RMetS
Royal Meteorological Society

The Pliocene: The last time Earth had >400 ppm of atmospheric CO_2

Grantham Institute
Climate Change and the Environment
An institute of Imperial College London

Evidence of Pliocene Antarctic ice mass loss from offshore sediments

Tina van de Flierdt

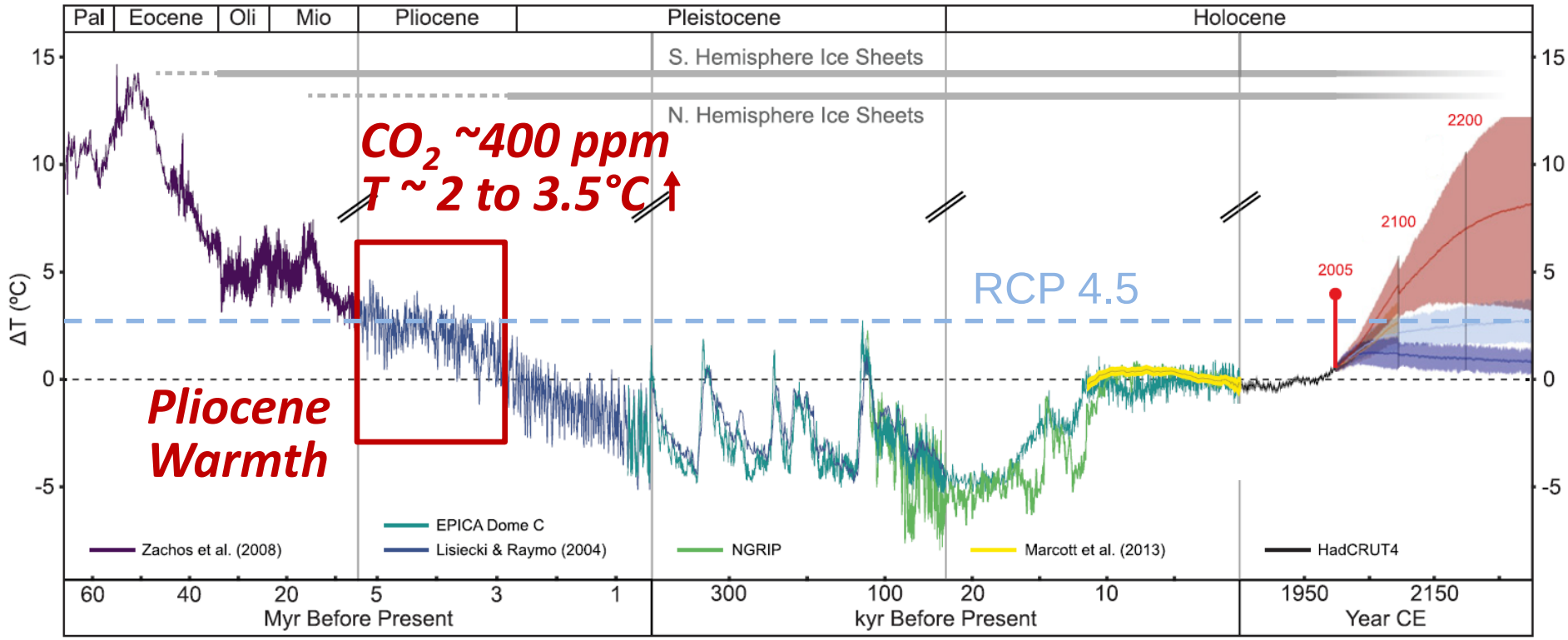
Rachel Bertram, Carys Cook (Imperial College London), Sidney Hemming (LDEO), Trevor Williams (TAMU), Carlota Escutia (U Granada), Richard Levy (GNS), Rob McKay (VW), Dan Hill, Aisling Dolan (U Leeds) & many more

DEPARTMENT OF
EARTH SCIENCE AND ENGINEERING

Imperial College London

M A G I C
Mass Spectrometry and Isotope Geochemistry at Imperial College London

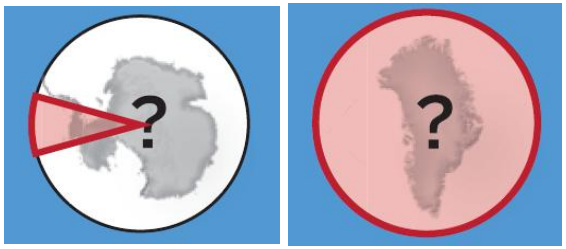
The Pliocene Warmth



Burke et al., 2018, PNAS

Global sea level ?

Dutton et al., 2015, Science

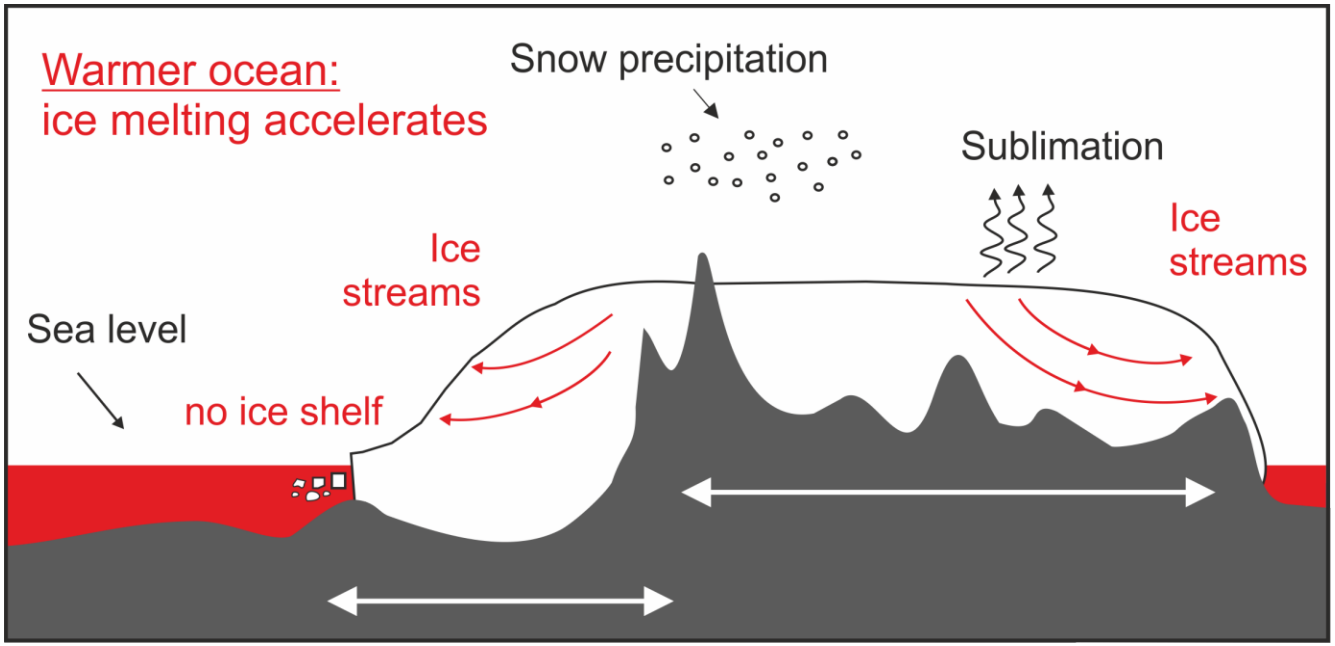


~5m + 53 m

~7 m

~10-20m ↑

Ice Sheets and Ocean Warming



Marine-based ice sheet

(e.g. West Antarctic Ice Sheet = **WAIS**)

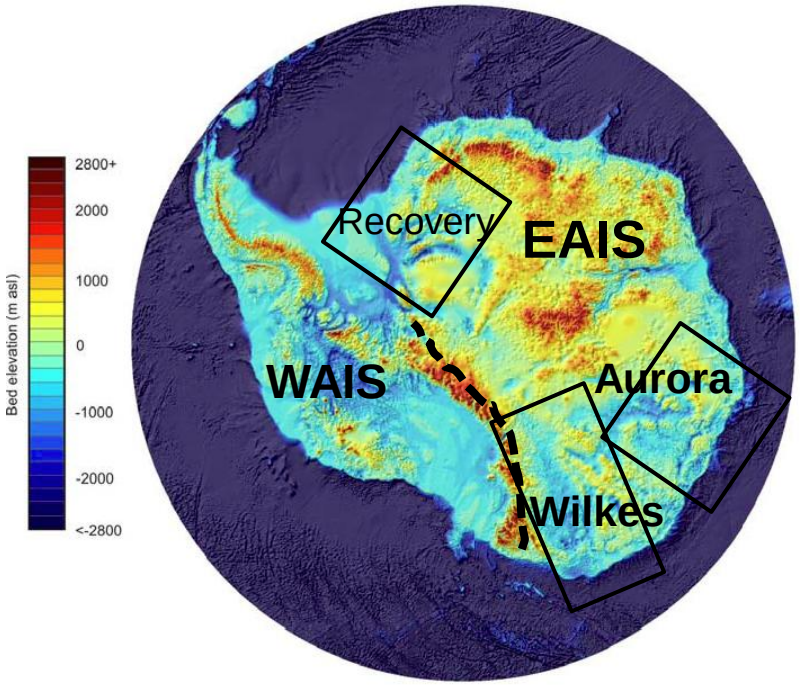
3.3m SLE

Continental-based ice sheet

(e.g. East Antarctic Ice Sheet = **EAIS**)

... but not everywhere ....

~19 m SLE

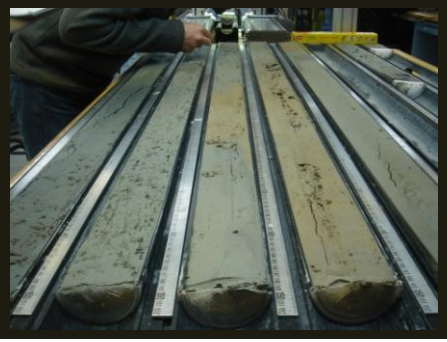


SLE = sea level equivalent

Pliocene Antarctic Ice Loss ?

<u>LEDs are wrapped around three London monuments at 28 metres above sea-level</u> to look forward 1000 years (year 3012).

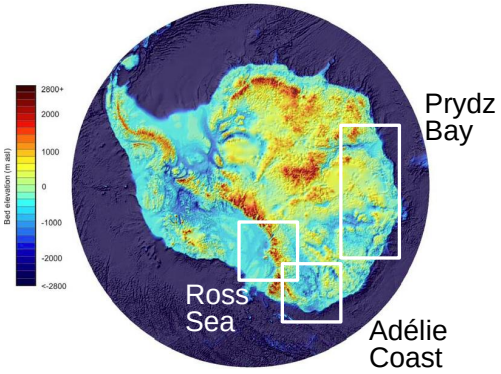
PLUNGE project (artist: Michael Pinsky)



The Approach

⇨ Drill Glaciomarine Sediment Records next to Ice
⇨ Determine Sediment Composition/Geochemistry
⇨ Infer Environmental Conditions & Ice Sheet History

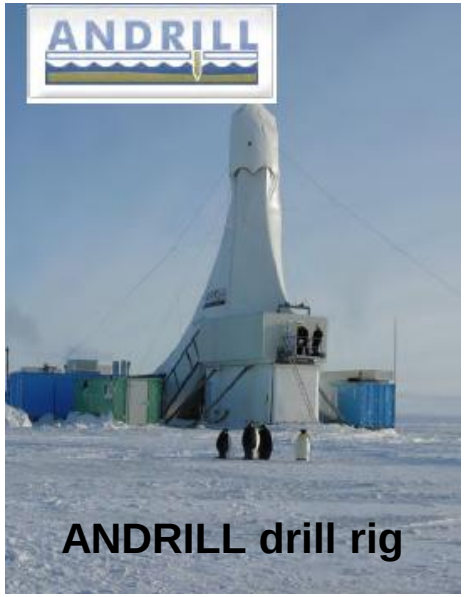
Three examples of Pliocene Antarctic Records



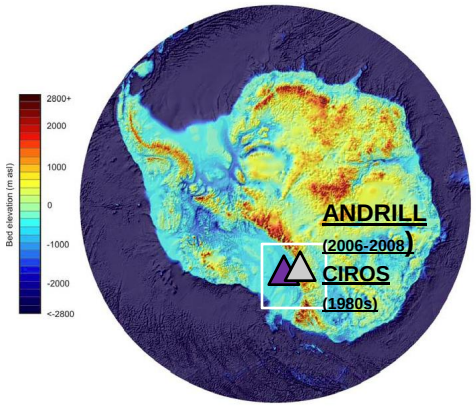
- Ross Sea (⇨ WAIS and EAIS constraints)
- Prydz Bay (⇨ Aurora Subglacial Basin, EAIS)
- Adélie Coast (⇨ Wilkes Subglacial Basin, EAIS)

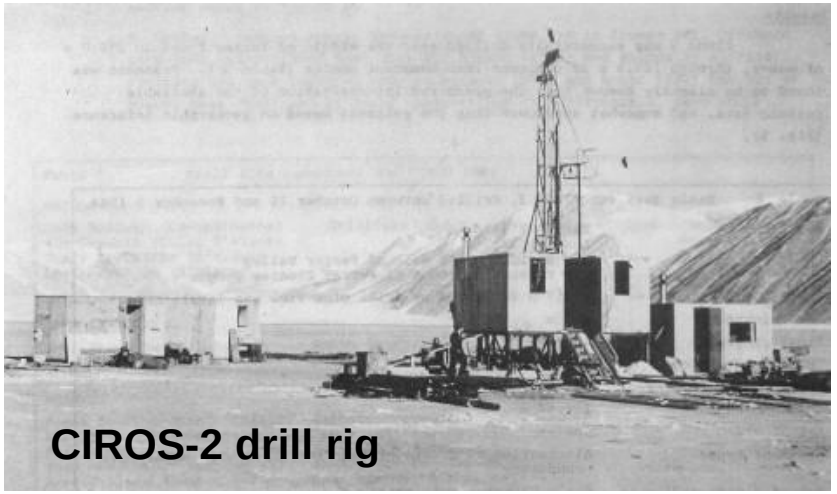
(1) Pliocene Ross Sea:

- ANDRILL (WAIS history) &
- CIROS-2 (EAIS outlet glaciers)



