The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

SMR/1884-1

Conference on Milankovitch cycles over the past 5 million years

22 - 24 March 2007

What caused Northern Hemisphere Glaciation 2.7 Myr ago?

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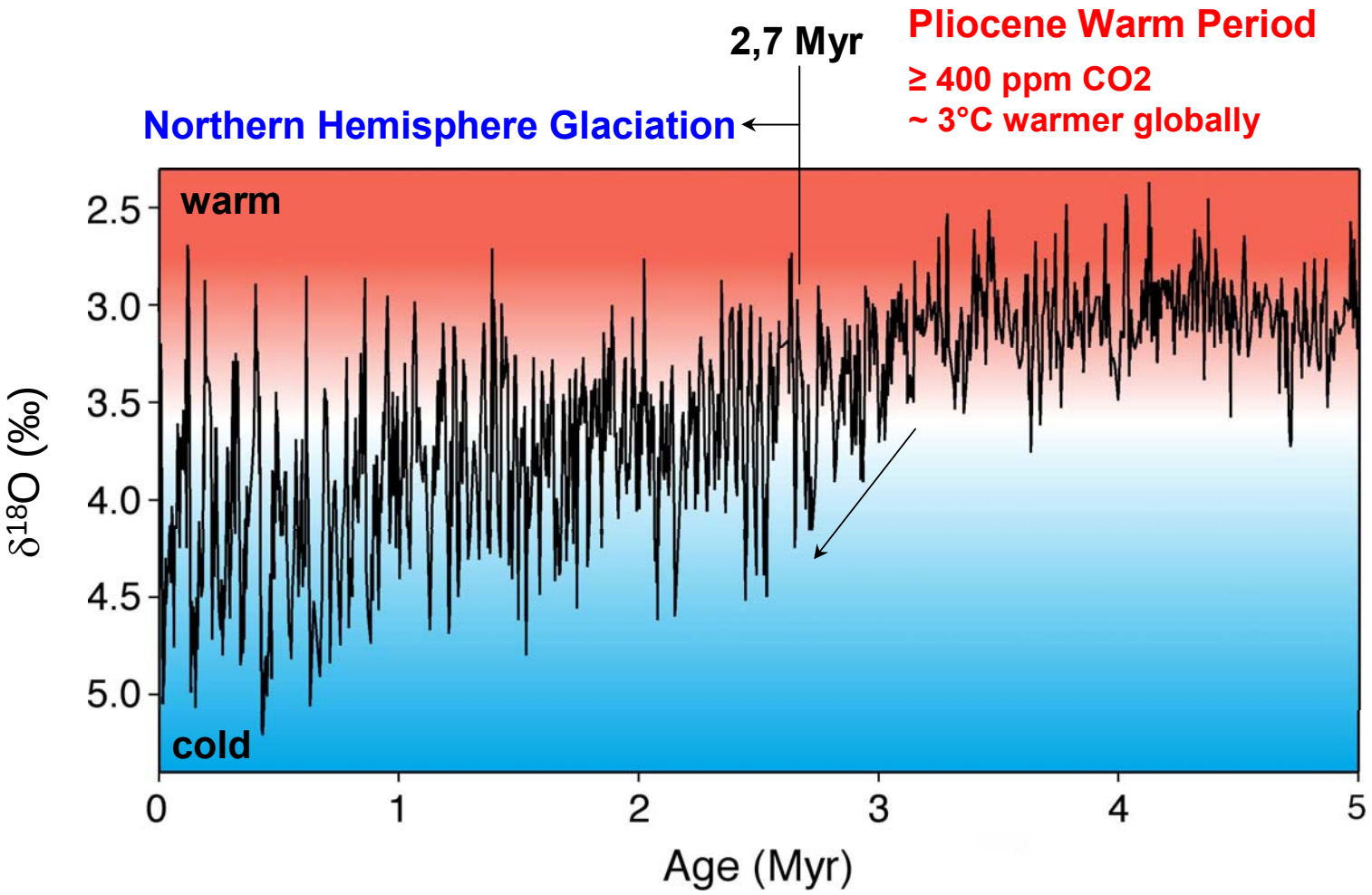
In collaboration with Daniel Sigman ,Ralf Tiedemann,

