Earth's Climate: Past, Present and Future; Concerns and Solutions

Week 2: Wednesday April 6, 2016

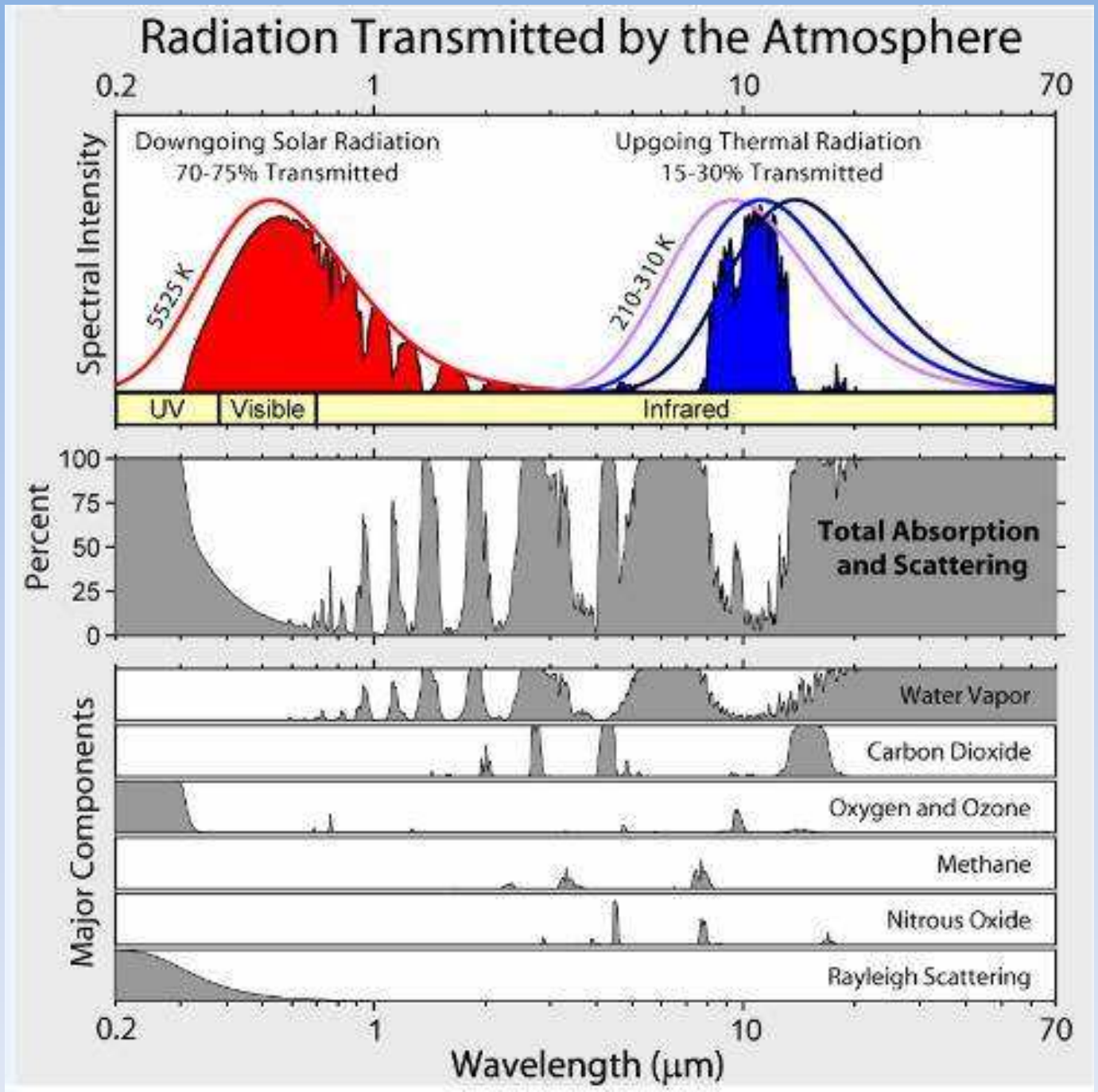
Paul Belanger

Earth's past climate history and what caused those changes

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**

But first

- A few thoughts / slides from last week


Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

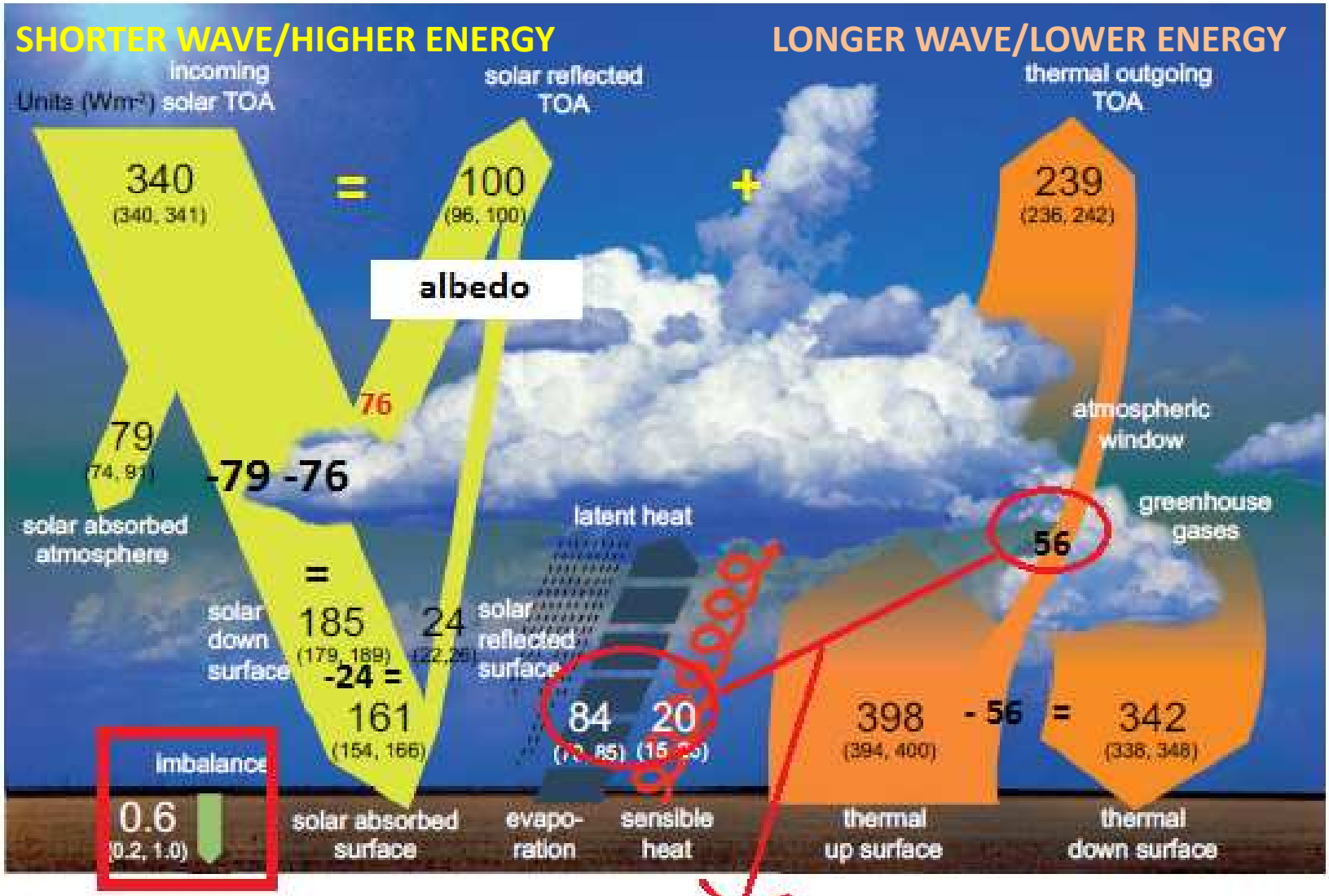
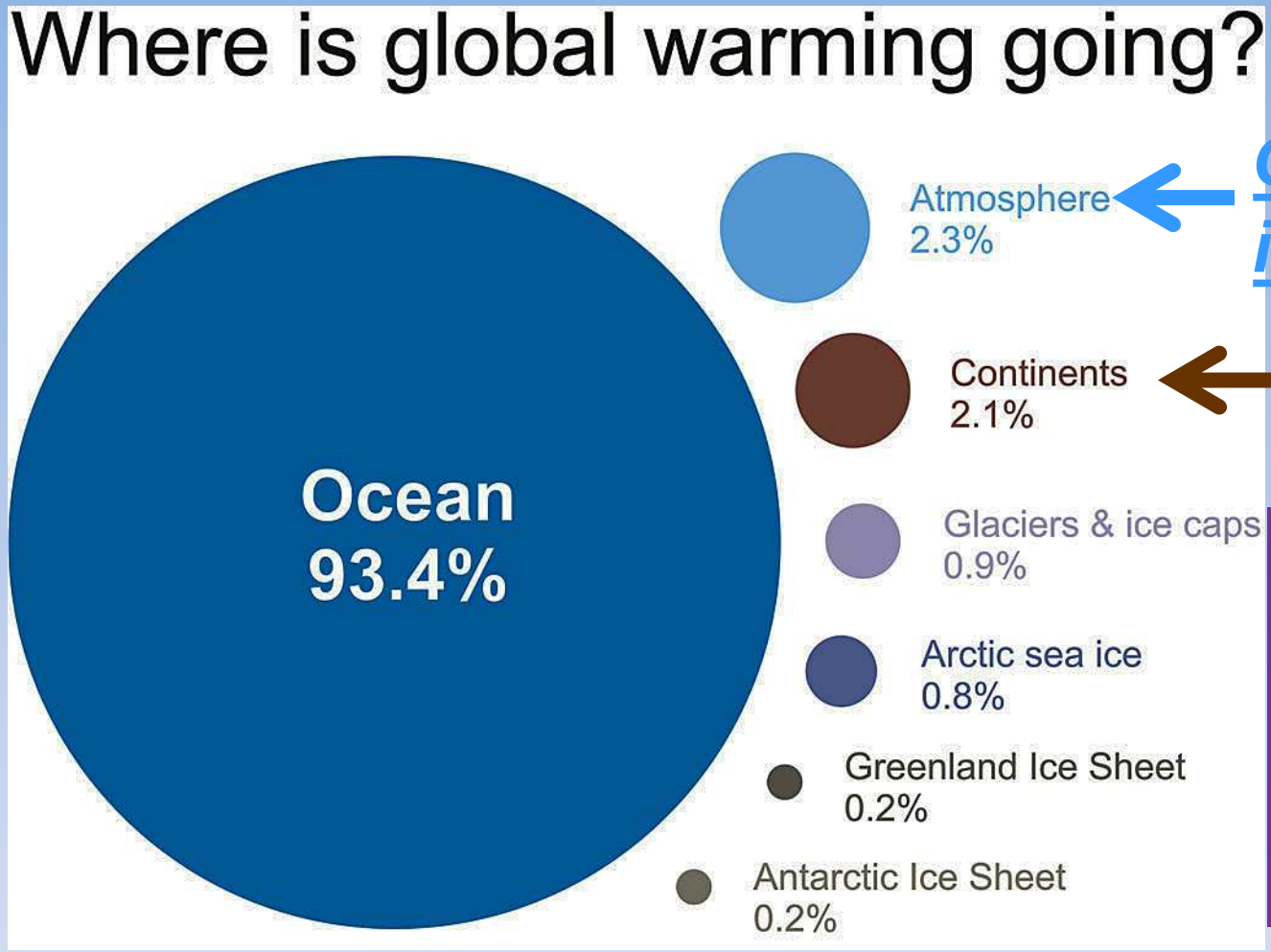


Figure 2.11: | Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m^{-2}, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in 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



