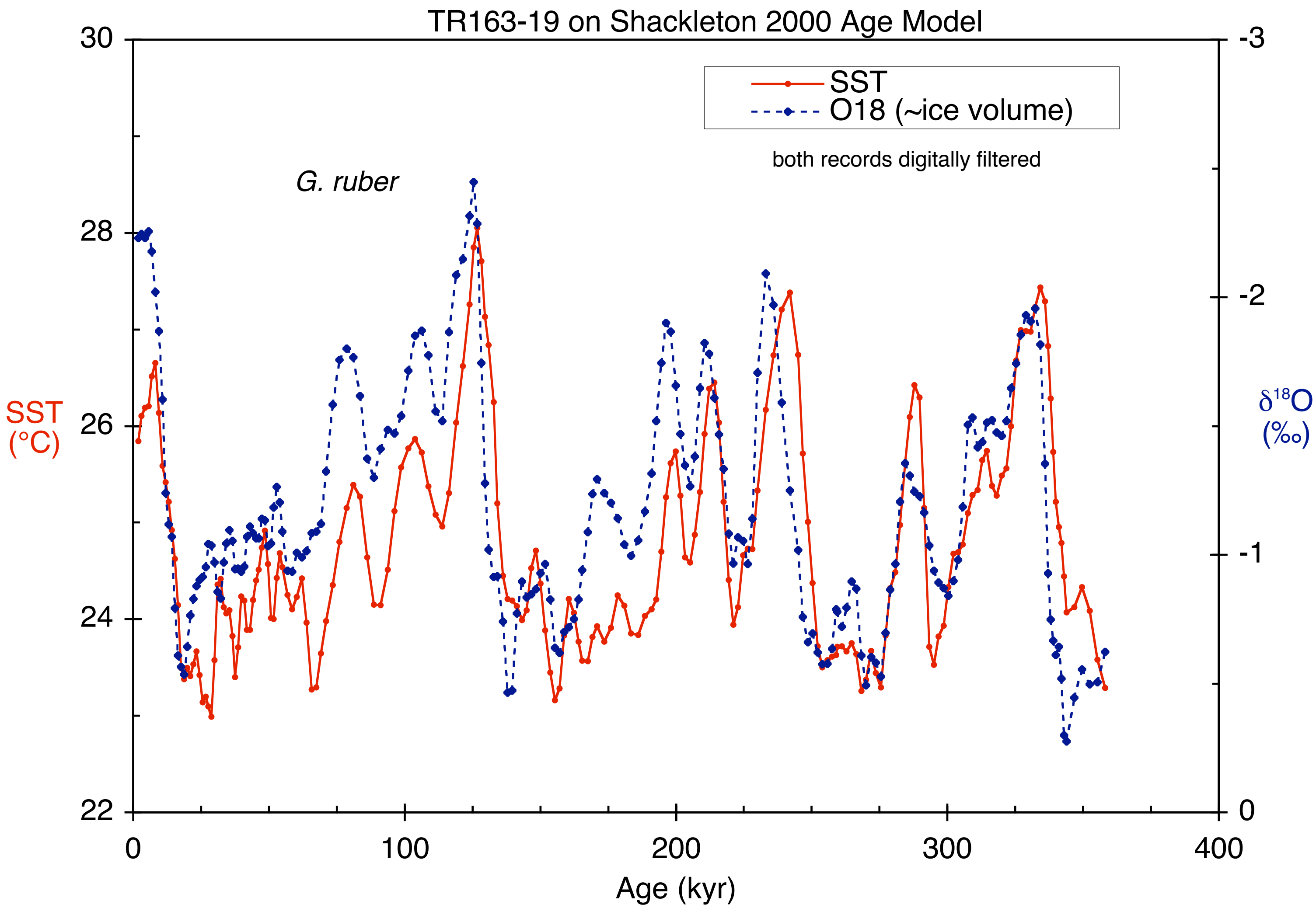
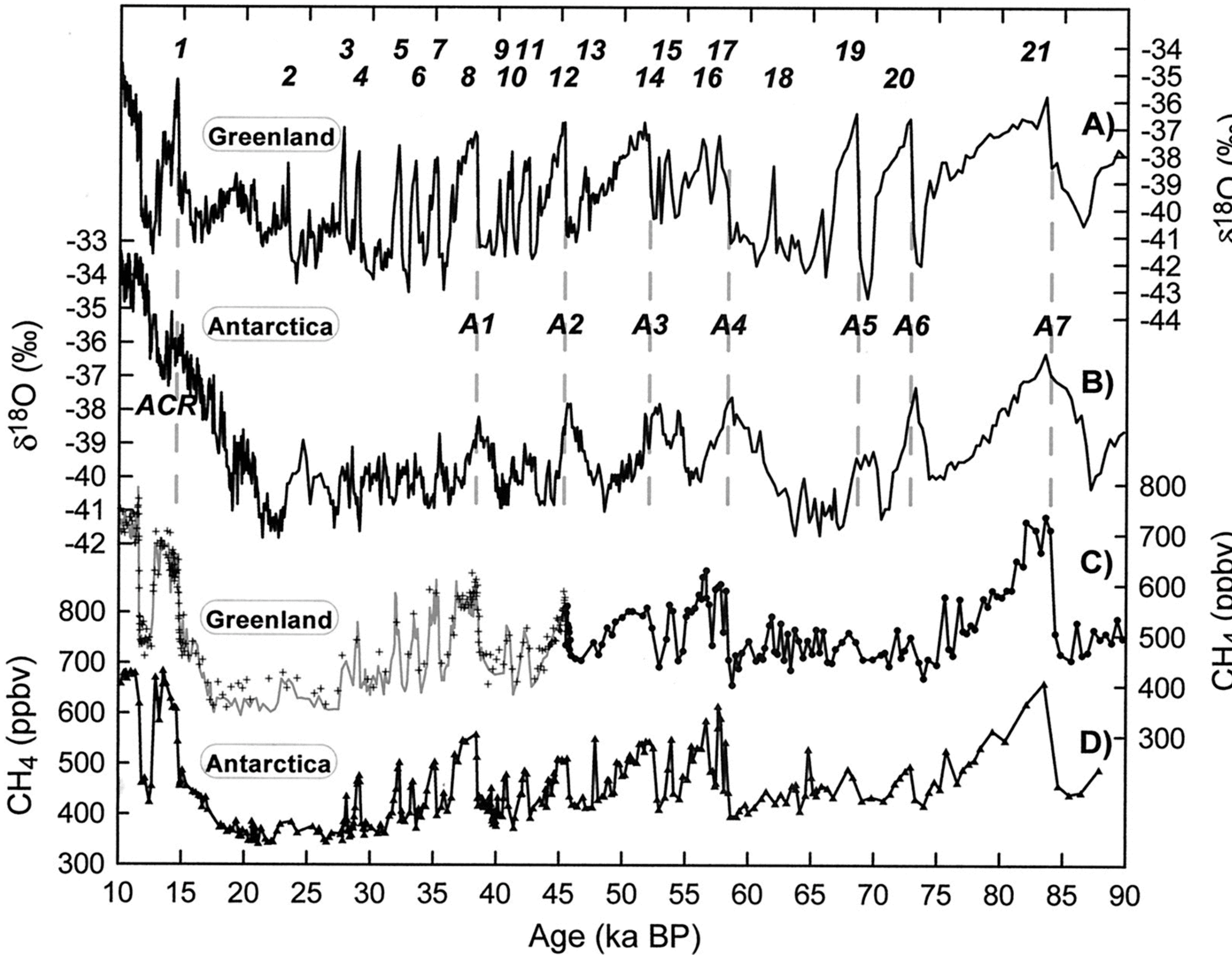
# Abrupt climate change

# Milankovitch-scale variability

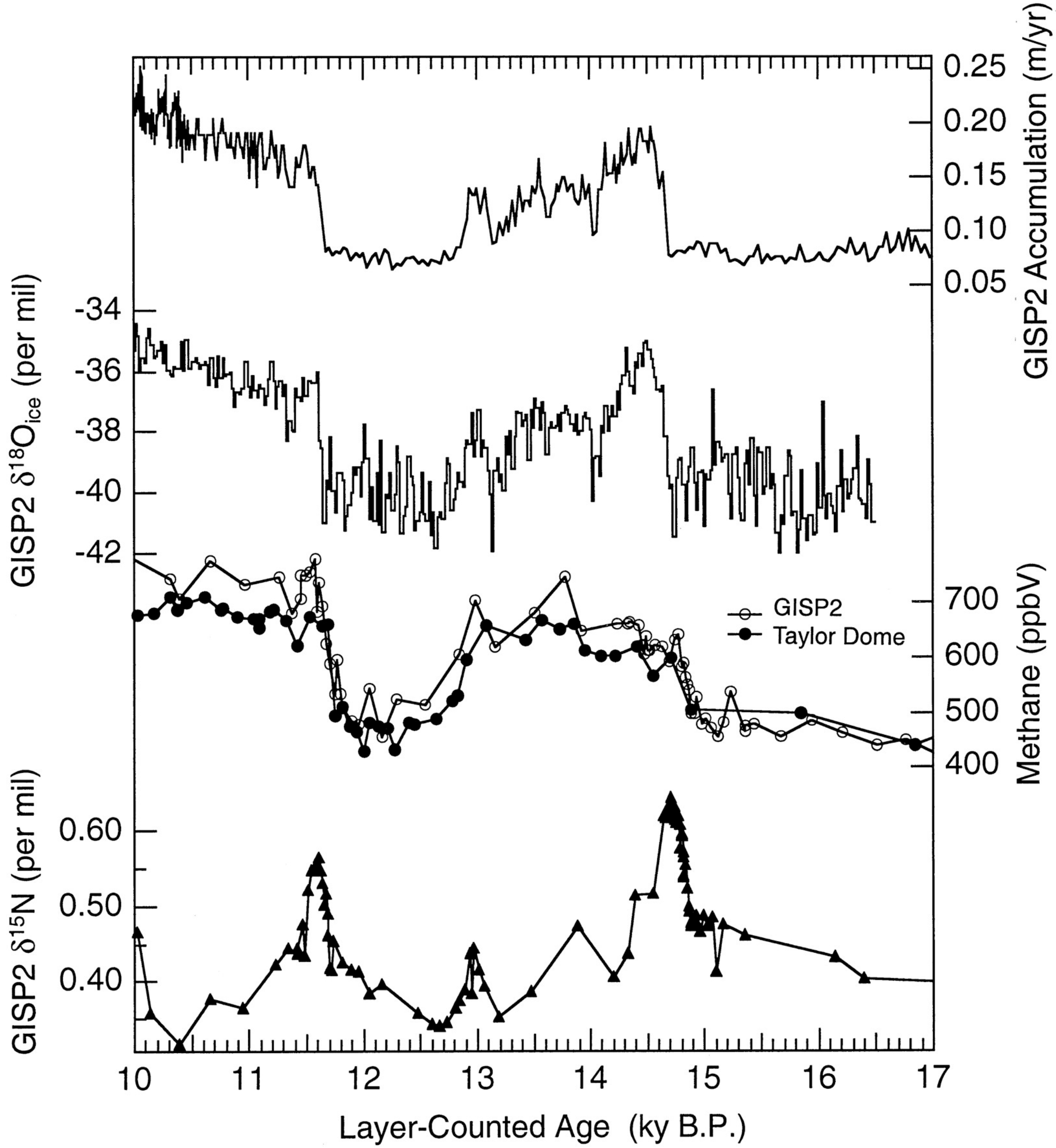


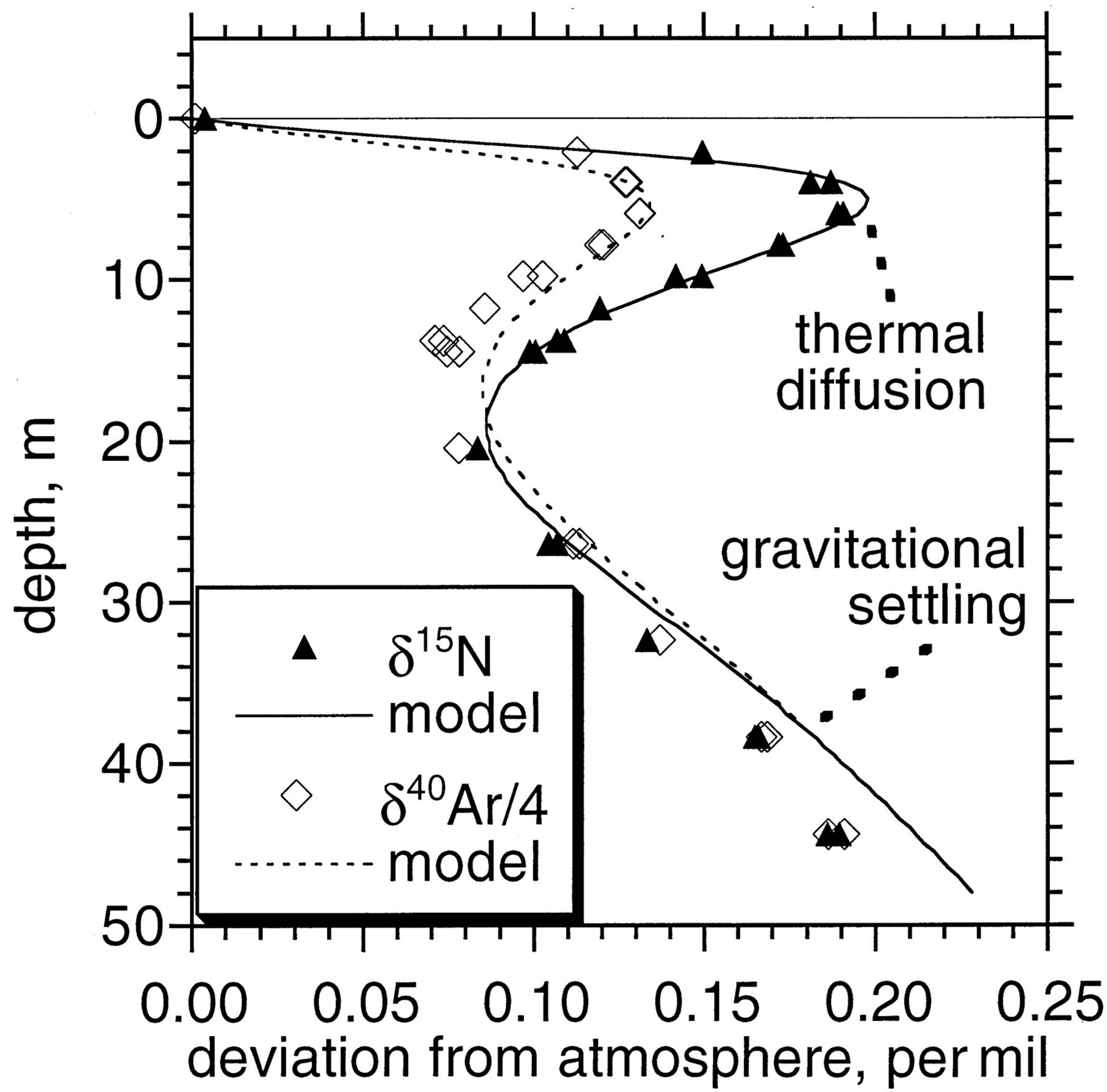
# Dansgaard Oeschger events



Younger Dryas:

The abrupt climate change "type event"

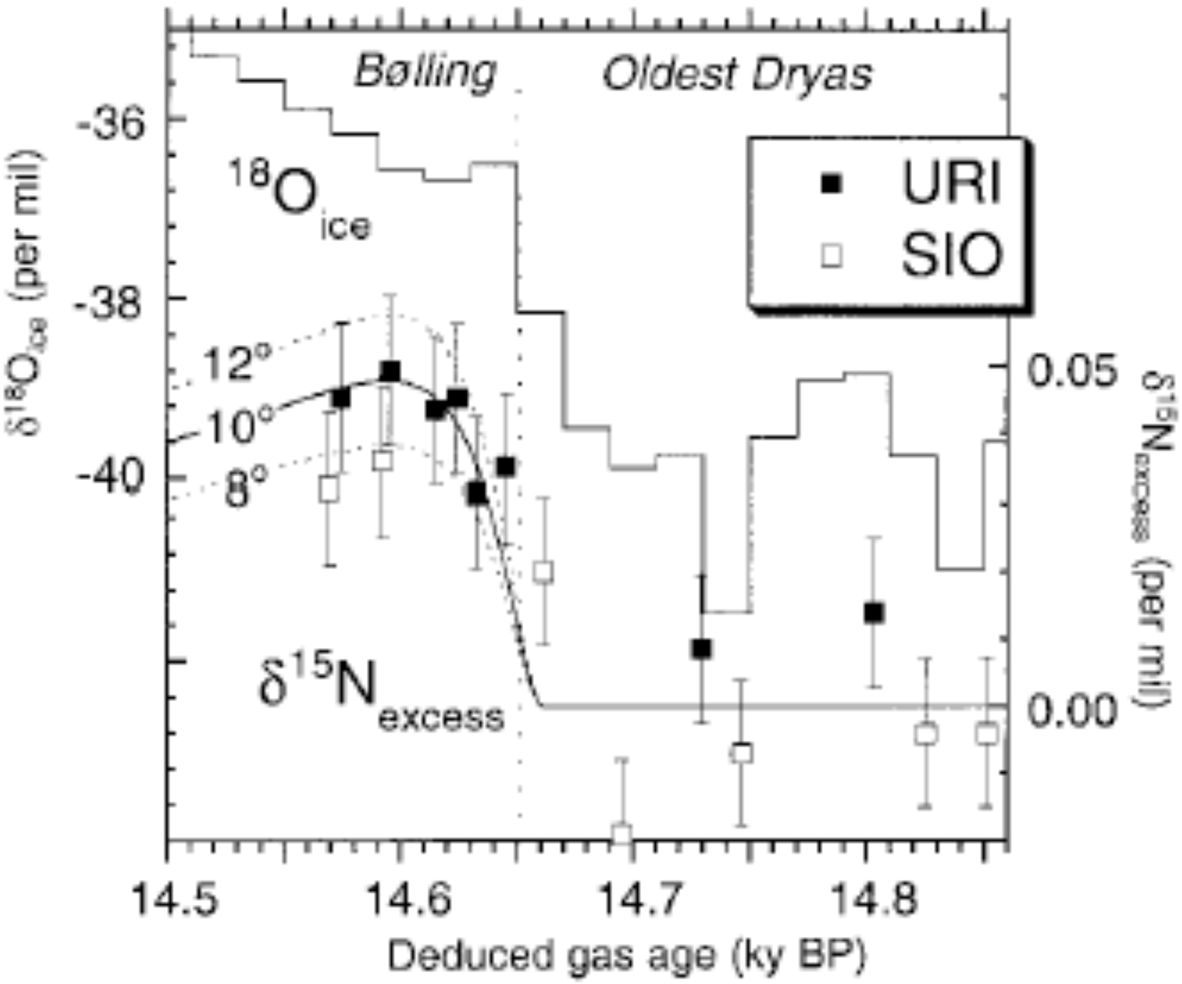




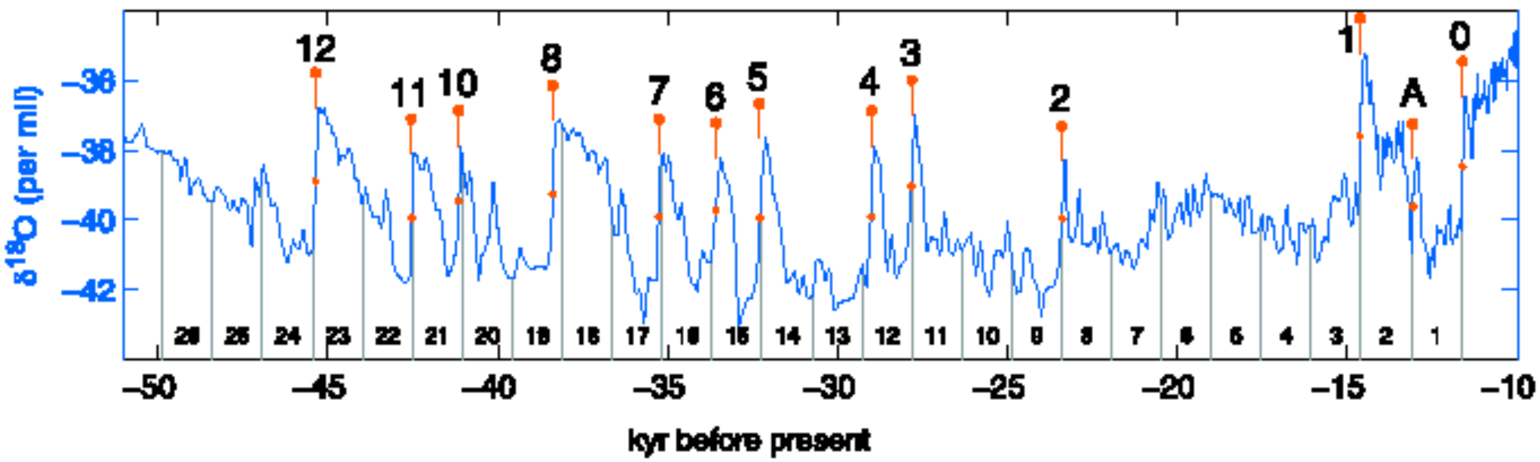

Diffusivities differ! Ratio is proportional to temperature difference

grav. enrich. $\sim e^{((Mdiff)gz/RT)}-1$

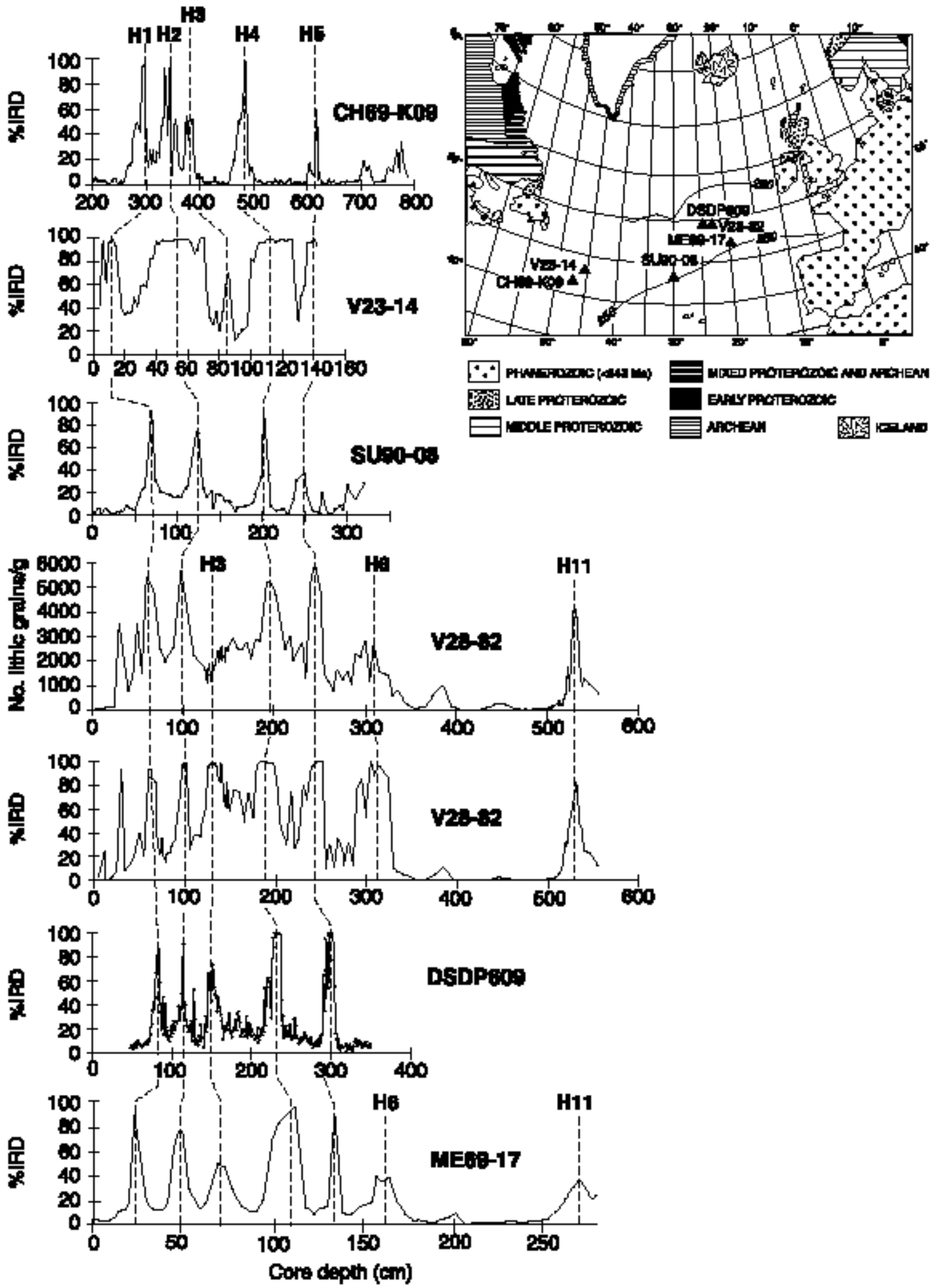
d15Nexcess = d15N-(d40Ar)/4



# Regular spacing of D-O events?



# 2. Iceberg discharges



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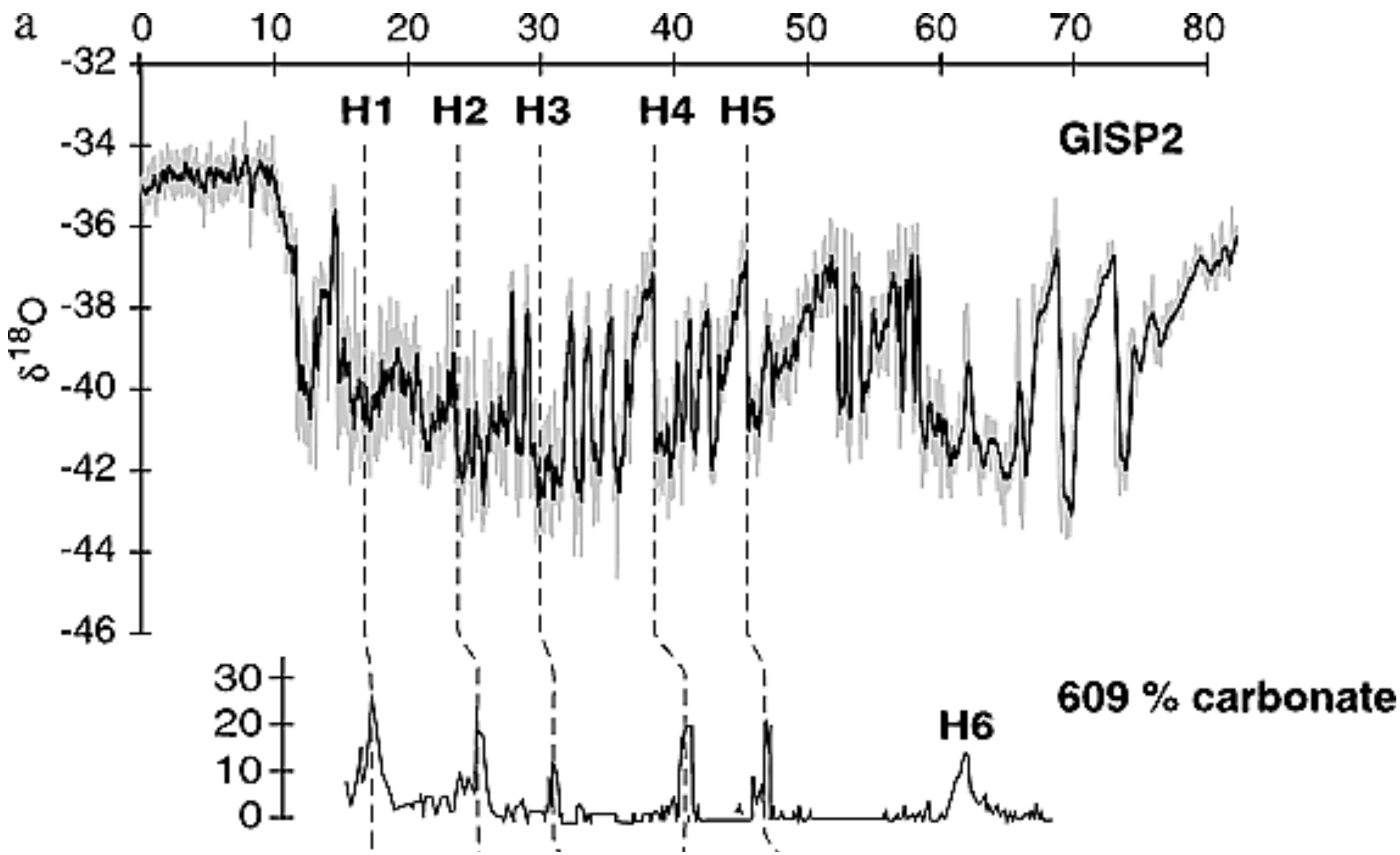
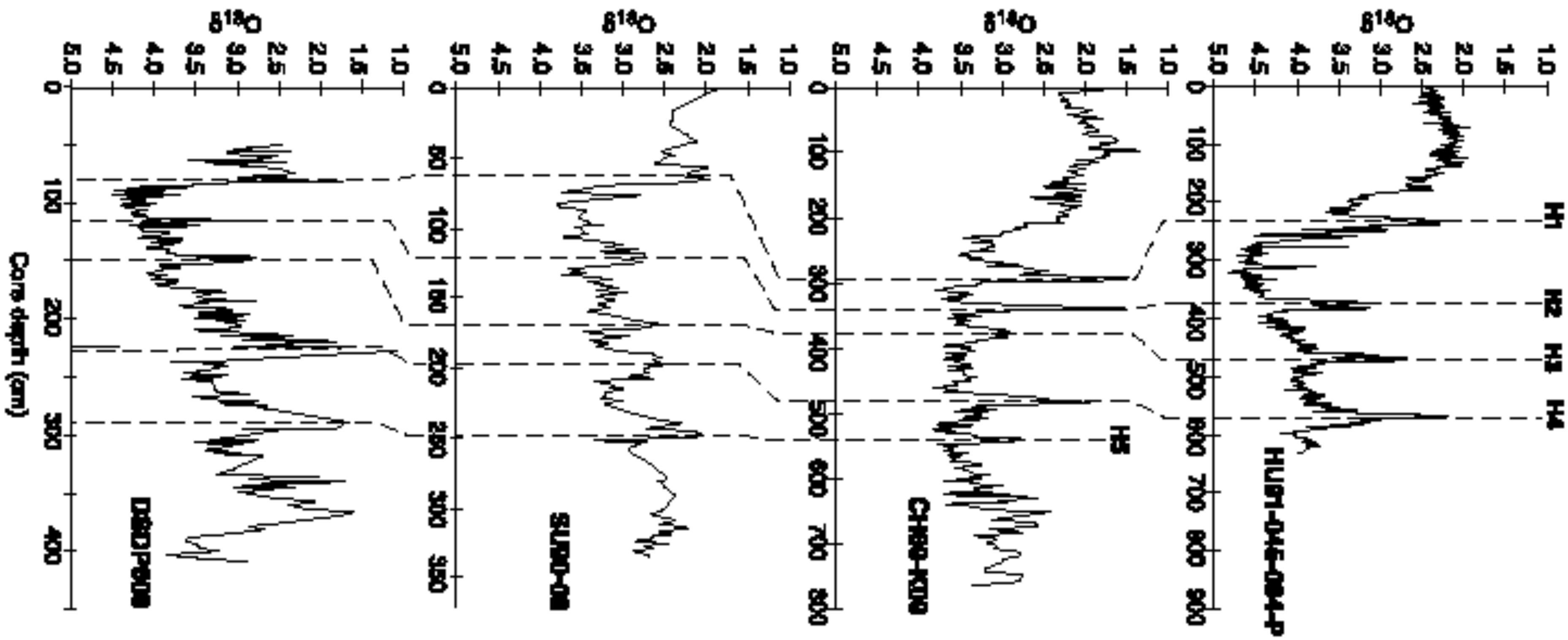
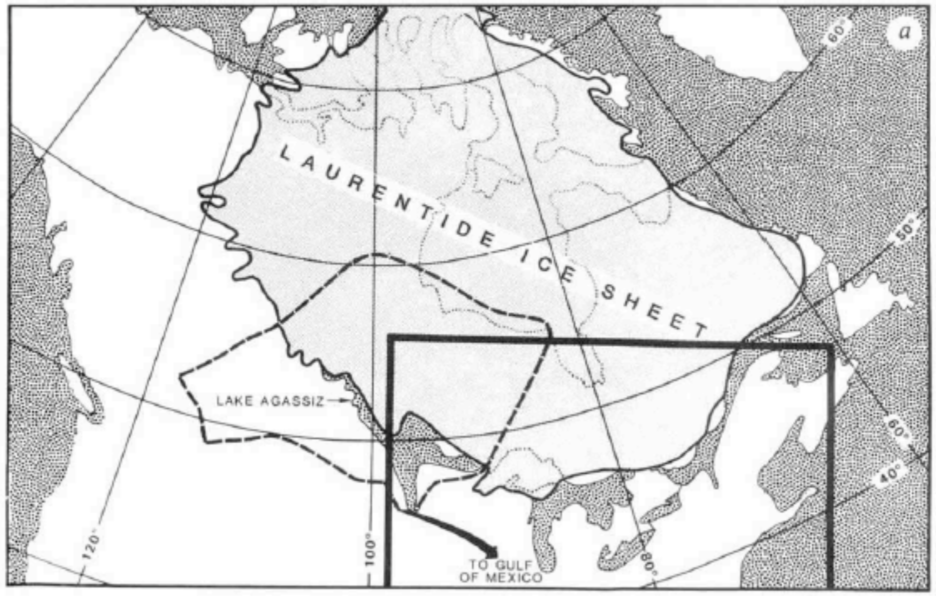