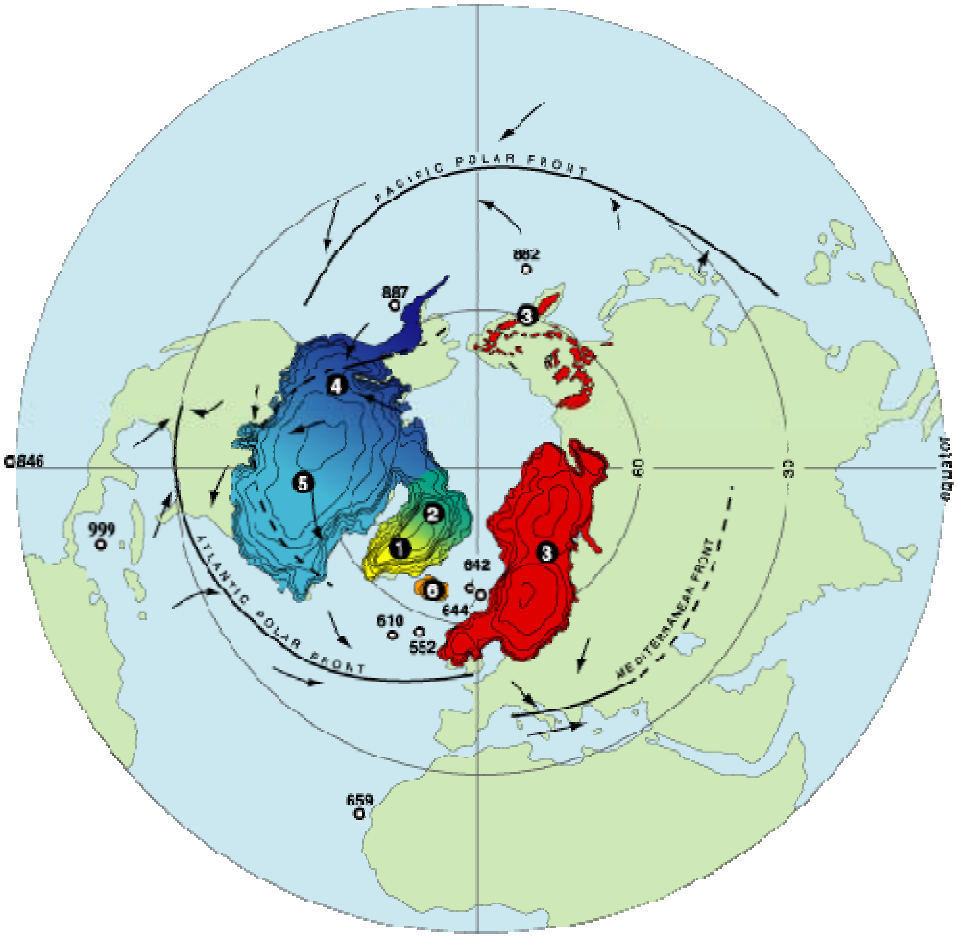
and many others over the past years

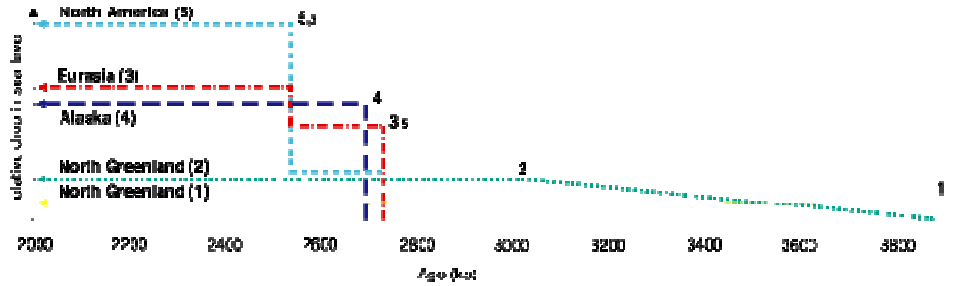
Global climate of past 5 Myr



Tiedemann et al., 1995

Massive Ice Sheets in the Northern Hemisphere since 2.7 Myr





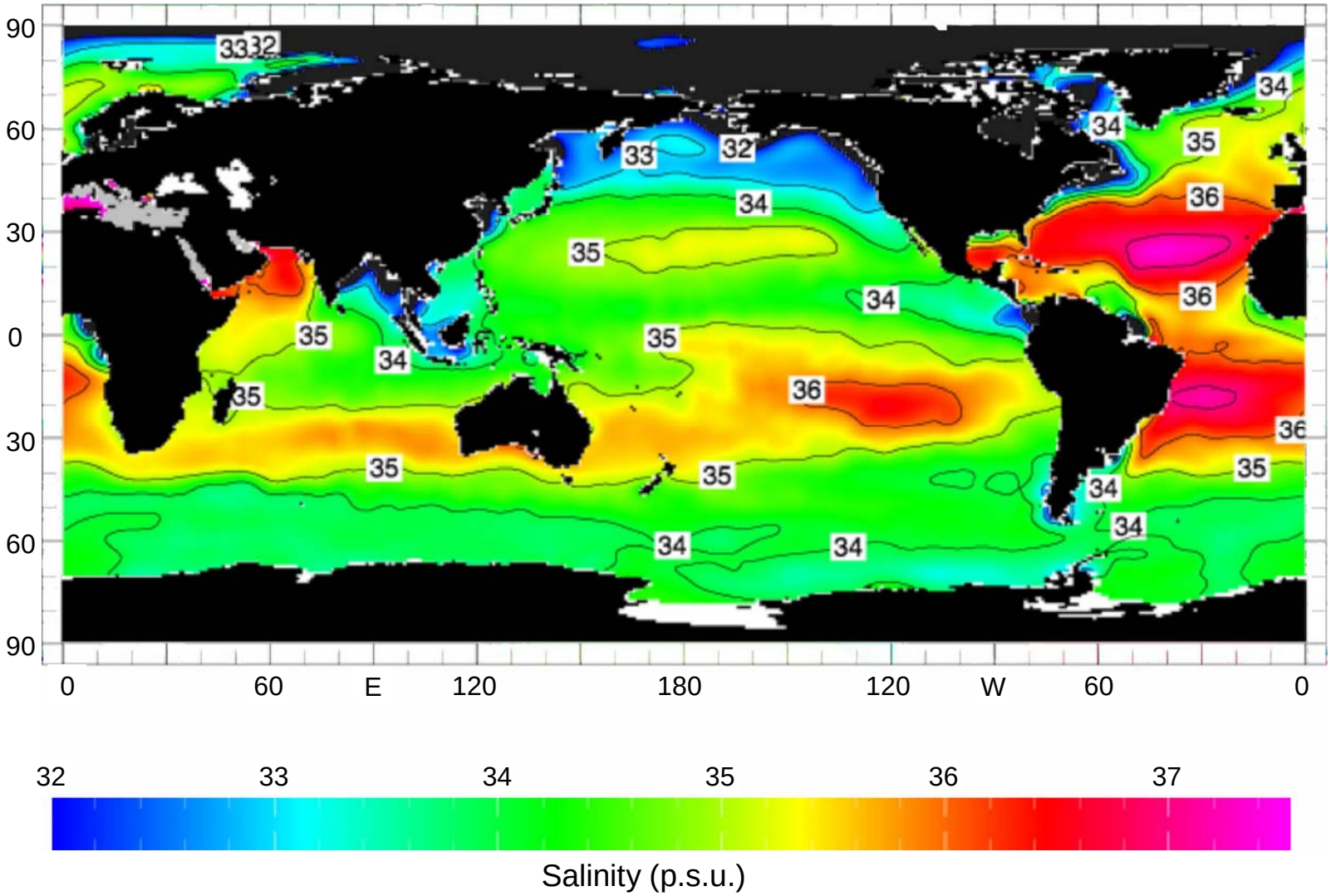
What is needed to build an ice shield?

1. The more polar continental areas must be sufficiently cold for precipitation to fall as snow rather than rain and for snow and ice to survive the warm summer melting season

2. Adequate moisture must be introduced to high northern latitudes to promote the accumulation of glacial ice

Salt asymmetry Atlantic-Pacific

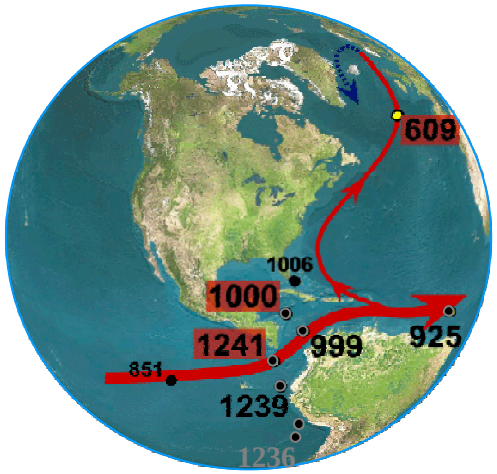
Atlantic 1 p.s.u. saltier than Pacific



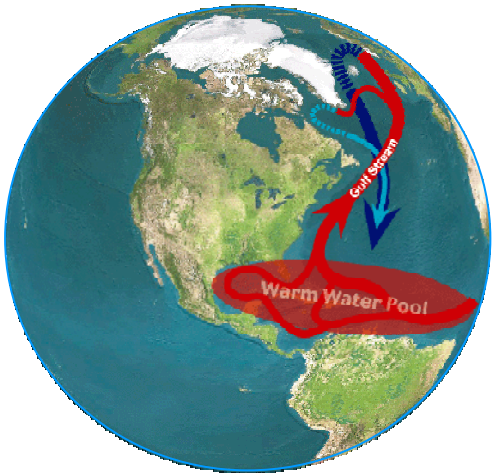
World Ocean Atlas, NOAA, 2000, from the great 'ingrid' at Lamont

Which kind of climatic and oceanic response do we expect from the closure of the Central American Seaway?

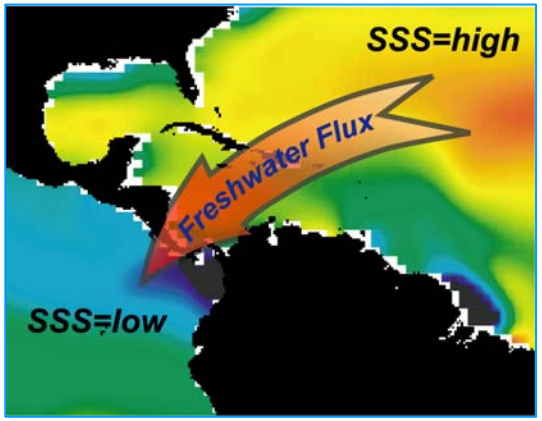
Panama open



Panama closed

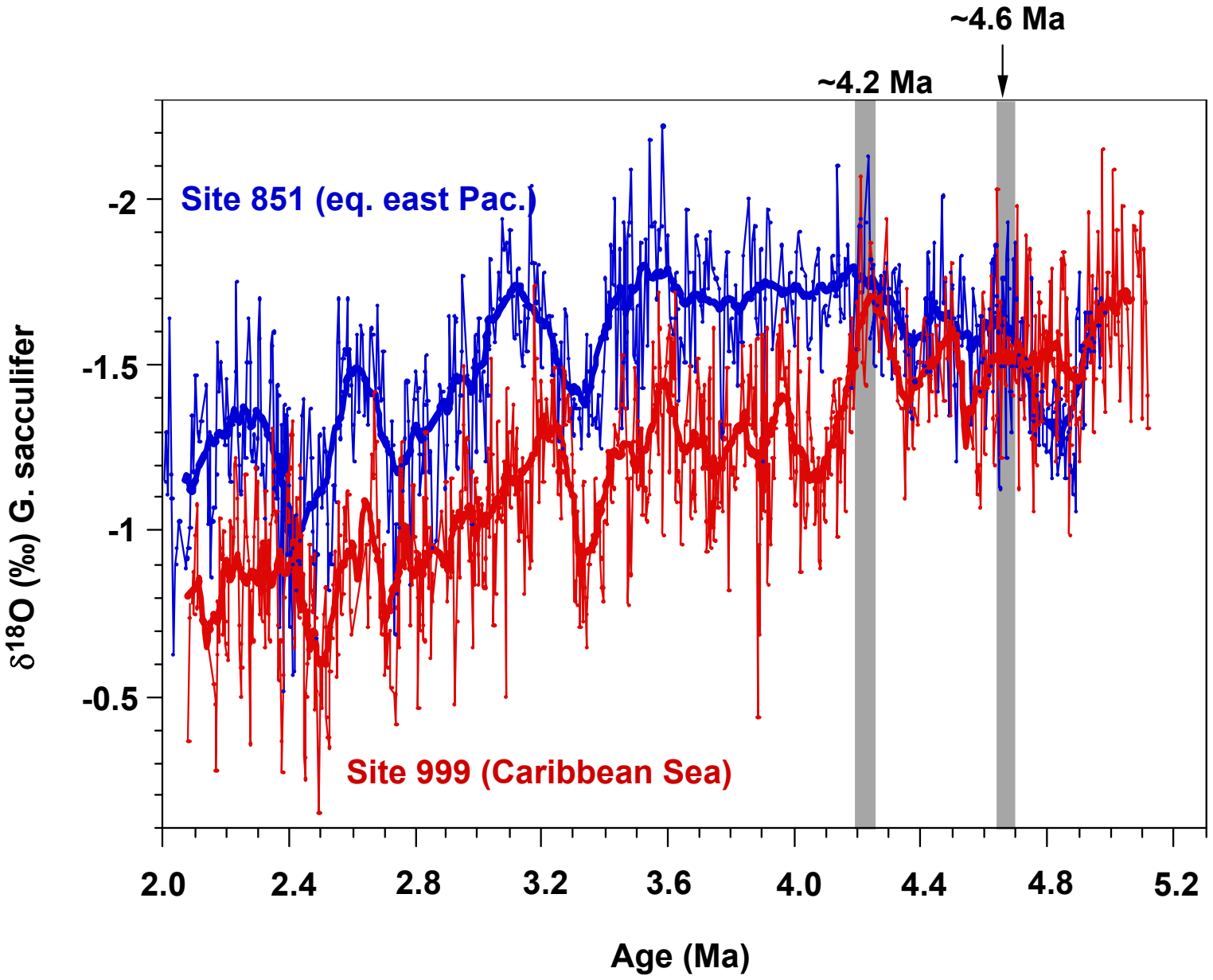


Panama closed



- Development of Atlantic-Caribbean warm water pool
- Establishment of the modern Pacific-Atlantic salinity contrast
- Intensification of the Gulf Stream:
  - Enhanced heat and salt transport into the N-Atlantic
  - Intensification of thermohaline circulation
- Warming of the Northern Hemisphere