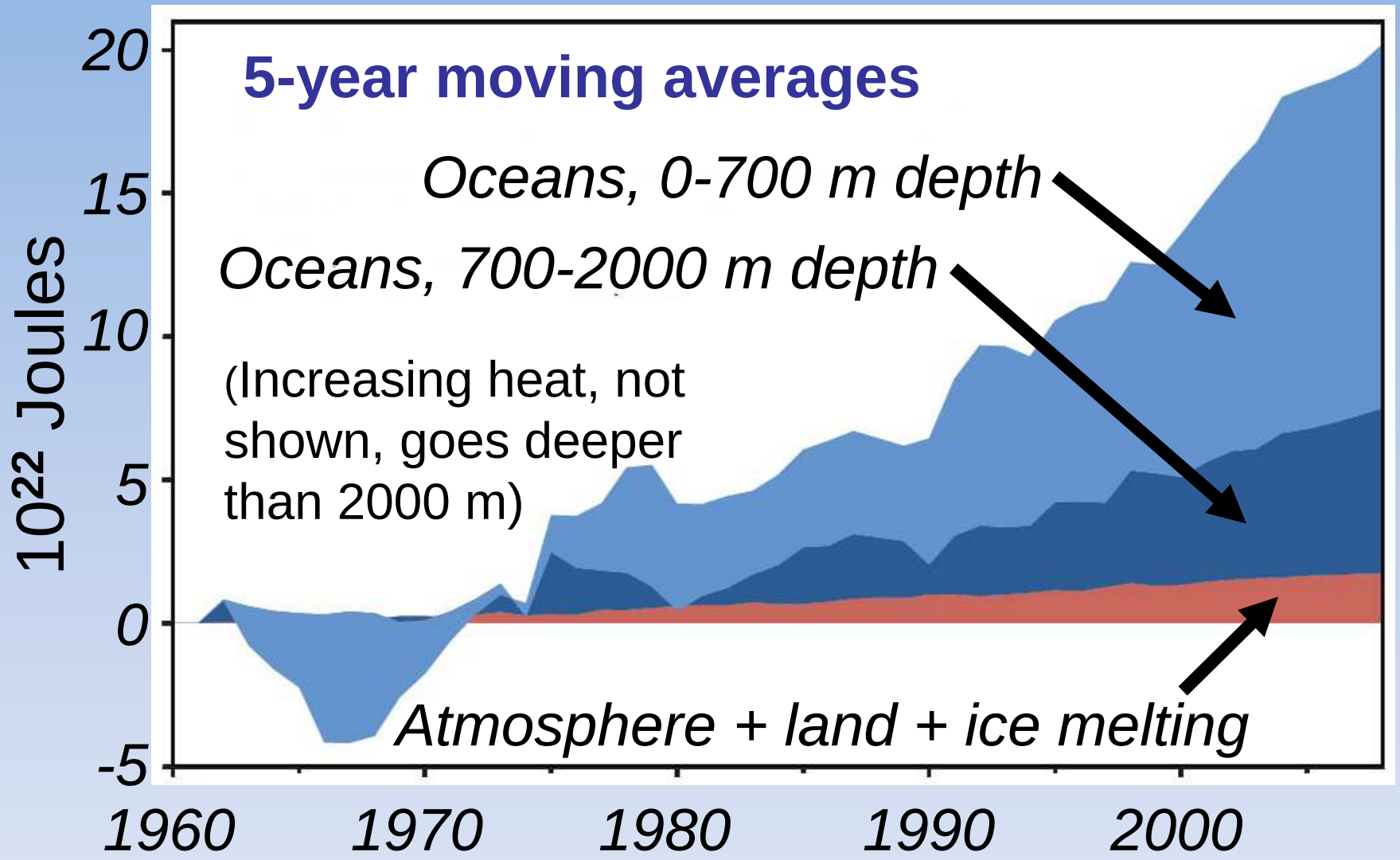
Only ~2% stays in atmosphere

~2% warms the land

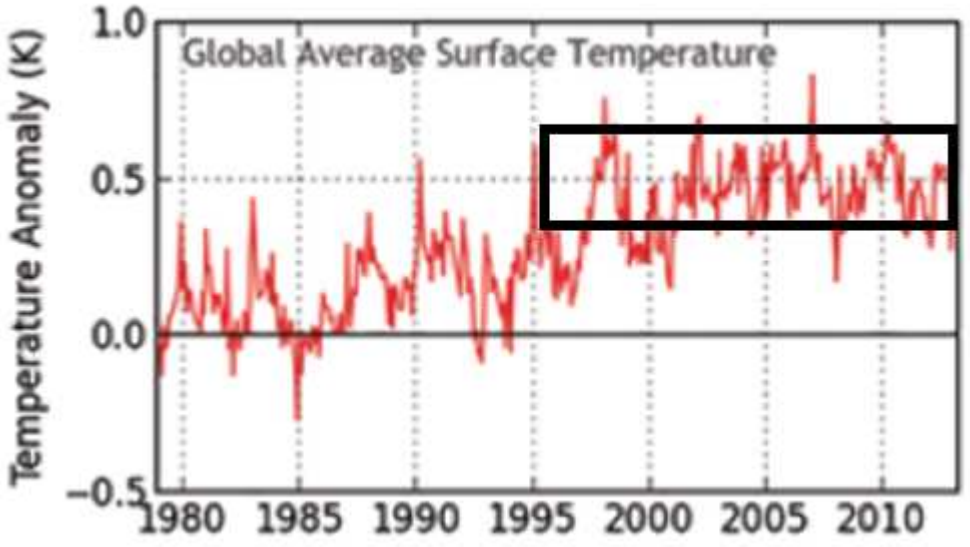
Melting ice absorbs ~2%

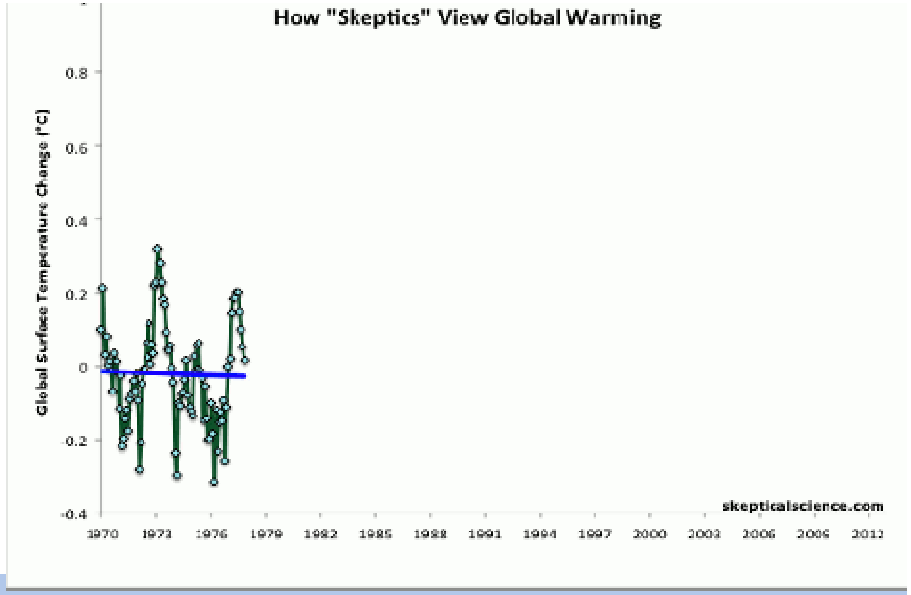
John Cook, from IGPP 2007 data; ~93% to oceans continues (NOAA/NODC, 2012)

Change in heat content, 1958-2011

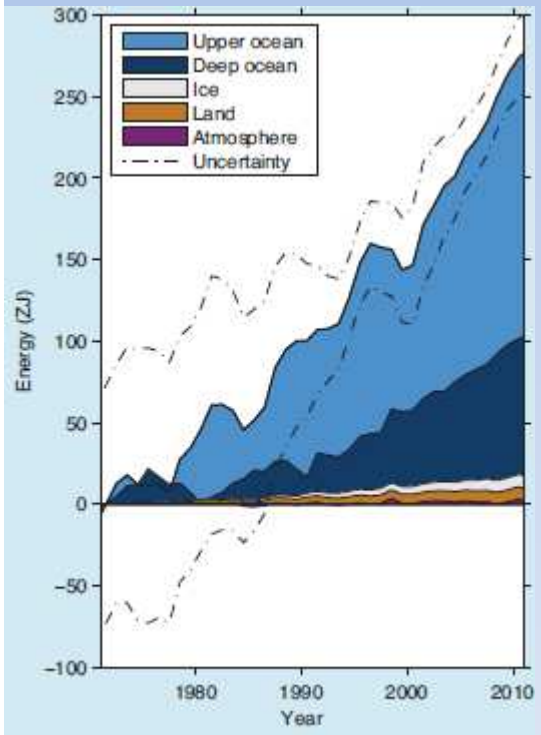


(NOAA 2012 data, Nuccitelli et al. 2012 plot)

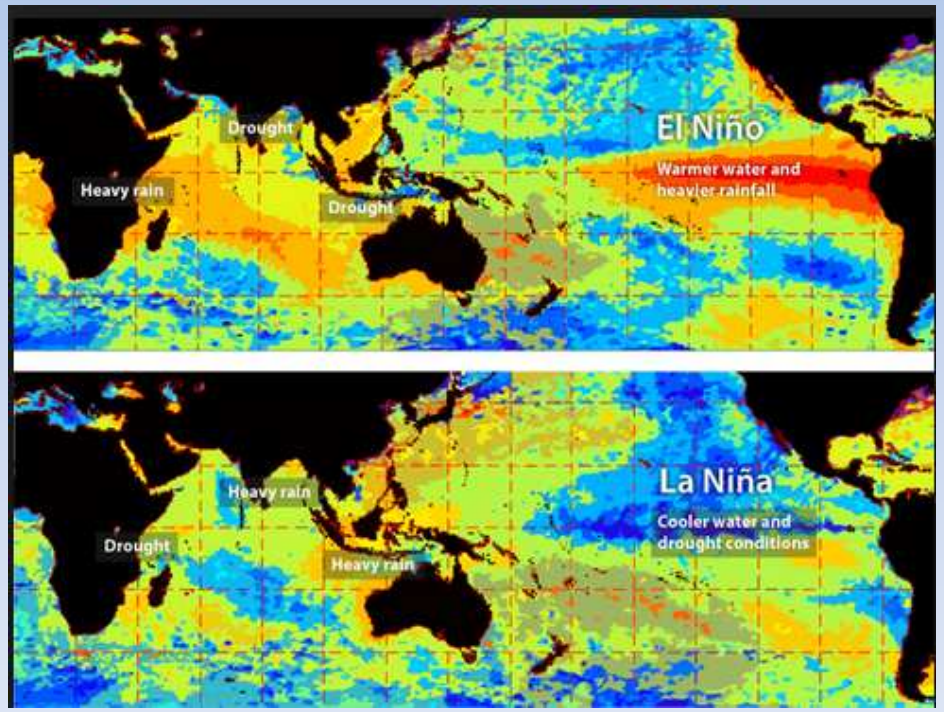


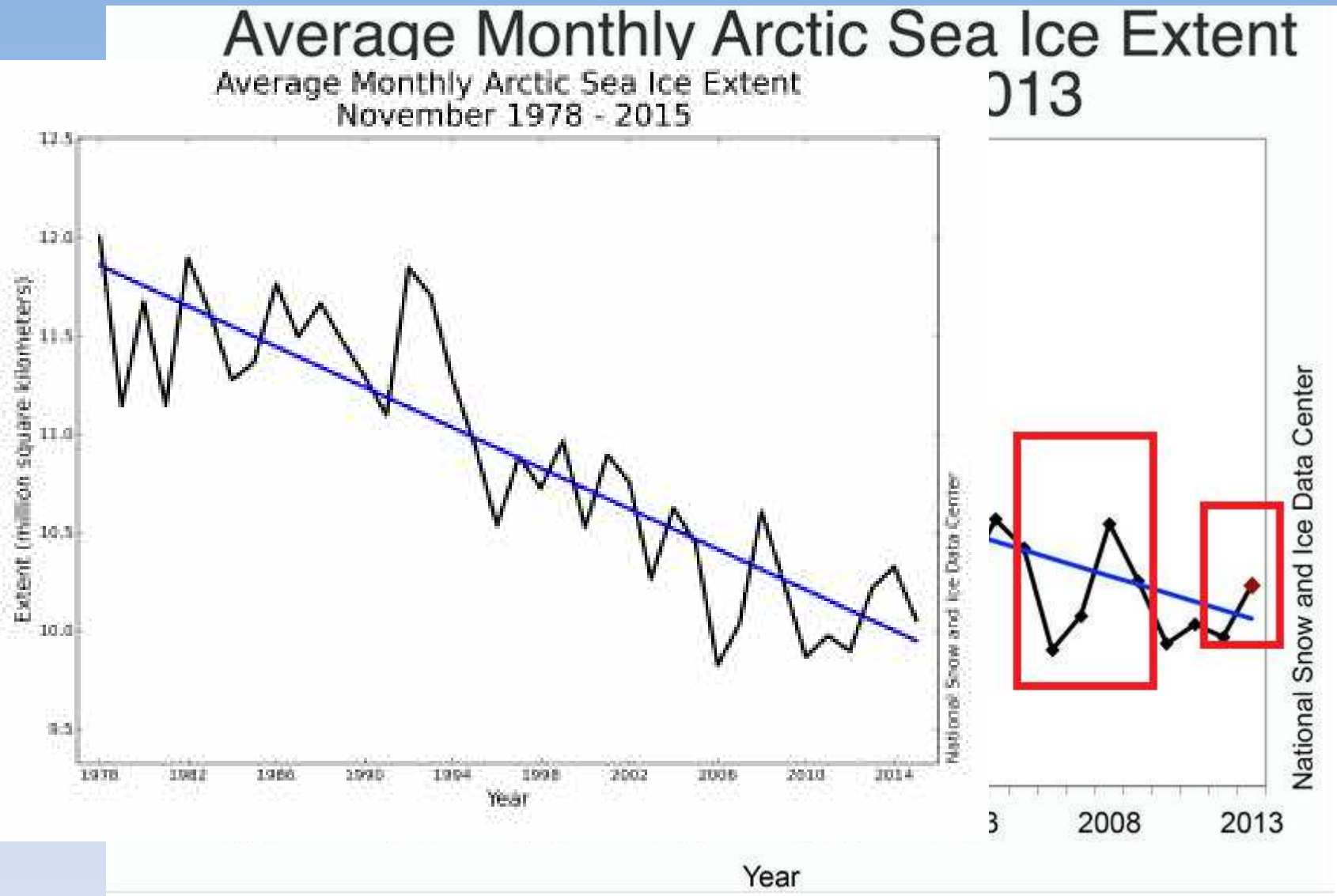


http://www.skepticalscience.com/graphics.php?g=47



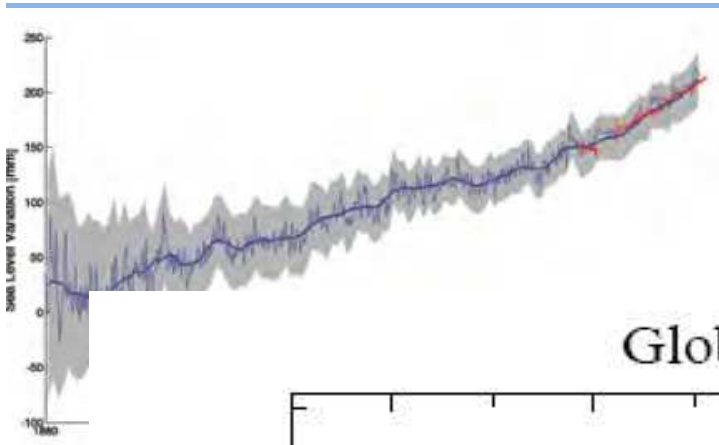
Box 3.1, Figure 1 | Plot of energy accumulation in ZJ (1 ZJ = 10^{21} J) withi



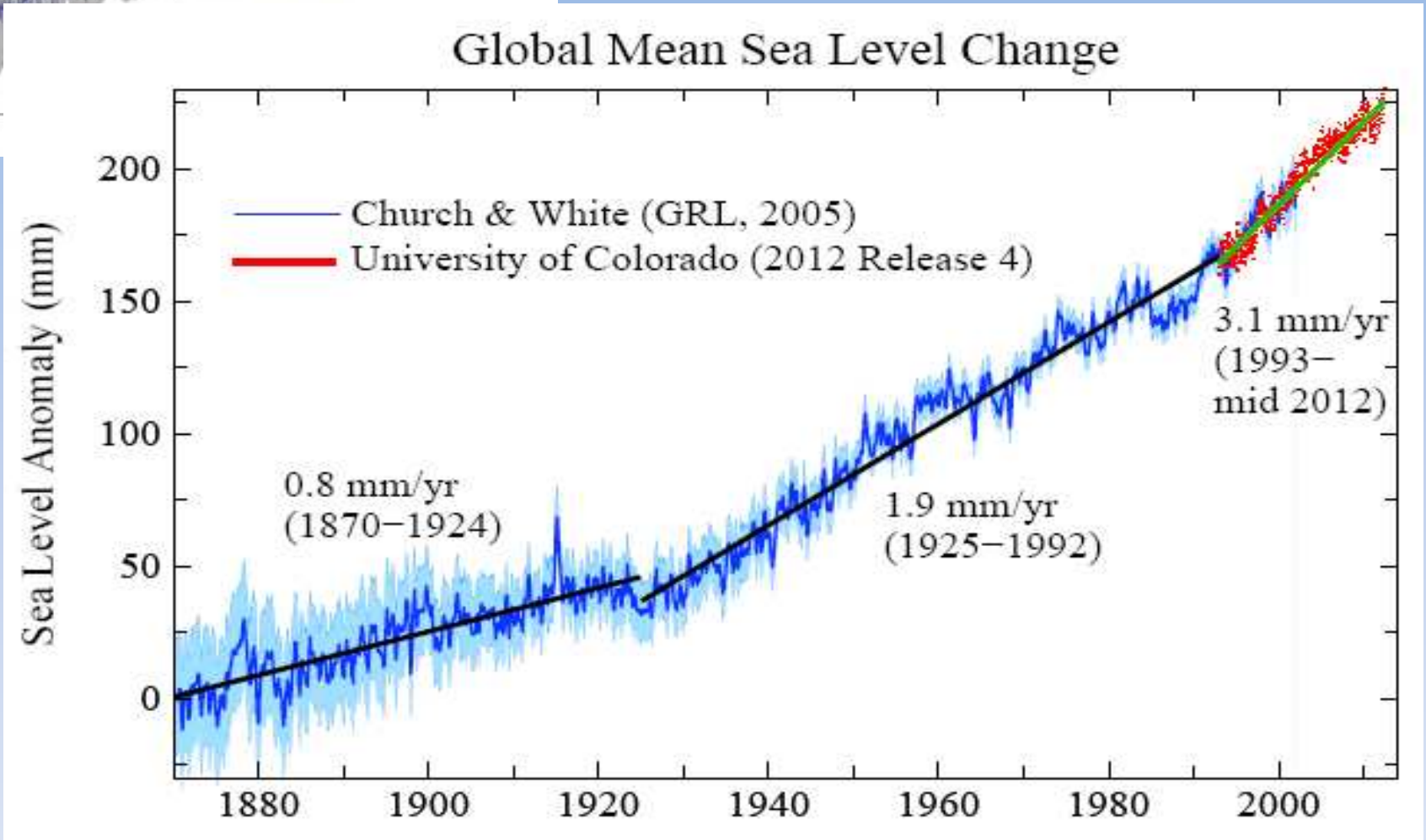


For more see: http://www.skepticalscience.com/melting-ice-global-warming.htm

http://nsidc.org/arcticseaicenews/2015/



14: HOW FAST IS SEA LEVEL RISING?

