Earth's Climate: Past, Present and Future

Fall Term - OLLI West: week 2, 9/23/2014

Paul Belanger

Earth's past climate history

1. Earth's deep past before the Cambrian (600 MaBP): hot and cold
2. Earth's past: Cambrian onward: mostly hot-house Earth; 100s parts per million (ppm)
3. Climate trend in the Cenozoic – the last 65 million years; proxy data from 3600ppm to <200 ppm.
4. More recent past: 180-280 part per million; how do we know – empirical data. Preview of next week's field trip
5. Today: 400 ppm and growing 2-3ppm/year

REVIEW OF WEEK 1 ITEM

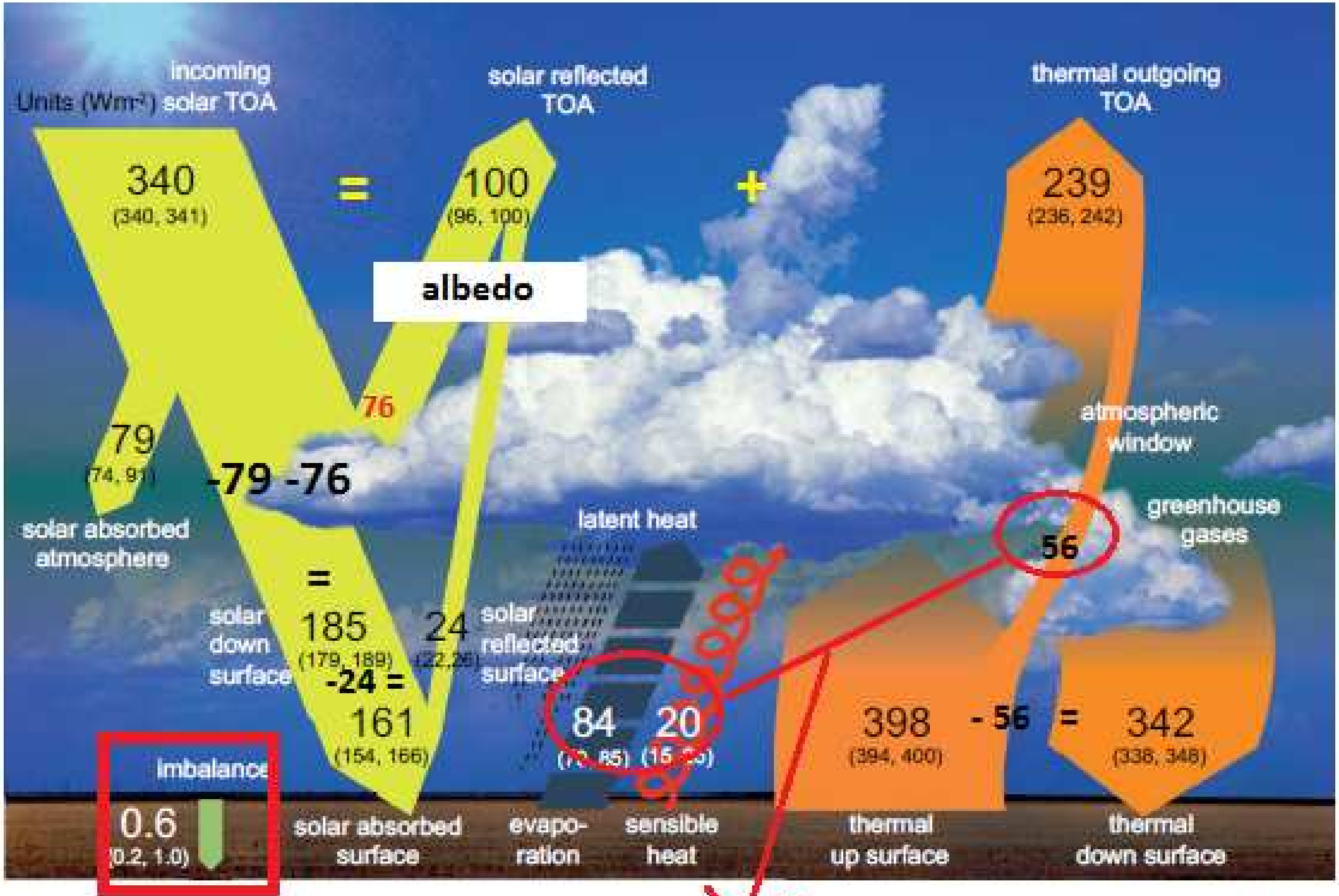


Figure 2.11: | Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m^{-2}, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)

161+342 = 503 - 2 outside
vs. 84+20+398=502 - 3 inside arrows

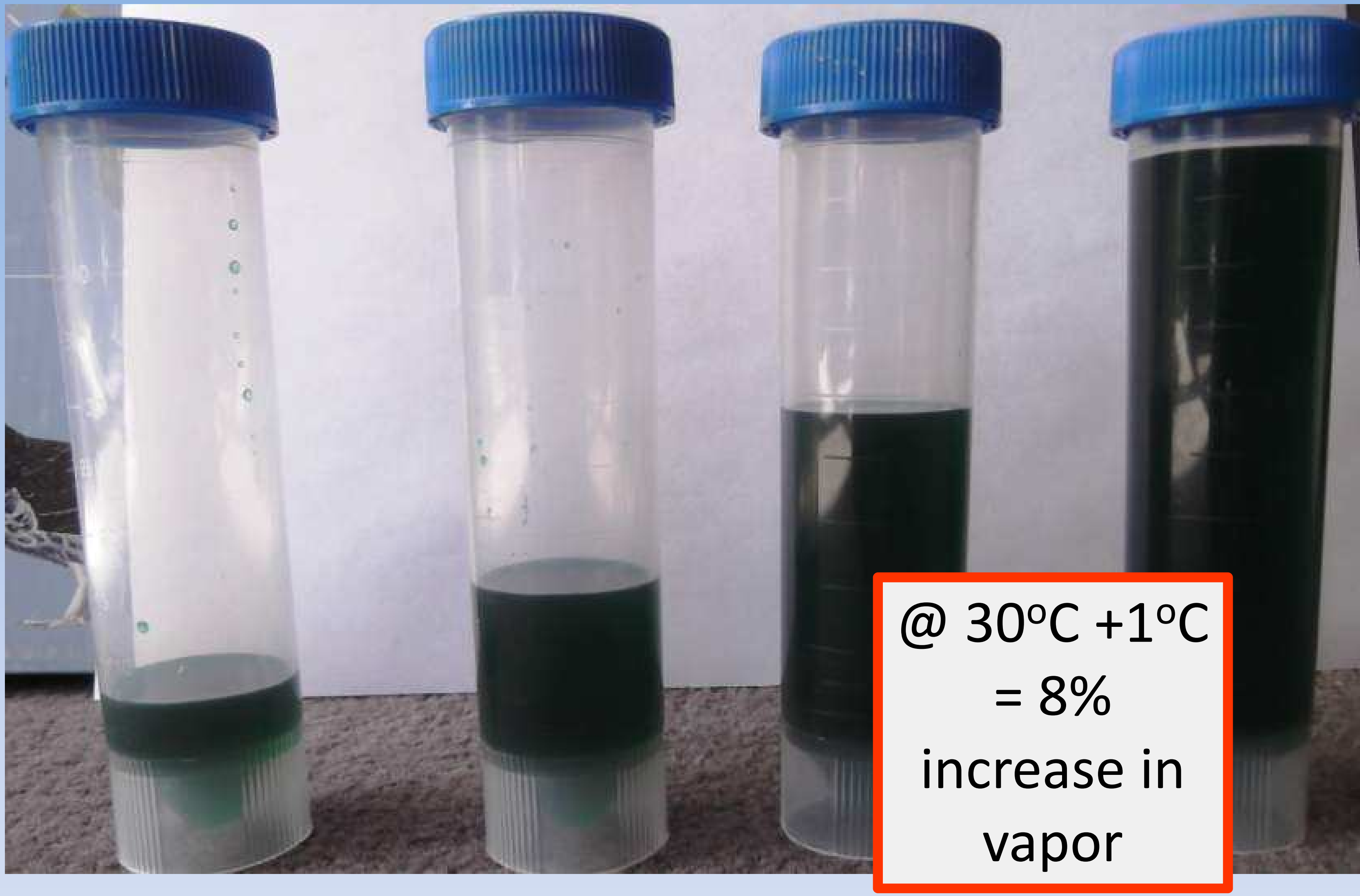
84 +20 +56 = 160
which =~ incoming 161 shortwave

- **Video I showed at end of week 1 class – what is climate:**
  - **You tube link: https://www.youtube.com/watch?v=bjwmrg__ZVw**

- **Video I didn't show – /don't have time – see syllabus:**
  - **The climate system, feedbacks, cycles and self-regulation 1.6**
  - **https://www.futurelearn.com/courses/climate-change-challenges-and-solutions/steps/3294/progress (7 mins)**
  - **an alternate: https://www.youtube.com/watch?v=lrPS2HiYVp8**
  - **What factors determine Earth's climate:**
  - See IPCC-AR5 (2013-2014) tab on my web page:
  - And this link from AR4 (2007) http://denverclimatestudygroup.com/?page_id=63
  - **http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-1.html**

climate system - the inter-relationship and feedback of:

- **Atmosphere**
- **Hydrosphere**
- **Biosphere**
- **Cryosphere**
- **Lithosphere (weathering reduces CO2; volcanism increases it)**



10ºC = (50ºF) 7.8 cc	20ºC = (68ºF) 15 cc	30ºC = (86ºF) 27.7 cc	40ºC = (104ºF) 49.8 cc

The Earth and its atmosphere

The most potent greenhouse gas is H_2O - vapor

The CO_2 greenhouse gas effect is concentrated in the polar regions ! ! !

The large H_2O greenhouse effect is controlled by temperature – H_2O saturation doubles with every 10°C increase

CO_2 is evenly distributed throughout the atmosphere

As a result It is concentrated in the lower atmosphere of the tropics

Particularly in the Arctic !

WEEK 2

Earth's past climate

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Earth's past climate

Earth's deep past and early atmosphere before the Cambrian (600 MaBP): hot and cold

- Earth self regulates 2.1 -2.3 Tim Lenton video – 9 minute overview
- Article Link: BBC Nature http://www.bbc.co.uk/nature/ancient_earth/Snowball_Earth
- You Tube – leaving for you to watch on your own: https://www.youtube.com/results?search_query=snow+ball+earth – various links

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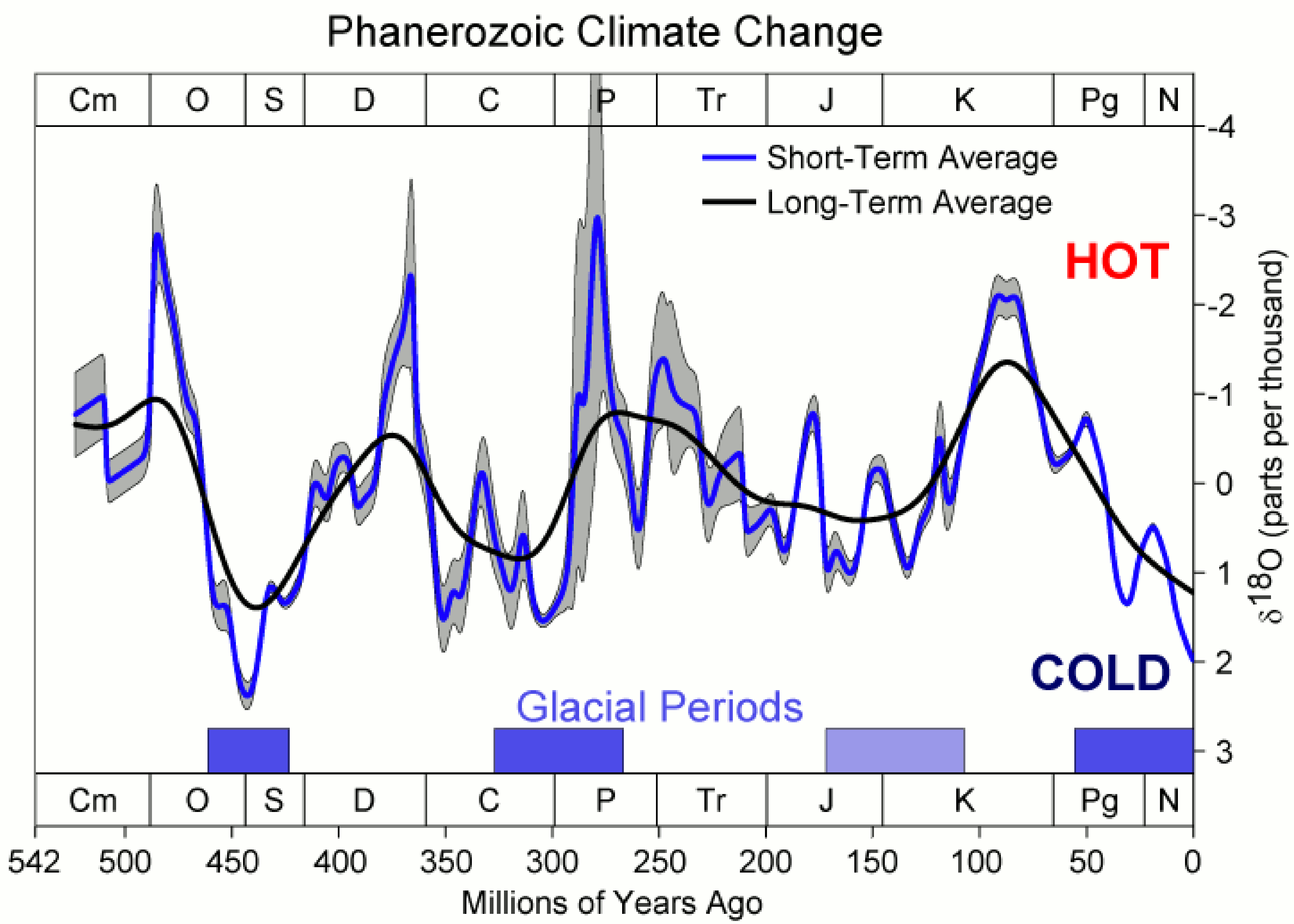
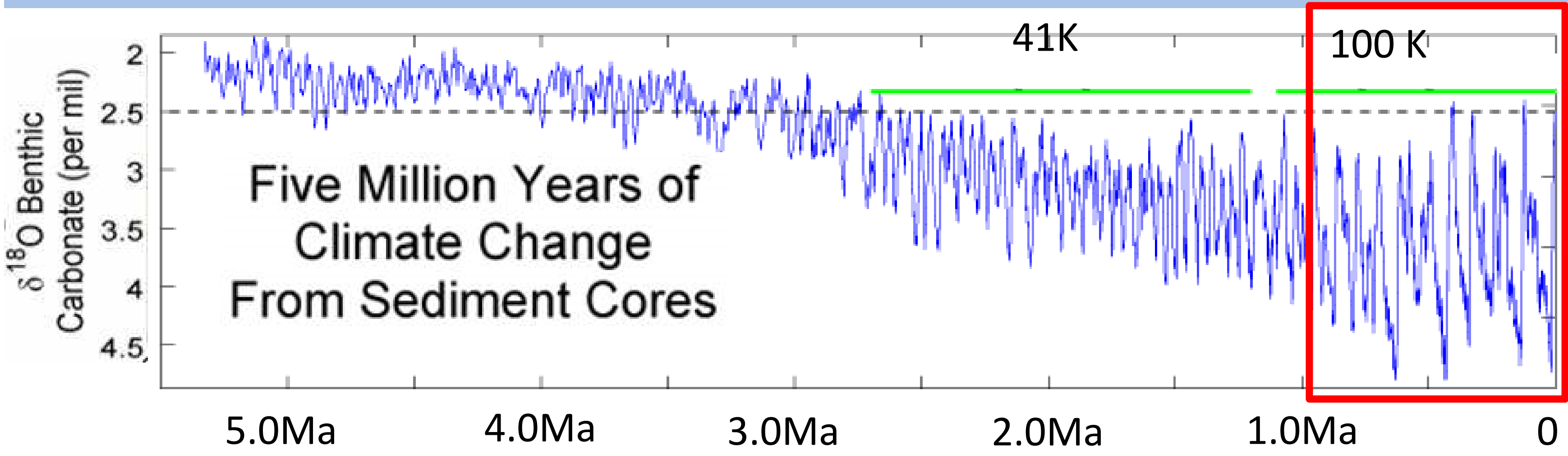