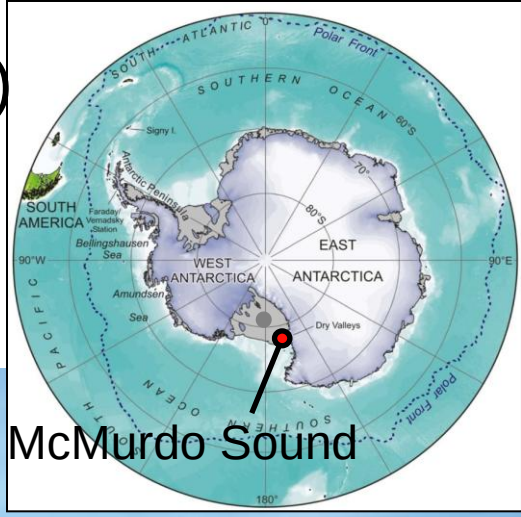
ANDRILL drill rig




CIROS-2 drill rig

ANDRILL (ANtarctic geological DRILLing)

First Geological Drilling from Ice Shelf as Platform



8 meter sea-ice platform

384 meter water column

Plio-Pleistocene

upper Miocene

mid-Miocene

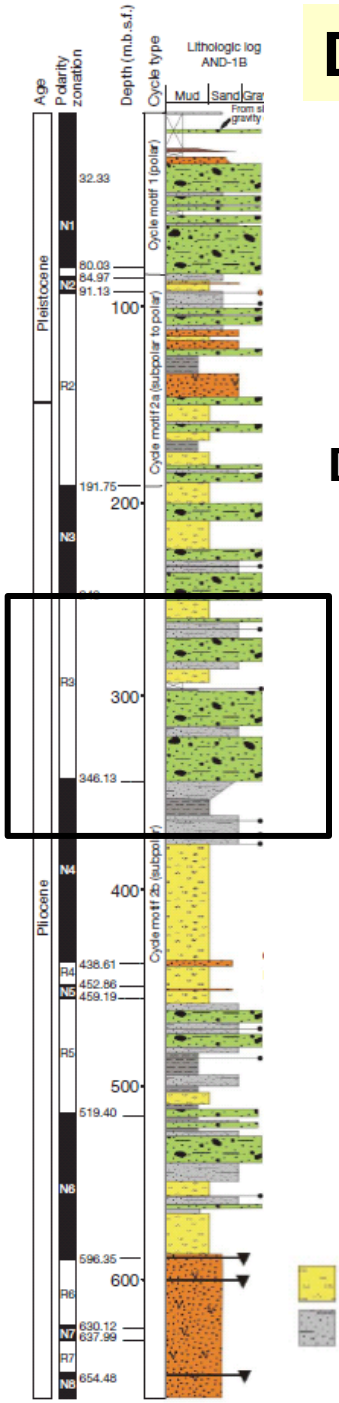
lower Miocene

1138 meter sediment column

98% core recovery

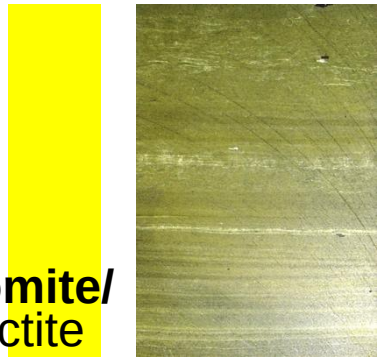
Angie Fox

Diatomites: evidence for WAIS collapse (no ice shelf)



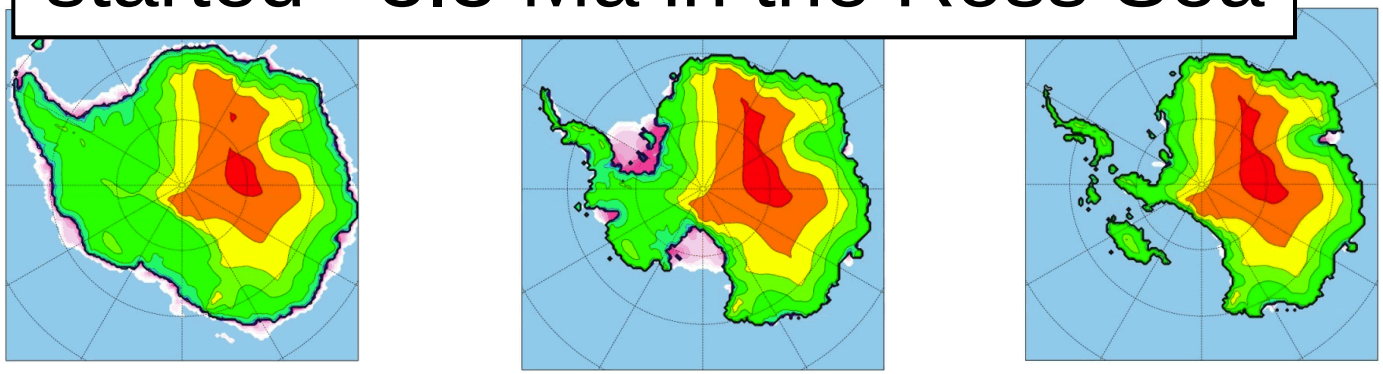
Diamictite

Diamictite/ **mudstone**



Diatomite/ diamictite

Ice expansion and cooling started ~3.3 Ma in the Ross Sea

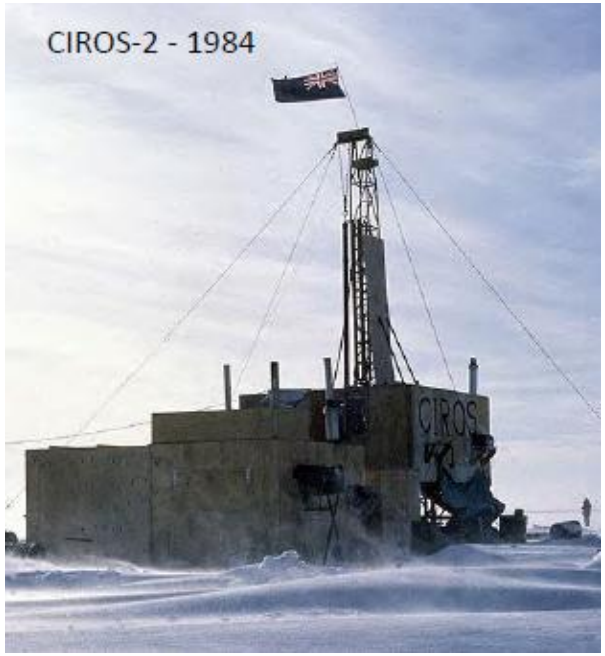


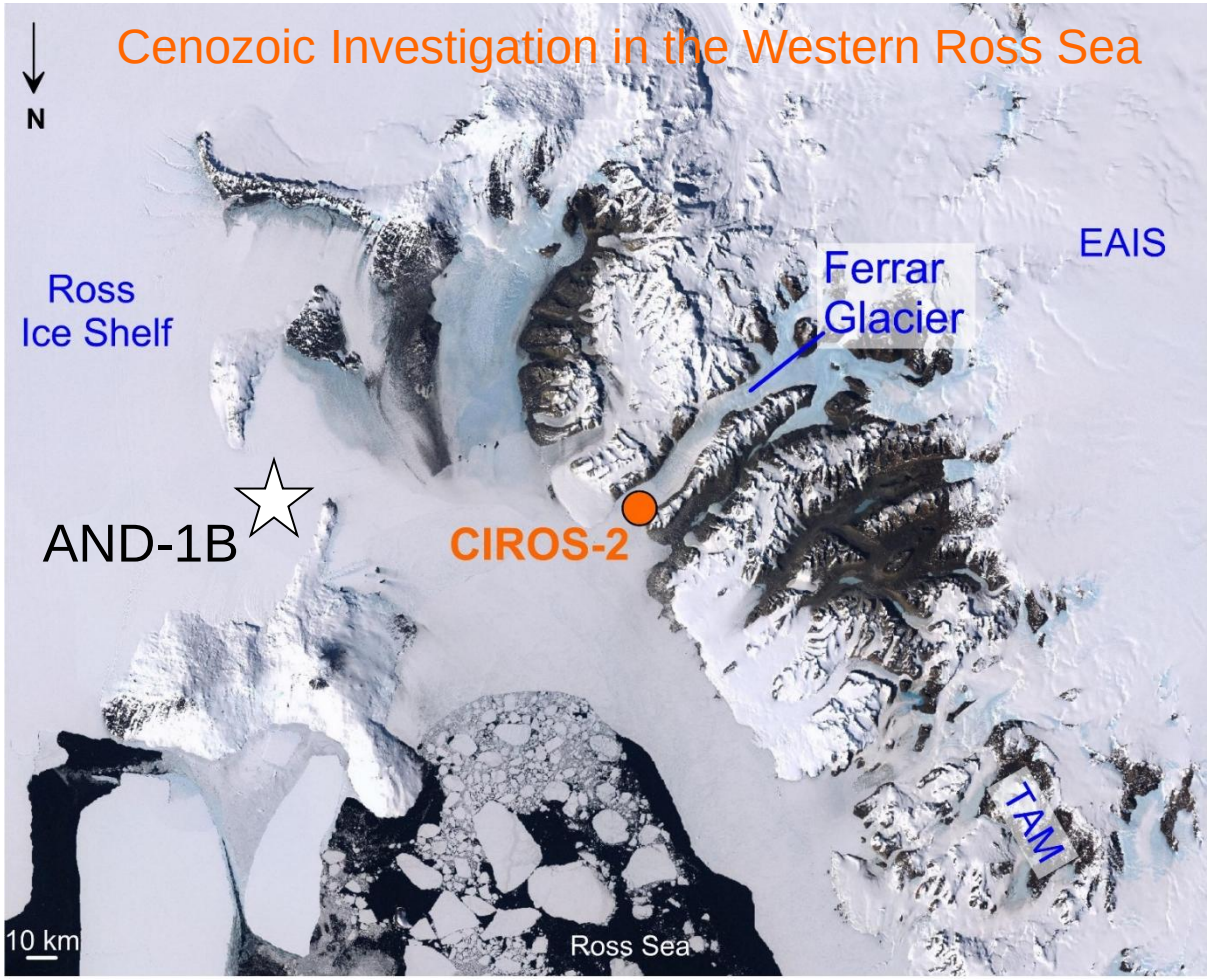
Naish et al., 2009

Pollard & DeConto, 2009

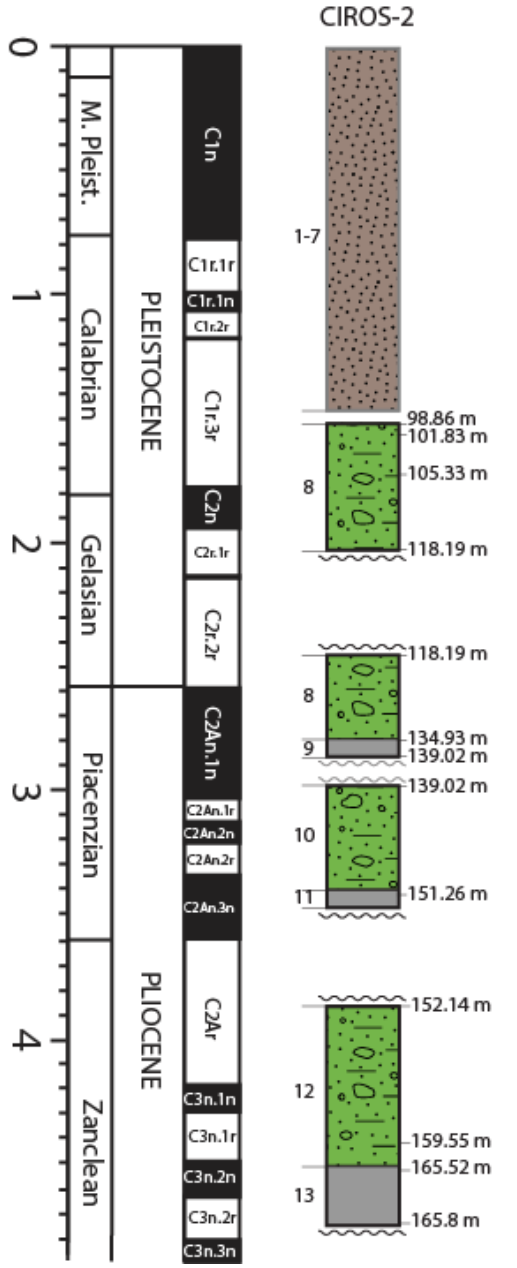
McKay et al., 2012

What Happened at the Terrestrial Margin around 3 Ma?

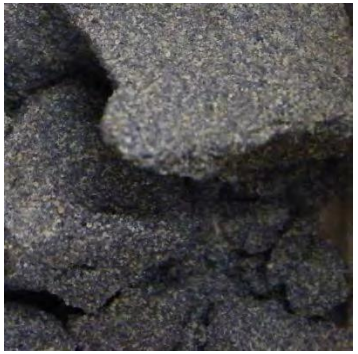




CIROS-2 site is located within the Ferrar Glacier valley (outlet glacier of the EAIS).

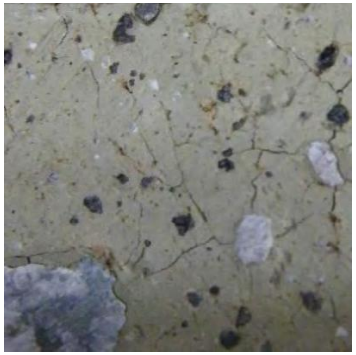


sandstone



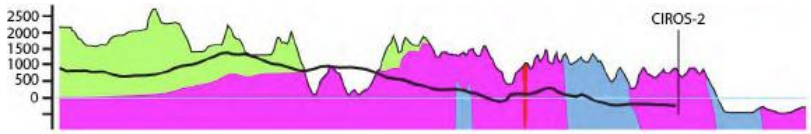
mudstone

diamictite



No obvious lithology change in Pliocene.

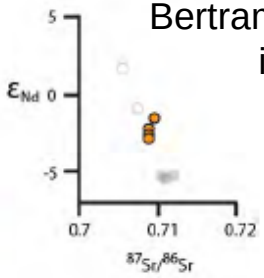
What about detailed (isotope) geochemical analyses of mudstones ?



Variable geology up valley.

