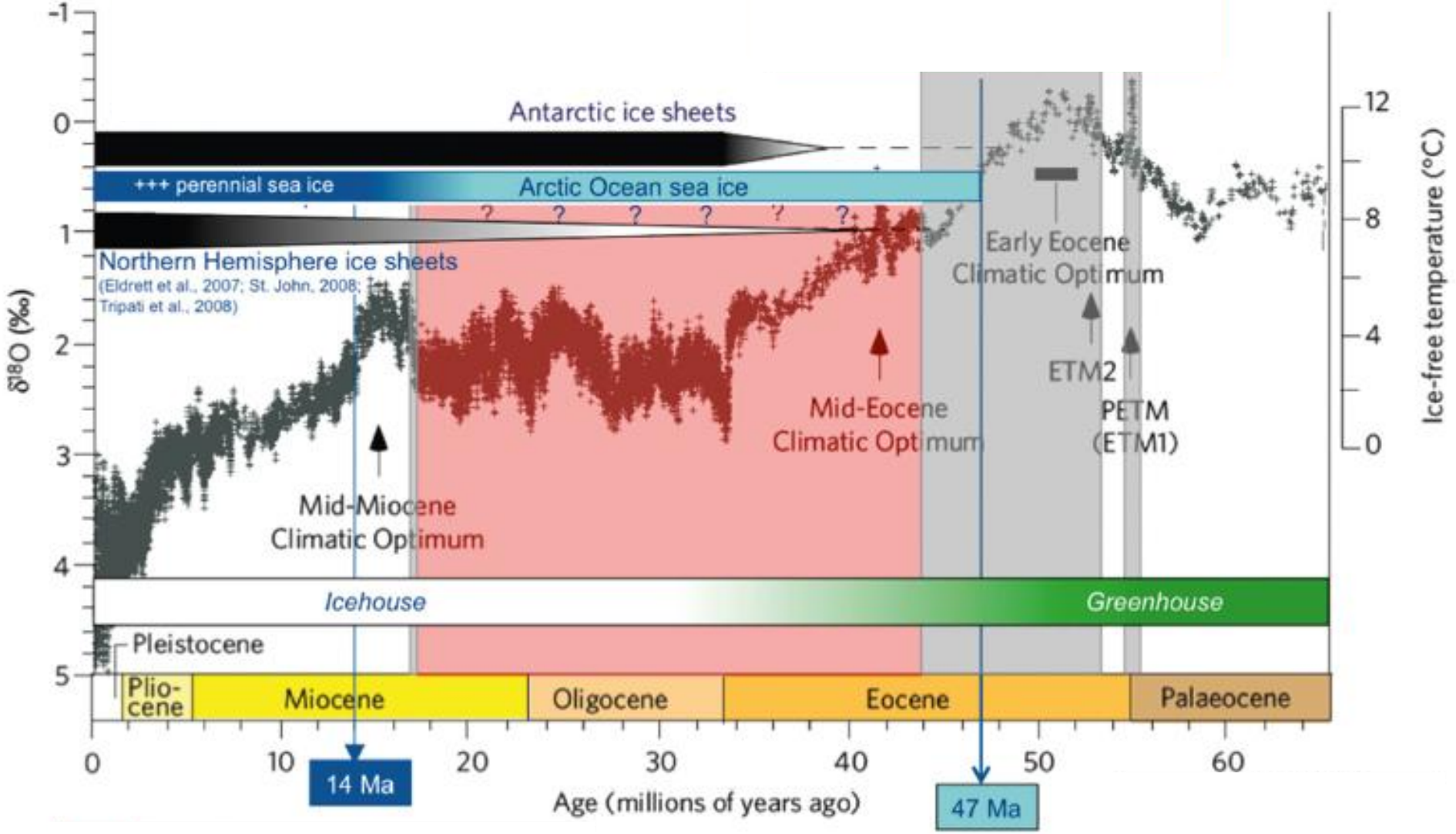
- Past Arctic Ocean Climate Evolution
- High-Latitude Marine Paleoclimatology
- Crustose coralline algal-based marine climate reconstructions

Jochen Halfar, University of Toronto

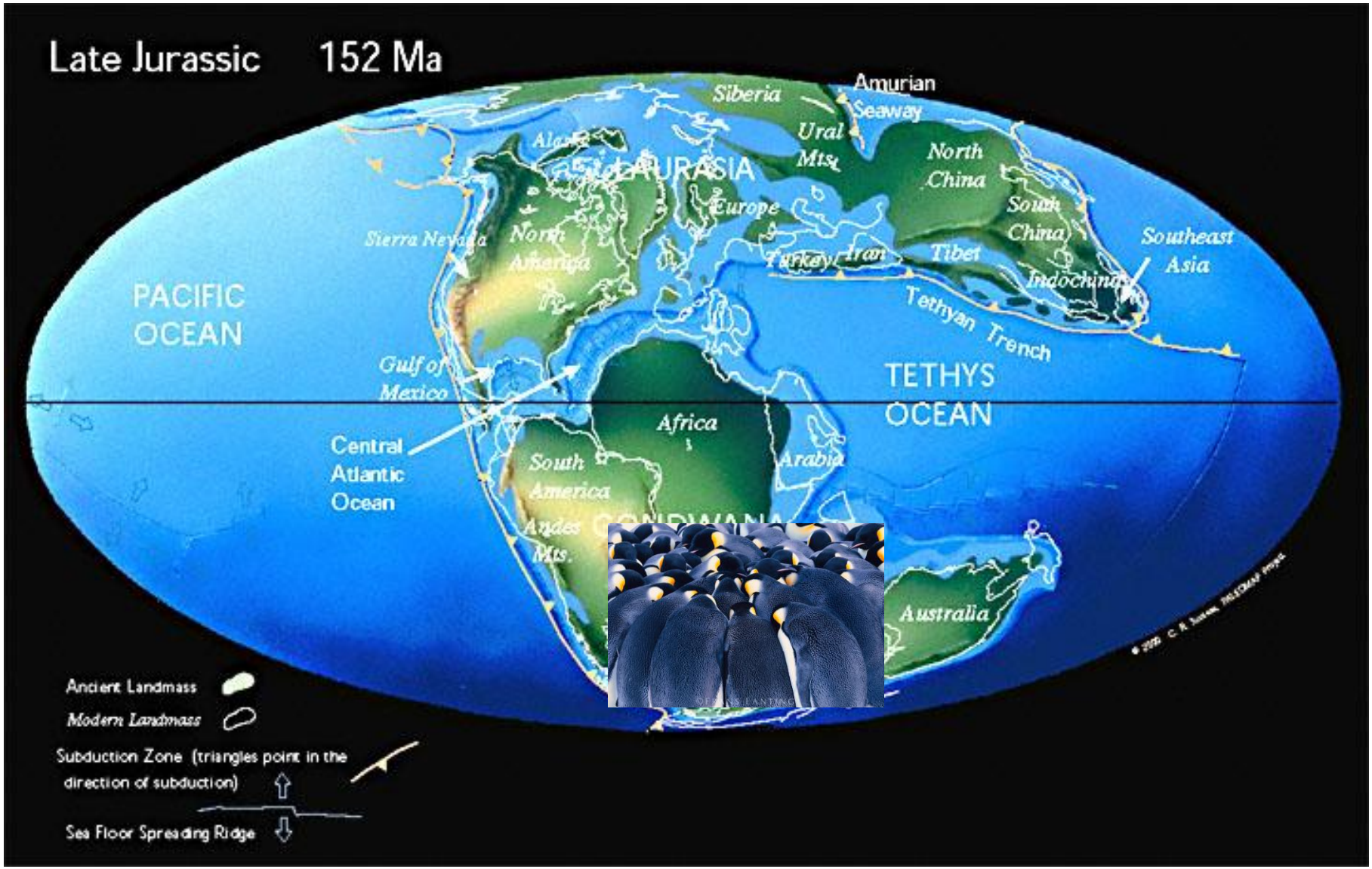
Past Arctic Ocean Climate Evolution



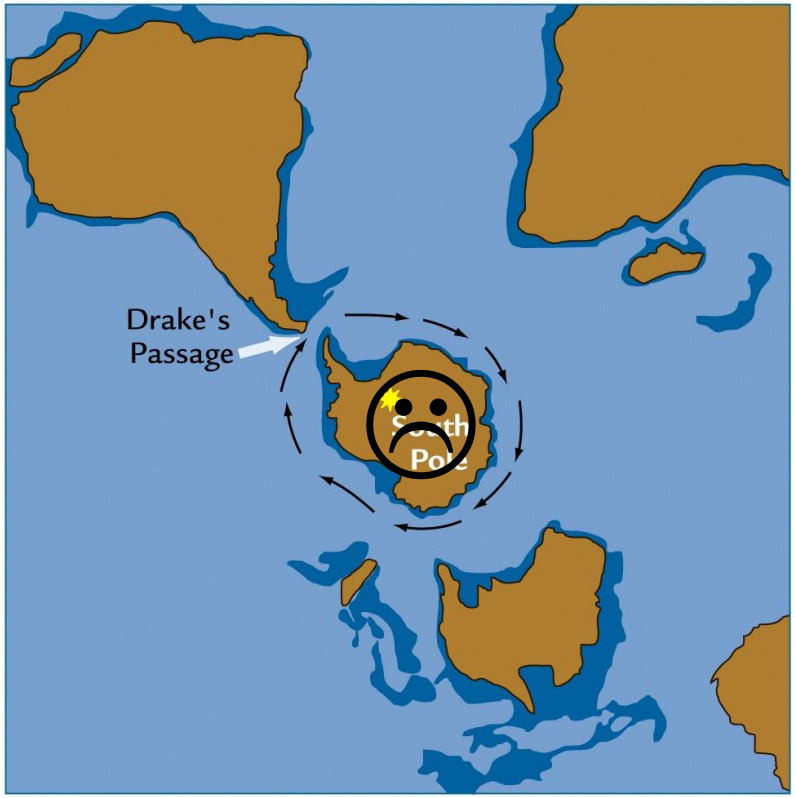
Stein et al. 2012

How to cool a planet?

Lets isolate Antarctica!



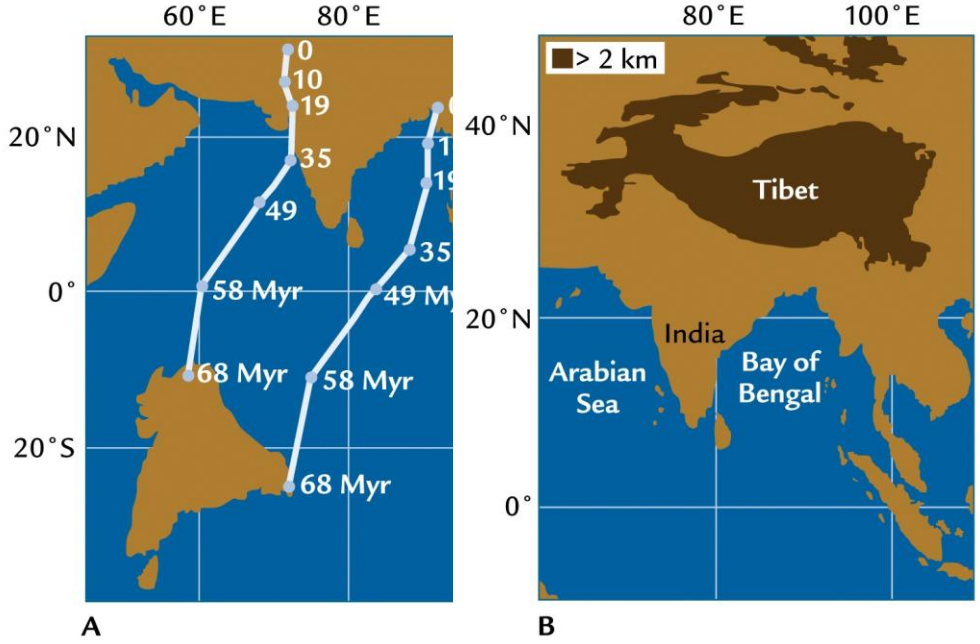
How to cool a planet?



- Oceanic Gateway Opening
- Initiation of Circumantarctic Current

~34 Ma

How to cool a planet?