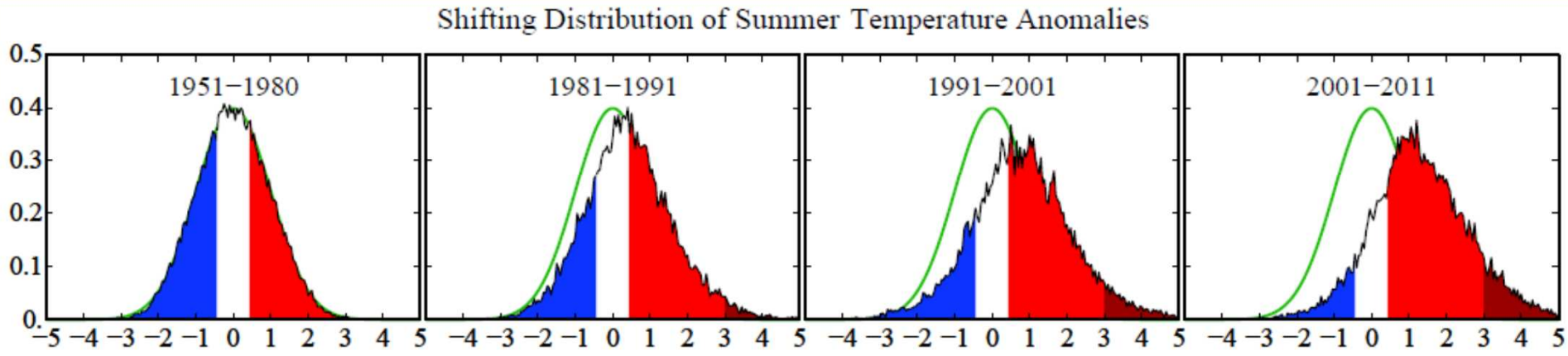


Blue: Sea level change from tide-gauge data *(Church J.A. and White N.J., Geophys. Res. Lett. 2006; 33: L01602)*
Red: Univ. Colorado sea level analyses in satellite era *(http://www.columbia.edu/~mhs119/SeaLevel/)*.

Loaded Climate Dice: global warming is increasing extreme weather events.

Extreme summer heat anomalies now cover about 10% of land area, up from 0.2%.

This is based on observations, not models.



Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies (relative to 1951-1980 mean) for Northern Hemisphere land in units of local standard deviation (horizontal axis). Temperature anomalies in the period 1951-1980 match closely the normal distribution ("bell curve", shown in green), which is used to define cold (blue), typical (white) and hot (red) seasons, each with probability 33.3%. The distribution of anomalies has shifted to the right as a consequence of the global warming of the past three decades such that cool summers now cover only half of one side of a six-sided die, white covers one side, red covers four sides, and an extremely hot (red-brown) anomaly covers half of one side.
Source: Hansen, J., Sato, M., and Ruedy, R., Proc. Natl. Acad. Sci., 2012.

Tricky question related to gas laws

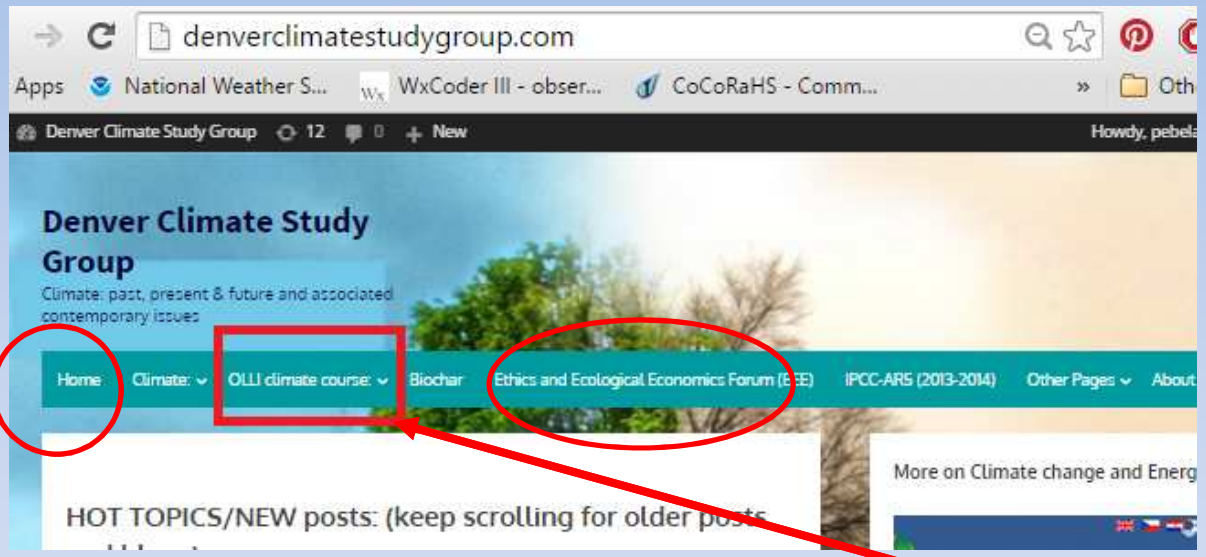
- TOA – TOP OF ATMOSPHERE
- Which is denser: 2 = ROOMS, BOTH SAME TEMP.
  A. 100% HUMIDITY
  B. 20% HUMIDITY
- El Nino/La Nina map and world temperatures

Explanation

- GAS LAWS
  - N_2 (78%), atomic mass 14 (7p/7n) x 2 = 28
  - O_2 (21%), atomic mass 16 (8p/8n) x2 = 32
  - H_2O (varies <1%), H – 1p x 2 = 2 + 16 = 18
- Water vapor mixed in air makes it LESS DENSE
- Why rain associated with LOW pressure
- Joule (ISU), calorie, BTU
  - Takes 80 cal to melt ice; 1 cal (4.2J)/ ^oC; 540 c to steam

WEB PAGE

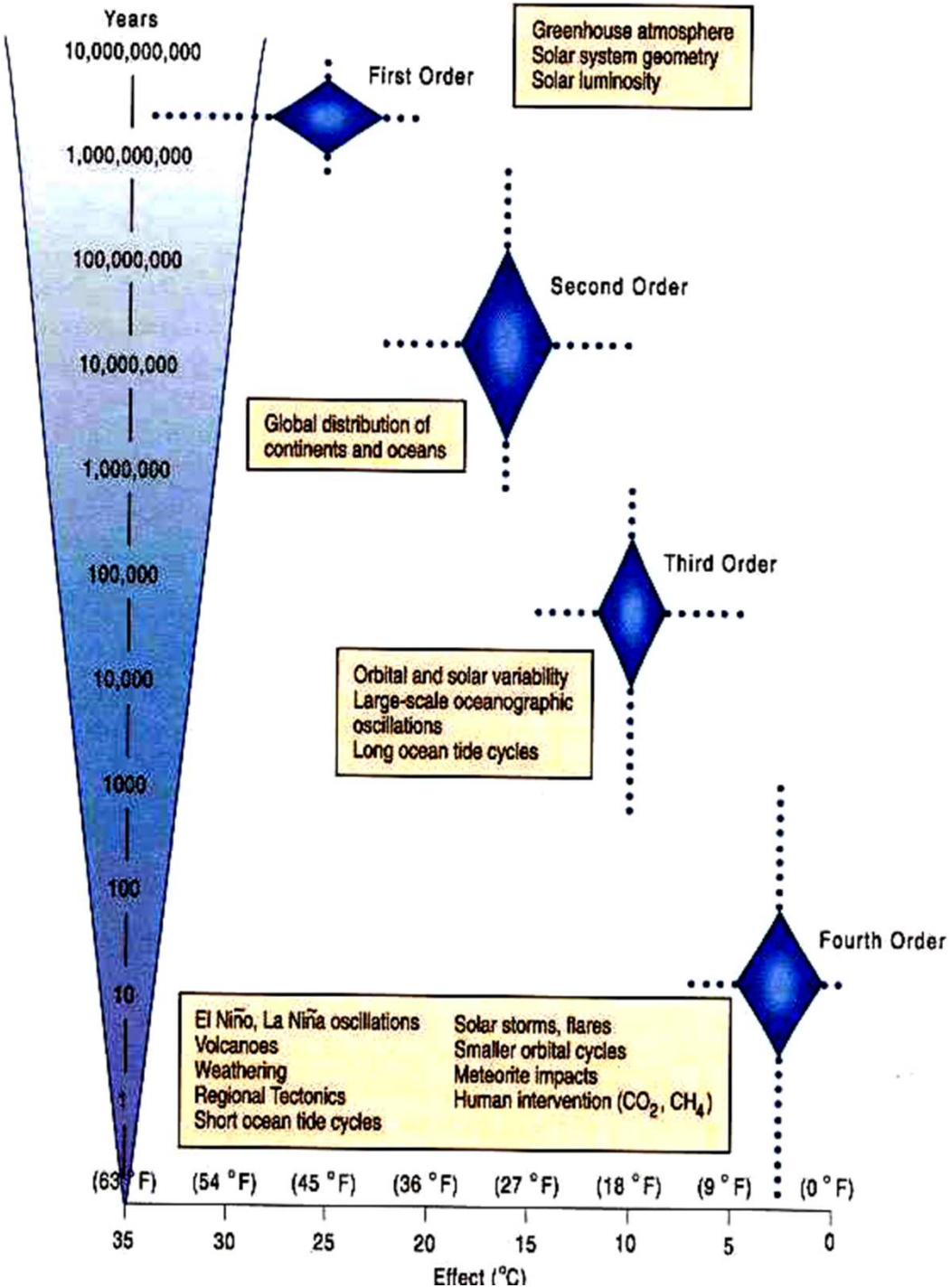
http://www.denverclimatestudygroup.com/



Past Earth History Objectives:

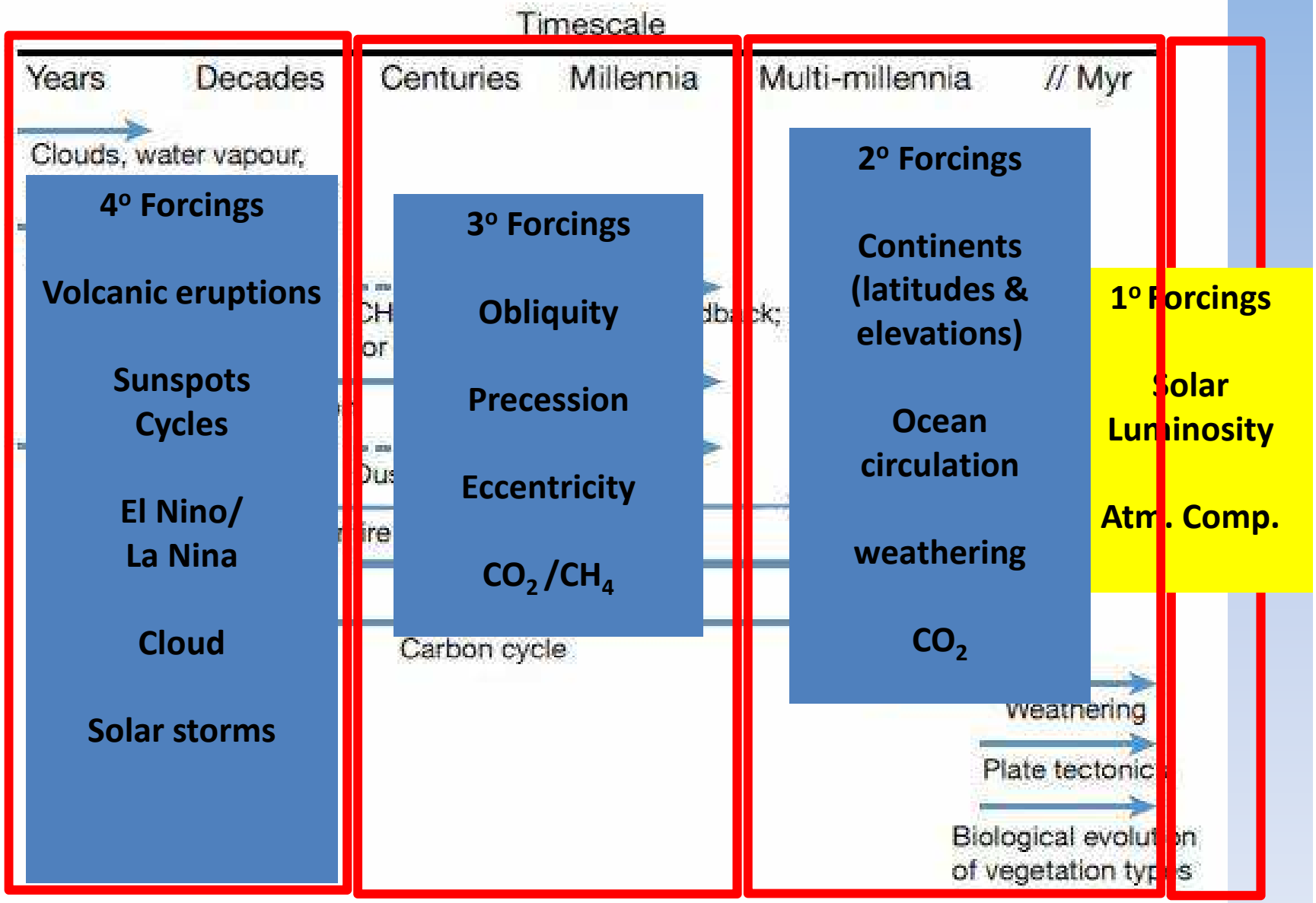
1. **Present you with the geologic evidence; Earth's past**
2. **Educate / That the science is sound**
3. **Understand the denial movement and how to counter it**
4. **Motivate you**
5. **Give you hope / look at potential game changers**