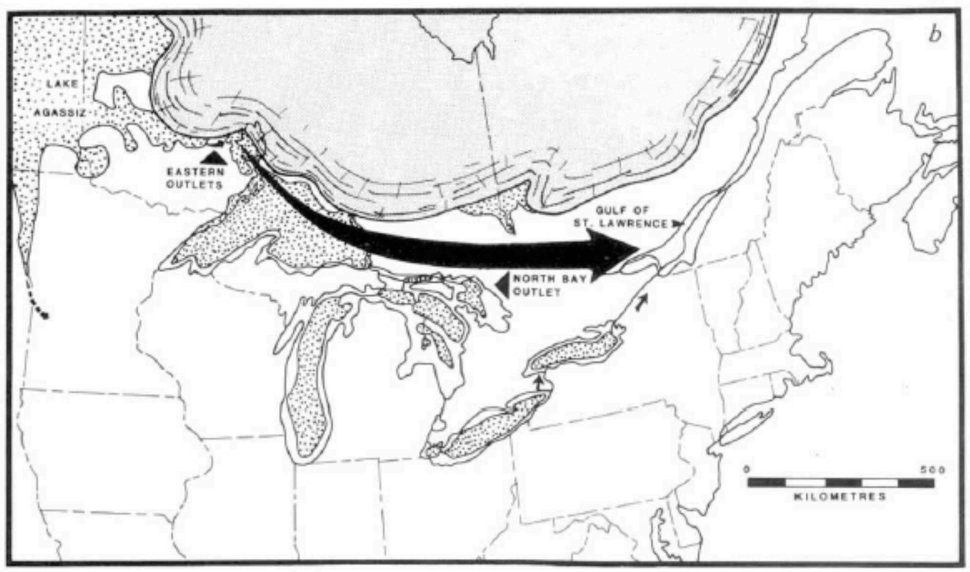

Hemming, 2004

# 2. Iceberg discharges






Area enlarged in *b*



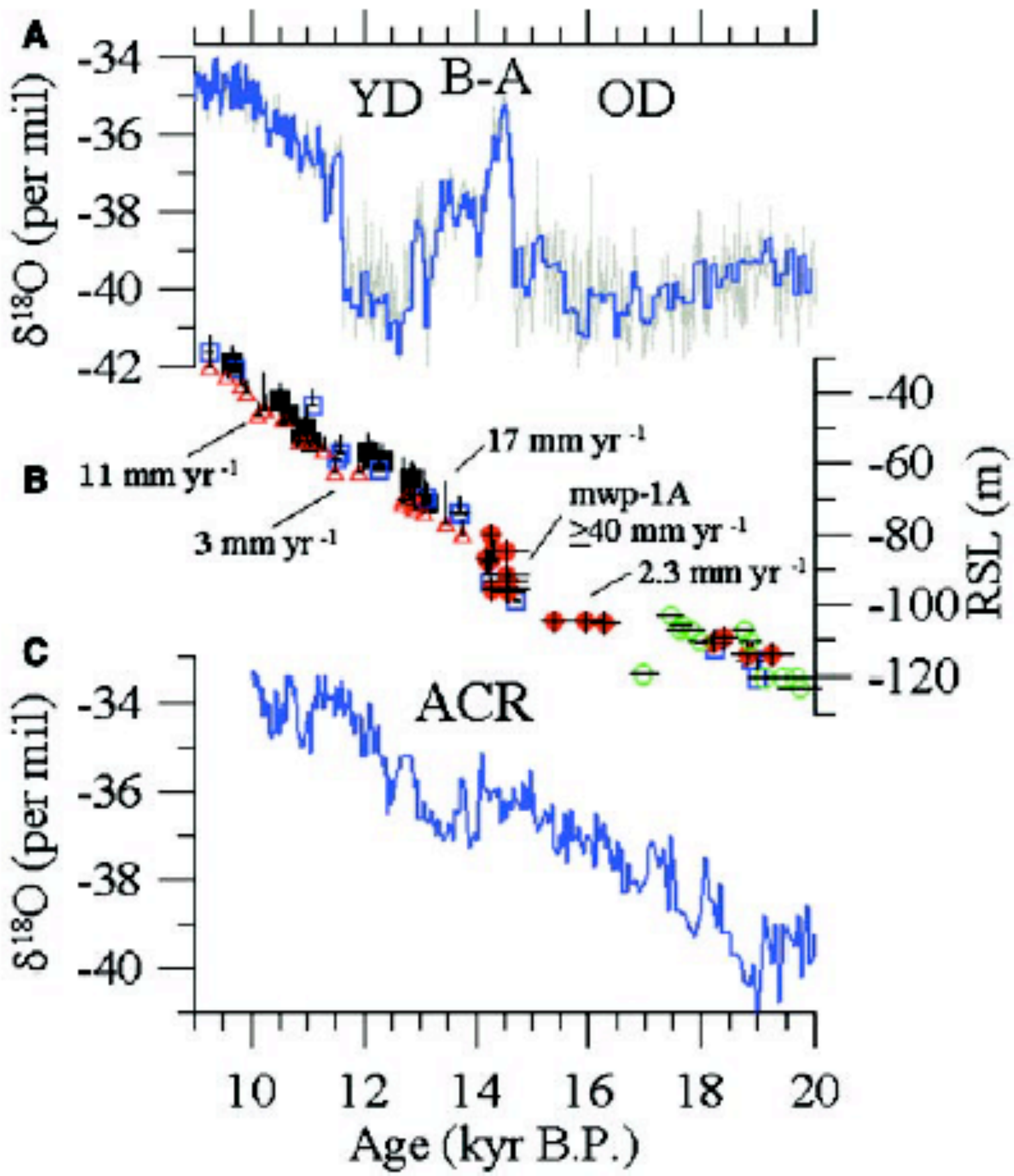
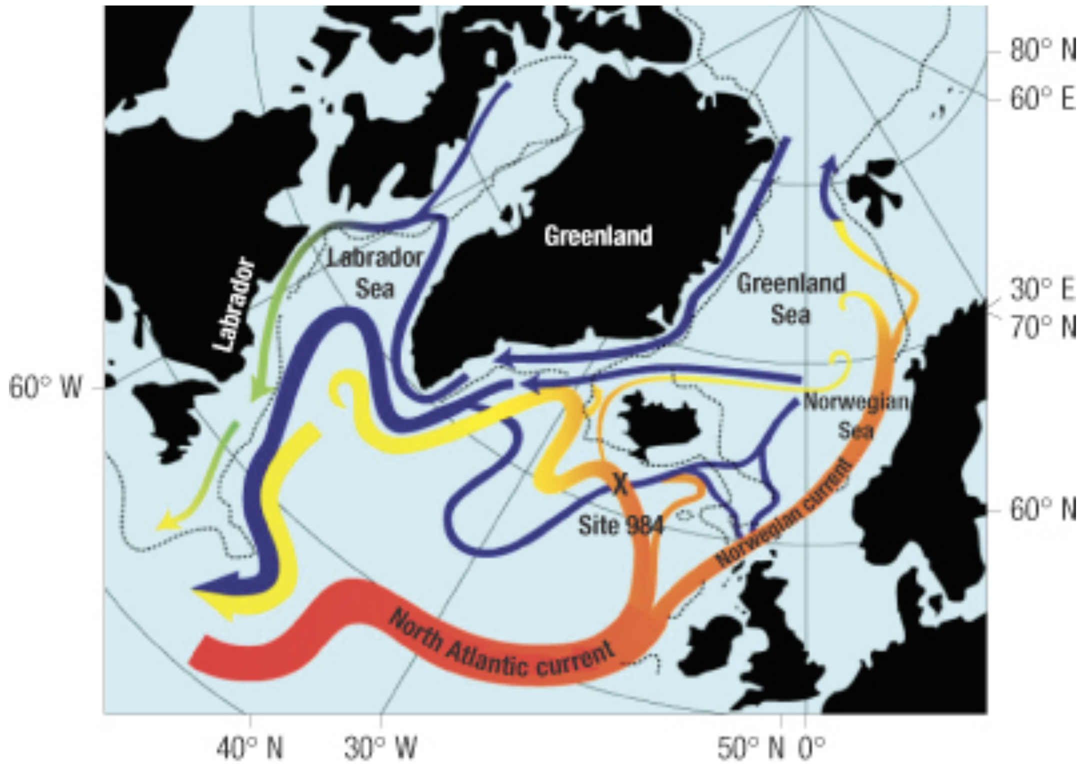
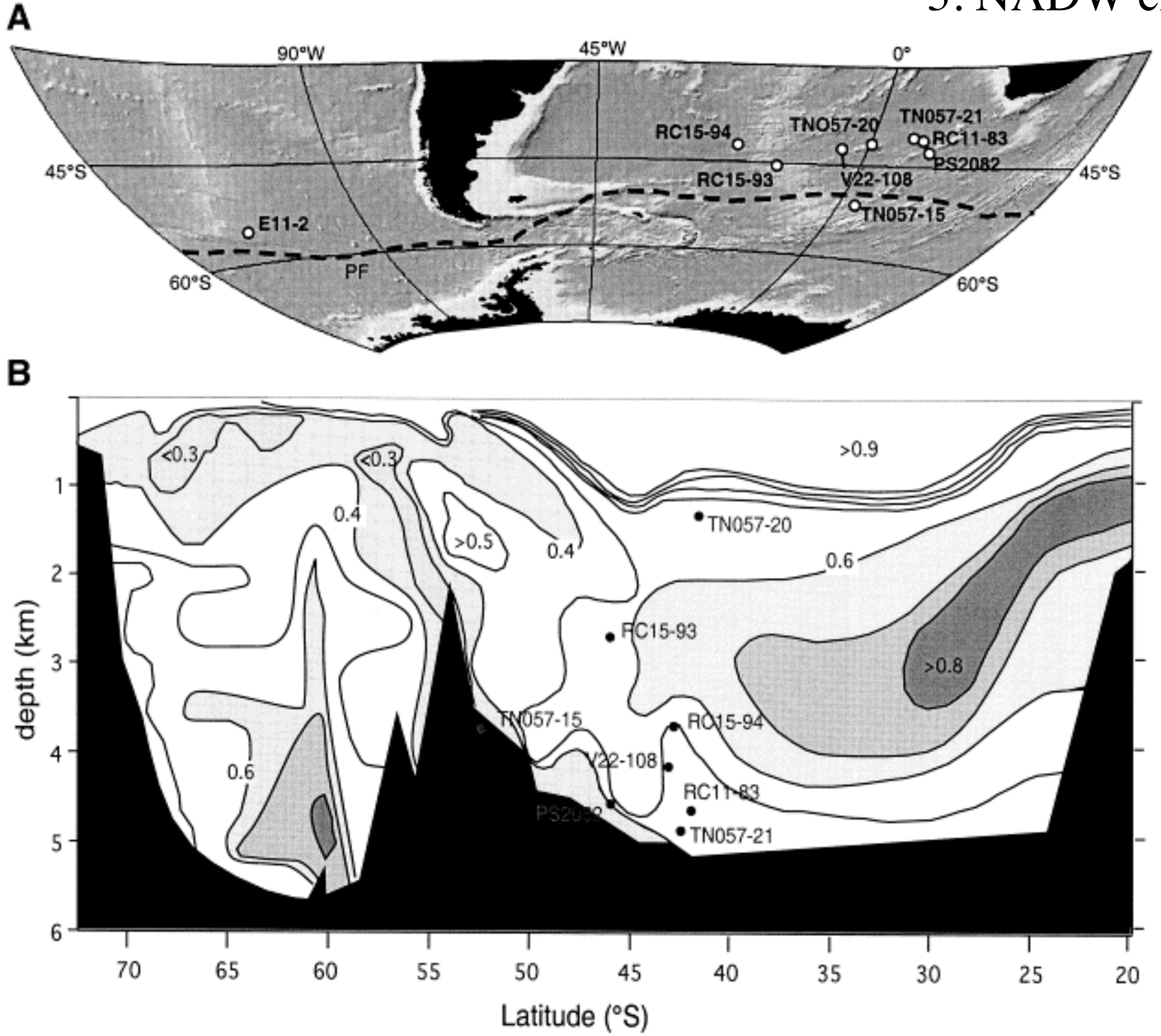



**Fig. 5.** Climate and sea-level records spanning the last deglaciation. (**A**) The Greenland Ice Sheet Project 2 (GISP2) oxygen isotope record (*40, 41*). OD is the Oldest Dryas cold period, and YD is the Younger Dryas cold period. (**B**) Relative sea-level (RSL) records from far-field sites. Also shown are average rates of sea-level rise for the periods 19 to 14.6, 14.6 to 14.1, 14.1 to 12.9, 12.9 to 11.6, and 11.6 to 6 kyr B.P. Data are from Bonaparte Gulf (green open circles) (*42*), Barbados U/Th dated corals (open blue squares) (*5*), Sunda Shelf (*9*), Tahiti (open red triangles) (*5*), and New Guinea (closed black squares) (*43*). (**C**) The Byrd ice-core oxygen isotope record on the GISP2 time scale (*34*). ACR is the Antarctic Cold Reversal.


80° N
60° E
Greenland
Labrador
Labrador Sea
Greenland Sea
30° E
70° N
60° W
Norwegian Sea
X
Site 984
Norwegian current
60° N
North Atlantic current
40° N
30° W
50° N
0°

## 3. NADW change



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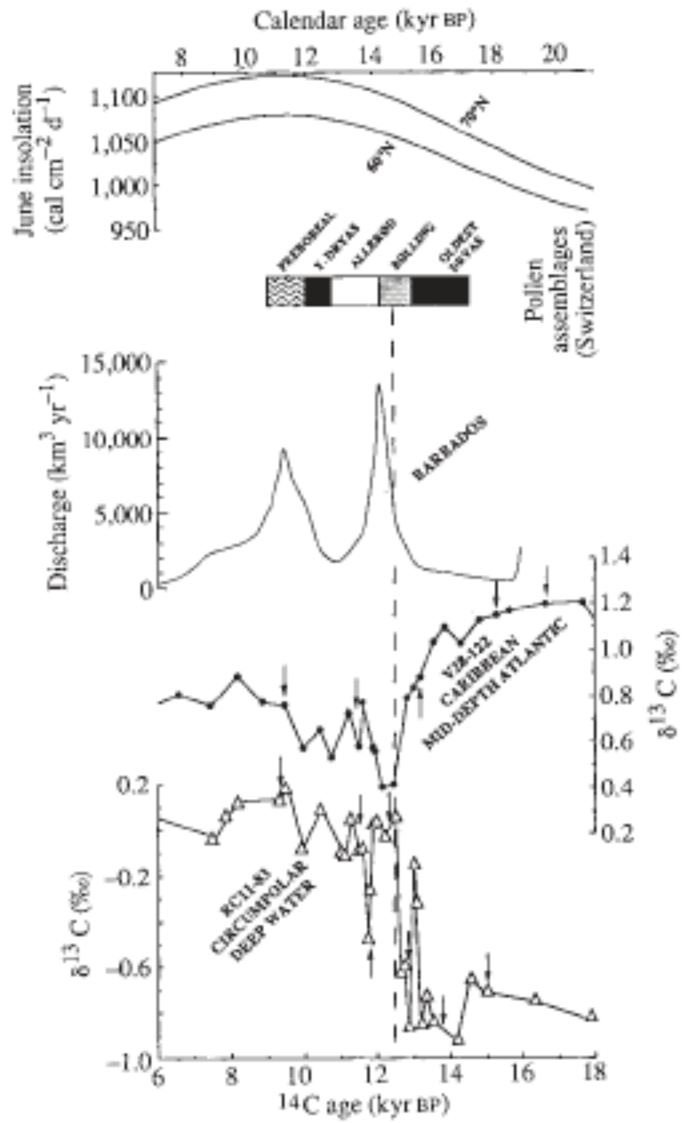



Resumption of high 13/12C in the South Atlantic corresonds with the abrupt warming.