Levy et al., 2012

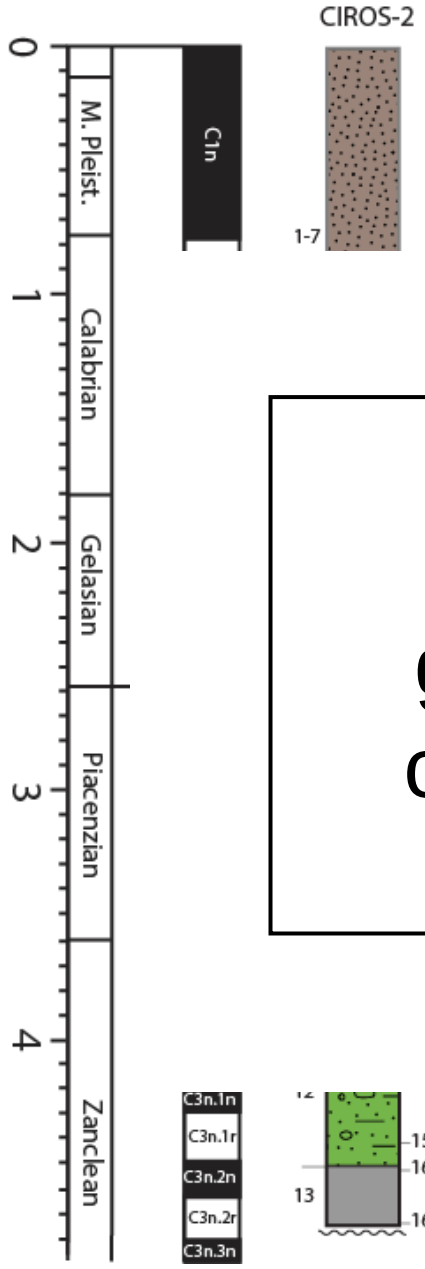
Bertram et al., in prep.

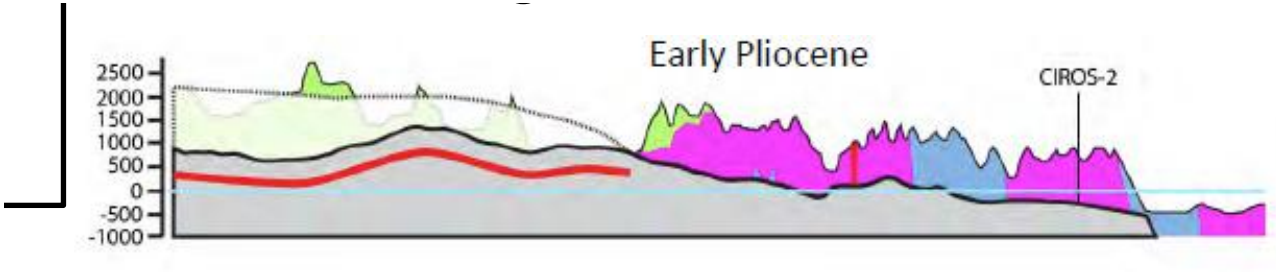


Late Pliocene (<3 Ma):

Erosion of upper & lower

Expansion of EAIS mountain glaciers coincided with marine cooling ~3 Ma in the Ross Sea





Levy et al., 2012

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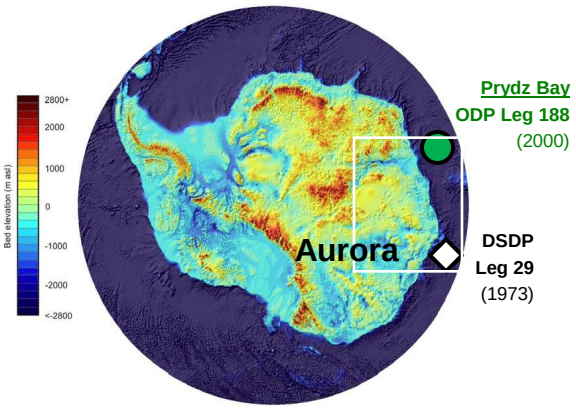
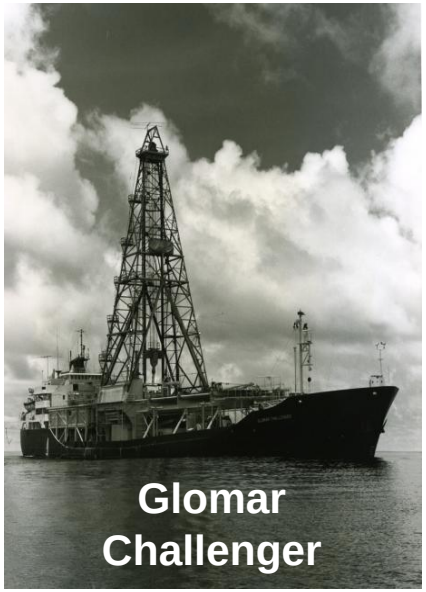
(2) Pliocene Prydz Bay (& Wilkes Land):

- marine-based part of EAIS;
- ODP Exp. 188; DSDP Leg 29

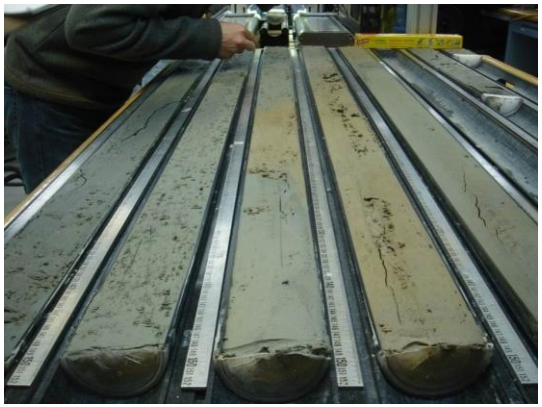




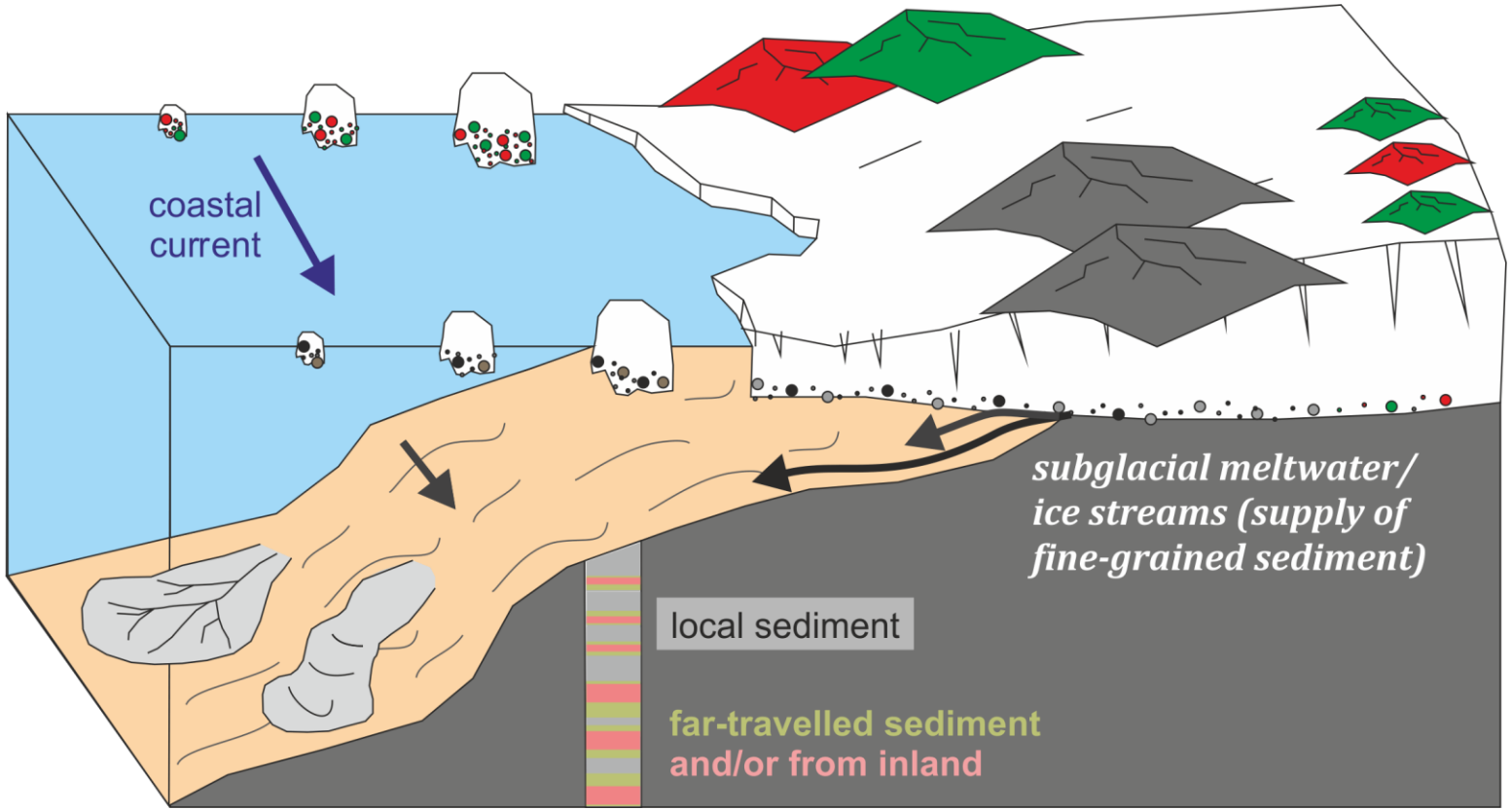
DSDP
DEEP SEA DRILLING PROJECT

OCEAN DRILLING PROGRAM
SCIENCE OPERATOR

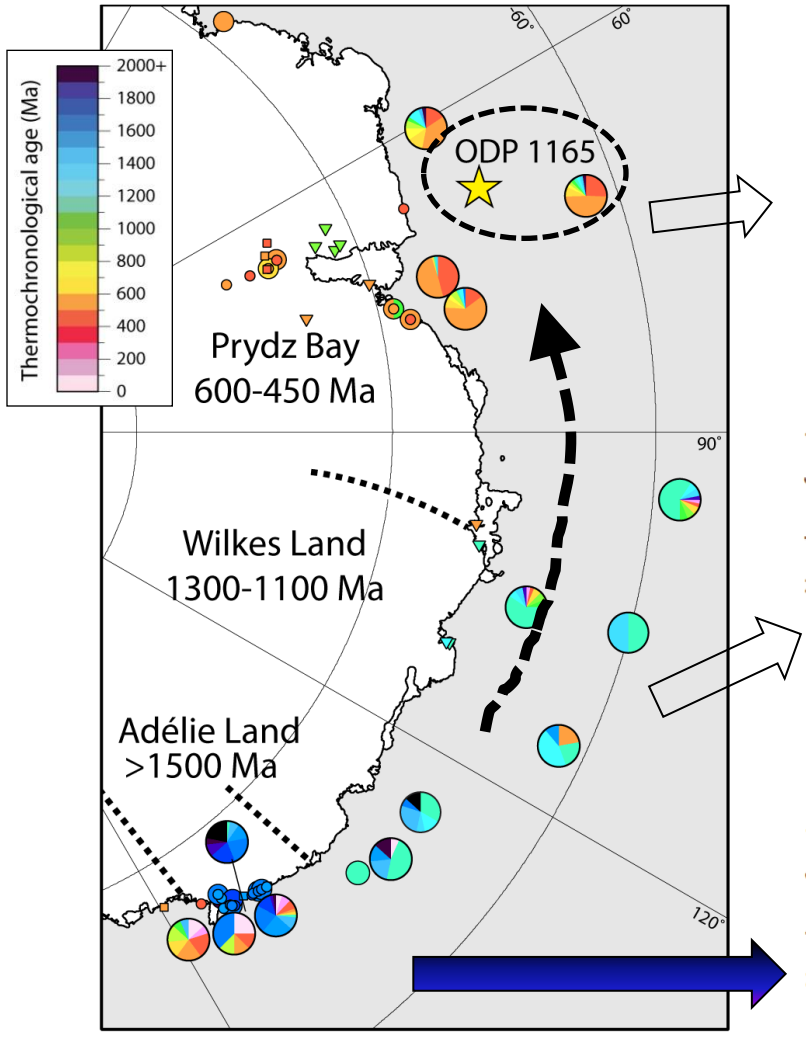
Ocean Drilling Program, Texas A&M University,



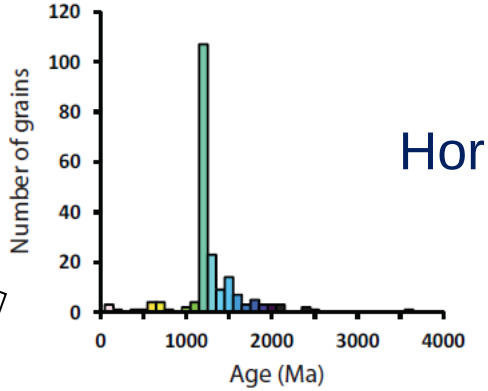
Geochemistry of *individual mineral grains* and *fine detrital sediment* fingerprints <u>continental sources</u>.



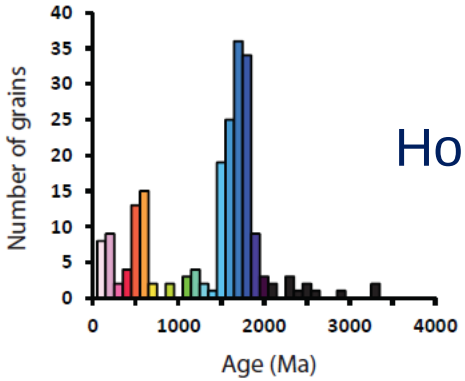
MODERN ICE-RAFTED DEBRIS FINGERPRINTS – EXCELLENT TRACERS OF GEOLOGICAL SECTORS



Prydz Bay
Hornblende $^{40}Ar/^{39}Ar$ age:
600-450 Ma

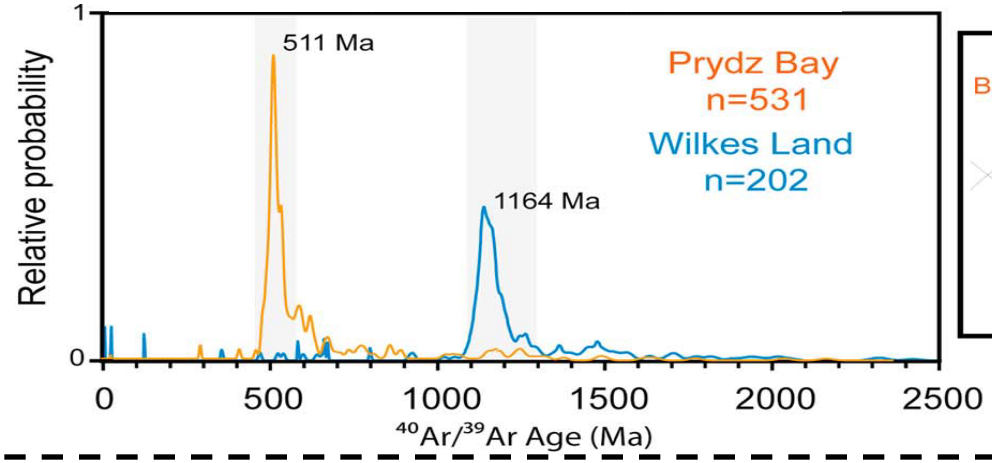


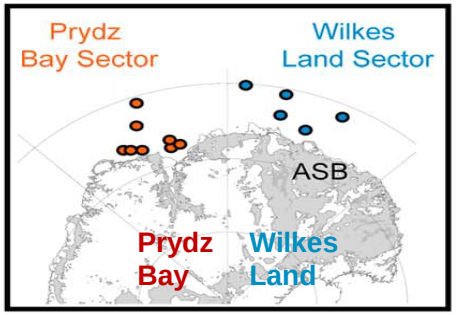
Wilkes Land
Hornblende $^{40}Ar/^{39}Ar$: age
1300-1100 Ma



