1.58 Ga
(orthogneiss, ID)

1.88 Ga
(orthogneiss, ID)

Goodge et al. (*J Geology*, 2010),
Goodge & Finn (*JGR*, 2010)



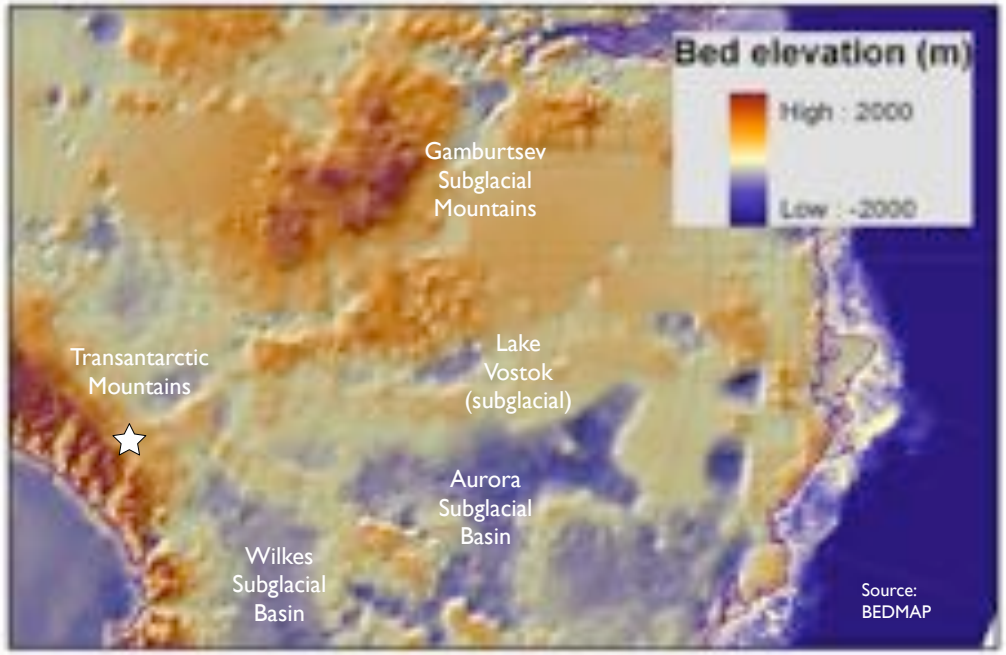

Camp Ridge, Miller Range
Compare to known crust of East Antarctica


What do we want to know
about ice-covered lithosphere?
composition
structure & fabric
age(s)
density
magnetic suceptibility
seismic velocity & anisotropy
heat production & heat flow
direct observation


What do we want to know
about ice-covered lithosphere?
composition
structure & fabric
age(s)
density
magnetic suceptibility
seismic velocity & anisotropy
heat production & heat flow
control for
remote sensing