- SO –
WHAT CONTROLS CLIMATE



Gerhard et al., 2001

FEEDBACKS



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

Earth's past climate

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Earth's past climate 1 of 2

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 and BBC article: http://www.bbc.co.uk/nature/ancient_earth/Snowball_Earth
- Nat geographic – not terribly good – but at 2:30 describe dropstones - evidence
- https://www.youtube.com/watch?v=mX3pHD7NH58 but at Better description of cause: http://www.sciencechannel.com/tv-shows/how-the-universe-works/videos/snowball-earth/

Earth's past climate 2 of 2

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

- 48 minutes https://www.youtube.com/watch?v=YOLbE8frMrM
- WIKI: https://en.wikipedia.org/wiki/Snowball_Earth
- Article Link: BBC Nature --- video is not currently working 9/20/2015 and 4/5/16 at http://www.bbc.co.uk/nature/ancient_earth/Snowball_Earth but here's a link about the video including a link to the transcript: http://www.bbc.co.uk/science/horizon/2000/snowballearth.shtml
- 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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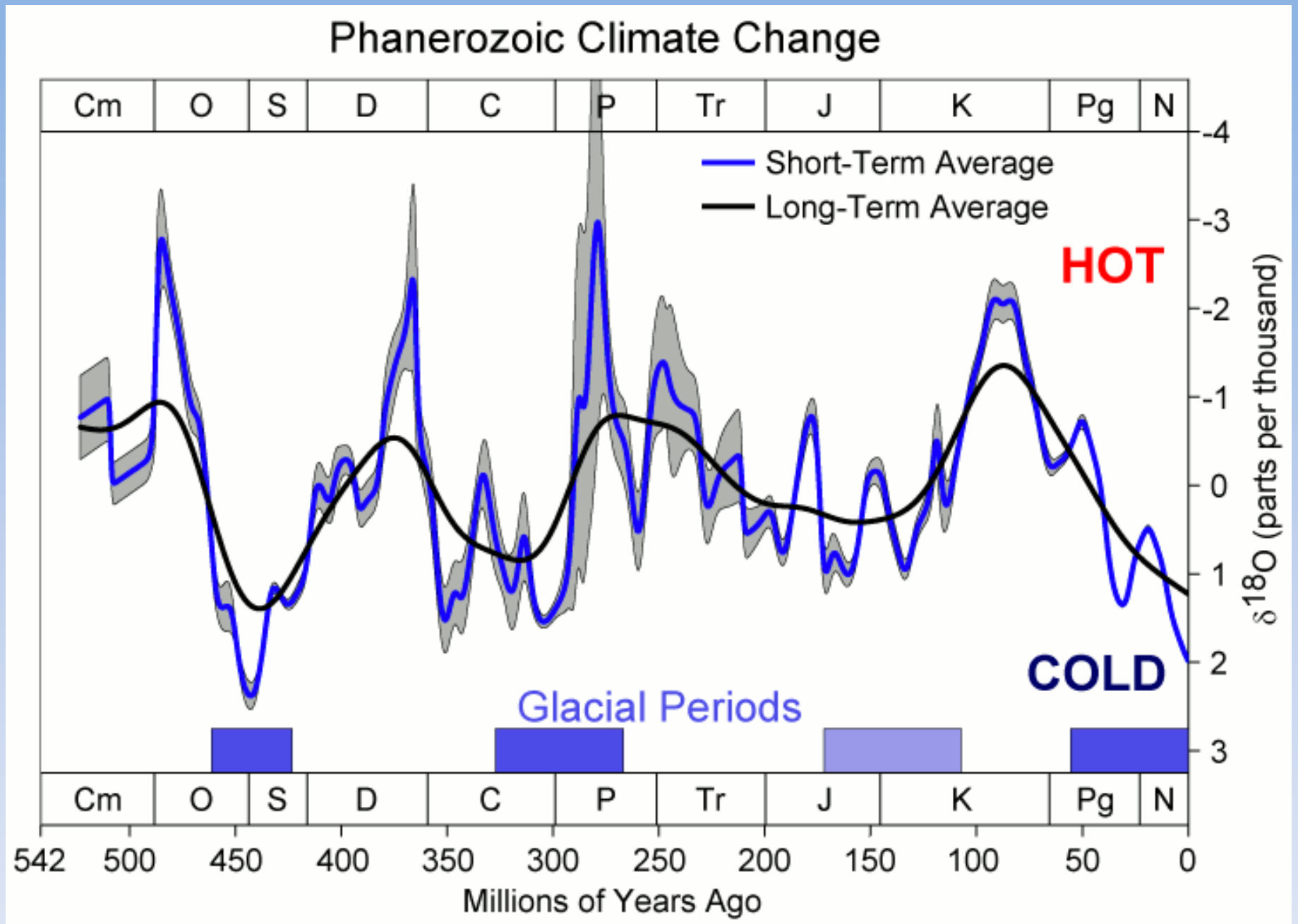
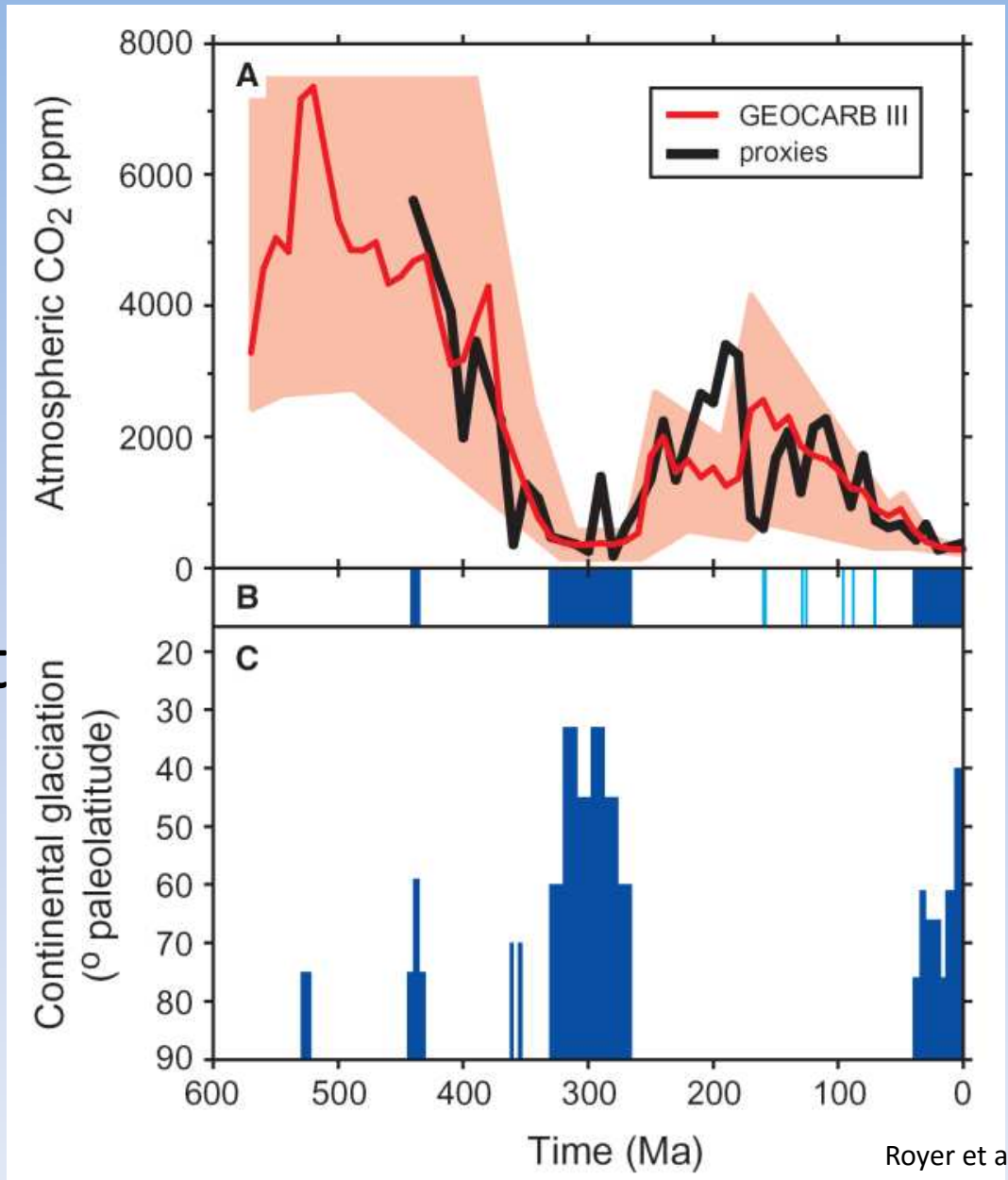


PALEOZOIC	MESOZOIC	CENOZ.

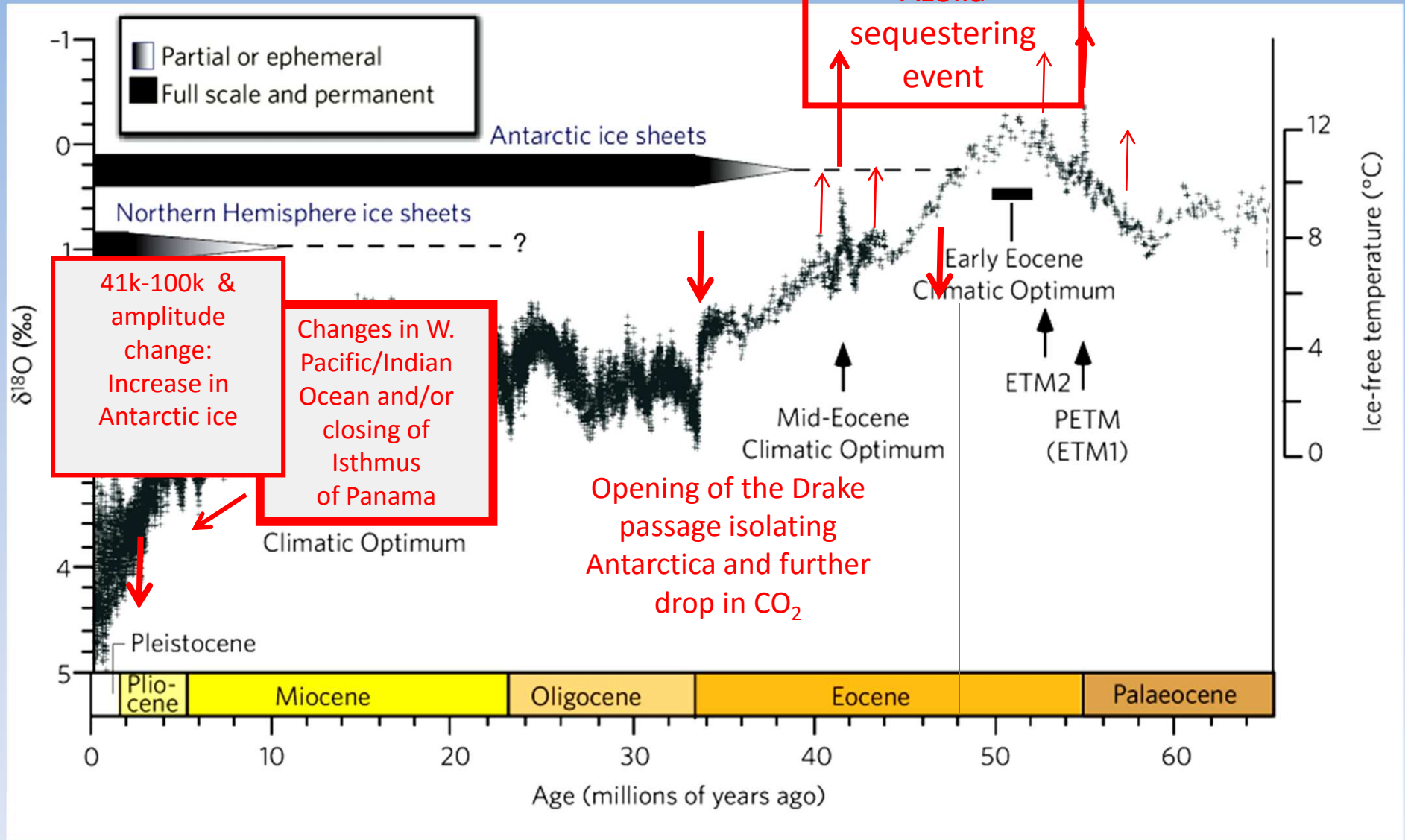
Alternating Greenhouse Earth / Ice-house Earth