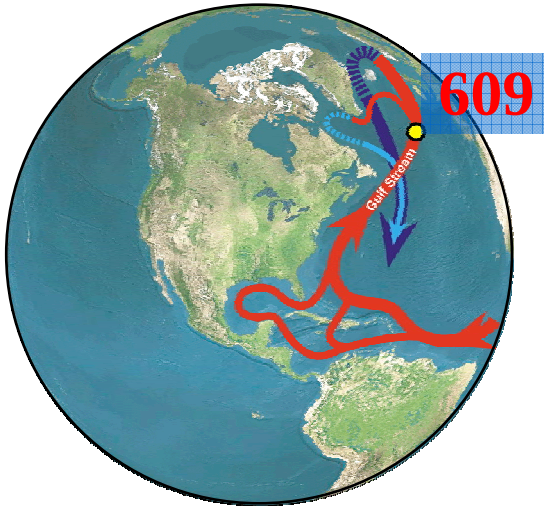
Effect of Panama closure on sea surface salinities

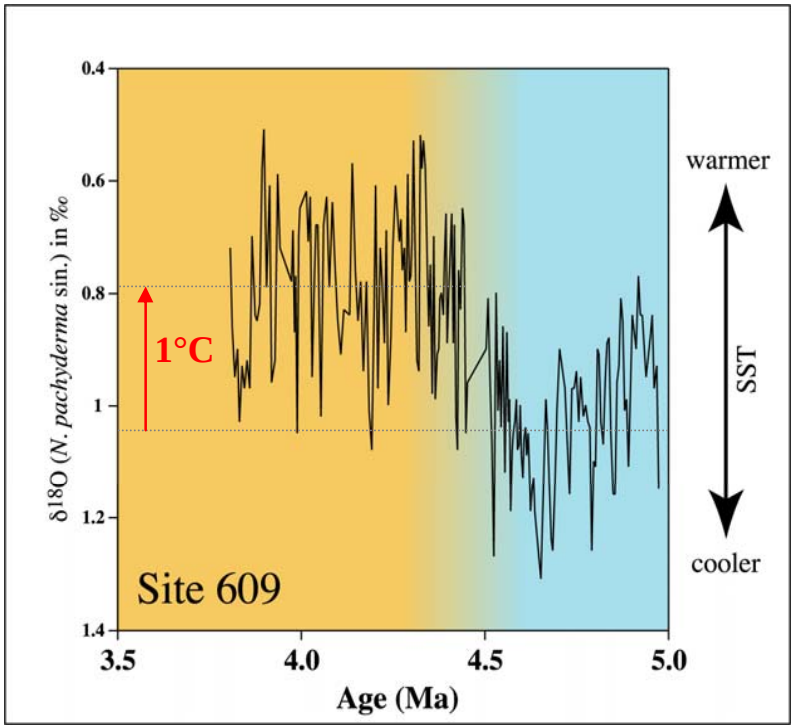


Haug et al., 2001
Data Site 851: Cannariato and Ravelo, 2000

What happened in the surface N-Atlantic?

The enhanced transfer of heat and salt (Gulf Stream) since 4.4 Ma should have warmed the N-Atlantic und W-Europe.





First results from Site 609:

warming of the N-Atlantic at 4.6 - 4.4 Ma

- ➔ SST increase of 1°C (0.25 ‰ $\delta^{18}O$)
- ➔ $\delta^{18}O$ SSS correction for 2psu
  --> increase of 5°C

Tiedemann and Haug, in prep

What happened in the deep Atlantic?

Atlantic Ocean water masses (salinity transect)

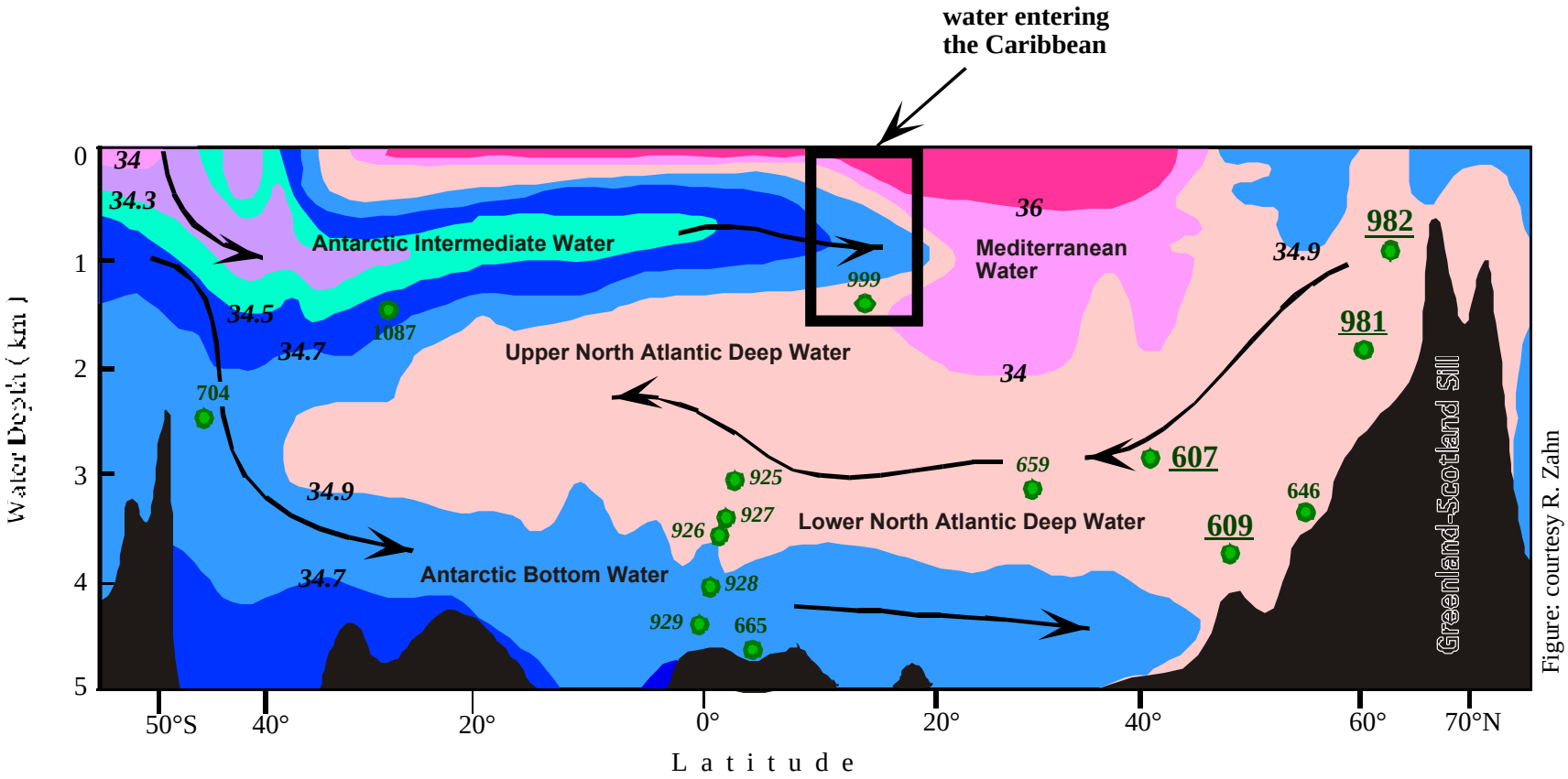
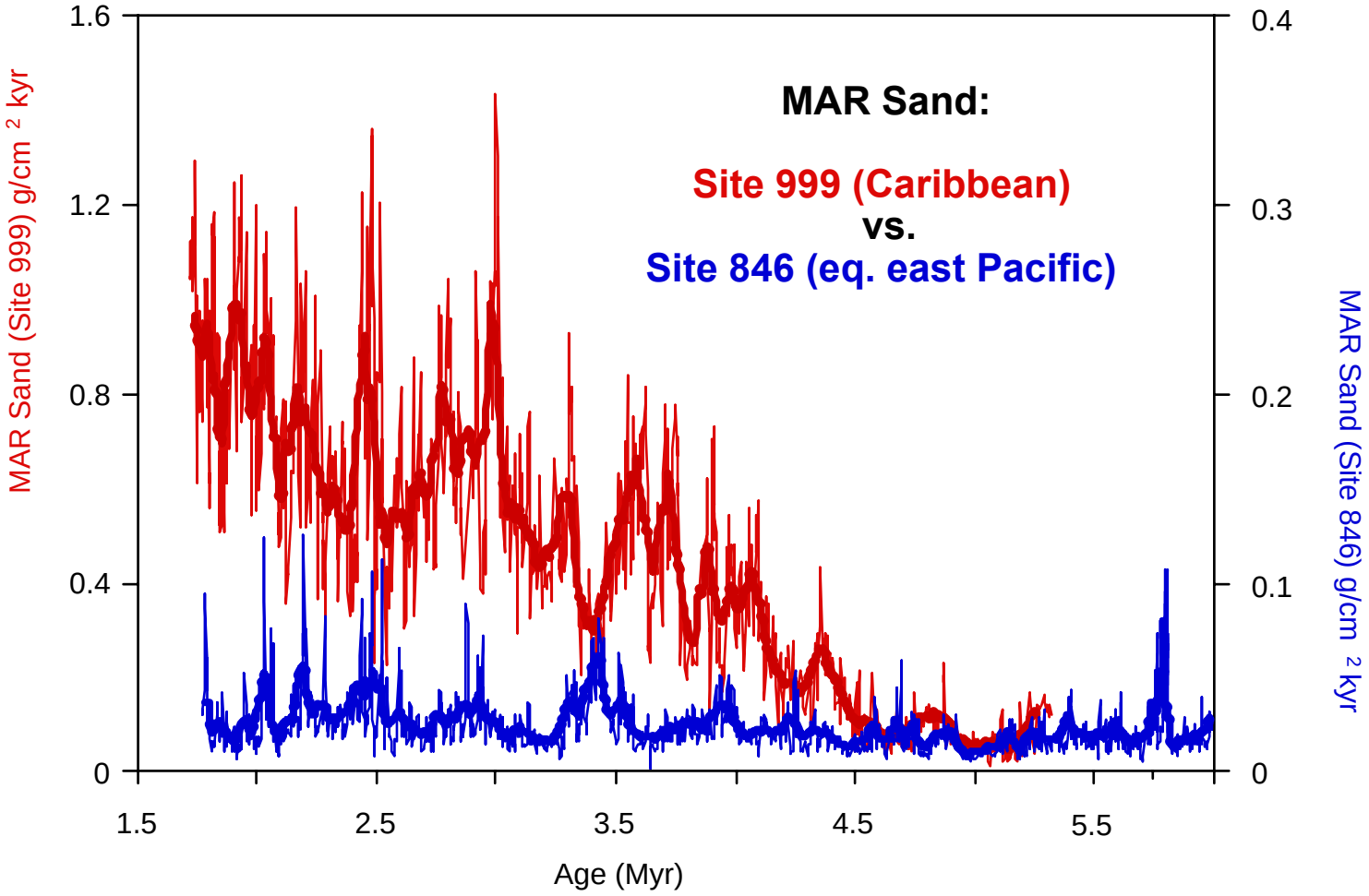