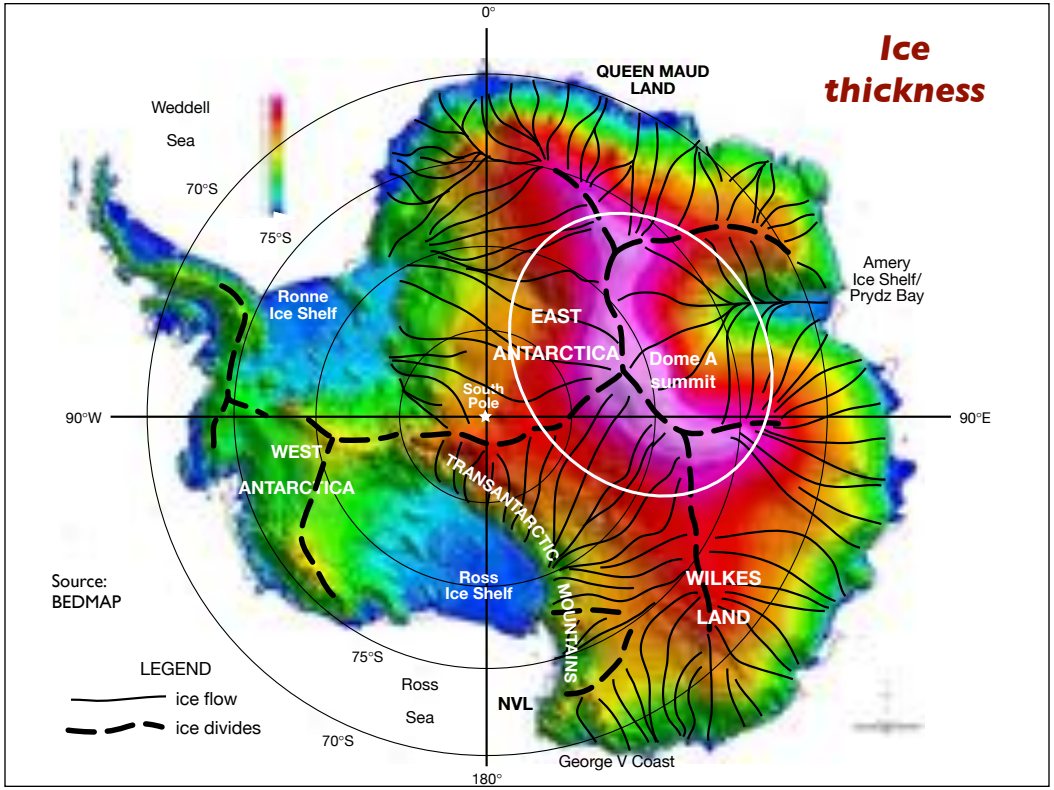

What do we want to know
about ice-covered lithosphere?
composition
structure & fabric
age(s)
density
magnetic suceptibility
seismic velocity & anisotropy
heat production & heat flow
ice sheet interface

Where do we want to look?

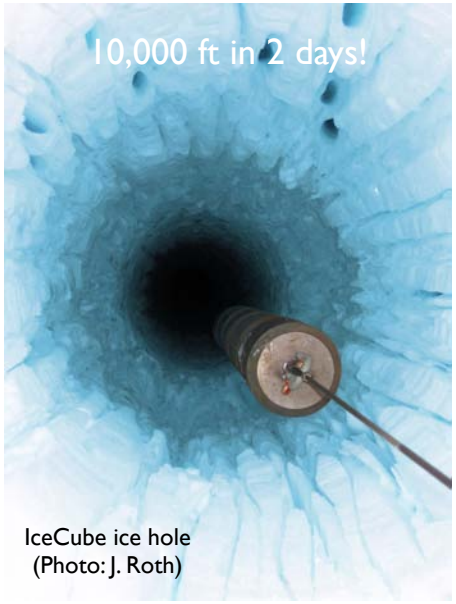


Scientific rationale for 1.5 Myr ice record

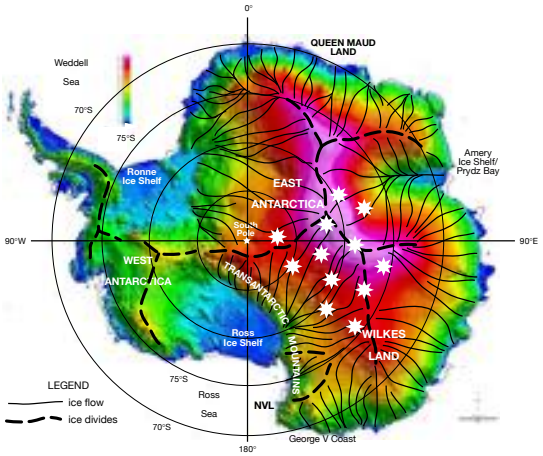
EPICA Dome C ice core, Lüthi et al. (2008); Lisiecki and Raymo (2005)


Ice thickness
0°
QUEEN MAUD LAND
Weddell Sea
70°S
75°S
Amery Ice Shelf/ Prydz Bay
Ronne Ice Shelf
EAST ANTARCTICA
Dome A summit
South Pole
90°W
90°E
WEST ANTARCTICA
TRANSANTARCTIC MOUNTAINS
Ross Ice Shelf
WILKES LAND
Source: BEDMAP
LEGEND
ice flow
ice divides
75°S
Ross Sea
NVL
70°S
George V Coast
180°

Next step?