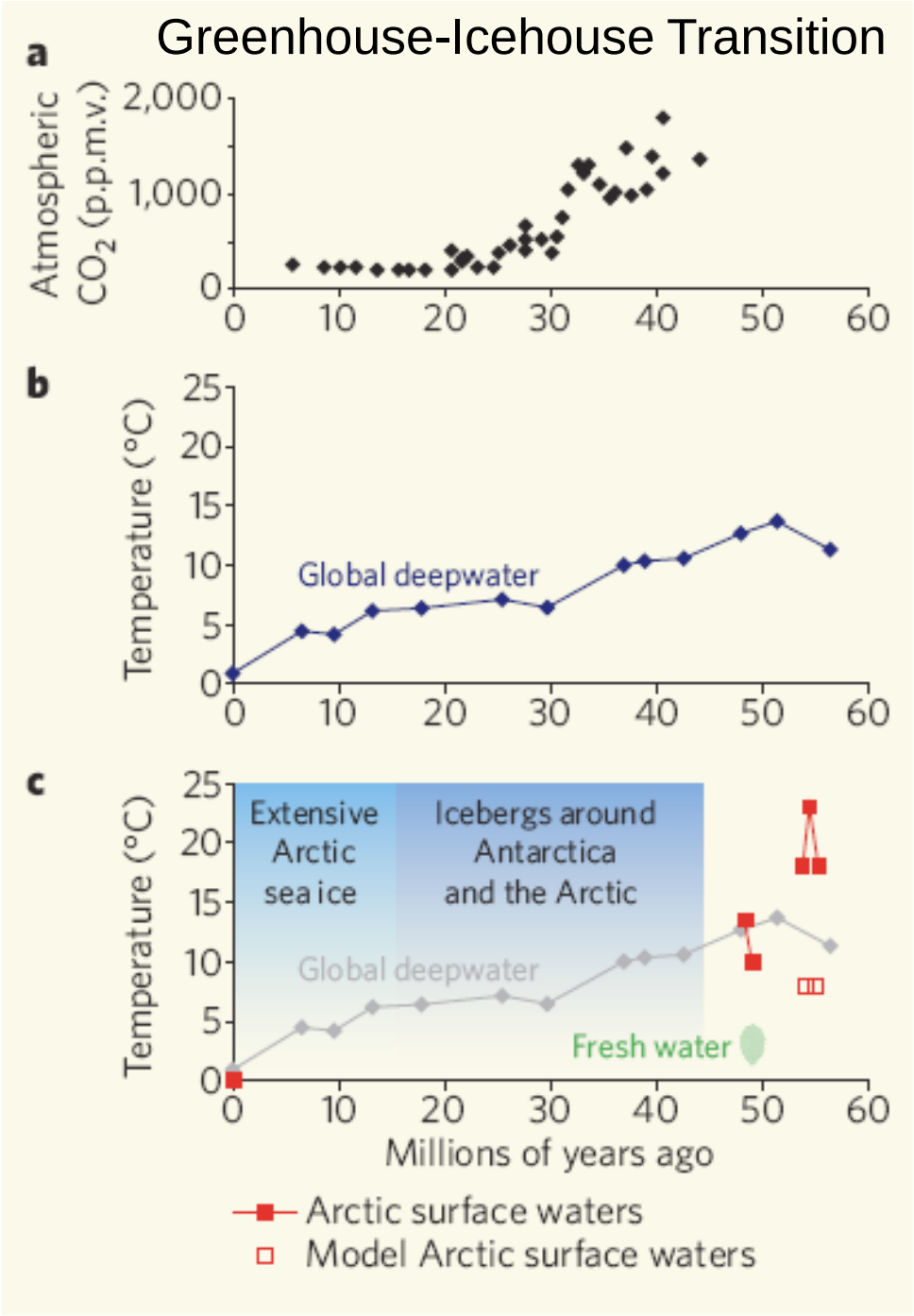


1. $CaSiO_3 + CO_2 + H_2O \rightarrow CaCO_3 + SiO_2 + H_2O$

- Main collision India-Asia ~35 Ma, and European Alps in Eocene (56-35 Ma)

- Weathering of Mountain Belts

- Drawdown of CO_2



- Arctic glaciation contemporaneous with Antarctica

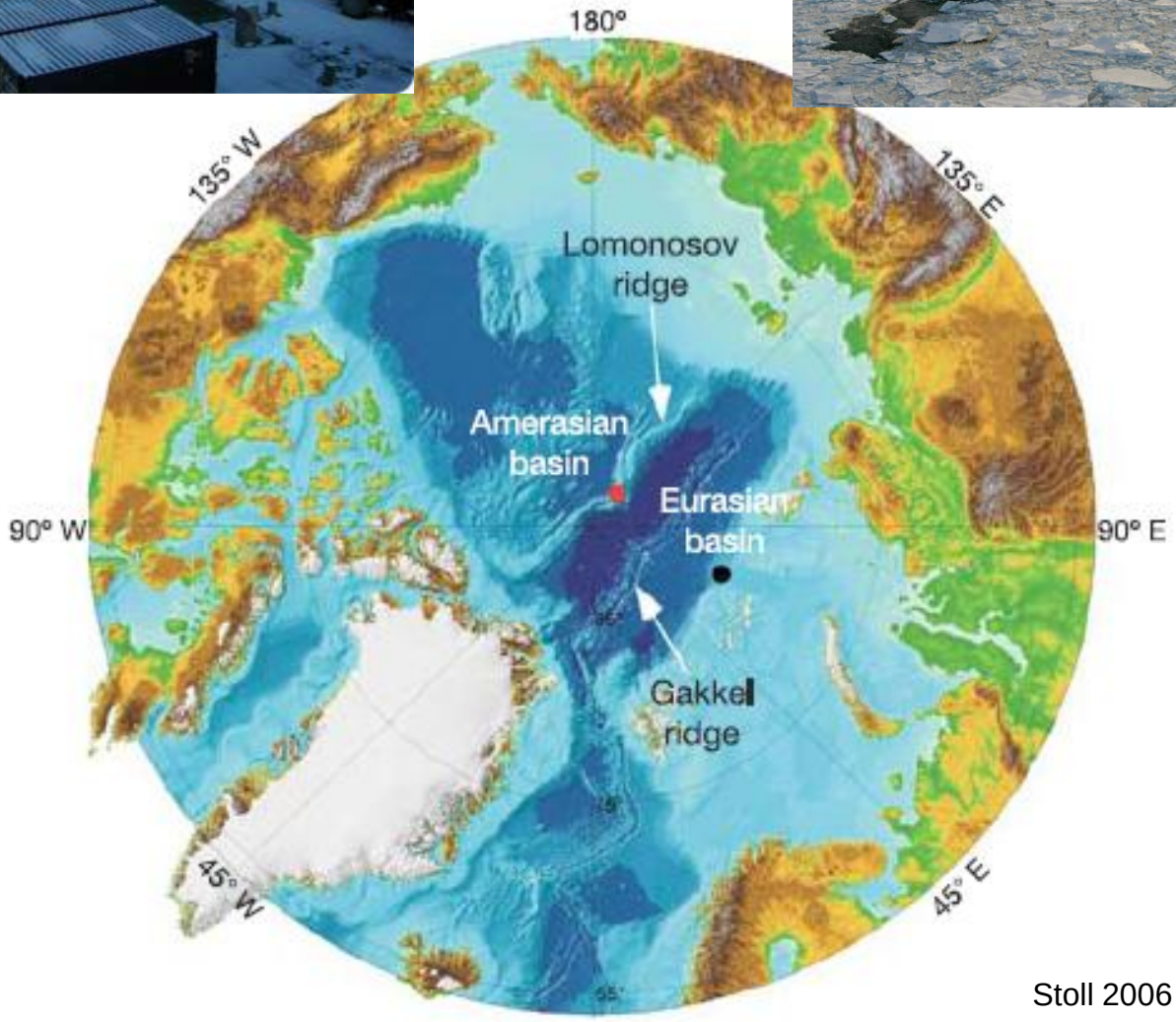
→ Bipolar glaciation

- Points to CO_2 as main driver

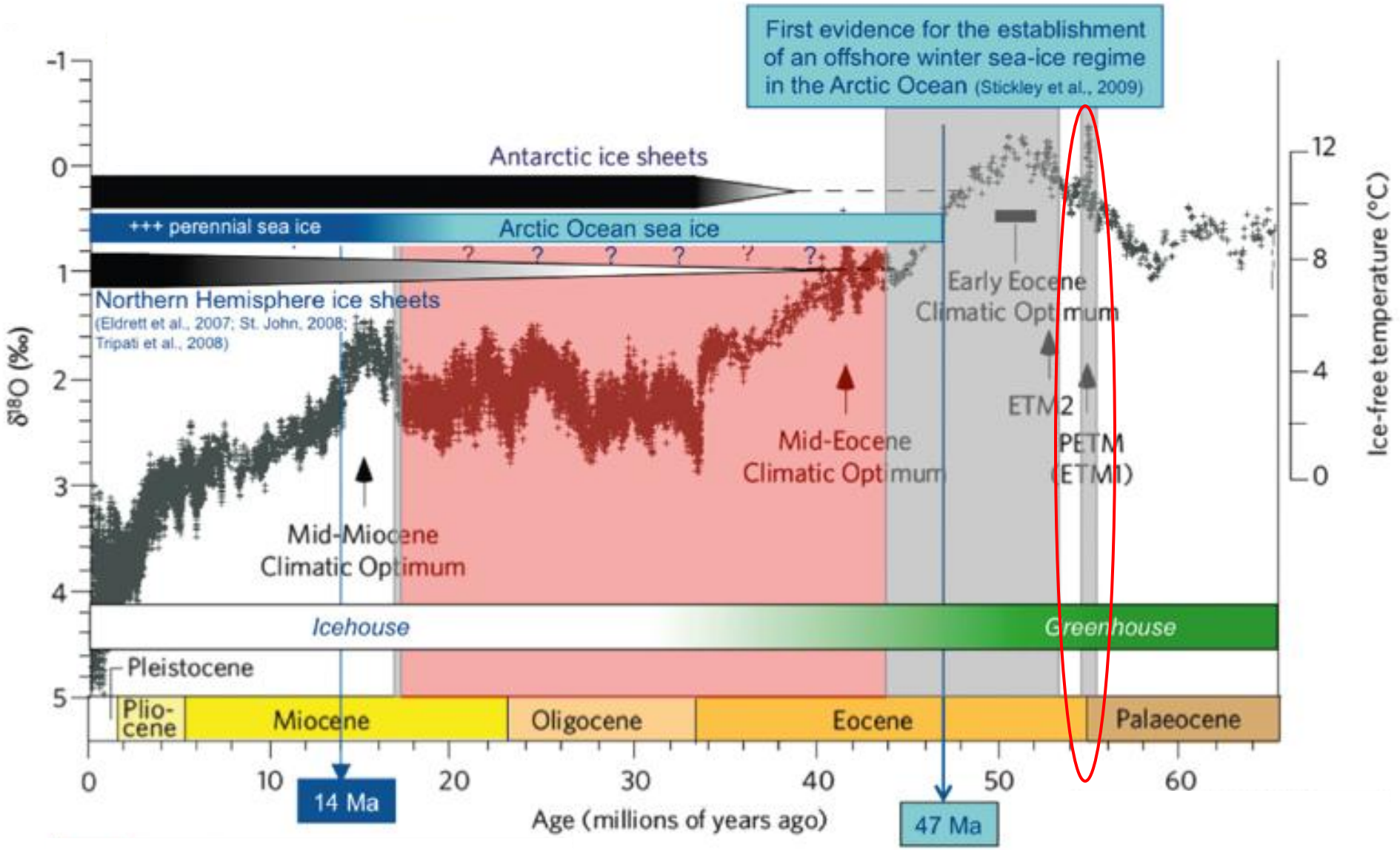
Stoll 2006

ACEX –
Arctic
Coring
Expedition

IODP -
Integrated
Ocean
Drilling
Program



Stoll 2006



Stein et al. 2012

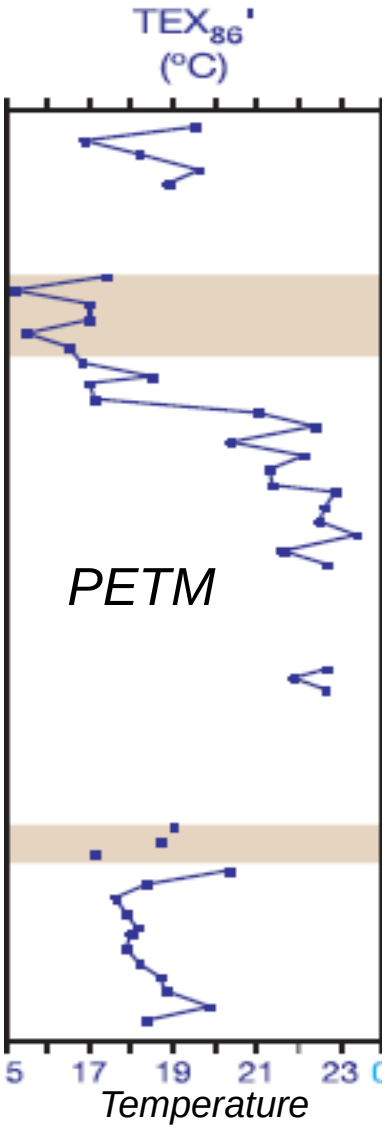
Paleocene-Eocene Thermal Maximum (PETM - 56 Ma)

