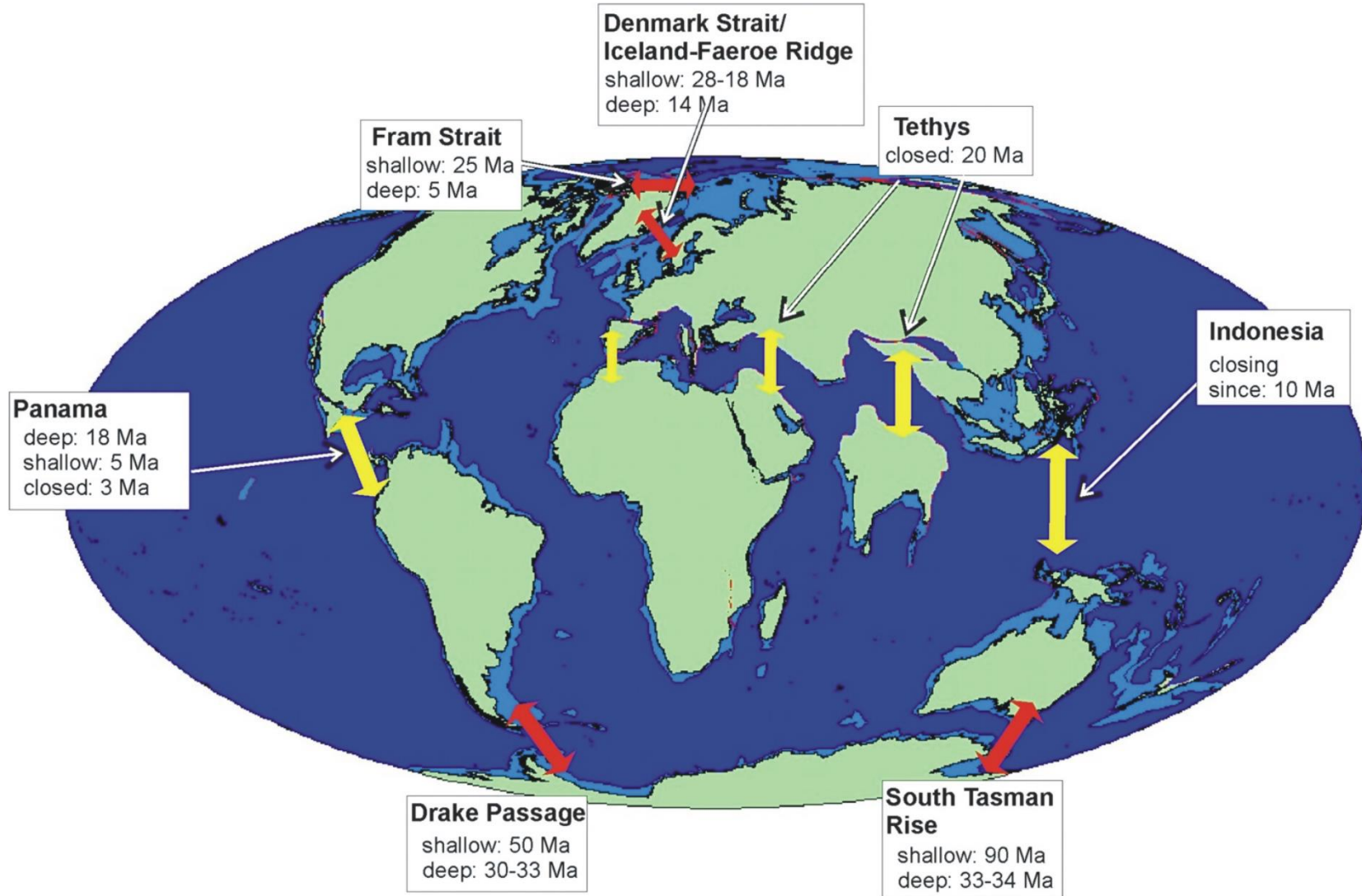
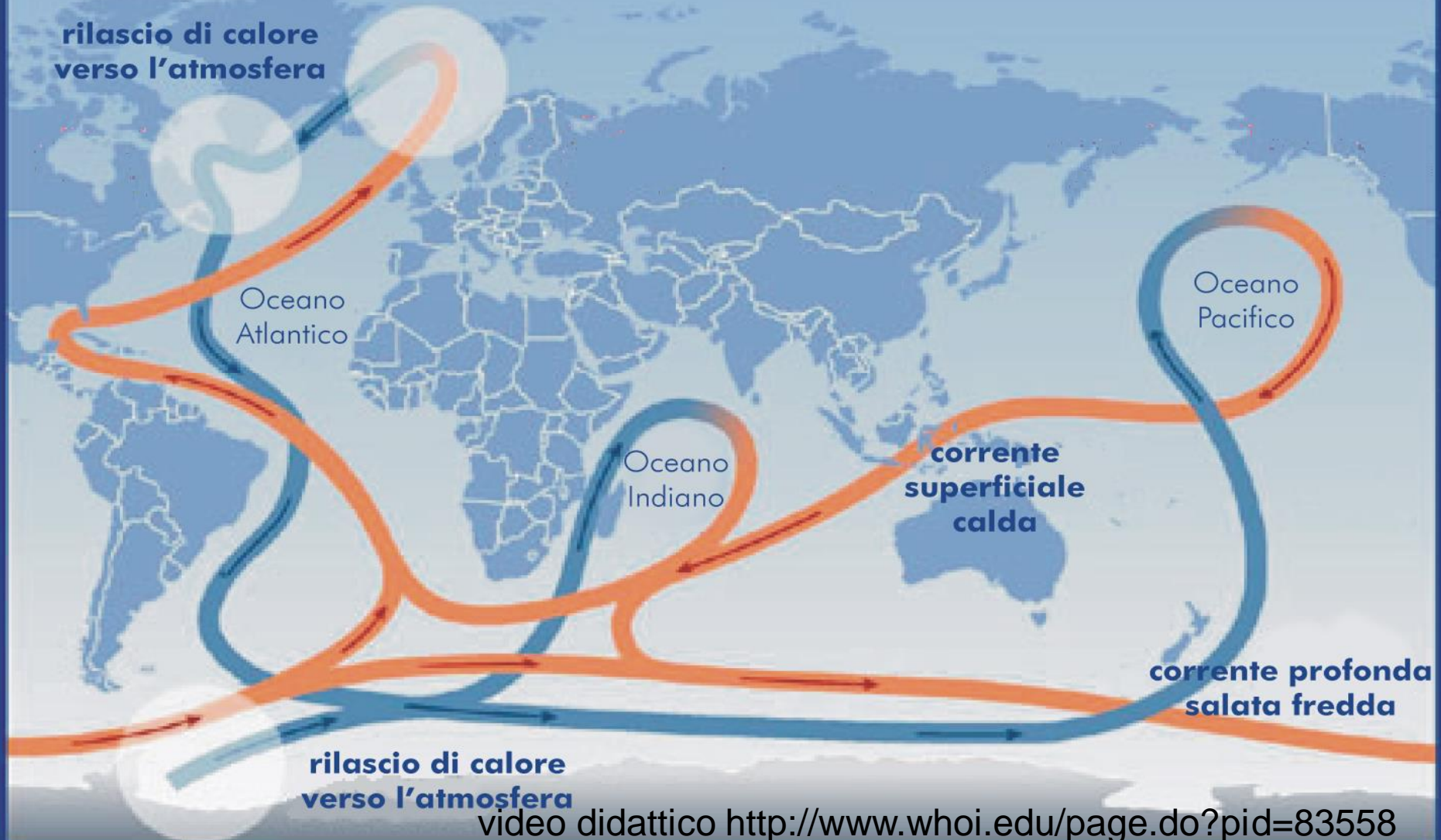


# Ocean Gateways



## CIRCOLAZIONE OCEANICA GLOBALE (CONVEYOR BELT)



video didattico <http://www.who.edu/page.do?pid=83558>

IPCC, 2001

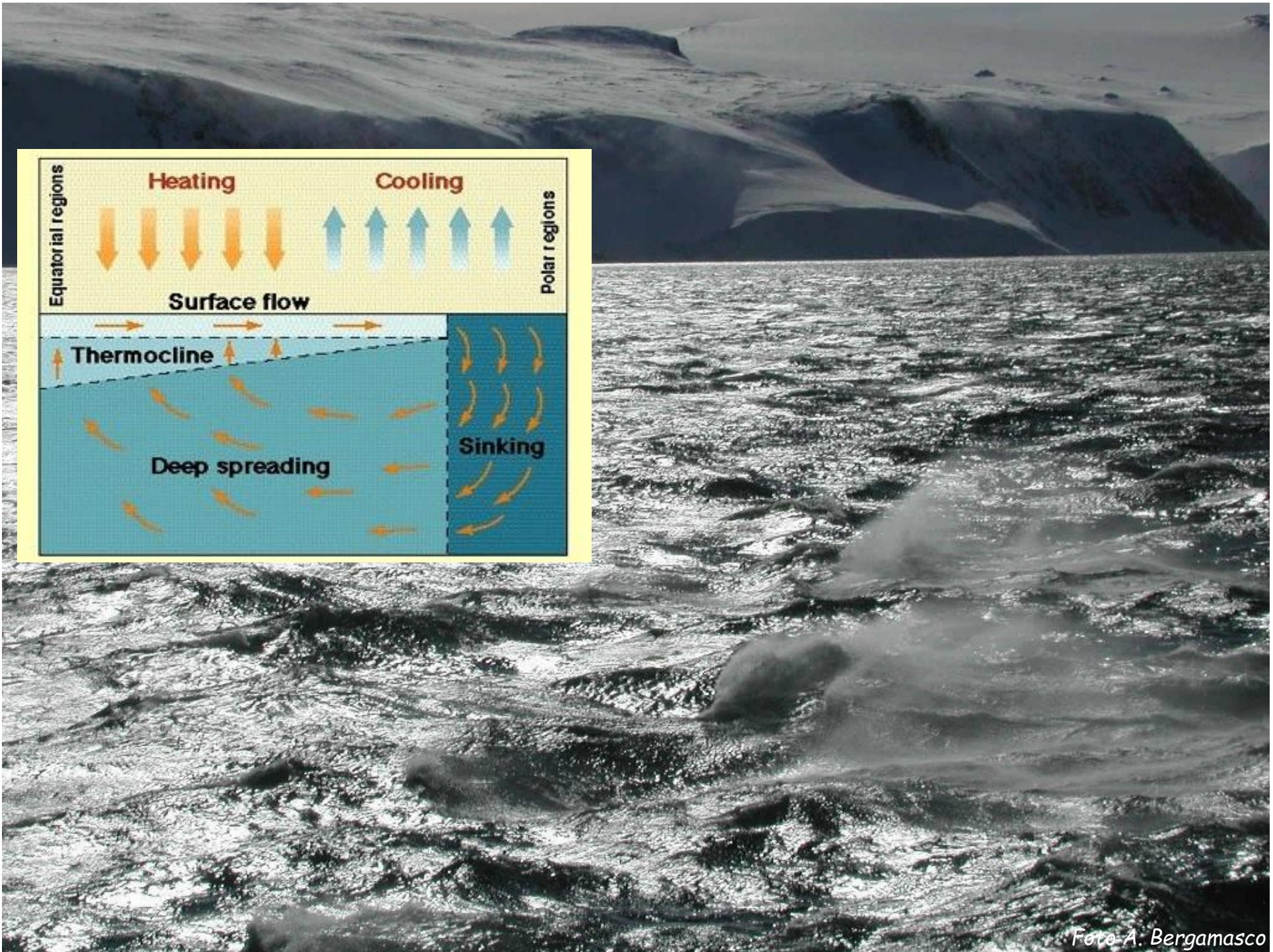


Foto A. Bergamasco



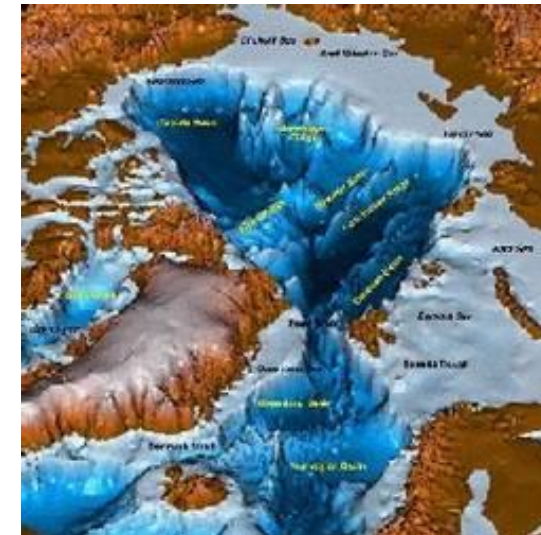
The main currents in the Arctic



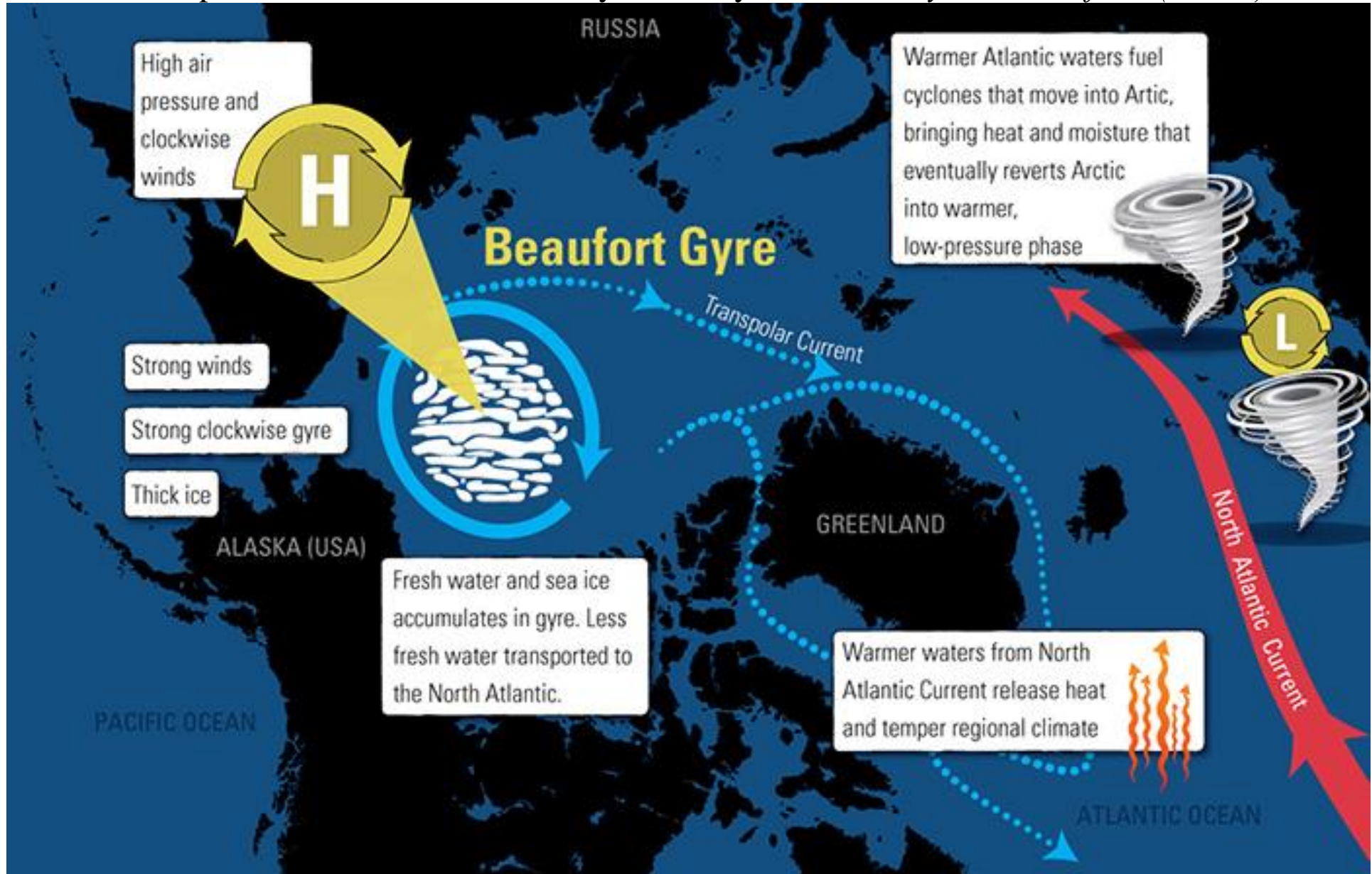
Outflow from the Arctic Ocean



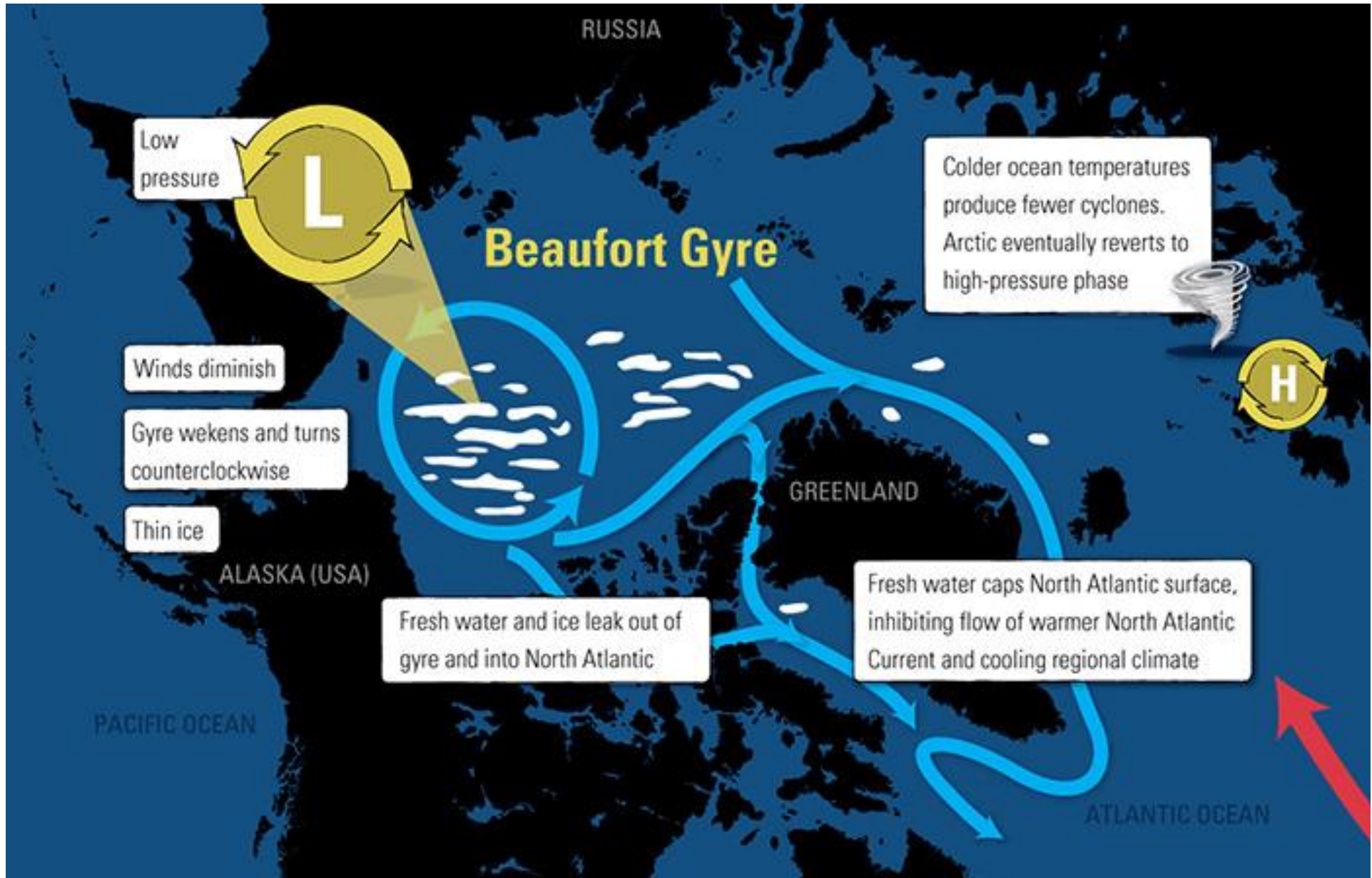
Areas of inflow for the Arctic Ocean



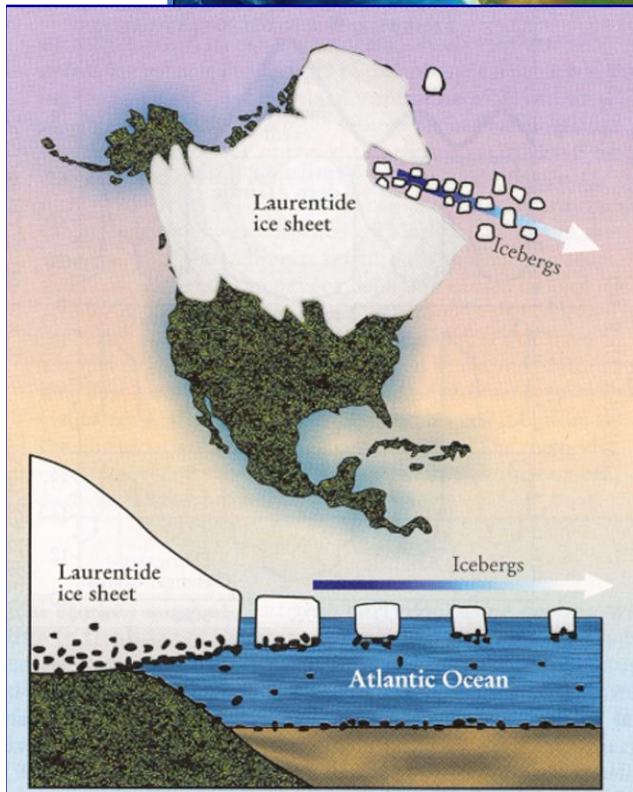
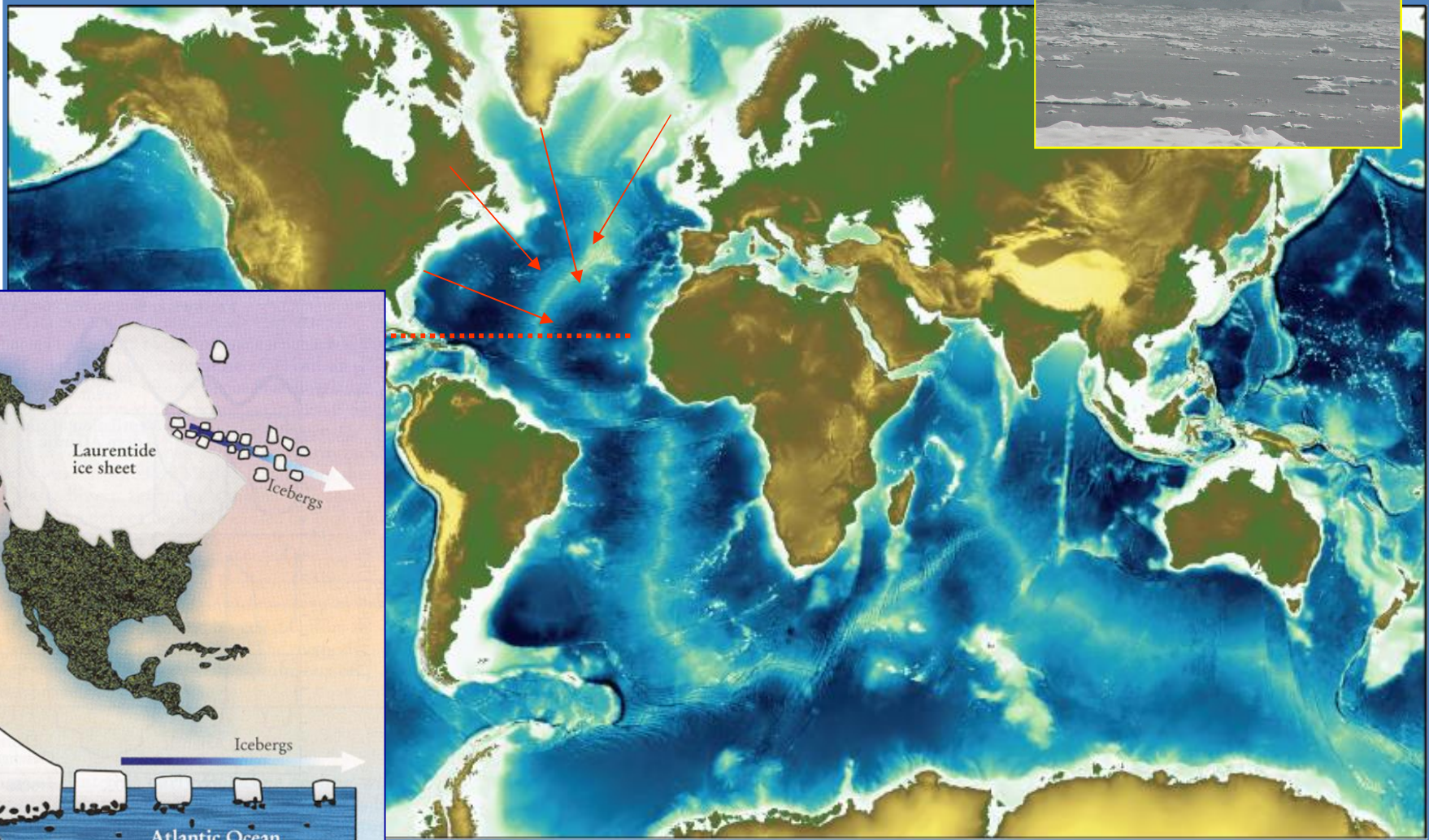
2015 Philosophical Transactions of the Royal Society, *Proshutinsky and Krishfield (WHOI), et al.*



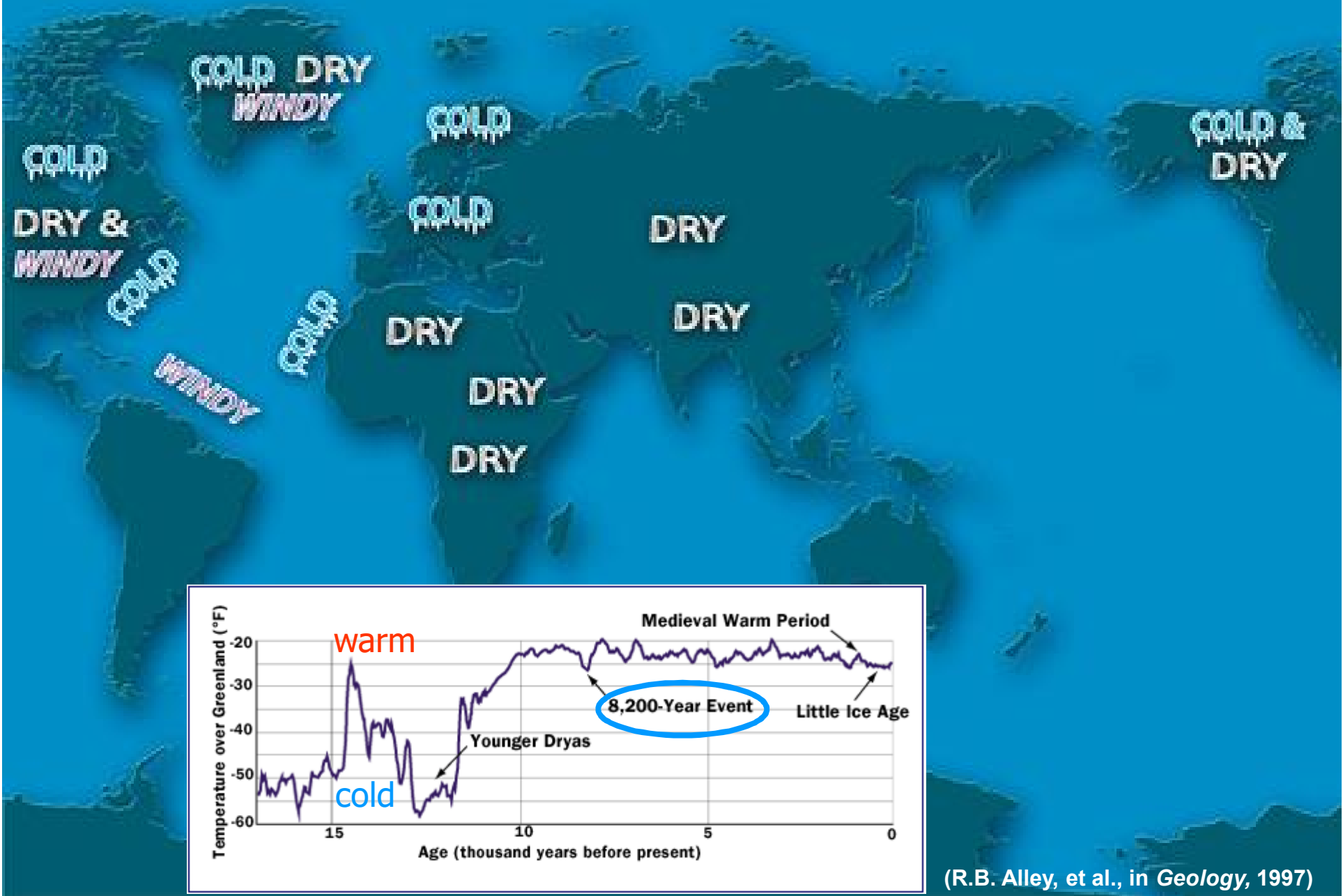
2015 Philosophical Transactions of the Royal Society, *Proshutinsky and Krishfield (WHOI), et al.*



# Iceberg discharge into the Atlantic Ocean 'HEINRICH EVENTS' 60 - 45 - 35 - 20 - 12 thousands of years ago



8200 years ago: a rapid global cooling following a warming period, lasted 100 years