Phanerozoic Climate Change
Cm
O
S
D
C
P
Tr
J
K
Pg
N
Short-Term Average
Long-Term Average
HOT
COLD
Glacial Periods
δ18O (parts per thousand)
-4
-3
-2
-1
0
1
2
3
542
500
450
400
350
300
250
200
150
100
50
0
Millions of Years Ago

Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



When CO_2 levels get below ~400-600 ppm Orbital parameters become more important than CO_2

Earth’s past climate

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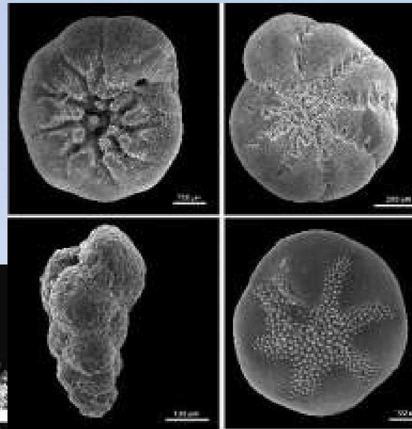
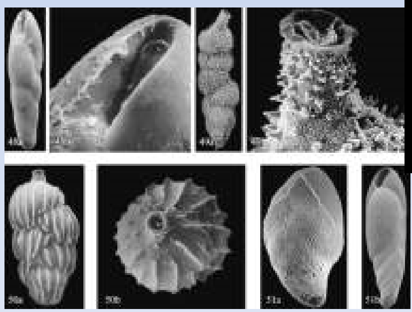
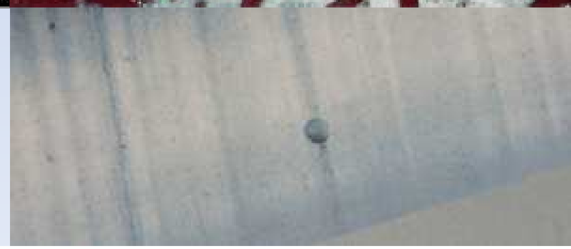
Scientific History of Climate change – PROXY DATA

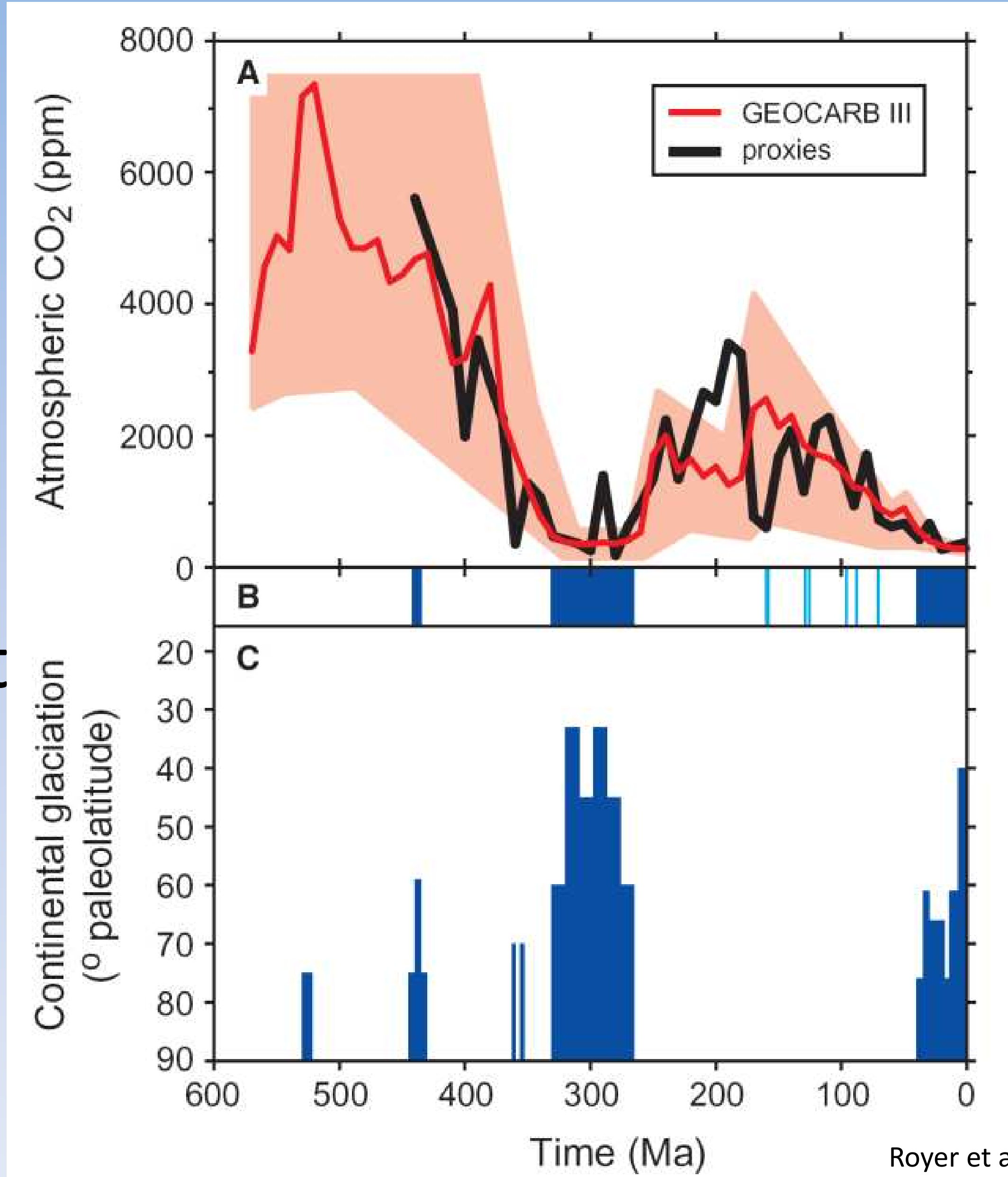






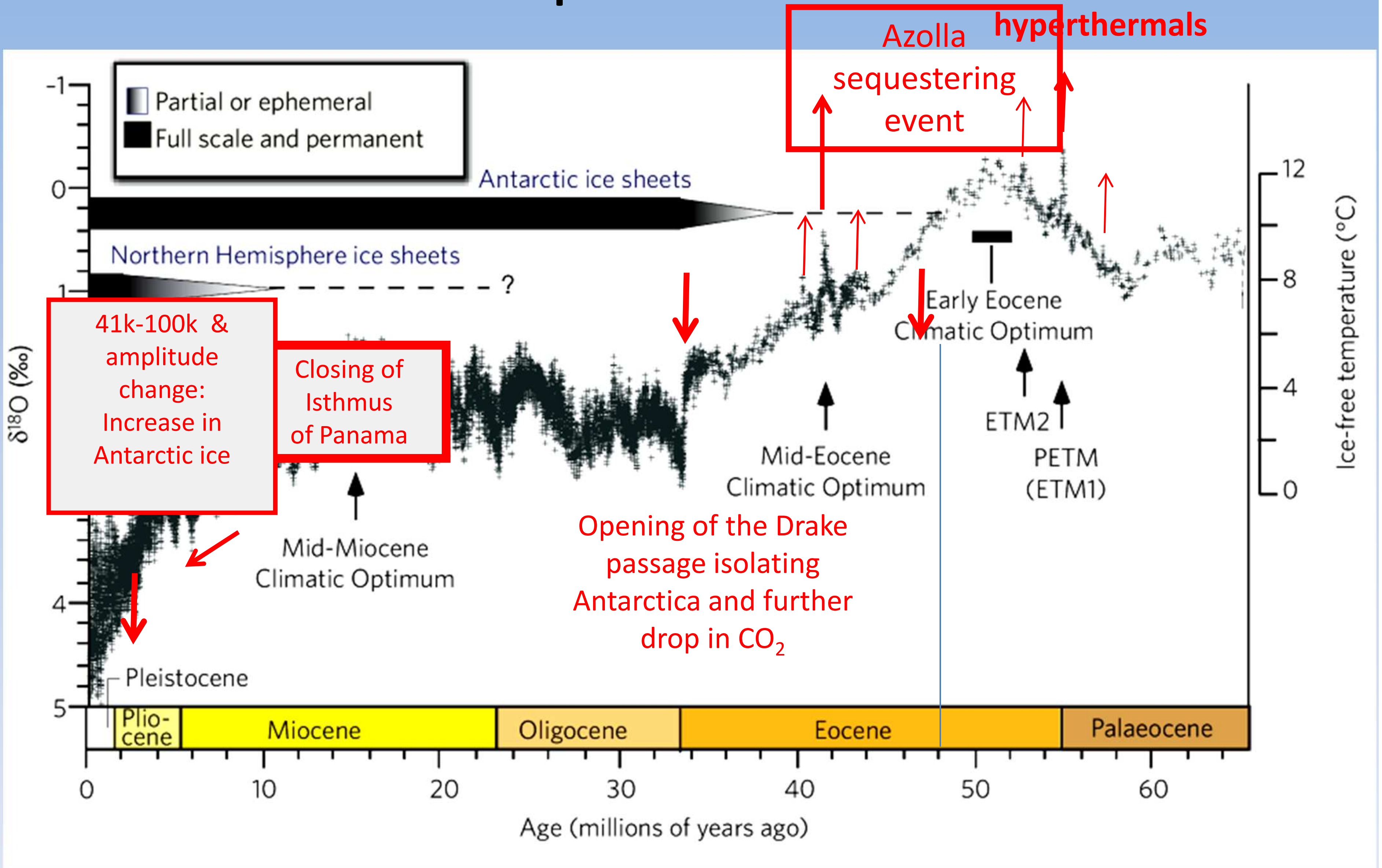
Alternating Greenhouse Earth / Ice-house Earth