# 3. NADW change

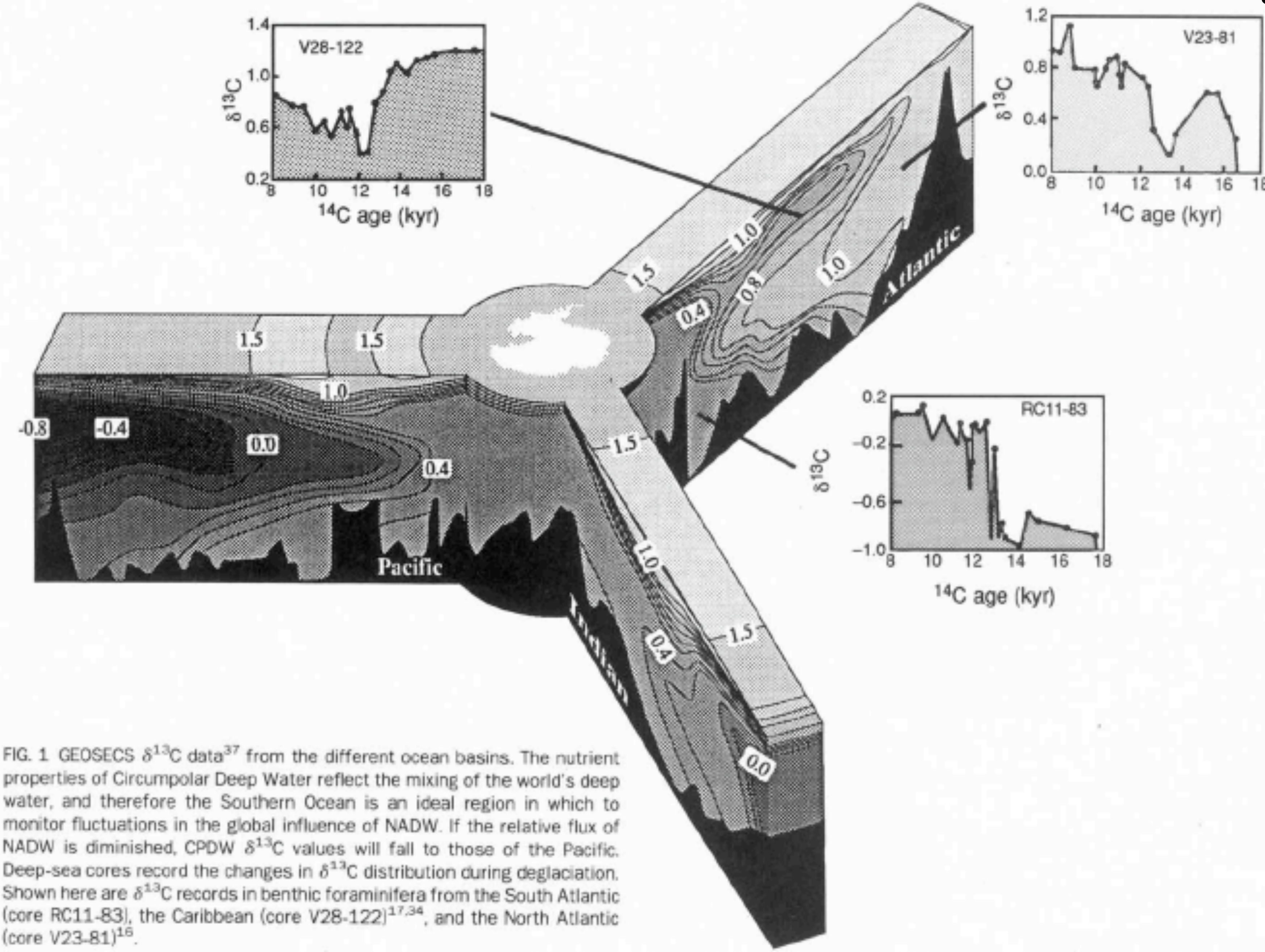
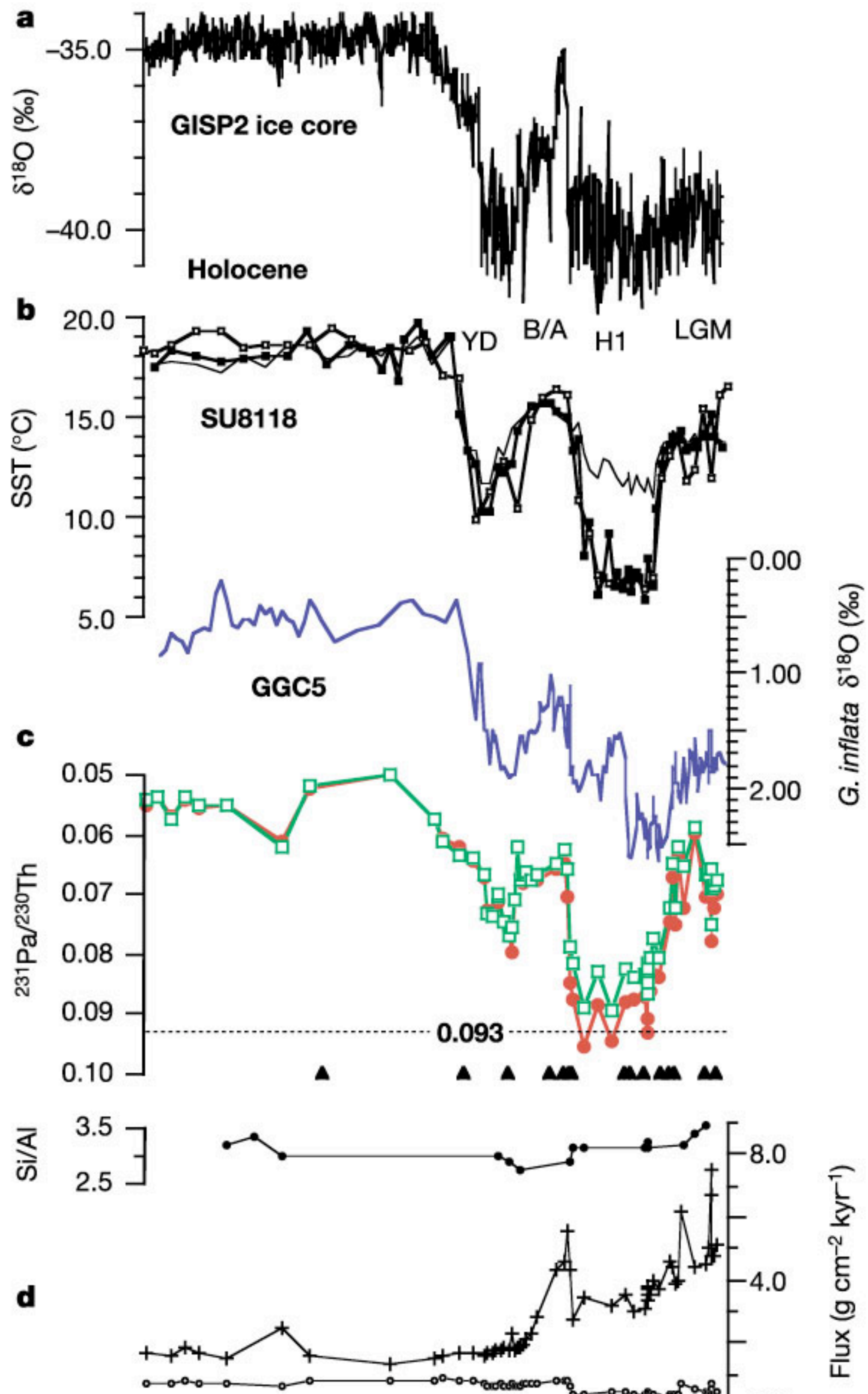
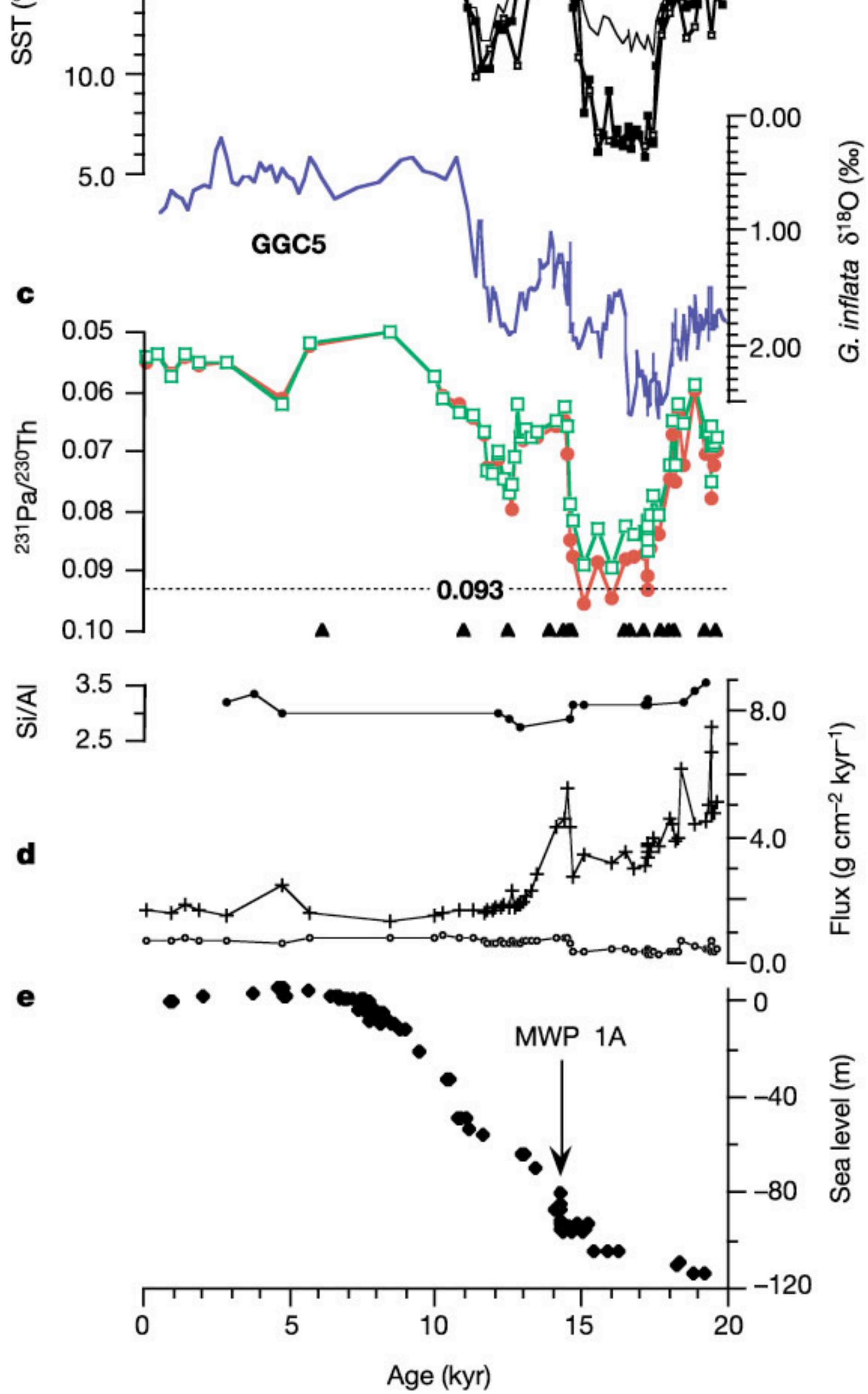



FIG. 1 GEOSECS $\delta^{13}C$ data[37] from the different ocean basins. The nutrient properties of Circumpolar Deep Water reflect the mixing of the world's deep water, and therefore the Southern Ocean is an ideal region in which to monitor fluctuations in the global influence of NADW. If the relative flux of NADW is diminished, CPDW $\delta^{13}C$ values will fall to those of the Pacific. Deep-sea cores record the changes in $\delta^{13}C$ distribution during deglaciation. Shown here are $\delta^{13}C$ records in benthic foraminifera from the South Atlantic (core RC11-83), the Caribbean (core V28-122)[17,34], and the North Atlantic (core V23-81)[16].