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



Royer et al., 2003

Cenozoic Deep Sea Climate Record



Zachos et al. 2008

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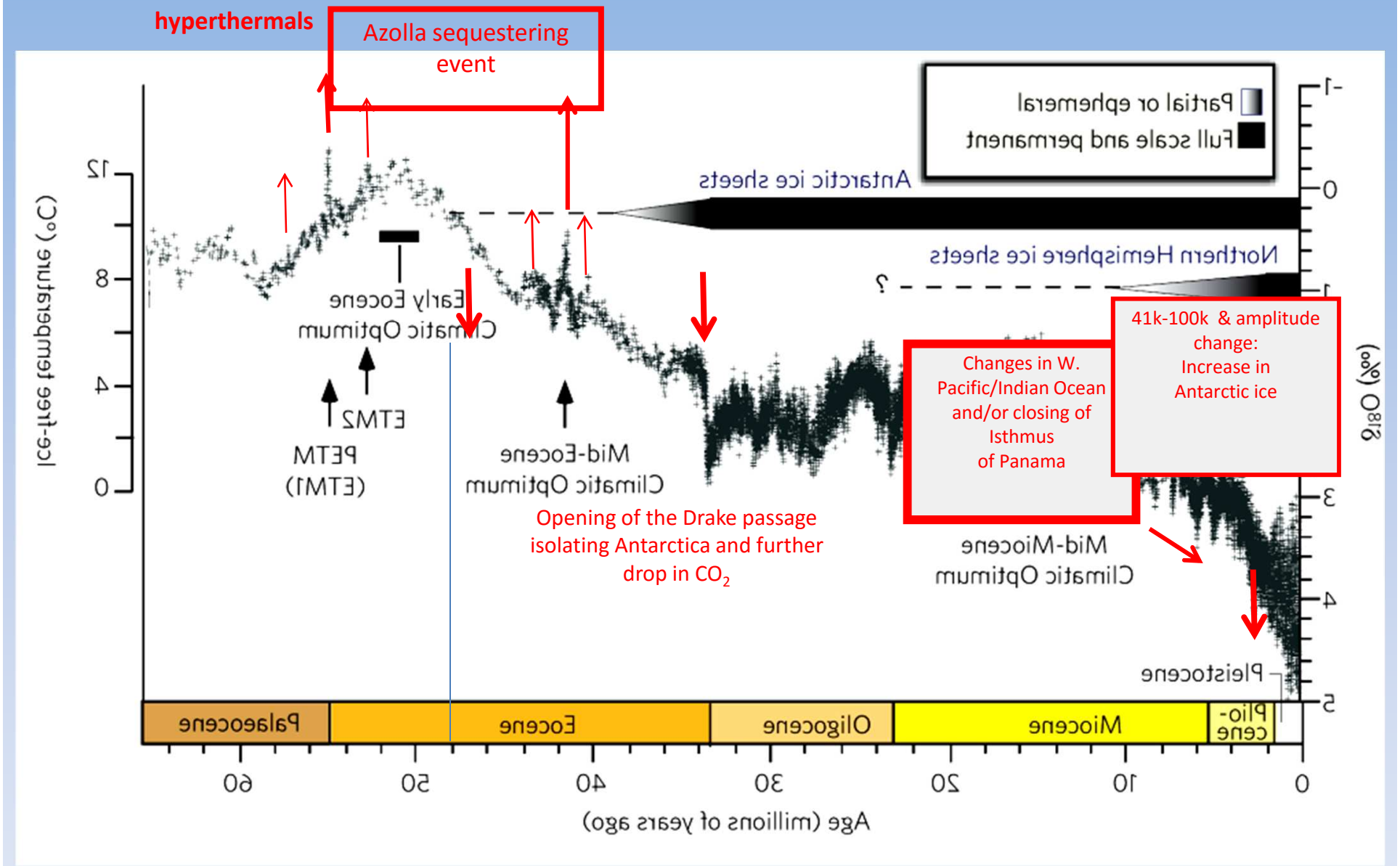
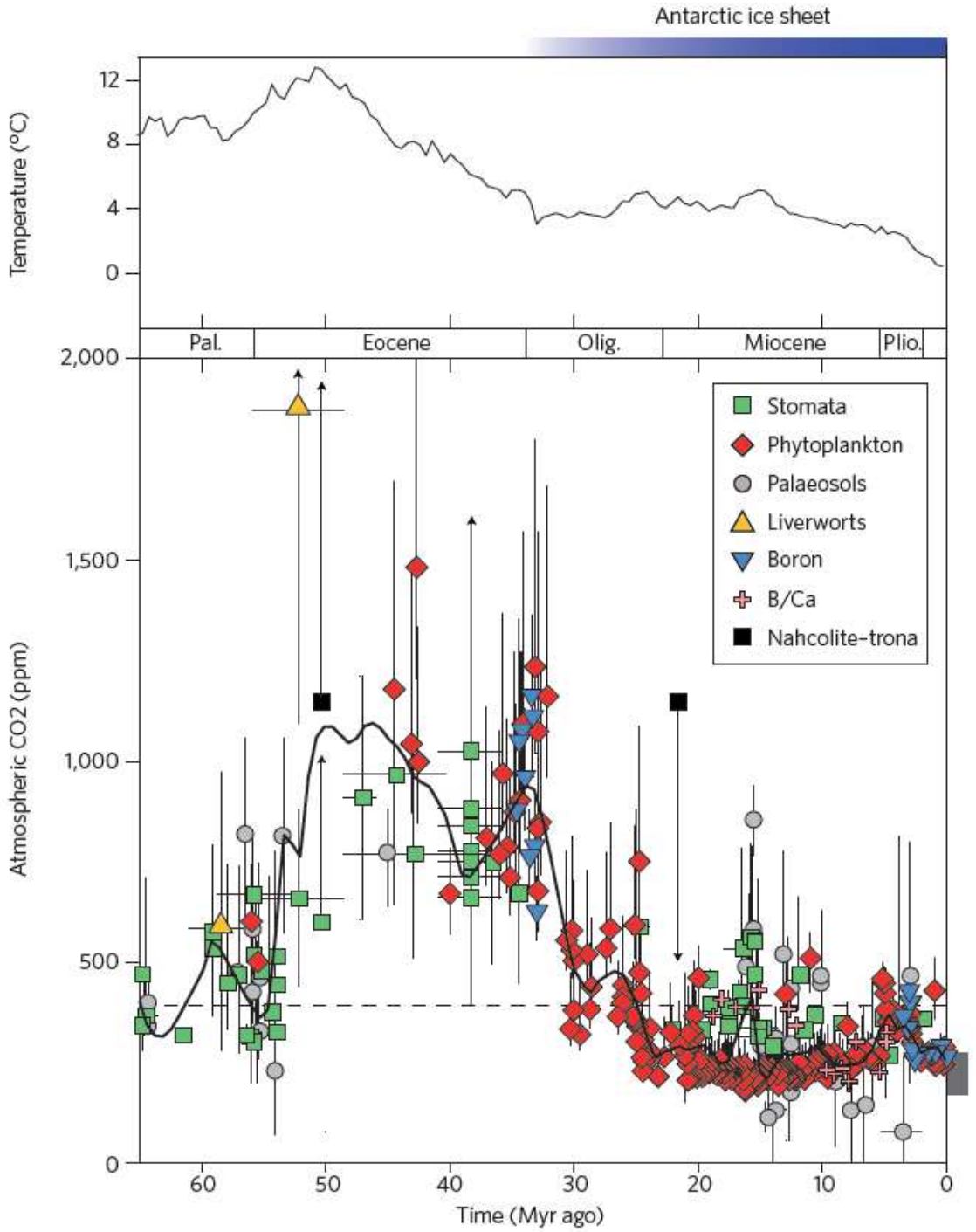
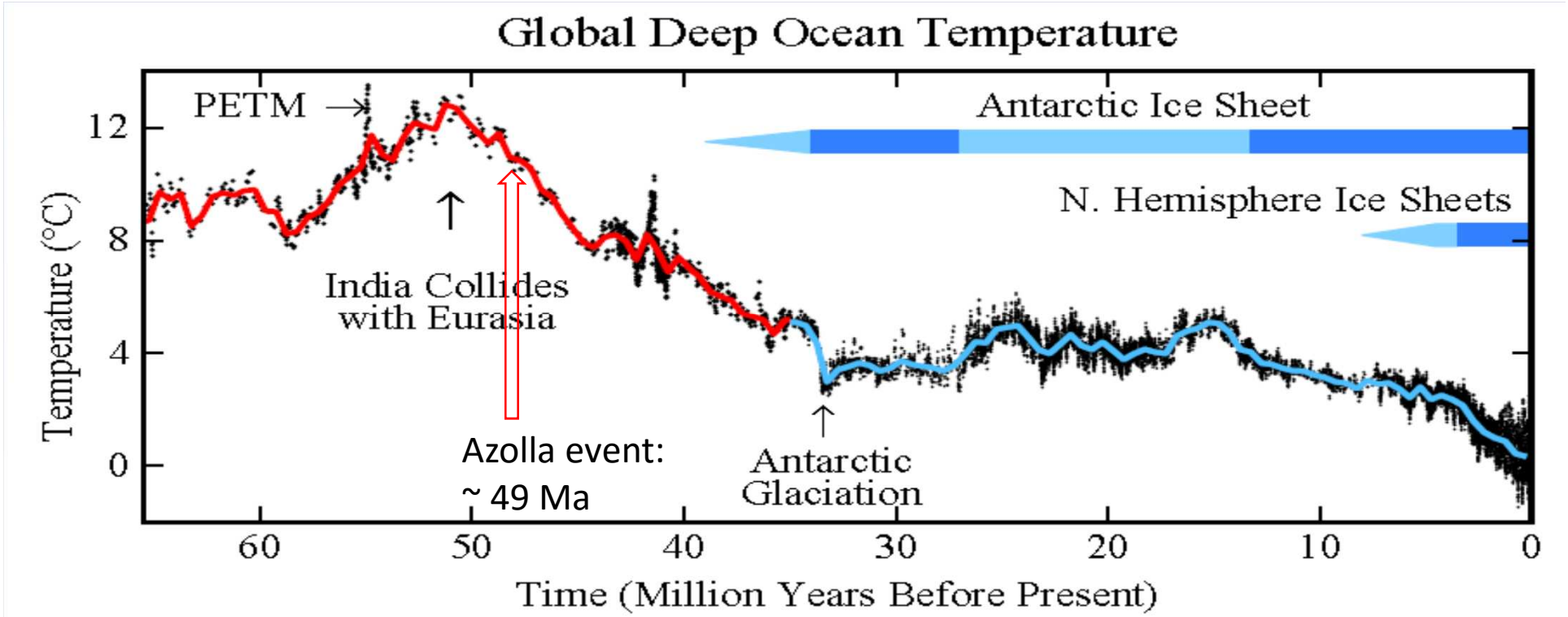


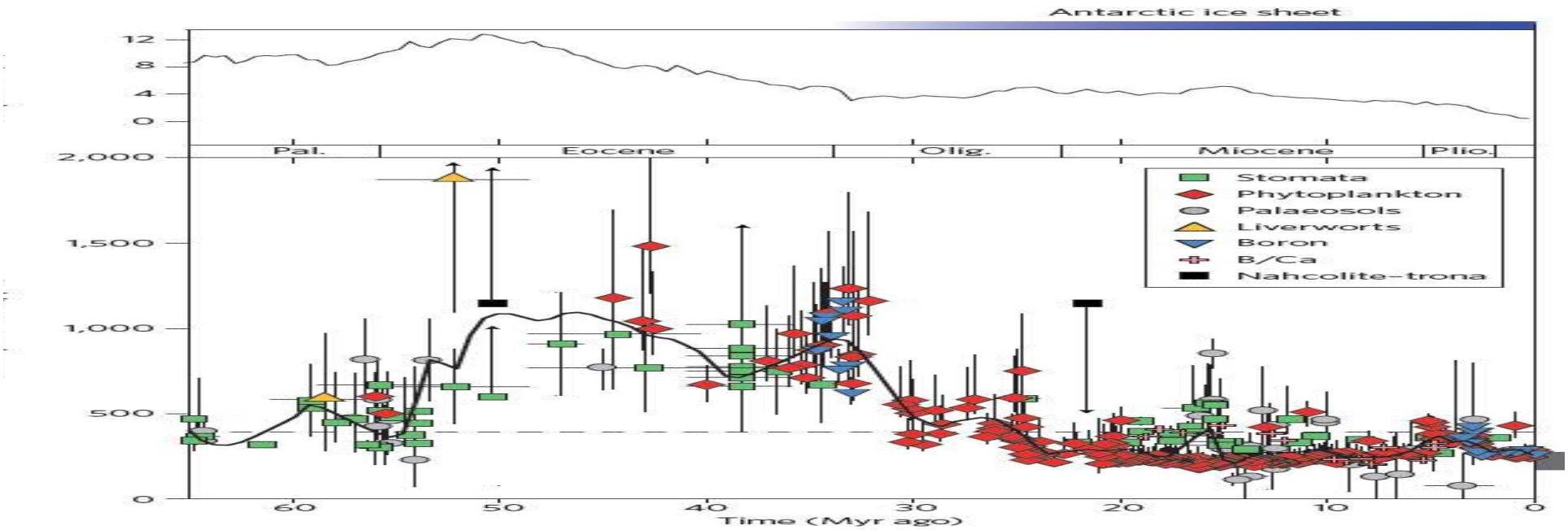
Zachos et al. 2008

Correlation of CO_2 and temperature over last 65 million years

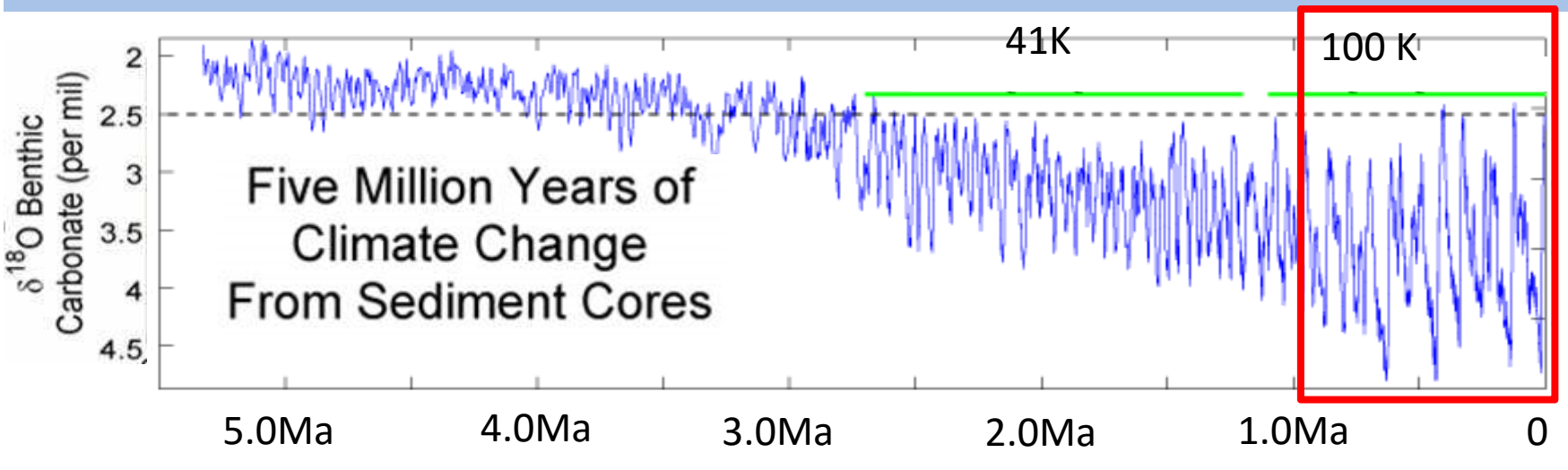


Beerling and Royer, Nature 2011

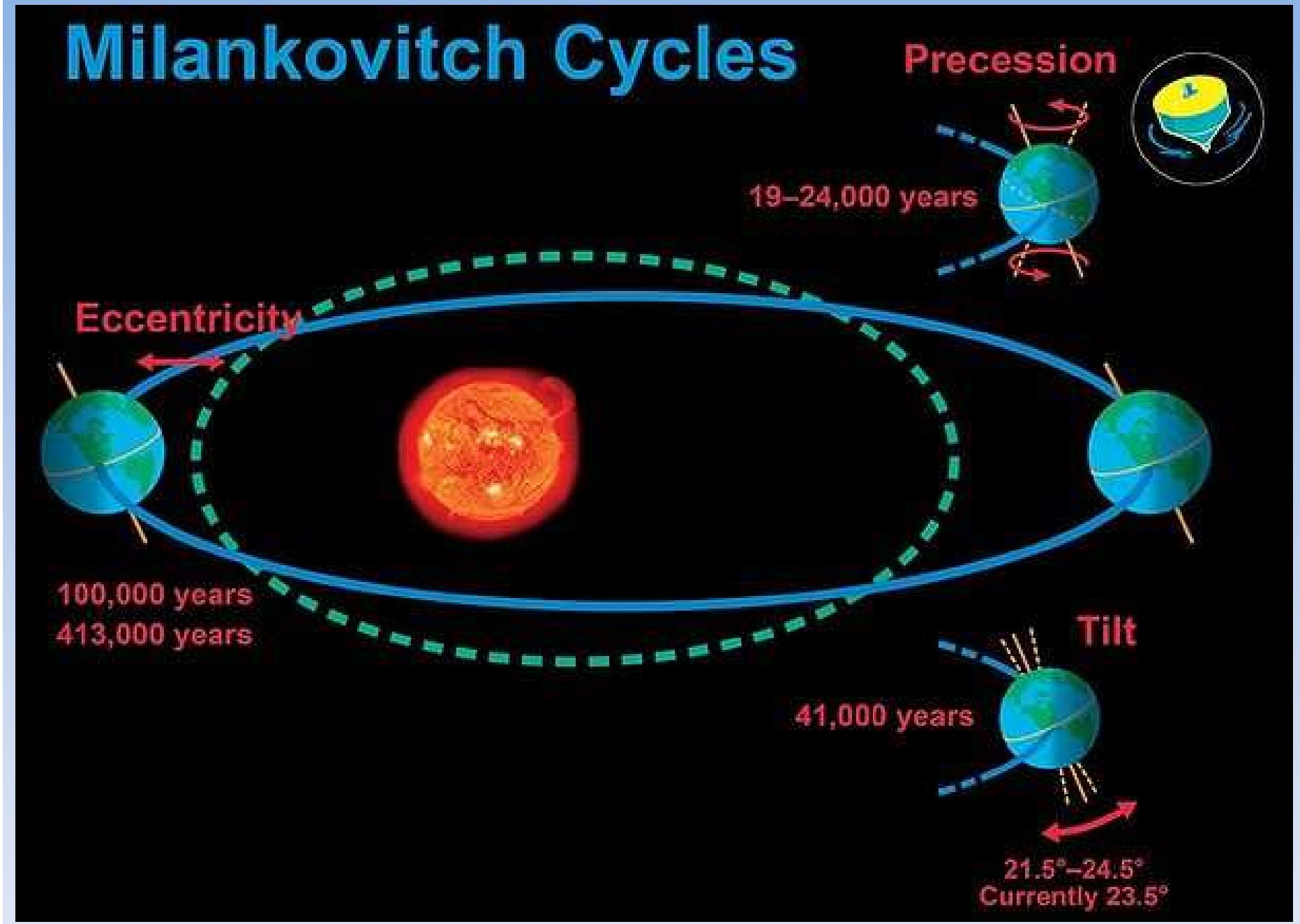

Global Deep Ocean Temperature
PETM
Antarctic Ice Sheet
N. Hemisphere Ice Sheets
India Collides with Eurasia
Azolla event:
~ 49 Ma
Antarctic Glaciation
Temperature (°C)
12
8
4
0
60
50
40
30
20
10
0
Time (Million Years Before Present)