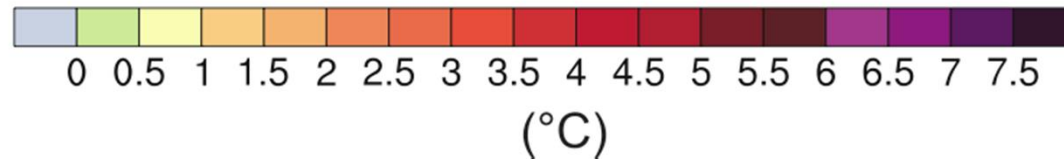
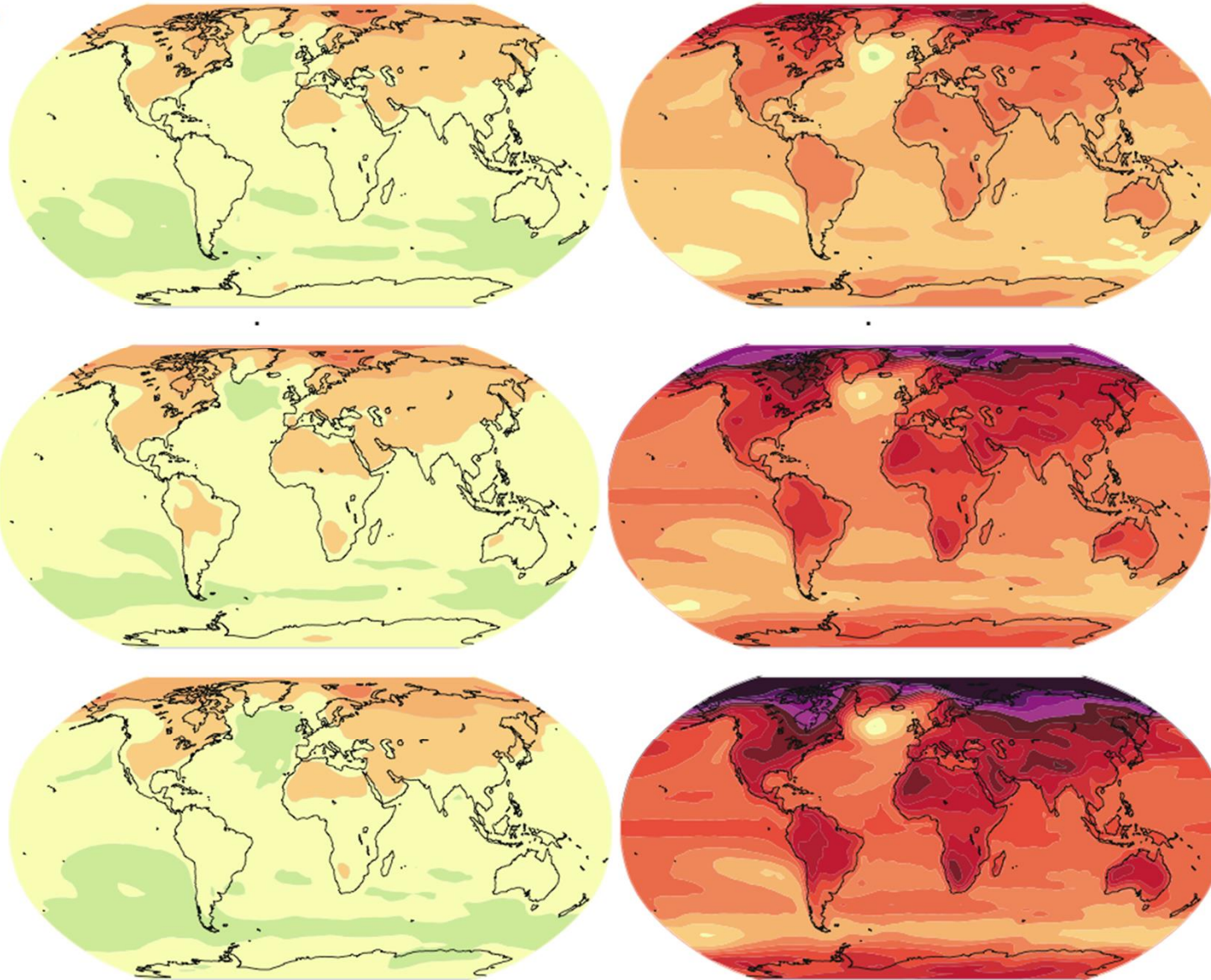


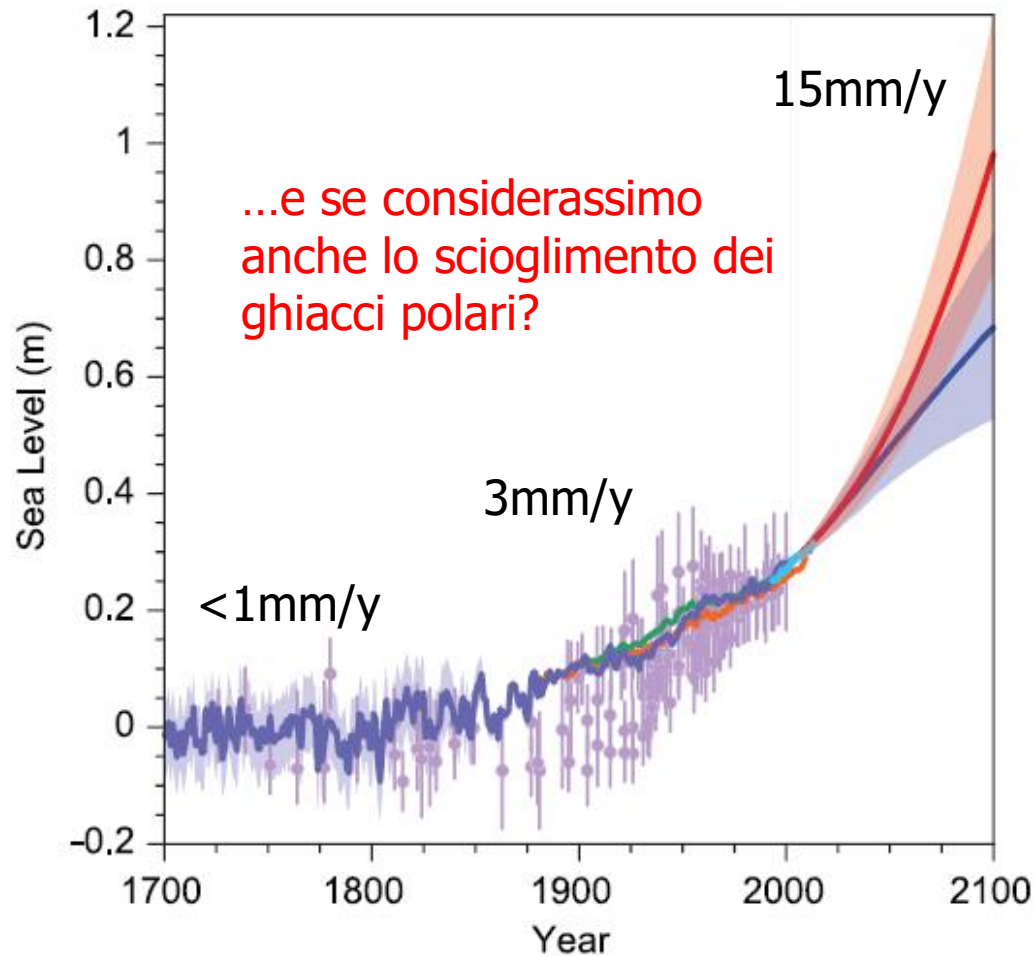
(R.B. Alley, et al., in *Geology*, 1997)



2020 - 2029

2090 - 2099



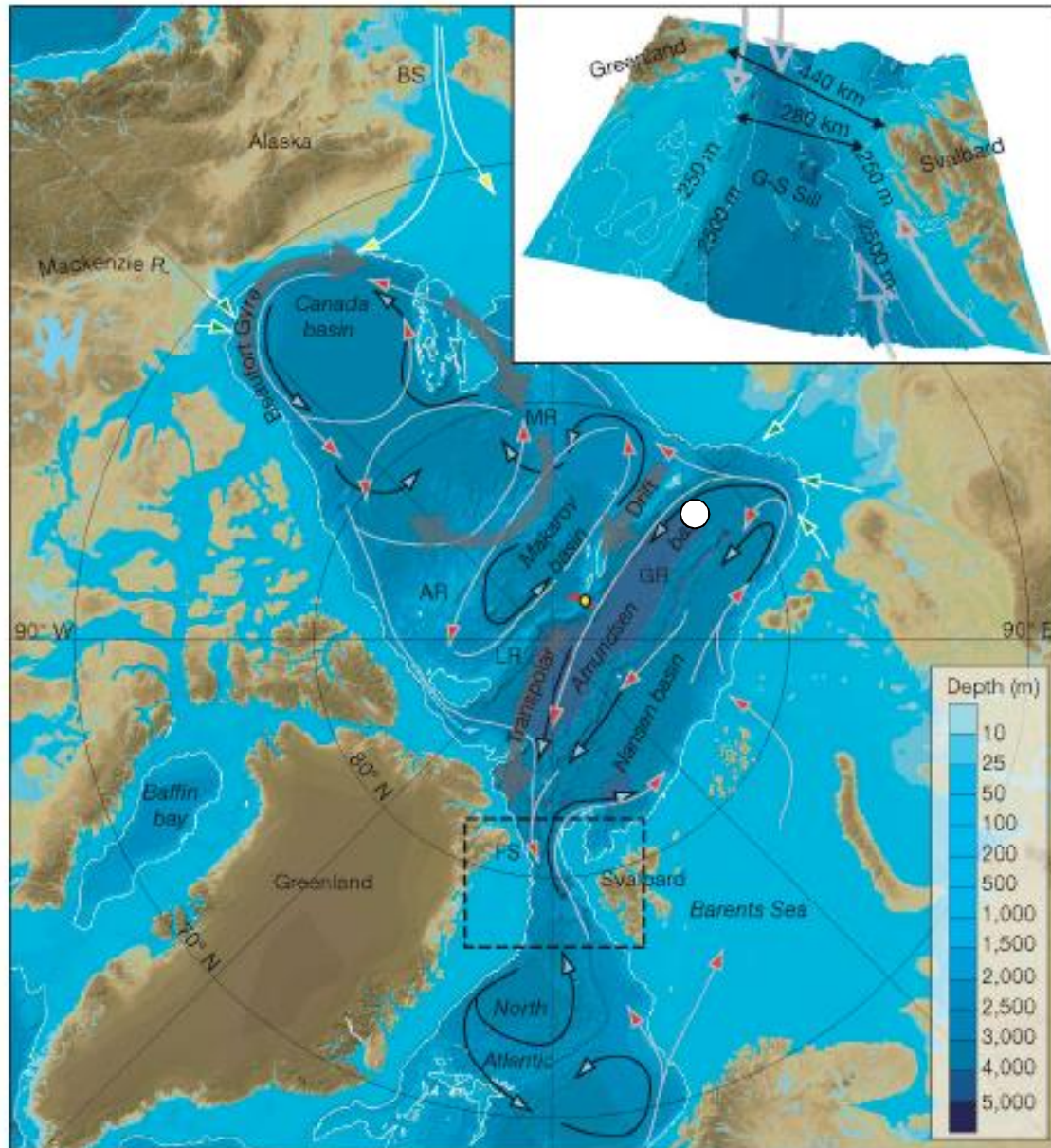


RCP 8.5  
(business as usual)

RCP 2.6

Representative  
(greenhouse gas)  
Concentration  
Pathways (RCPs)

*Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century....IPCC AR5, 2013*



### Still open questions:

When did the Arctic Ocean begin having its modern configuration?

When did the Fram Strait and Bering Strait fully open?

What is the origin of the Arctic Ocean ridges?

Ø. Engen et al. / *Tectonophysics* 450 (2008) 51–69

55

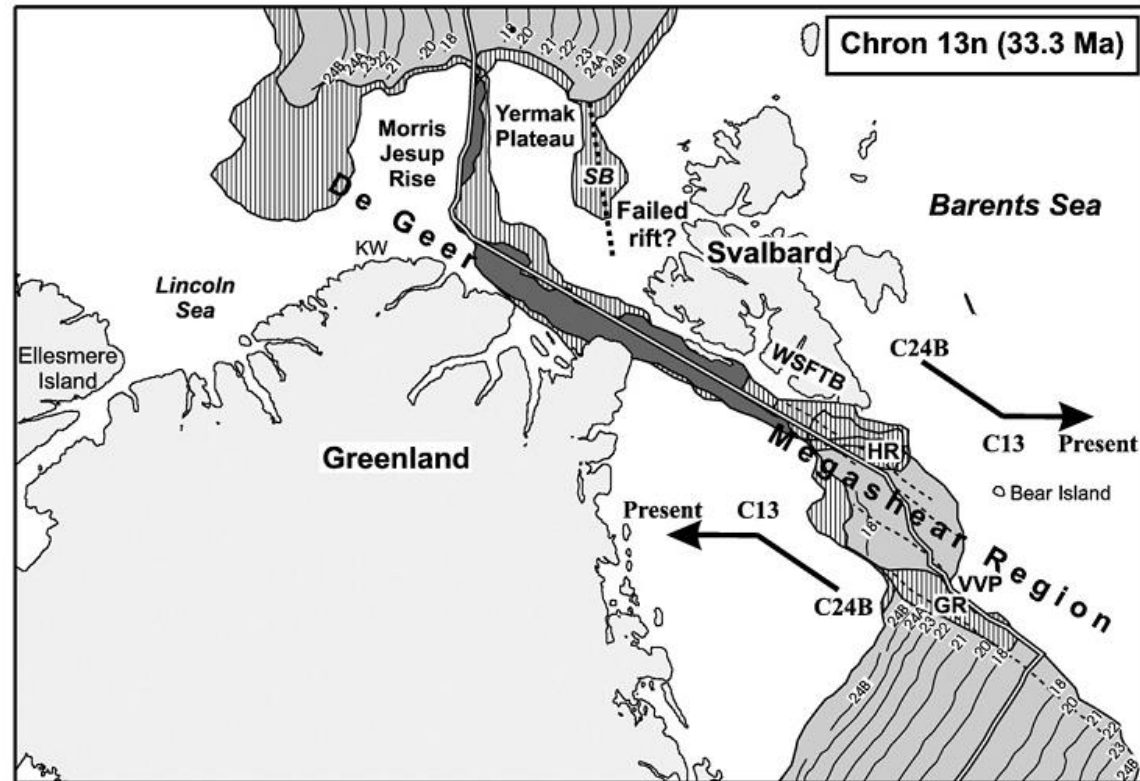
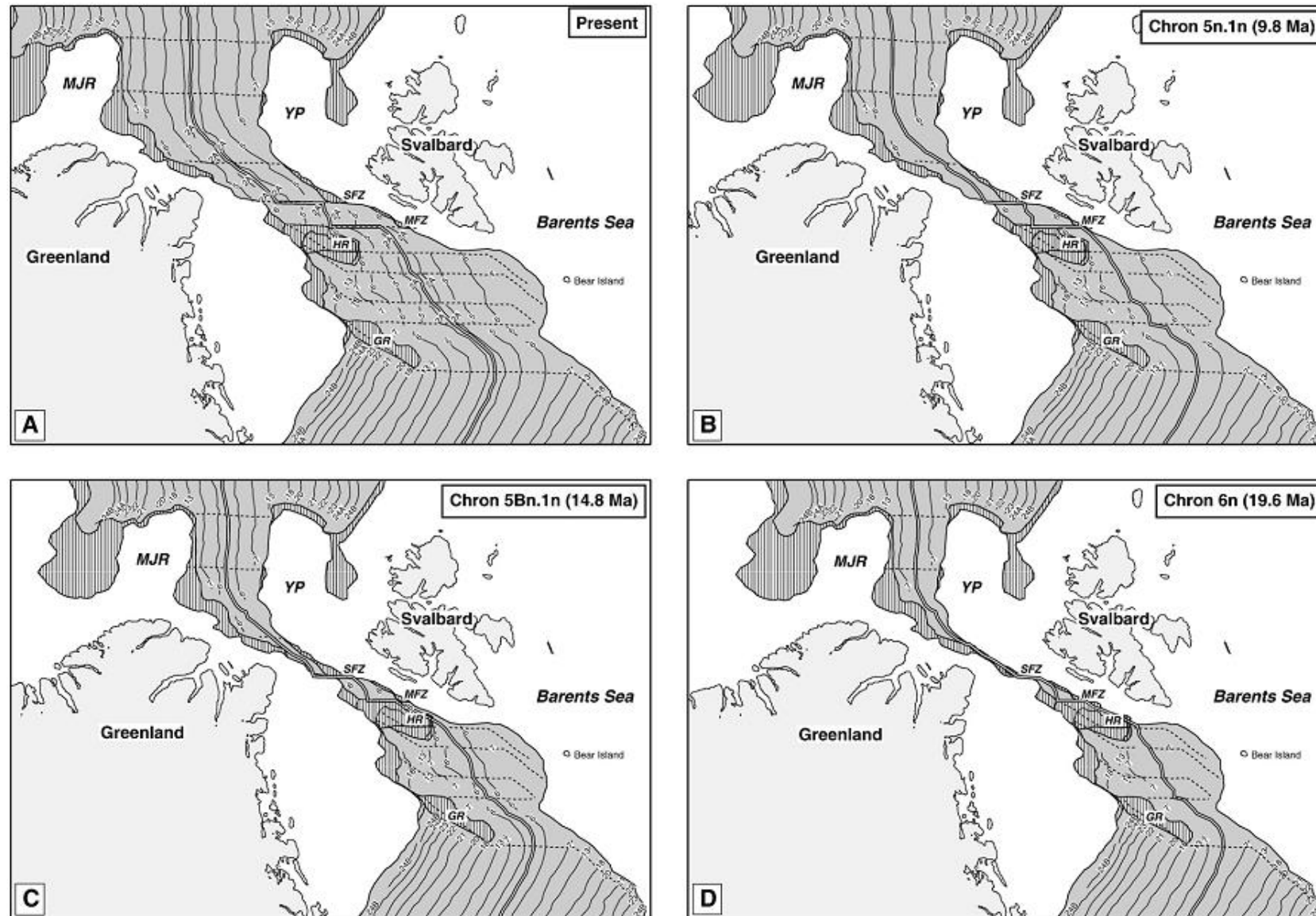


Fig. 4. Plate tectonic reconstruction of the Fram Strait region to Chron 13 times (earliest Oligocene), when relative plate motion between Greenland and Eurasia changed from right-lateral shear to oblique divergence (arrows). Area of crustal overlap (dark grey) indicates crustal stretching and thinning prior to breakup of the Lena Trough. The Sophia Basin (SB) may be a failed Eocene attempt to connect the Eurasia Basin and the Norwegian–Greenland Sea and might have facilitated early water exchange. WSFTB, West Spitsbergen Fold and Thrust Belt; other abbreviations as in Figs. 1 and 2.



Ø. Engen et al. / Tectonophysics 450 (2008) 51–69

Fig. 12. Plate tectonic reconstruction of the Fram Strait gateway. Eurasia is kept fixed and Greenland and North America rotated using the poles in Table 1. Oceanic crust is shaded and magnetic seafloor spreading anomalies shown as annotated bold lines. COT and uncertain crustal provinces hachured as in Fig. 2. Flowlines of relative plate motion shown by dashed lines. Reconstructions indicate (A) present-day Lena Trough; (B) Development of first well developed seafloor spreading anomalies during late Miocene times (~10 Ma); (C) Formation of an initial, narrow oceanic corridor during early Miocene times (20–15 Ma); and (D) closure between Svalbard and NE Greenland prior to early Miocene times (~20 Ma).



L'Italia (Prof. D. Rio Univ. Padova, micropaleontologo) ha partecipato all'unica perforazione profonda effettuata nell'Oceano Artico dall'Integrated Ocean Drilling Program, il leg 301 IODP ACEX del 2004.

Durante tale leg sono stati prelevati 400 m circa di sedimenti sul Lomonosov ridge



La perforazione ha rivelato che le glaciazioni sono più antiche di quanto si era precedentemente stimato: ci sono IRD (Ice rafted debris) trasportati da icebergs e/o sea ice fino al entro dell'Artico e rilasciati in sedimenti di 17 milioni di anni. Precedentemente erano stati documentati solo in sedimenti di 6-10 Ma



**Vidar Viking**

**Oden**

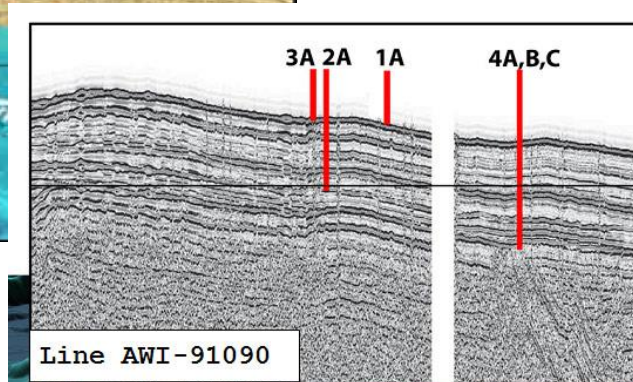
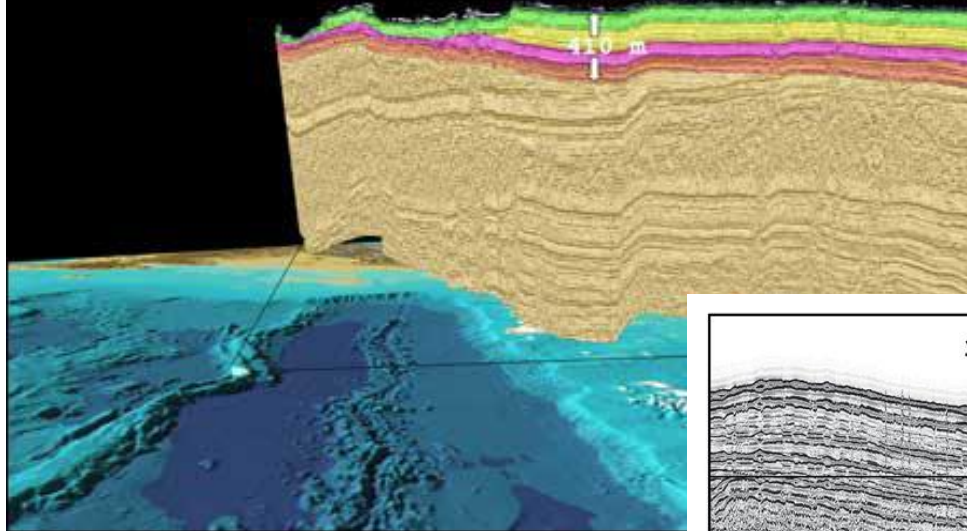
**Sovetskiy  
Soyuz**

**Vidar Viking could keep its position for max. 9 days**



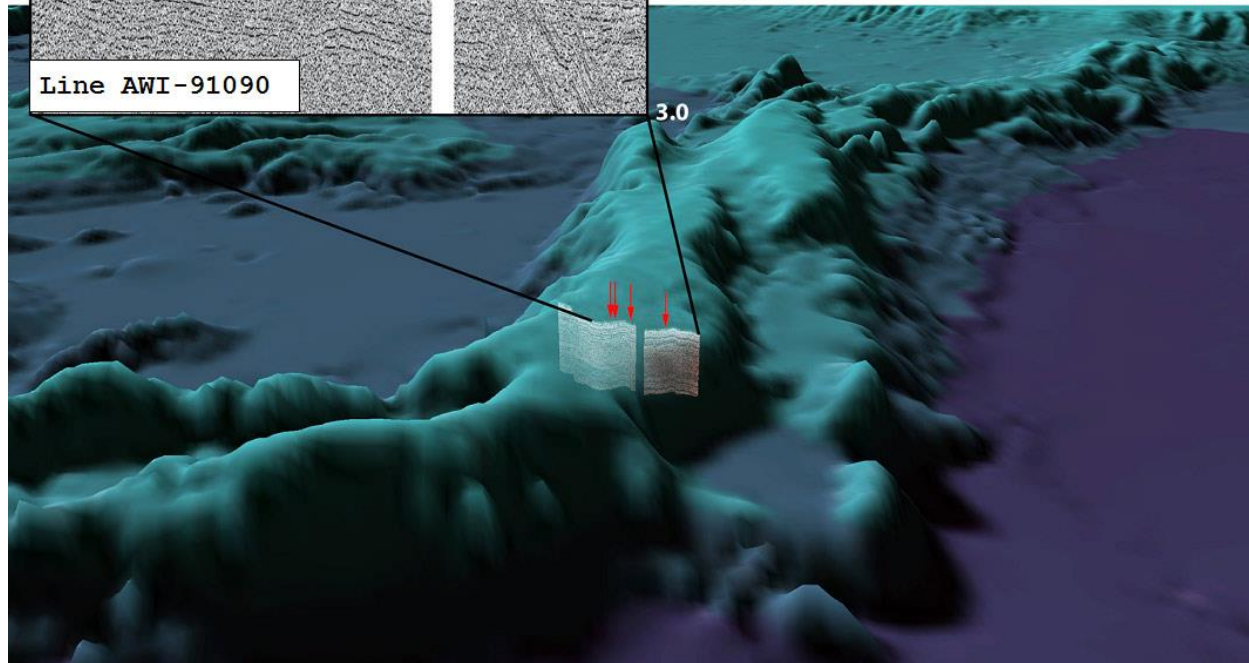


Seismic Reflection Cross-Section of the Lomonosov Ridge (AWI-91091) at ~87° 40' N  
Jokat et al., 1992; 1995



Terminal Depths:

Site M0001:	—
Site M0002:	272.7 m
Site M0003:	15.0 m
Site M0004:	427.9 m



## IODP leg 302 in the Arctic Ocean (2004)

Co-chiefs: Backman, J., Moran, K., Evans, D.,

- “ Provided the timing of the deep. water connection to the North Atlantic Ocean of the Arctic Ocean: a key driver of the deep. water formation in the North Atlantic and Arctic Oceans, which in turn is a key driver of global climate.
- “ Confirmed that the Lomonosov Ridge is constructed of continental crust, genetically linked to the Barents Shelf.
- “ Revealed that the Cenozoic cooling in the Arctic occurred 17 Ma and possibly of 46 Ma ago, synchronously with that in the Antarctic, contrary to previous hypotheses.

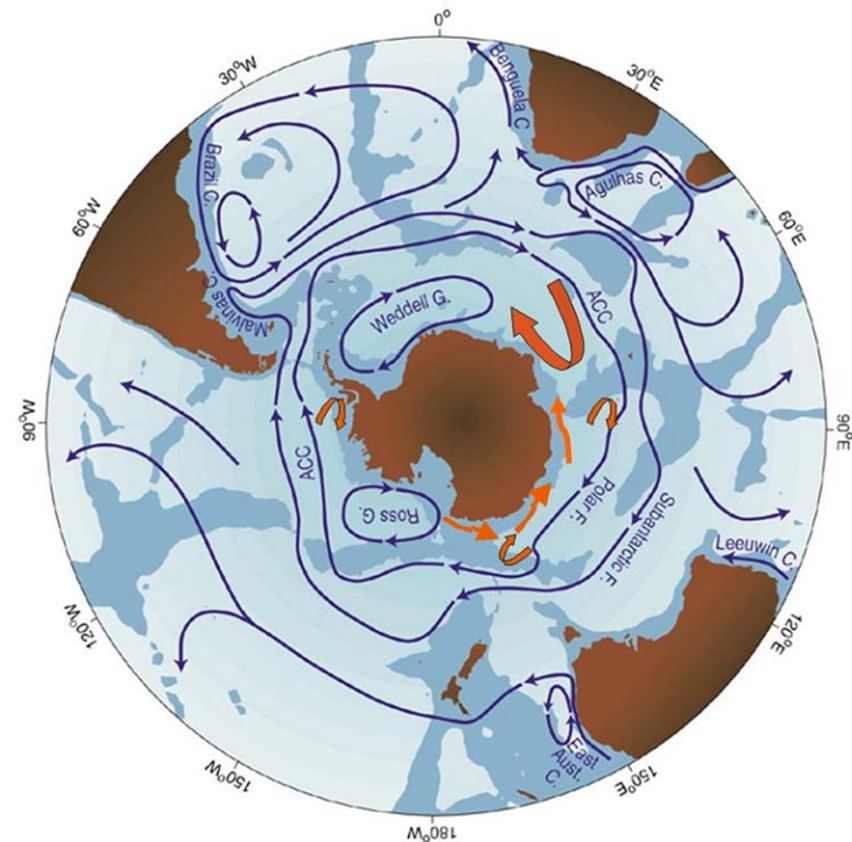
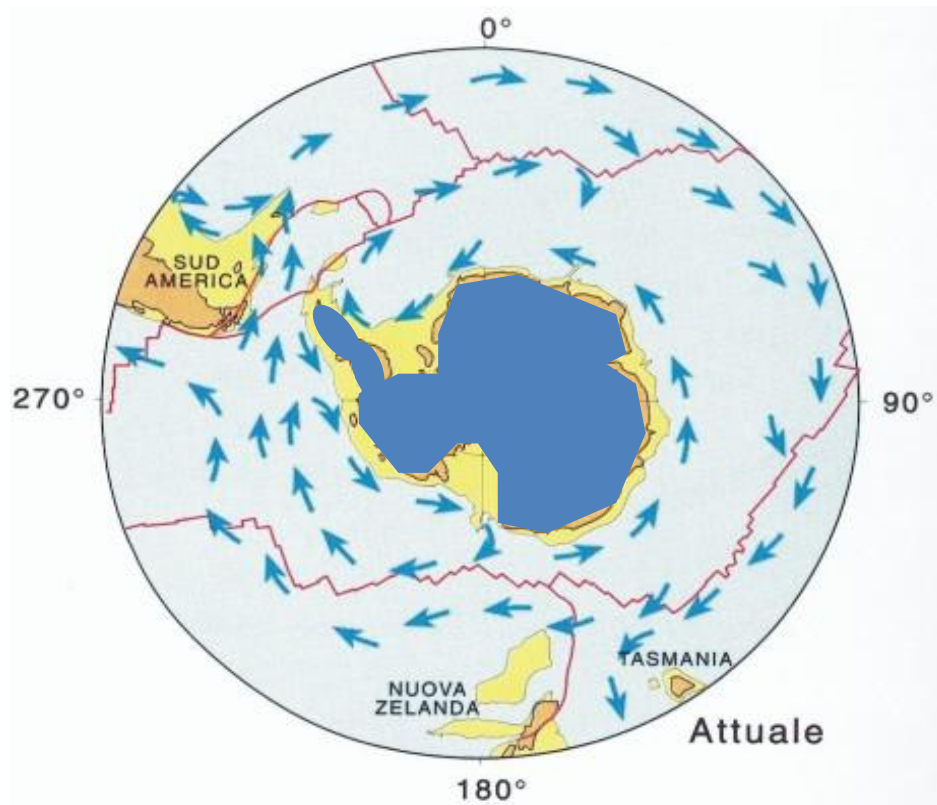
Condizioni ambientali tipiche degli attuali regimi tropicali 55 Milioni di anni fa, con scarsa ventilazione, acqua dolce e condizioni anossiche (Arctic pond) intorno a 48.5 milioni di anni fa (rocce madri di idrocarburi)



ACC transport of 100-150 Sverdrups ( $1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1}$ ).