Adélie Land
Hornblende $^{40}Ar/^{39}Ar$ age:
>1500 Ma

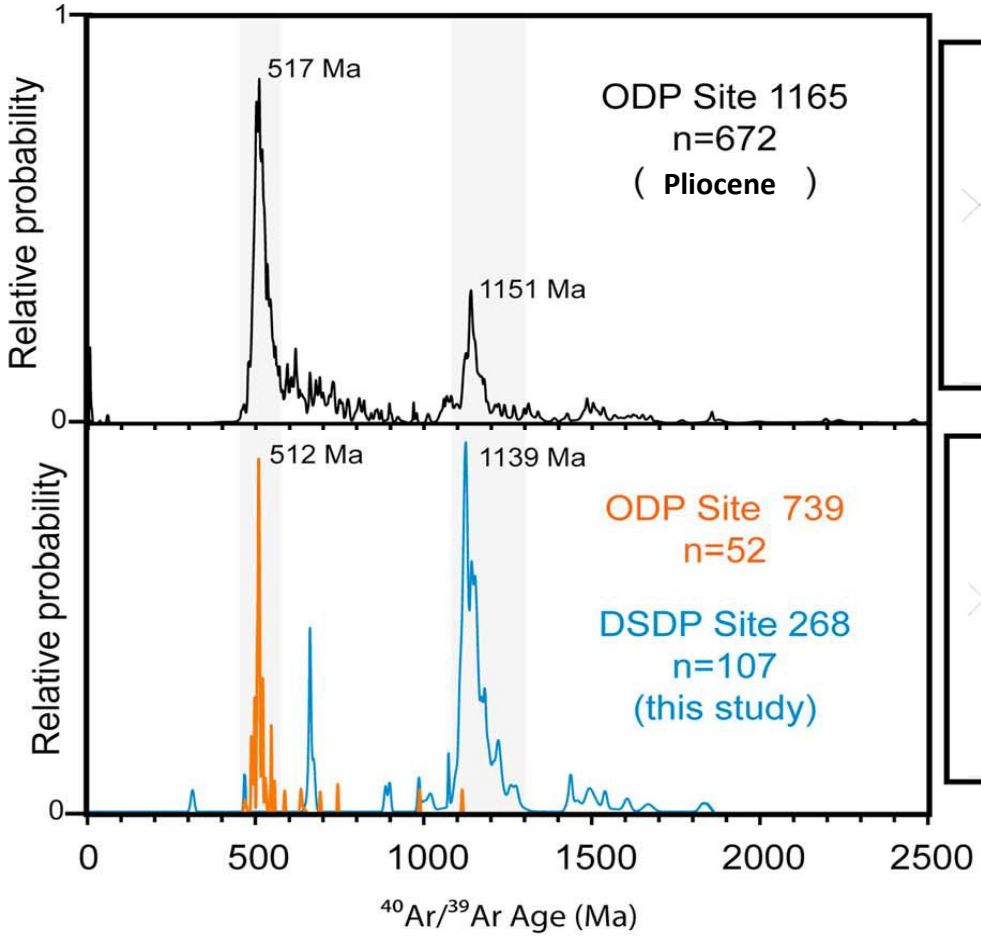
Williams et al., 2010; Pierce et al., 2011 & 2014

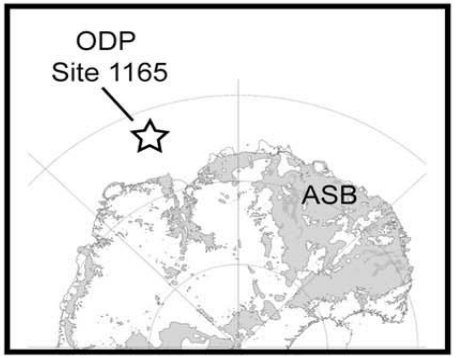


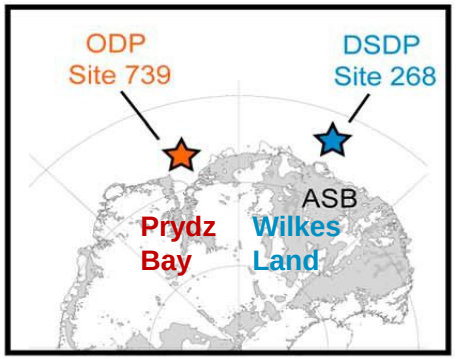


Today

clearly distinct signatures around coast







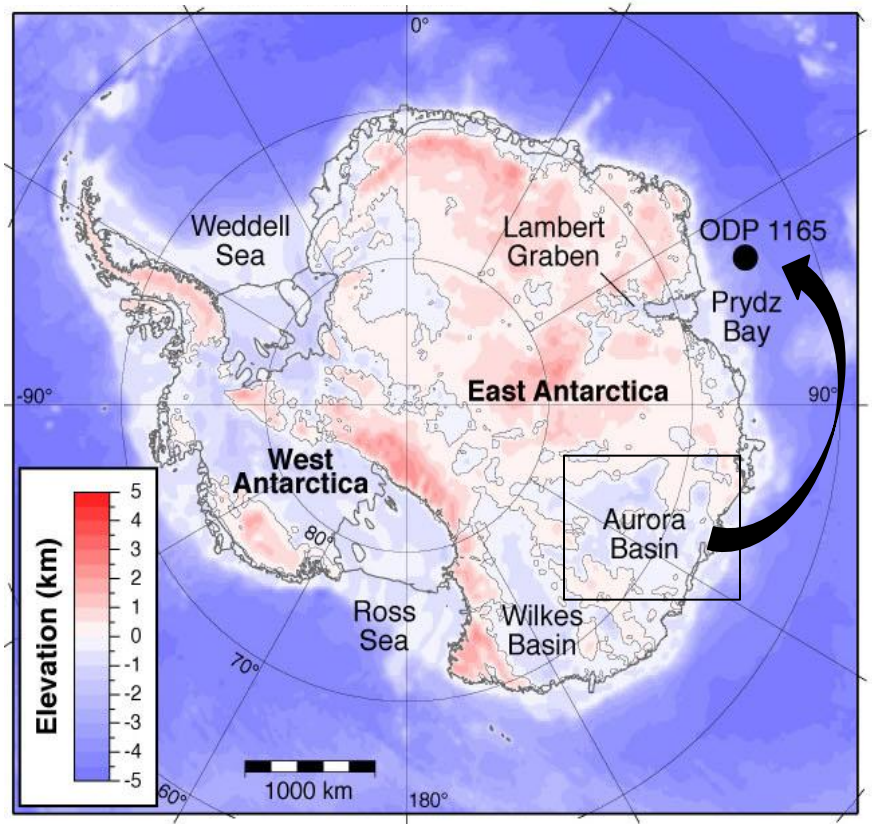
Pliocene

two distinct age peaks at ODP 1165

= far-travelled Wilkes Land IRD

Cook et al., 2014

Implications of IRD Findings for Places of Ice Instability under Pliocene Climate



→ low lying Aurora Subglacial Basin was unstable providing 'Wilkes Land' signature !

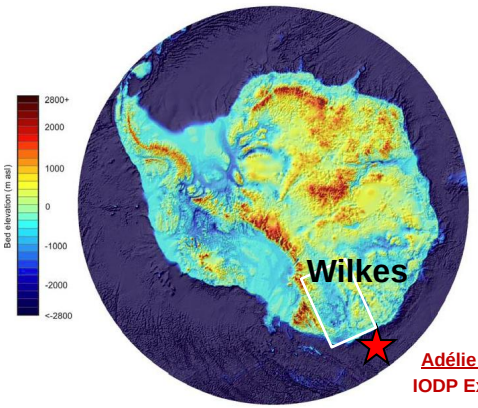
→ cooling sea surface temperatures led to a larger presence of far travelled icebergs

IODP
INTEGRATED OCEAN DRILLING PROGRAM

What about a more proximal drill location?

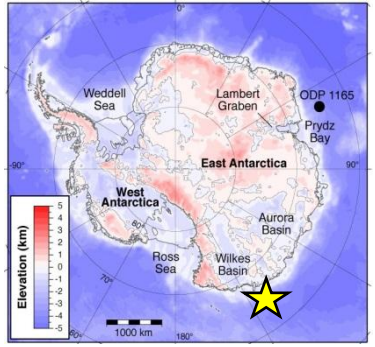
(3) Offshore Adélie Land:

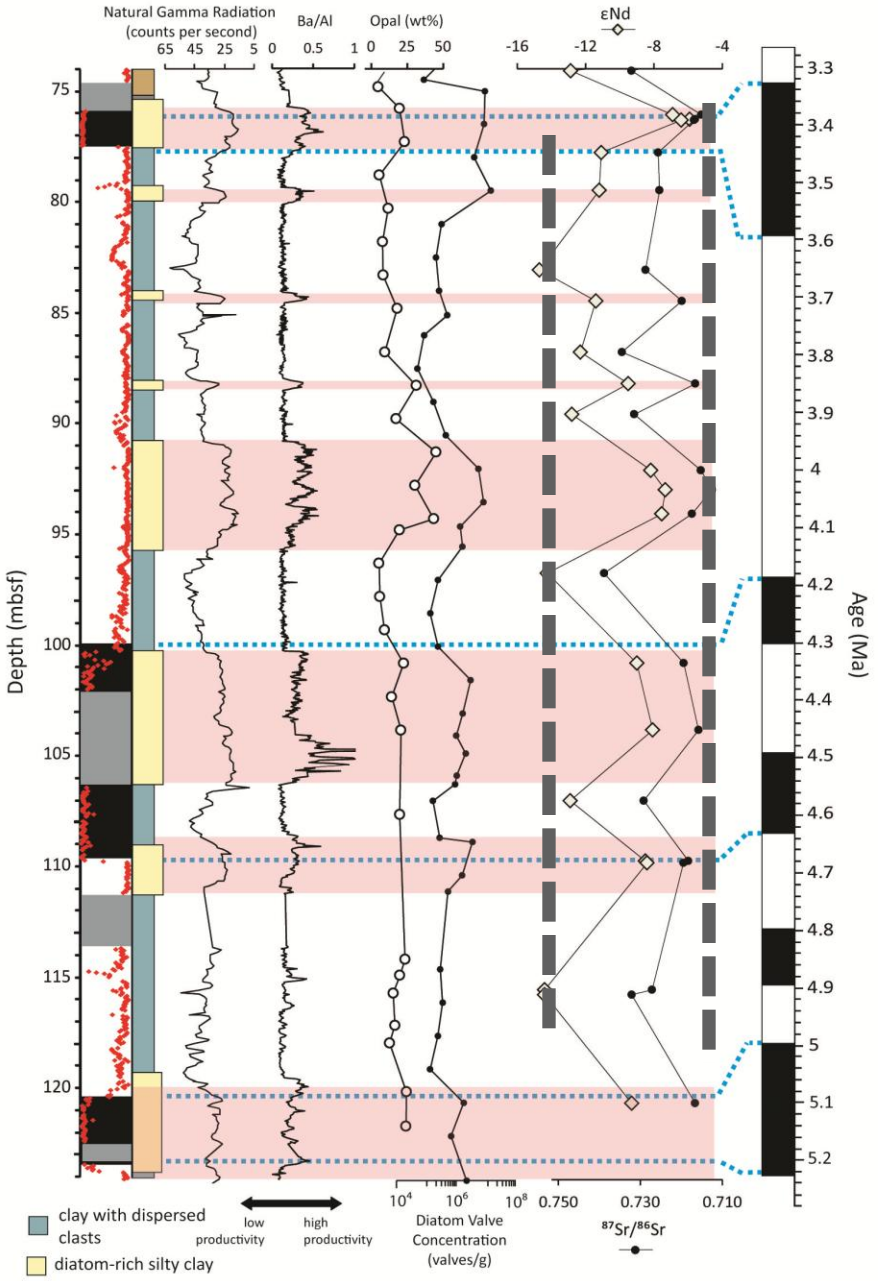
- marine-based part of EAIS;
- IODP Exp. 318



Adélie Coast
IODP Exp 318
(2010)

WARM EARLY PLIOCENE INTERVALS





Characteristics:

- diatom and opal-rich
- low in clays
- high productivity

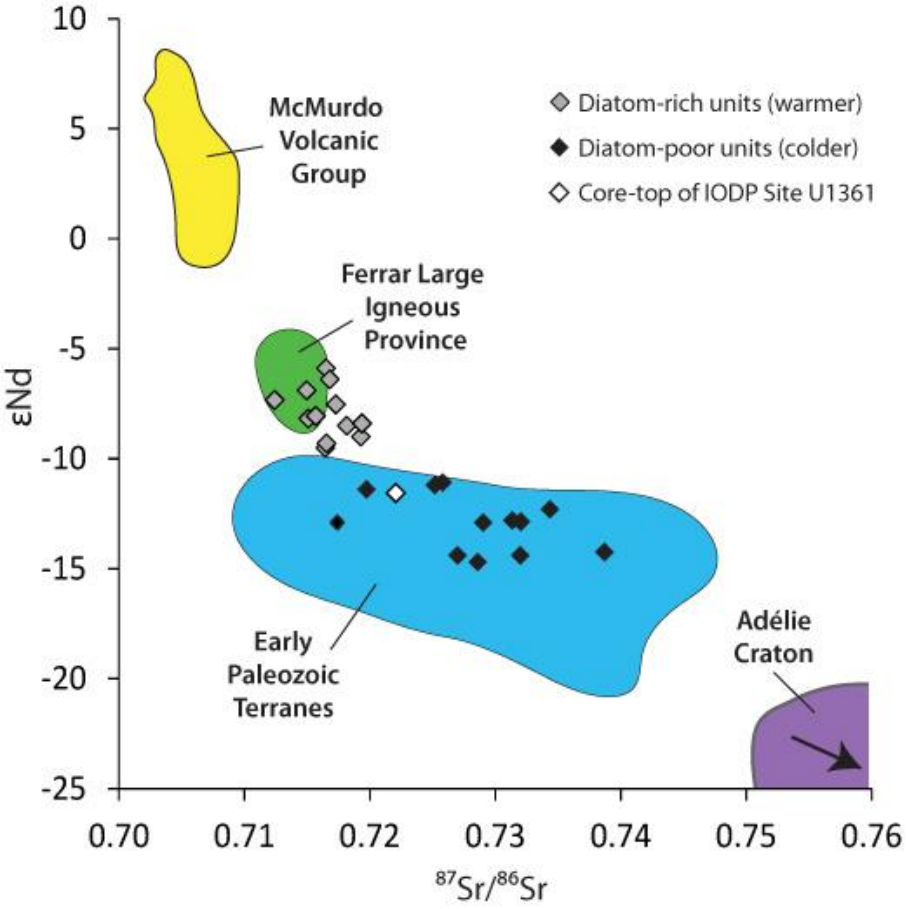
WARM

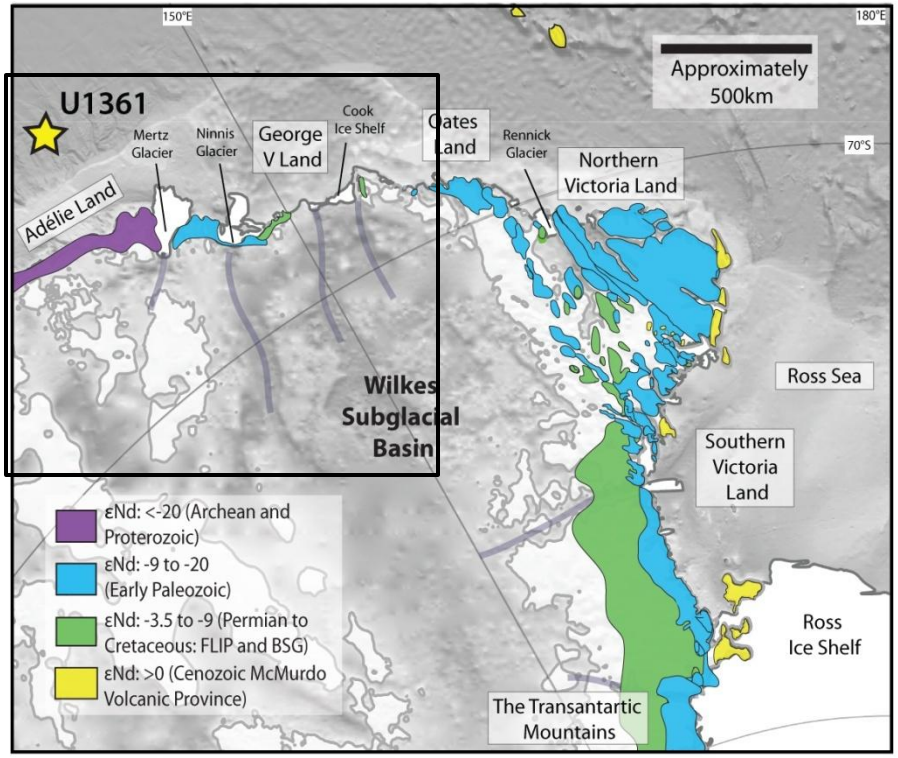
⇨ **higher Nd and lower Sr isotopes in warm intervals**

Cook et al. (2013), Nature Geoscience

Cook et al. (2013)

Local Geology and Source Signatures





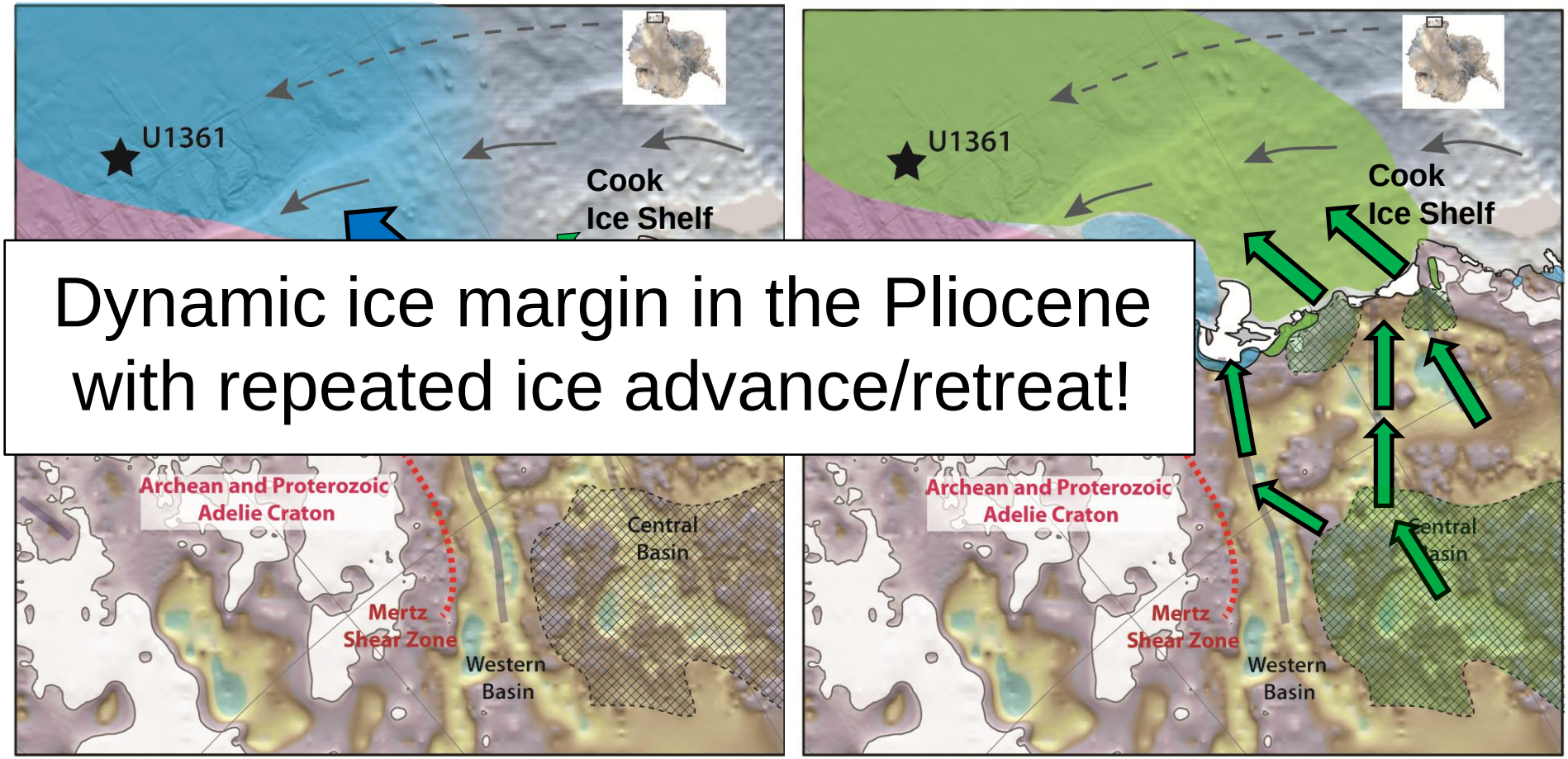
Four main geological terranes.

Sediments from **warmer** and **colder** times come from different sources.

Mechanism behind Provenance Change

GLACIAL INTERVALS

WARMEST INTERGLACIALS



Dynamic ice margin in the Pliocene with repeated ice advance/retreat!

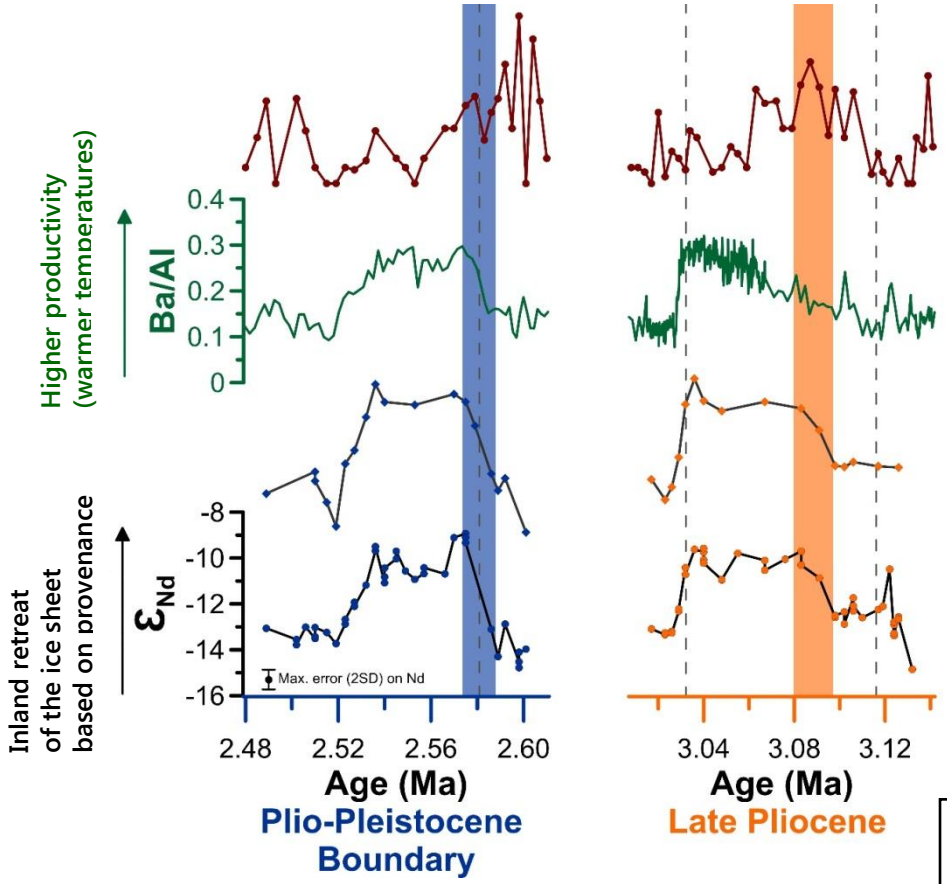
Modified from Cook et al. 2013 with data from Fretwell et al. 2012 and Ferraccioli et al. 2009

Provenance similar to today
→ Erosion of local **Lower Paleozoic** rocks
→ **Ice sheet fairly similar to today**

Very different provenance !
→ Erosion of **Devonian-Cretaceous** rocks
→ **Retreat of ice sheet into the basin**

New suborbital data indicate time-scale of ice retreat of a few thousand years

Bertram et al., 2018, EPSL



1

2a

2b

Deglacial sequence:

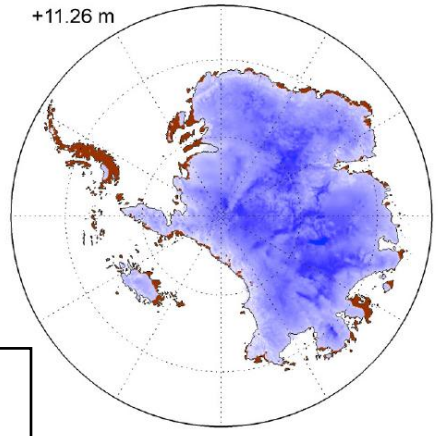
(1) IRD calving
(= warming)

⬇

(2a) productivity increase
(= sea ice retreat)

⬇

(2b) provenance change
(= ice margin retreat)



In agreement with models.

DeConto & Pollard, 2016

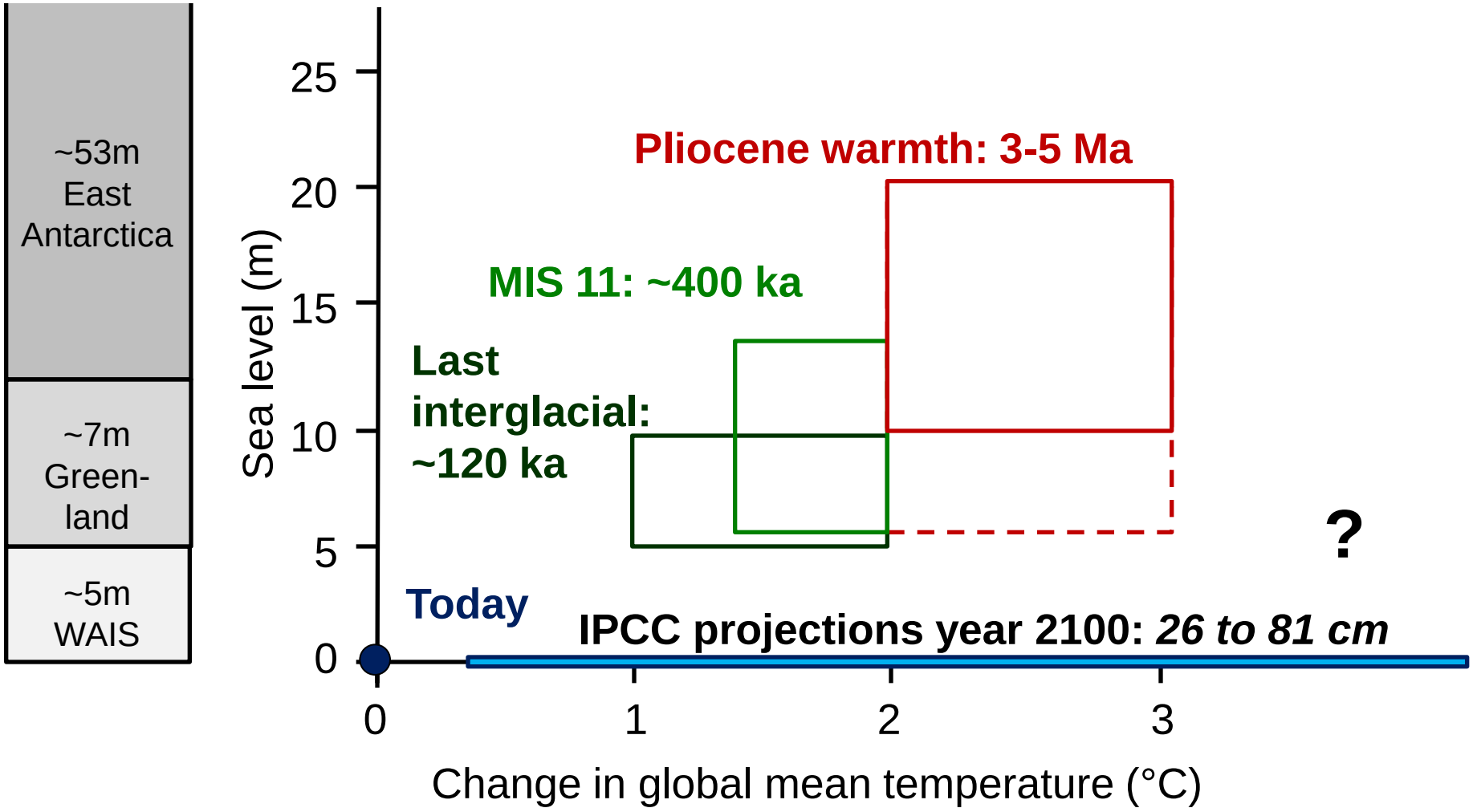
Pliocene Antarctic Ice Loss as seen From Marine Sediments

Ross Sea: WAIS collapsed + EAIS outlet glaciers retreated (transition to more advanced ice in Late Pliocene)

Prydz Bay: Indication for collapse of Aurora Subglacial Basin (+ indication for cooler sea surface temperatures in Late Pliocene)

Adélie Land: Dynamic ice margin throughout the Pliocene in Wilkes Subglacial Basin (and into the Pleistocene)

Palaeoclimate data urge us to look beyond the year 2100 when thinking about our future ...