Geologic cycles:
Climate through the Phanerozoic:
Carbon is the culprit



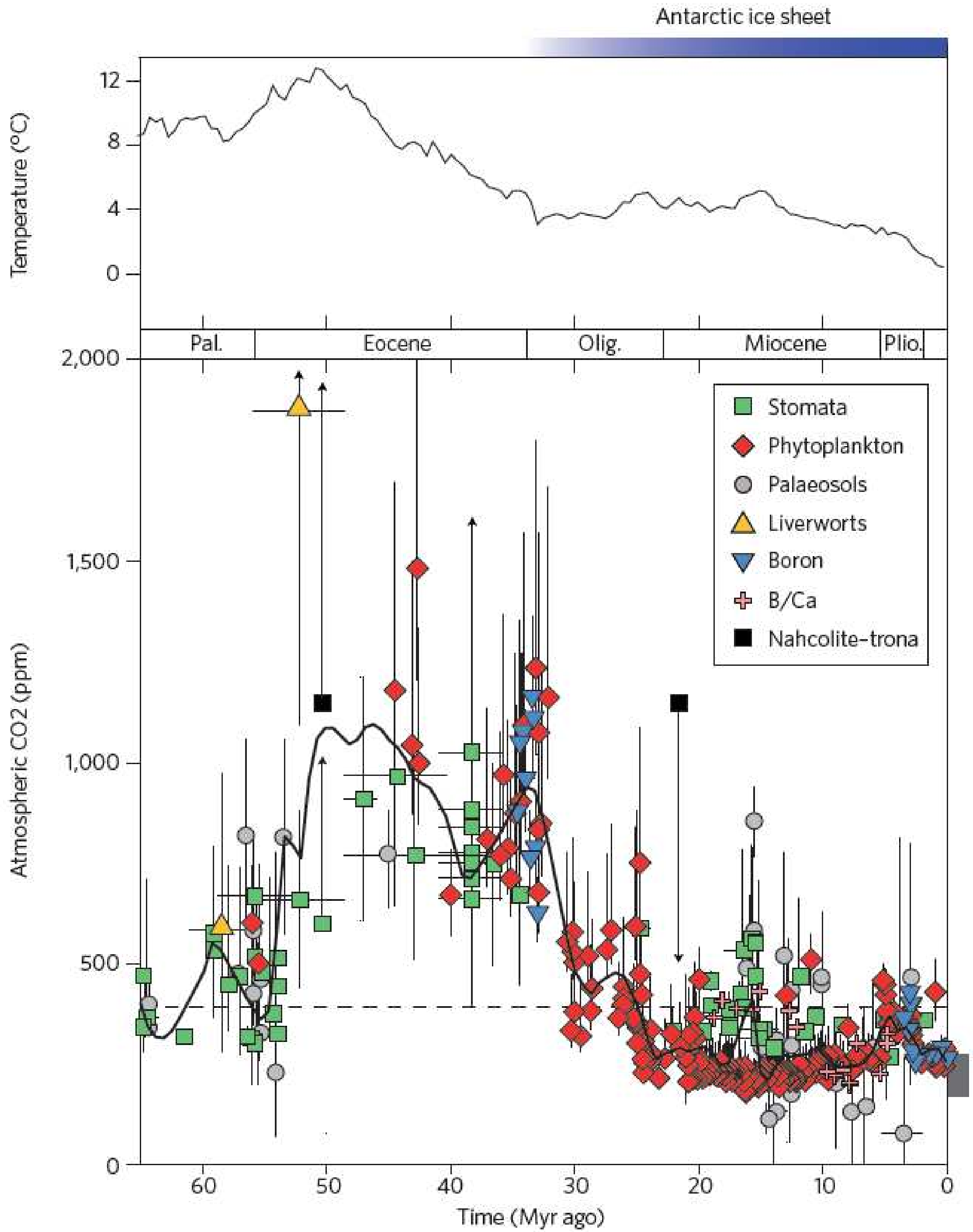
Royer et al., 2003

Cenozoic Deep Sea Climate Record



Zachos et al. 2008

Correlation of CO_2 and temperature over last 65 million years



Beerling and Royer, Nature 2011

Long-term Carbon Cycle: rocks

Two generalized reactions…

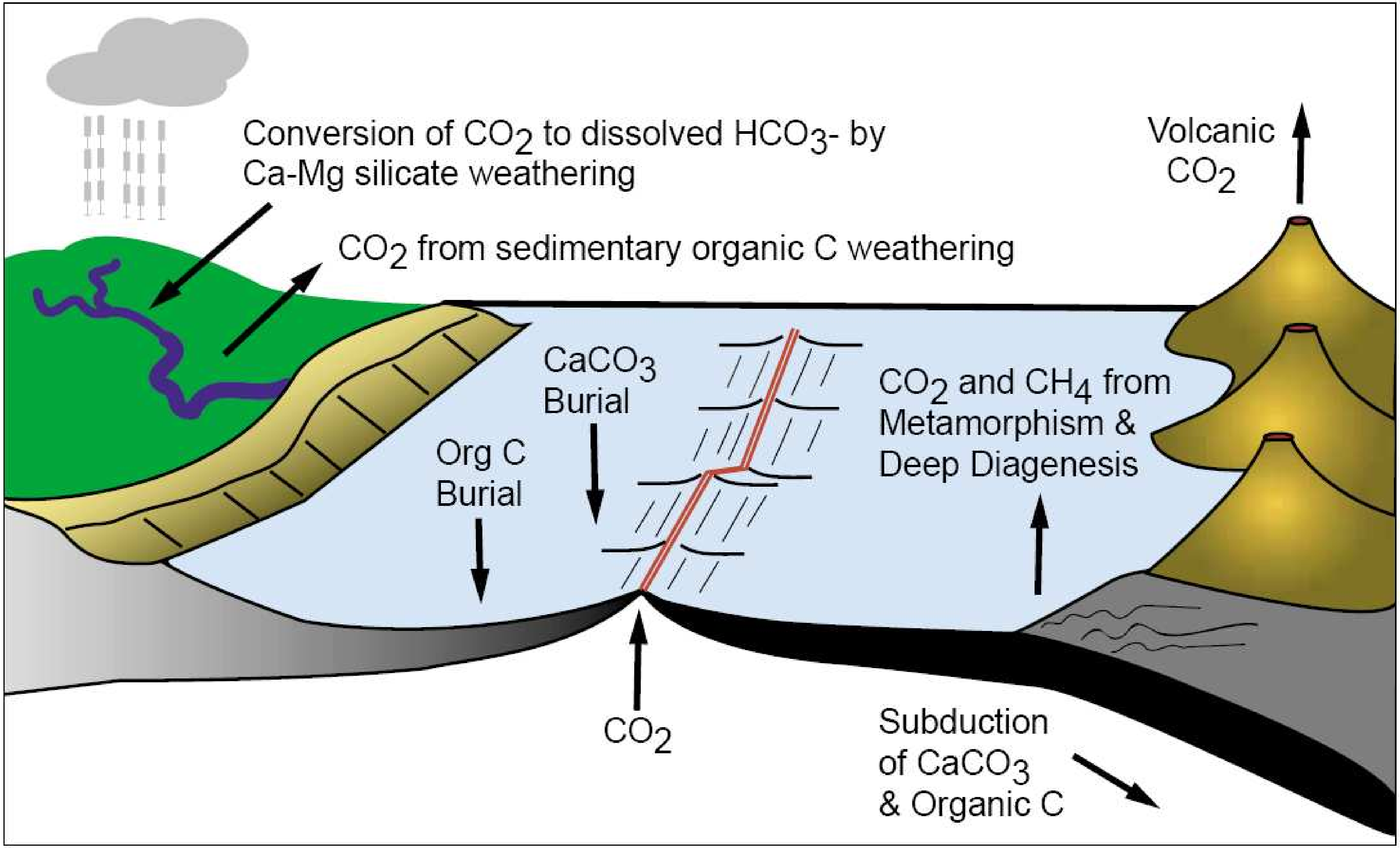
Photosynthesis/Respiration

$CO_2 + H_20 \leftrightarrow CH_2O + O_2$

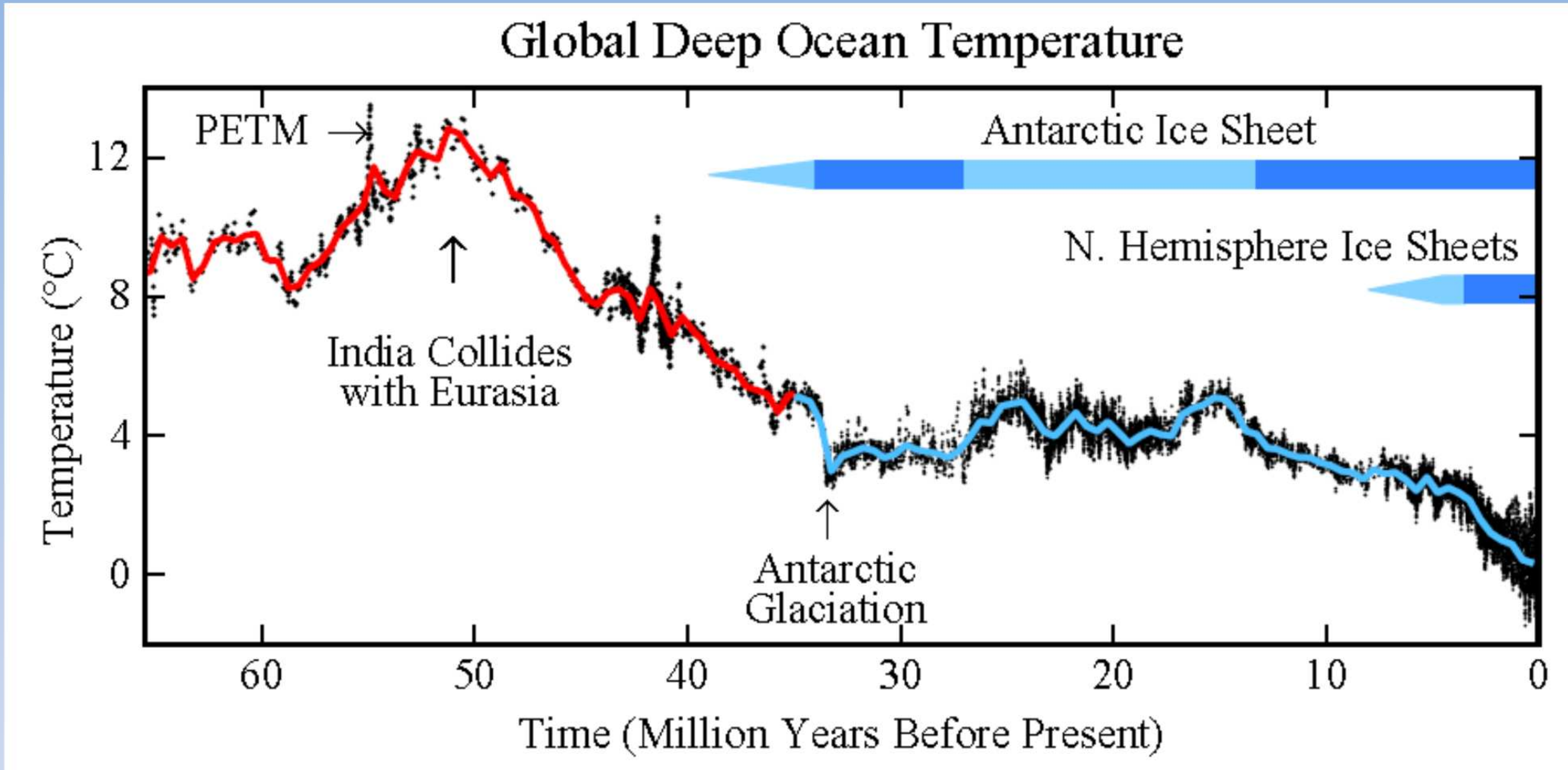
Weathering/Precipitation

$CO_2 + CaSiO_3 \leftrightarrow CaCO_3 + SiO_2$

Long-term carbon cycle: *rocks*



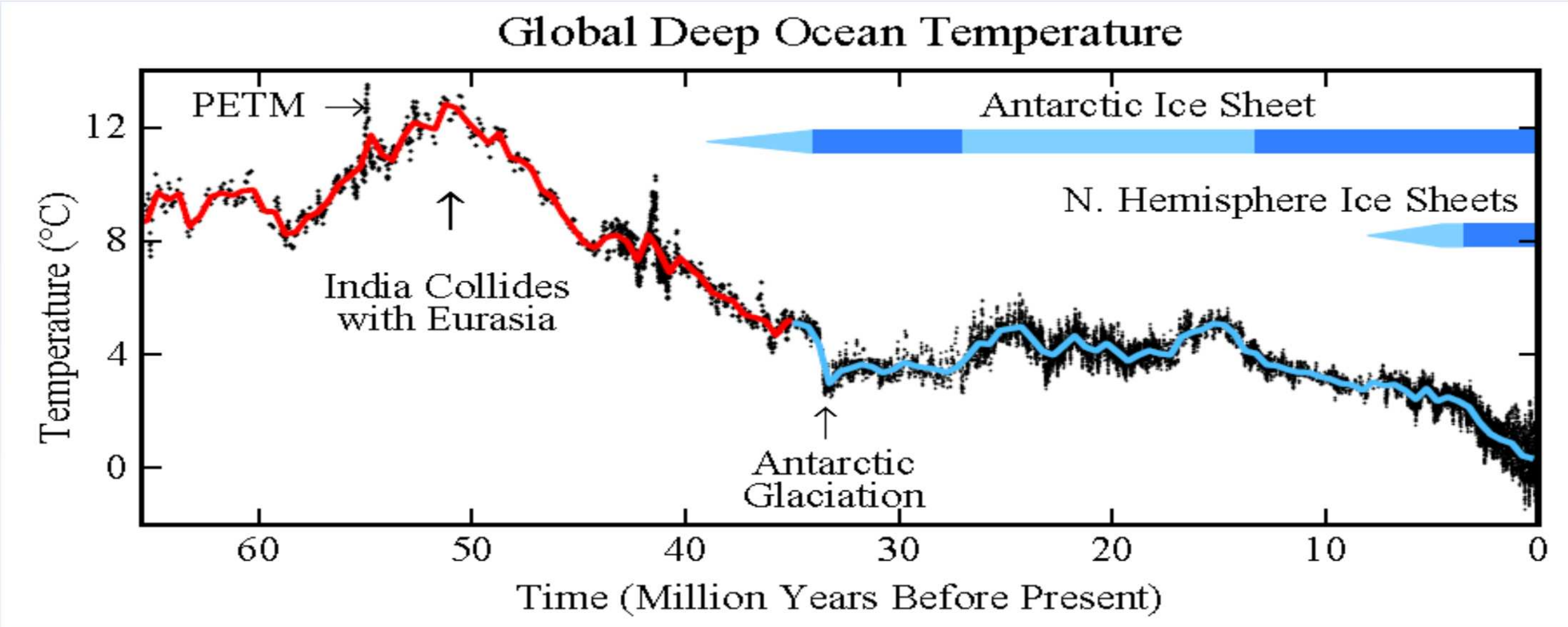
Berner, 2001

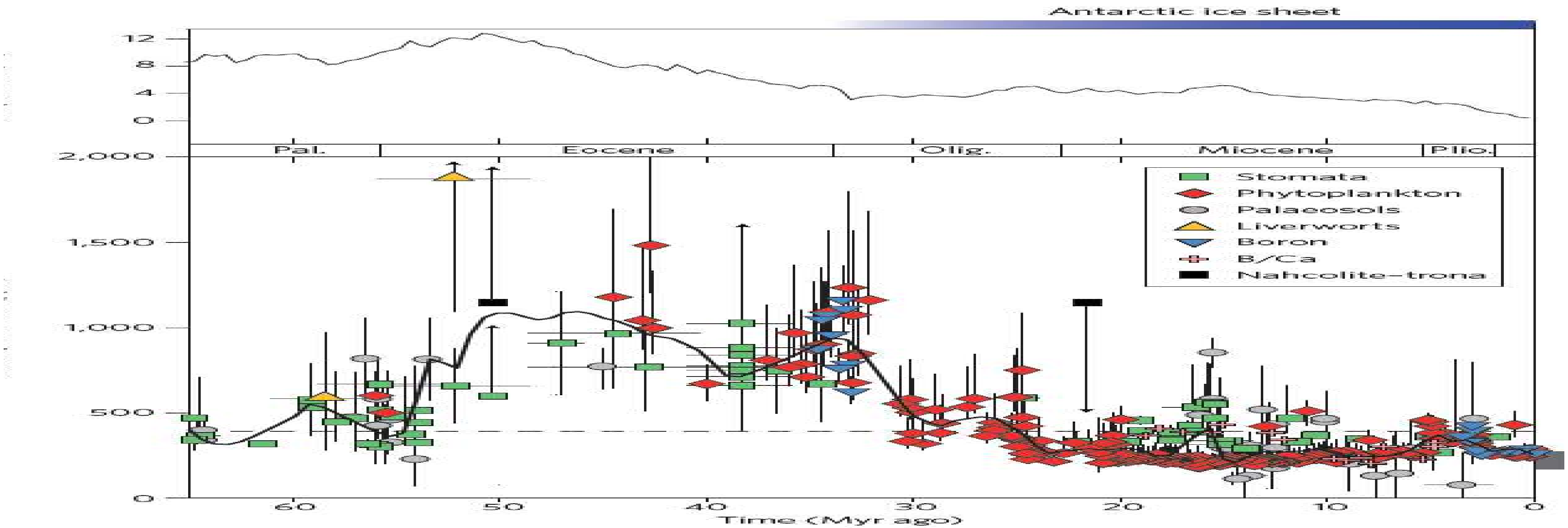


50 million years ago (50 MYA) Earth was ice-free.