Mean ACC temperature ranges from  $-1$  to  $5^\circ\text{C}$ , depending on the time of year and location. The mean surface salinity decreases poleward, in general, from 34.9 at  $35^\circ\text{S}$  to 34.7 at  $65^\circ\text{S}$ .

The ACC extends from the sea surface to depths of 2000-4000 m and can be as wide as 2000 km. ACC flows eastward at  $20 \text{ cm s}^{-1}$  in regions between the fronts, driven by strong westerly winds. The average wind speed between  $40^\circ\text{S}$  and  $60^\circ\text{S}$  is 15 to 24 knots with strongest winds typically between  $45^\circ\text{S}$  and  $55^\circ\text{S}$ .



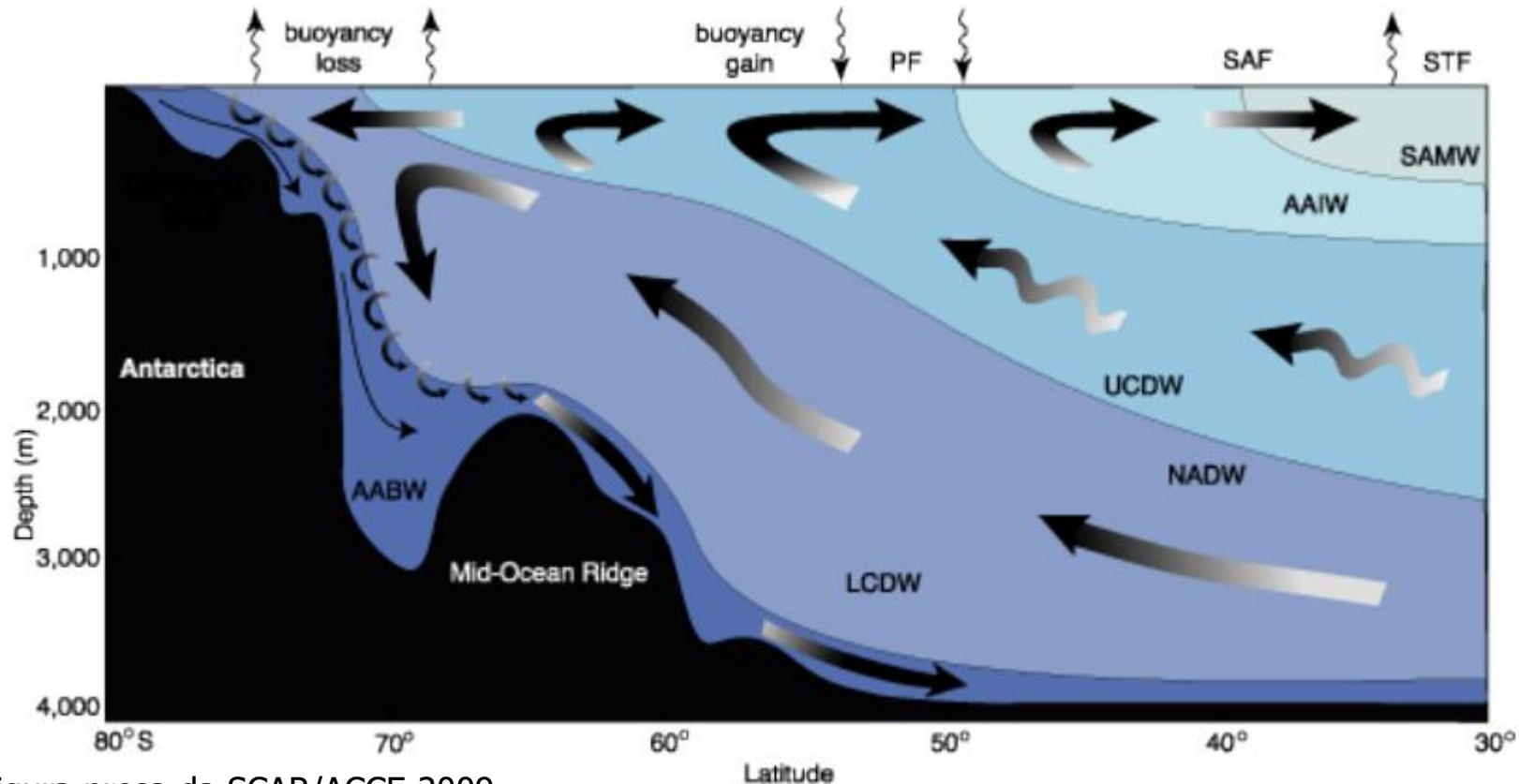
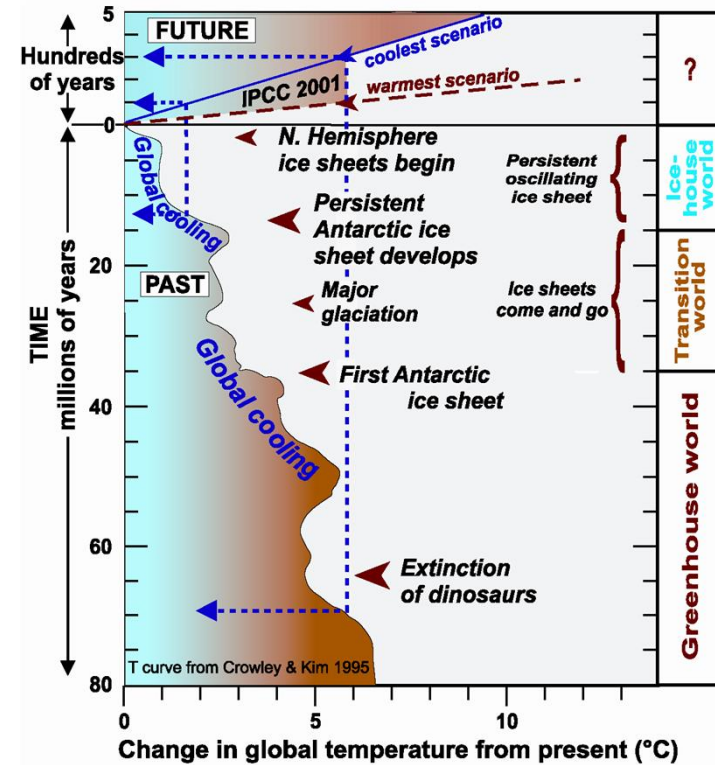
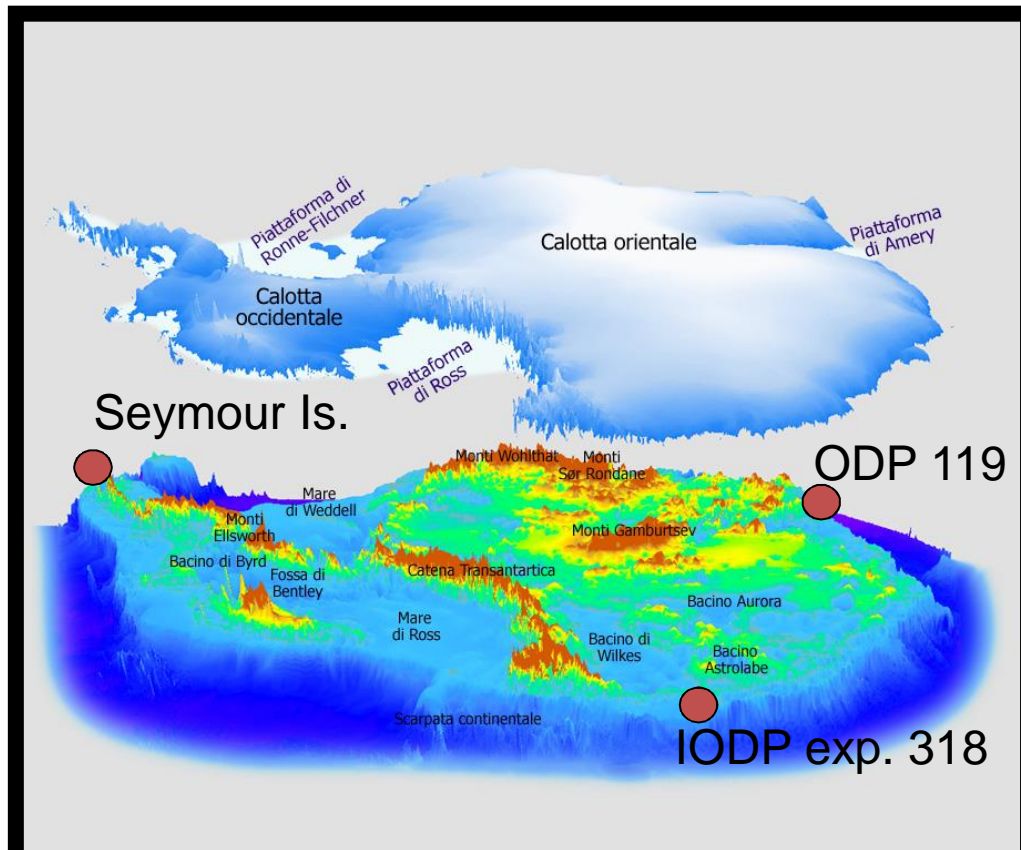
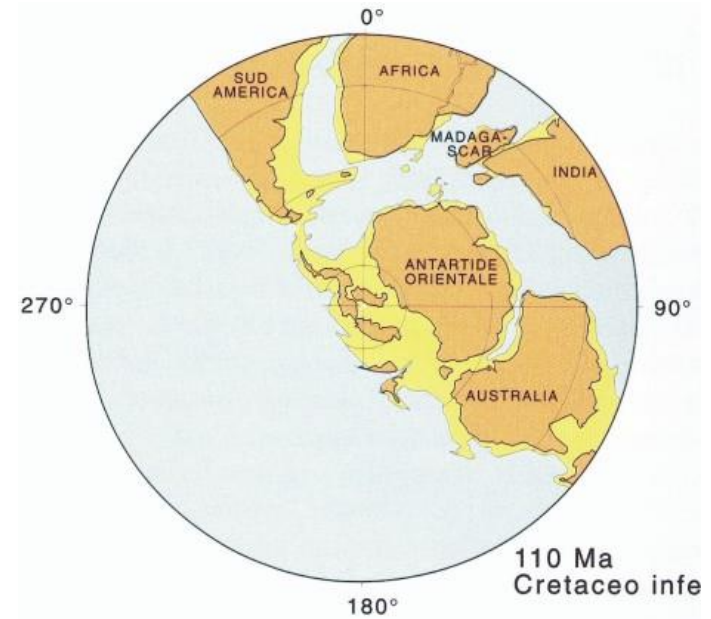


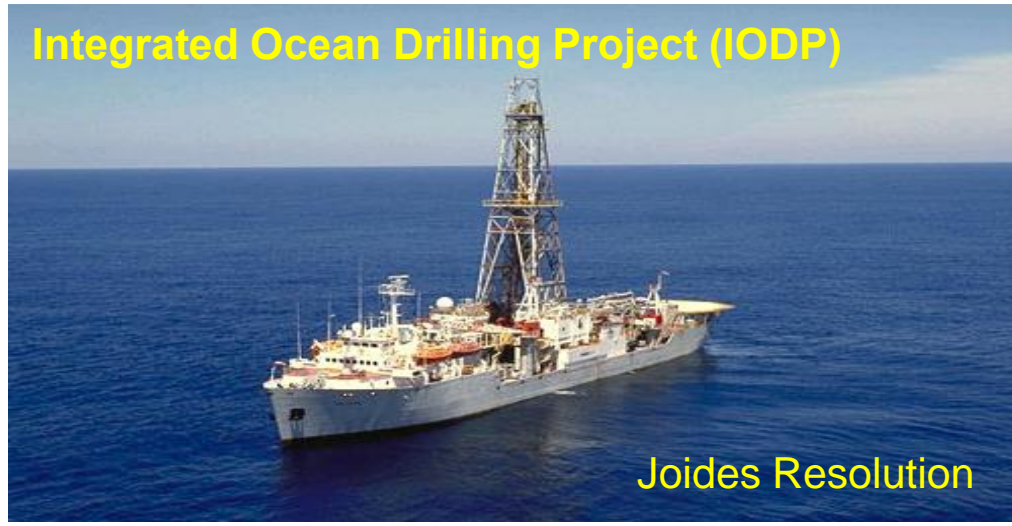
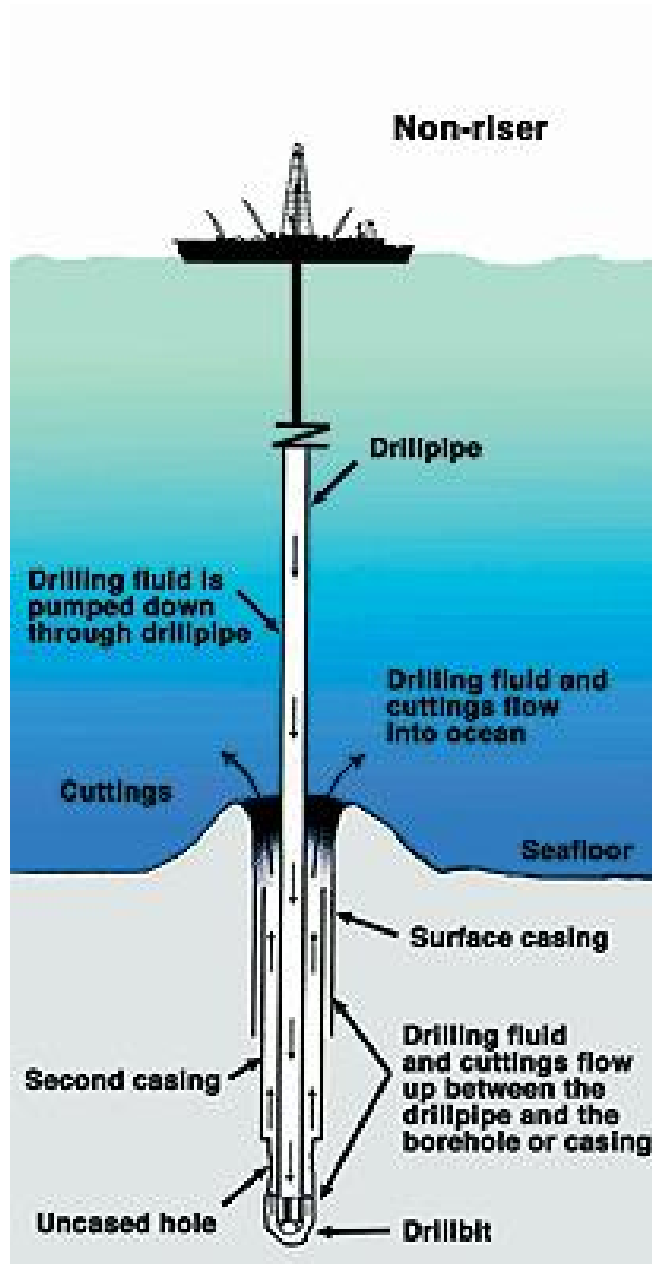
Figura presa da SCAR/ACCE 2009

PF . Polar Front; SAF . Sub-Antarctic Front; and STF . Subtropical Front  
AABW . Antarctic Bottom Water; LCDW and UCDW, Lower and Upper Circumpolar Deep Waters; NADW . North Atlantic Deep Water; AAIW . Antarctic Intermediate Water and SAMW . Sub-Antarctic Mode Water (from Speer et al., 2000).



Greenhouse world

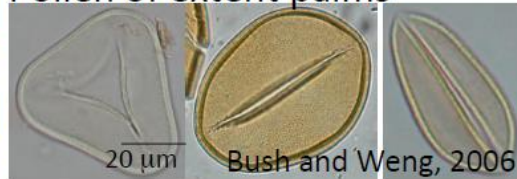




# Pollen from the e. Eocene peak greenhouse conditions Wilkes Land IODP Site 1356



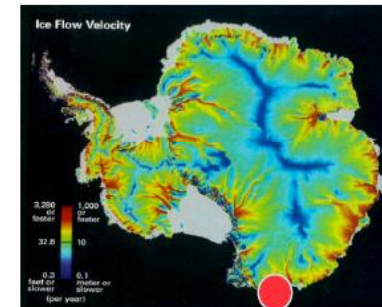
Pollen of extent palms



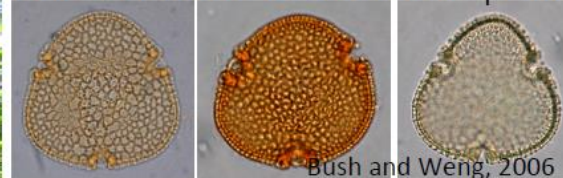
Pollen from Wilkes Land



Mean Annual T: >13.3 °C  
Cold Month mean T: >5°C + 3°C  
Warm Month mean T: >22.8 °C



Pollen of extent Bombacaceae plants



Pollen from Wilkes Land

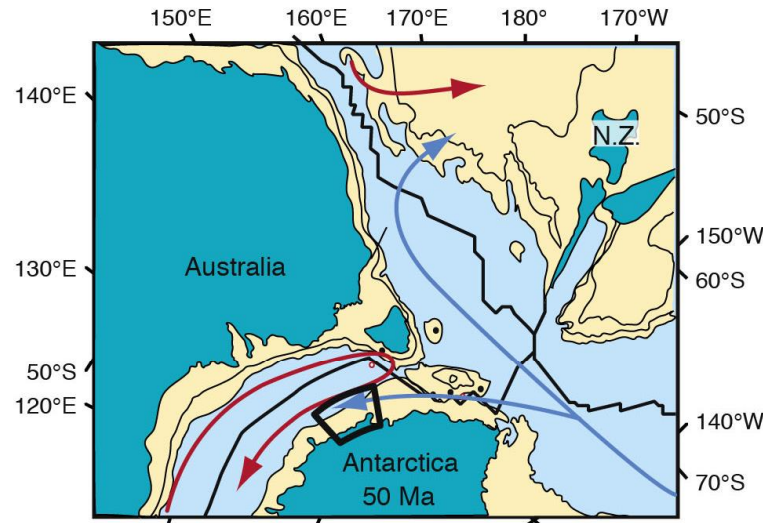


Mean Annual T: >16.8 °C  
Cold Month mean T: >10.6 °C + 3°C  
Warm Month mean T: >21.5 °C

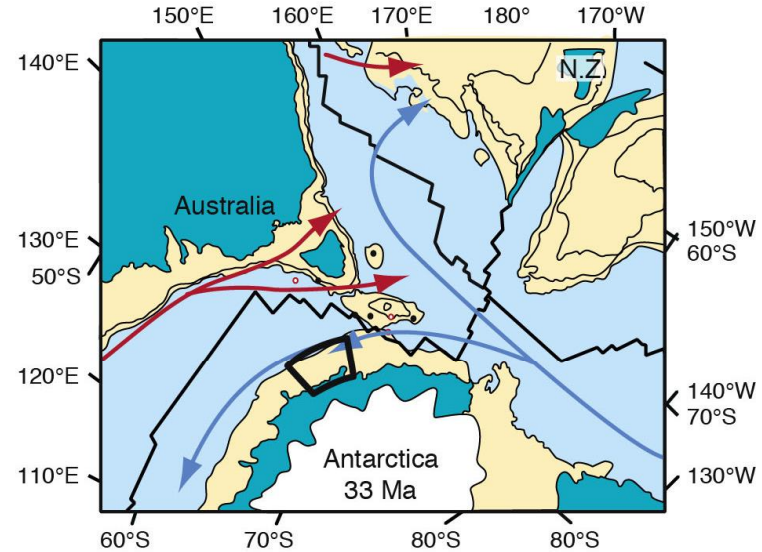
*Pross et al., Nature, 2012*  
*Contreras et al., 2013*



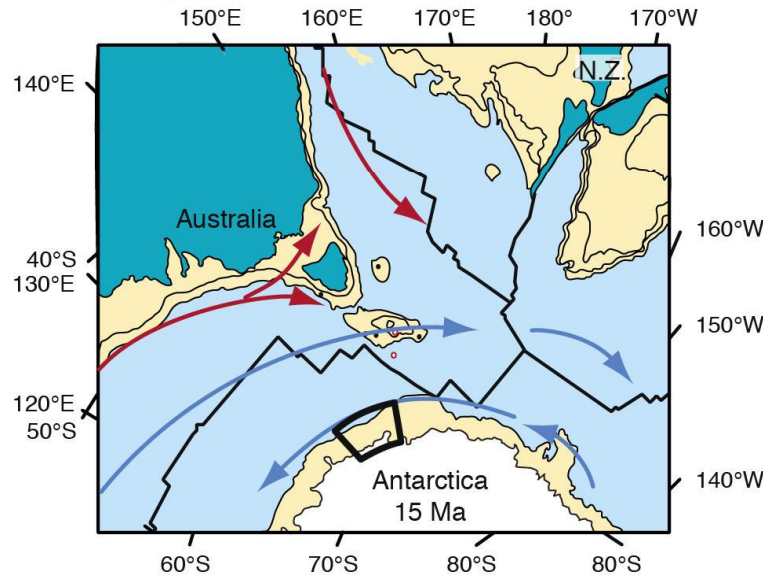
### A. 50 Ma, Early Eocene








### B. 33 Ma, Early Oligocene



### C. 15 Ma, Middle Miocene



-  IODP 318 sites
-  Warm currents
-  Cool currents
-  ODP Leg 189 sites
-  DSDP Leg 29 sites

Eocene records of Antarctic vegetation and landscape history (e.g. Lewis et al., 2007, Hambrey et al., 2007, Wilson et al., 2011).

The Eocene/Oligocene boundary unconformity was crossed by exp. 318, and sub-tropical vegetation was found at 53.6. 51.9 Ma in the early Eocene (Pross et al., 2012).

LETTER

IODP Exp. 318 (2010)

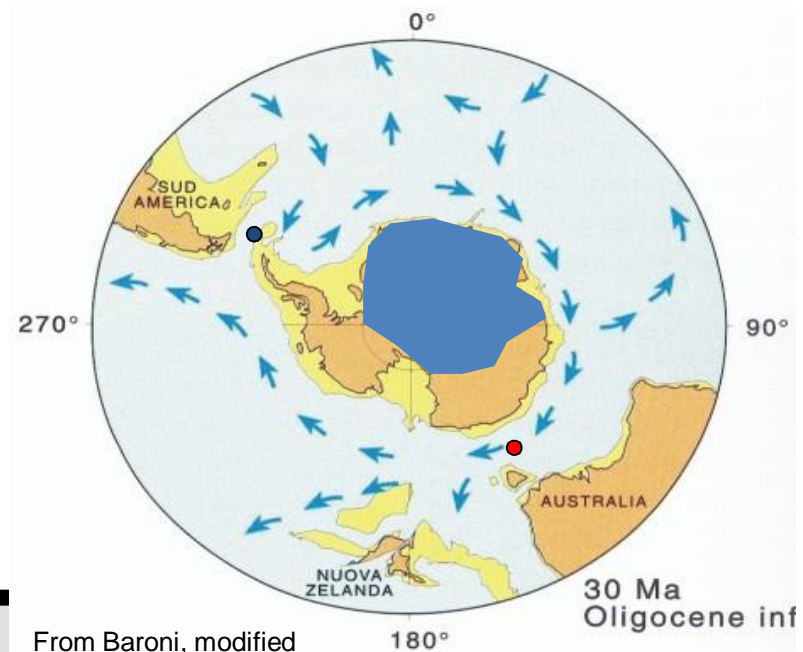
doi:10.1038/nature11300

## Persistent near-tropical warmth on the Antarctic continent during the early Eocene epoch

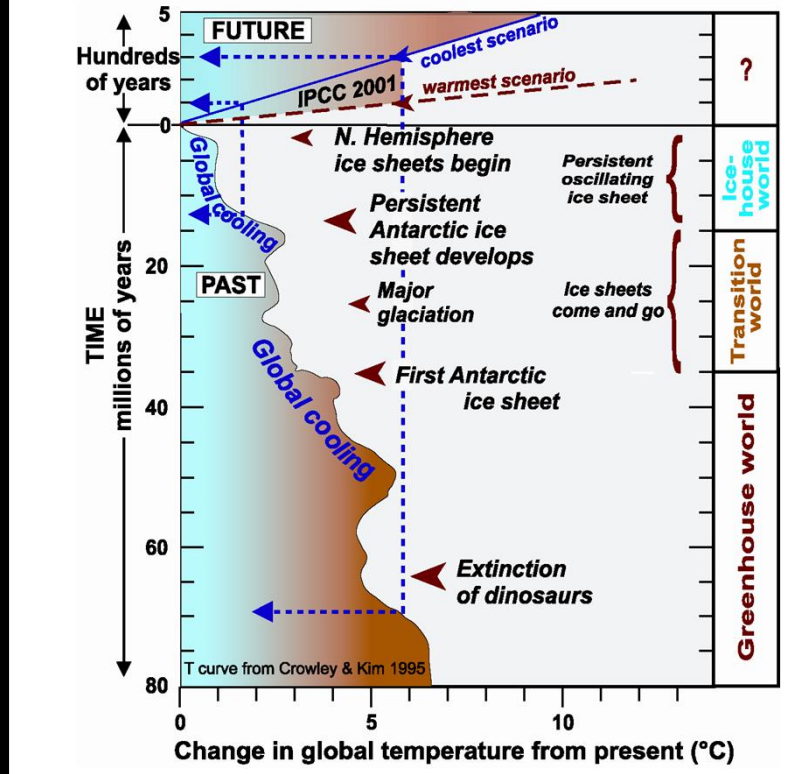
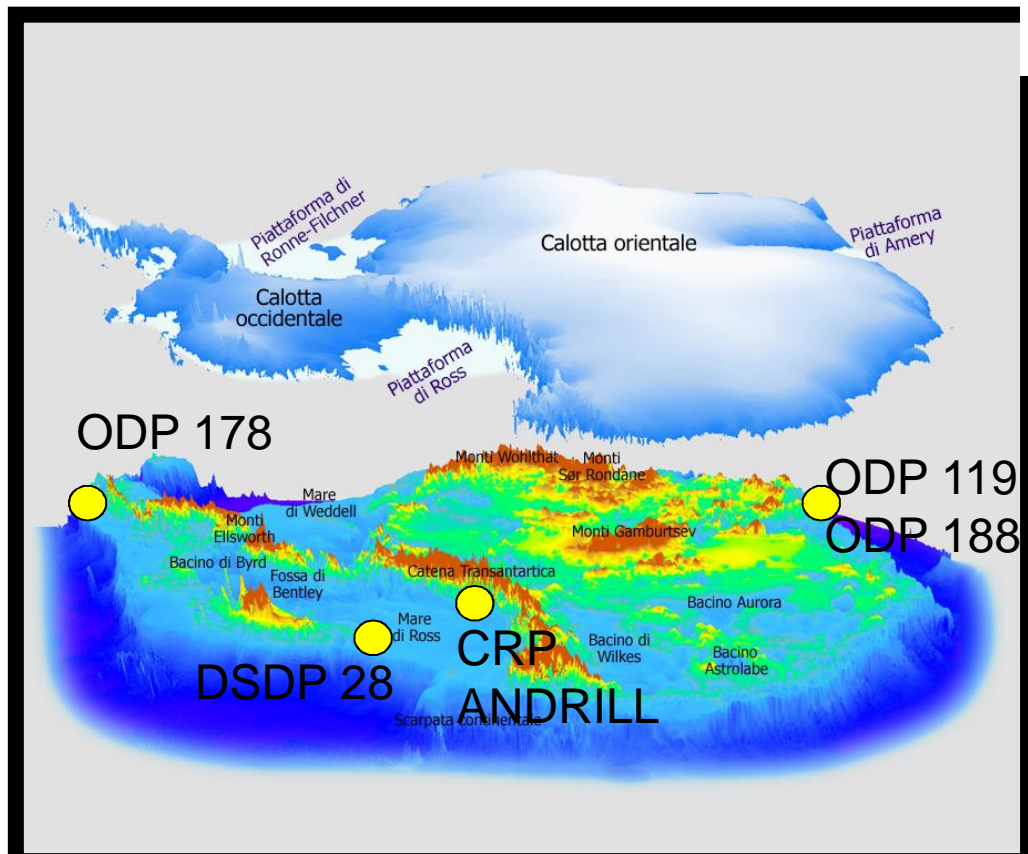
Jörg Pross<sup>1,2</sup>, Lineth Contreras<sup>1</sup>, Peter K. Bijl<sup>3</sup>, David R. Greenwood<sup>4</sup>, Steven M. Bohaty<sup>5</sup>, Stefan Schouten<sup>6</sup>, James A. Bendle<sup>7</sup>, Ursula Röhl<sup>8</sup>, Lisa Tauxe<sup>9</sup>, J. Ian Raine<sup>10</sup>, Claire E. Huck<sup>11</sup>, Tina van de Flierdt<sup>11</sup>, Stewart S. R. Jamieson<sup>12</sup>, Catherine E. Stickley<sup>13</sup>, Bas van de Schootbrugge<sup>1</sup>, Carlota Escutia<sup>14</sup>, Henk Brinkhuis<sup>3</sup> & Integrated Ocean Drilling Program Expedition 318 Scientists\*