Figure: courtesy R. Zahn

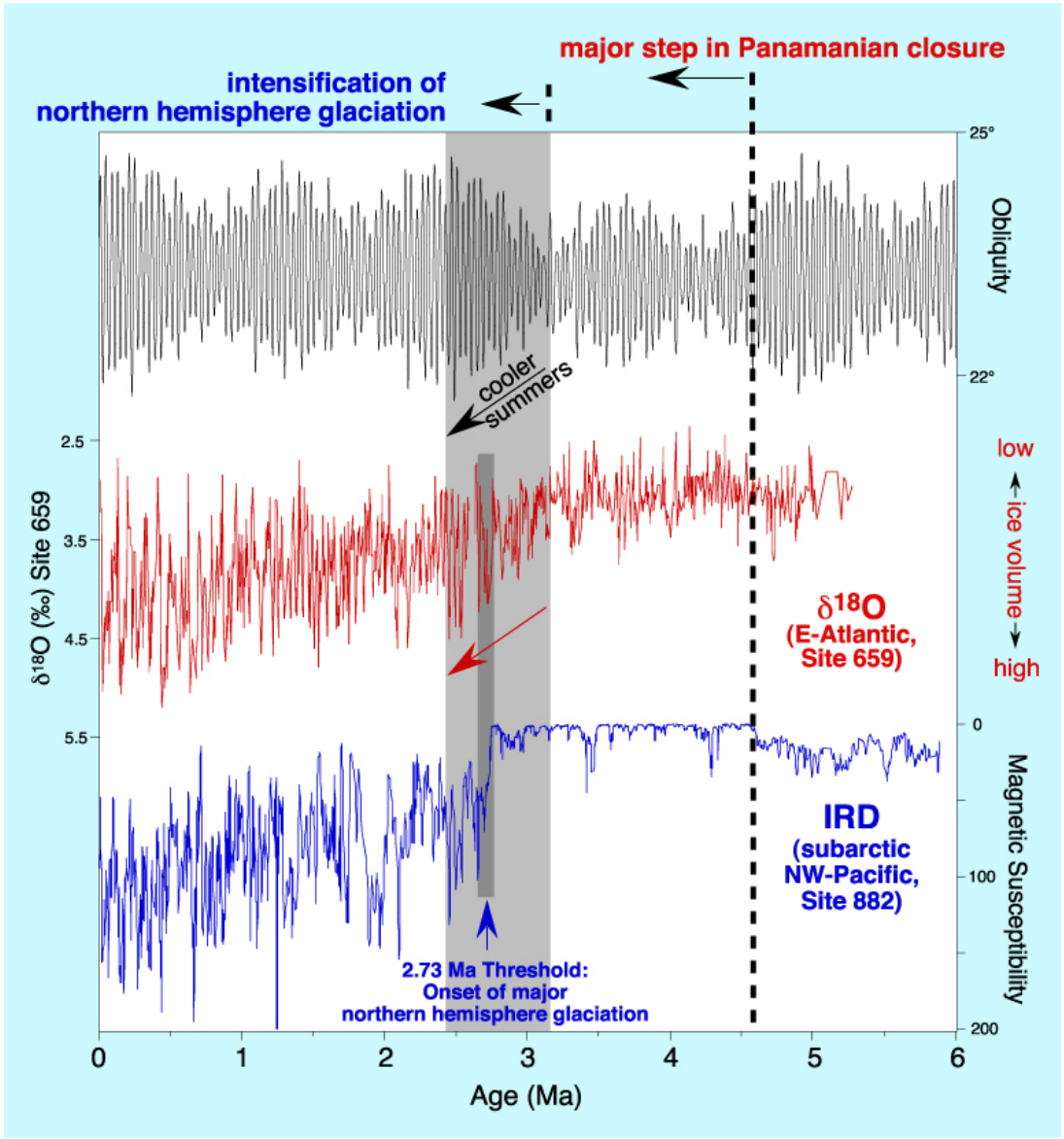
What happened in the deep Atlantic?

Caribbean carbonate dissolution history



Haug and Tiedemann, 1998

Panama and major Northern Hemisphere Glaciation

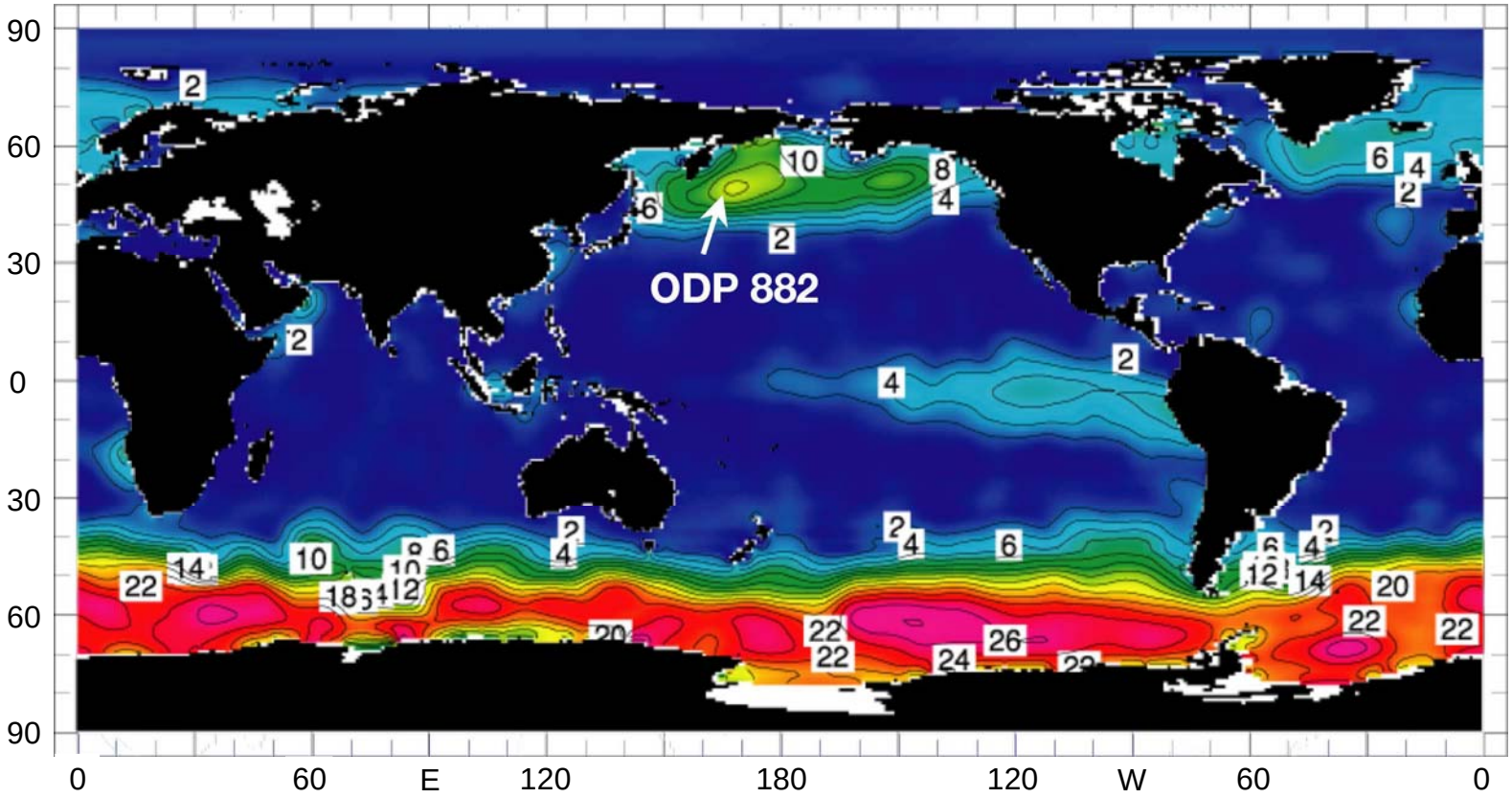


-> the timing is wrong!

Haug und Tiedemann, 1998; Haug et al., 1999

Role of the subarctic North Pacific and the Southern Ocean?