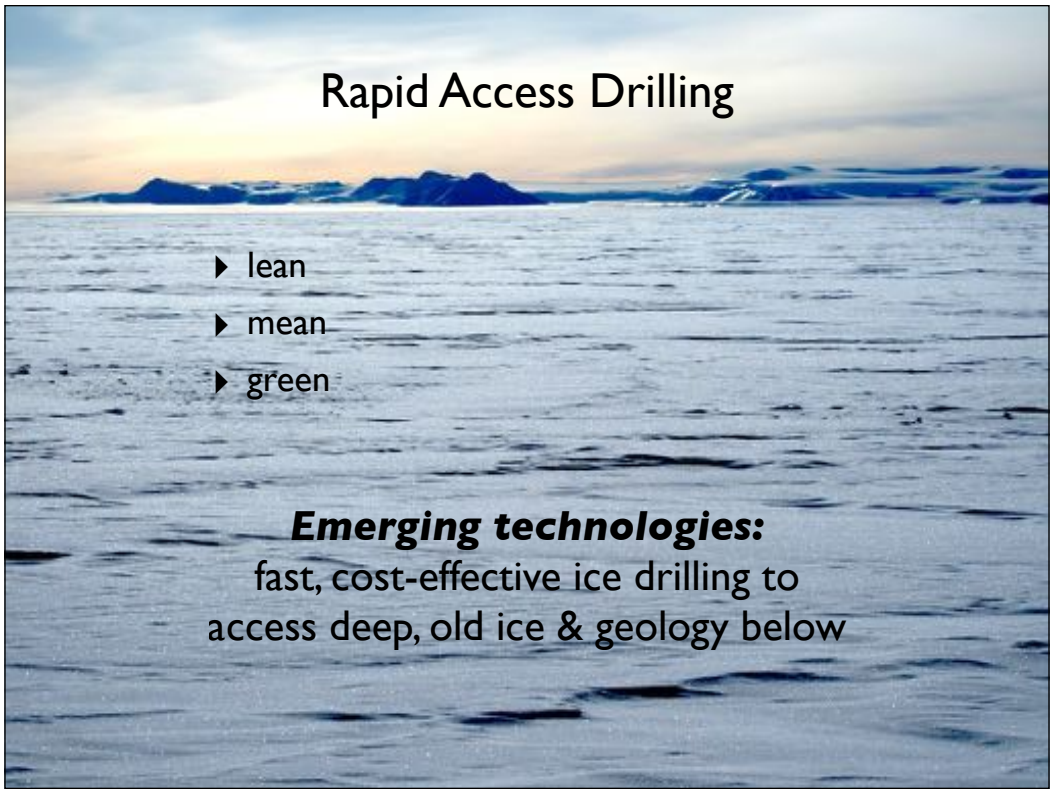


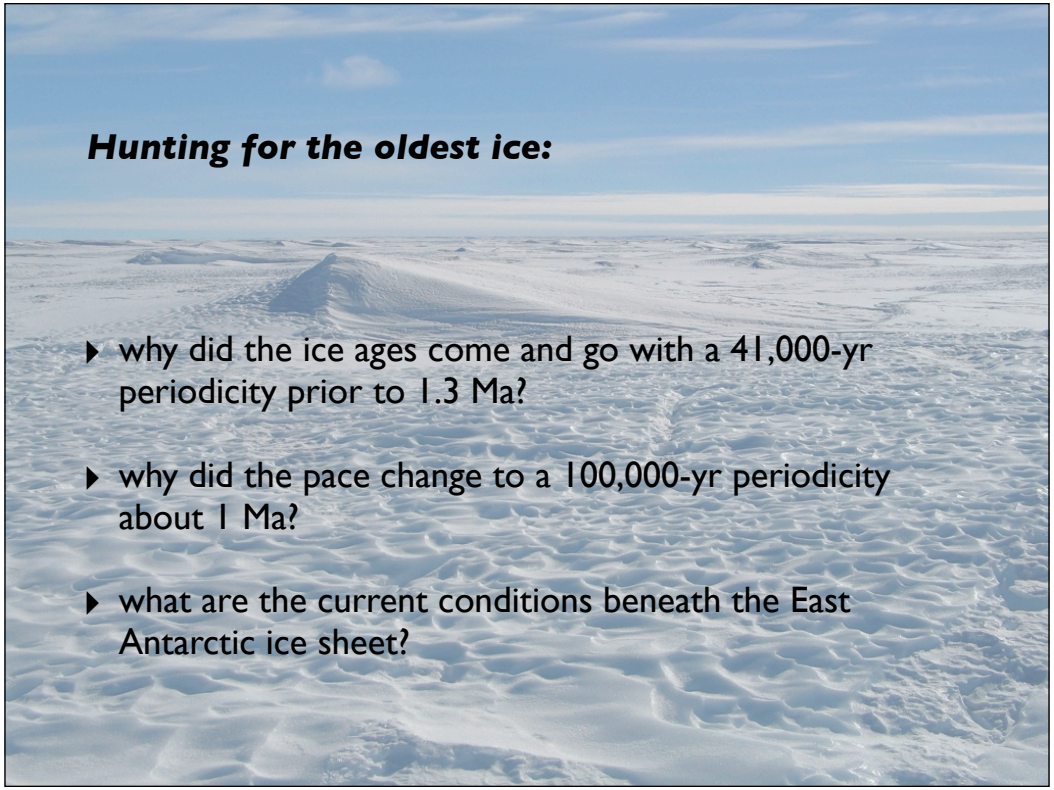
IceCube ice hole
(Photo: J. Roth)