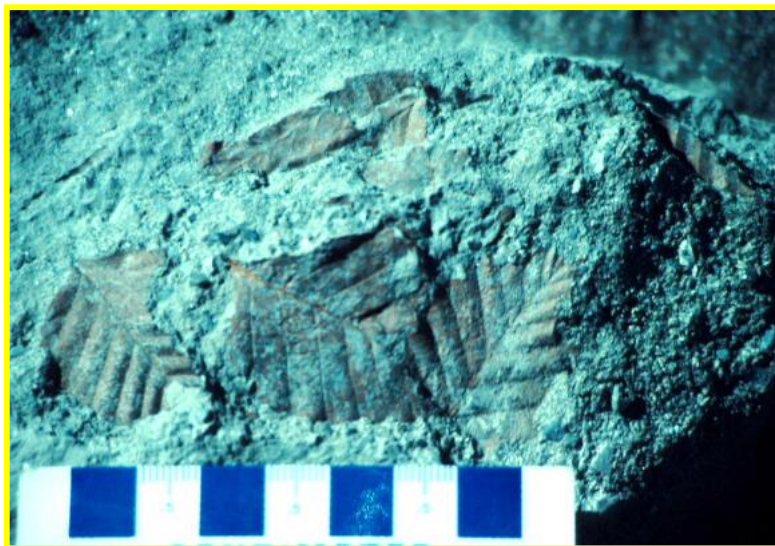
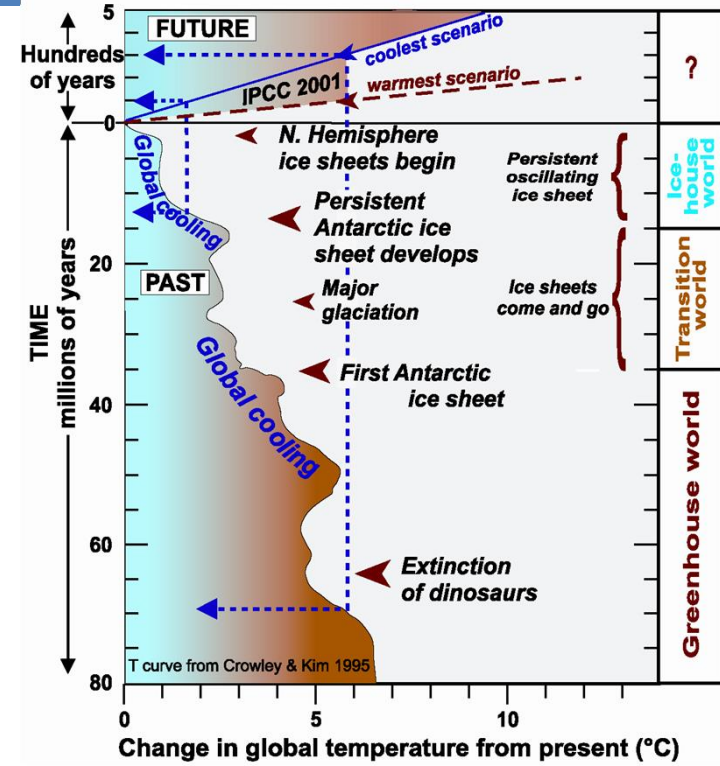
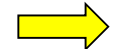
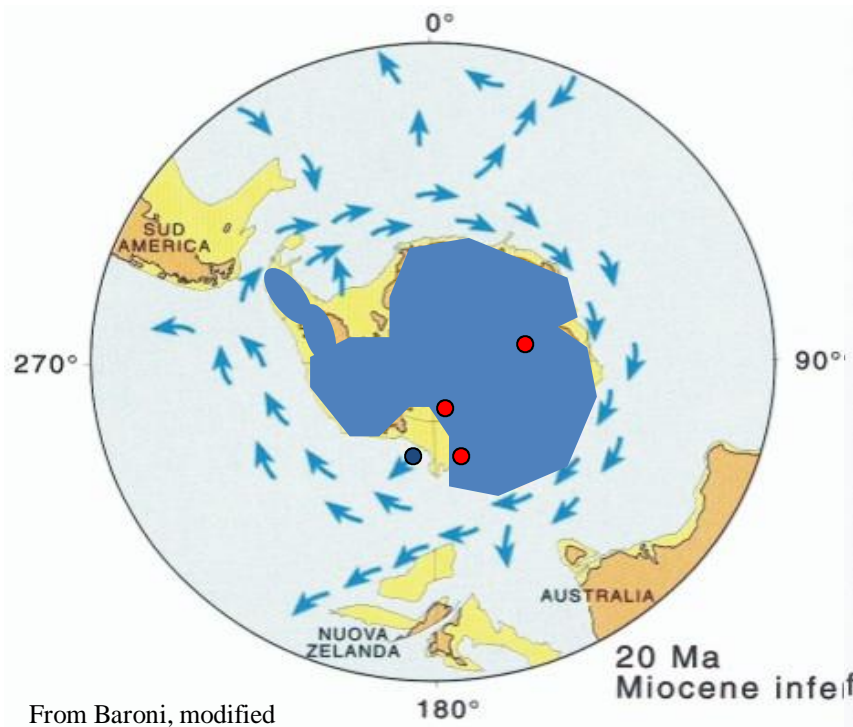


Transitional world



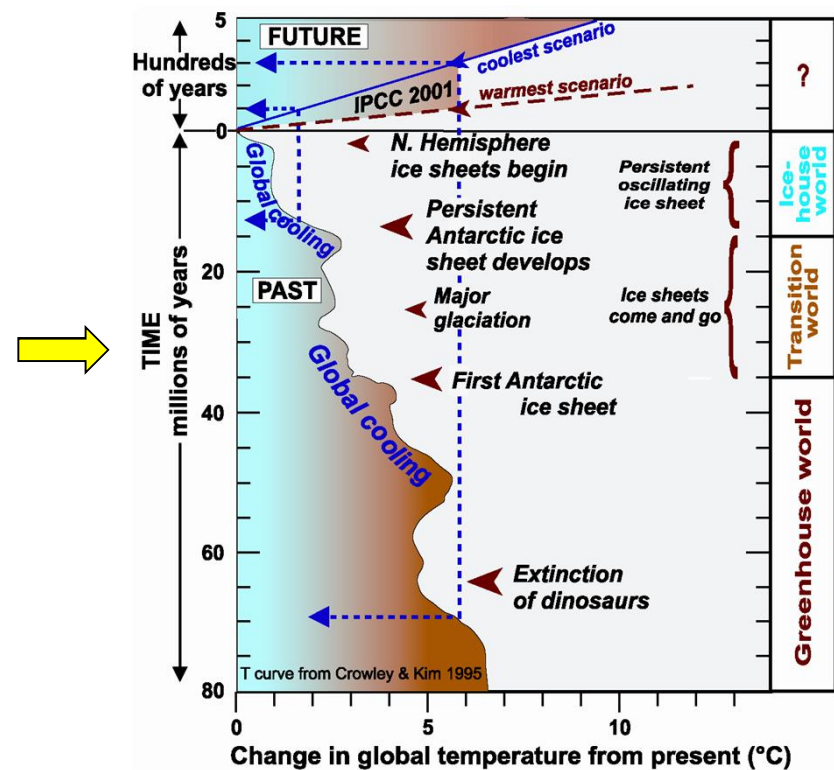
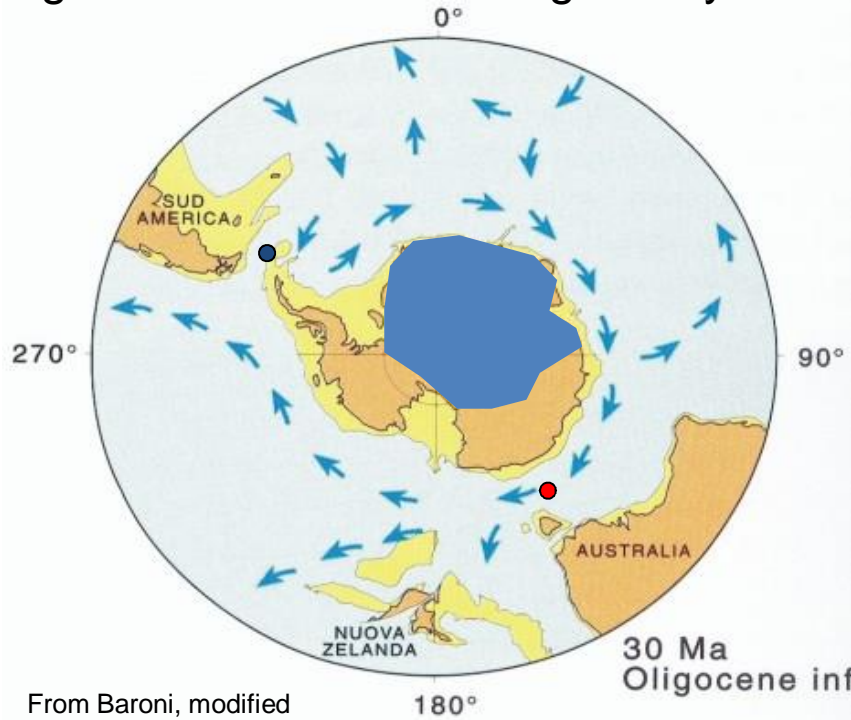
From Baroni, modified



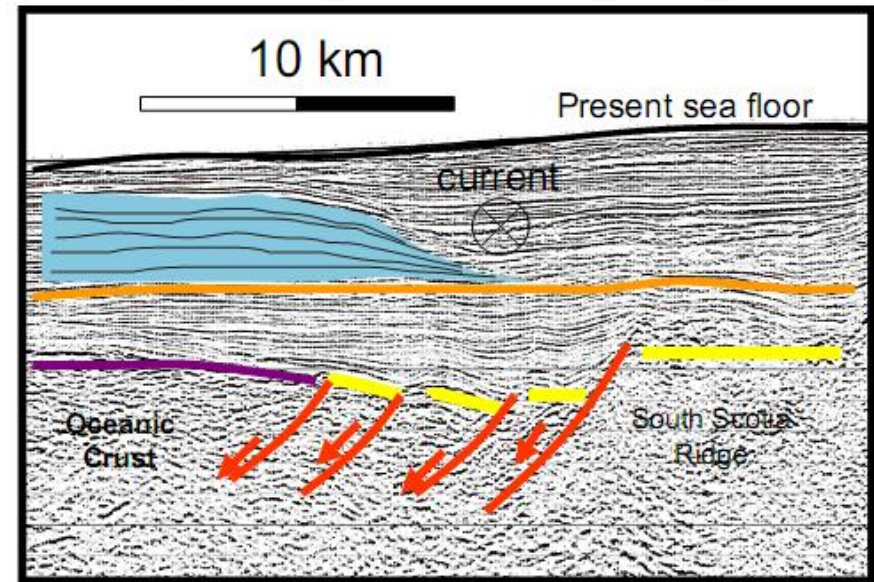
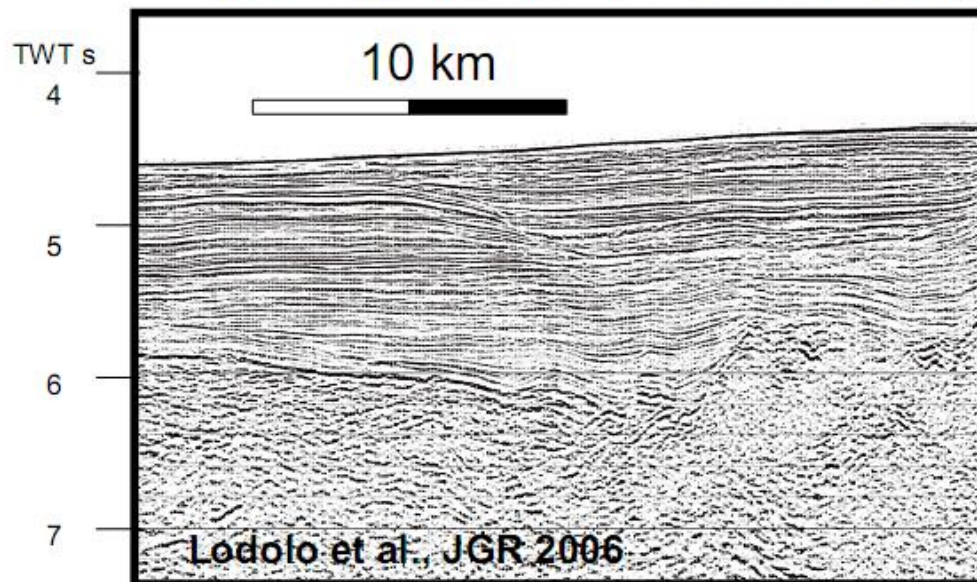


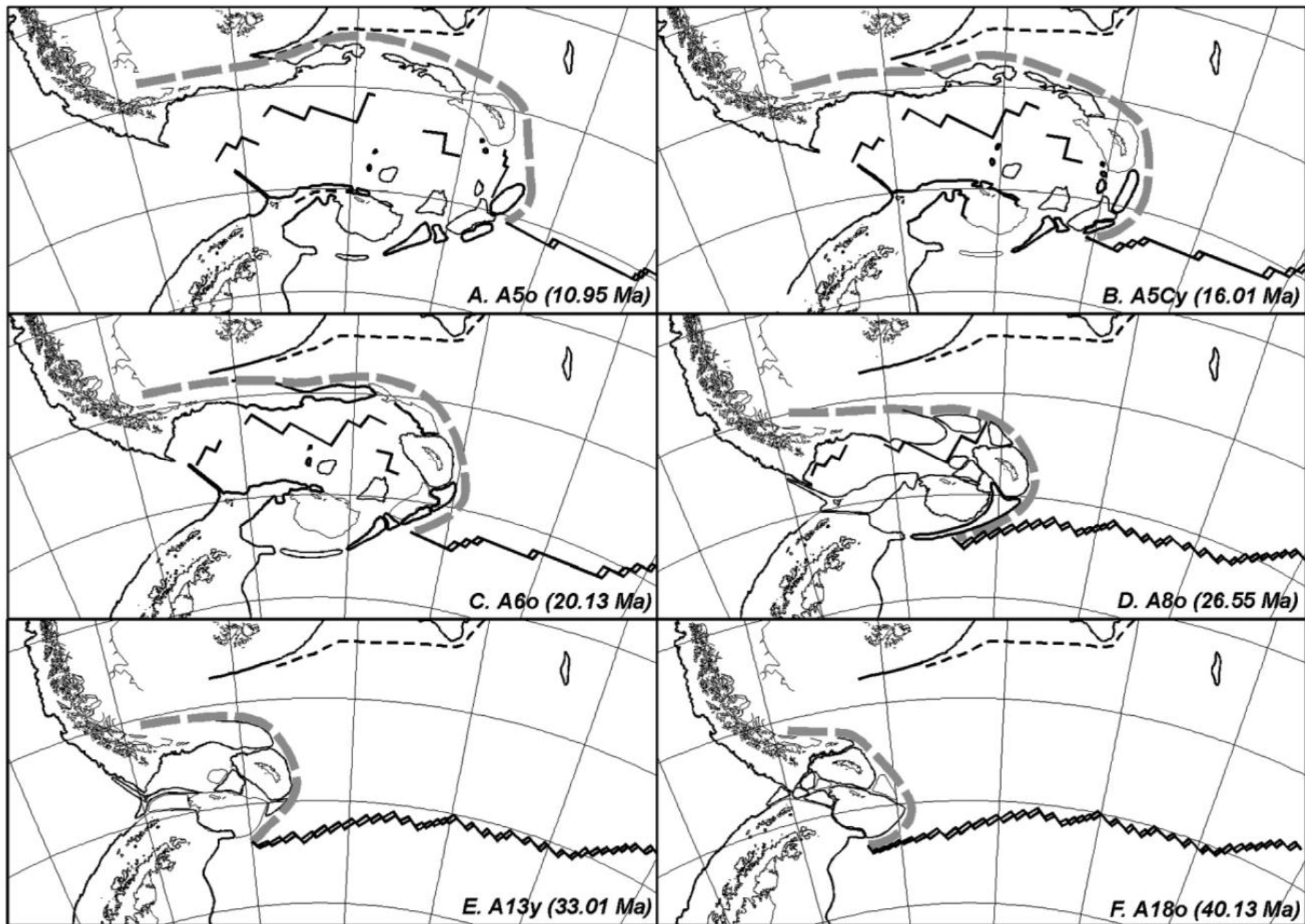
Sirius Formation - Foto by D. Harwood

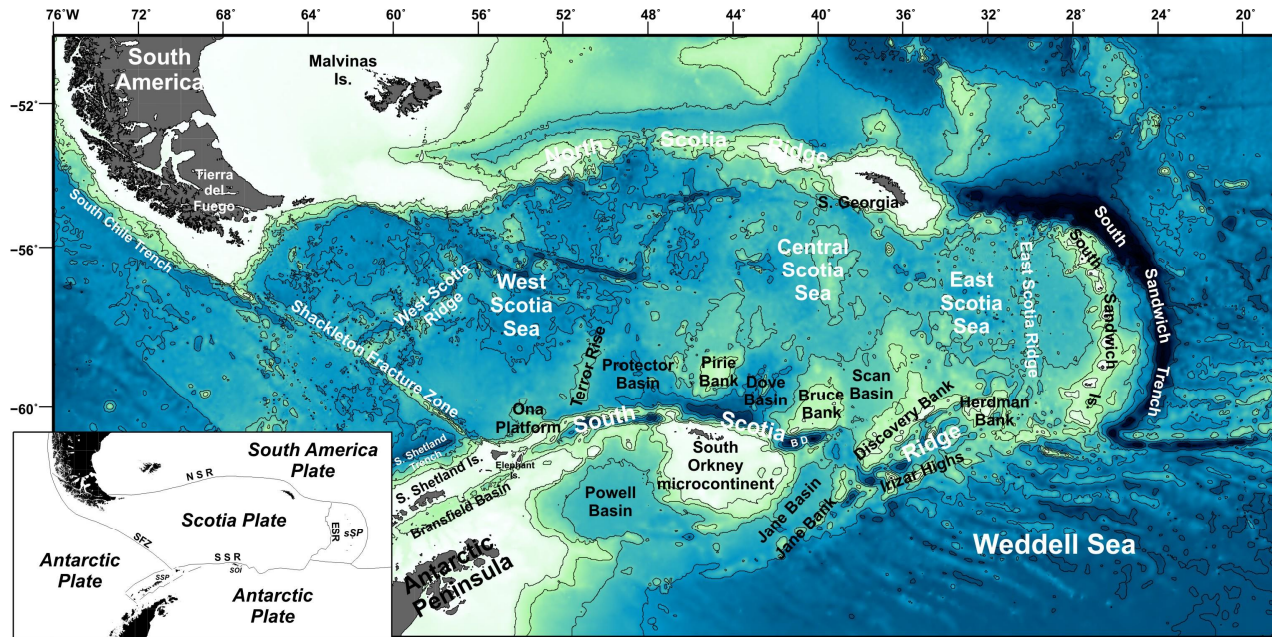
# Opening of Tasman and Drake gateways



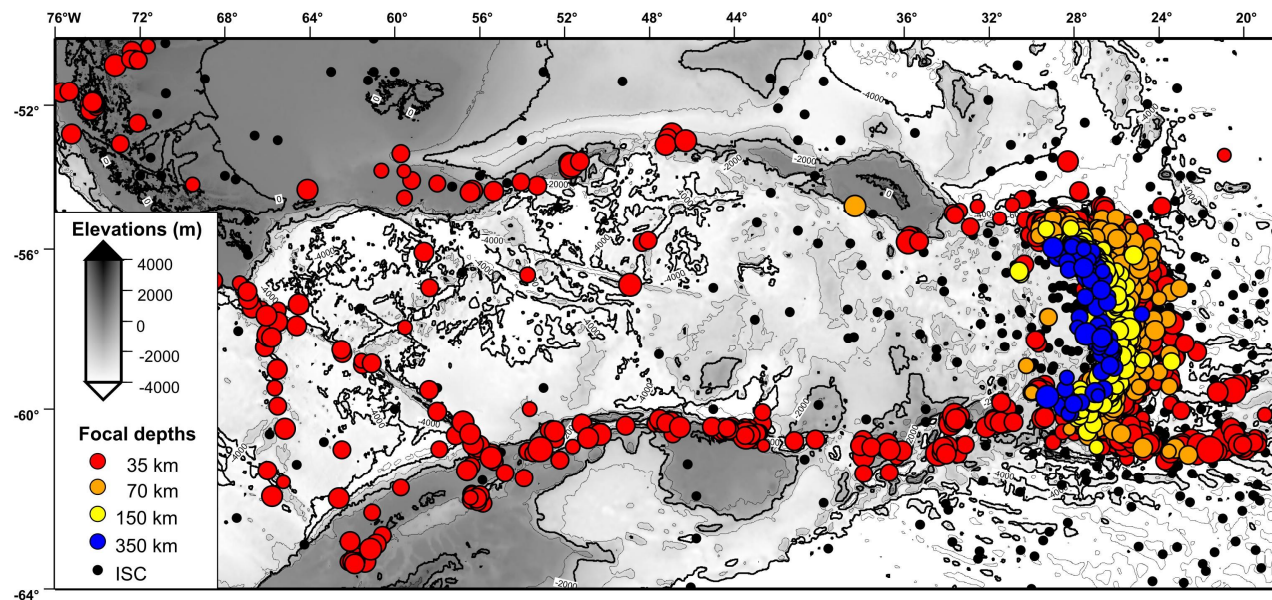
## Current-controlled sediment drift forming after the opening of the Drake passage



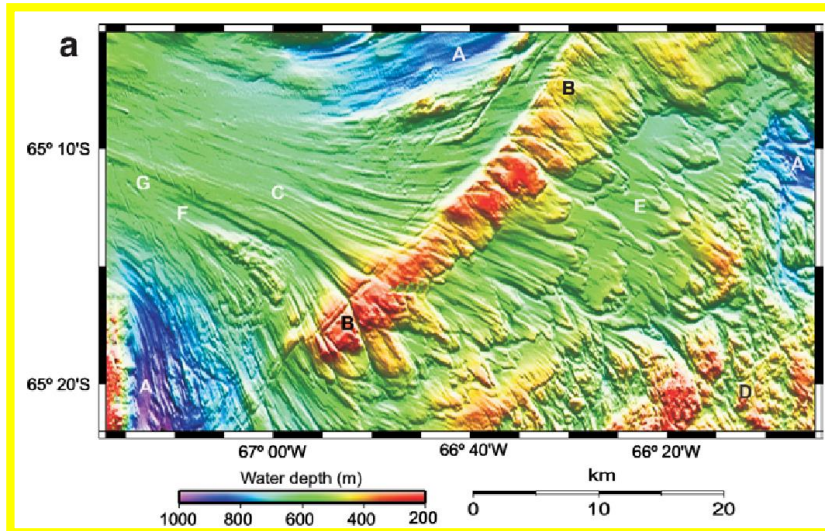
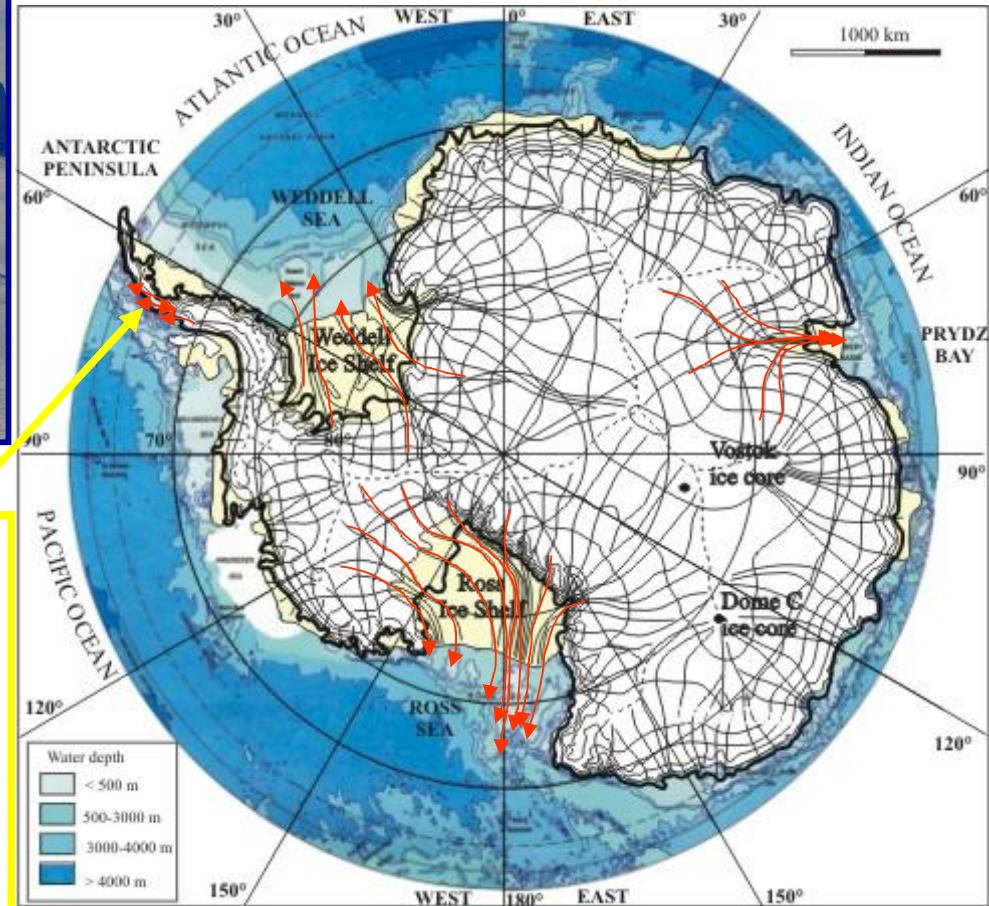




*Principali  
elementi morfo-  
strutturali della  
placca di Scozia  
(sopra) e  
distribuzione  
degli eventi  
sismici (sotto)*

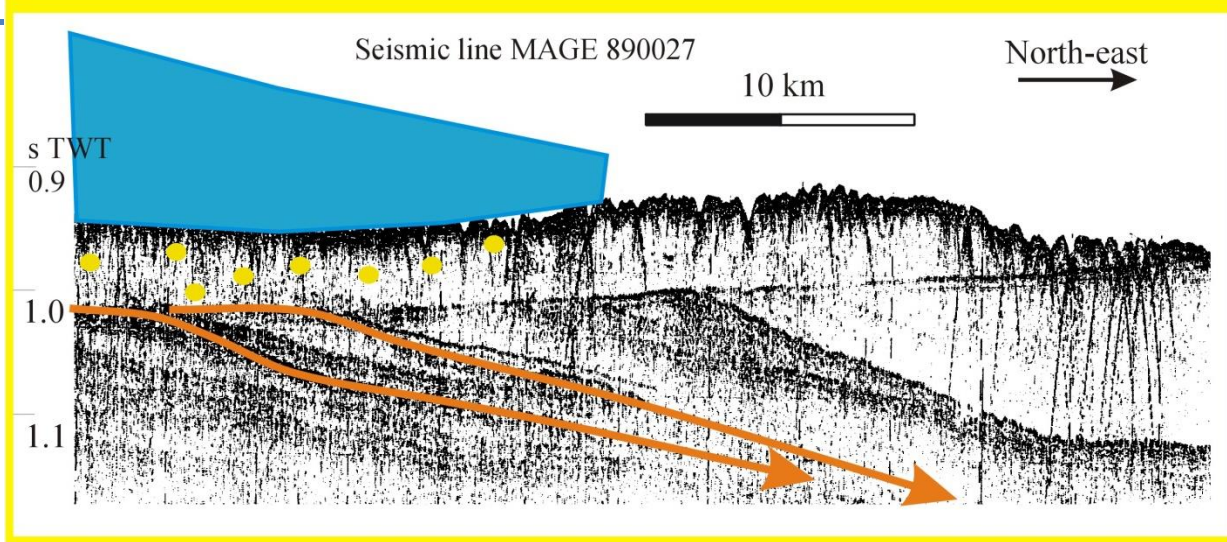


# QUATERNARIO

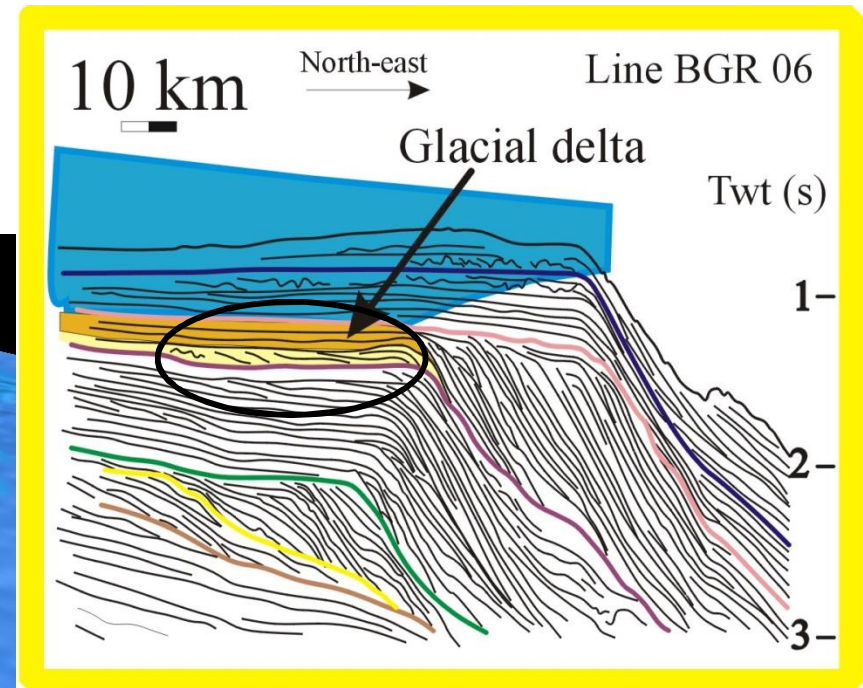
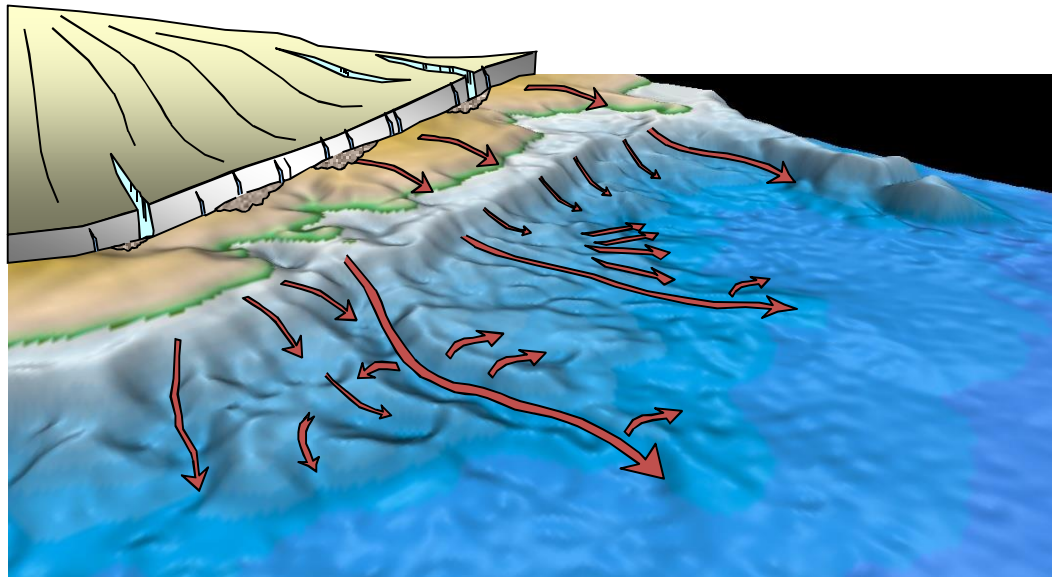