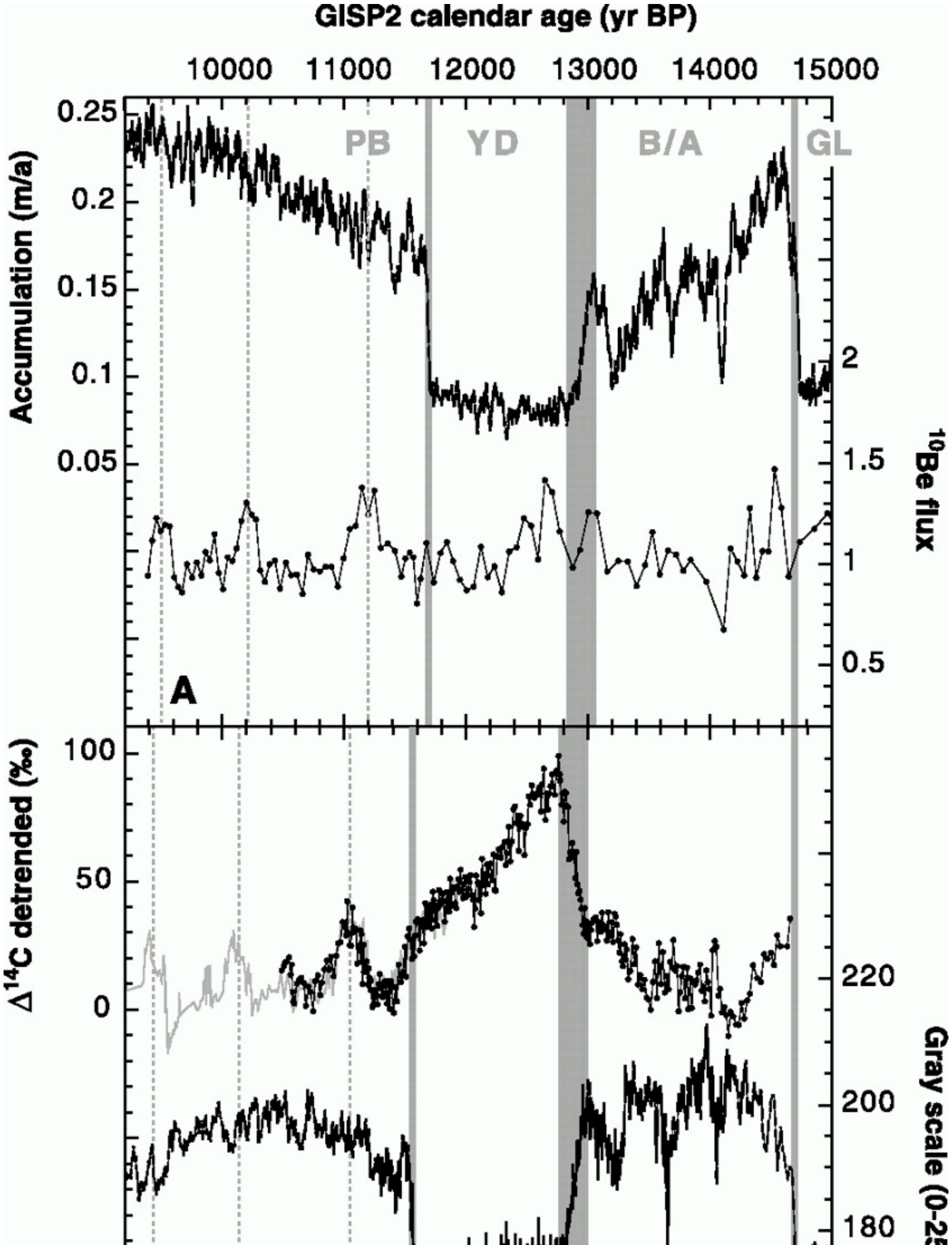
# 3. NADW change



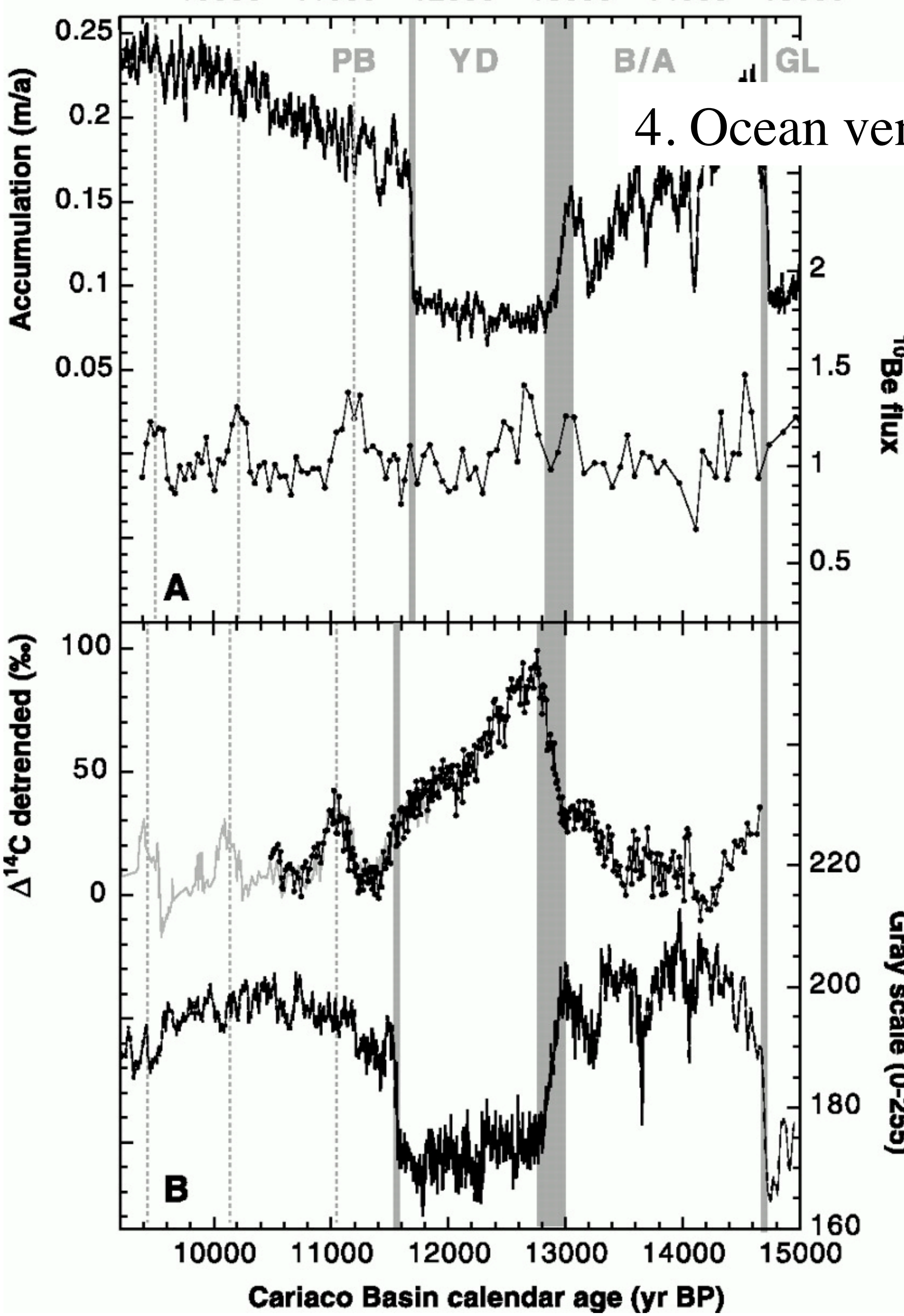


SST (
10.0
5.0
GGC5
c
0.00
1.00
2.00
G. inflata δ18O (‰)
0.05
0.06
0.07
0.08
0.09
0.10
231Pa/230Th
0.093
Si/Al
3.5
2.5
8.0
4.0
0.0
Flux (g cm−2 kyr−1)
d
e
0
−40
−80
−120
Sea level (m)
MWP 1A
0
5
10
15
20
Age (kyr)