Rapid access drilling

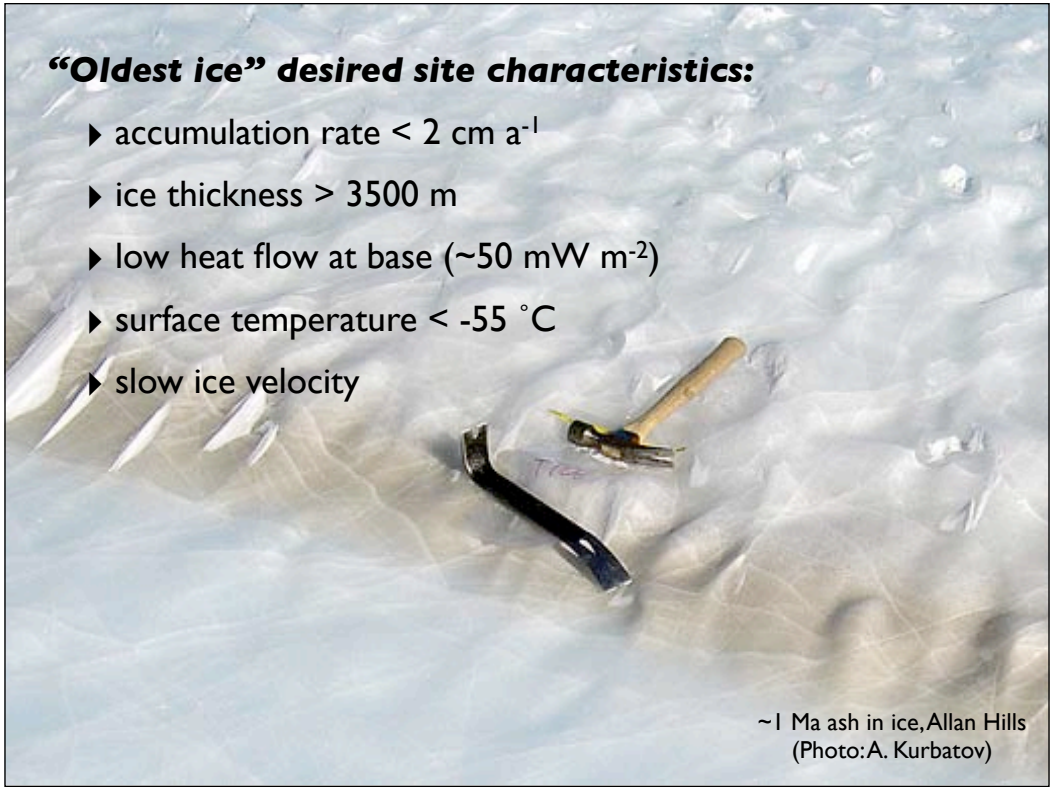
- ice conditions
- deep ice samples
- rock cores
- biota?