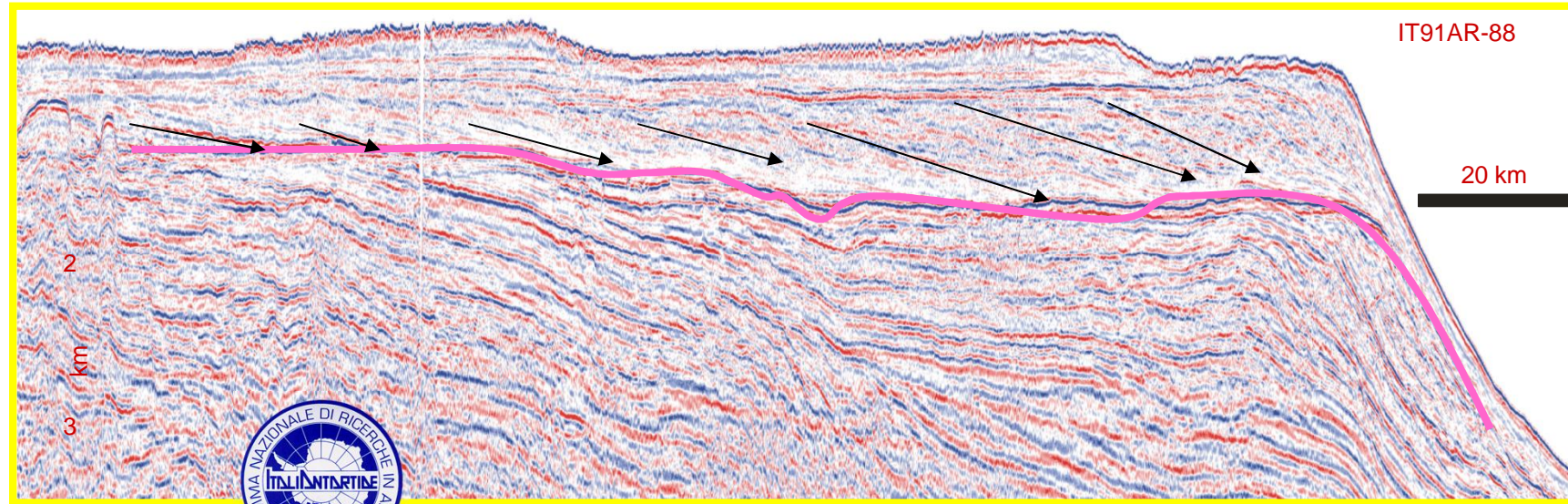
Eos, vol. 84, 11, March 2003



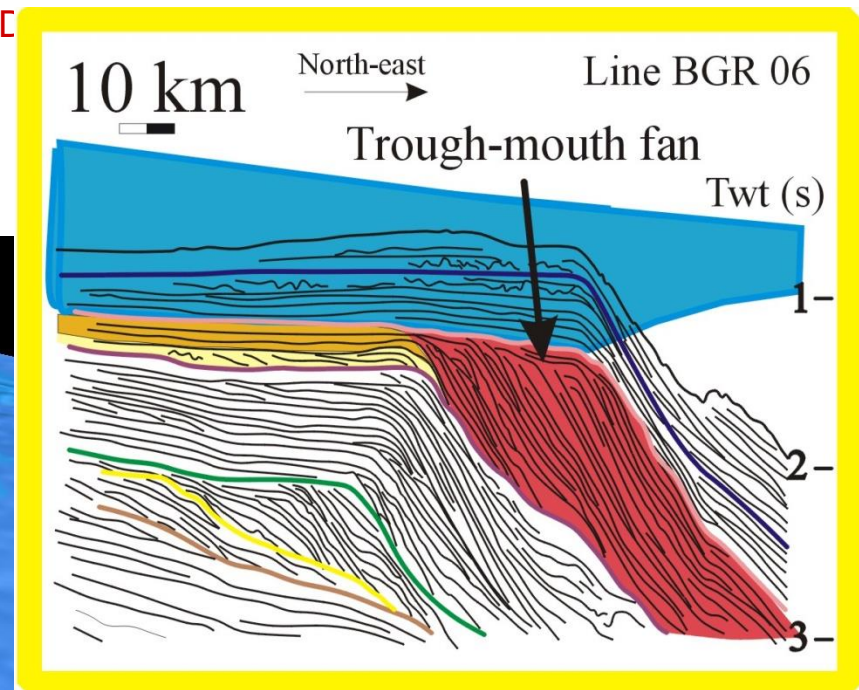
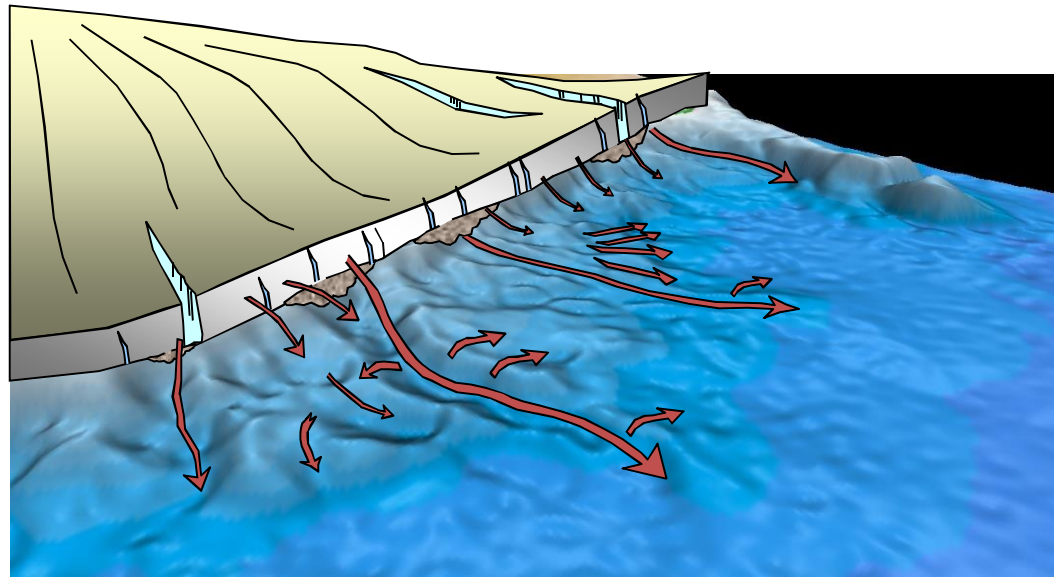


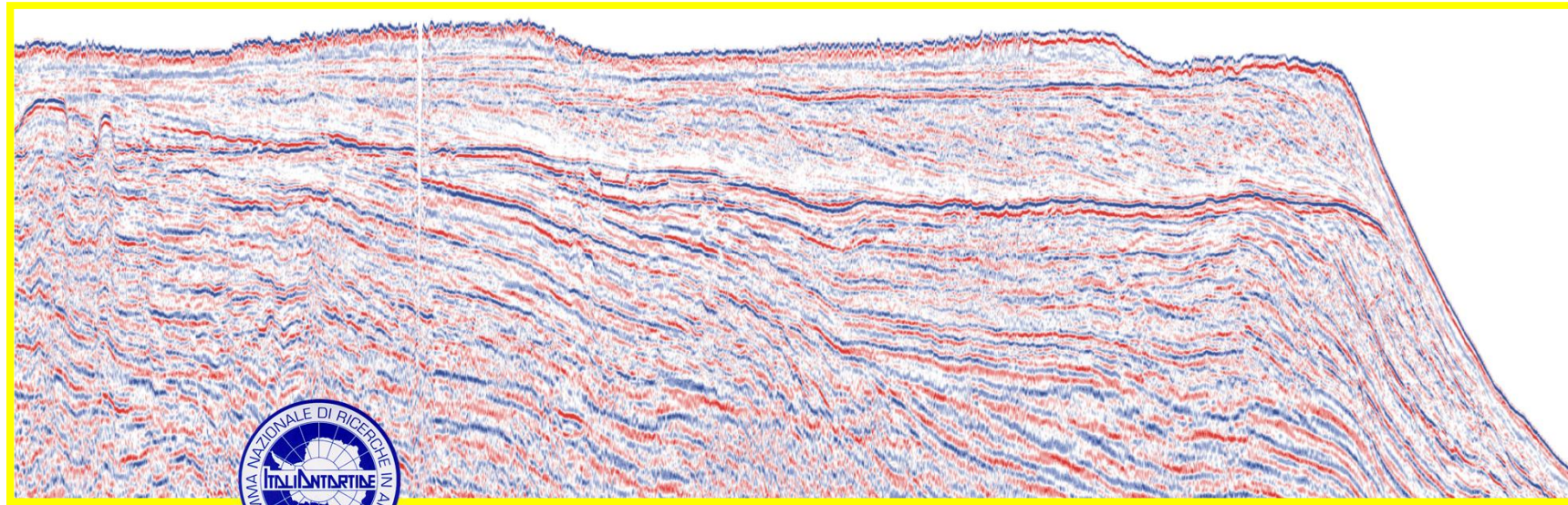
Nelle fasi di massima espansione i sedimenti alla base del ghiaccio sono depositi sul ciglio del margine continentale.





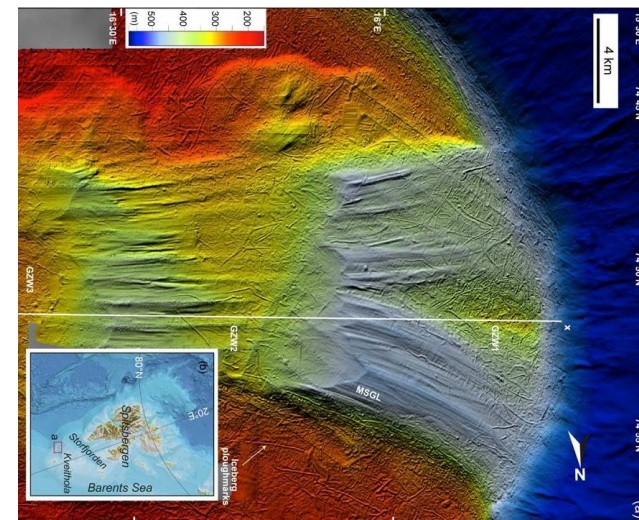
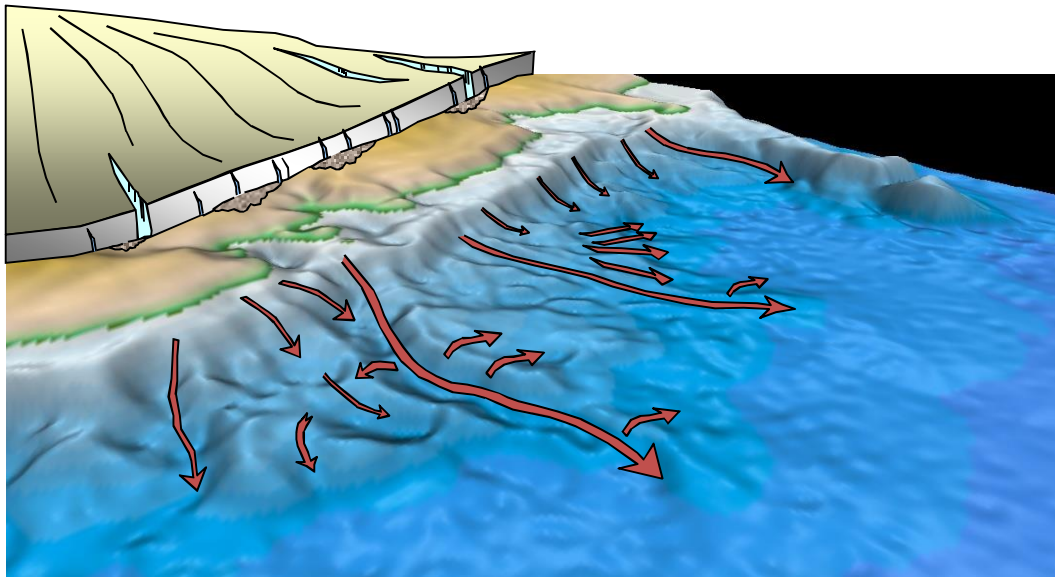
Sauli, Busetti, D

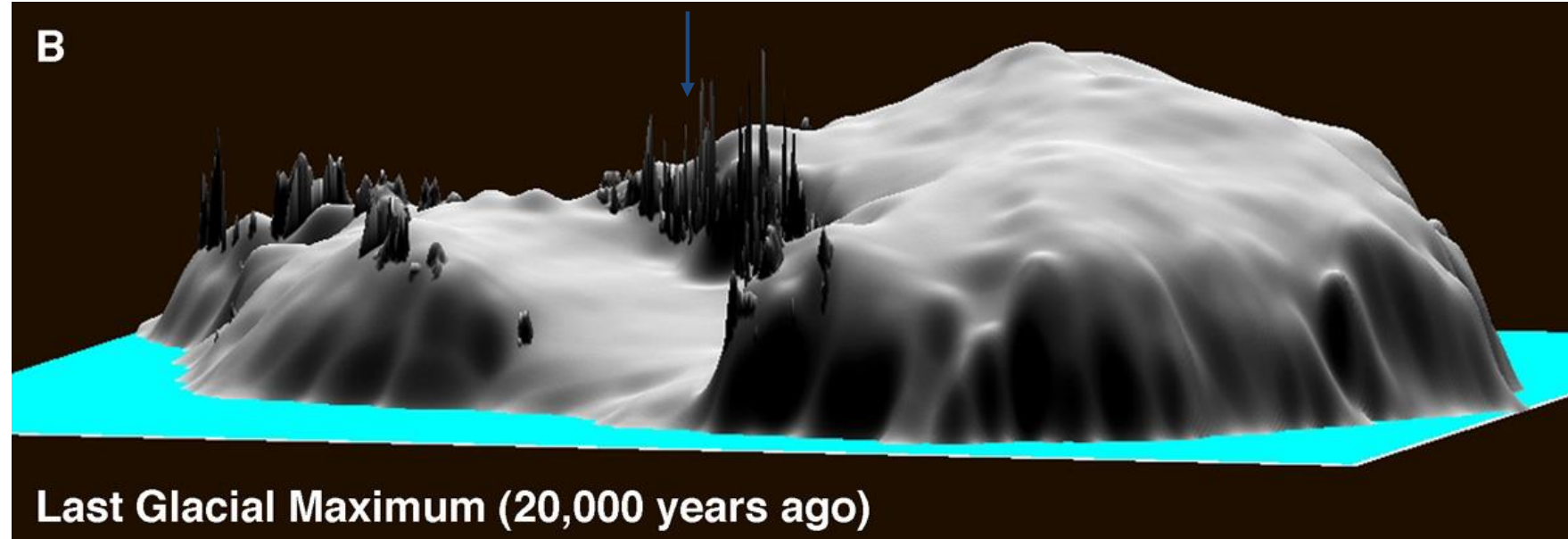




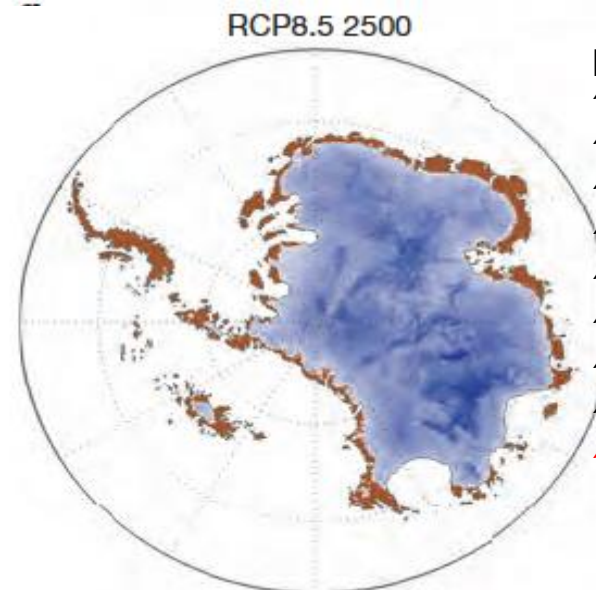
Sauli, Buseti, De Santis, Wardell (Marine Geology 2014)

Rebesco M., Urgeles R., Özmaral A., Coribar Scientific Party, in press in: Dowdeswell J.A., et al., (Eds.) *Atlas of Submarine Glacial Landforms*. Geological Society of London Memoir.





Antarctic octopus (*Paraleledone turqueti*).  
Credit: E. Jorgensen, NOAA 2007



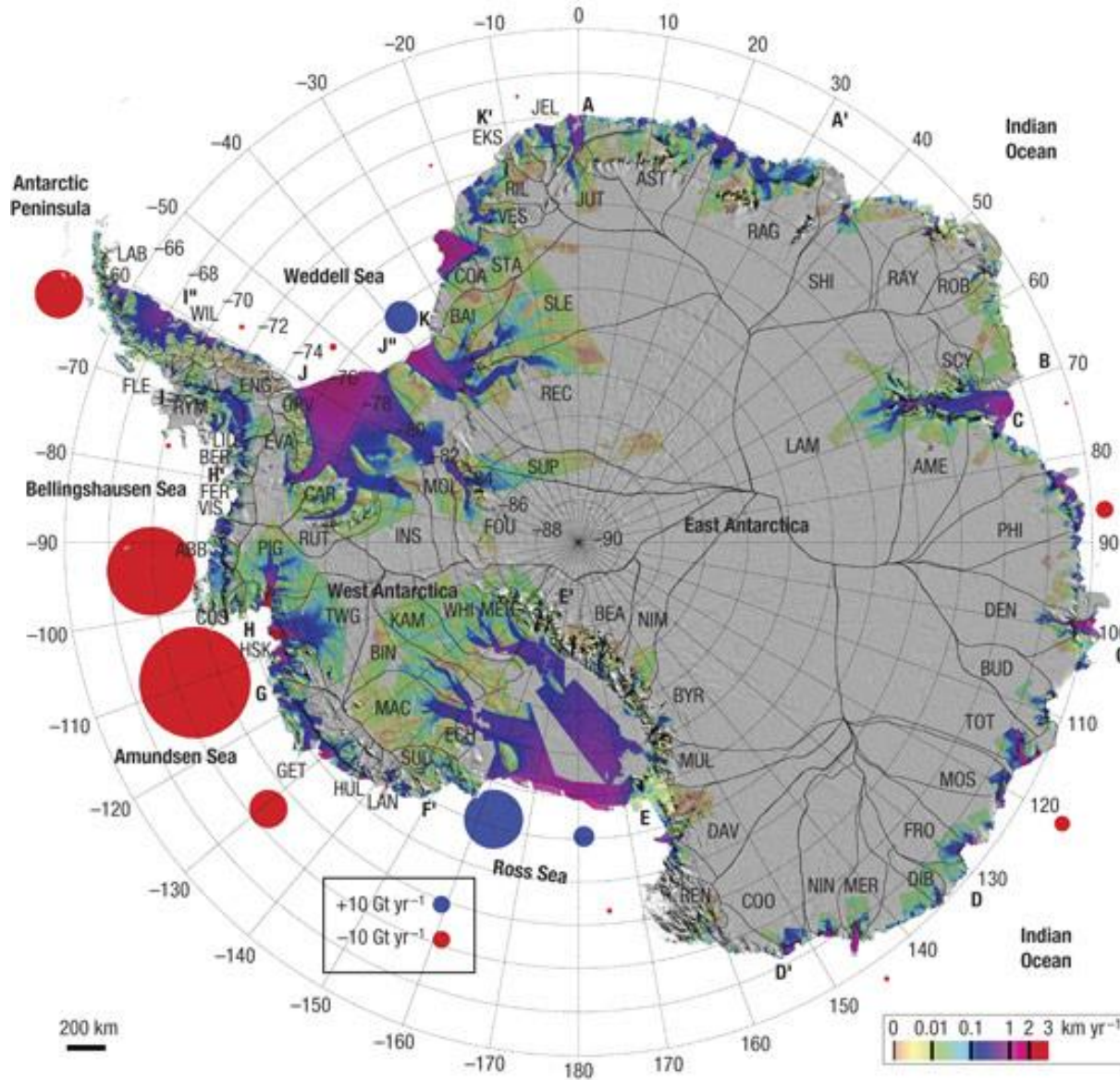
**Mid Pliocene**

- " 350-400ppm CO<sub>2</sub>
- " +3°C global average air,
- " +3-5°C Antarctic SST (Ross)
- " +8°C Arctic SAT (Lake E)
- " GMSL ~ +20m
- " Up to 7m from GIS
- " Up to +4m WAIS
- " Up to +13m EAIS
- " AIS contribution ???

*DeConto and Pollard 2016 (Nature)*

# Ice velocity and ice mass loss/gain

Rignot et al. (2007)

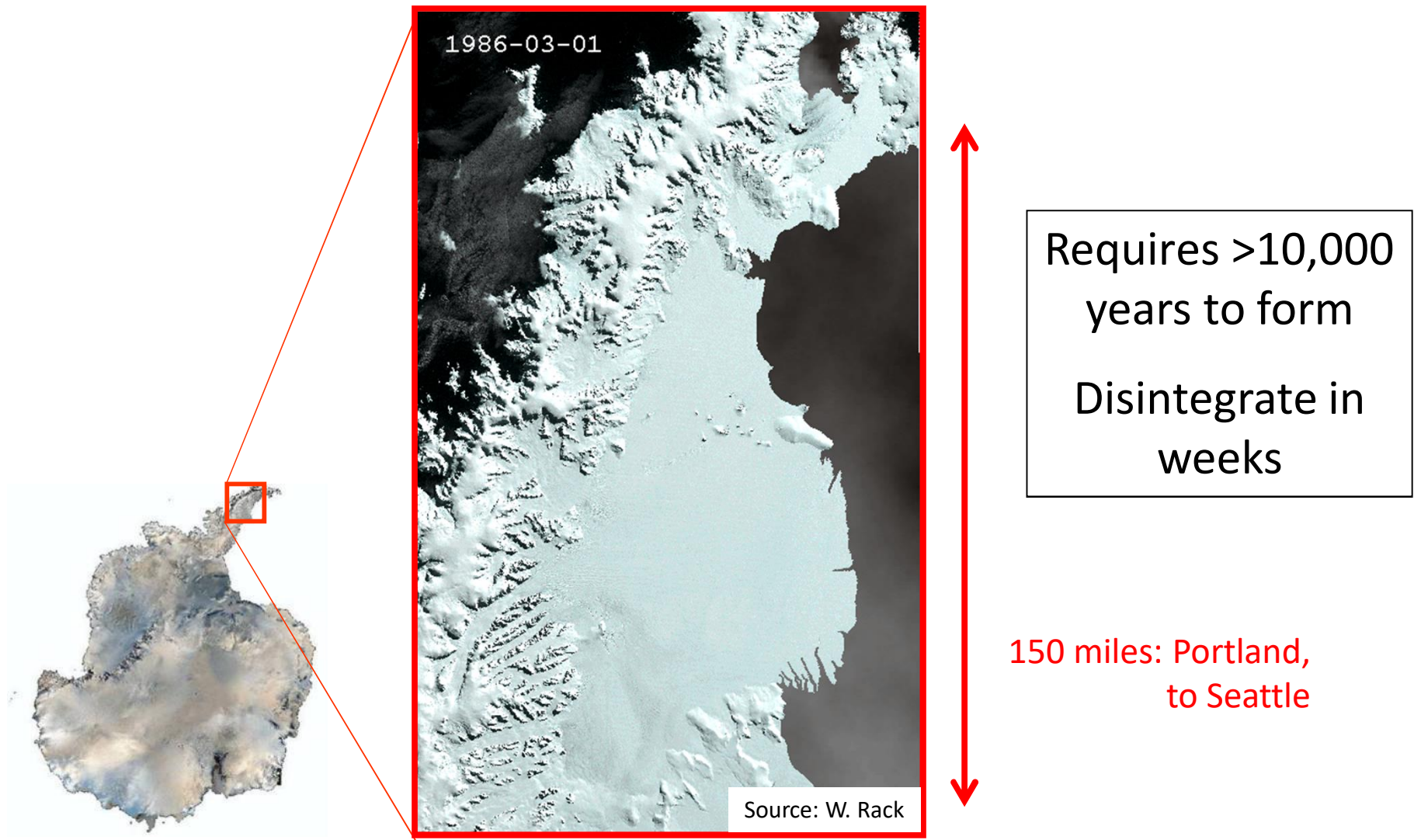




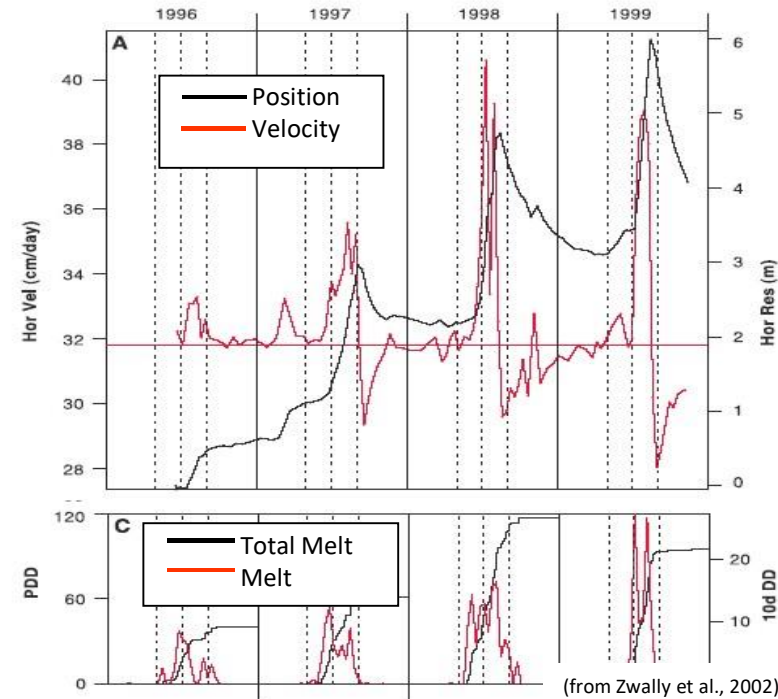
## 3 major types of changes to ice flow rate:

1. Faster ice flow in summer in Greenland
2. Rapidly disintegrating ice shelves
3. Rapid retreat, thinning and acceleration of outlet glaciers