Atmospheric CO_2 amount was of the order of 1000 ppm 50 MYA.

Atmospheric CO_2 imbalance due to plate tectonics ~ 10^{-4} ppm per year.


Global Deep Ocean Temperature
PETM
India Collides with Eurasia
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
Antarctic Glaciation
Temperature (°C)
12
8
4
0
60
50
40
30
20
10
0
Time (Million Years Before Present)


Antarctic ice sheet
12
8
4
0
Pal.
Eocene
Olig.
Miocene
Plio.
2,000
1,500
1,000
500
0
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
60
50
40
30
20
10
0
Time (Myr ago)

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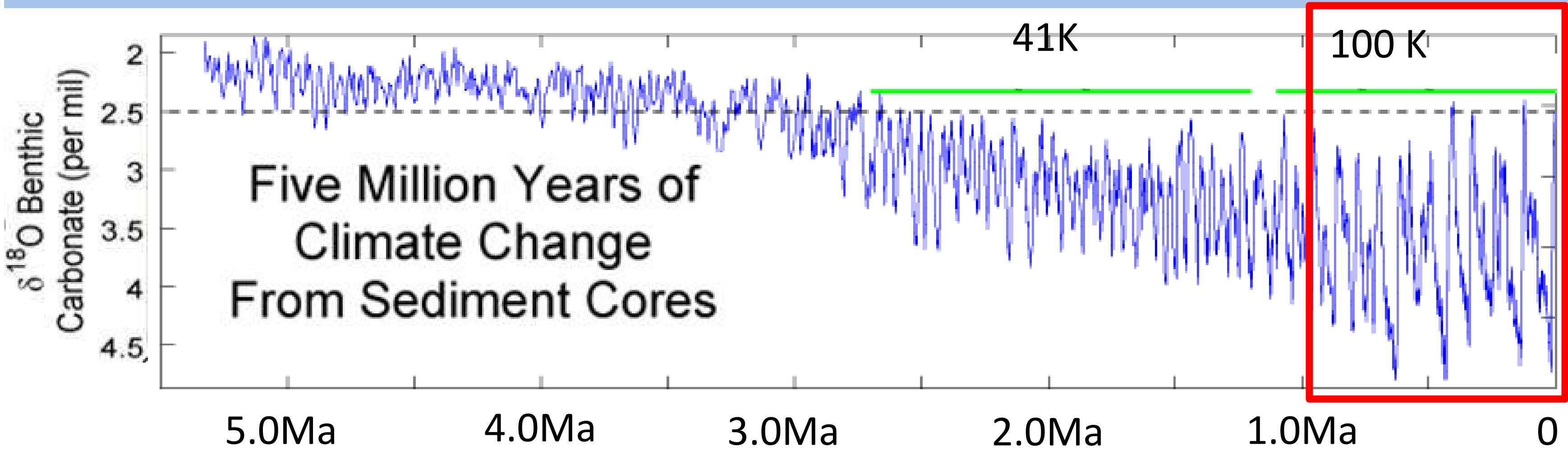
Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



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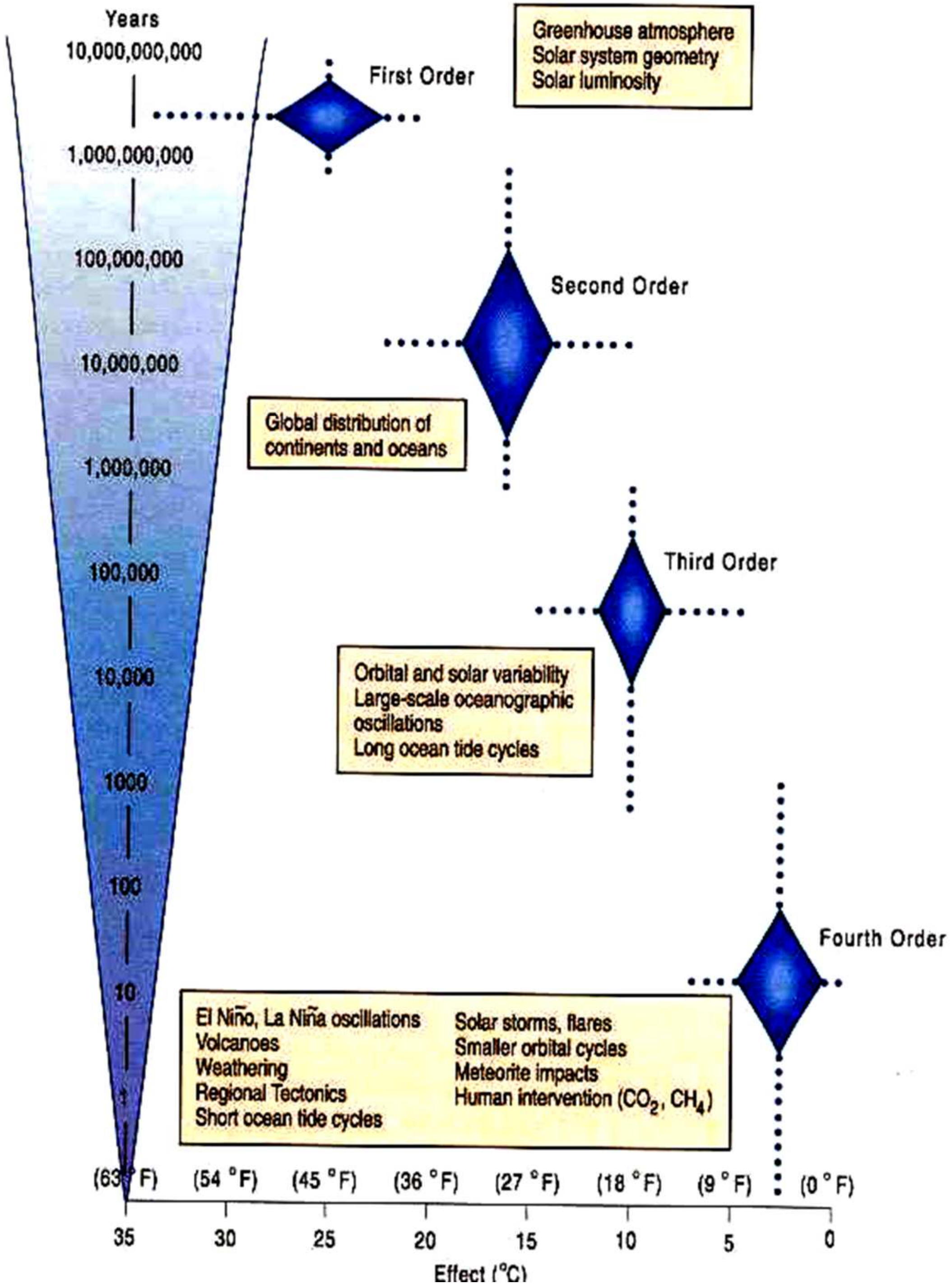
- SO –