Rapid Access Drilling
lean
mean
green
Emerging technologies:
fast, cost-effective ice drilling to
access deep, old ice & geology below

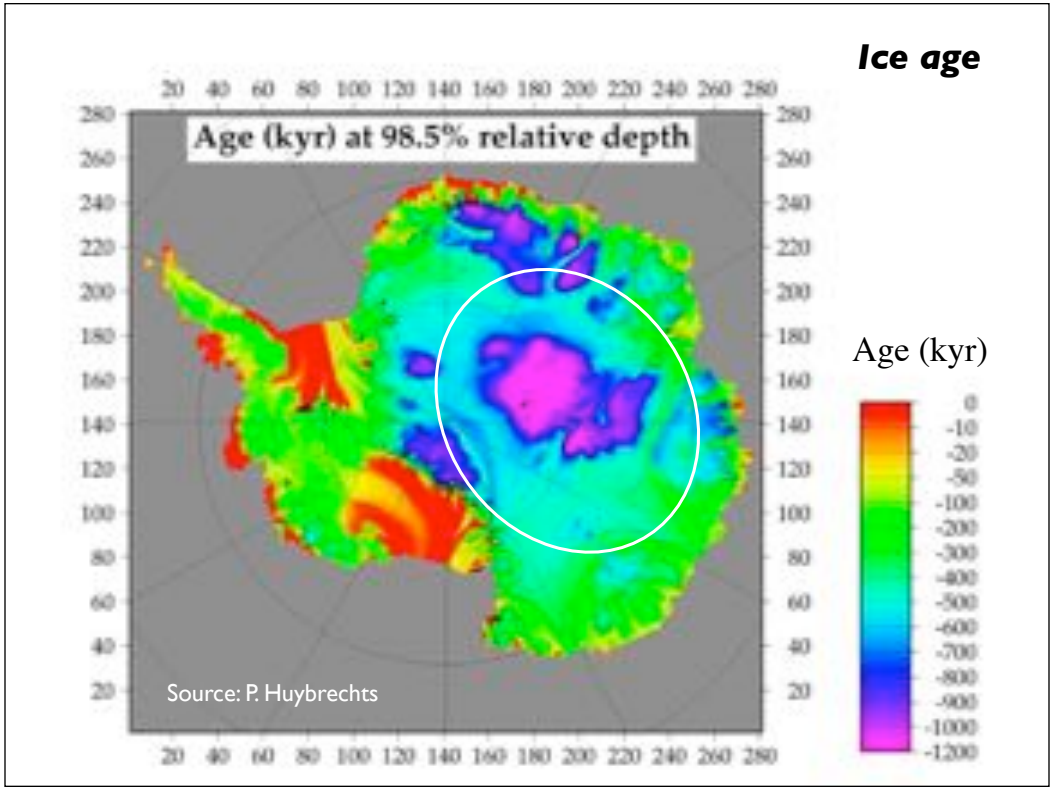

Hunting for the oldest ice:
- why did the ice ages come and go with a 41,000-yr periodicity prior to 1.3 Ma?
- why did the pace change to a 100,000-yr periodicity about 1 Ma?
- what are the current conditions beneath the East Antarctic ice sheet?