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)

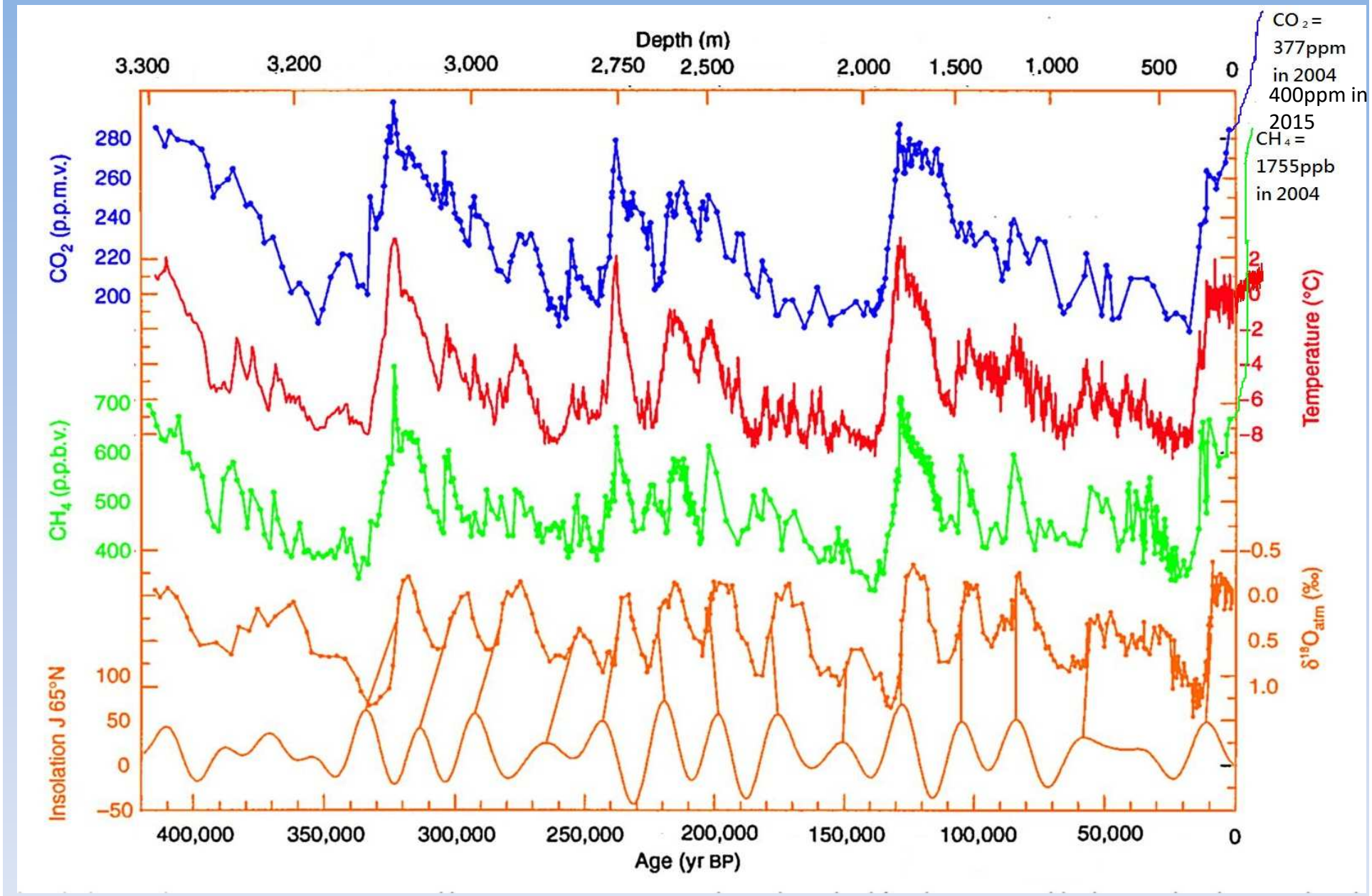
Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



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

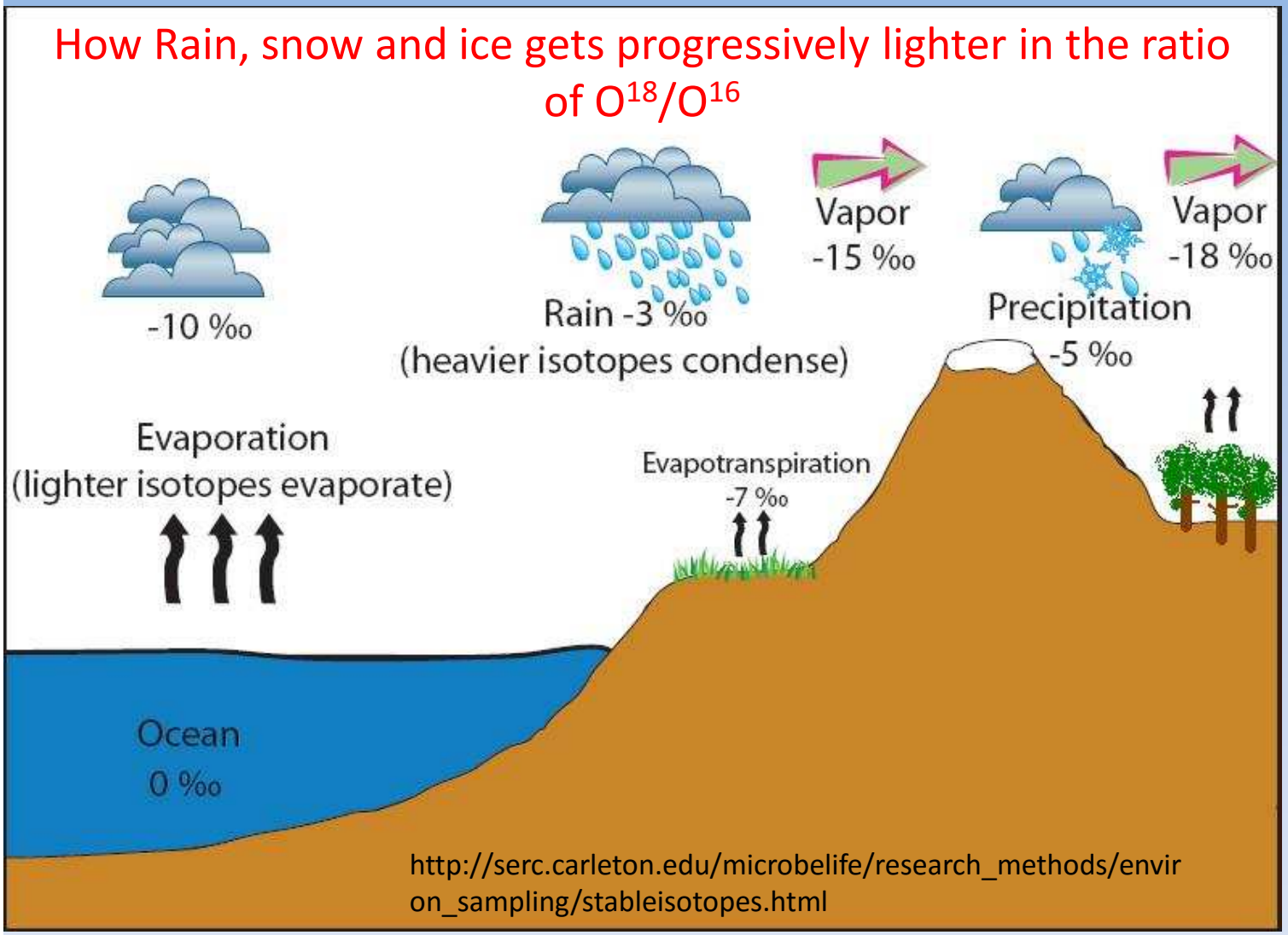


http://cnx.org/content/m38572/1.5/



http://www.antarcticglaciers.org/climate-change/

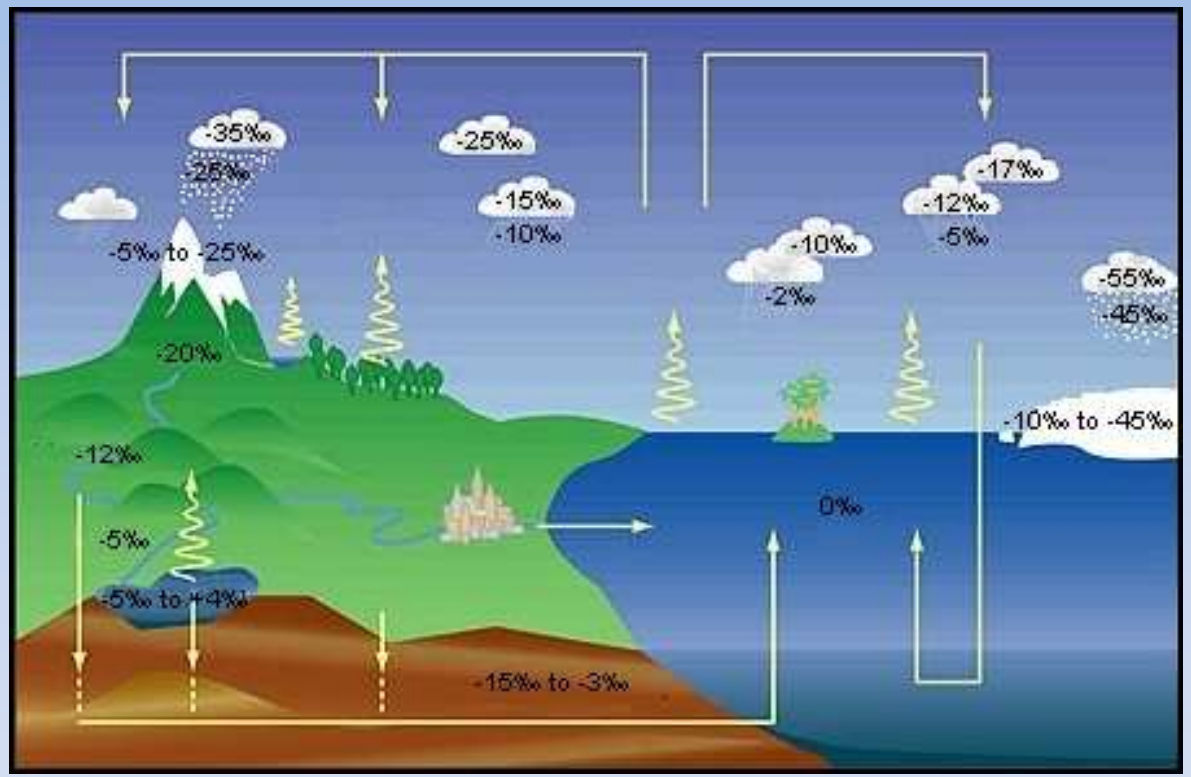
How Rain, snow and ice gets progressively lighter in the ratio of O^{18}/O^{16}



http://serc.carleton.edu/microbelife/research_methods/environ_sampling/stableisotopes.html

Normal Oxygen has 6 protons and 6 neutrons referred to as O^{16}. The rarer stable isotope of oxygen has 2 extra neutrons and is referred to as O^{18}

How Rain, snow and ice gets progressively lighter in the ratio of O^{18}/O^{16}



http://atoc.colorado.edu/~dcn/SWING/overview.php

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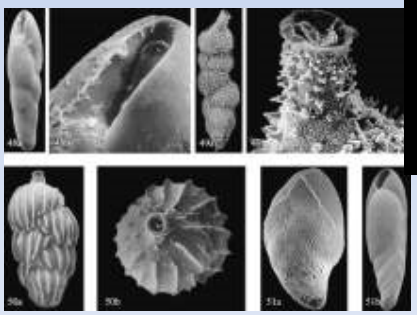
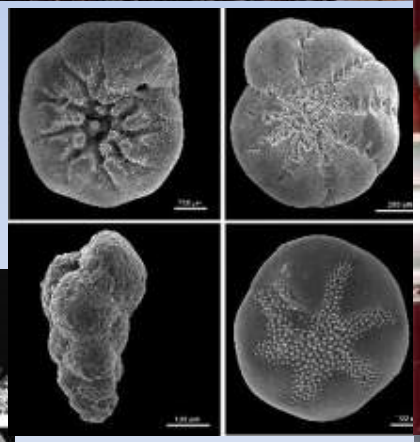
Scientific History of Climate change – PROXY DATA