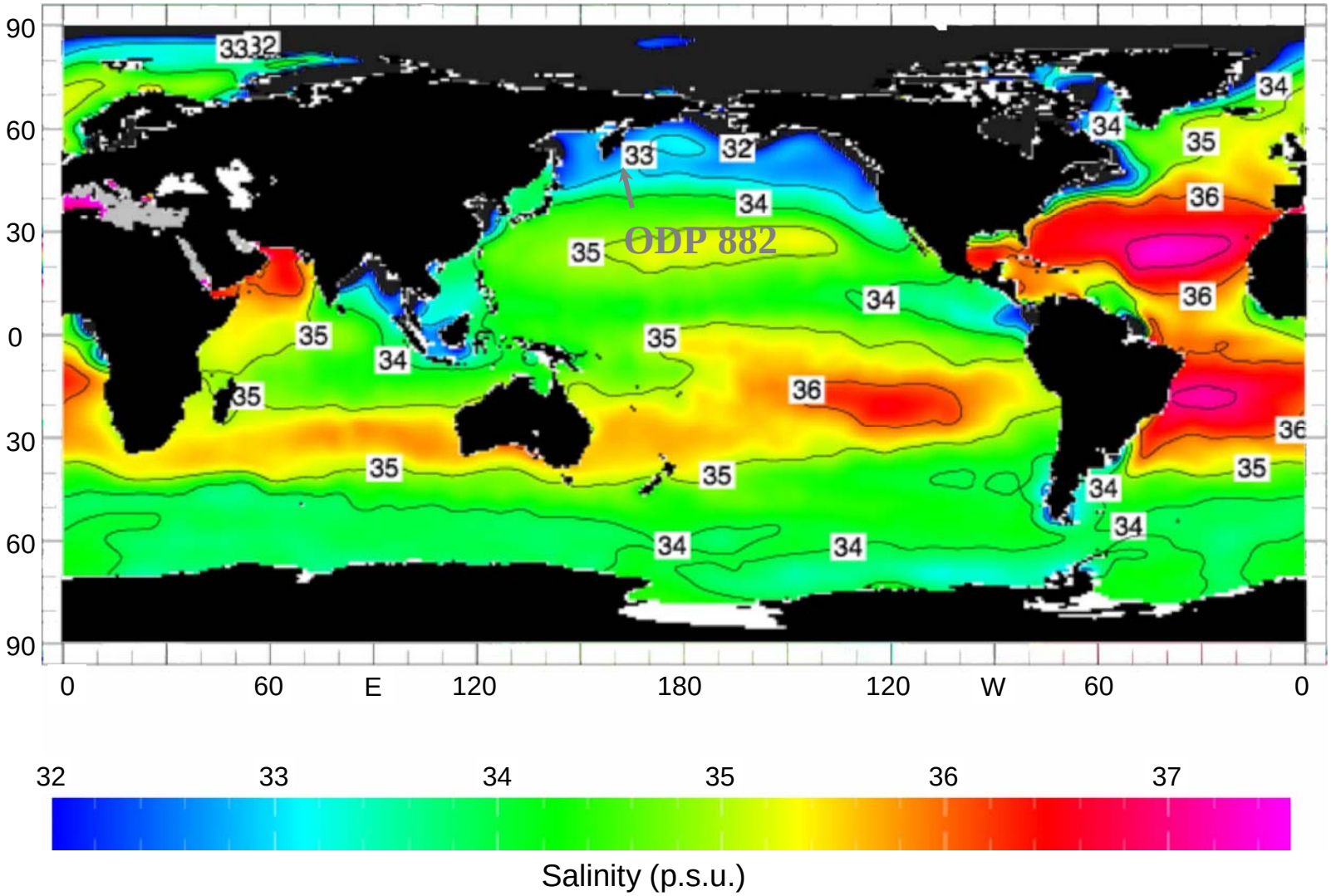
Nitrate concentration



World Ocean Atlas, NOAA, 2000, from Lamont's 'ingrid'

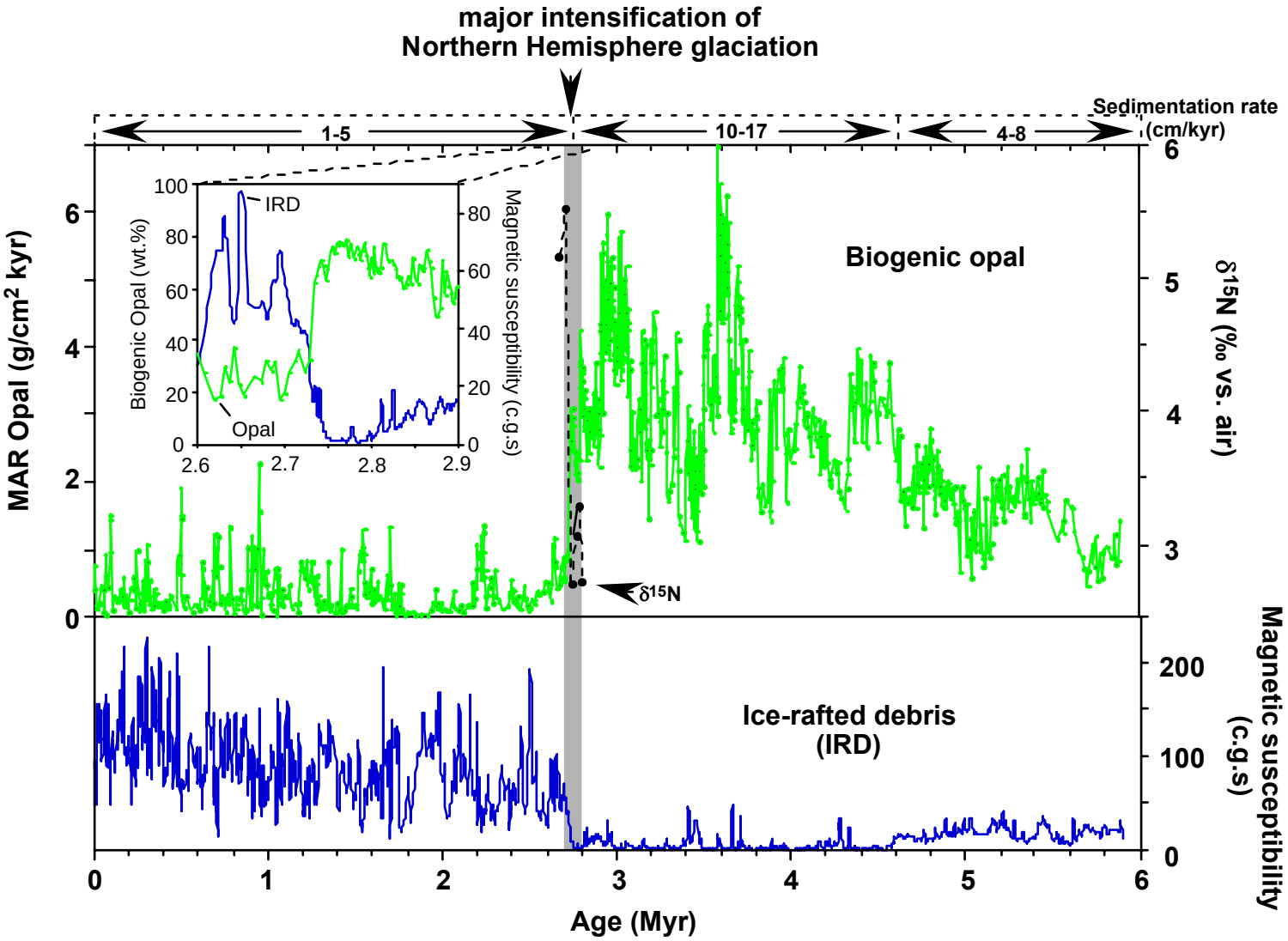
Salt asymmetry Atlantic-Pacific

Atlantic 1 p.s.u. saltier than Pacific, S-Pacific 1 p.s.u saltier than N-Pacific



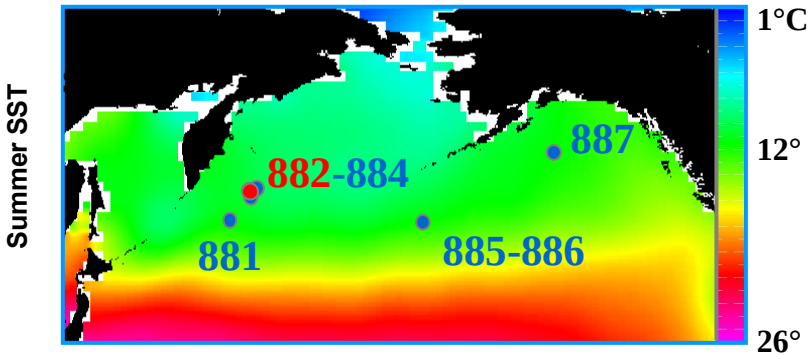
World Ocean Atlas, NOAA, 2000, from the great 'ingrid' at Lamont