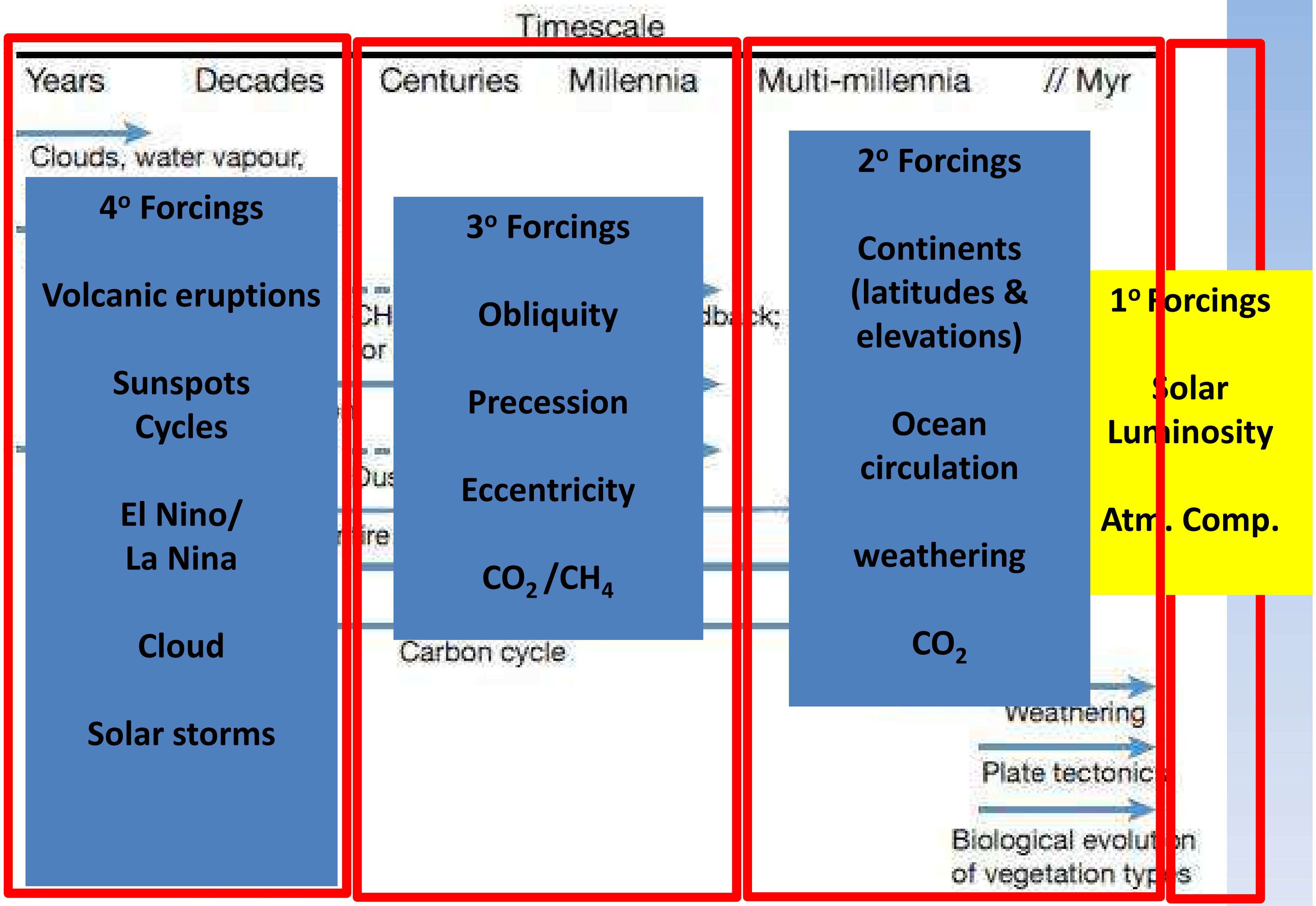
WHAT CONTROLS

CLIMATE



Gerhard et al., 2001

FEEDBACKS

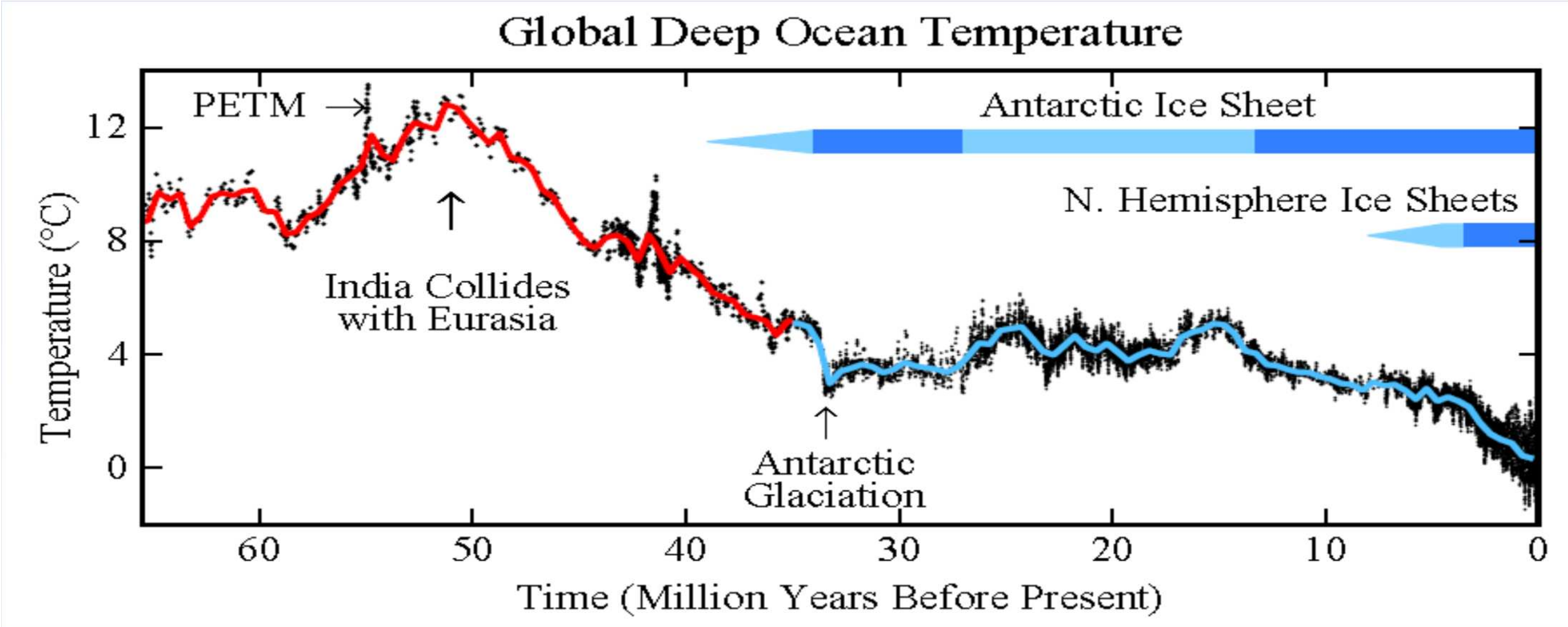


Rohling, et al., (PALAESENS Project mbrs), 2012

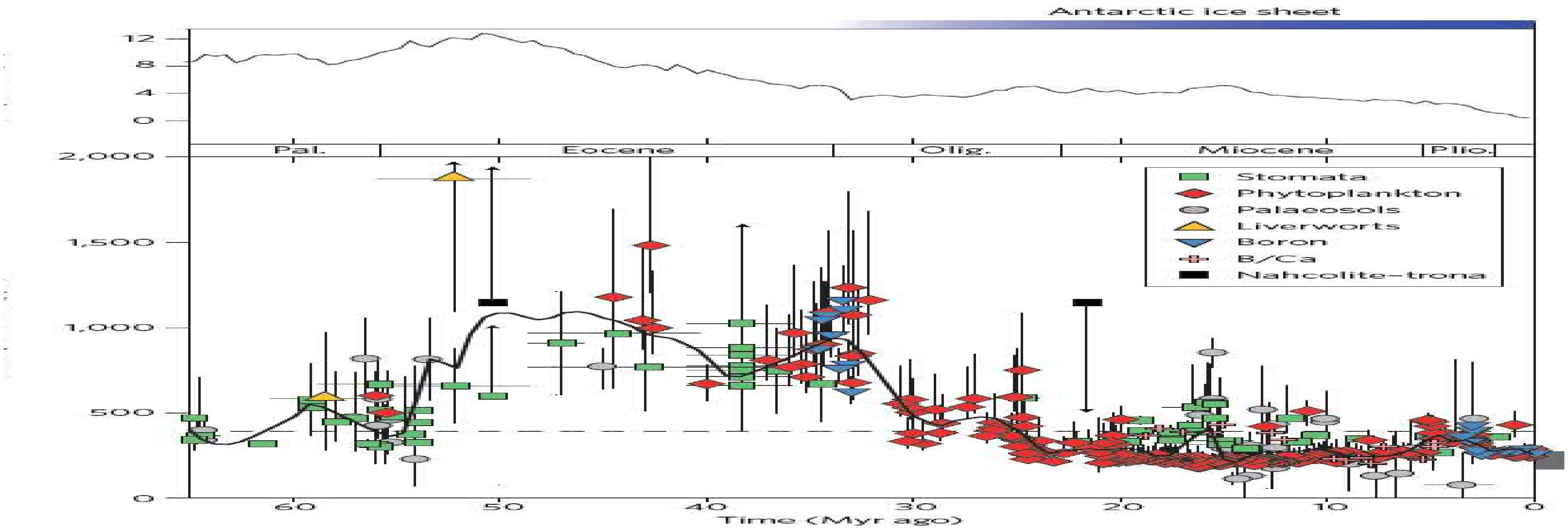
End of week 2

EXTRAS FOLLOW

Paleocene/Eocene Thermal Maximum
PETM

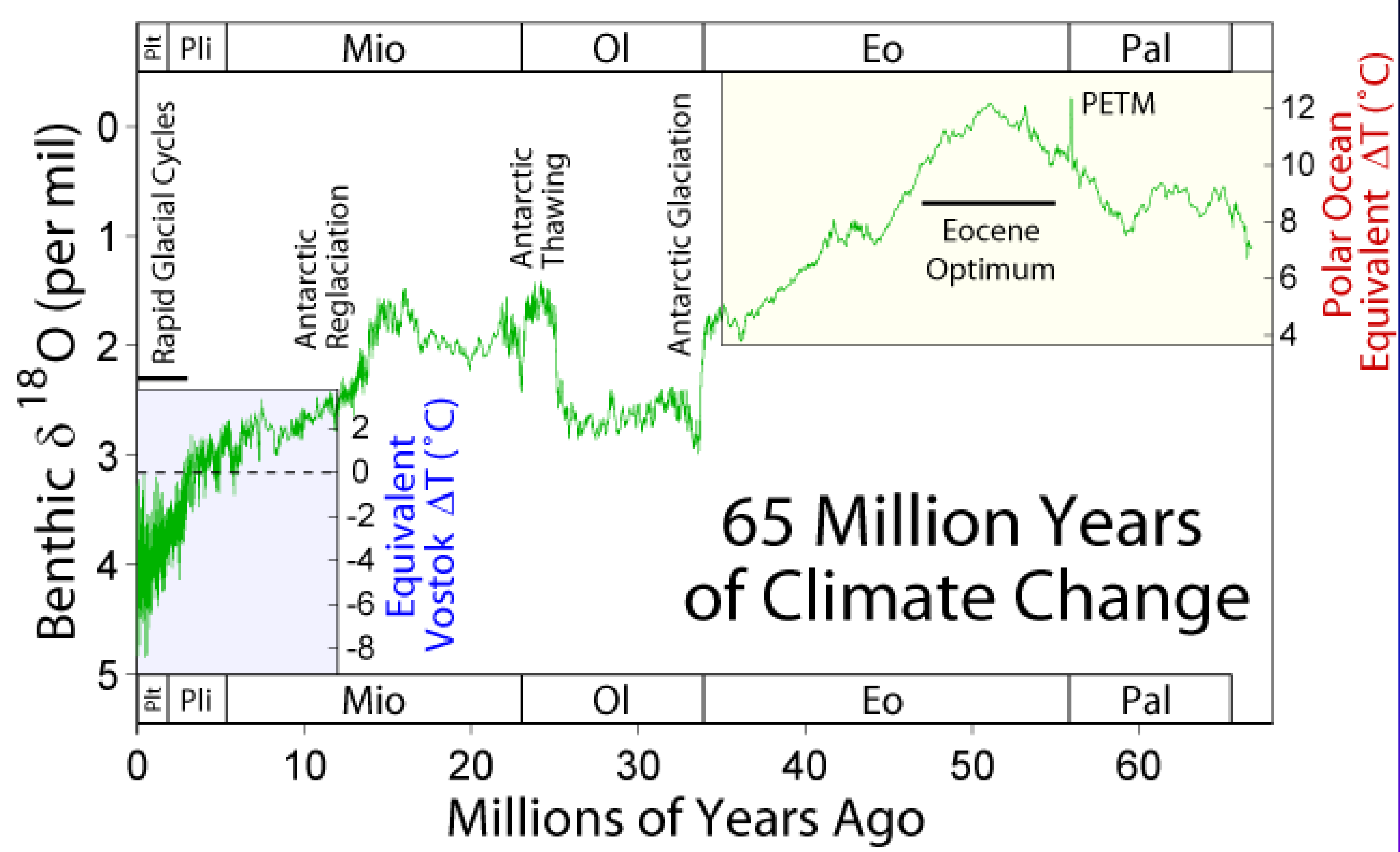


Global Deep Ocean Temperature
PETM
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
India Collides with Eurasia
Antarctic Glaciation
Temperature (°C)
Time (Million Years Before Present)



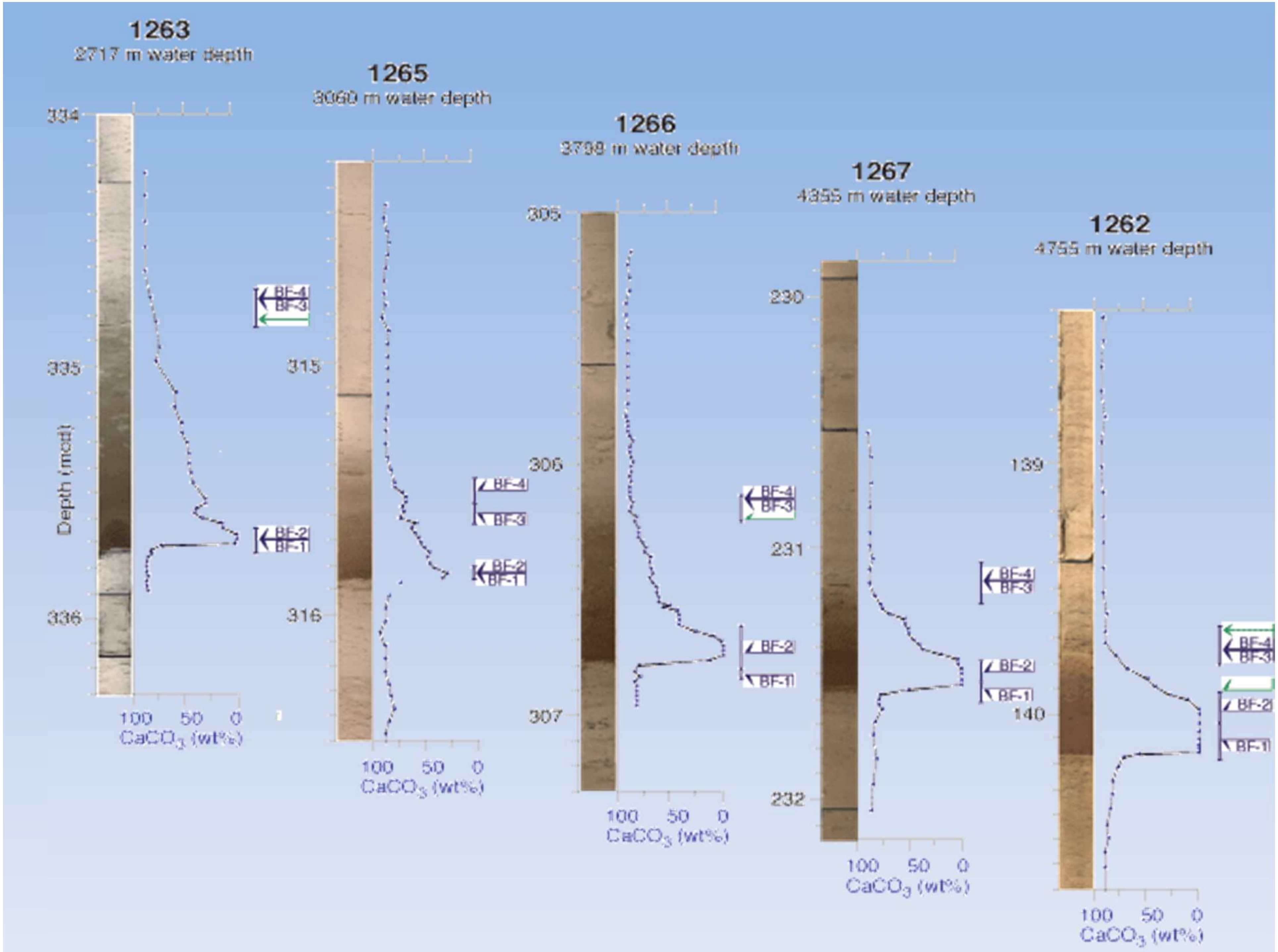
Antarctic ice sheet
Pal.
Eocene
Olig.
Miocene
Plio.
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
Time (Myr ago)

Proxy data: stable isotopes



Wikipedia


PMAG
56 55 52 51 50 49 48 47 46 45


1263
2717 m water depth
1265
3060 m water depth
1266
3798 m water depth
1267
4355 m water depth
1262
4755 m water depth
Depth (mcd)
334
335
336
315
316
305
306
307
230
231
232
139
140
BF-4
BF-3
BF-2
BF-1
100 50 0
CaCO3 (wt%)