Long-term Carbon Cycle: rocks

Two generalized reactions…

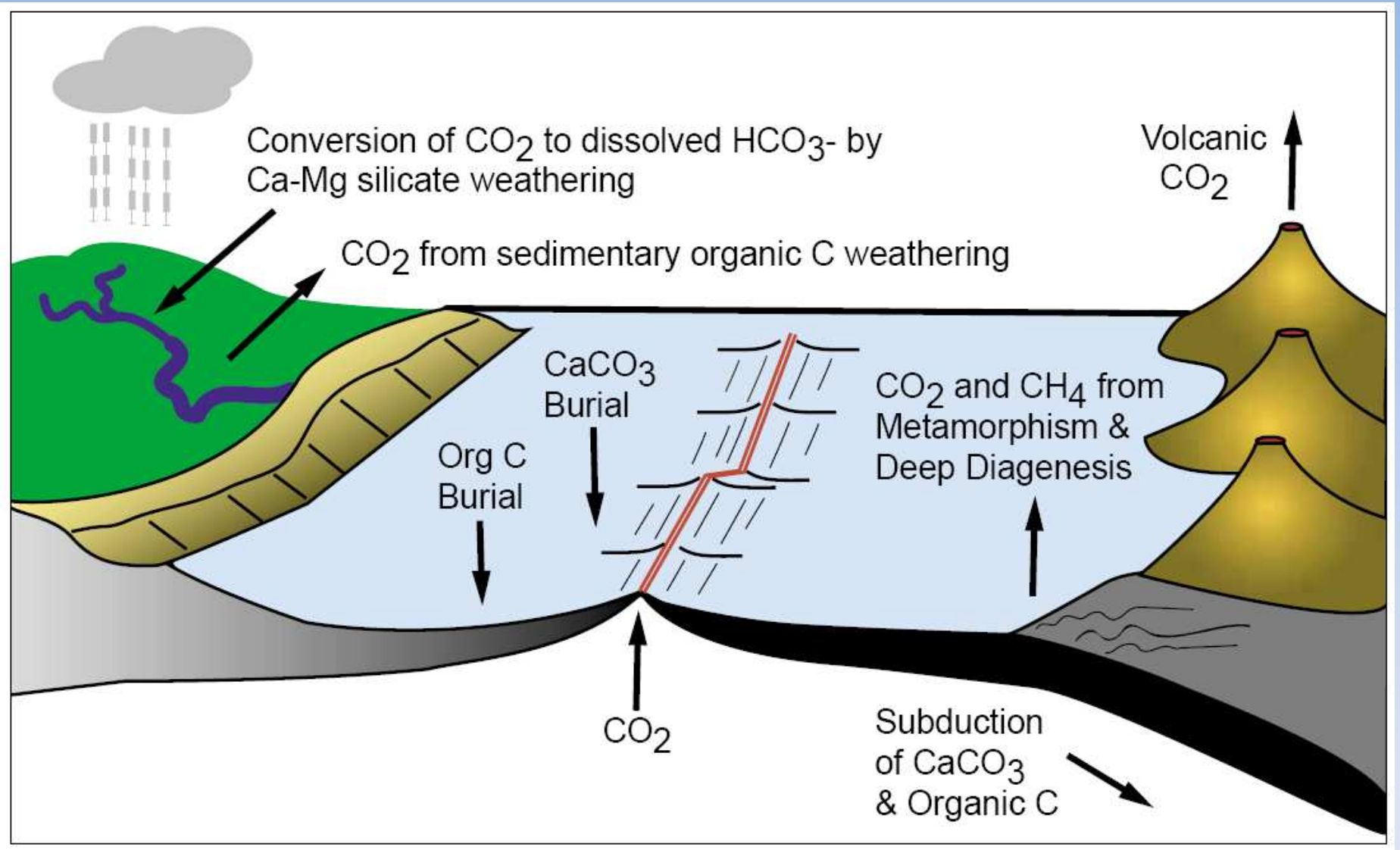
Photosynthesis/Respiration

$$CO_2 + H_20 \leftrightarrow CH_2O + O_2$$

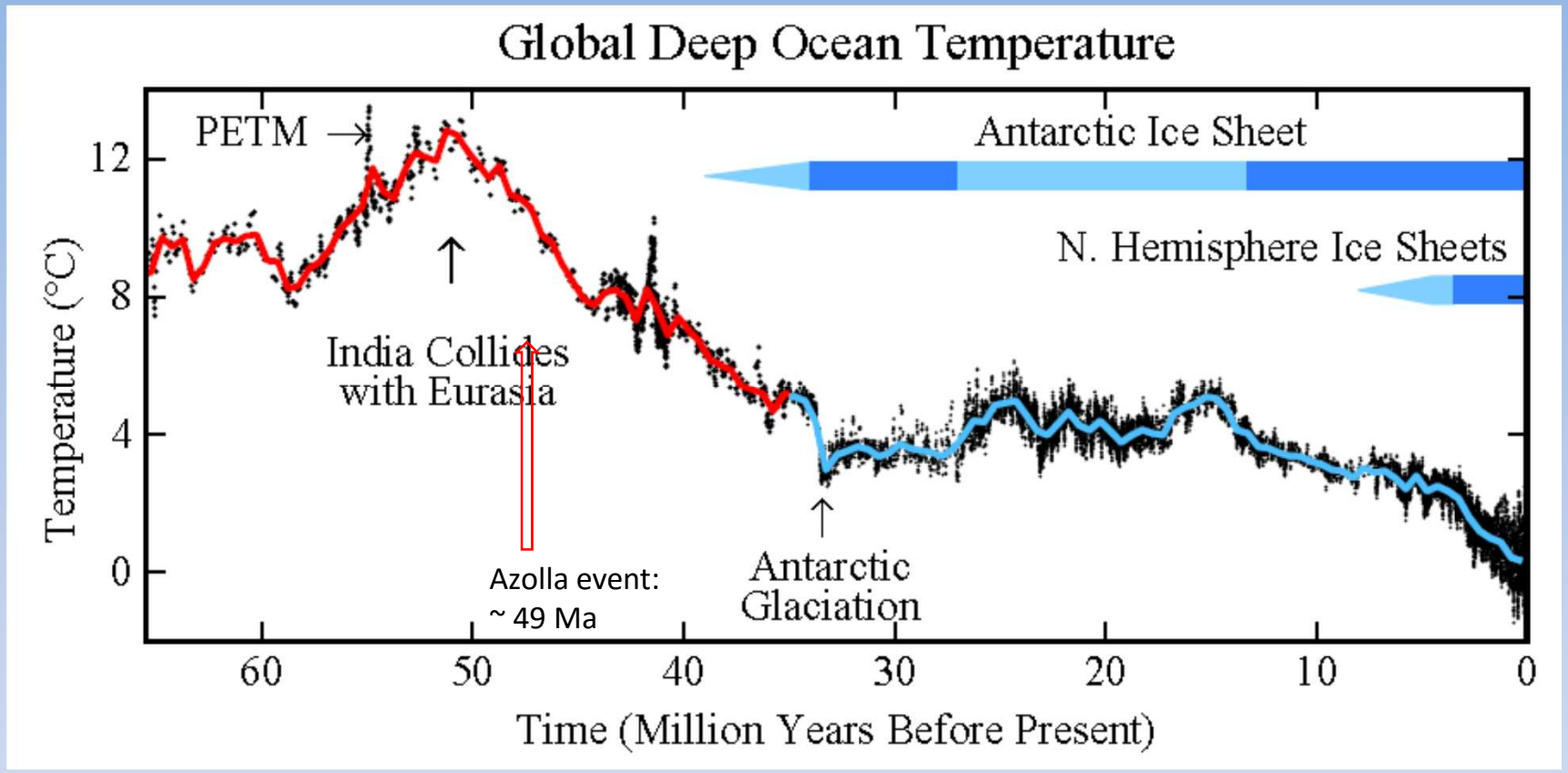
Weathering/Precipitation

$$CO_2 + CaSiO_3 \leftrightarrow CaCO_3 + SiO_2$$

Long-term carbon cycle: *rocks*



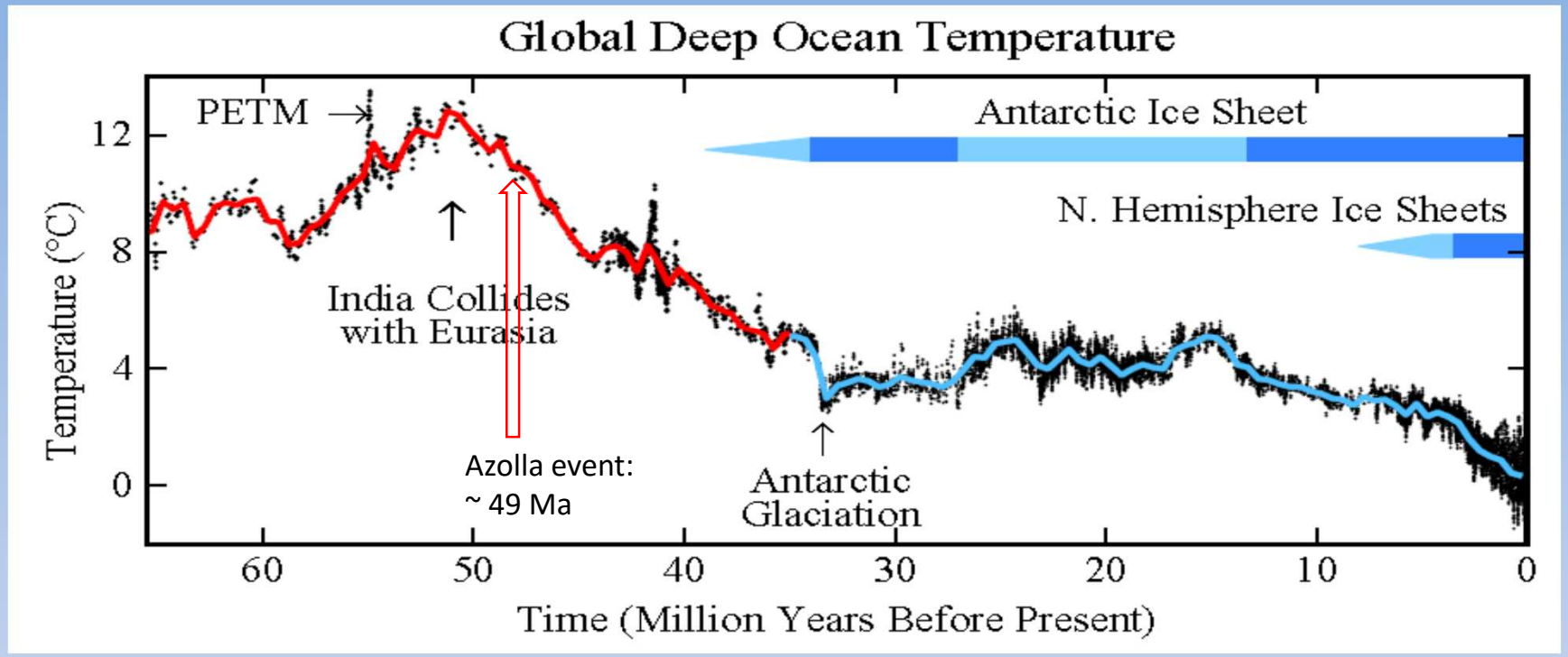
Berner, 2001



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.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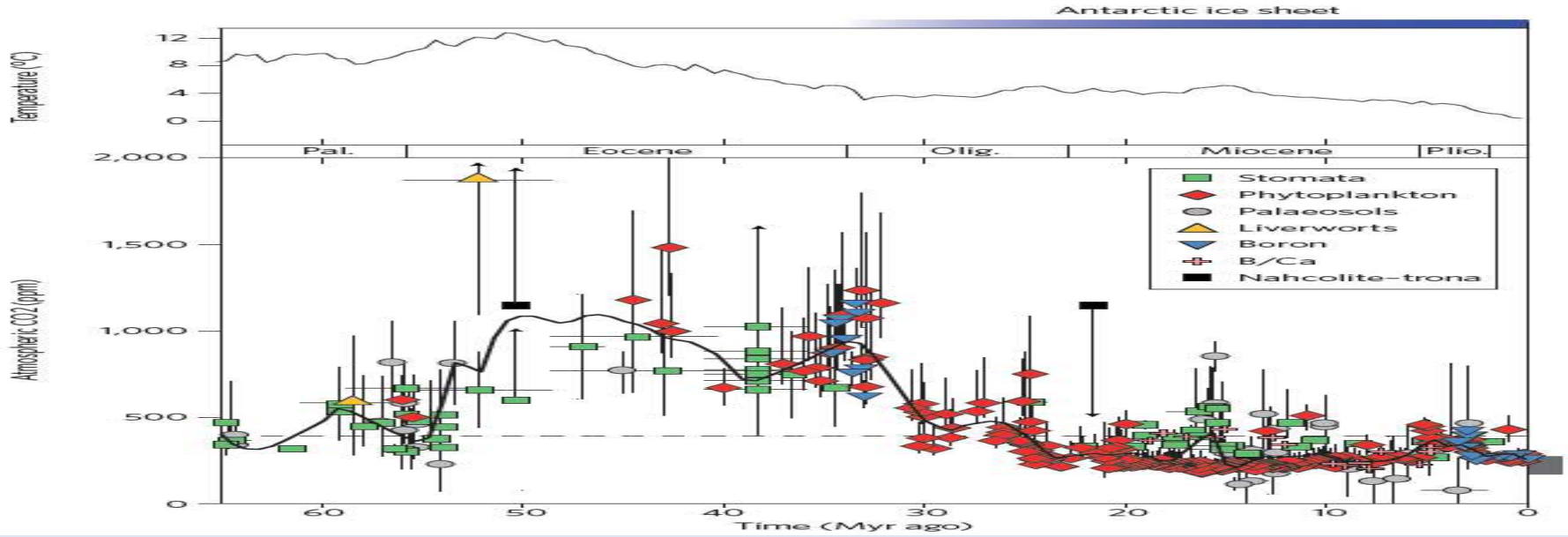
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Temperature (°C)
12
8
4
0
Pal.
Eocene
Olig.
Miocene
Plio.
2,000
1,500
1,000
500
0
Atmospheric CO2 (ppm)
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
60
50
40
30
20
10
0
Time (Myr ago)

So – what changed?