- Massive carbon release to atmosphere in short time (<5 ka)

- Comparable to today's CO_2 increase (amount and timing)

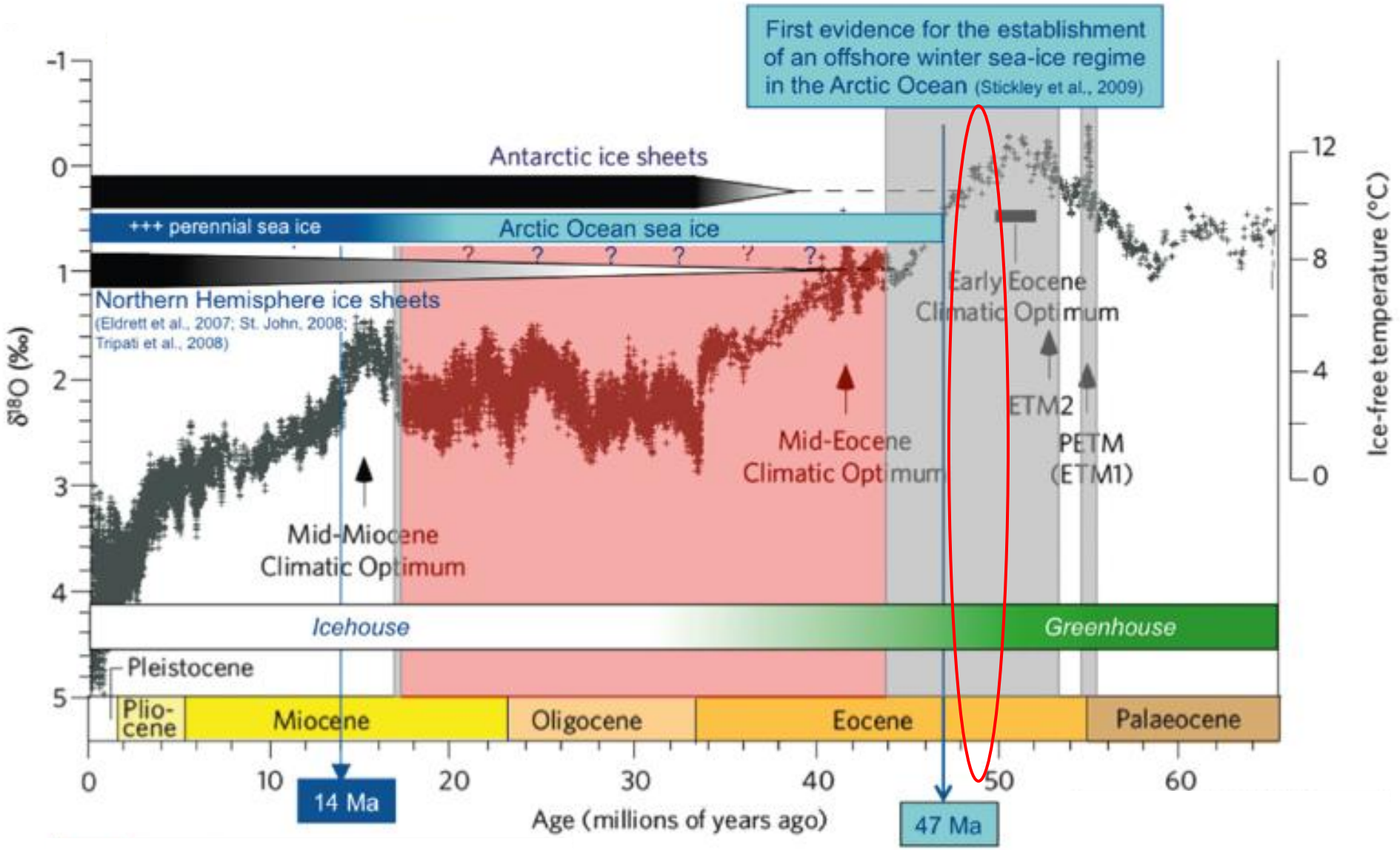
- Caused short global scale warming (duration ~200ka)

Paleocene-Eocene Thermal Maximum (PETM - 56 Ma)



Sluijs et al. 2011

- Arctic sea surface temperatures increased from 18 to 23℃
- Supergreenhouse
- Invasion of subtropical marine species
- Before, after and during PETM Arctic ice free



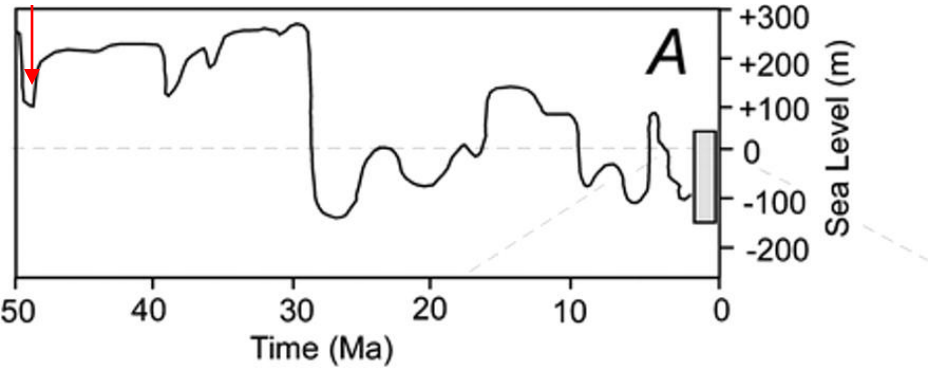
Stein et al. 2012

Freshwater Lake (49 Ma ago)

Brinkhuis et al. 2006

Freshwater Lake (49 Ma ago)

- No inflow of warm salty currents (related to sea-level drop?)

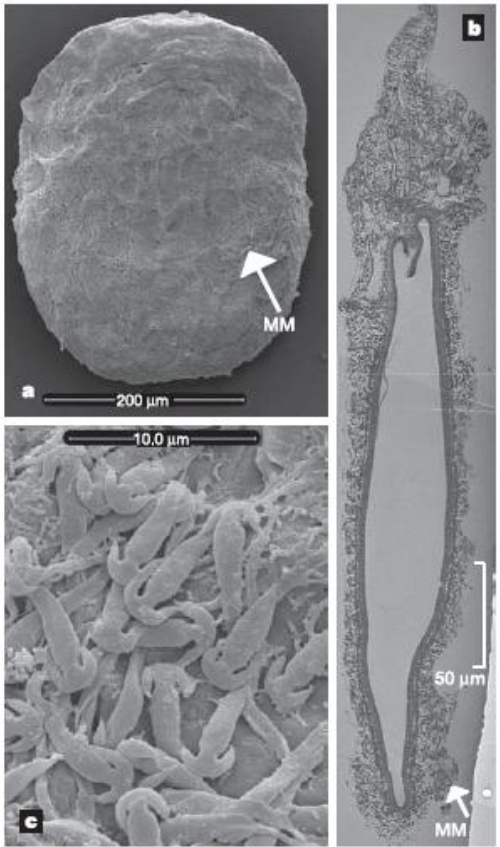


Brinkhuis et al. 2006

Freshwater Lake (49 Ma ago)

- No inflow of warm salty currents (related to sea-level drop?)

- Evidence aquatic fern *Azolla*
  (grows only in less than 0.2% salt)



Brinkhuis et al. 2006

Freshwater Lake (49 Ma ago)

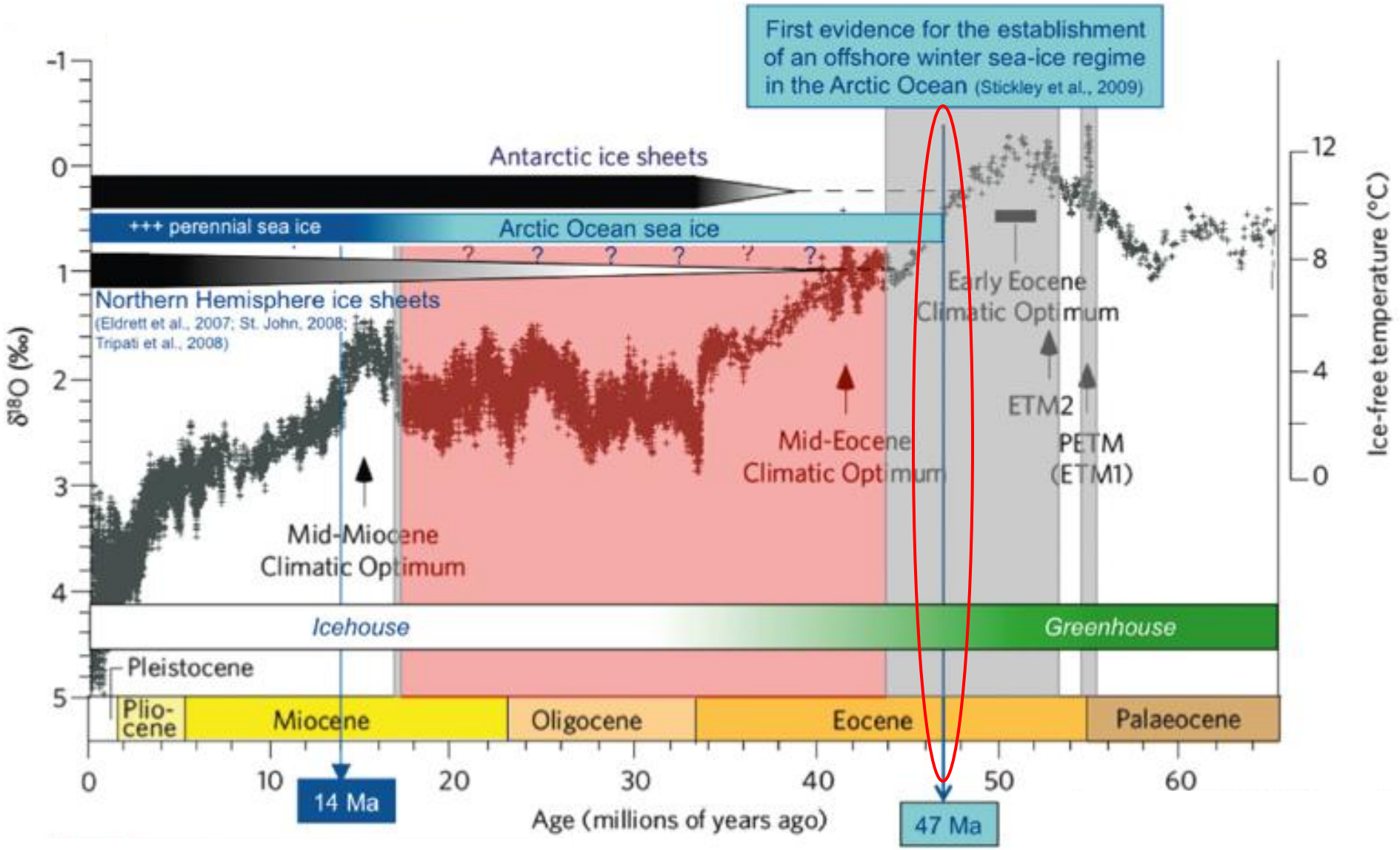
- No inflow of warm salty currents (related to sea-level drop?)