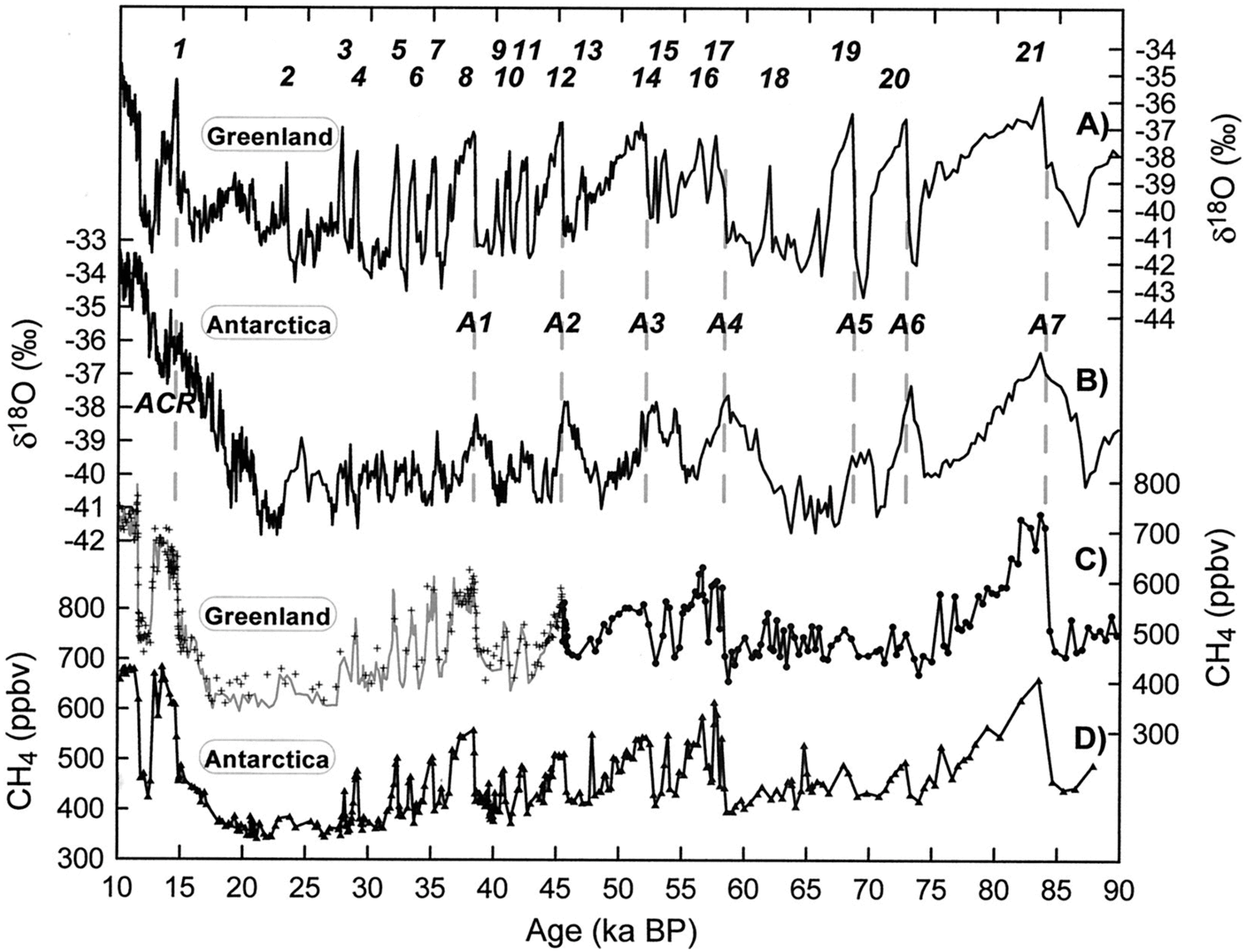
# 4. Ocean ventilation change



# 4. Ocean ventilation change



5. Muted/out of phase signals in S. Hemisphere



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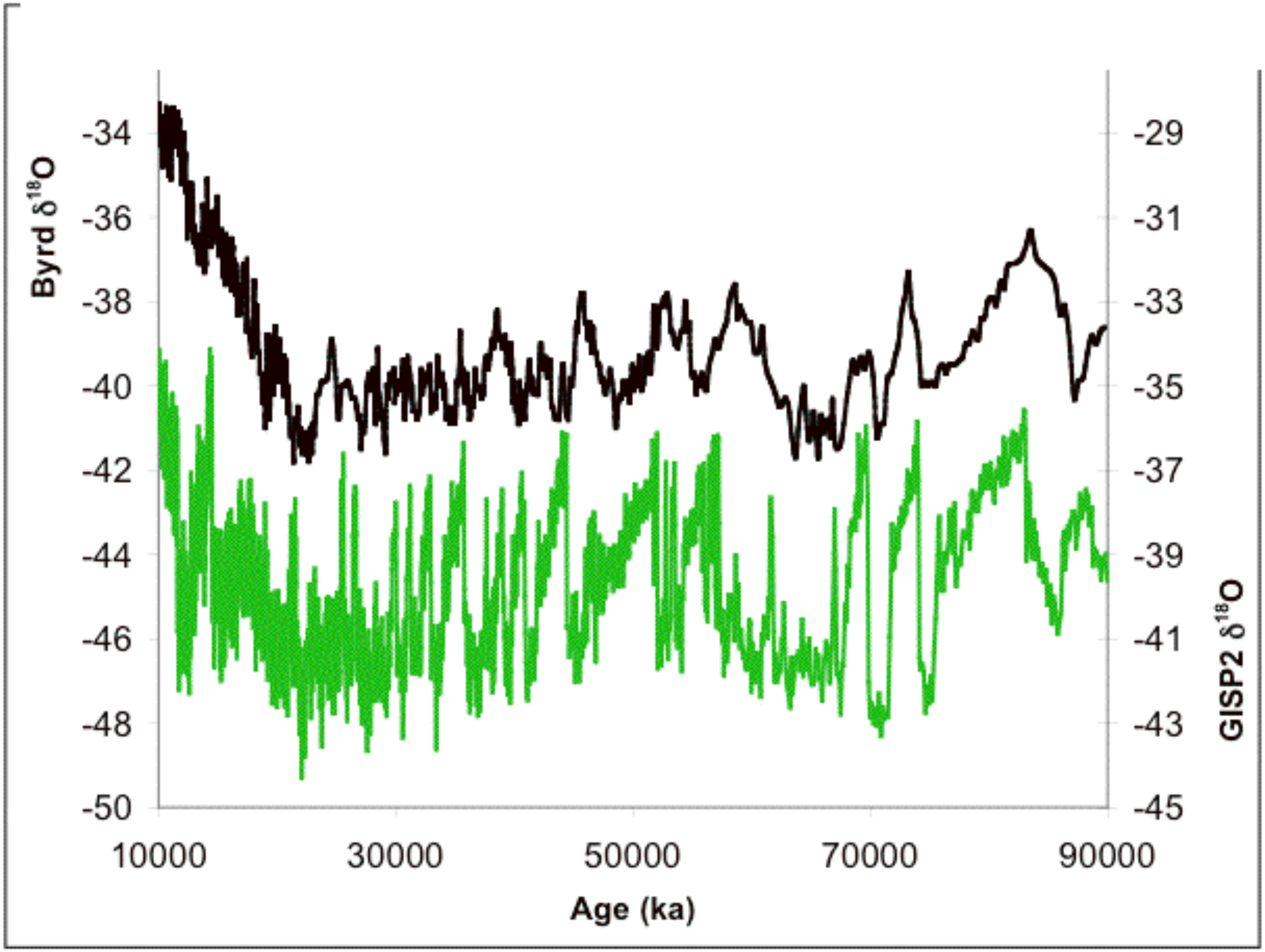
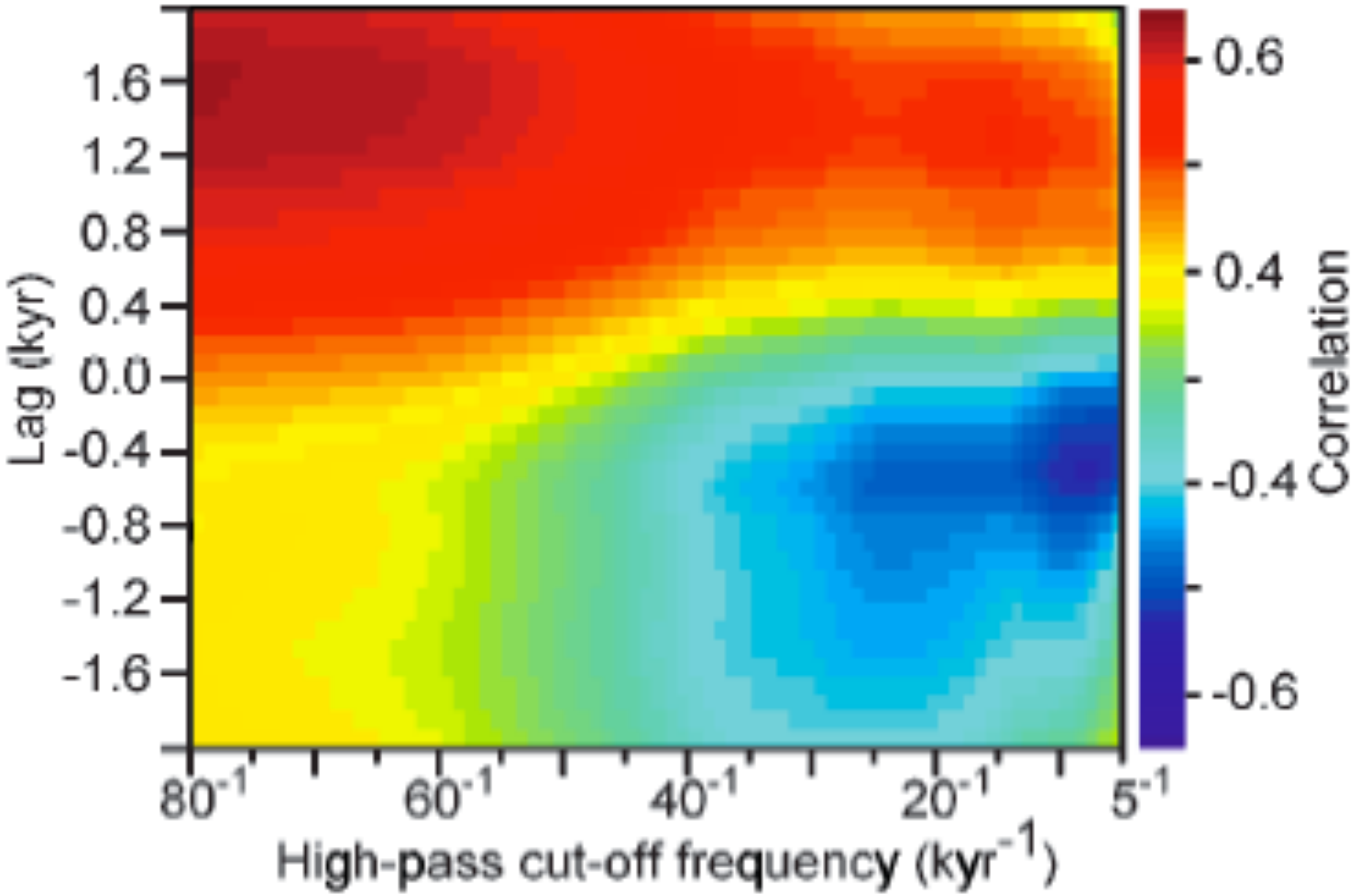
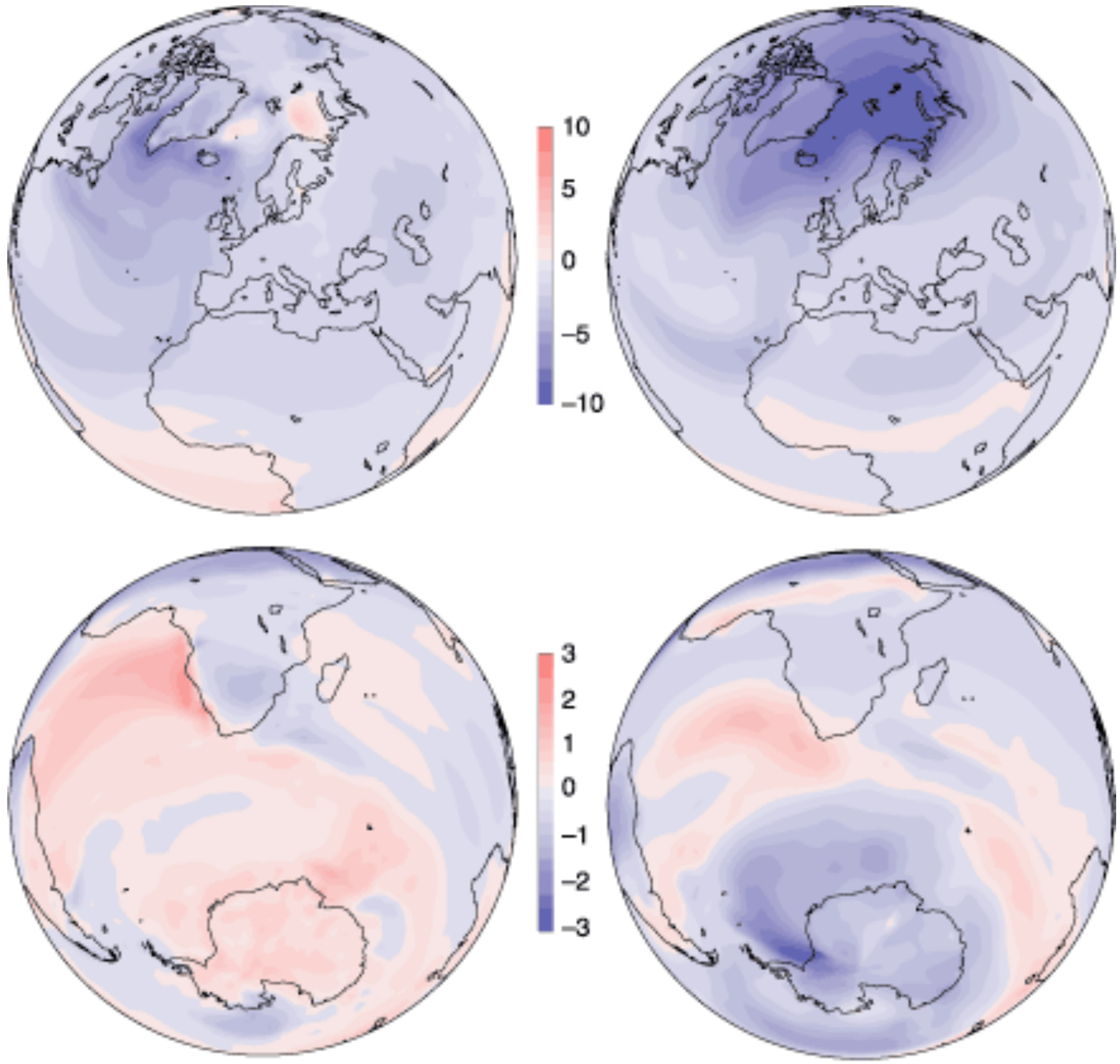