Thanks for your attention!

Kristian Gerhard Jebsen Foundation

The Leverhulme Trust

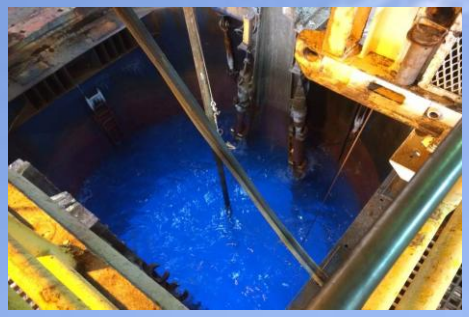
NSF

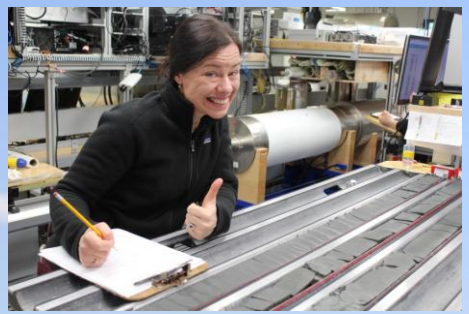
Grantham Institute for climate change

EXCELLENCE IN SCIENCE

NERC SCIENCE OF THE ENVIRONMENT

IODP INTEGRATED OCEAN DRILLING PROGRAM





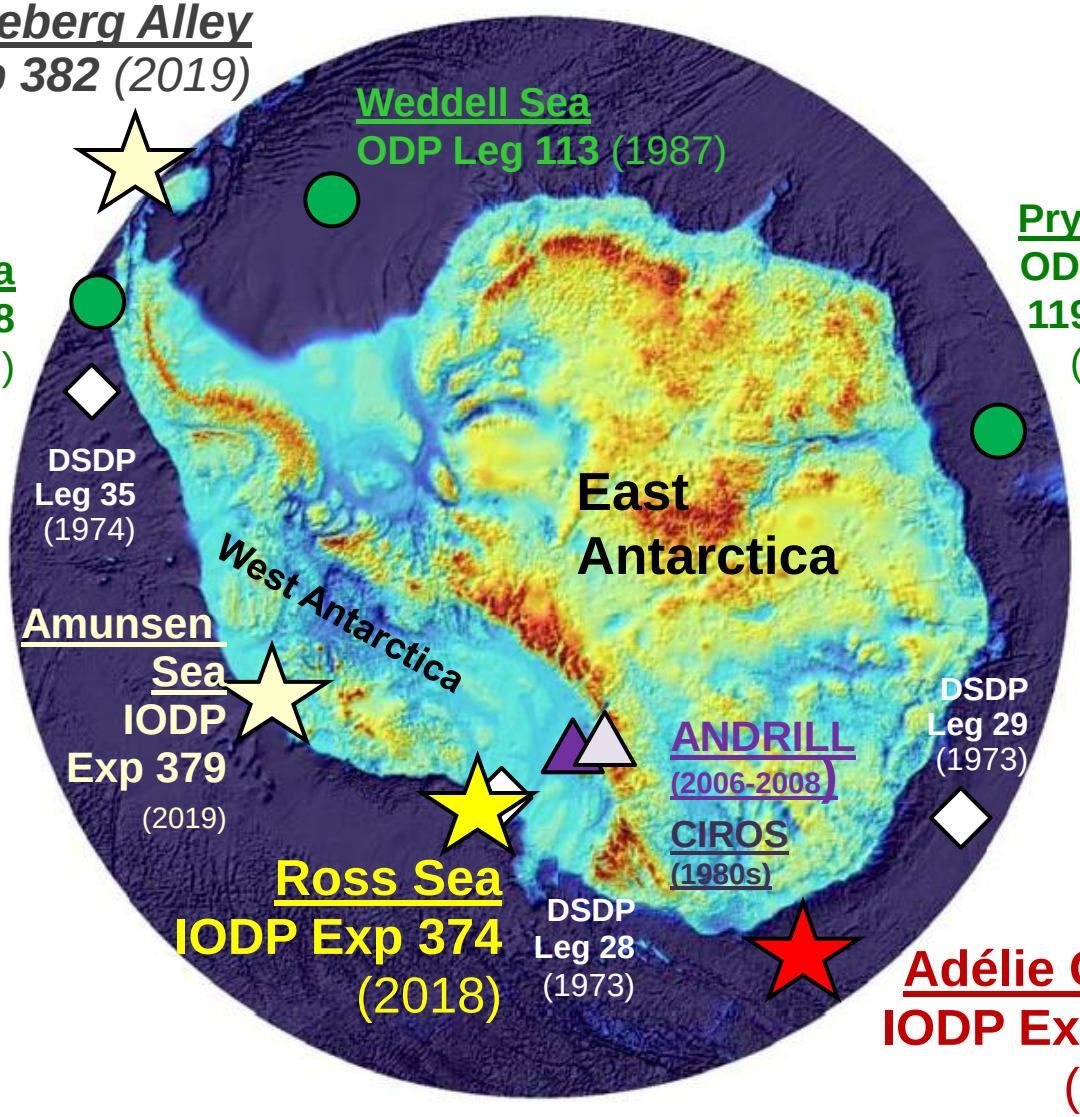
JOIDES Resolution (scientific drillship since 1985)

Derrick: 62 m

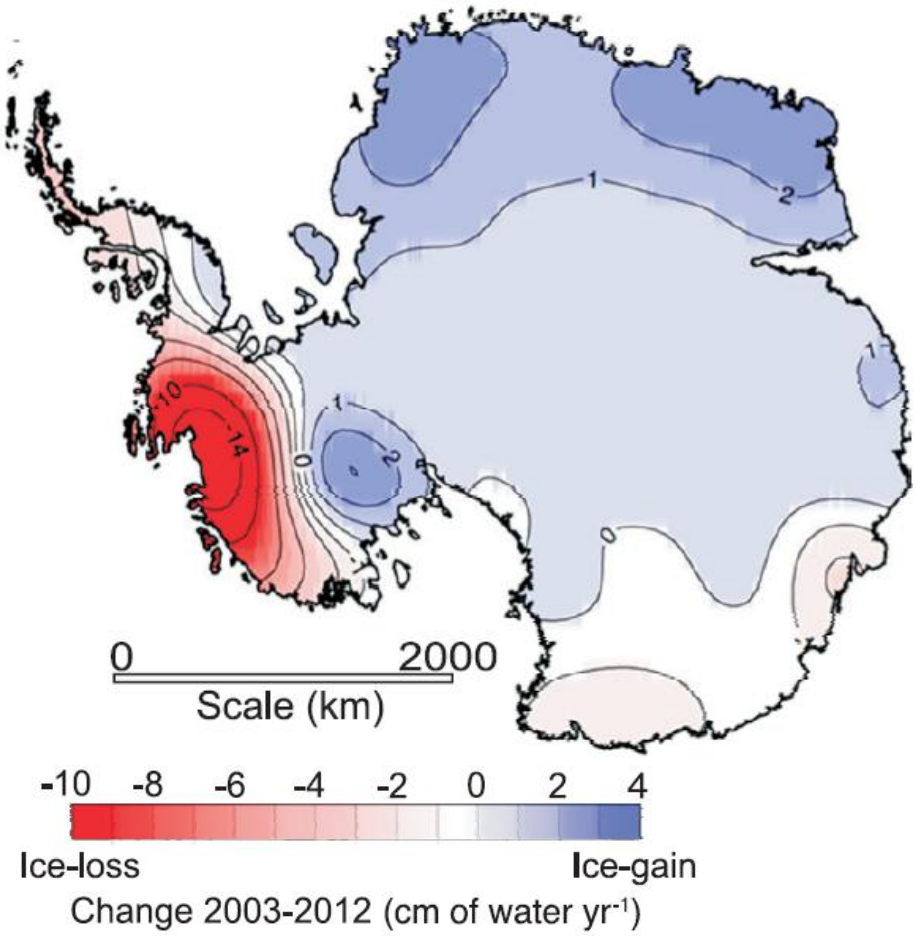
IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

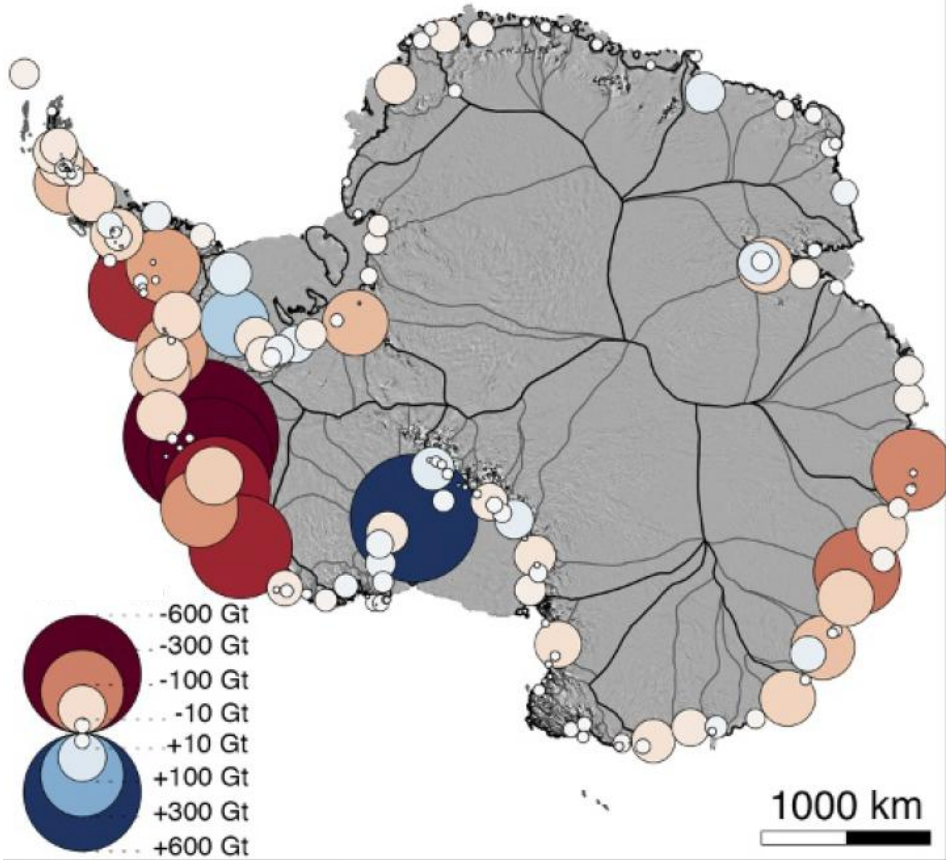
Length: 143 m

Four Decades of Antarctic Drilling



Modern Antarctic Ice Loss





Ice loss/gain (2017 – 1979)

GRACE data, IPCC AR5, WG 1, Chapter 4

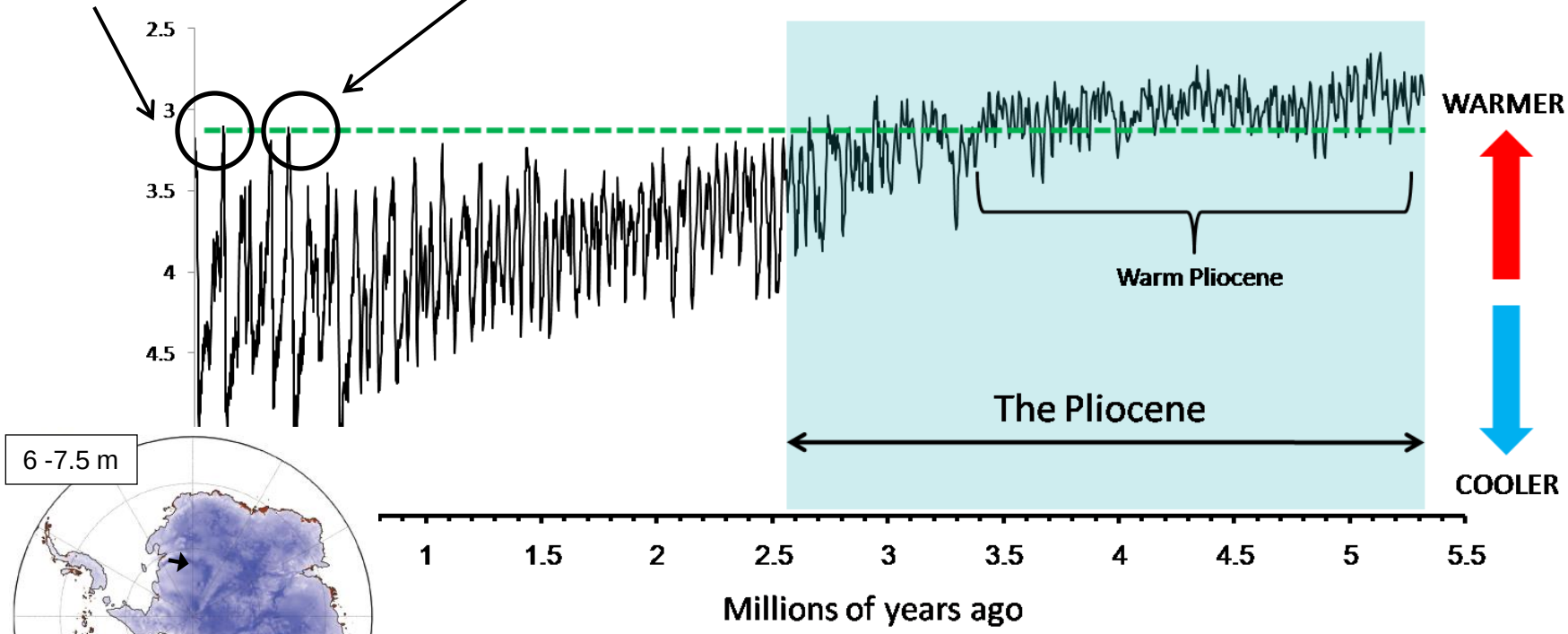
SMB data: 1979 – 2017; Rignot et al., 2019