- Evidence aquatic fern *Azolla* (grows only in less than 0.2% salt)

- Arctic freshwater overflowed into adjacent basins

- Often anoxic conditions at seafloor

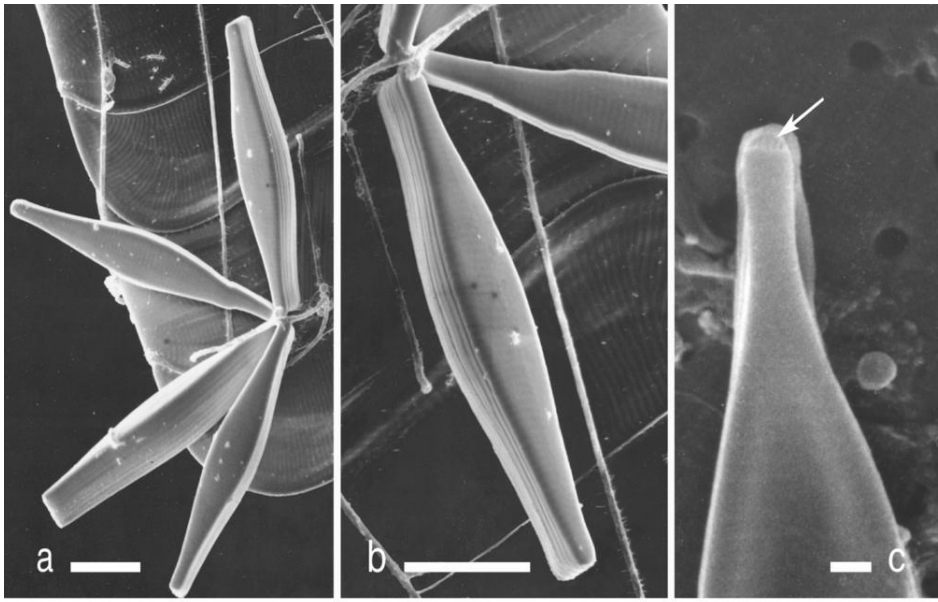
Brinkhuis et al. 200



Stein et al. 2012

First Sea Ice at 47.5 Ma

Evidence A: Sea Ice Algae (Diatom – *Synedropsis* sp.)

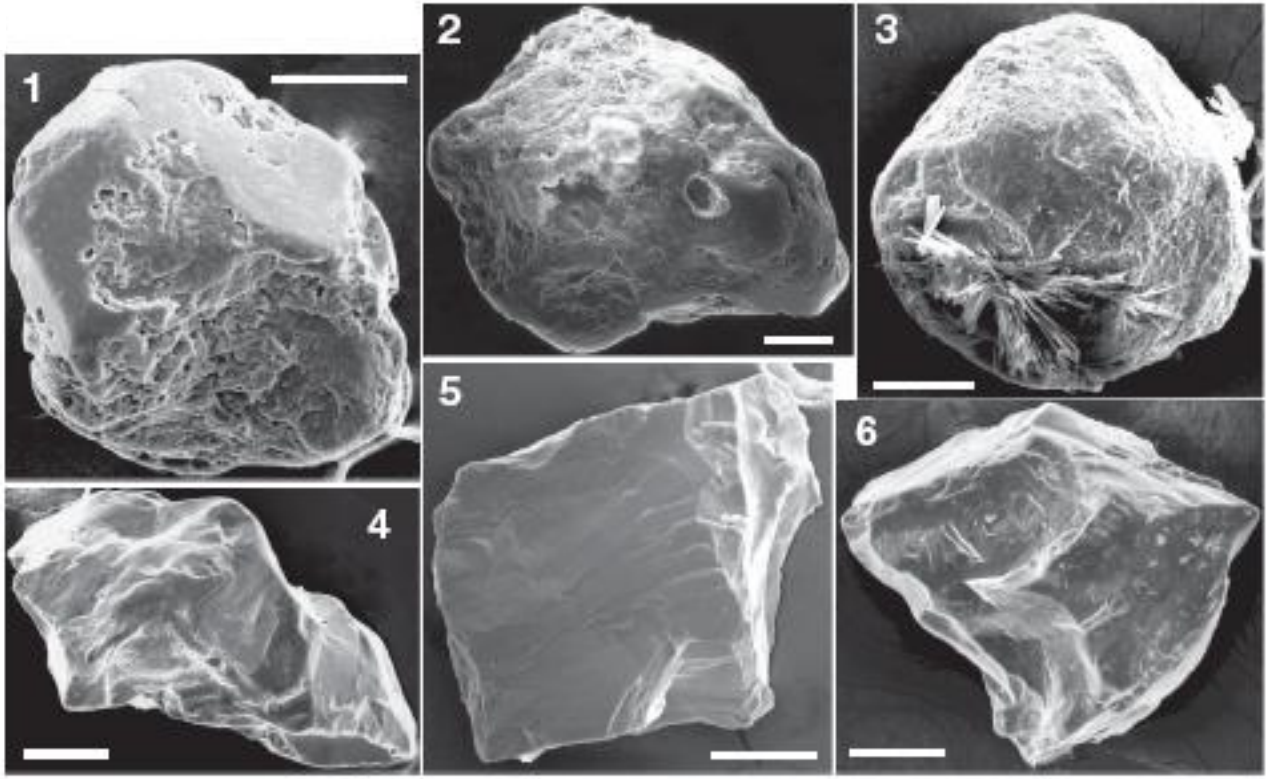


Synedropsis hyperboreoides

Stickley et al. 2009

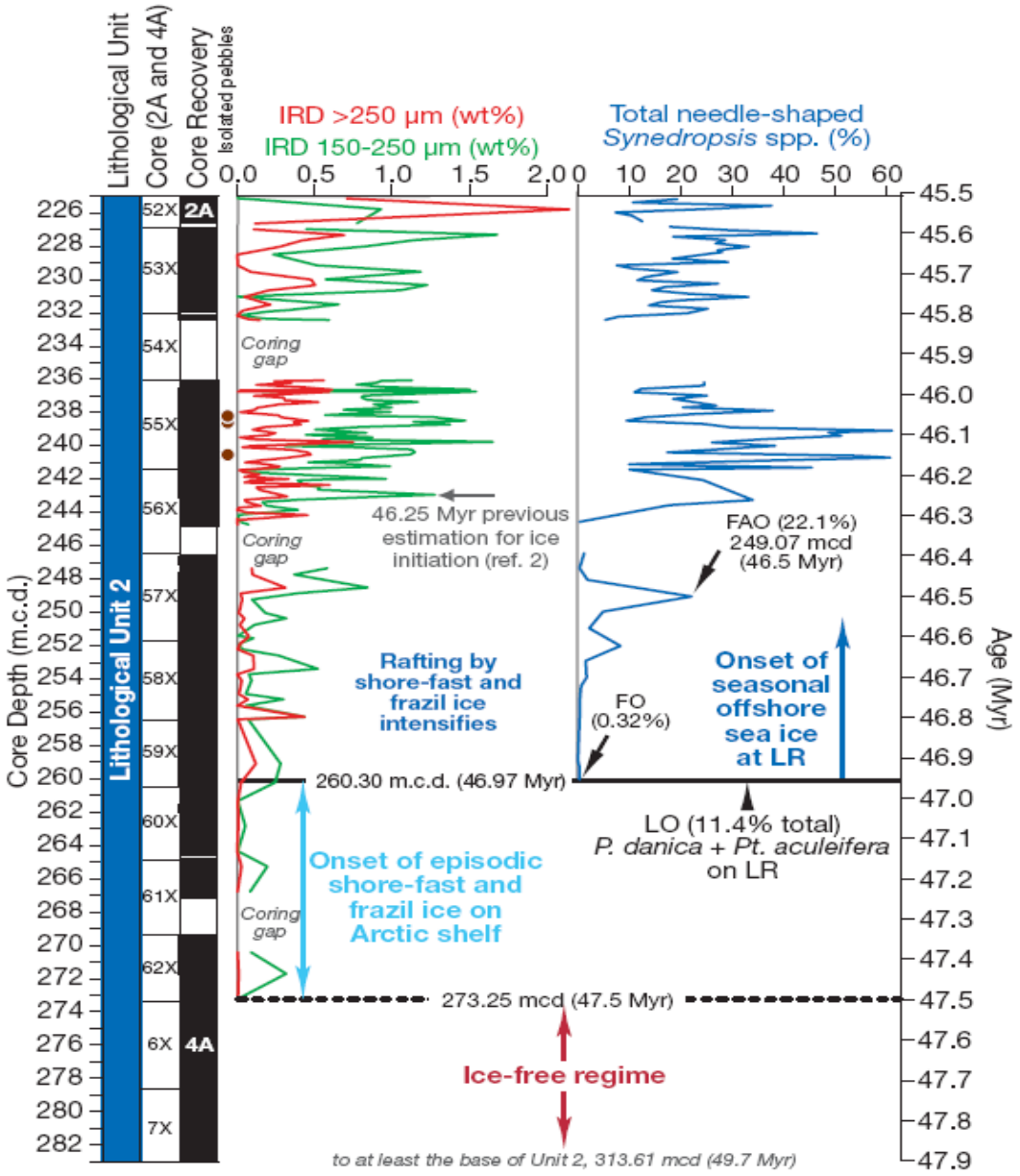
First Sea Ice at 47.5 Ma

Evidence B: Ice Rafted Debris (IRD)



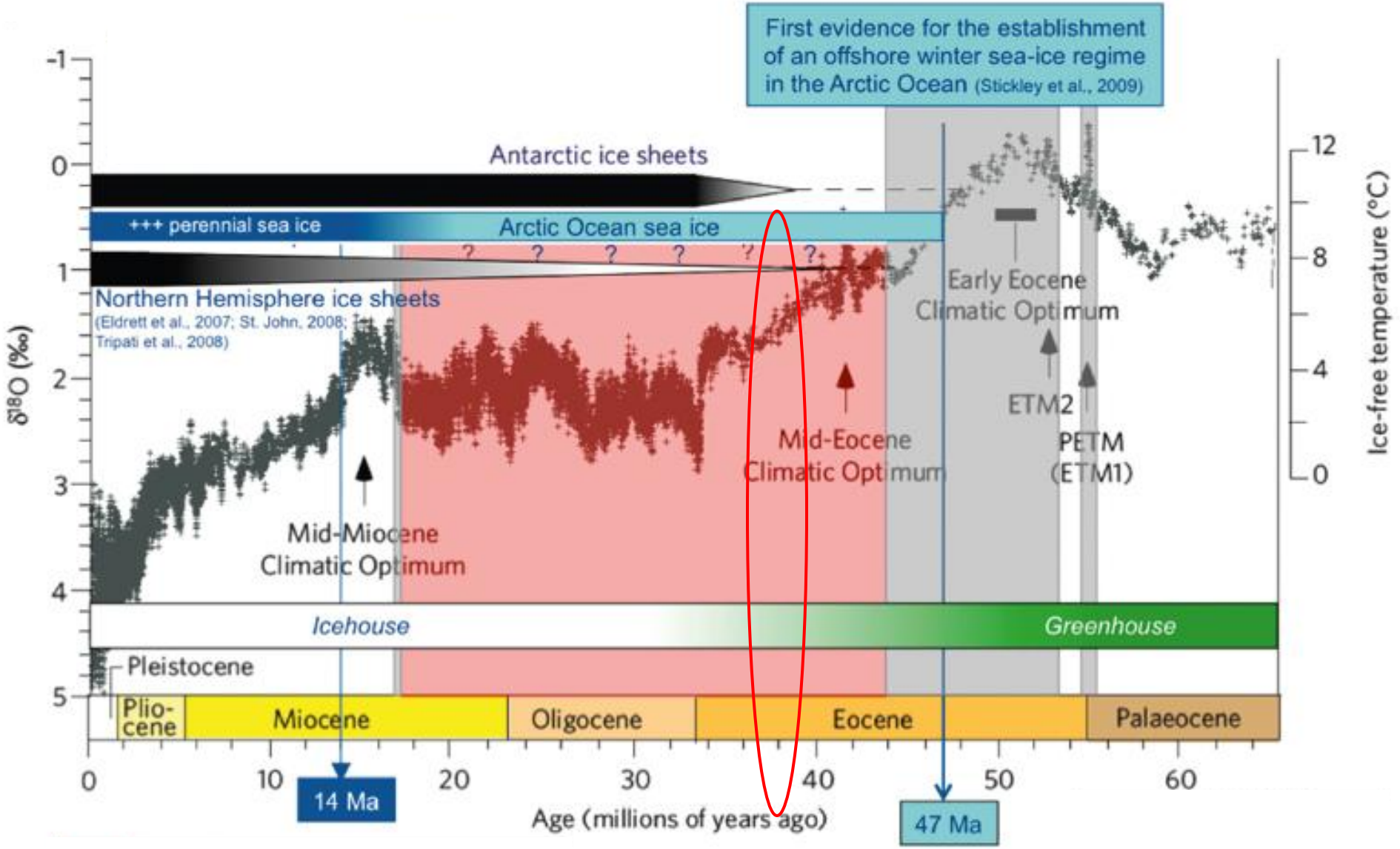
Stickley et al. 2009

First Sea Ice at 47.5 Ma



- Shore-fast ice at 47.5 Ma
- Seasonal sea ice at 46.9 Ma
- Icebergs at 46.25 Ma
- Slightly earlier than onset of glaciation in Antarctica
- Less saline waters in Arctic