PETM - THE LAND RECORD

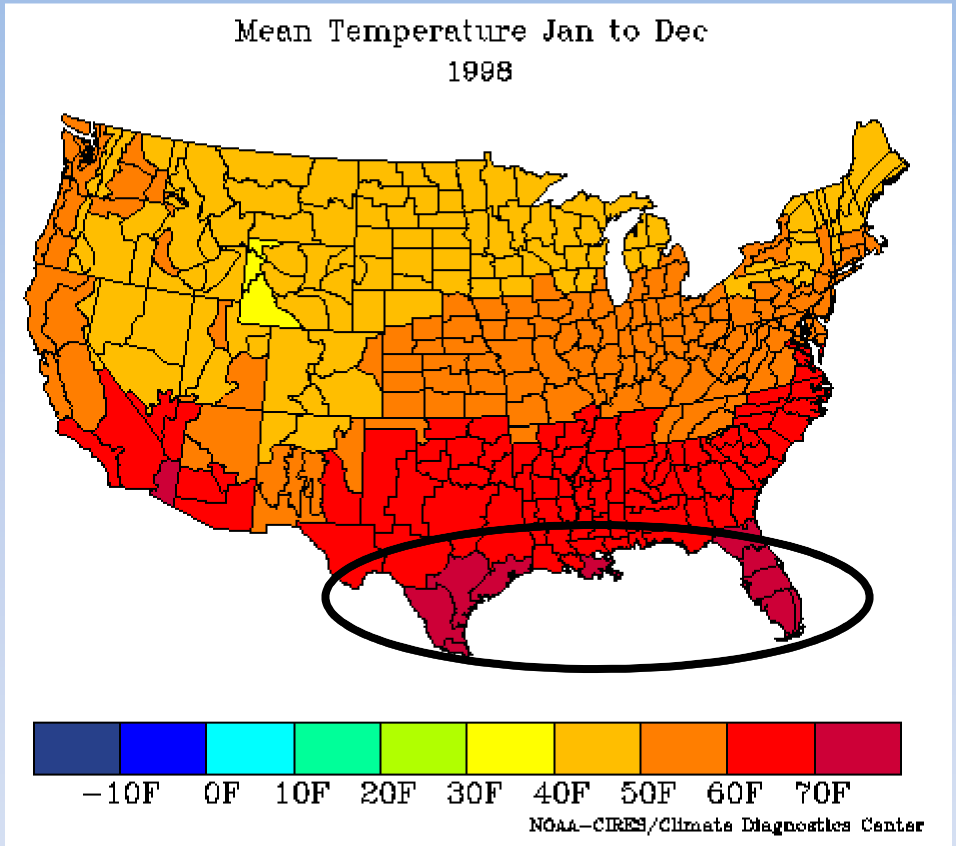
Bighorn Basin

- PETM interval in fluvial deposits with excellent alluvial paleosols - seen as color bands, which are soil horizons
- Found in Willwood Fm
- Reds, purples due to iron oxides in B horizons

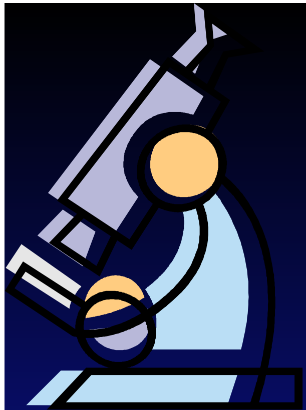
Paleosol Density

Bighorn Basin Climate

- Plant fossils and isotopes show Mean Annual Temperature of 20º to 25º C or 68 to 77º F
- Similar to Gulf Coast region today



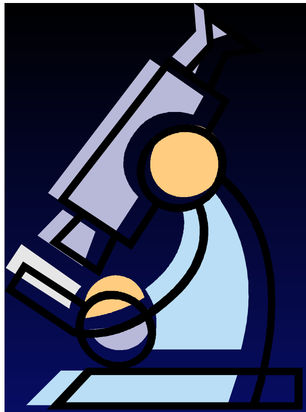
PROXY DATA-EXTRAS

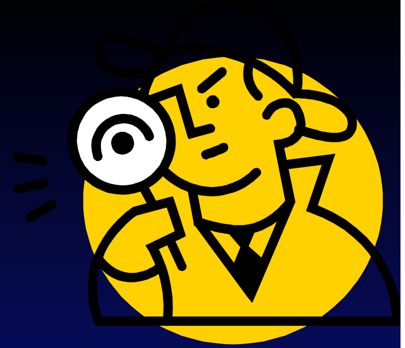


FROM CSI TO GSI: GEOLOGICAL SAMPLE INVESTIGATION

LET THE EVIDENCE SPEAK

FOR ITSELF





WE CALL THIS EVIDENCE

“PROXY” DATA

SOME OF THE EARLIEST PROXY DATA WAS FROM TERRESTRIAL DEPOSITS

- Strandlines/shorelines
- Moraines
- Till
- Kettle lakes, etc.

We may know what caused these today, but imagine back then?

IT'S THE INTERPRETATION THAT'S NOT ALWAYS CORRECT

Darwin observed ancient Alpine shorelines:
interpreted as ocean shoreline

Agassiz – later correctly interpreted as ice-dammed lake-shore strandlines/shoreline

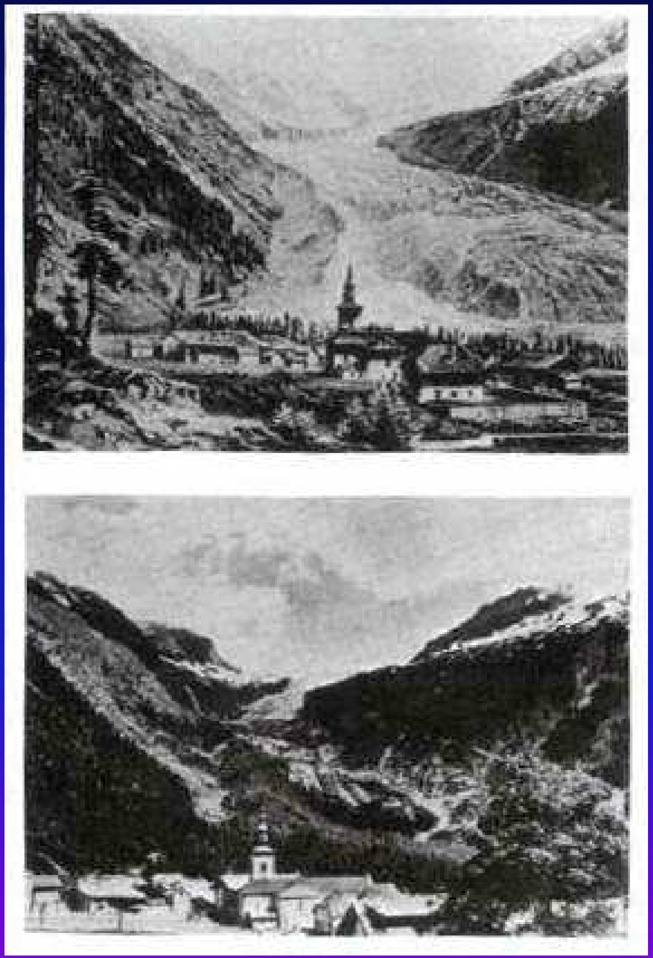
Louis Agassiz

Louis Agassiz

Born	May 28, 1807 Haut-Vully, Switzerland
Died	December 14, 1873 (aged 66) Cambridge, Massachusetts
Fields	Paleontology, Glaciology, Geology, Natural History
Alma mater	University of Erlangen-Nuremberg

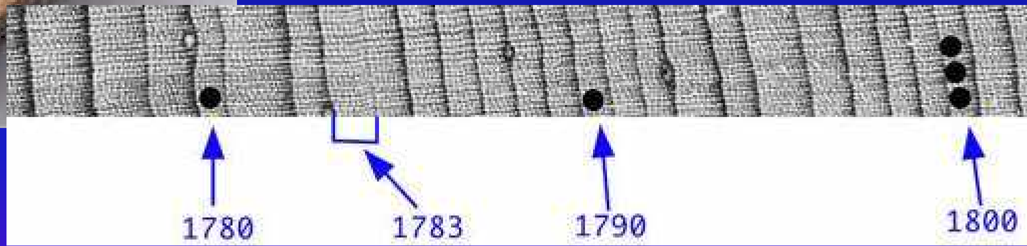
- **Jean Louis R. Agassiz**
- **“Father” of Glaciology**
- 1807-1873
- Paleontologist
- Glaciologist