Late Pleistocene Interglacials:
Significant for our short term future …

MIS 5e (~125 ka)
T = +1.0 – 2.0°C
CO_2 ~300 ppm
Sea level: +6-9m

MIS 11
T = +1.5 – 2.0°C
CO_2 ~300 ppm
Sea level: +6-13m

Paris Agreement aims to limit global warming to <2°C

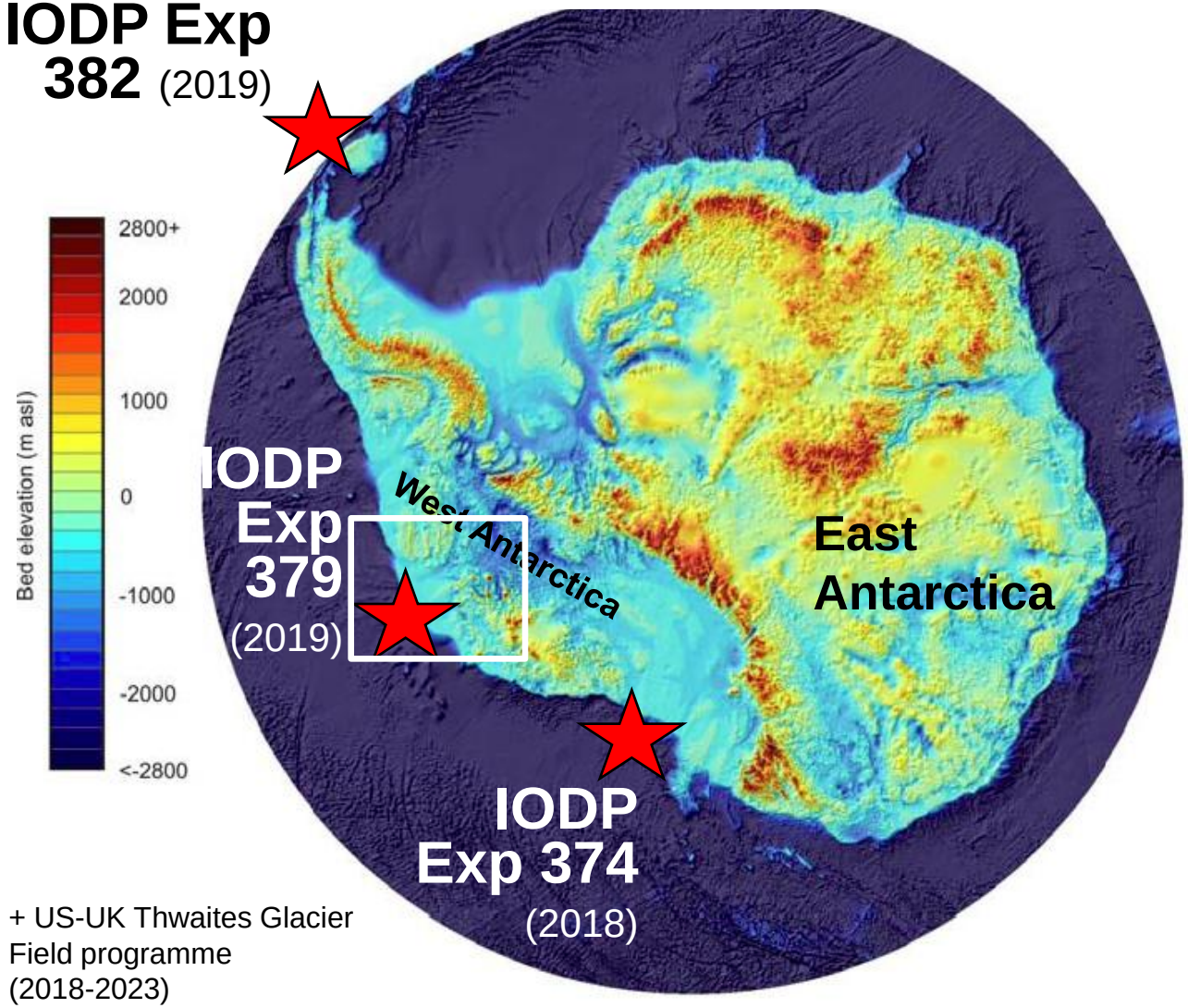


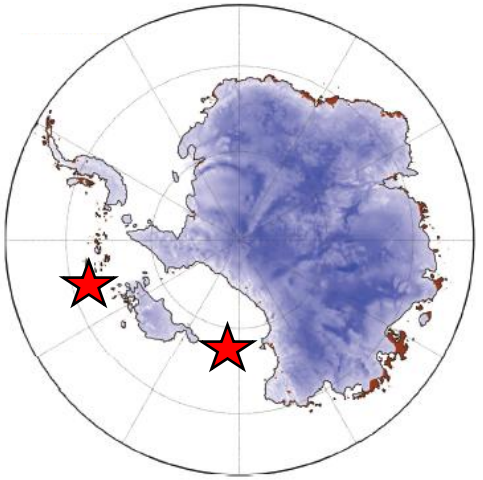
Modified from Lisieki and Raymo, 2005

DeConto and Pollard, 2016; MIS 5e

MIS = Marine Isotope Stage

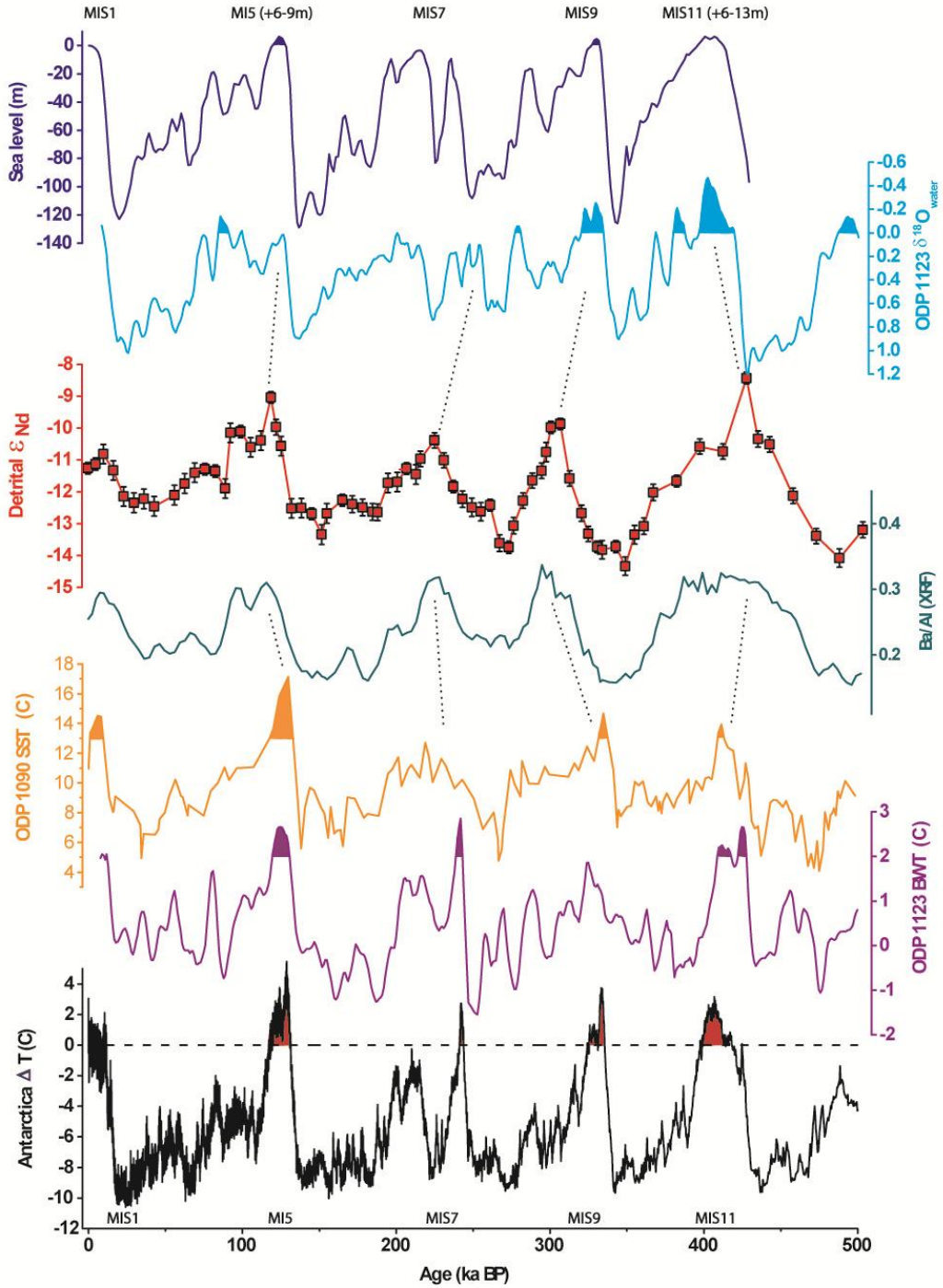
What About West Antarctica and More Moderate Warming of 1-2°C ?





This is what the model predicts.

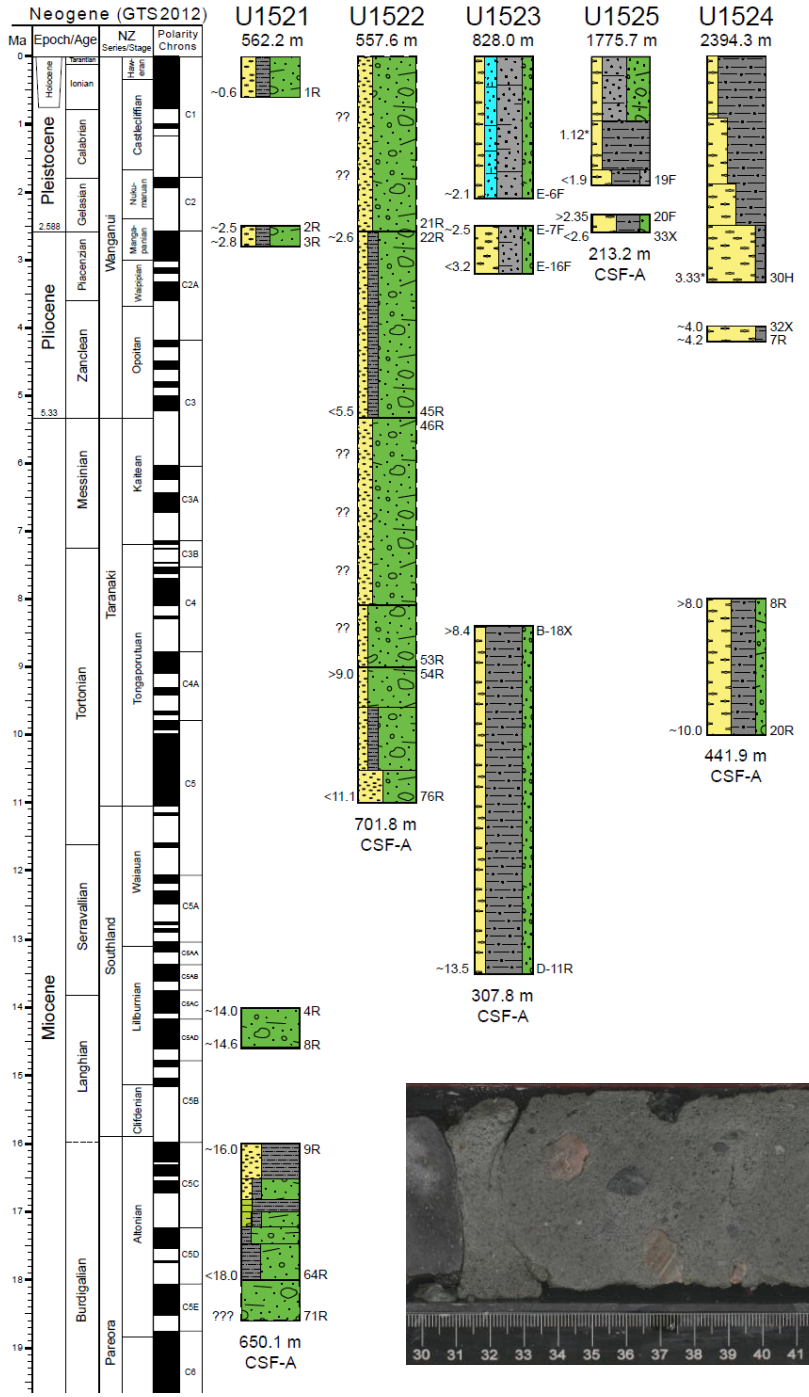
+ US-UK Thwaites Glacier Field programme (2018-2023)



- Correlation with benthic $\delta^{18}O$ and global sea level **indicates East Antarctic sea level contribution**
- ***ice in Wilkes Subglacial basin retreats during late Pleistocene interglacials***
- **regional warming above 2°C for extended periods** coincides with observed ice loss

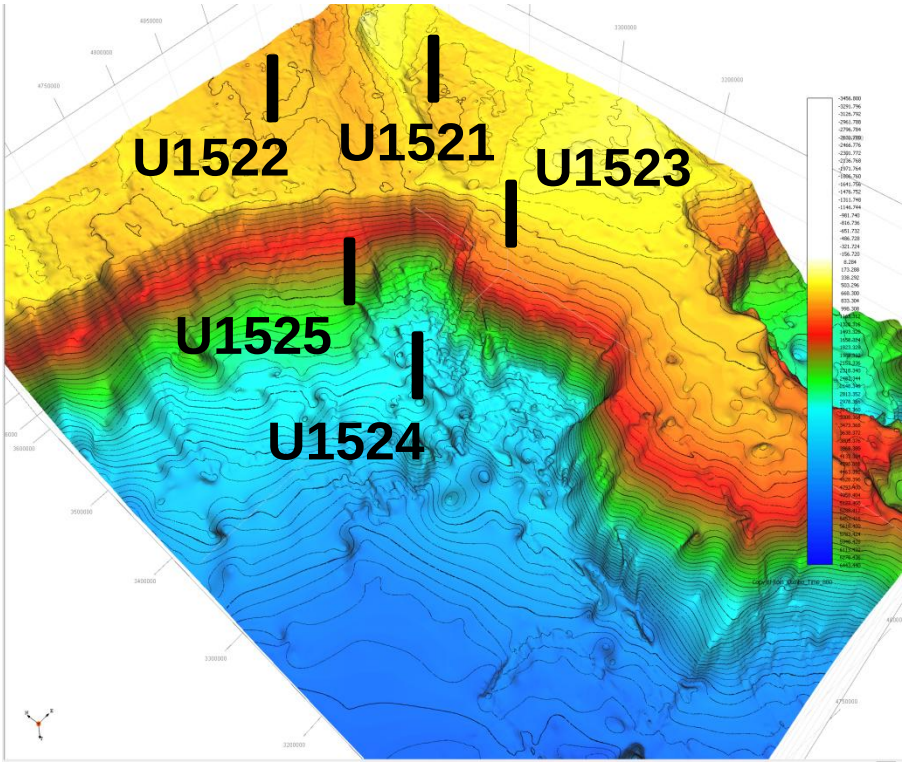
Wilson et al., 2018

IODP Exp. 374, Ross Sea West Antarctic Ice Sheet History, Jan – March, 2018



What did we achieve?