Stickley et al. 2009

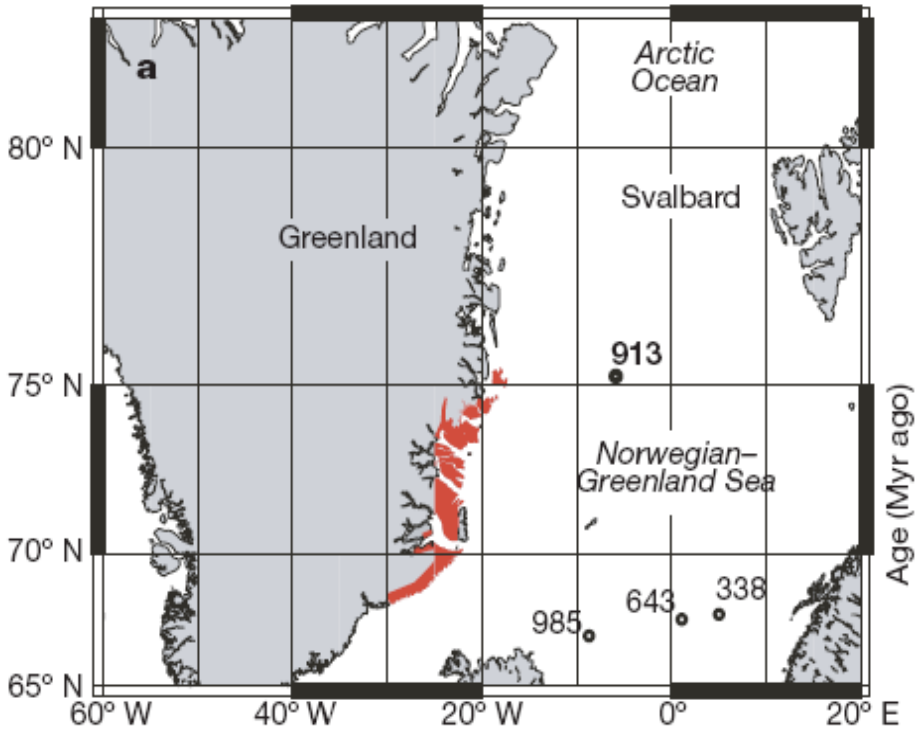


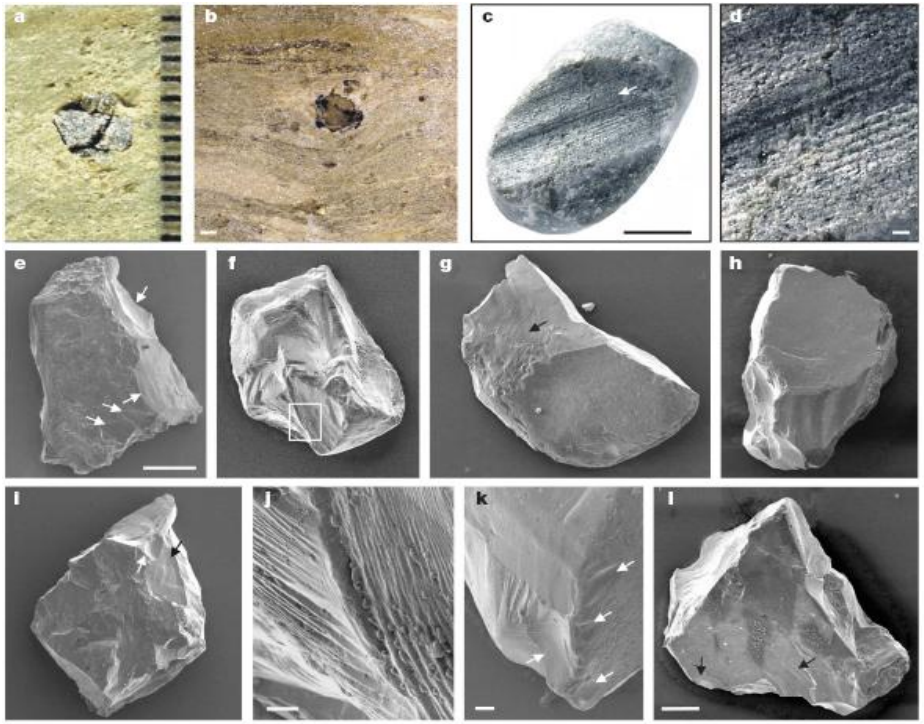
Stein et al. 2012

Greenland glaciers at 38 Ma

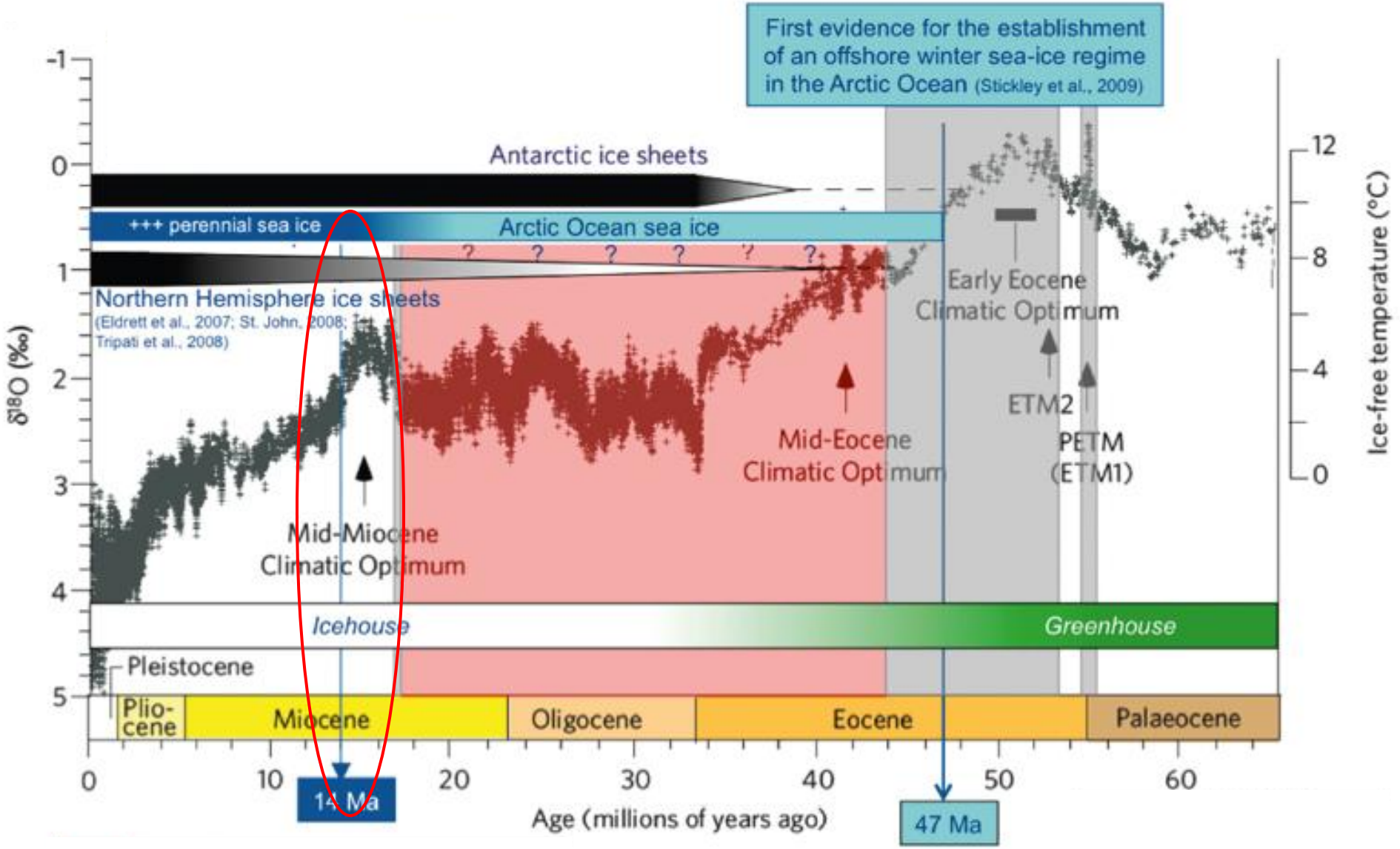
- Ice rafted debris in sediment core off Eastern Greenland