Steig and Alley, 2002


10
5
0
−5
−10
3
2
1
0
−1
−2
−3

# 6. Changes in the low latitudes.

Cariaco basin

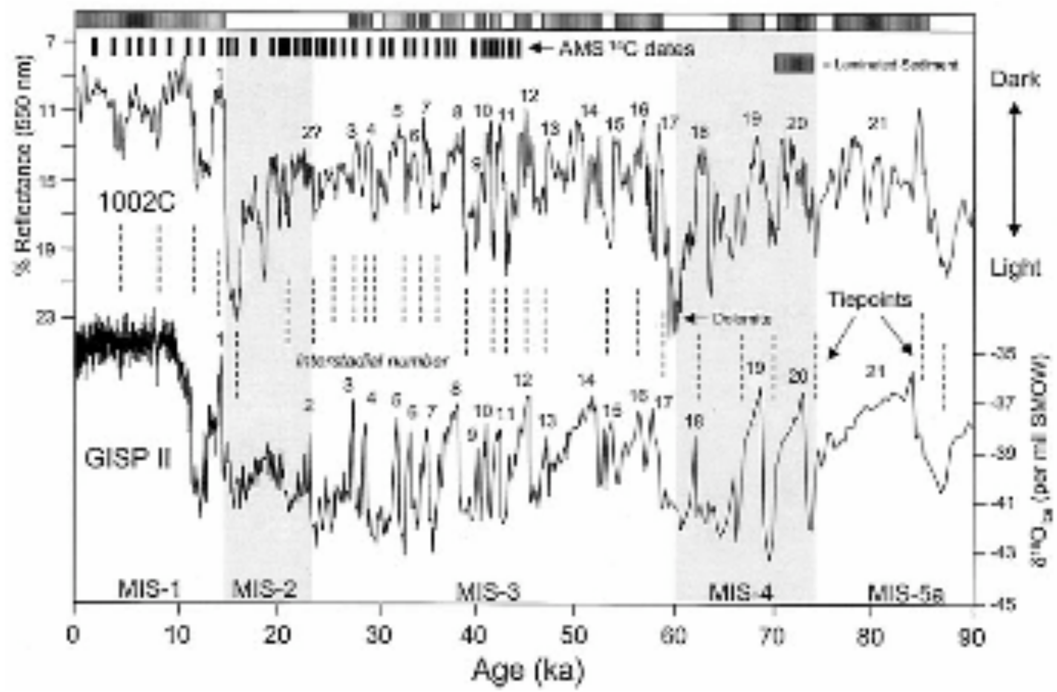
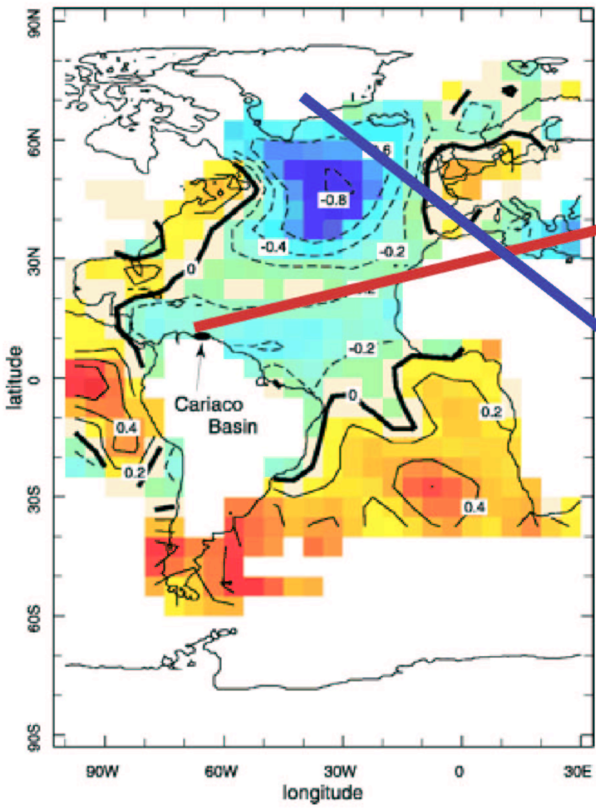
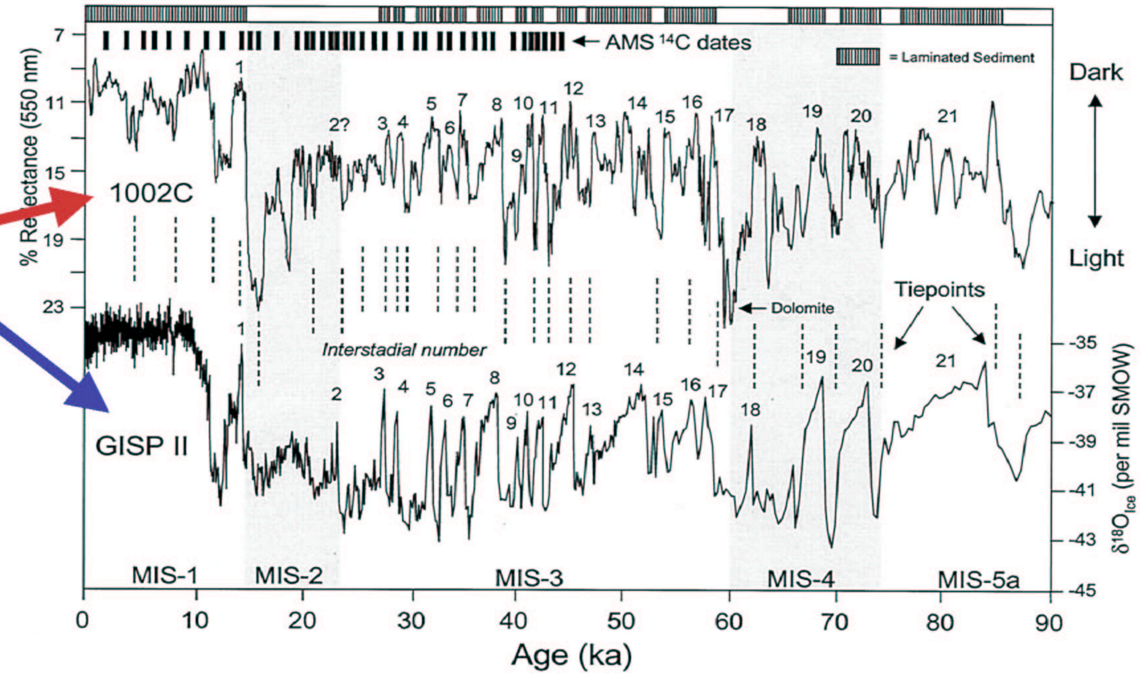



**Fig. 1.** Comparison of measured color reflectance (550 nm) (five-point moving average) of Cariaco Basin sediments from ODP Hole 1002C to $\delta^{18}O$ from the GISP II ice core (9). MIS boundaries in Hole 1002C are from (7), and detailed age control over the upper 22 m is based on AMS $^{14}C$ dating of the planktic foraminifer *G. bulloides* (10). Additional visual tie points between the color reflectance and GISP $\delta^{18}O$ records are shown. The distribution of laminated intervals is indicated across the top. The presence of a semi-indurated dolomite layer in Hole 1002C at 28.3 m below the sea floor resulted in minor core disturbance at this level. Deposition of dark, generally laminated sediments preferentially occurs during warm interglacial or interstadial times (numbered events), whereas deposition of light-colored bioturbated sediments was restricted to colder stadial intervals of the last glacial. Sediment color variations in the Cariaco Basin are driven by changing surface productivity, with increased organic rain leading to darker sediments and, through remineralization reactions, periods of anoxic or near-anoxic conditions in the deep basin. SMOW, standard mean ocean water.