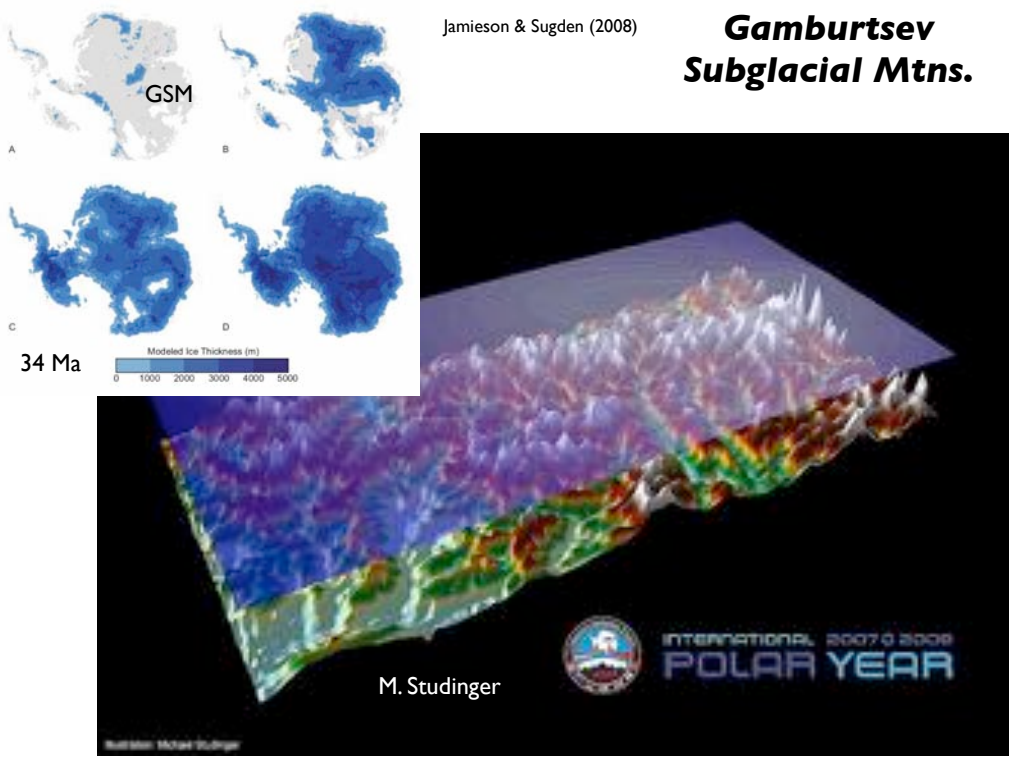
Accessing the oldest ice

- "old ice" will be located near the bed & will be highly compressed
- target ice will likely be 50-100 m thick, but at the bottom of a 4-km borehole
- drilling a deep core ($20-50M over 5-10 years) without knowing if the target ice in fact exists, is a high-risk endeavor with little science benefit if it fails
- ***rapid access*** provides deep-ice reconnaissance at relatively low cost in time & resources (several holes in a season at approximately $100K per hole)


"Oldest ice" desired site characteristics:
accumulation rate < 2 cm a-1
ice thickness > 3500 m
low heat flow at base (~50 mW m-2)
surface temperature < -55 ˚C
slow ice velocity
~1 Ma ash in ice, Allan Hills
(Photo: A. Kurbatov)

Ice age

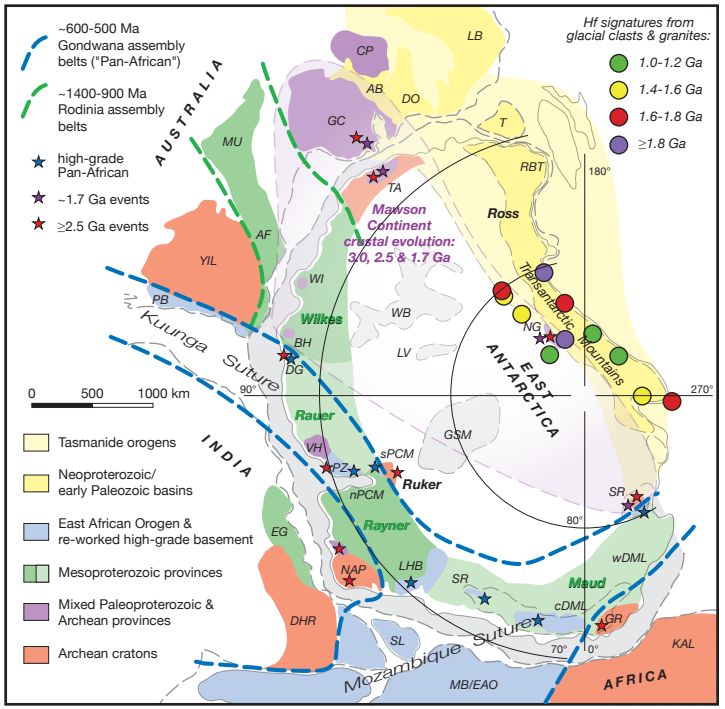

Age (kyr) at 98.5% relative depth
Source: P. Huybrechts
Age (kyr)
0
-10
-20
-50
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1200



Jamieson & Sugden (2008)

Gamburtsev Subglacial Mtns.

Mapping continental crust of East Antarctica



- combine geophysical imaging & geochemical "remote sensing" from proxy materials
- ages unknown from outcrop!
- learn about deep interior of East Antarctica
- test the paleogeography of supercontinents like Rodinia