- Glacial Ice



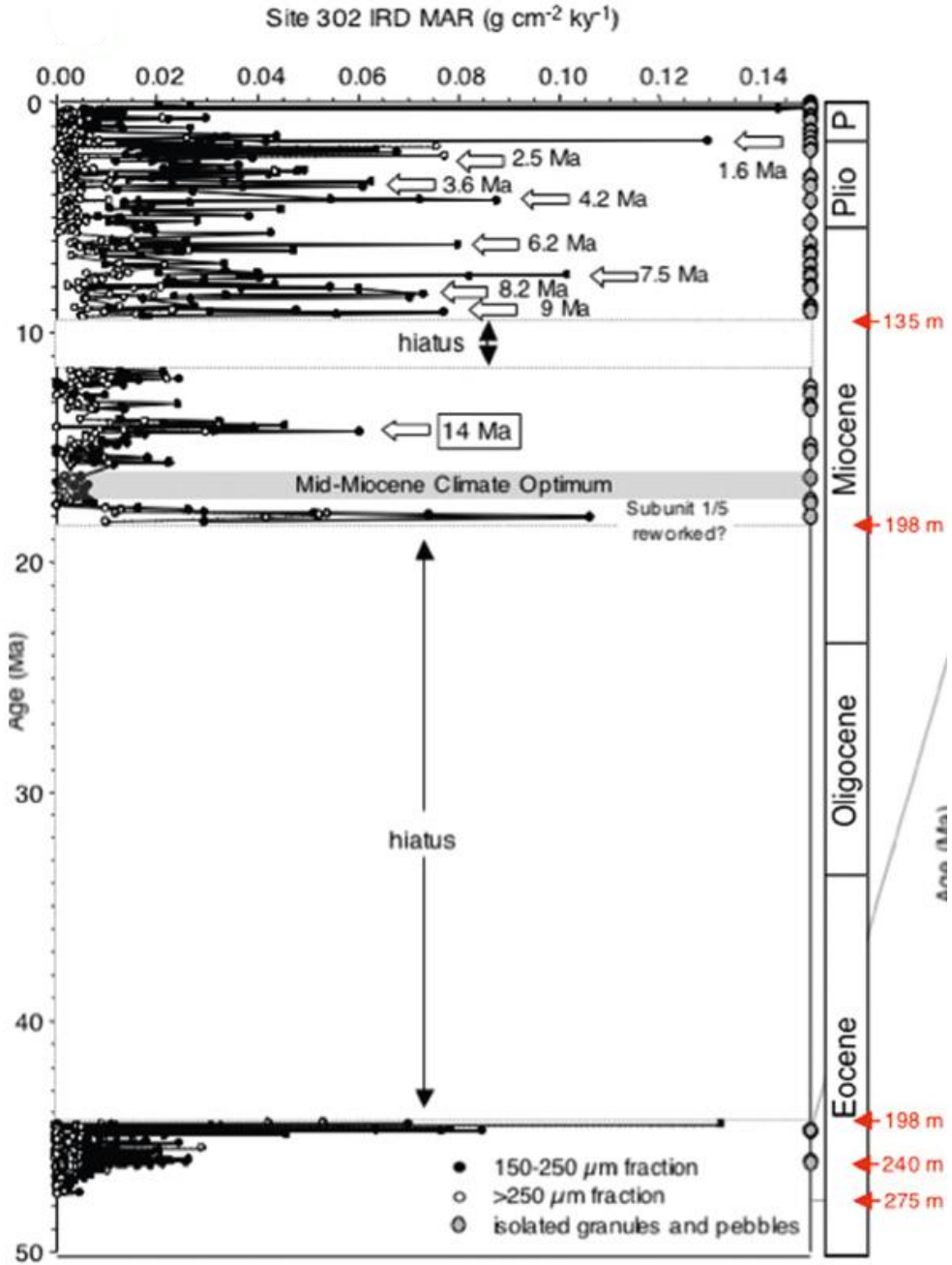


Eldrett et al. 2007



Stein et al. 2012

Miocene Sea Ice Evolution

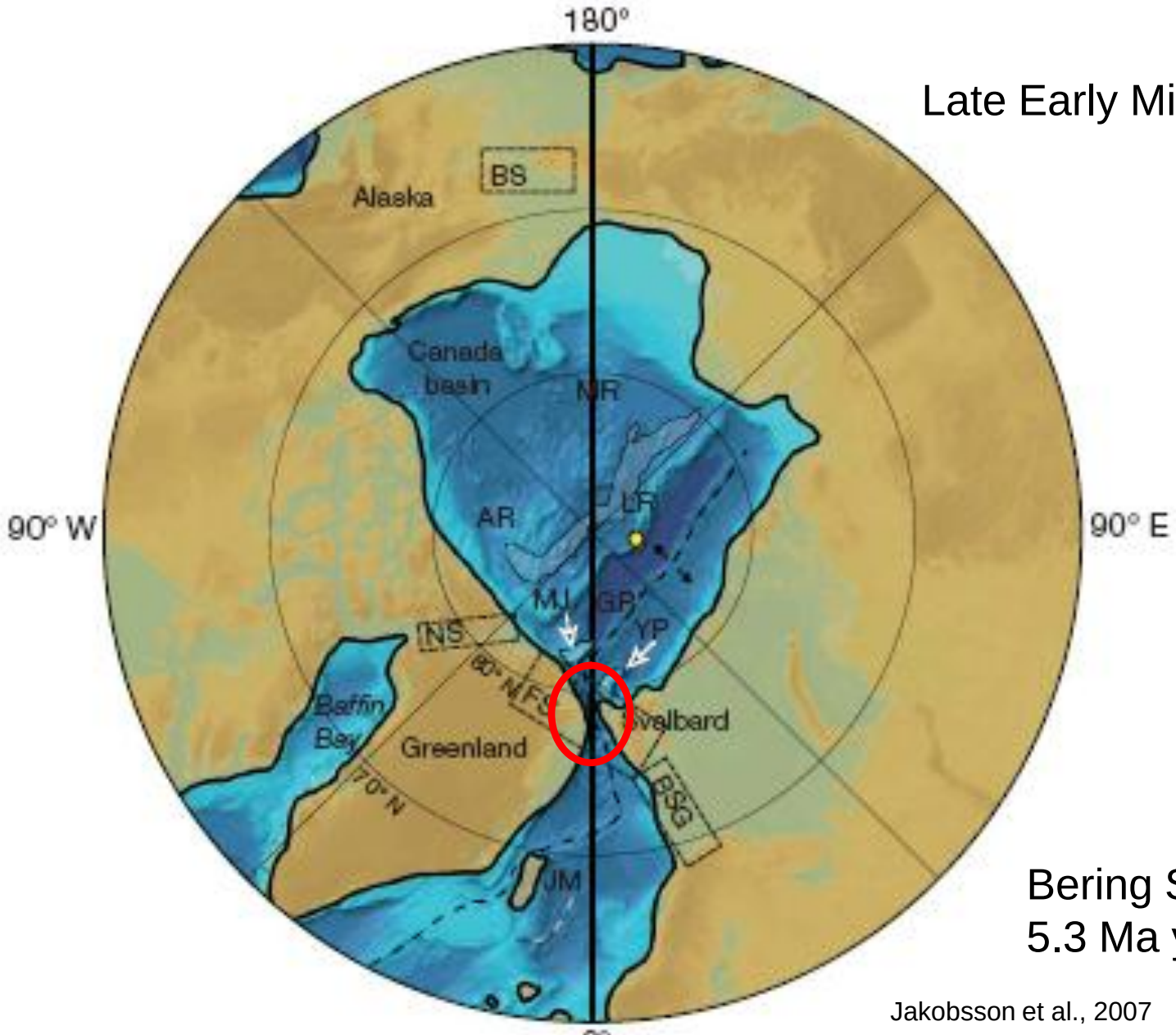


- Ice decline at Mid-Miocene Climate Optimum

- Continuous ice since 14 Ma

Stein et al. 2012

Opening of Fram Strait

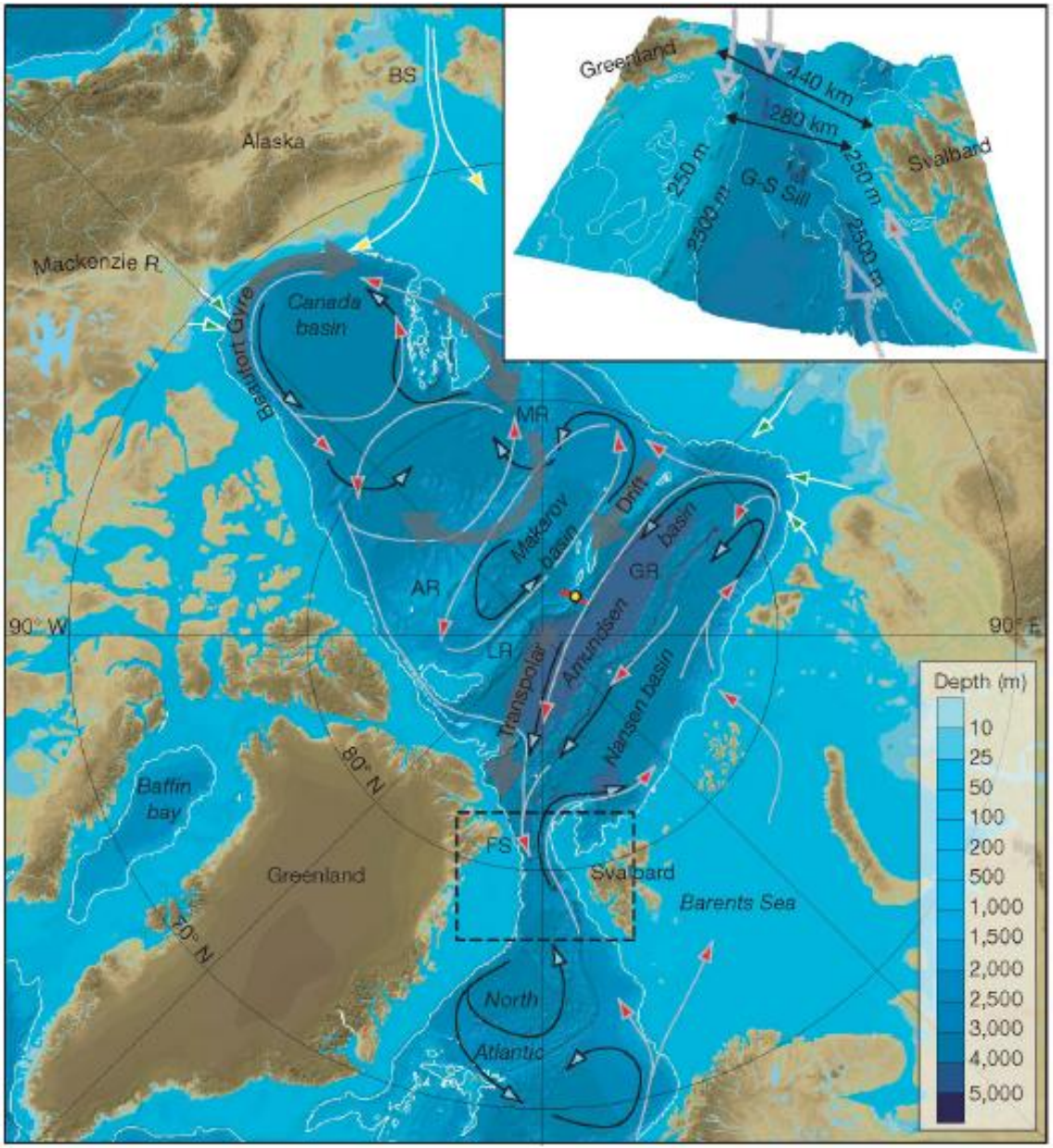


Late Early Miocene ~17.5 Ma

Bering Strait only opened 5.3 Ma years ago

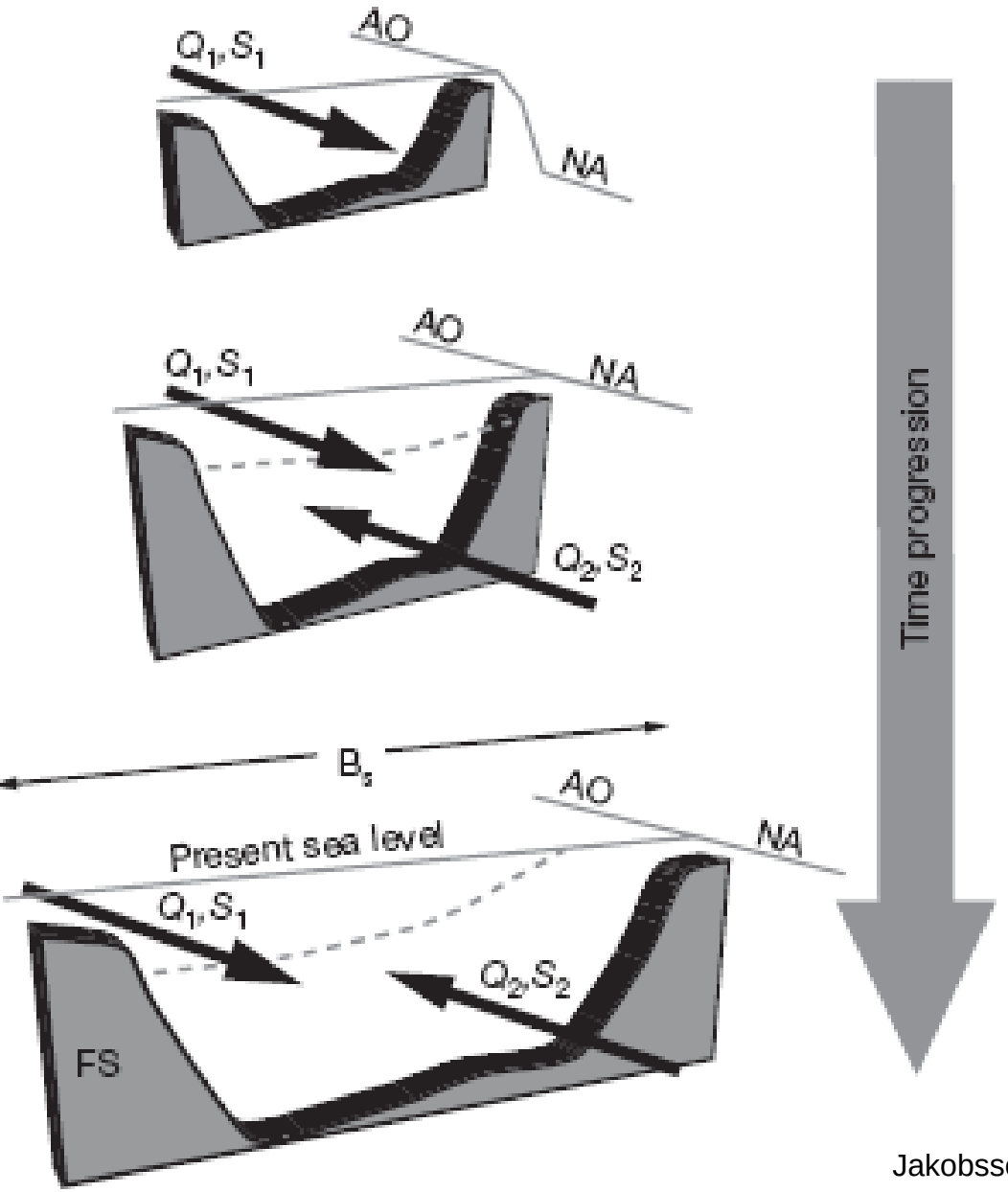
Jakobsson et al., 2007

Opening of Fram Strait



Jakobsson et al., 2007

Opening of Fram Strait



Oxygen poor
'lake stage' (*Azolla – 49 Ma*)