# Dramatic decade of ice sheet behavior

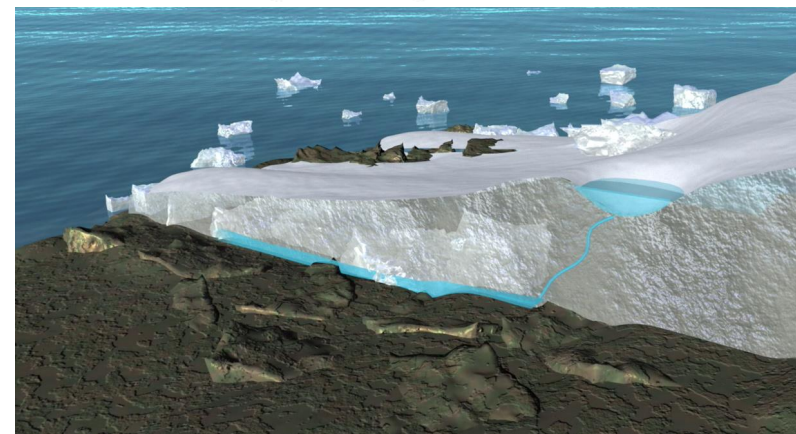


# Water as a Lubricant



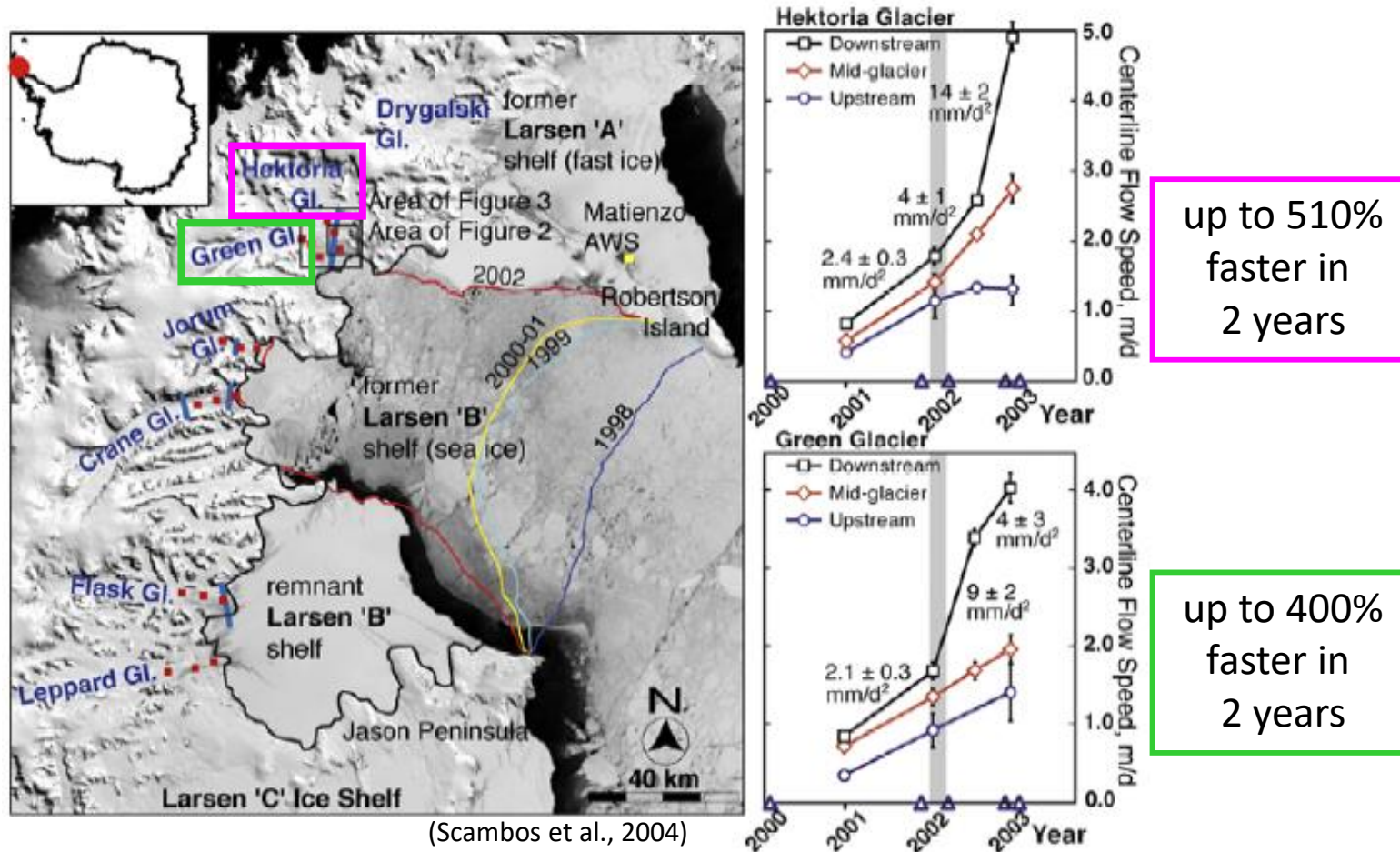
Glacier flow increases 10-15%  
Slower ice increases up to 70%

(from Joughin et al., 2008)



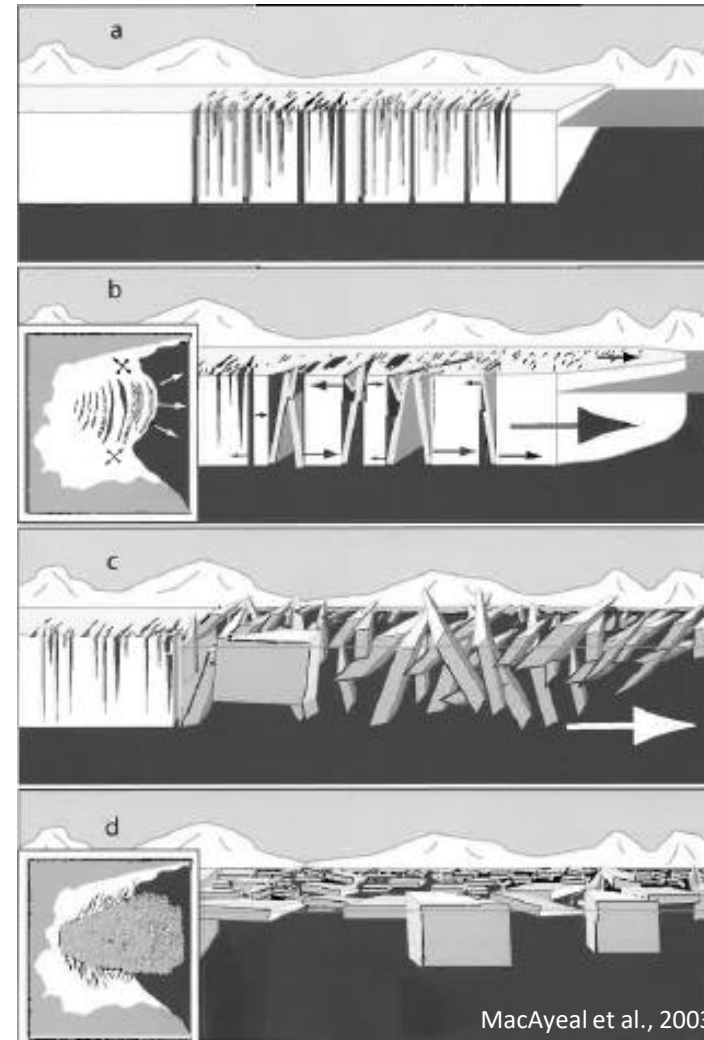
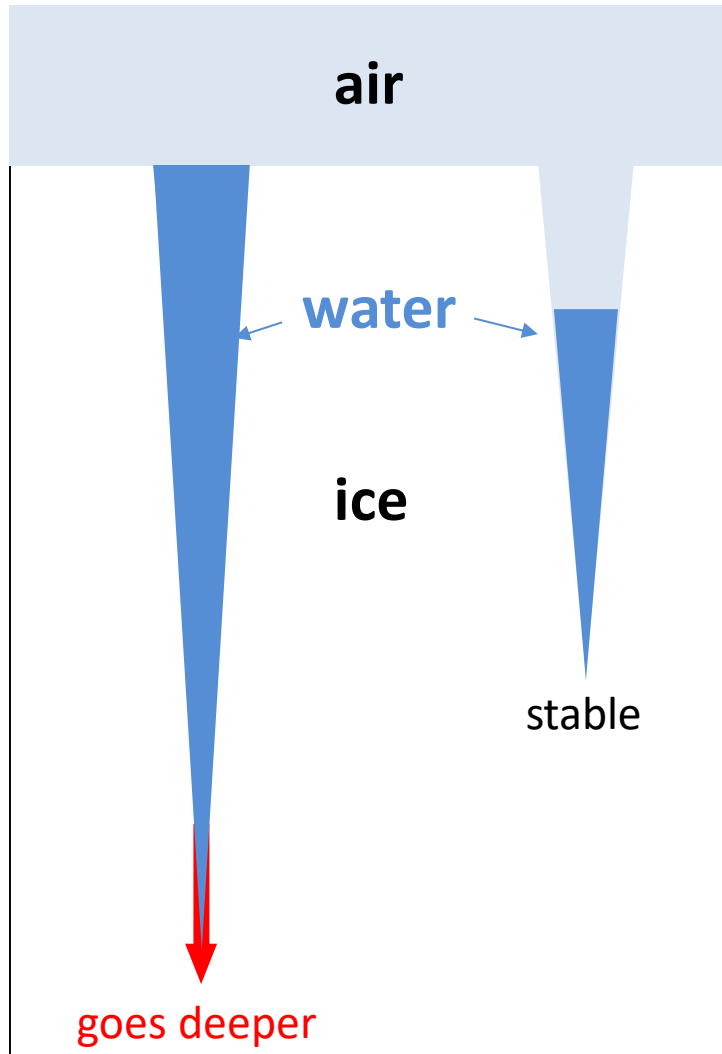


# Consequence of Ice Shelf Loss

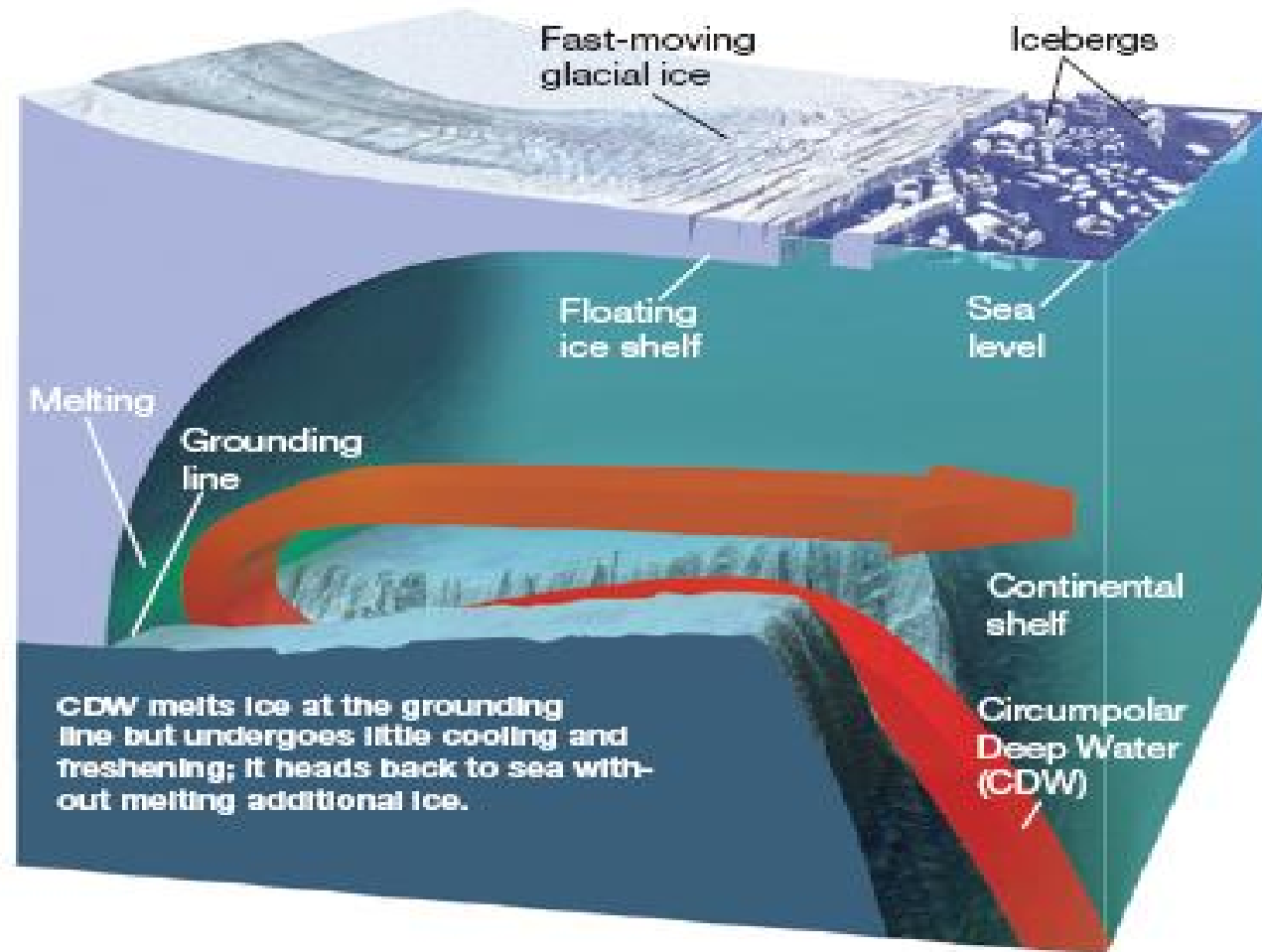


Formerly buttressed glaciers accelerate

# Water as a Wedge

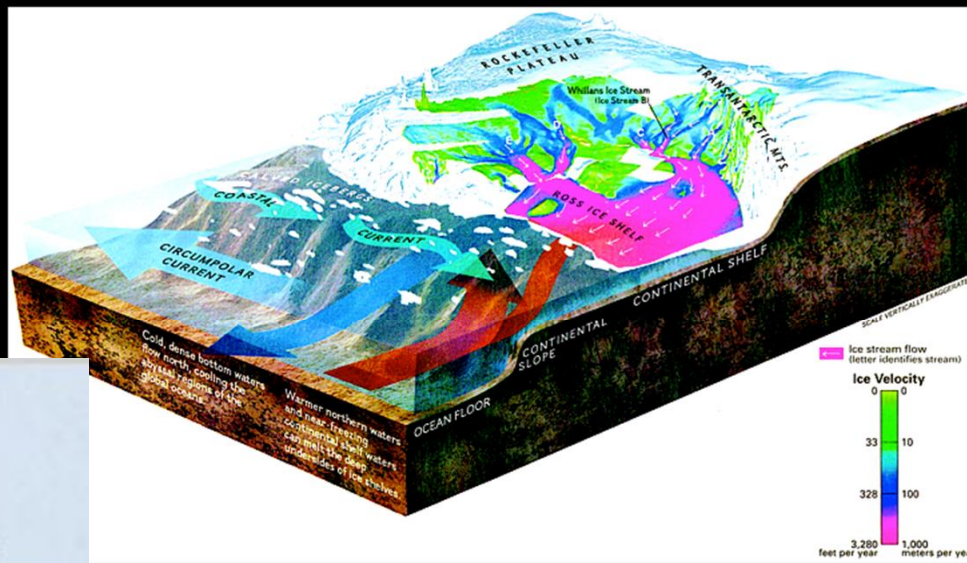
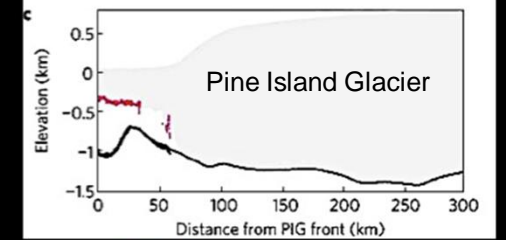
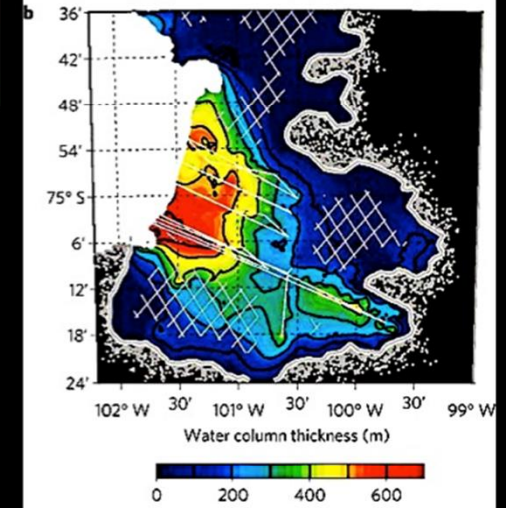
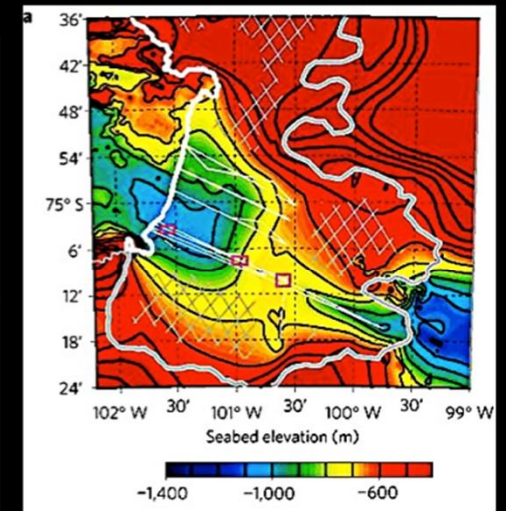
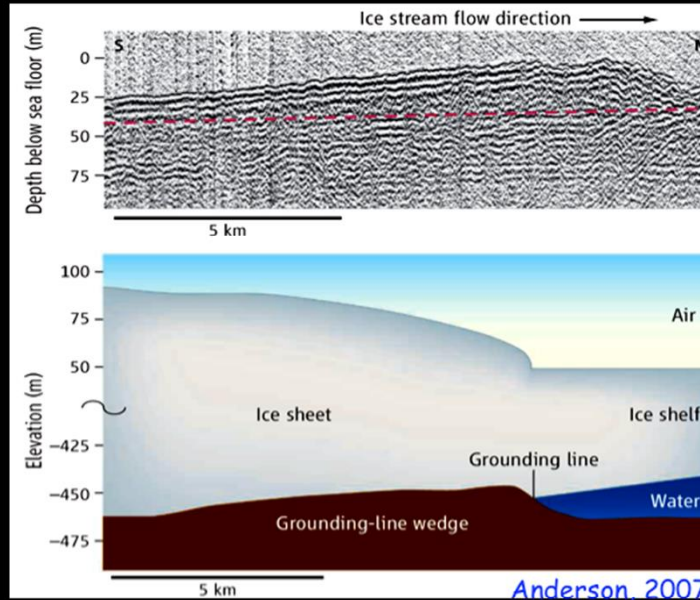
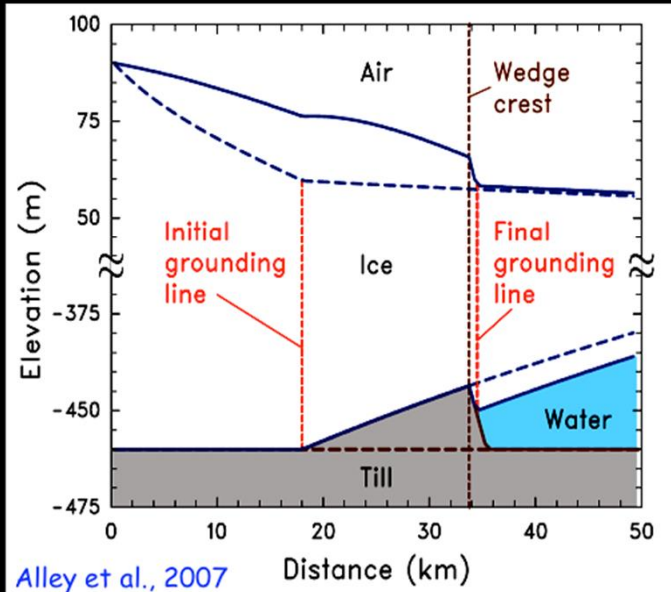


# Water as a Heater



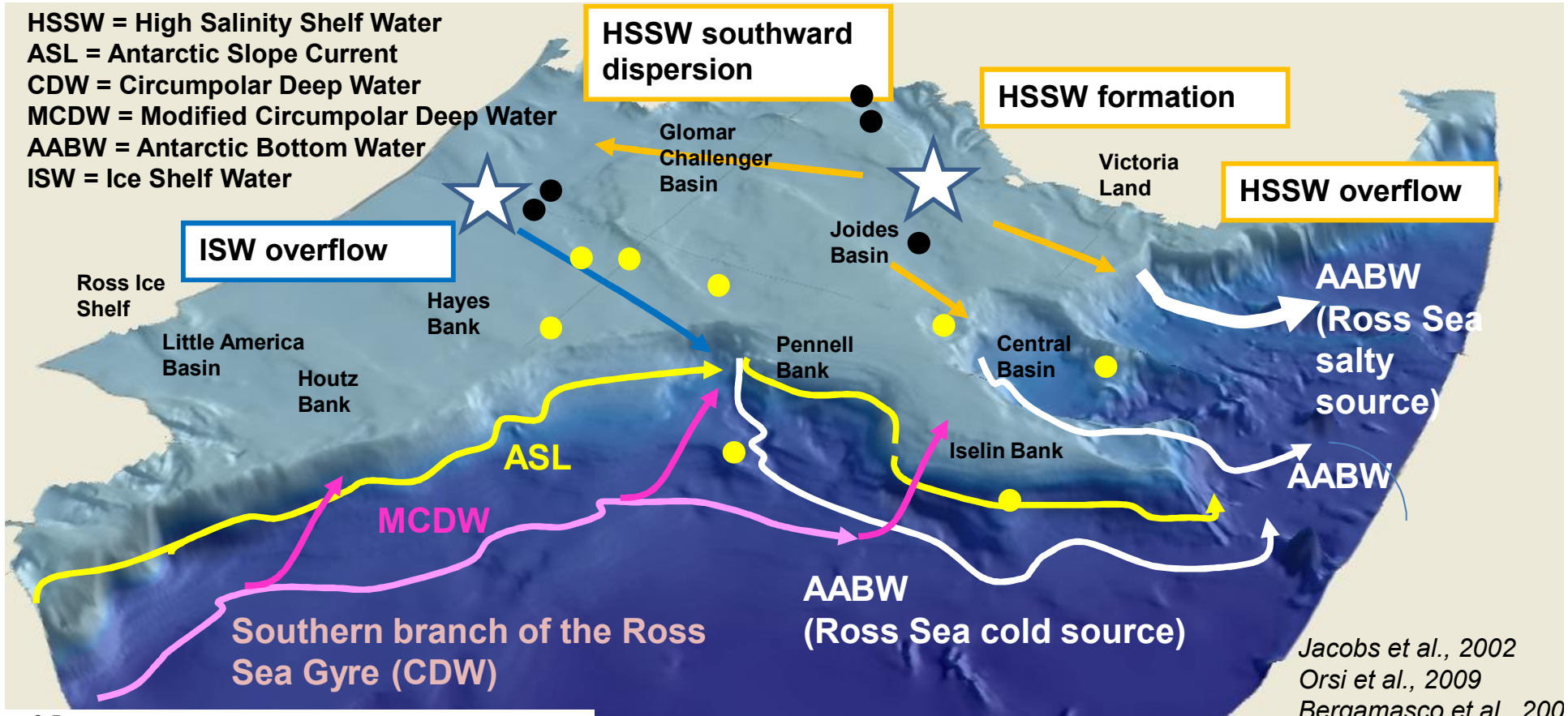
(illustration (c) Frank Ippolito)

# Grounding-zones and ice shelf ocean cavities

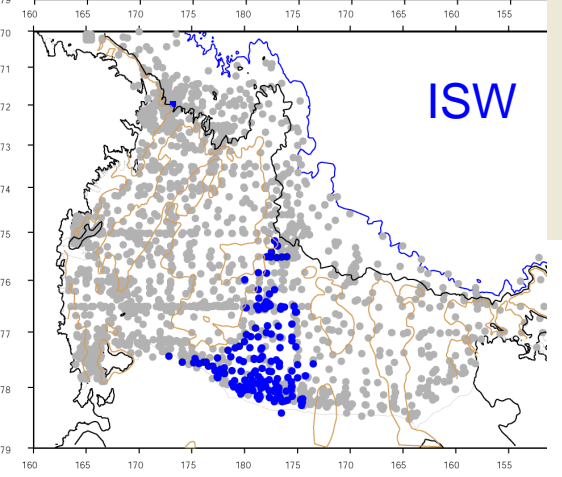
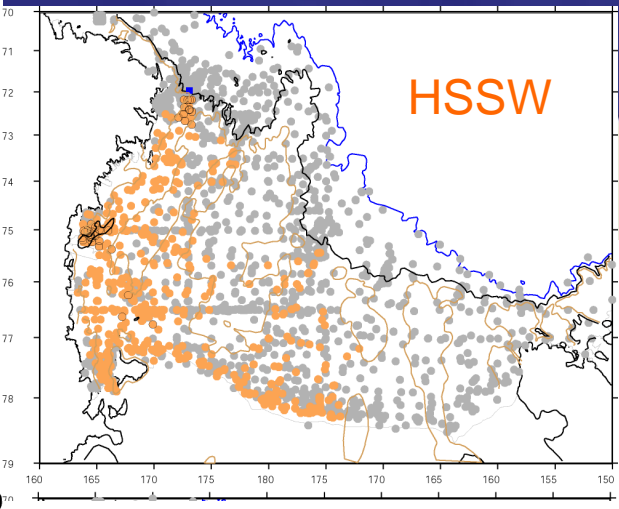
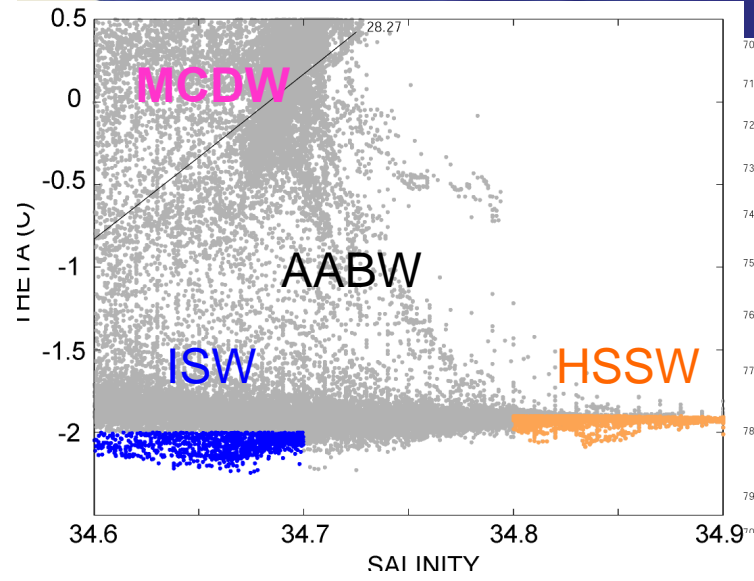


Siple Coast & RIS - Nat. Geog.