- 5 sites (three shelf and two rise)
- ~1700m of sediments recovered from ~3000m cored depth
- Ages: middle Miocene to recent
- Best ever recovery on the Antarctic shelf by conventional drilling (63.3% at U1521)

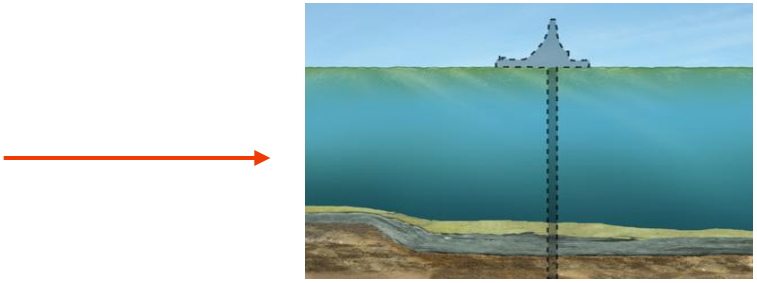


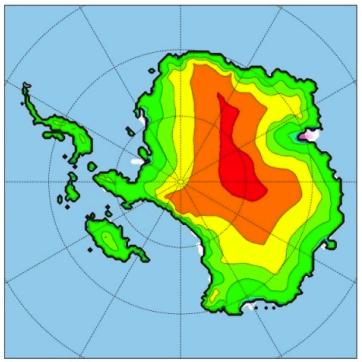
IODP Expedition 318: 'Wilkes Land'

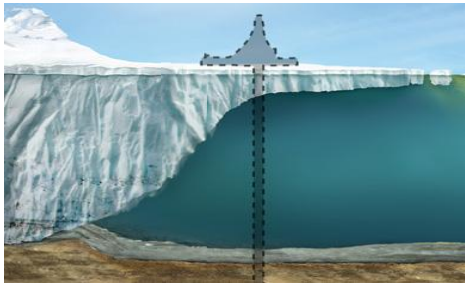
→ recovered fantastic records of Pliocene environmental conditions

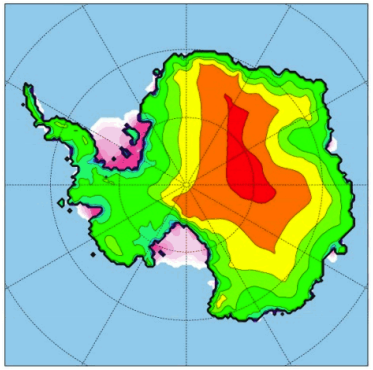
IODP
INTEGRATED OCEAN DRILLING PROGRAM

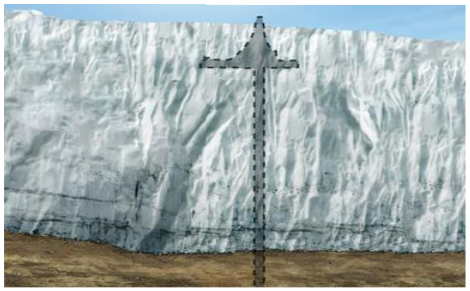
Drill core evidence of past WAIS collapse

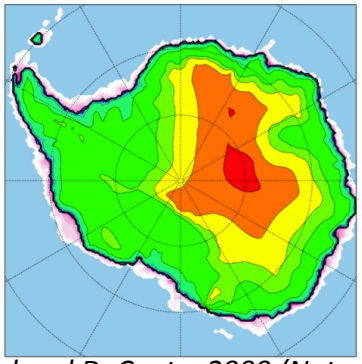






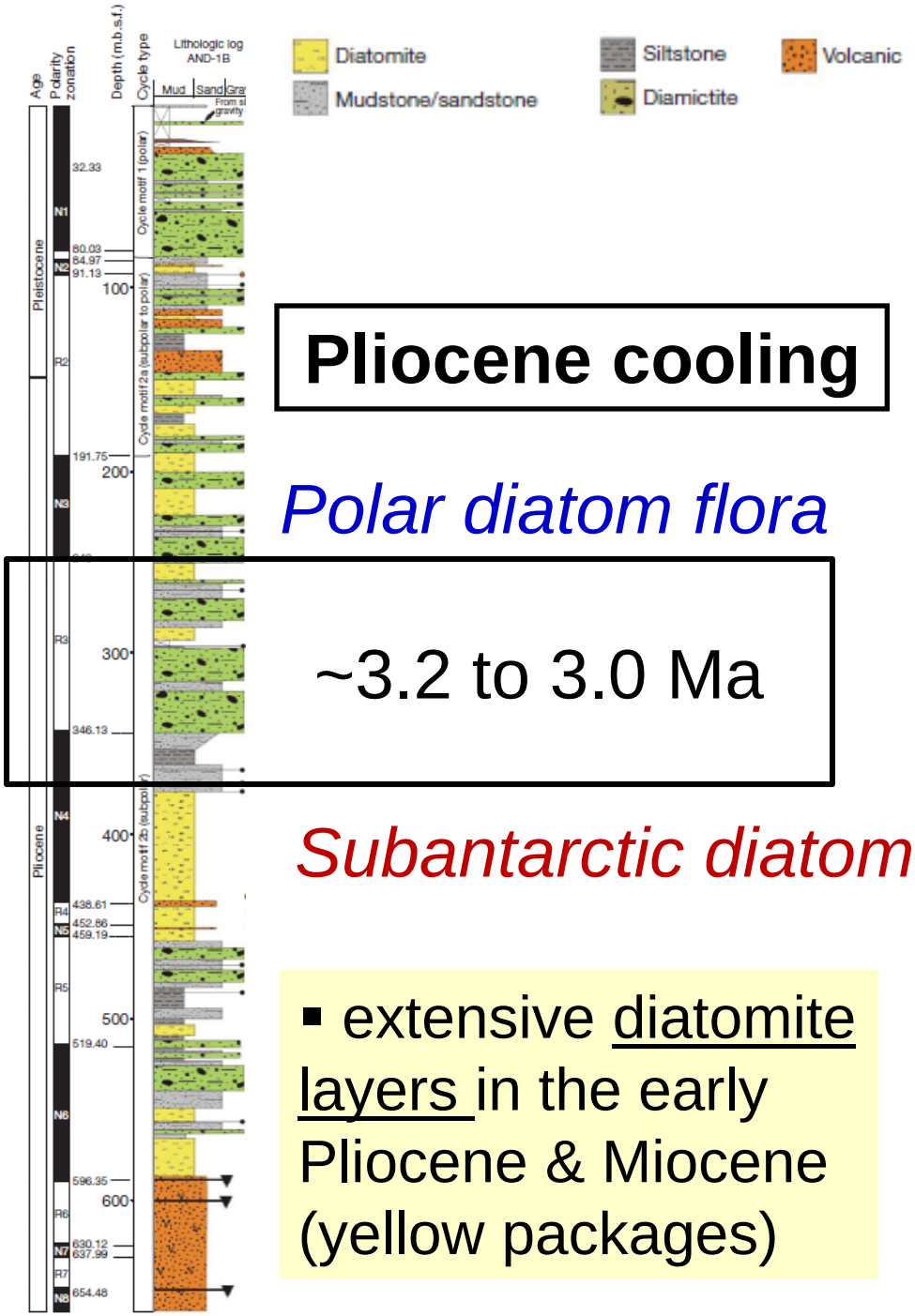






Pollard and DeConto, 2009 (Nature)

ANDRILL team

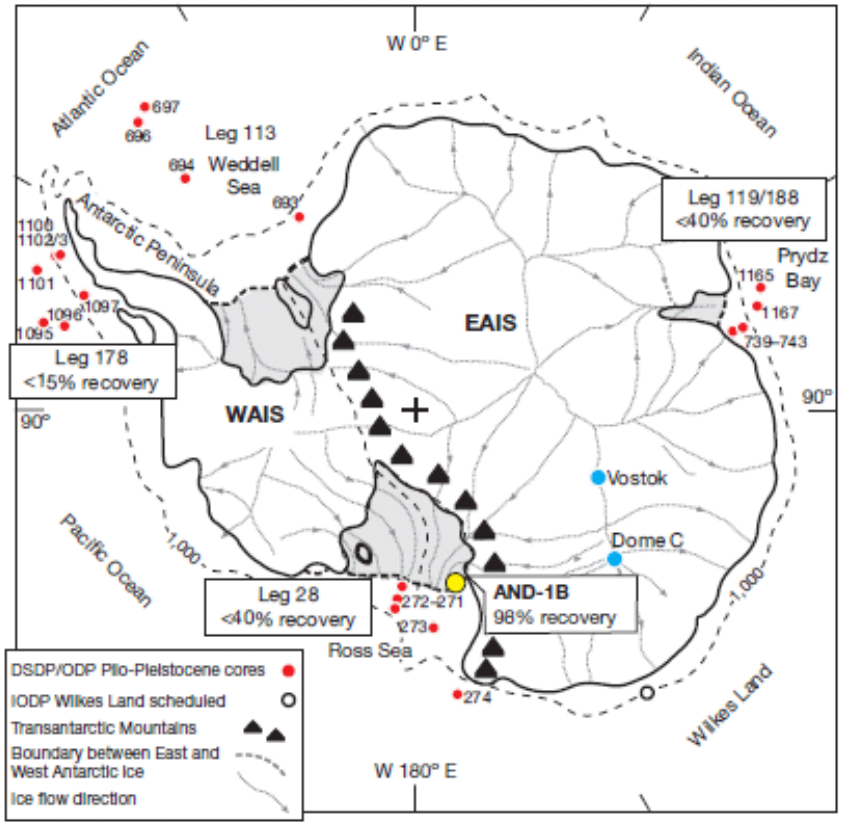


Pliocene cooling

Polar diatom flora

~3.2 to 3.0 Ma

Subantarctic diatom flora



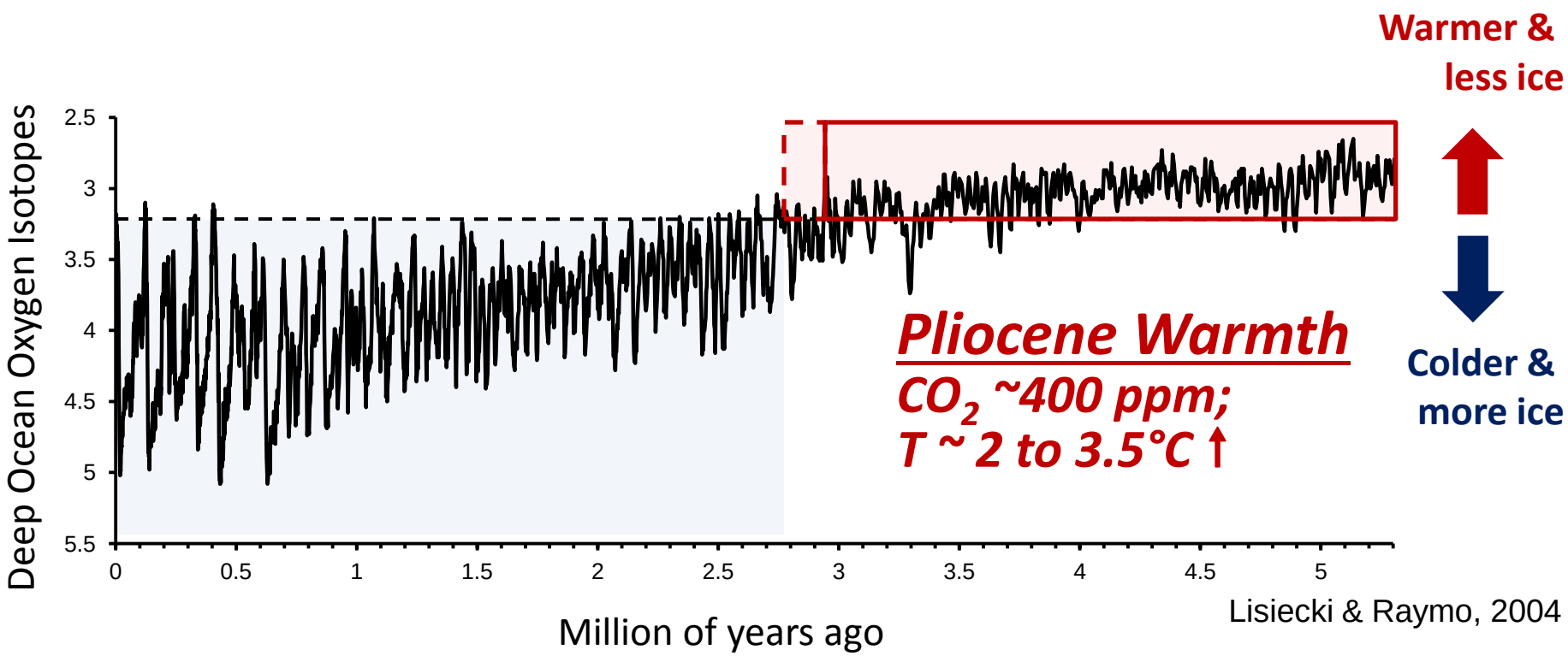
Naish et al., 2009
McKay et al., 2012

- extensive <u>diatomite layers</u> in the early Pliocene & Miocene (yellow packages)

⇨ **open water conditions in the Ross Sea**

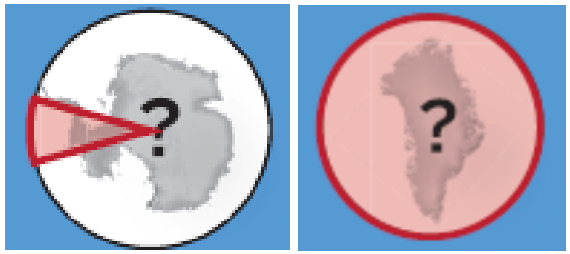
(no buttressing Ross ice shelf = collapsed WAIS)

The Pliocene



Lisiecki & Raymo, 2004

Global sea level ?



~5m + 53 m ~7 m

~10-20m ↑

Four Decades of Antarctic Drilling