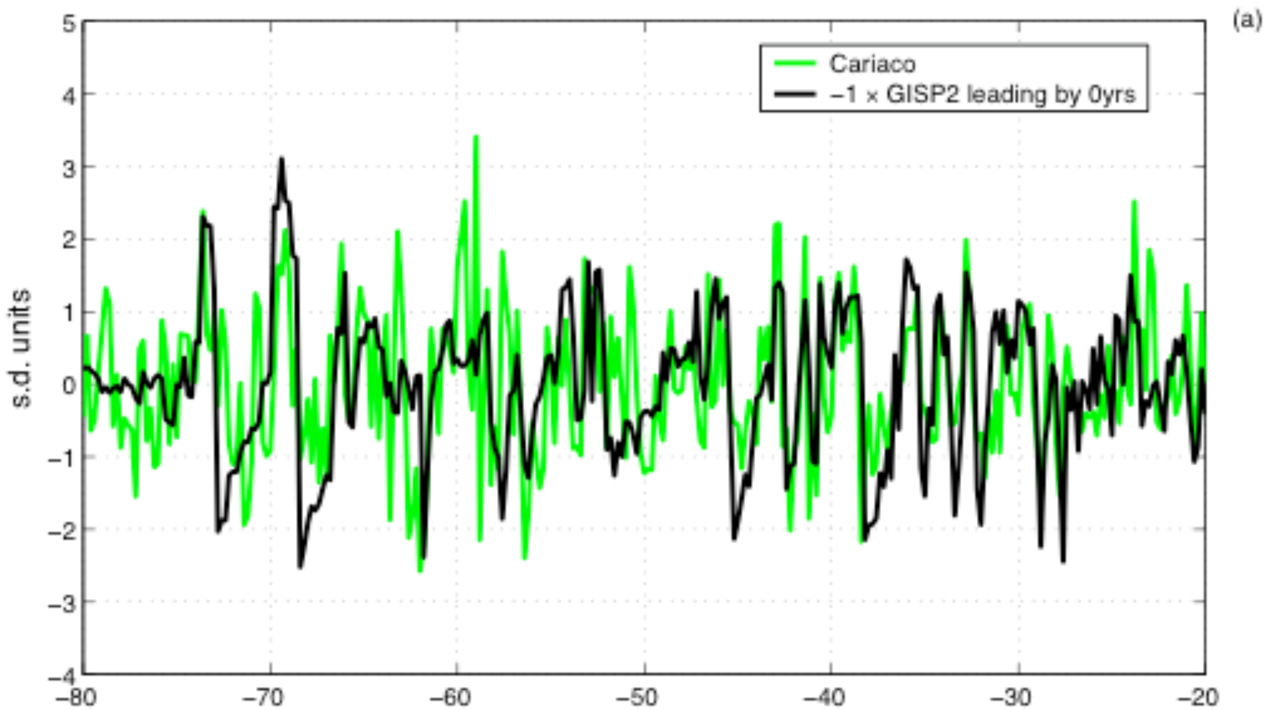




Present -----------------------------------------------> 90Kbp

Black et al. 1999

Peterson et al. 2001

# GISP2 and Cariaco



# Santa Barbara: Bioturbation

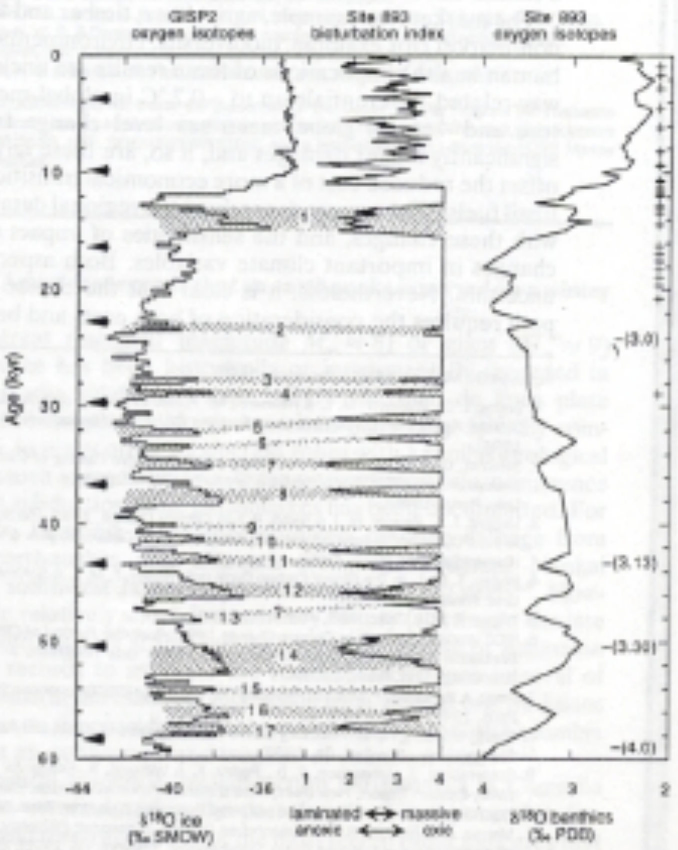
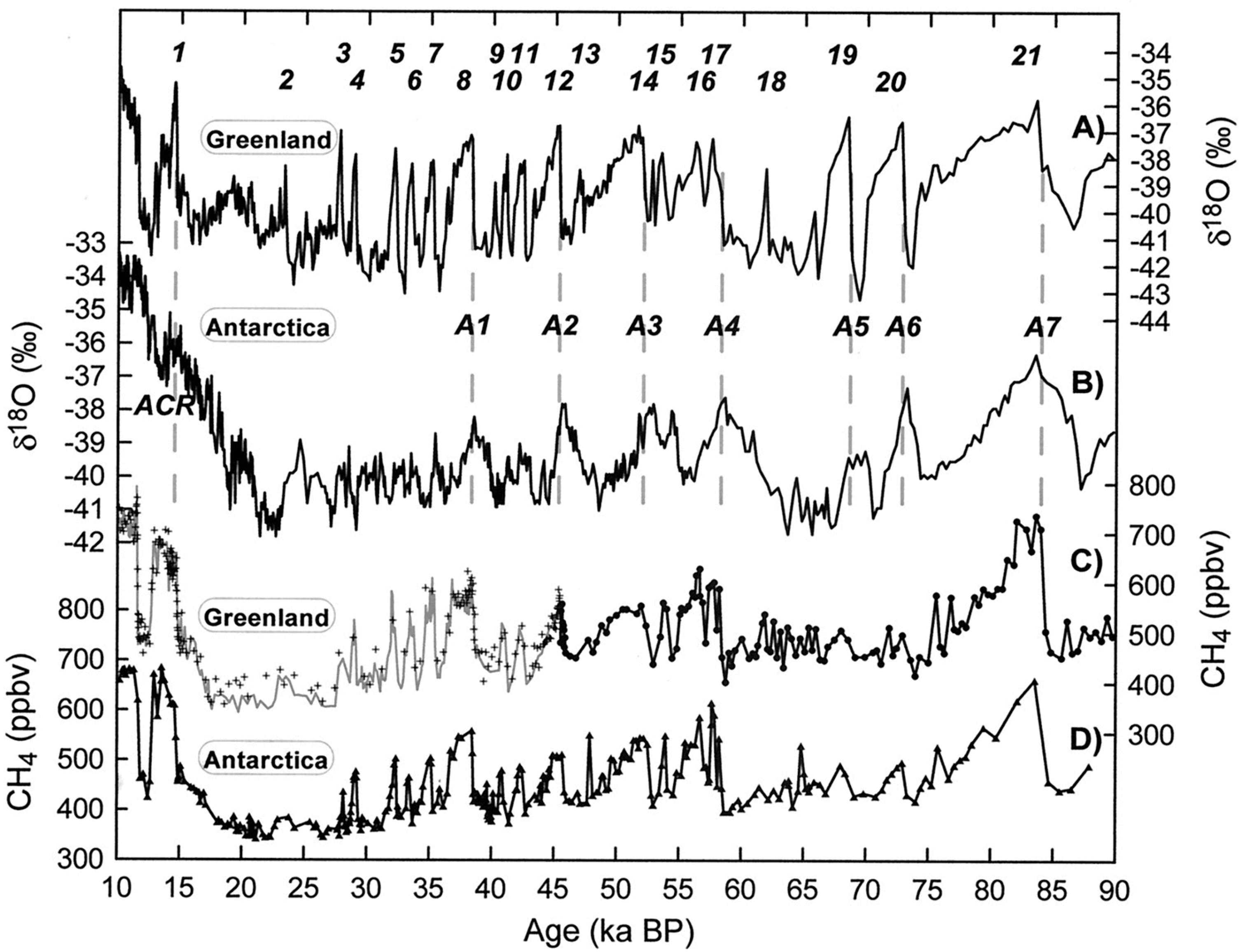
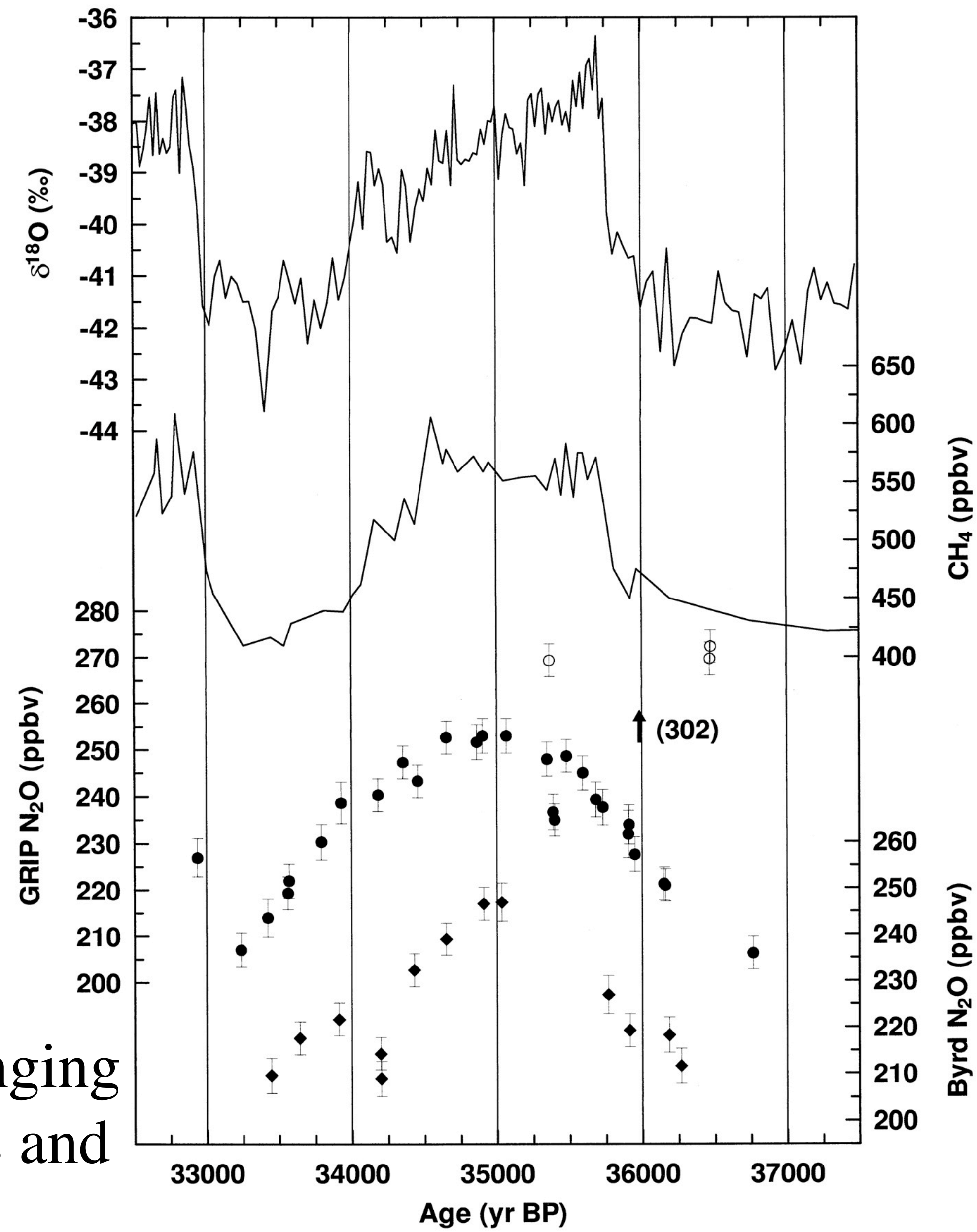



FIG. 2 Comparison of Site 893 bioturbation index and benthic foraminiferal $\delta^{18}O$ records with $\delta^{18}O_{ice}$ time-series from GISP2. Note the excellent correlation of Site 893 anoxia (lamination) events to 16 of 17 of the warm interstadials of GISP2. Bioturbation index is presented as a 49-cm (~300–400 yr) running average to dampen high-frequency variation and to match the resolution of the GISP2 record. Chronologies for GISP2 (ref. 7) and Site 893 were independently derived. Radiocarbon age control points (+) and SPECMAP data used for the Site 893 age model are shown to the right. Numbers in parentheses refer to standard data of the SPECMAP stratigraphy[25,28]. The base of each core interval in Hole 893A is indicated by arrows to the left. Between 500 and 1250 yr may be missing at the two uppermost core breaks[43]. Mean total error in analysis and calendar-year correction of the radiocarbon ages is 195 yr (ref. 27).

# 7. Methane Changes



# N2O changes!




"The main candidates for changing sources of N2O are the oceans and terrestrial soils."

# Key features of D-O vents

1. Abrupt changes in the North Atlantic, occurring quite regularly.
2. Less abrupt and smaller changes elsewhere but with the same (similar) timing.
3. Changes in NADW frequently (always?) occur around the same time.
4. Changes in atmospheric composition (but only small changes in $CO_2$).
5. Around the time of some events were big iceberg discharges and perhaps sea level rises.

# Dansgaard/Oeschger (D/O) events have a footprint throughout (at least) the Tropics and Northern Hemisphere