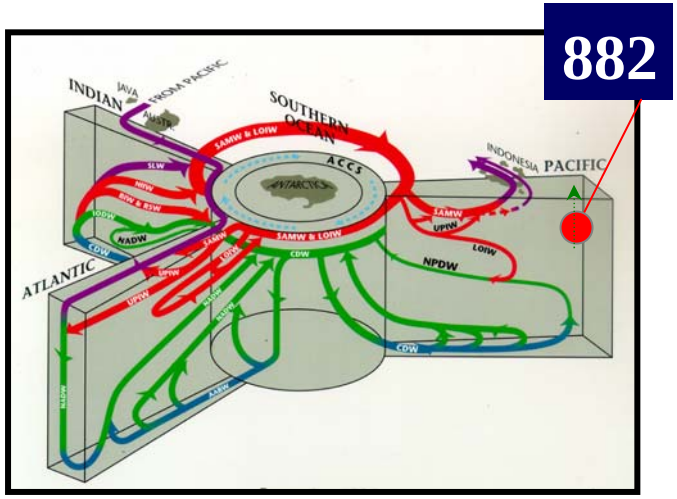
Subarctic North Pacific ODP Site 882



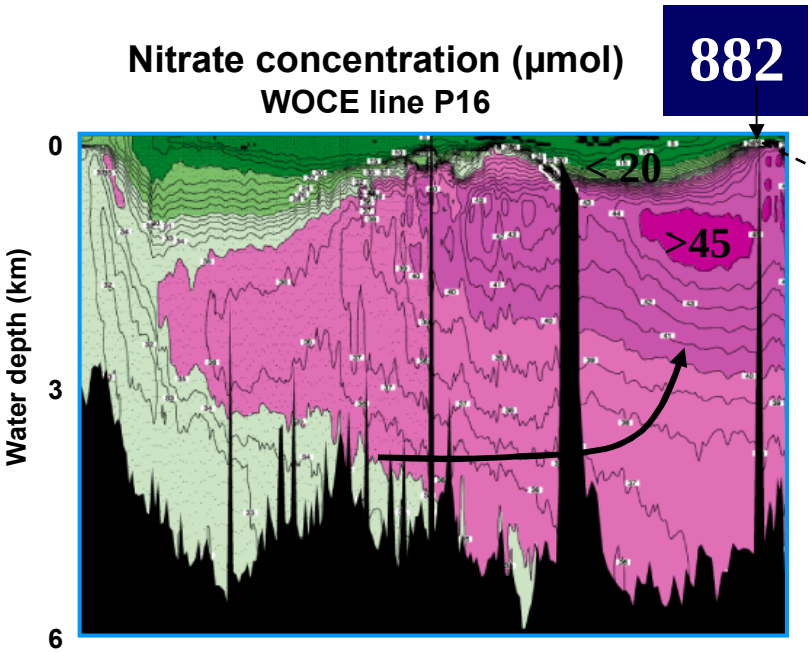
Haug et al., 1999

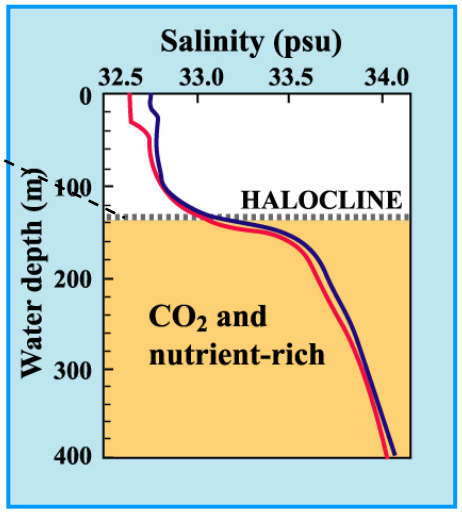
What happened in the subarctic North Pacific 2.7 Ma ago?





Nitrate concentration (μmol)
WOCE line P16

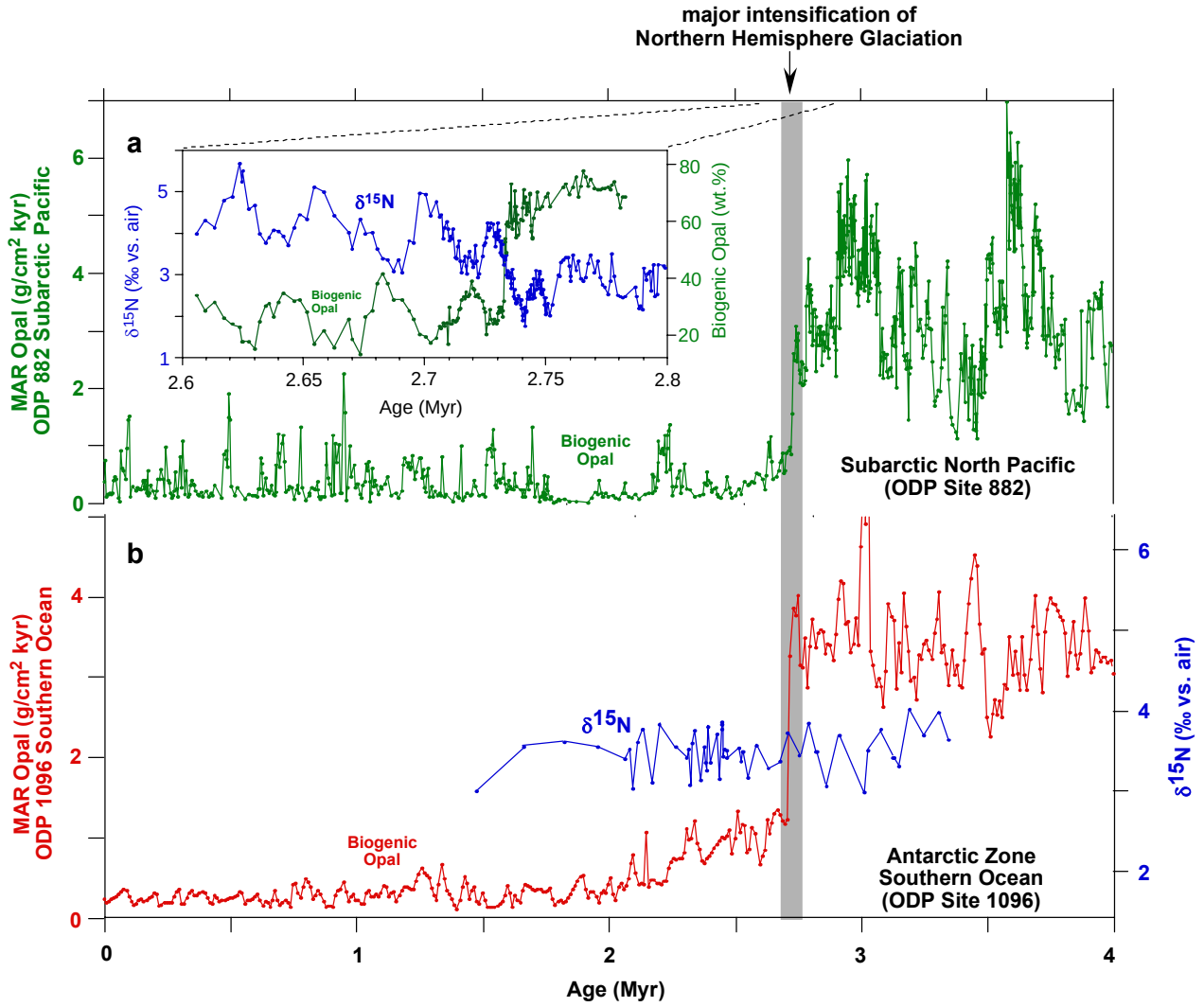




The modern N-Pacific contains the largest nutrient reservoir

The permanent halocline limits N-Pacific CO_2 exhalation to the atmosphere

Cold climates and polar ocean stratification

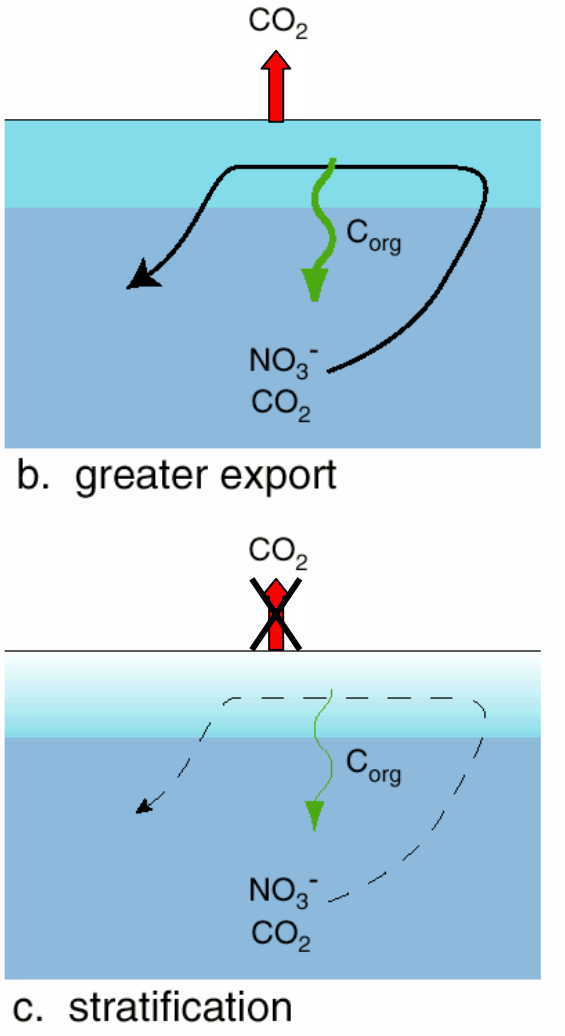


ODP 882
(subarctic N-Pacific)

ODP 1096
(Southern Ocean)

Sigman, Jaccard, Haug, 2004
ODP 1096 Opal data from Hillenbrandt and Fütterer, 2000