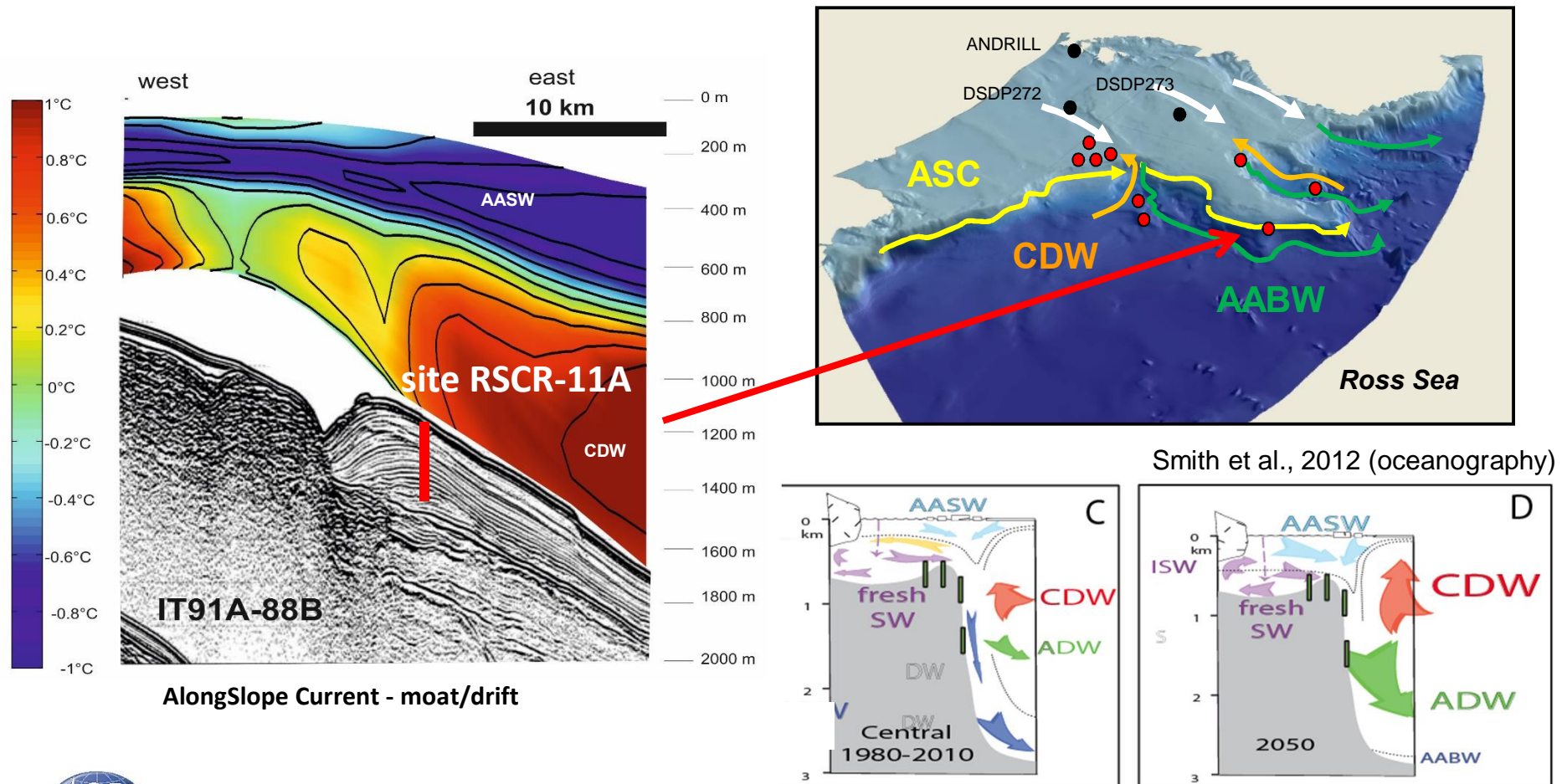
**HSSW = High Salinity Shelf Water**  
**ASL = Antarctic Slope Current**  
**CDW = Circumpolar Deep Water**  
**MCDW = Modified Circumpolar Deep Water**  
**AABW = Antarctic Bottom Water**  
**ISW = Ice Shelf Water**



*Jacobs et al., 2002*  
*Orsi et al., 2009*  
*Bergamasco et al., 2000*



*IODP Expedition 374 (2018) Hypothesis to test: The vigor of the Antarctic Slope Current (ASC), and surface/bottom water variance is the main control on oceanic heat flux onto the Ross Sea Continental Shelf*



**Table 1:** Summary of slope transects sampled on the George V continental shelf.

Station	Depth range	Occurrence of <i>Errina</i> sp.	Dominant community	Seafloor image
82to83	400-1200 m	Sparse: 800-920 m Dense: 900 m	Medium density soft corals and bryozoans	
79to88	435-1395 m	Sparse: 440-570 m; Dense: 570-950 m	Dense <i>Errina</i> sp. and demosponge	
66	650-950 m	Dense: 650-950 m	Dense <i>Errina</i> sp. and demosponge	
63	420-430 m	Sparse: 430 m	Medium density soft corals and gorgonian whips	
33	740-770 m	None	Sparse demosponge	

## Physical controls on deep water coral communities on the George V Land slope, East Antarctica

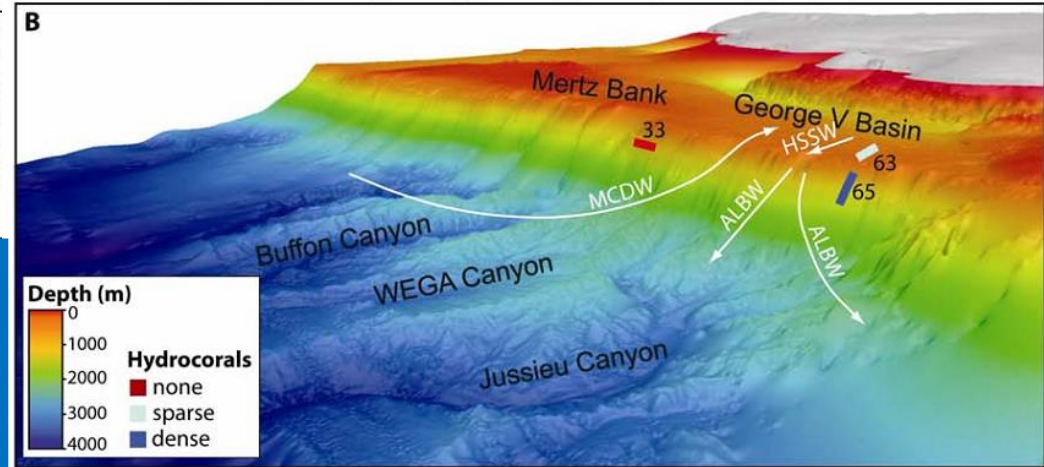
ALEXANDRA L. POST<sup>1</sup>, PHILIP E. O'BRIEN<sup>1</sup>, ROBIN J. BEAMAN<sup>2</sup>, MARTIN J. RIDDLE<sup>3</sup> and LAURA DE SANTIS<sup>4</sup>

<sup>1</sup>Marine and Coastal Environment Group, Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia

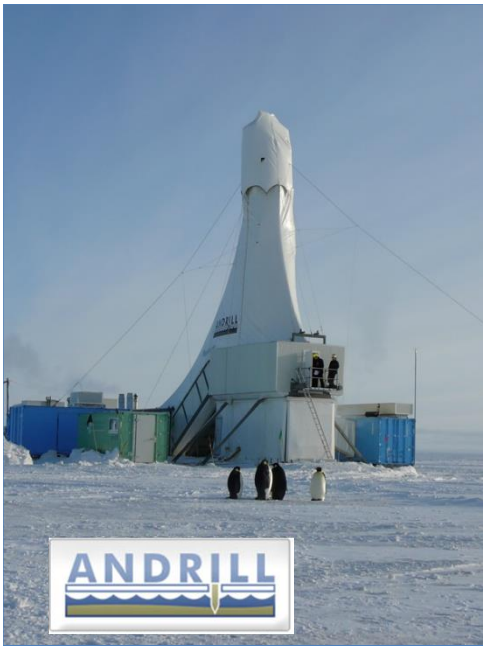
<sup>2</sup>School of Earth and Environmental Sciences, James Cook University, PO Box 6811, Cairns, QLD 4870, Australia

<sup>3</sup>Environmental Protection and Change, Australian Antarctic Division, Channel Highway, Kingston, TAS 7050, Australia

<sup>4</sup>Instituto Nazionale di Oceanografia e Geofisica Sperimentale, Borgo Grotta Gigante 42/c, Sgonico, Trieste 34010, Italy  
Alix.Post@ga.gov.au



In profondità, dove gli iceberg non possono arare il fondo del mare, sulla testata dei canyon che convogliano le correnti fredde antartiche, ricche di nutrienti, esistono colonie di coralli e spugne

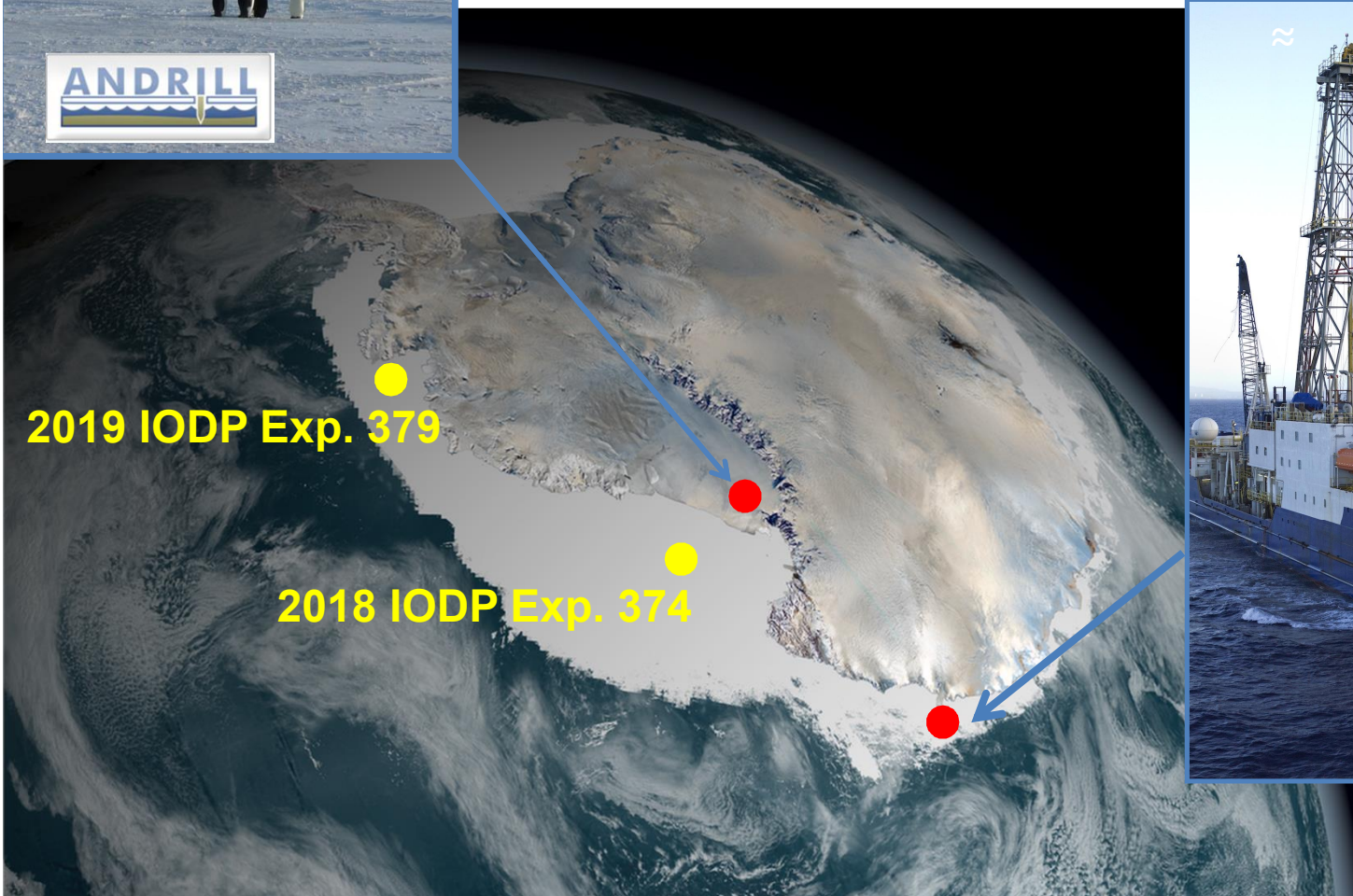


## ANDRILL

Direct evidence of West Antarctic Ice Sheet collapse

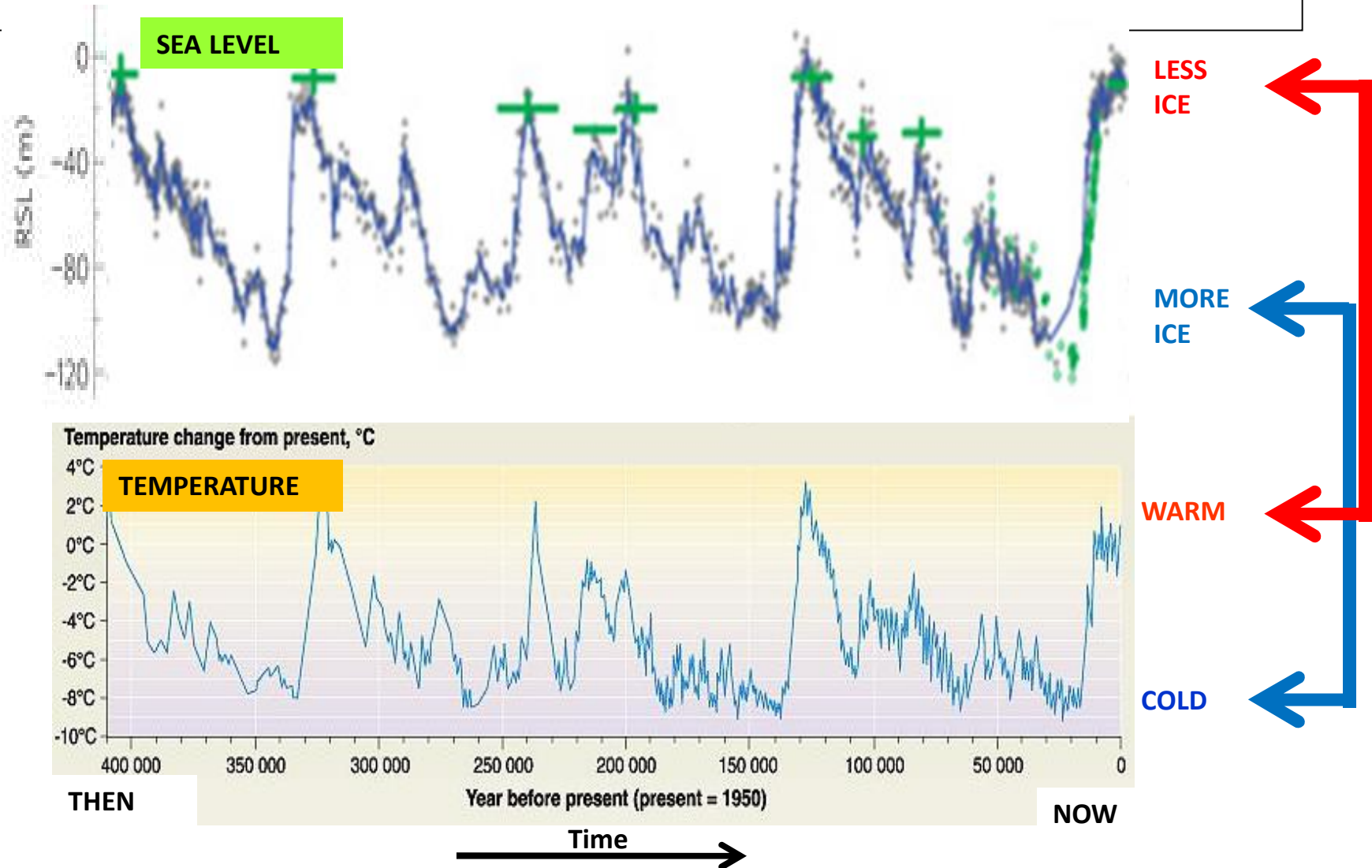
## IODP – Leg 318

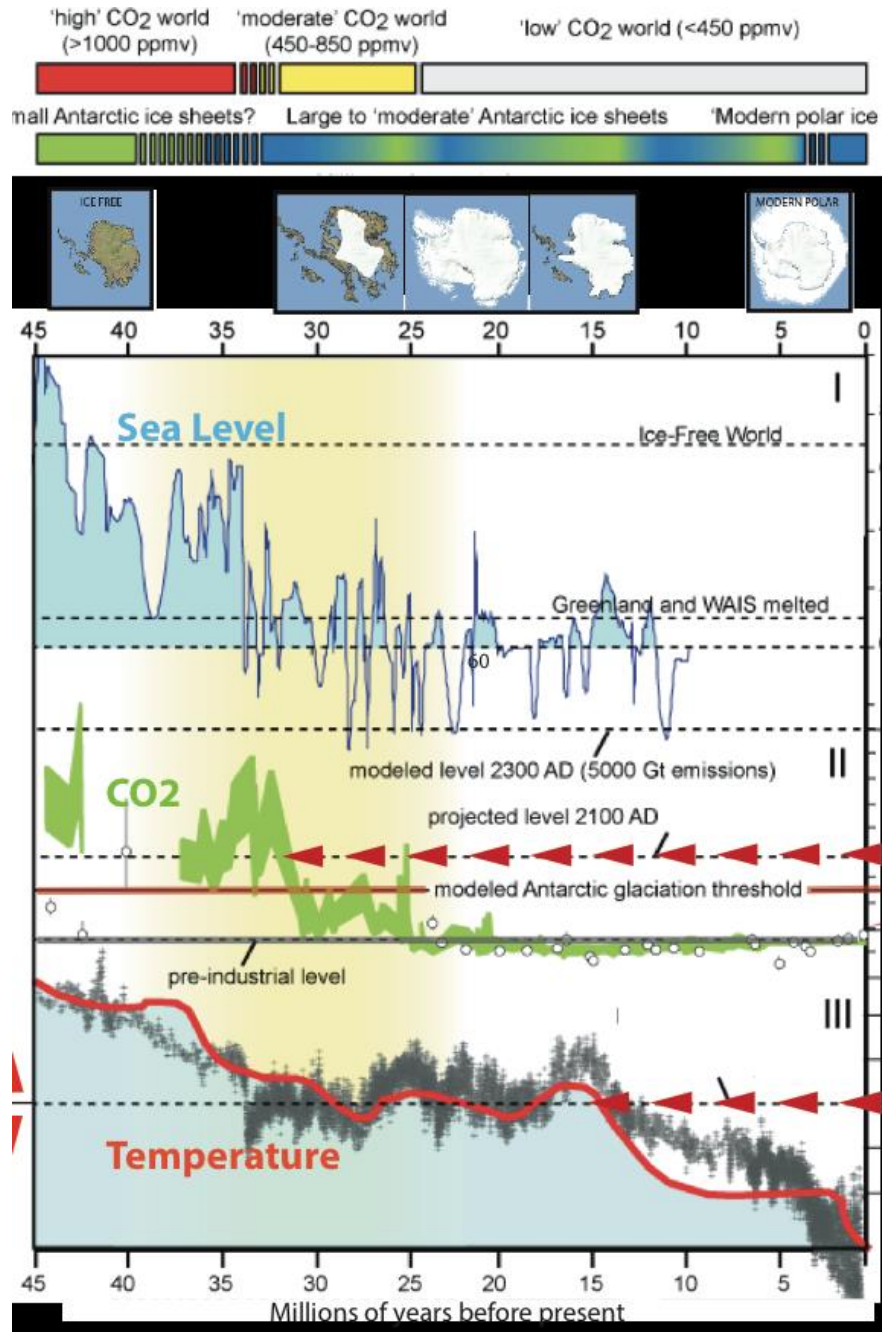
Direct evidence of East Antarctic Ice Sheet retreat





# History Lesson: Less ice in warmer climates





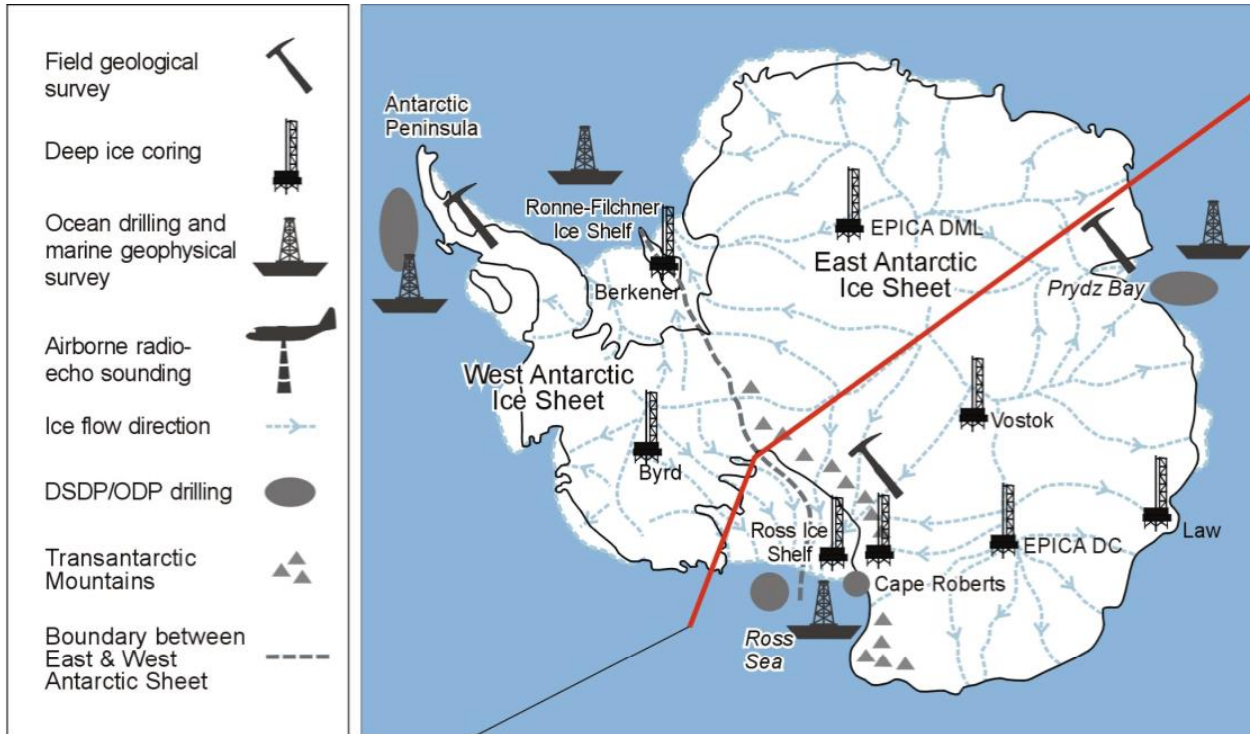
**Northern Hemisphere permanent ice sheets start around 3 million years ago**

**Antarctic ice sheet start around 34 million years ago**

**Projected 2100 CO2 concentrations, IPCC AR5 RCP8.5  
TAKE US BACK TO WHEN ANTARCTICA DID NOT SUPPORT ICE SHEETS**

**Projected 2100 T (°C), IPCC AR5 RCP8.5  
NOT EXPERIENCED IN OUR PLANET SINCE AROUND 15 Ma**

Warmer less ice  
Colder more ice

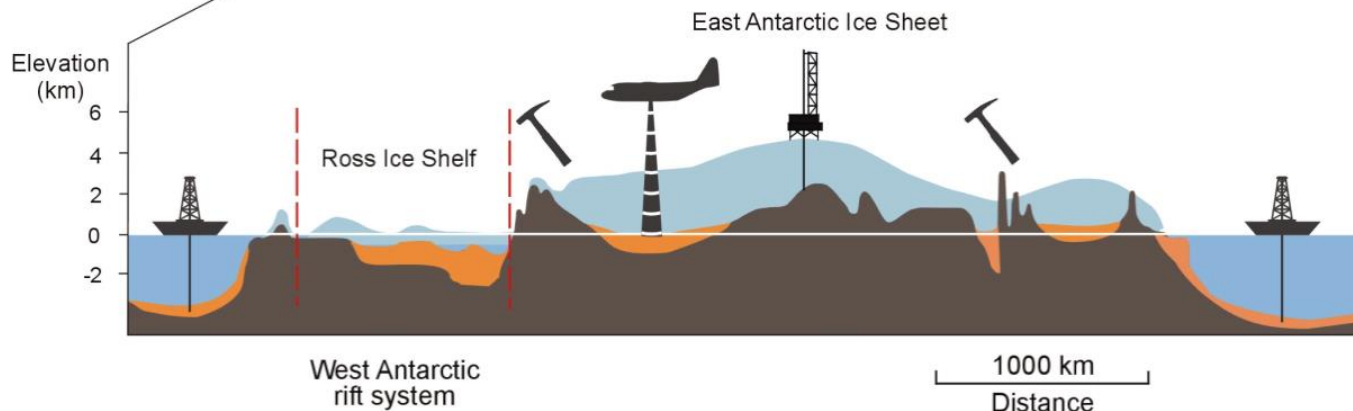


# Sedimentary Records in Antarctica

Outcrops:  
*99.7% of Antarctica is ice covered*

Subglacial records

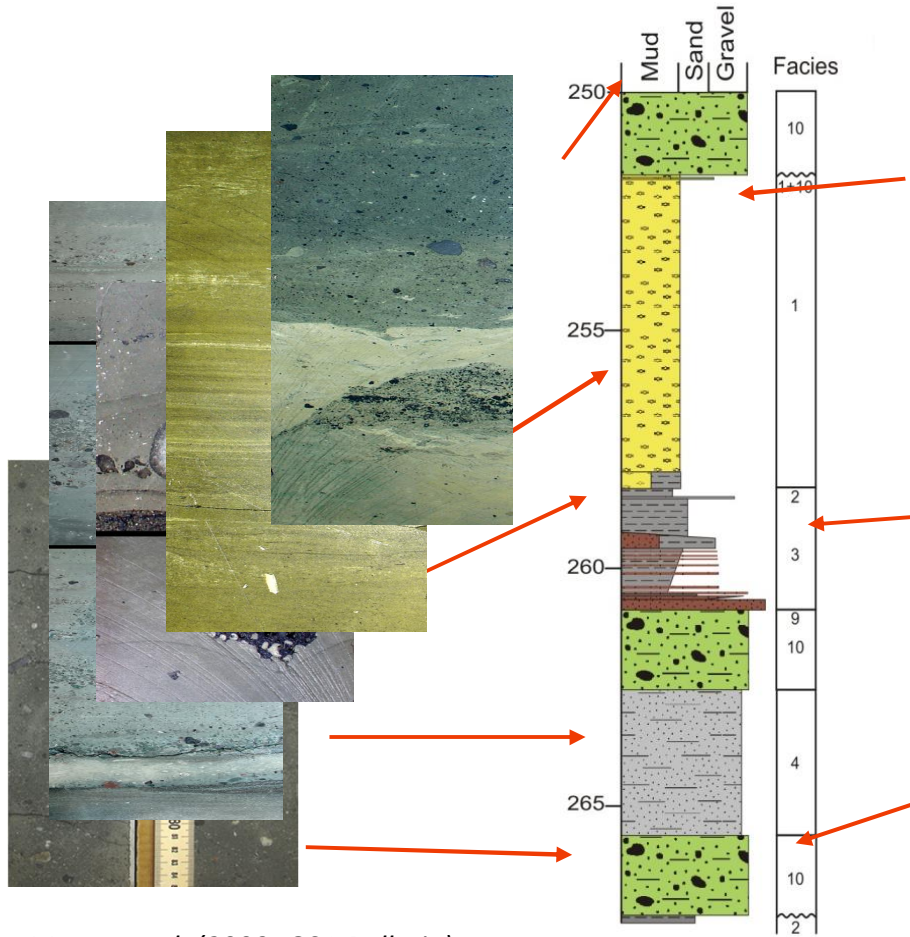
Marine records



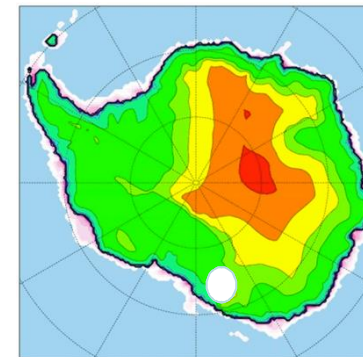
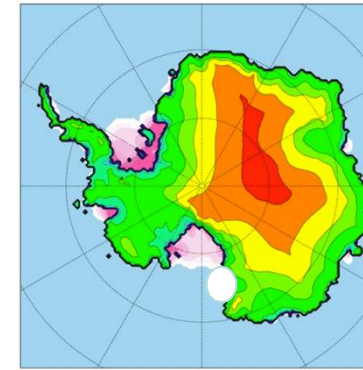
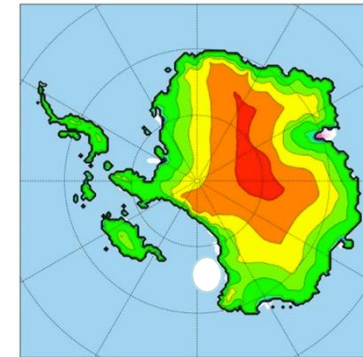
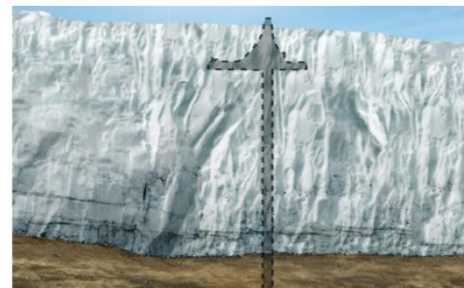
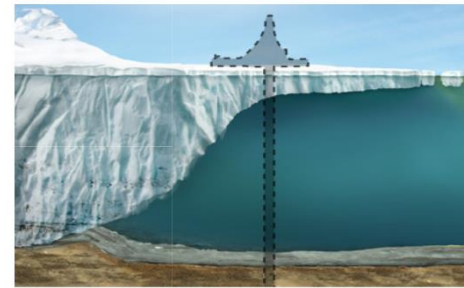
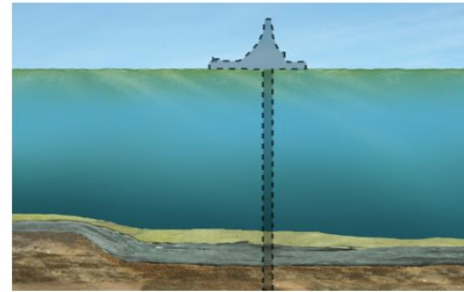


# Drill core evidence of past West Antarctic Ice Sheet collapse

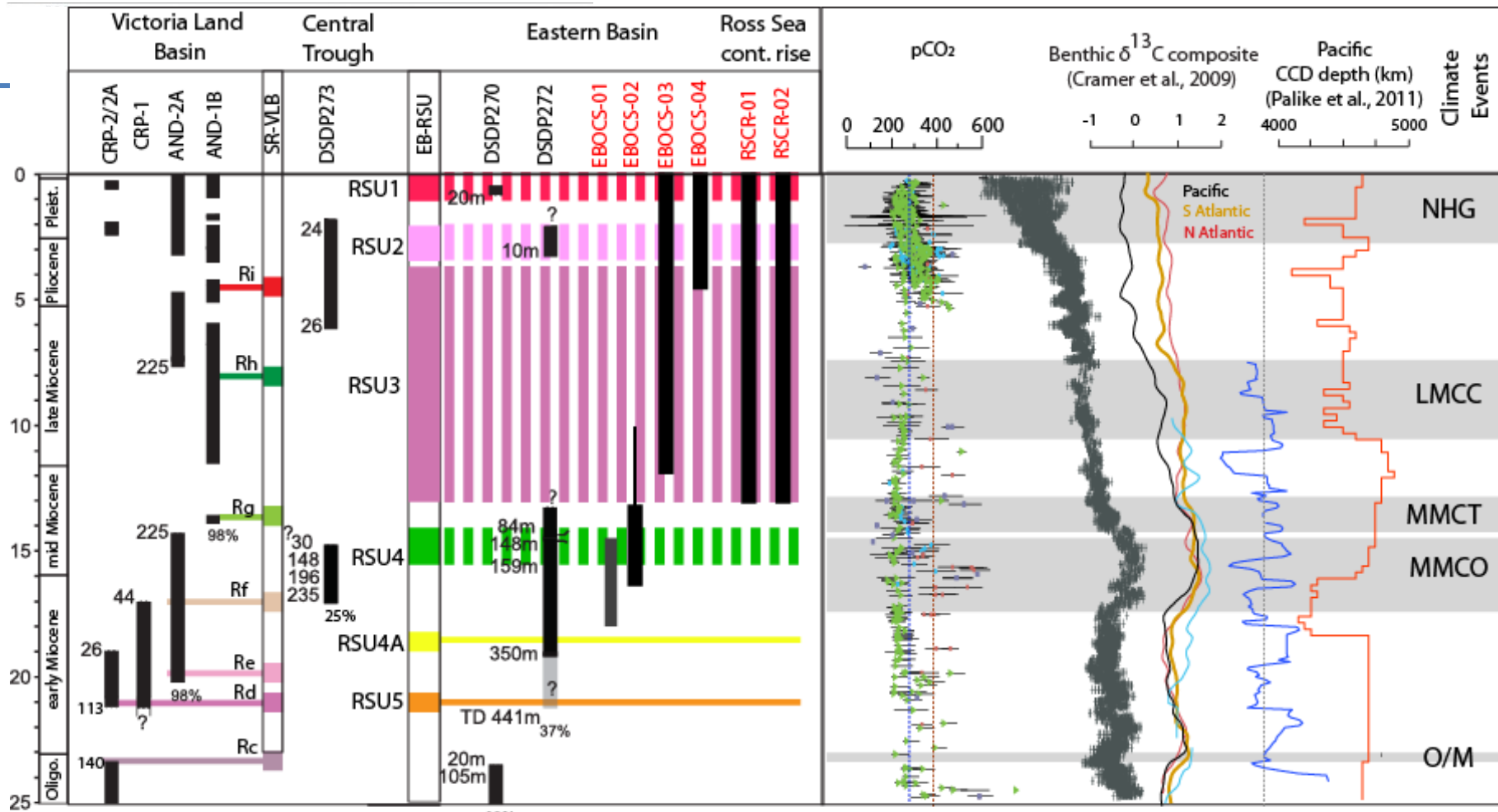
## Glacial-Interglacial glacialmarine cycles