Transitional 'estuarine sea'
phase with variable ventilation

Fully ventilated 'ocean'
phase starting 17.5 Myr ago

Jakobssen et al. 2007

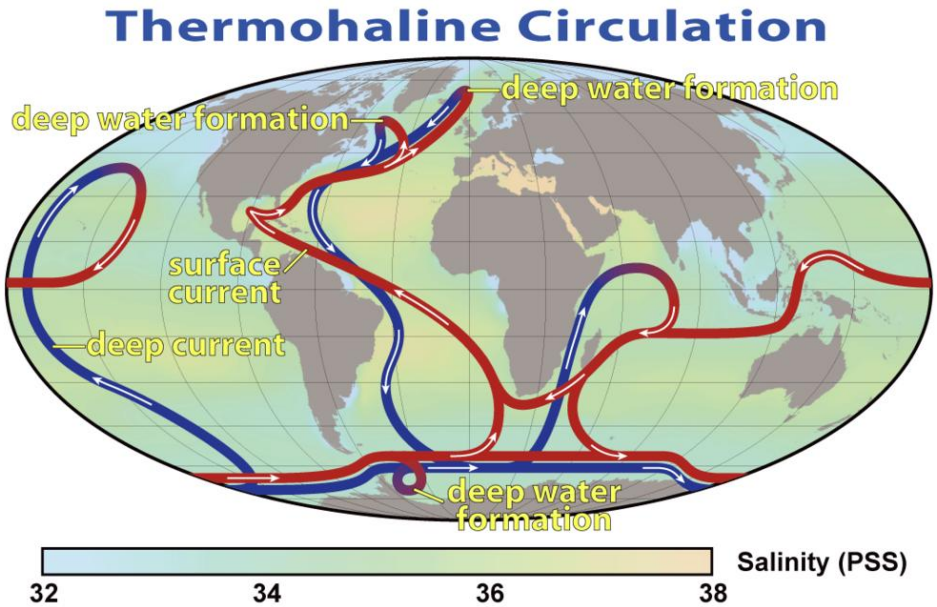
Opening of Fram Strait

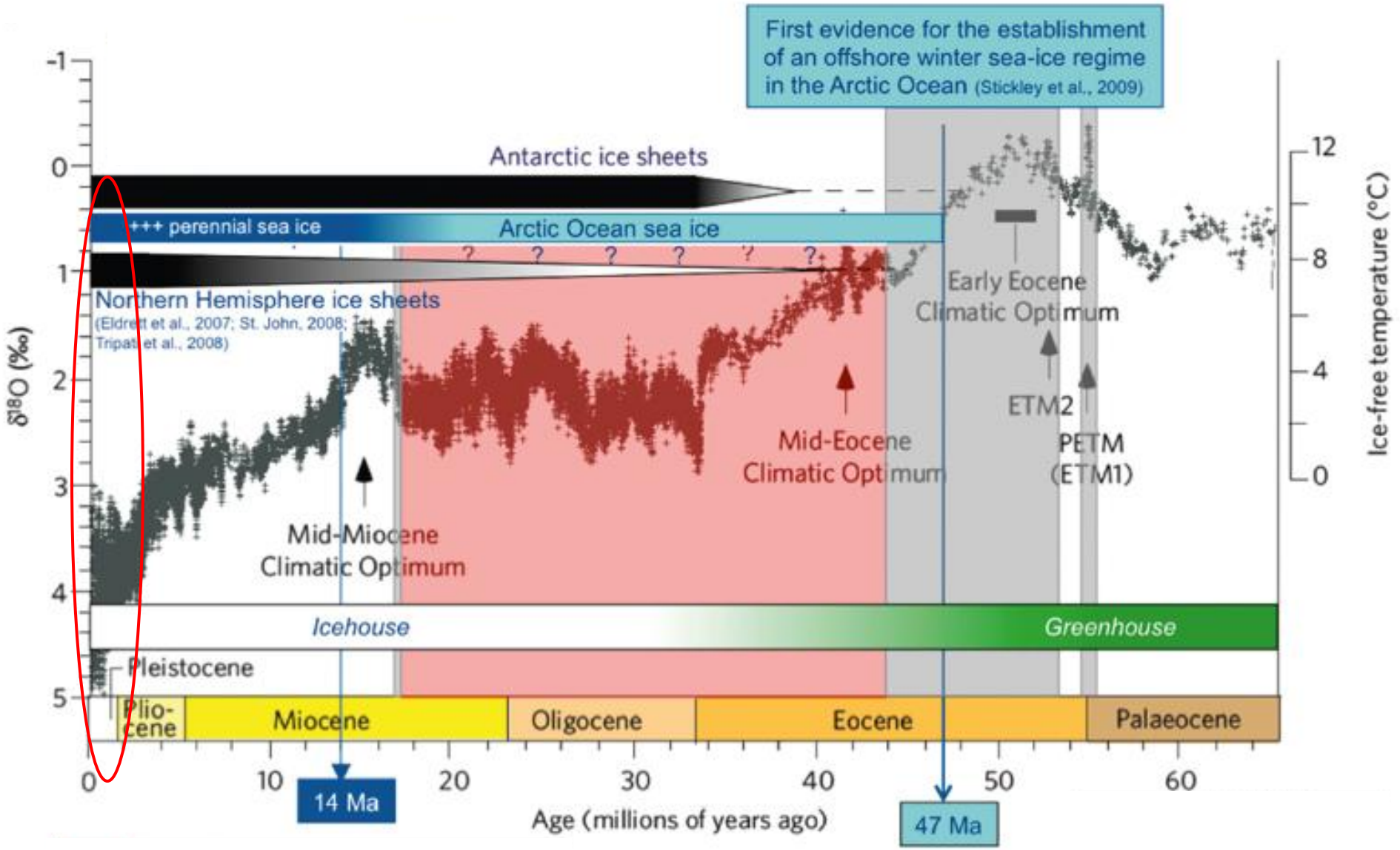
- Onset of modern circulation regime

- Warm salty currents feed into the Arctic

- After releasing heat, waters become dense enough to sink as North Atlantic Deepwater (driver of thermohaline circulation)

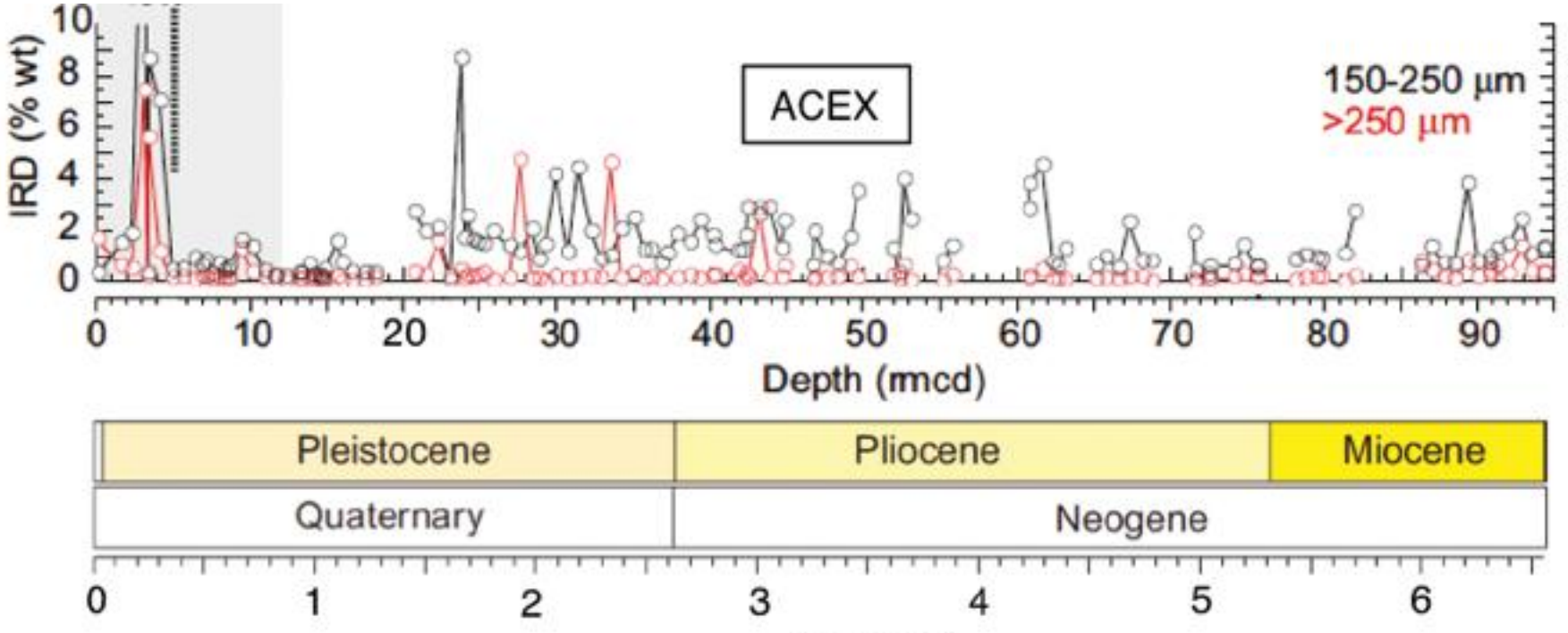
- Fluctuations in the intensity of these currents and deepwater formation participated in causing or amplifying climate change events





Stein et al. 2012

Pleistocene Ice Ages (2.6 Myr)

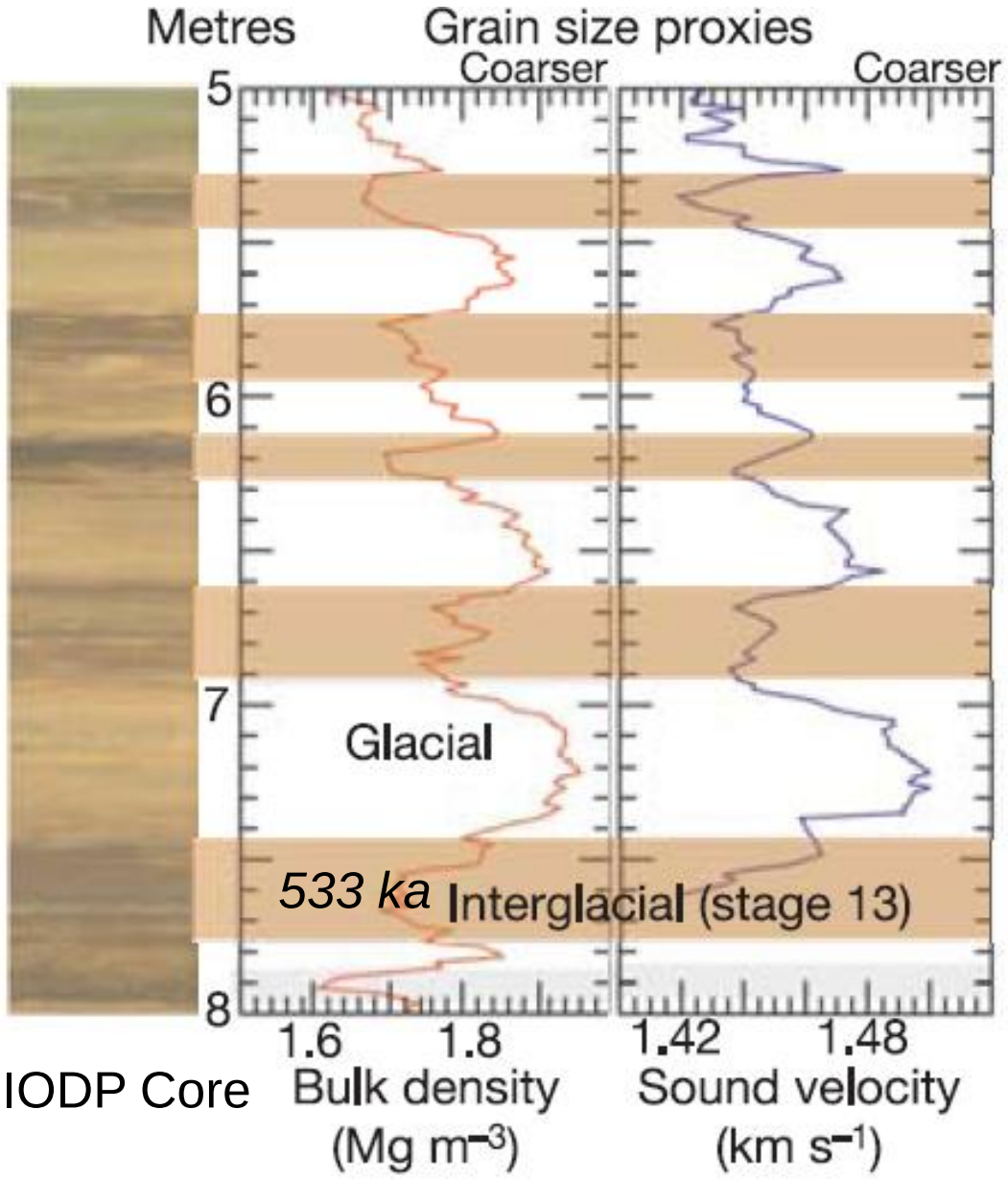


Why little IRD in early Pleistocene?