The Ocean's Biological Pump



A. Warm climate scenario

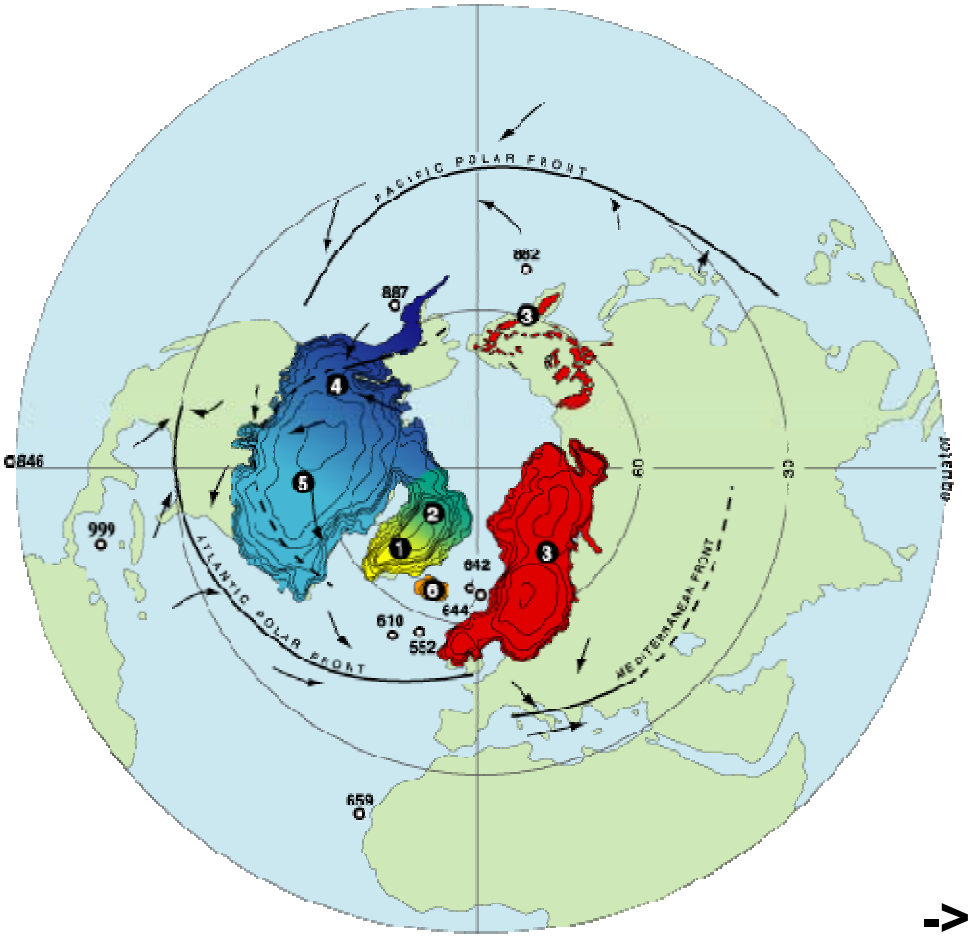
- no freshwater cap
- biopump'leak'

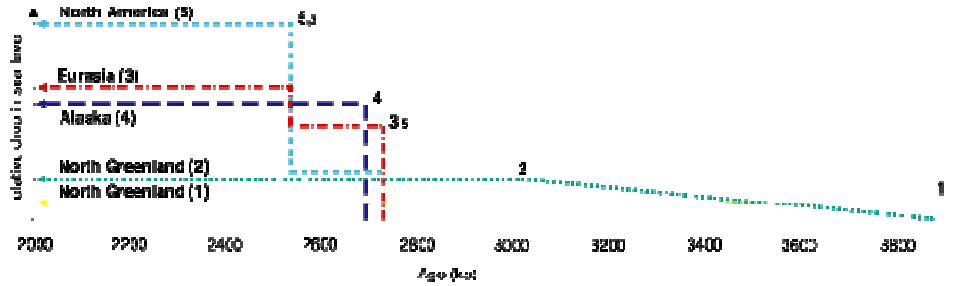
B. Cold climate scenario

- freshwater cap
- biopump efficient

Sigman and Haug, 2003

Massive Ice Sheets in the Northern Hemisphere since 2.7 Myr





What is needed to build an ice shield?

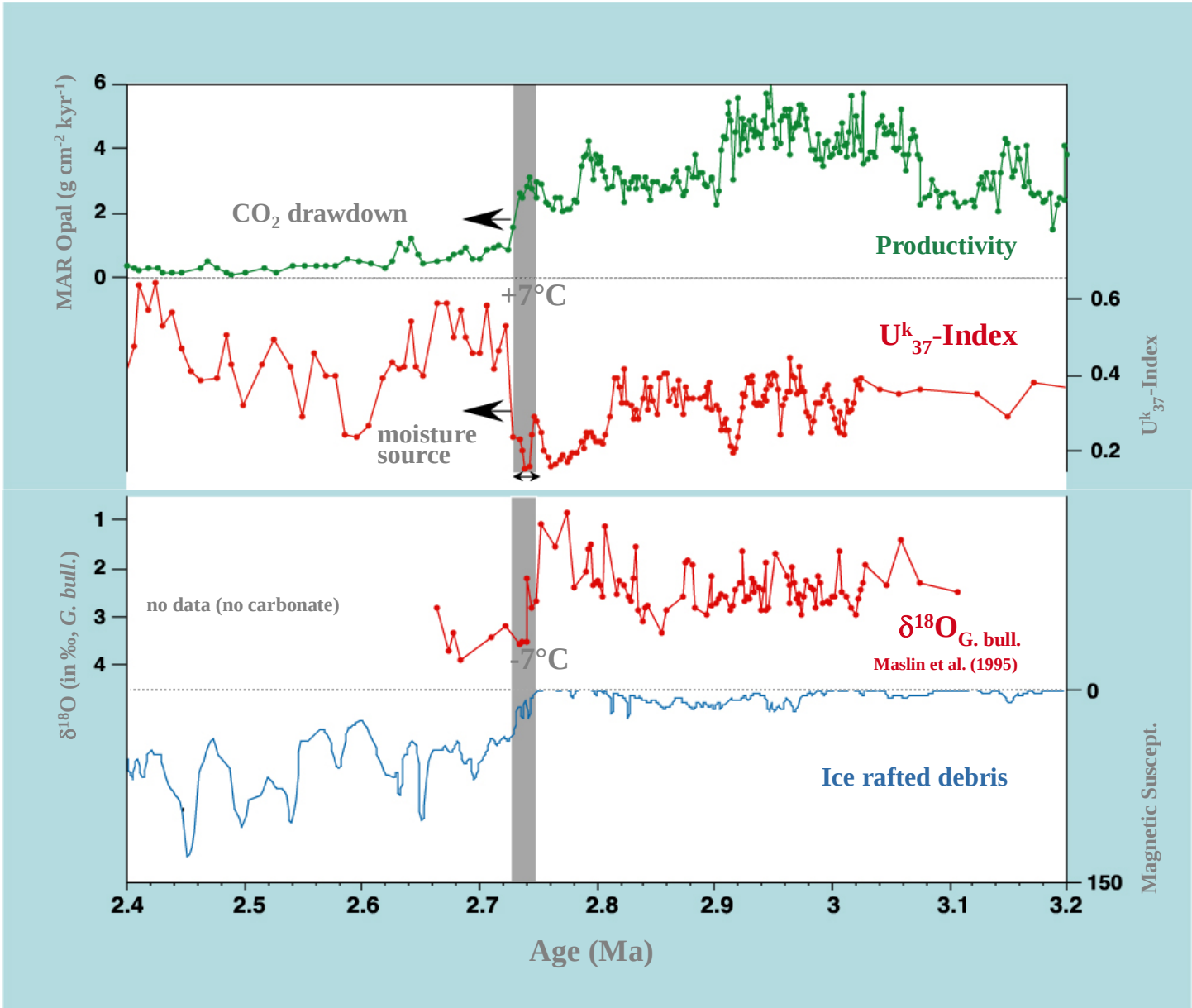
1. The more polar continental areas must be sufficiently cold for precipitation to fall as snow rather than rain and for snow and ice to survive the warm summer melting season

2. Adequate moisture must be introduced to high northern latitudes to promote the accumulation of glacial ice

-> Where is the moisture source!?

Where is the moisture source?

Site 882 (subarctic NW-Pacific)

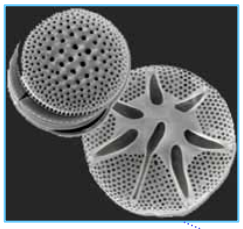


Haug et al., 2005

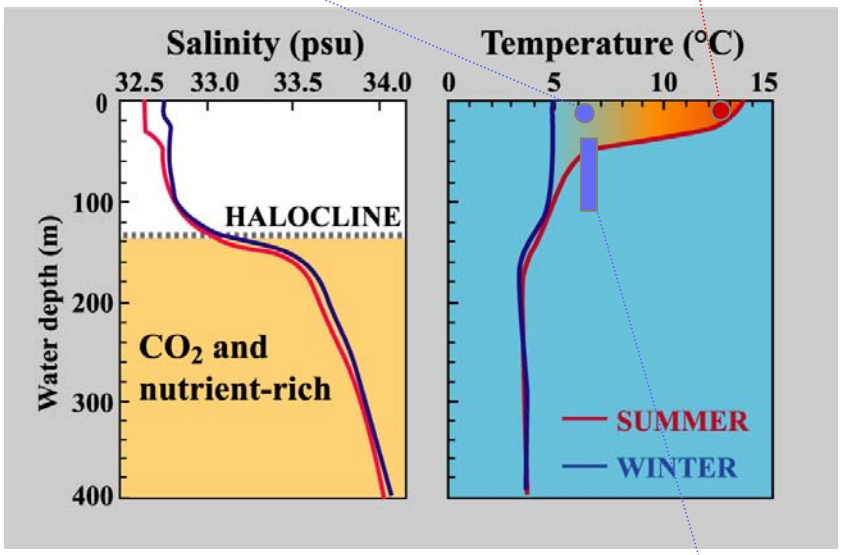
Subarctic North-Pacific Seasonality: Oceanography and Biology