McKay et al. (2009, GSA Bulletin)

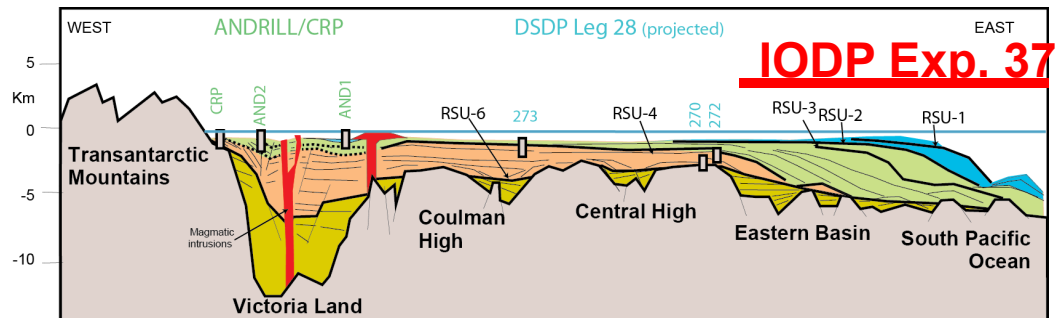


Naish et al., 2009; Nature; Pollard and DeConto, 2009 (Nature)



O/M = Oligocene/Miocene boundary  
 MMCO = Middle Miocene Climatic Optimum    LMCC = Late Miocene Carbonate Crash  
 MMCT = Middle Miocene Climatic Transition,    NHG = Northern Hemisphere glaciation

▲ alkenones  
 ● boron  
 ● stomata  
 ● paleosol  
 5 4 3 2 1 20 0 -20 -40  
 Ocean Benthic Oxygen Isotopes (Zachos et al. 2008)  
 Sea Level NJM Sea level (m above present) (after Kominz et al., 2008)

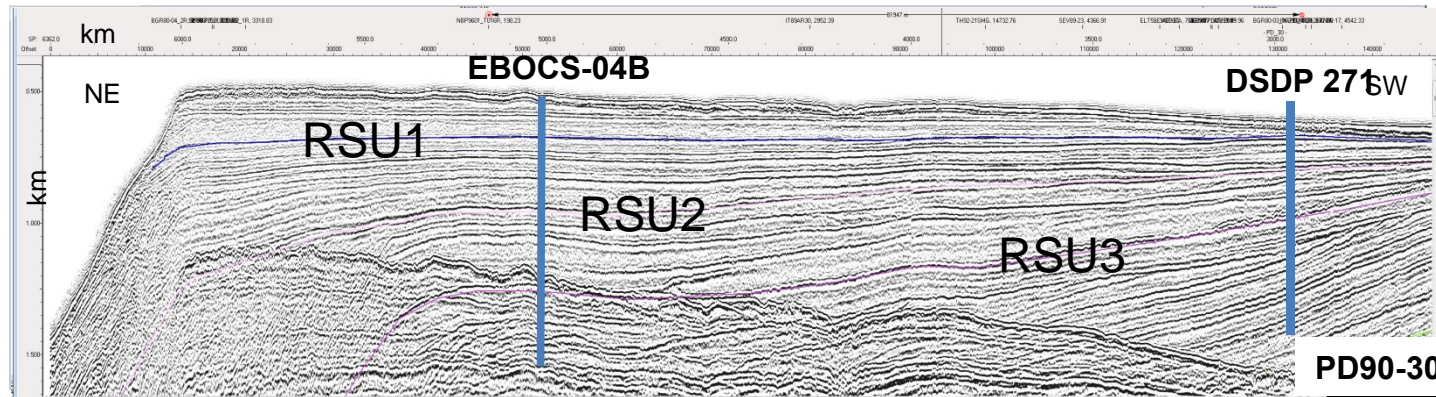


**IODP Exp. 374**

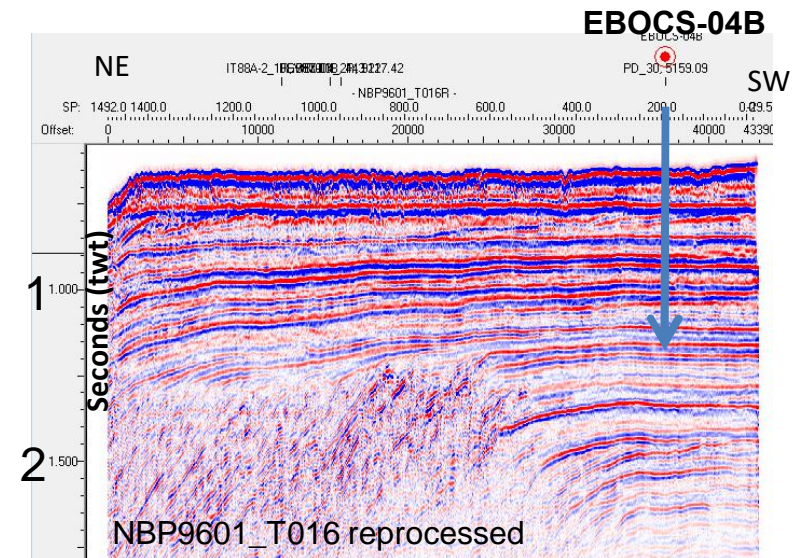
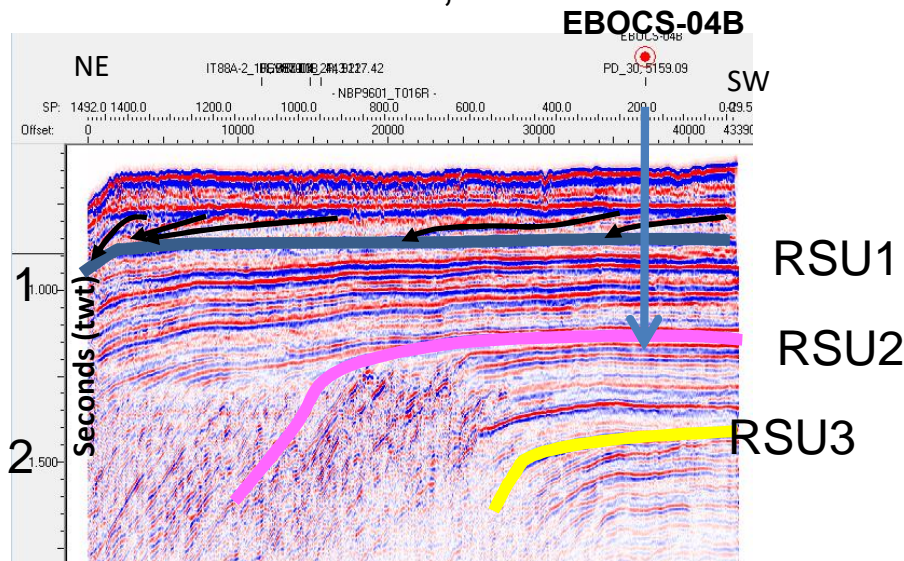
- Pliocene-today (polar environment)
- Miocene-Pliocene (temperate-polar environment)
- Oligocene-Miocene (glaciation onset)
- Cretaceous-Oligocene (no ice?)

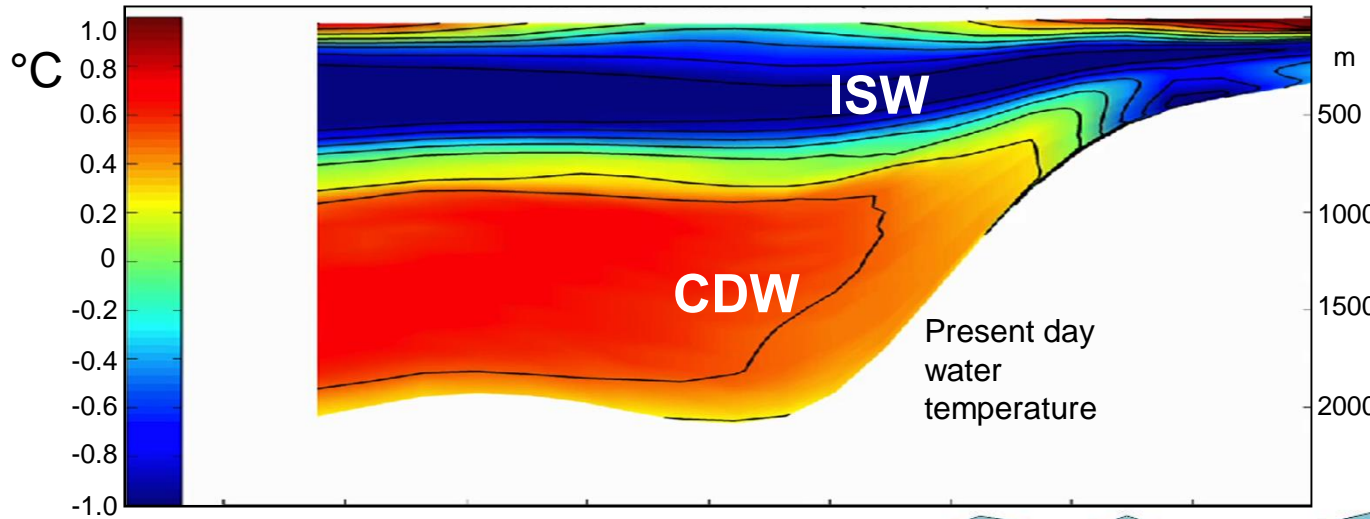
McKay et al., 2013 (IODP prop. 751)

# IODP Exp. 374

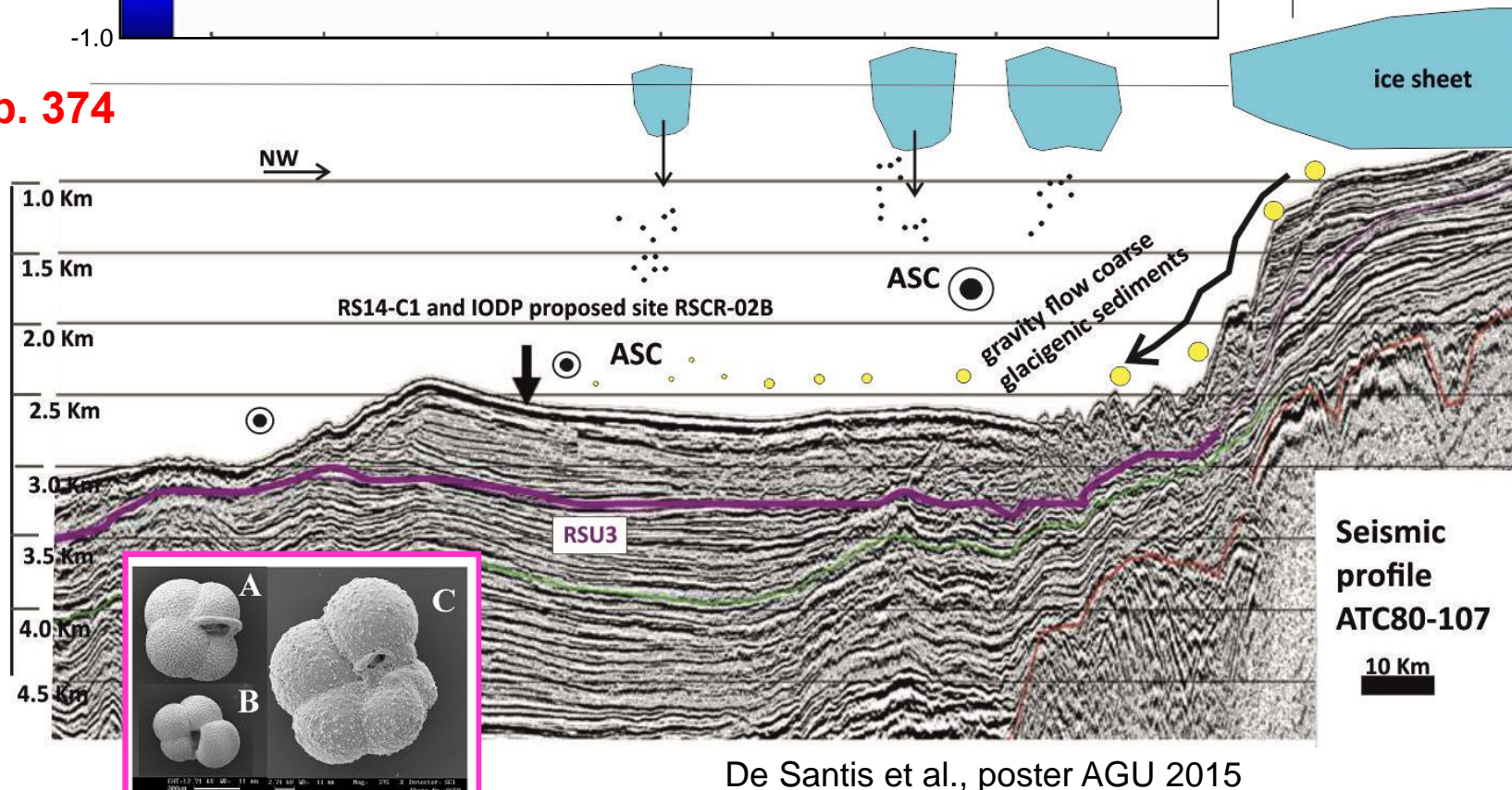


Anderson and Bartek., 1990

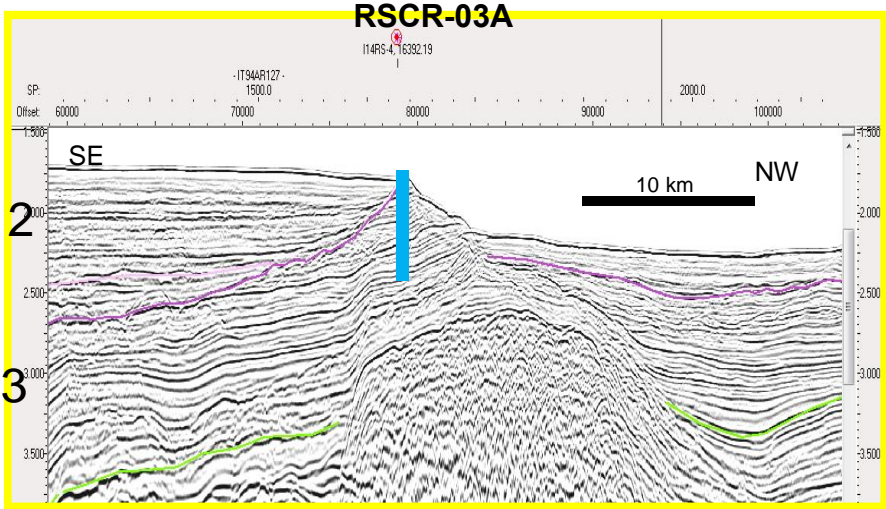
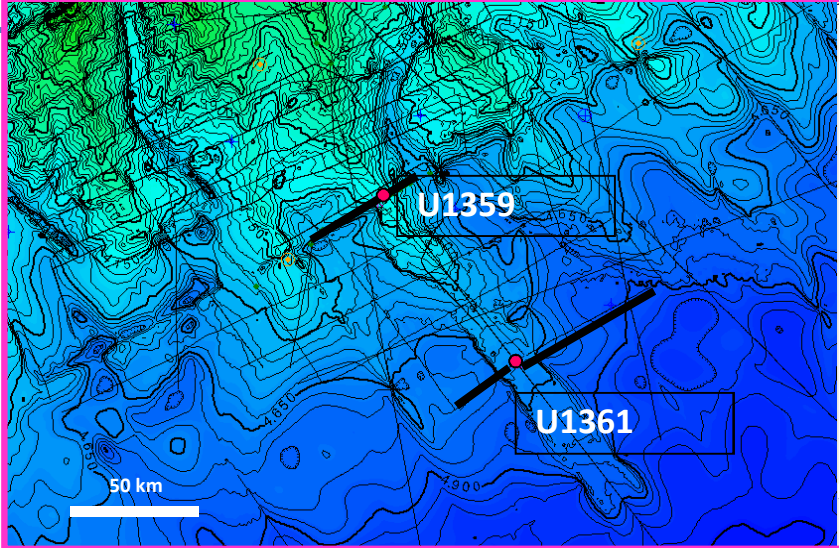
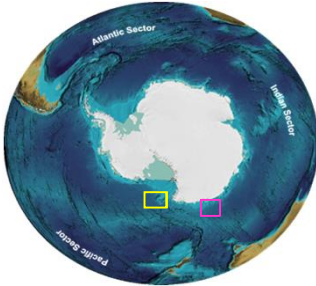
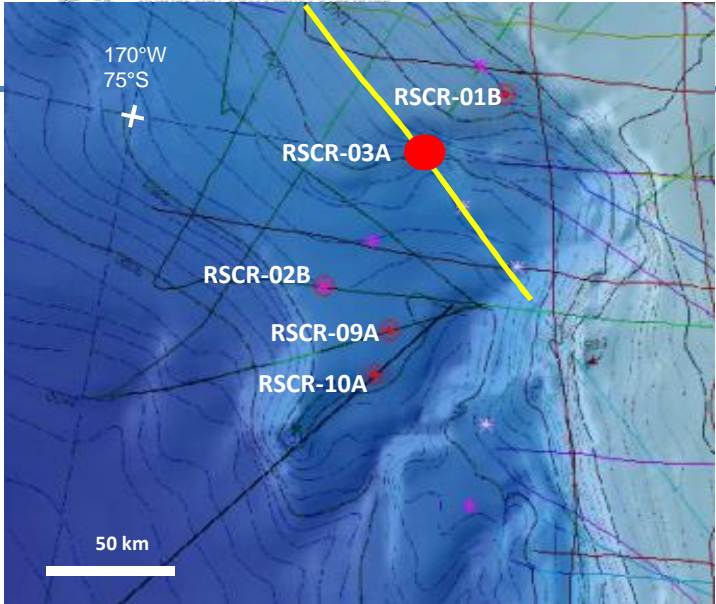




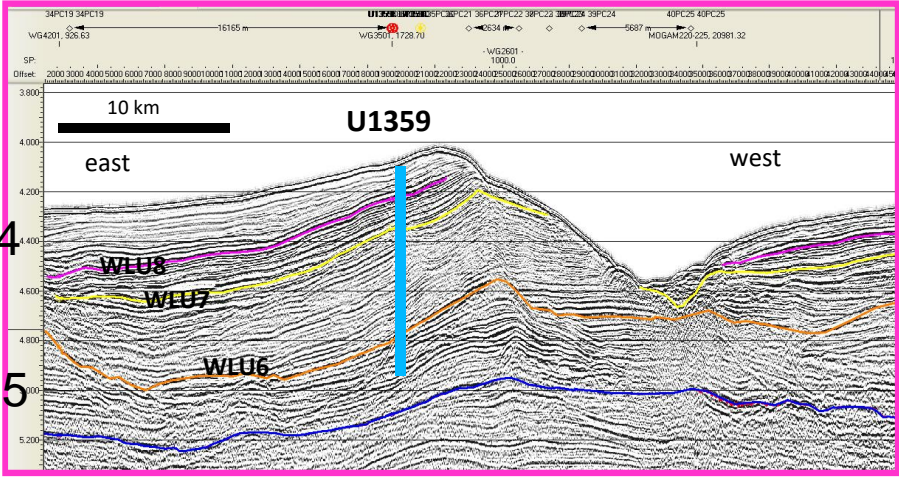
**IODP Exp. 374**



De Santis et al., poster AGU 2015



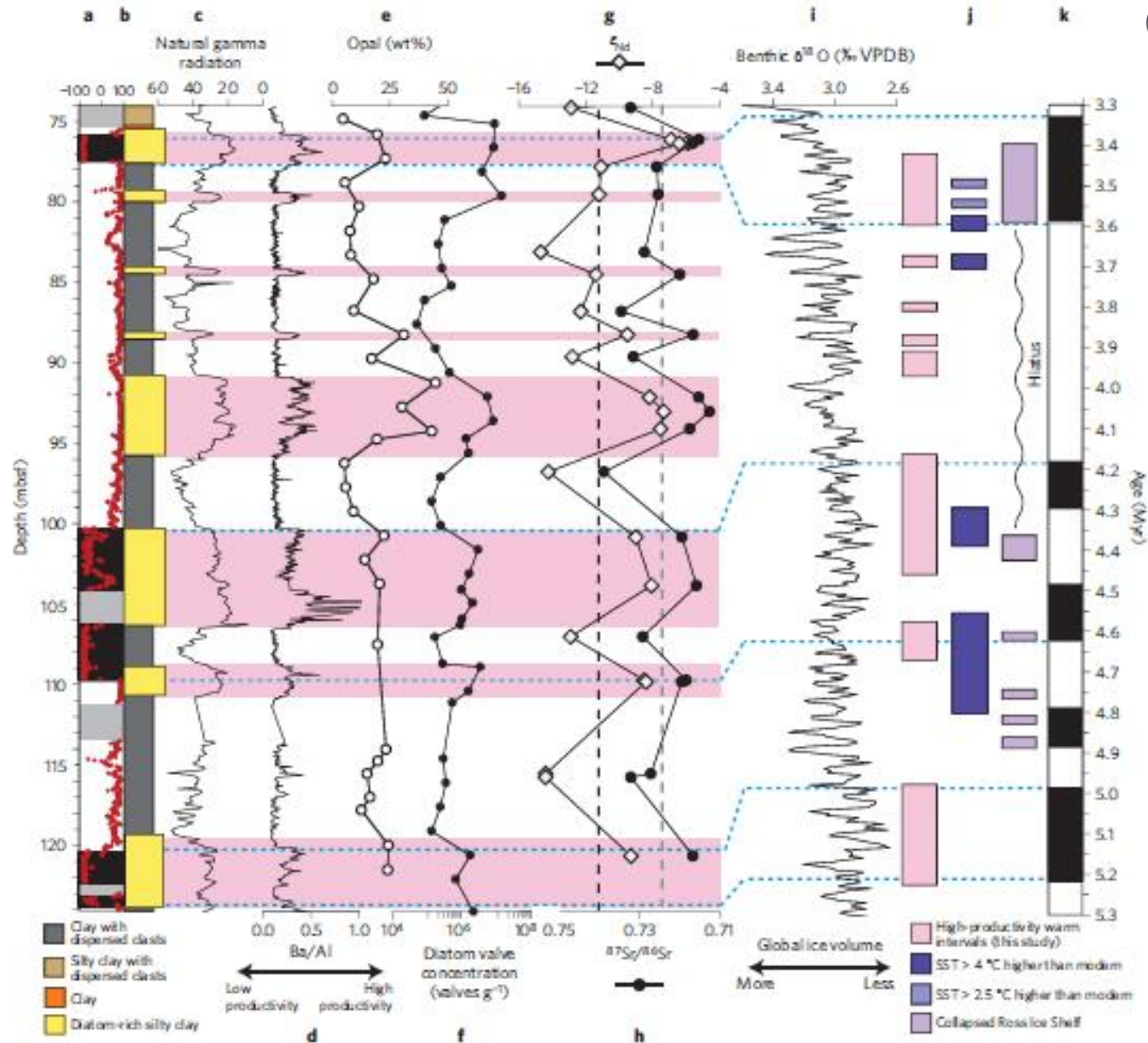
IT94AR-127 (Ross Sea)



WEGA 2601 (Wilkes Land)

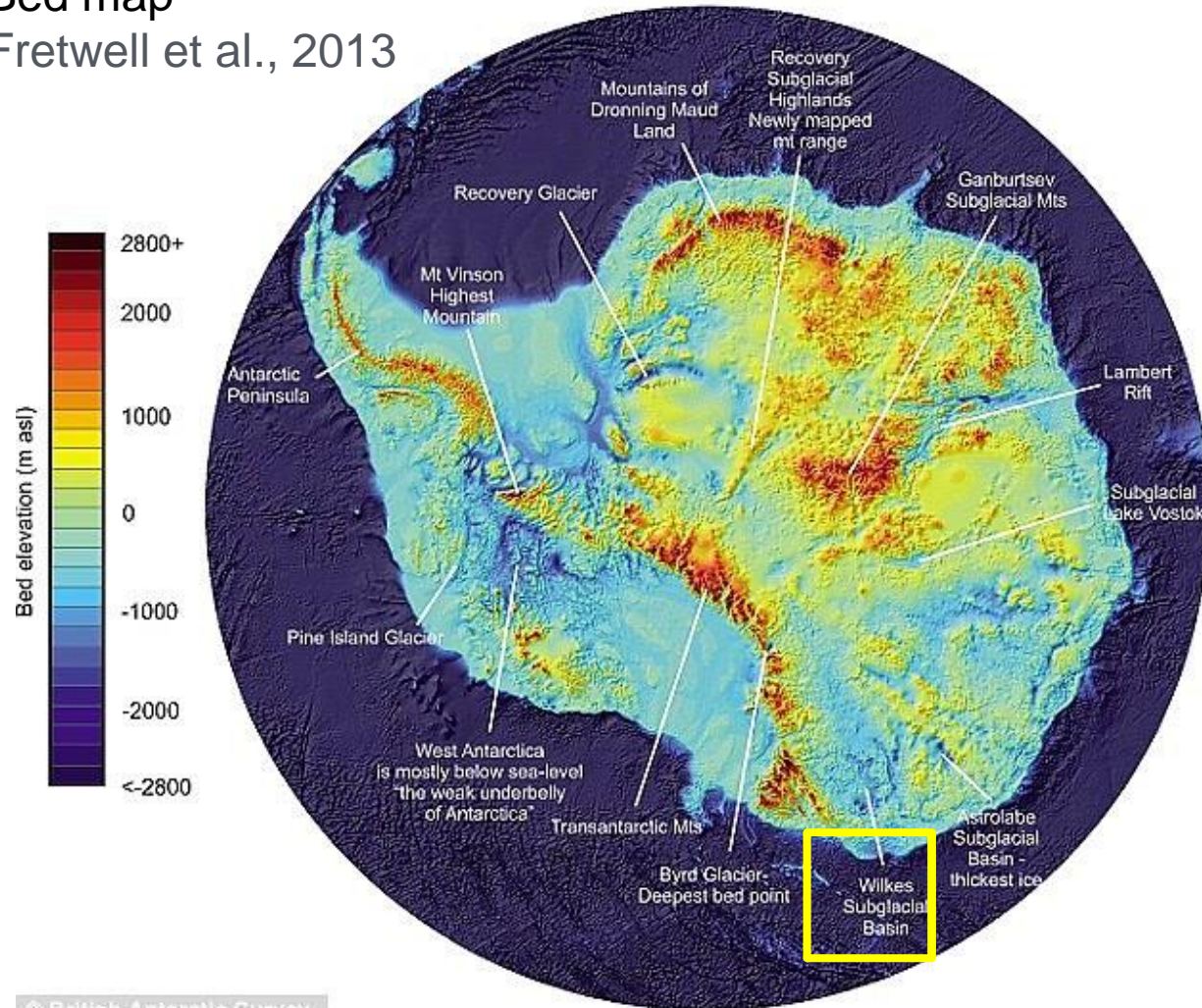


Cook et al., 2013

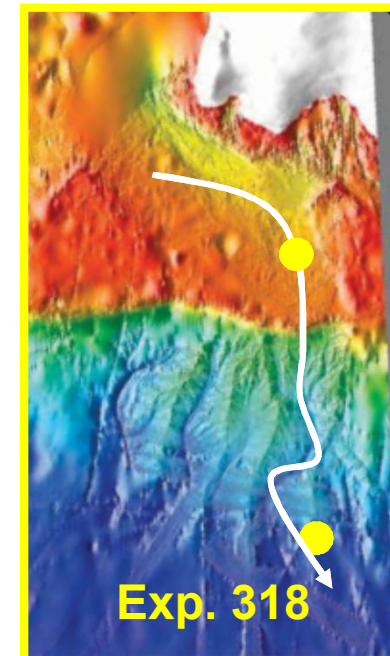


# Bed map

Fretwell et al., 2013



## Antarctic bottom water pathway



Escutia et al., 2010;  
Patterson et al., 2014