- Stable ice pack reduces transport and melting

- Lower inflow of Atlantic-derived warm water reduces basal melting of sea ice

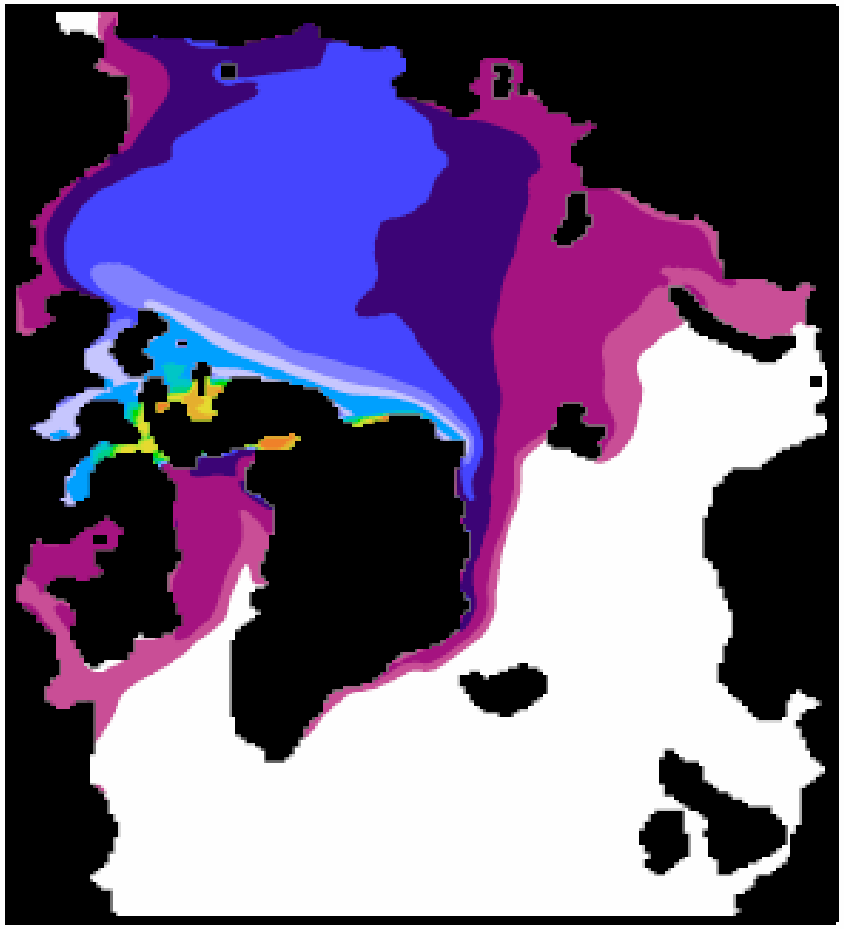
Pleistocene Ice Ages (2.6 Myr)

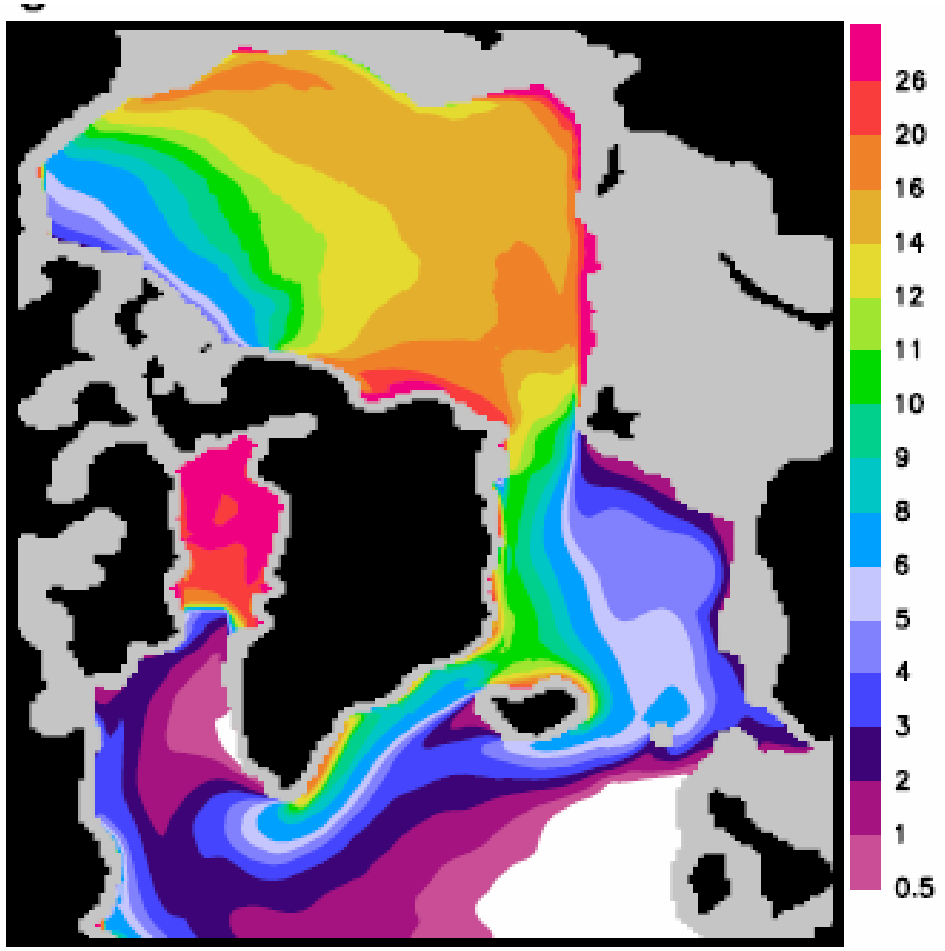


Coarser ice rafted material during glacial

Moran et al. 2006

Last Glacial Maximum





Modern Sea Ice Thickness

Last Glacial Maximum Sea Ice Thickness

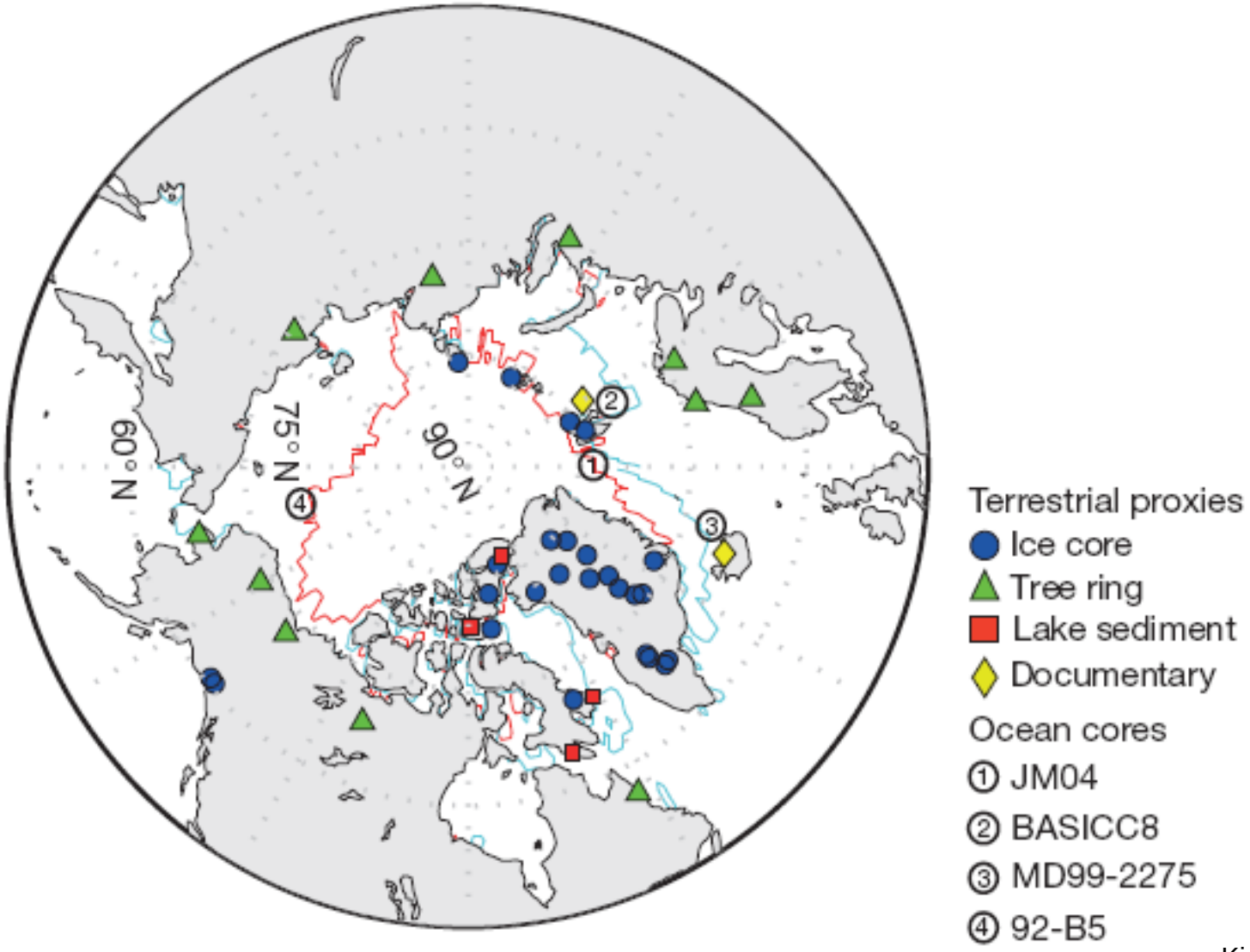
Staerz et al 2012

Last Glacial Maximum (~20ka)

Summer Ice Extent

Stein et al. 2012

Past 1500 years (late Holocene)



Kinnard et al. 2011

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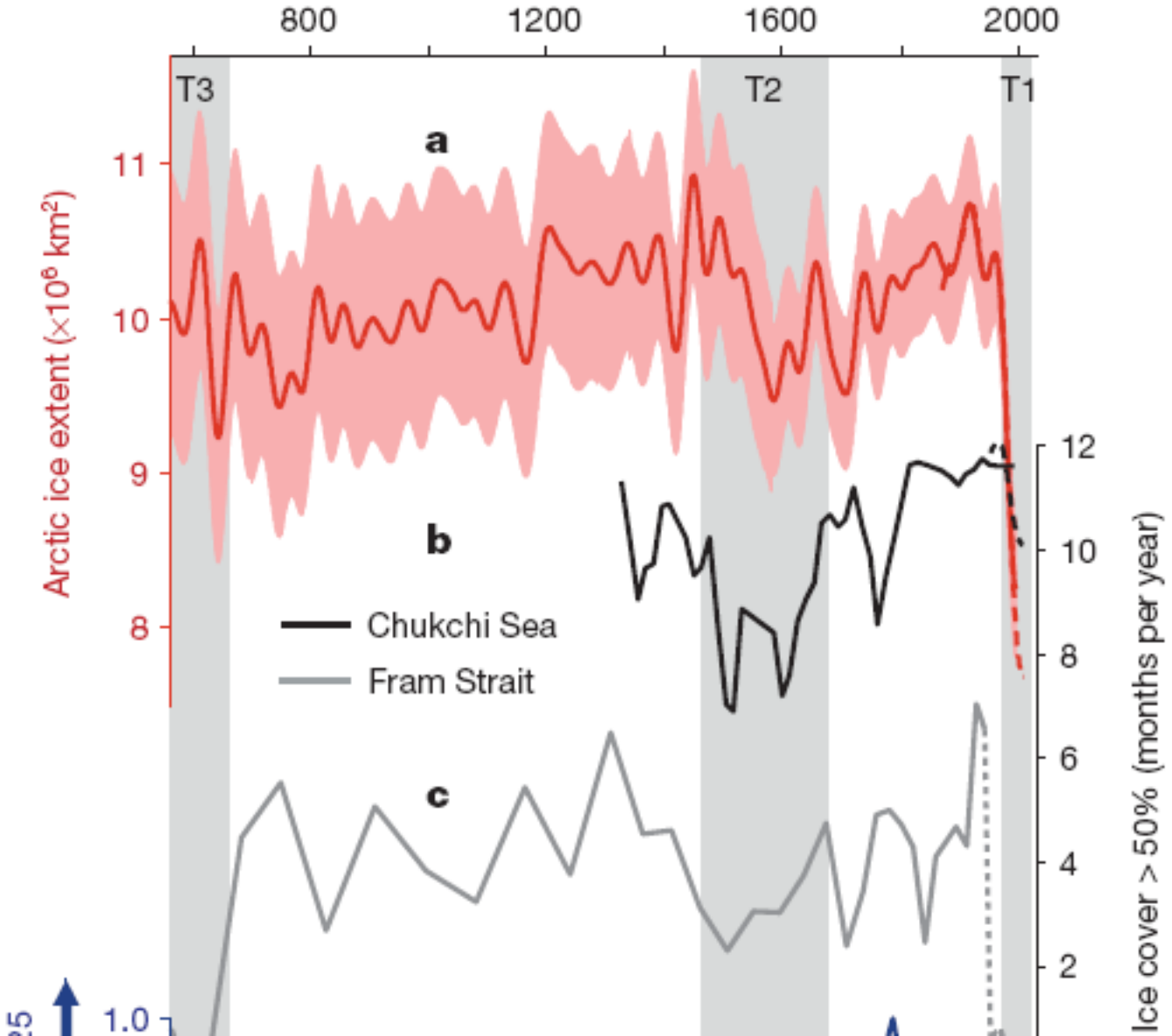

Kinnard et al. 2011