Subarctic N-Pacific

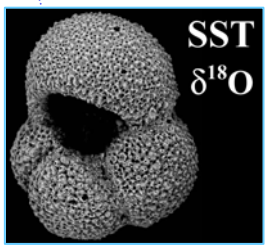
Diatom-bloom (spring)



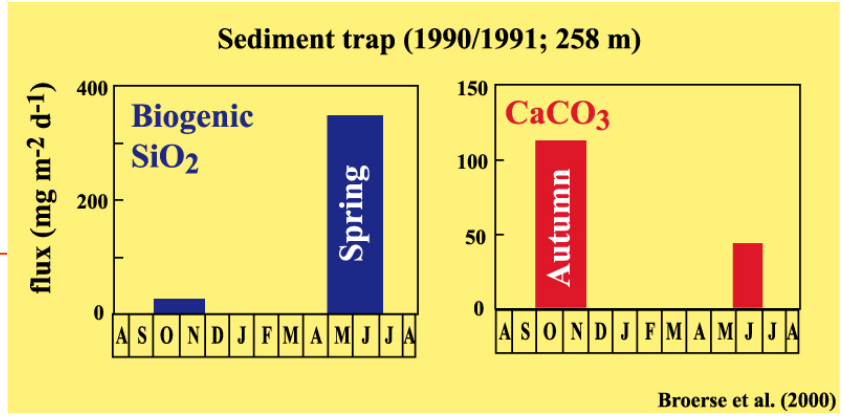
Coccolith-bloom (autumn)



Seasonal SST–contrast



G. bulloides



Formation of permanent subarctic halocline

↓

Reduced mixing and heat exchange (surface layer – ocean interior)

↓

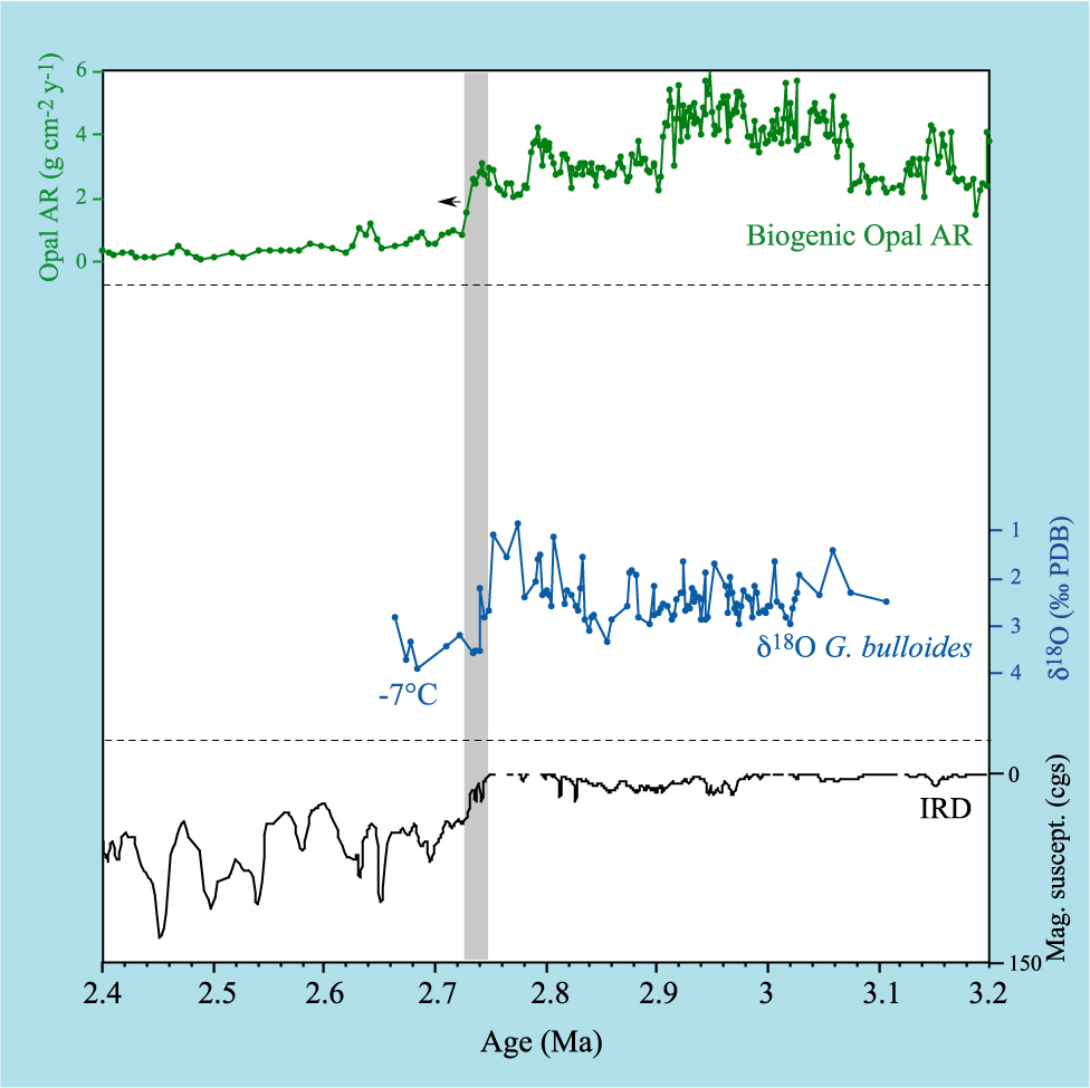
Amplification of saisonal SST contrast Today = 10°- 12°C

↓

Increased evaporation (autumn)

The N-Pacific - Moisture addition for N-America

Site 882



- Temperature decrease in the "Mixed Layer" (winter+spring)

↓

- Formation subarctic halocline
- Decrease in productivity
- Higher SST (summer + autumn)
- More moisture and enhanced evaporation

↓

Accumulation of ice (enhanced supply of IRD)

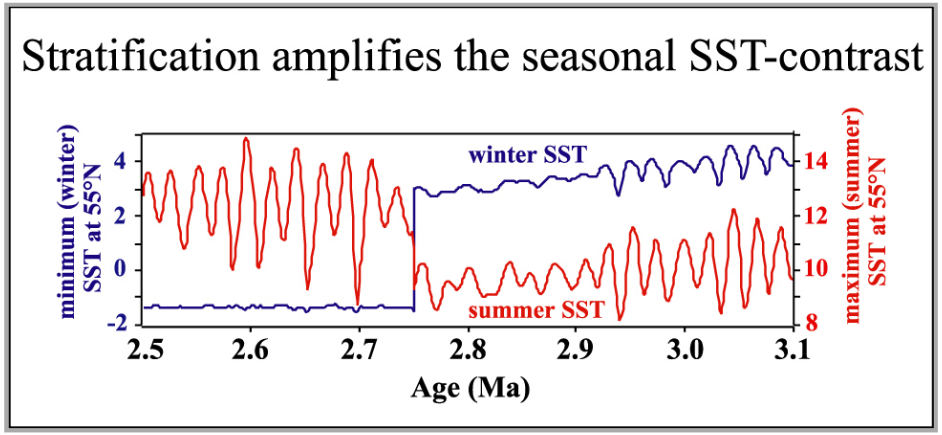
Haug et al., 2005

Testing the link between subarctic Pacific stratification and ice sheet growth

– Experiments with the "Earth System Model CLIMBER-2" – by Andrey Ganopolski

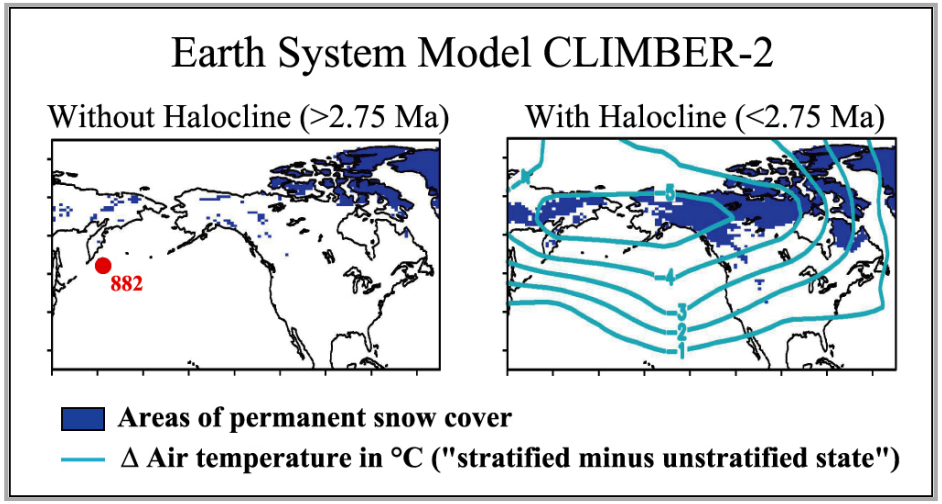
Reduction of freshwater input by
0.2 Sv into the subarctic Pacific
(ca. 20% of the modern pecipitation)

→ lack of modern halocline



Area of permanent snow cover
increased during the cold orbital
configuration, due to a remaining high
evaporation in autumn

→ glaciation of N-America



Haug, Ganopolski, et al., 2005