Photographic proxy data/evidence

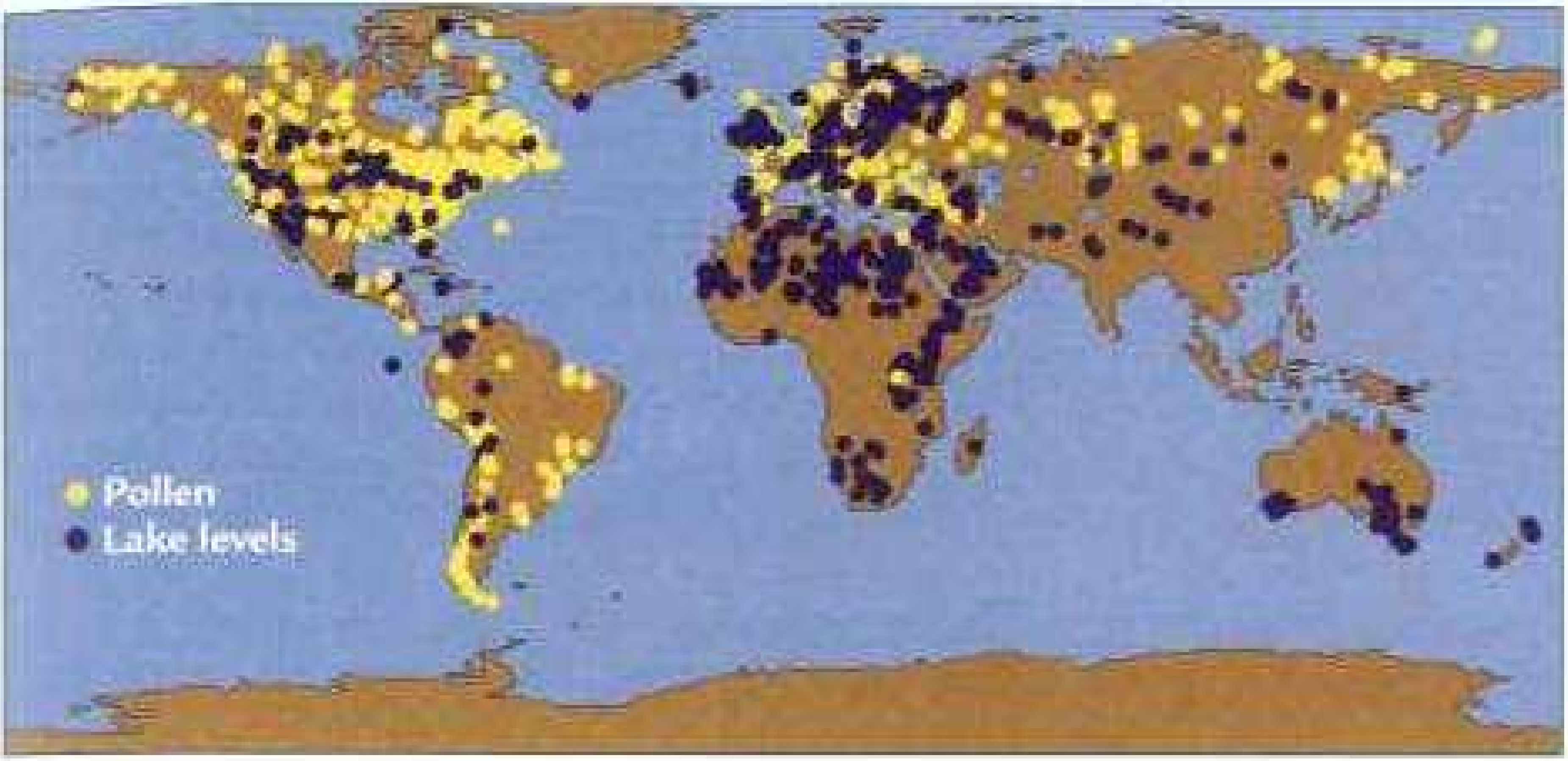


Ruddiman, 2008

EARLY PROXY DATA: TREE RINGS

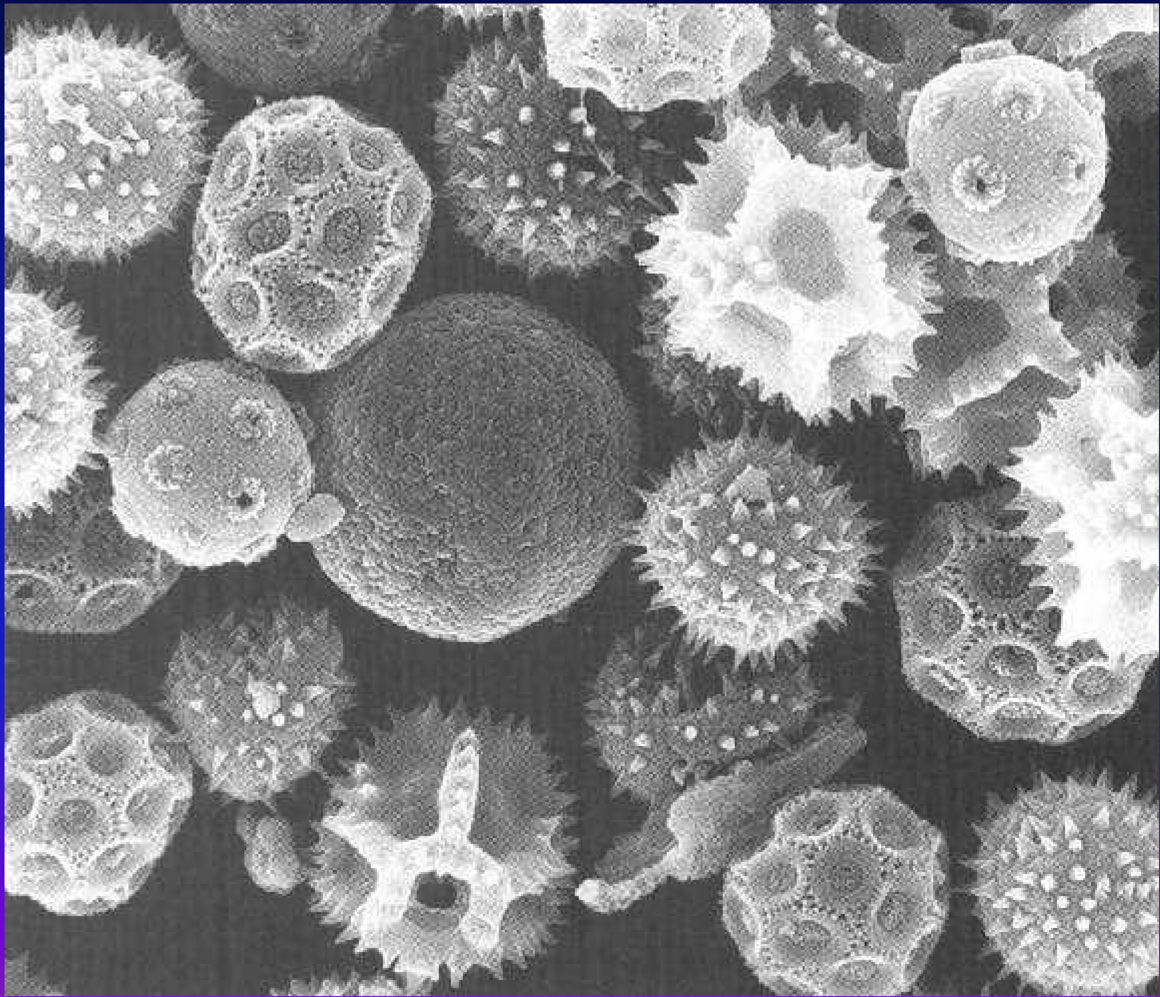


Pollen & Lake core data

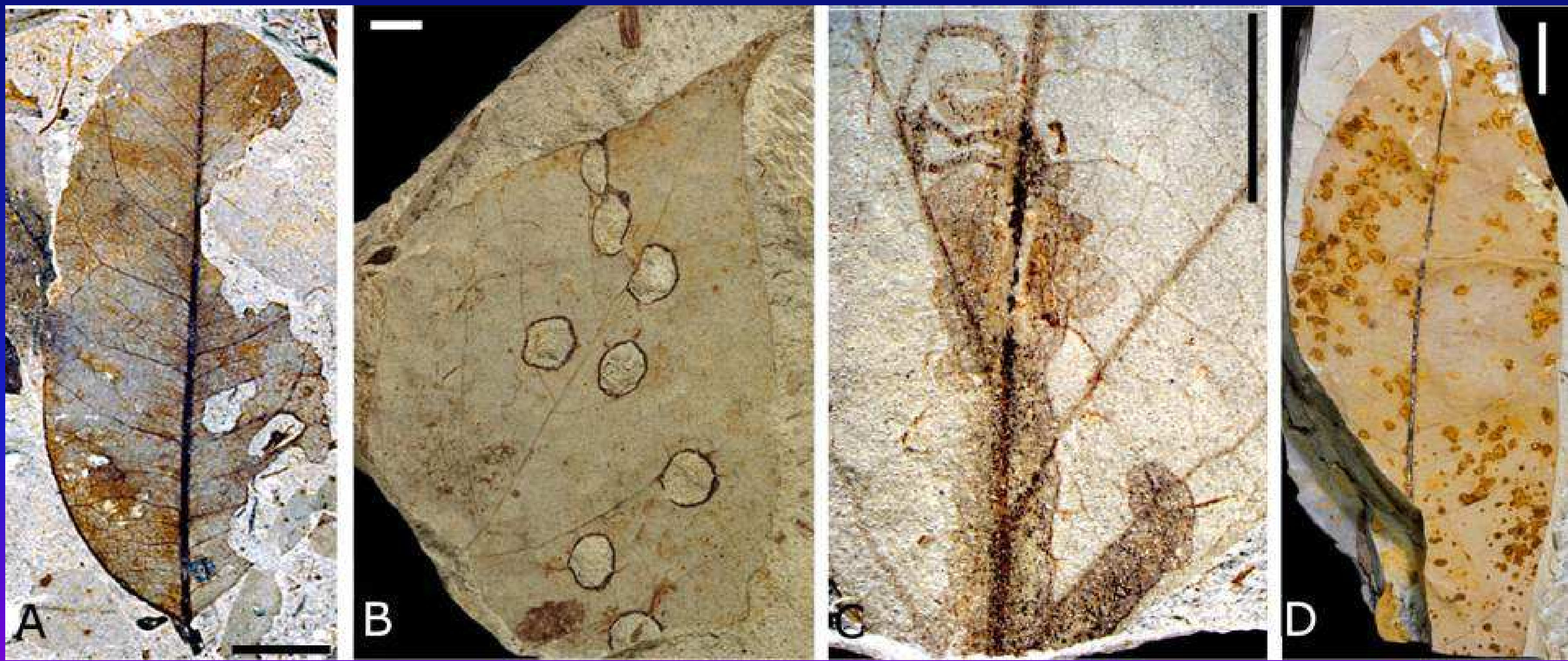


Ruddiman, 2008

PROXY DATA: POLLEN DATA



PROXY DATA: LEAVES



Tree rings, corals, ice cores

Ruddiman, 2008

PROXY DATA:
ICE CORES

TERRESTRIAL DATA

North American:
- Wisconsin
- Illinoian
- Kansan
- Nebraskan

European:
- Wurm
- Riss
- Mindel
- Gunz

LATER EVIDENCE CAME FROM THE MARINE RECORD

NOT WITHOUT IT'S PROBLEMS, BUT MORE COMPLETE

Cesare Emiliani in the early 1950s when he was doing his pioneering research at the University of Chicago (Photo from the Archives of the Rosenstiel School of Marine and Atmospheric Science, University of Miami).

Cesare Emilani:

Paleontologist, Chemist

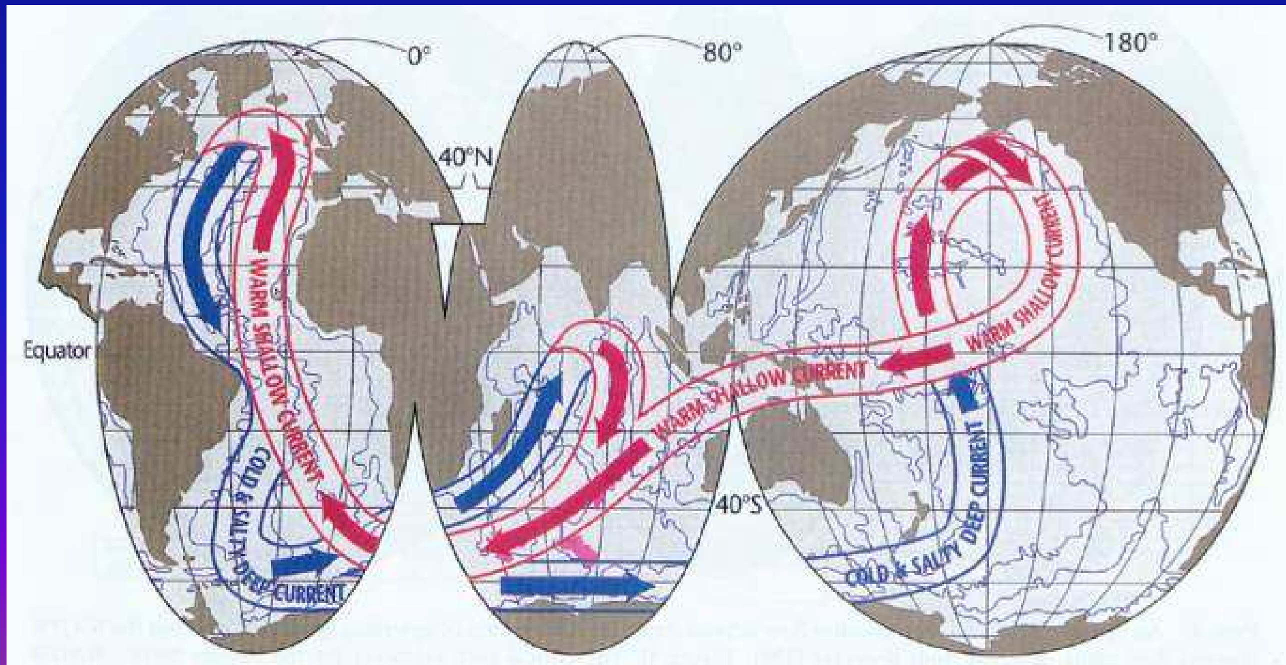
Father of Paleoceanography

Other Paleoceanographers

Wally Broecker

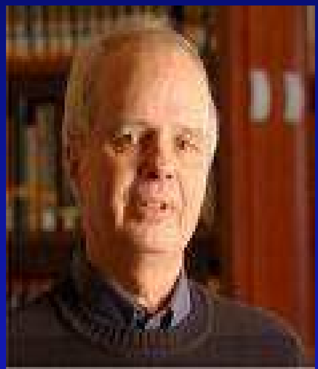
Thermal-haline

"conveyor" belt of circulation

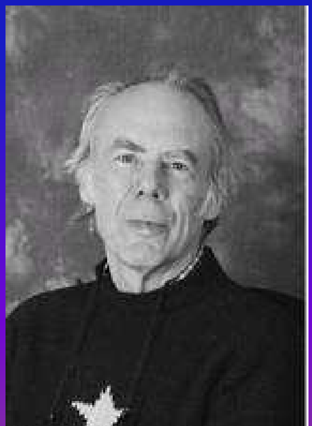


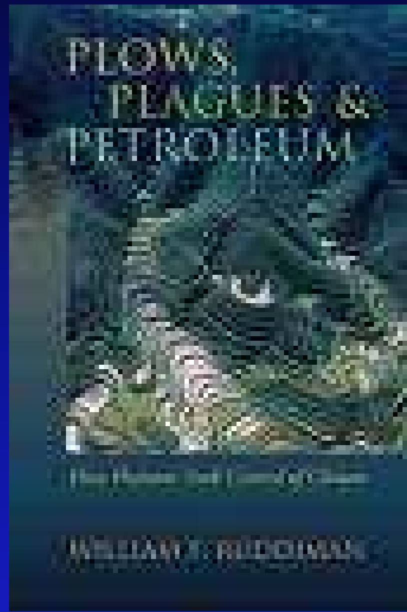
Other Paleoceanographers

Bill Ruddiman



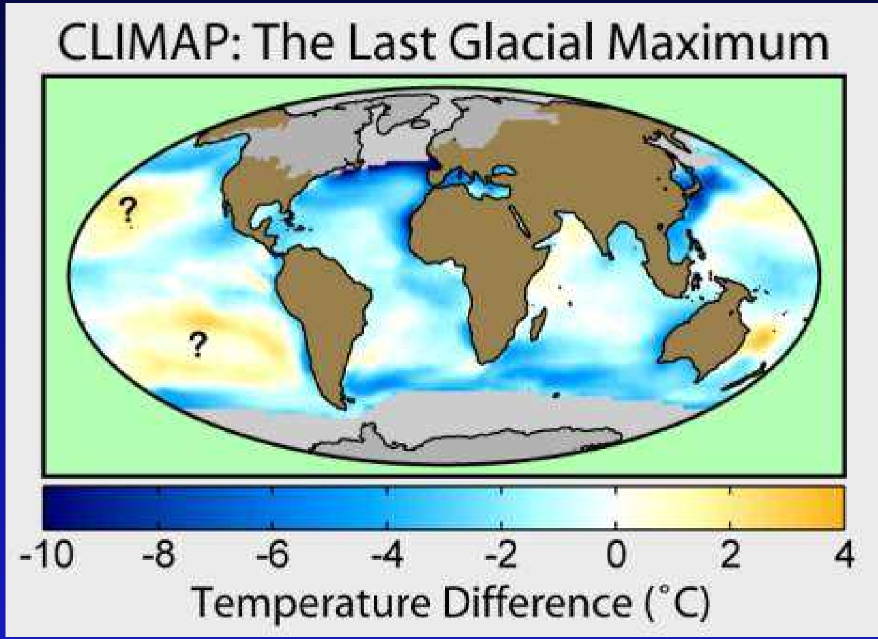
Nick Shackleton

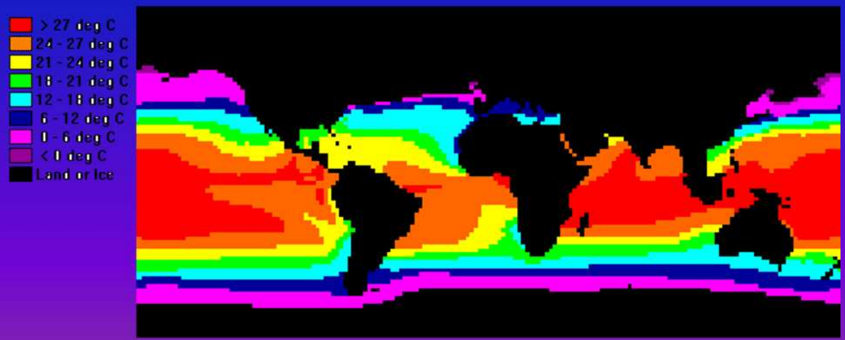


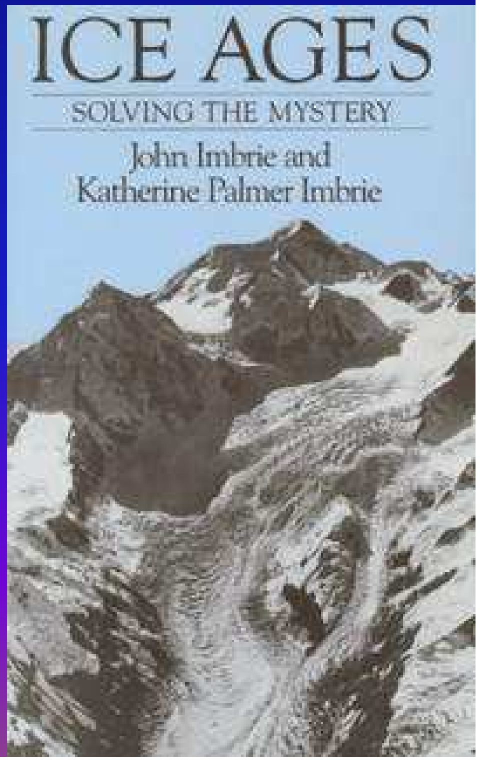


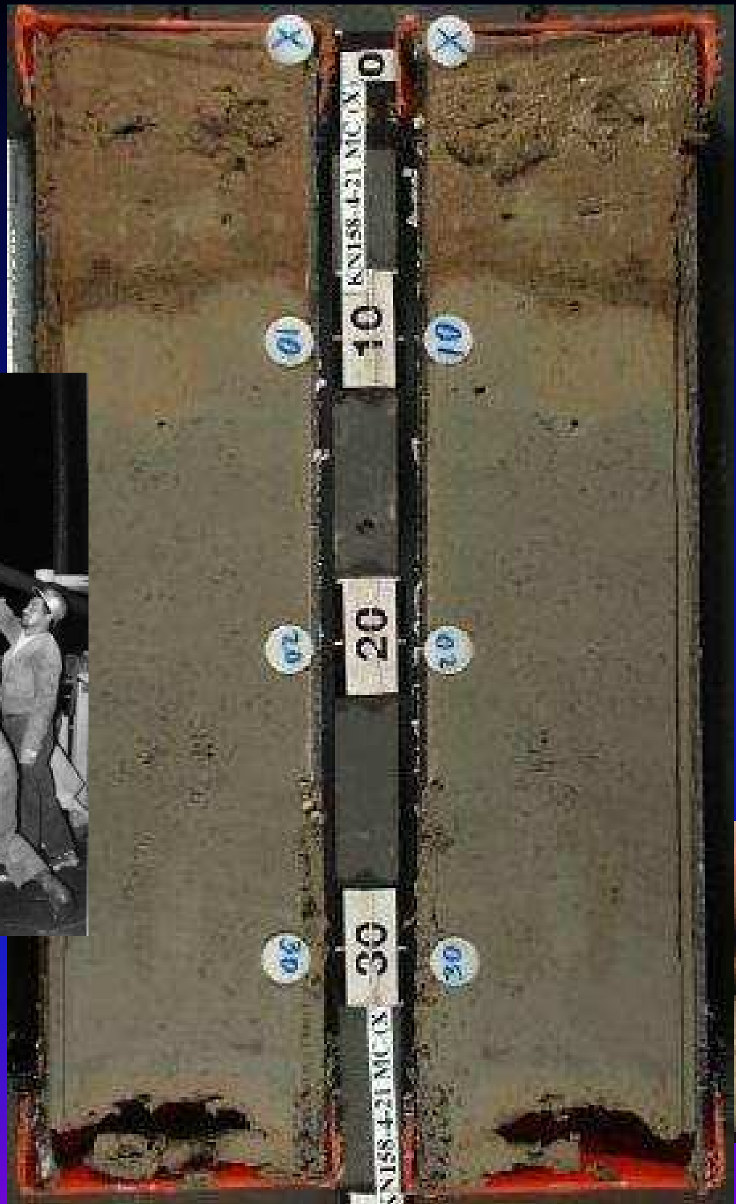
Other Paleoceanographers

John Imbrie:
CLIMAP

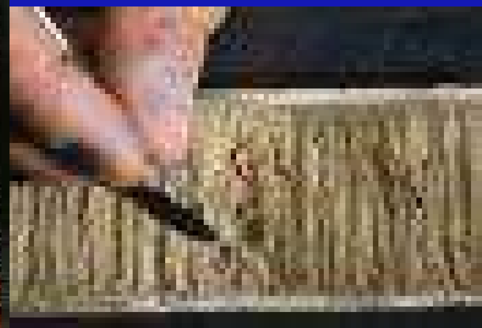




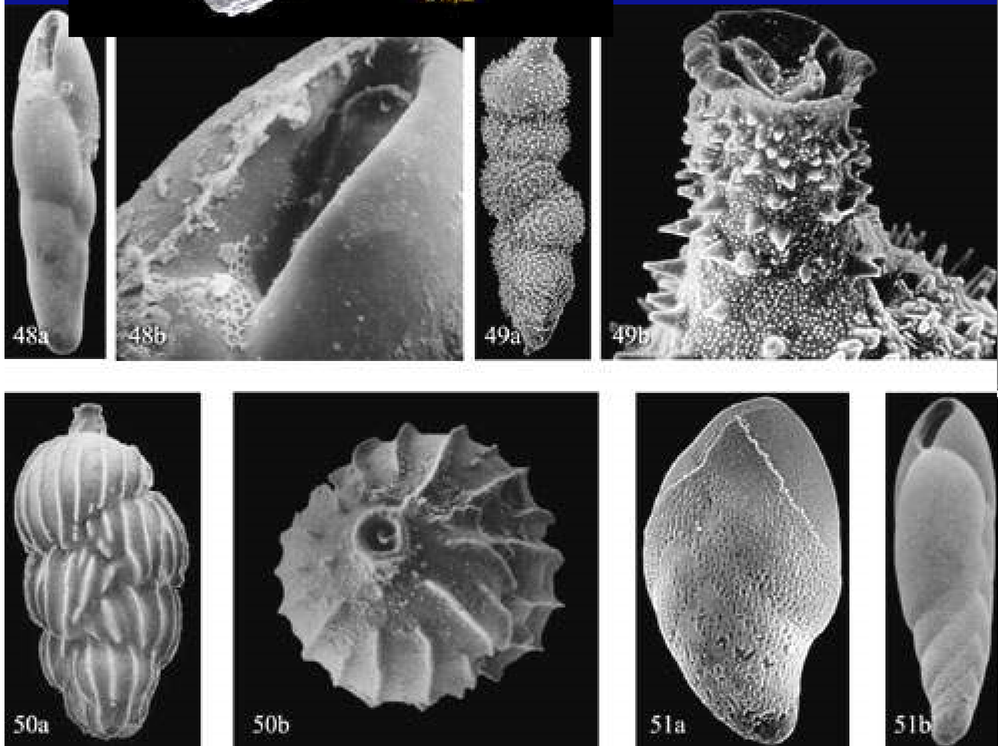


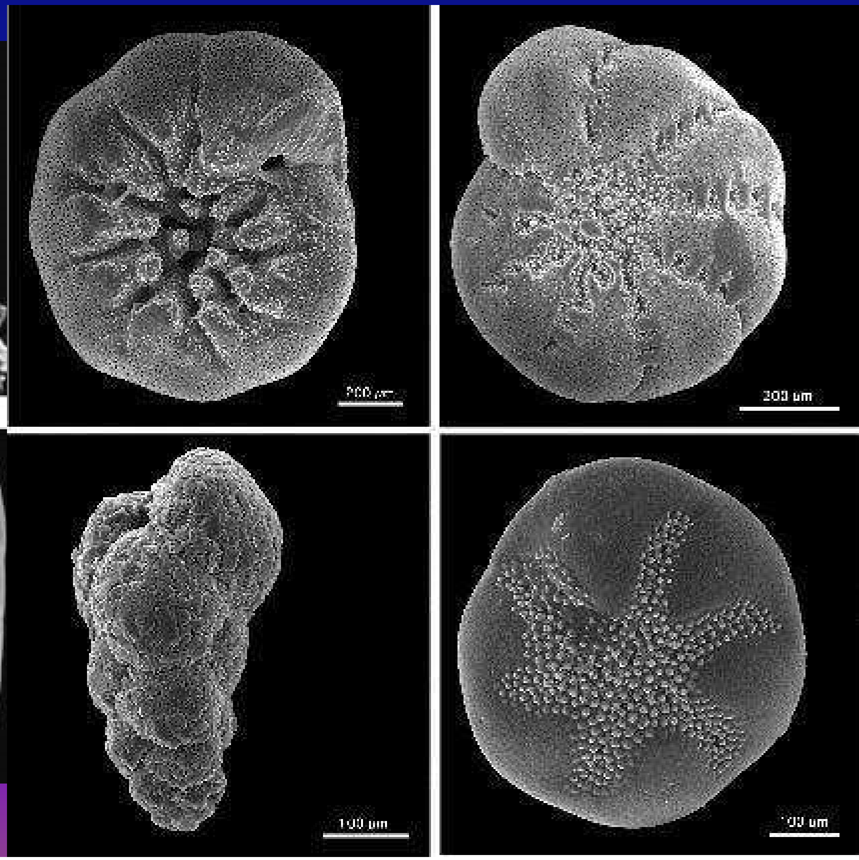


PROXY DATA: CORE DATA

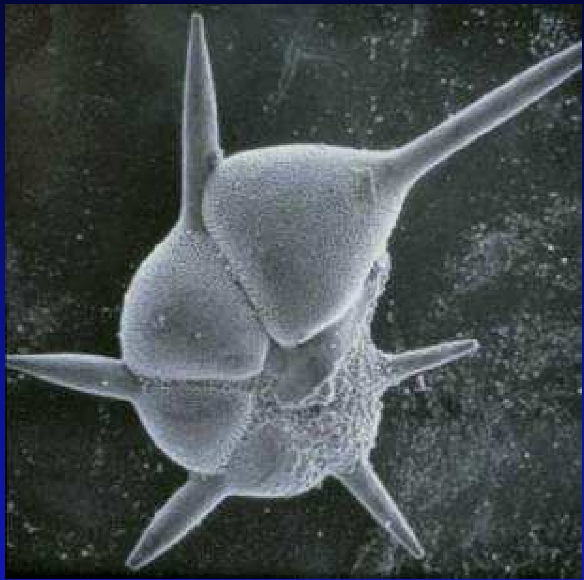


PROXY DATA: BENTHIC FORAMS

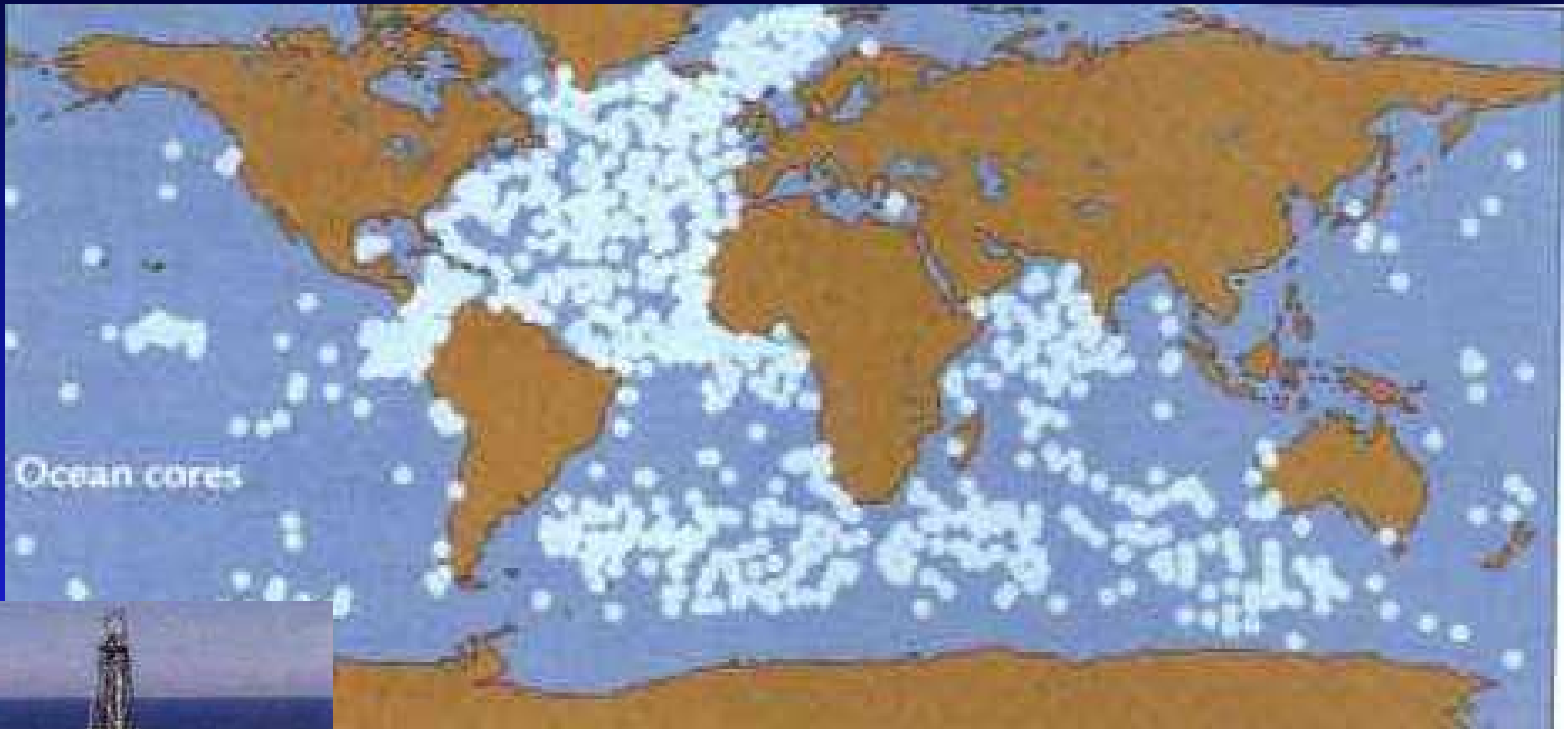




PROXY DATA: PLANKTONIC FORAMS



Deep Sea Coring



Ruddiman, 2008