Volcanism decreased; some slowing of spreading rates: less CO_2 emitted by volcanoes

Weathering/Precipitation increased; India colliding into Asia/Himalayans

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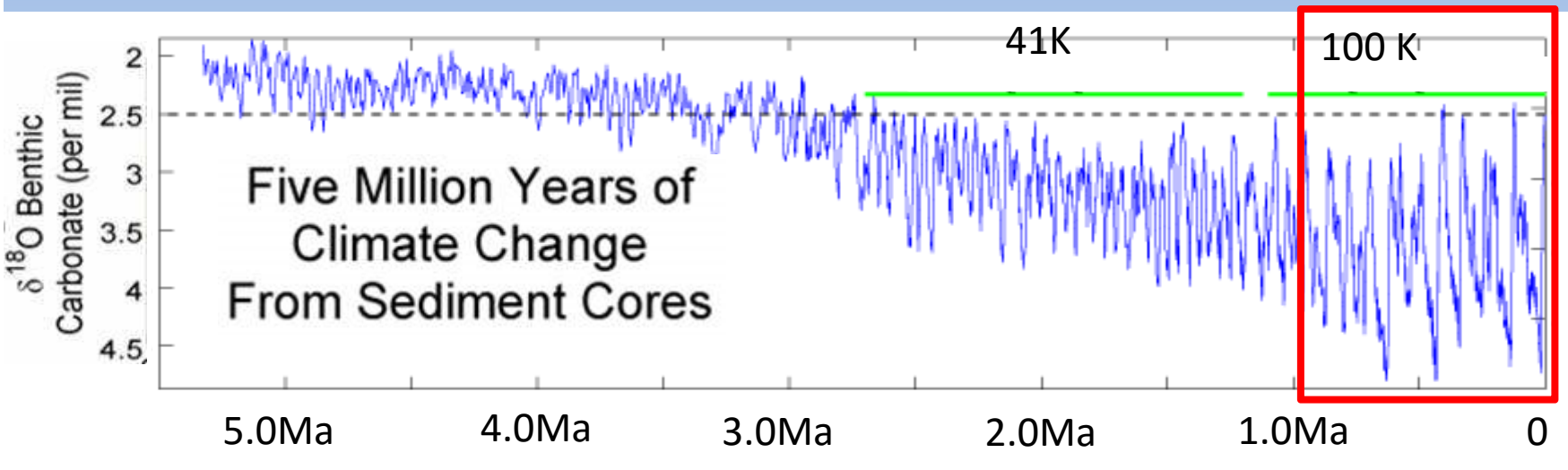
Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



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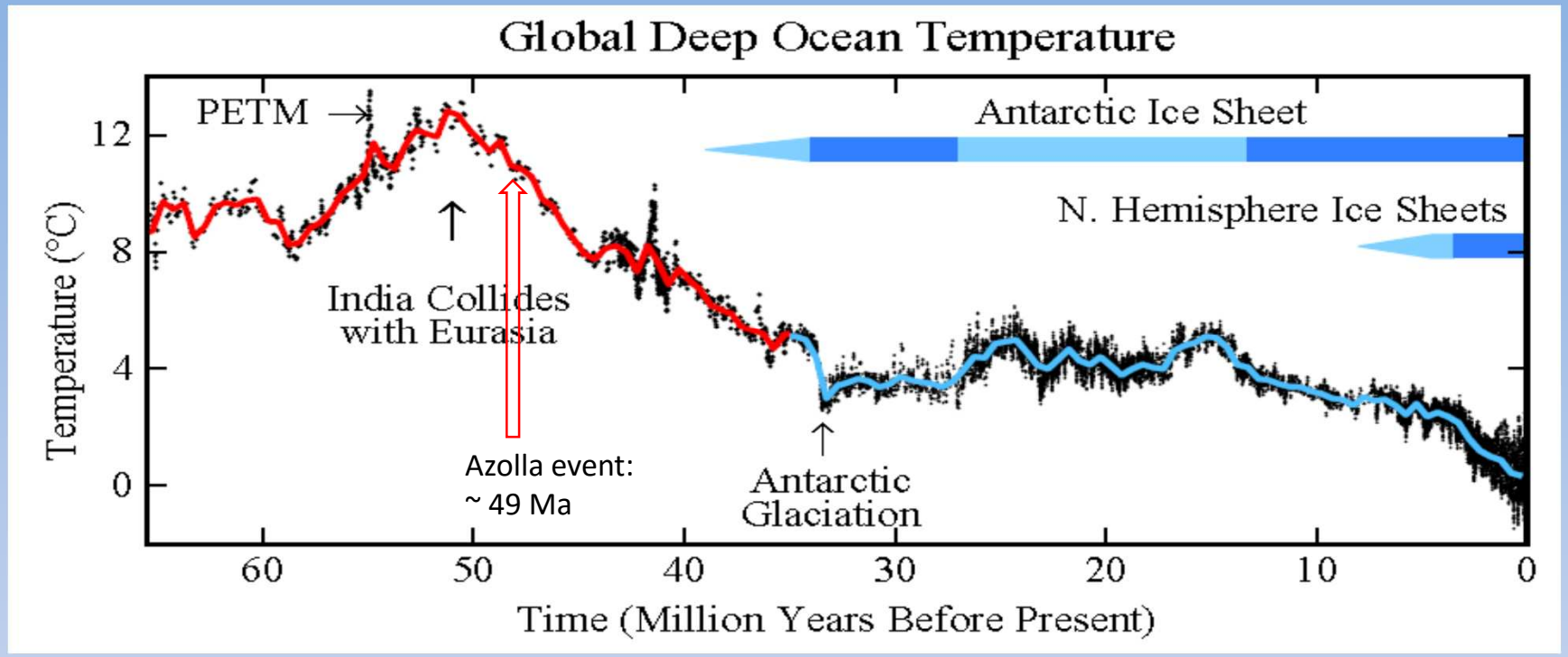
End of week 2
EXTRAS FOLLOW

Paleocene/Eocene Thermal Maximum
PETM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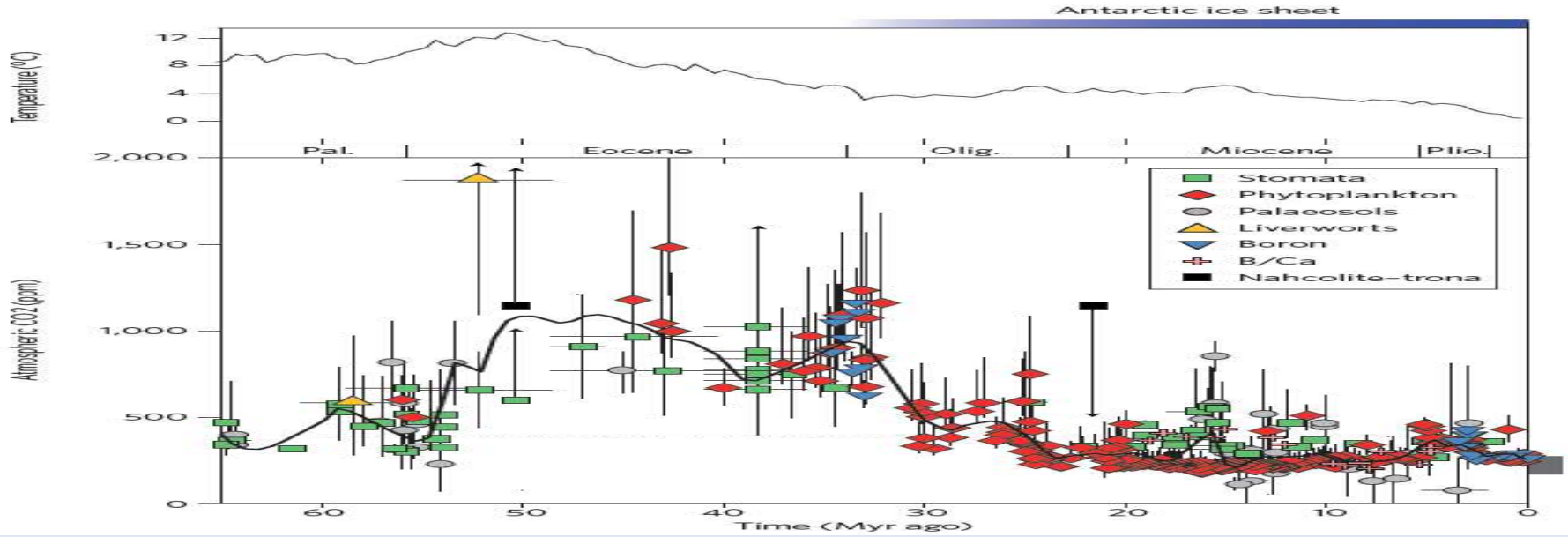
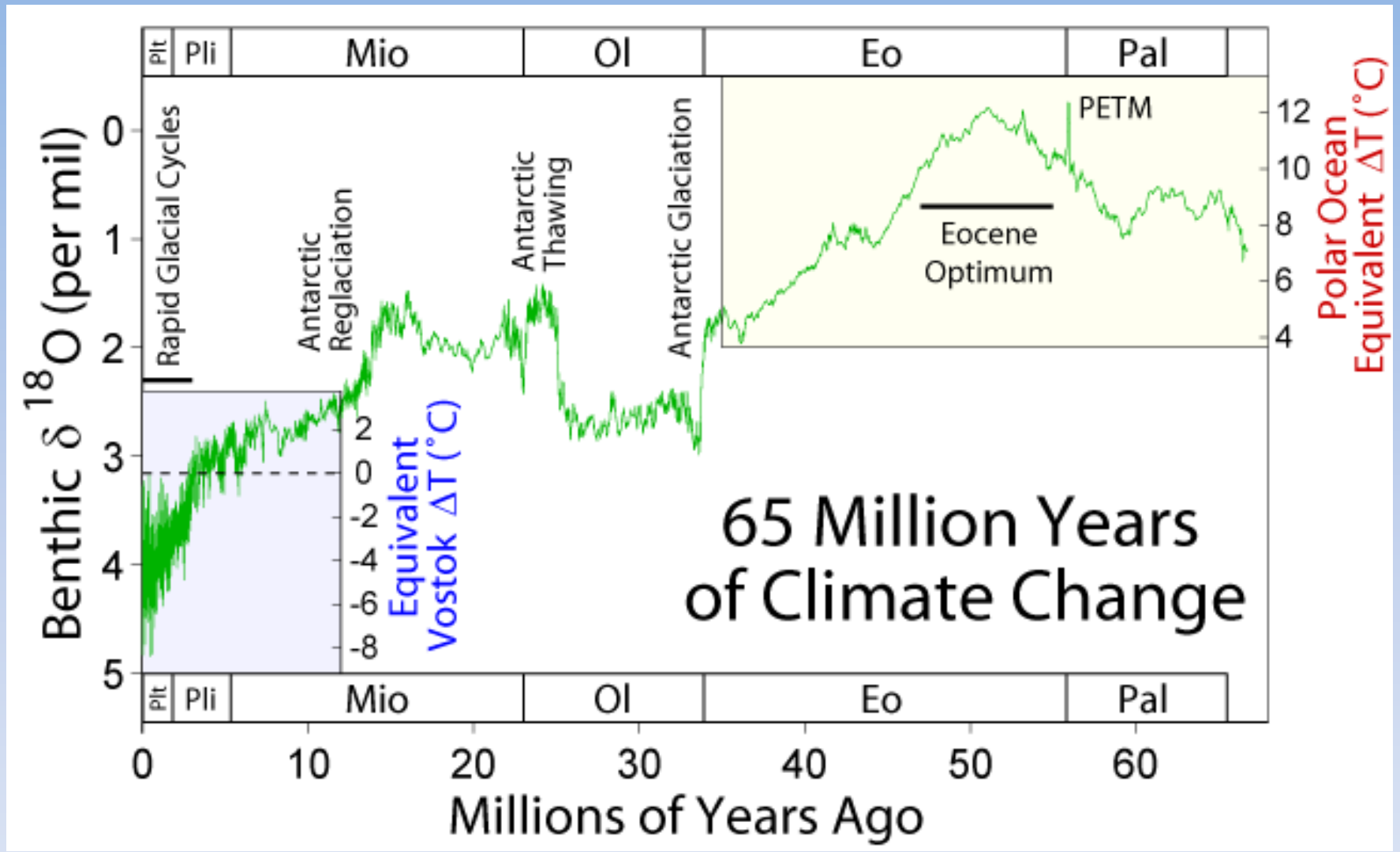
Azolla event: ~ 49 Ma
Antarctic Glaciation
Temperature (°C)
12
8
4
0
60
50
40
30
20
10
0
Time (Million Years Before Present)

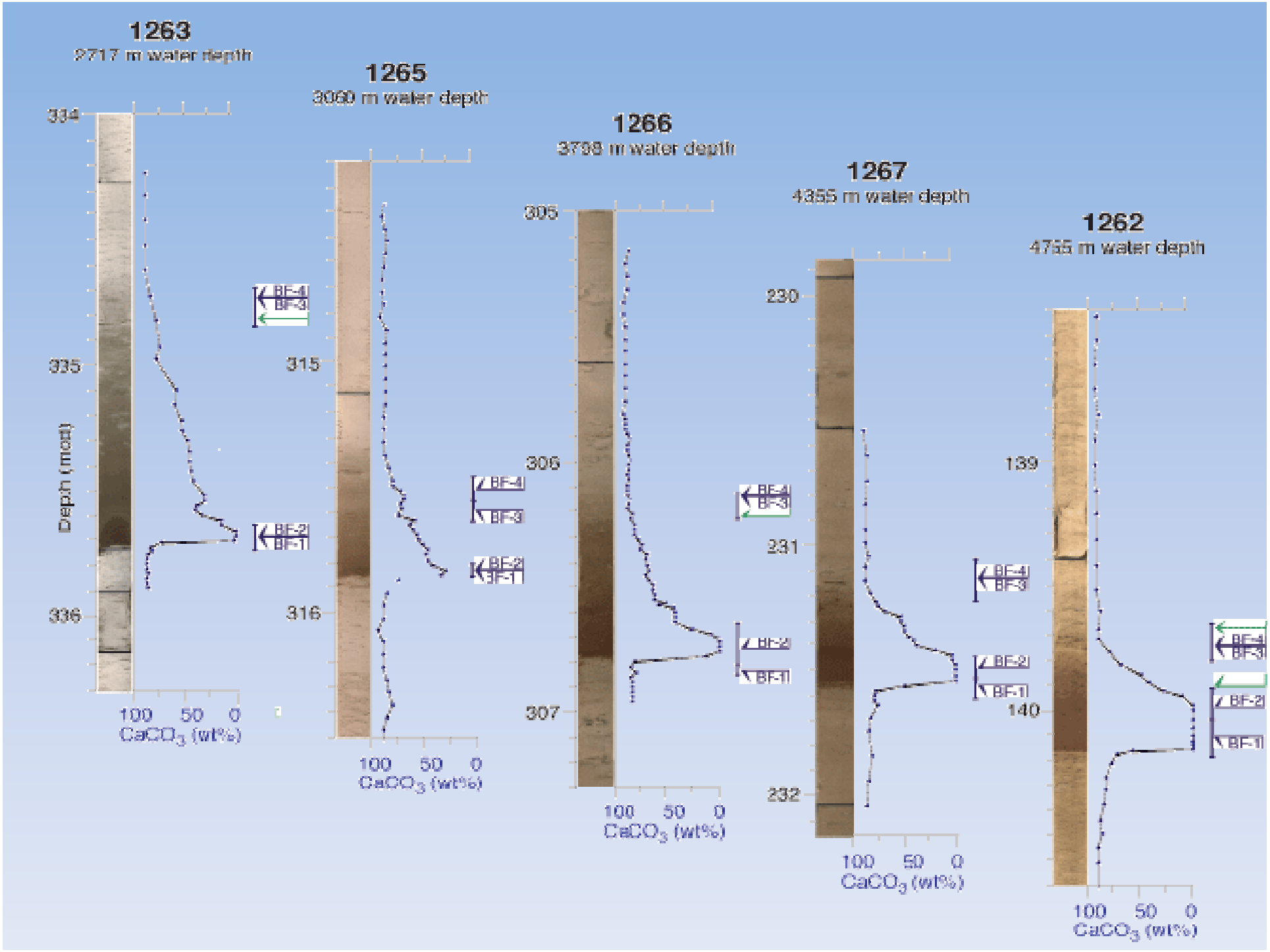

Antarctic ice sheet
Temperature (°C)
12
8
4
0
Pal.
Eocene
Olig.
Miocene
Plio.
2,000
1,500
1,000
500
0
Atmospheric CO2 (ppm)
Stomata
Phytoplankton
Palaeosols
Liverworts
Boron
B/Ca
Nahcolite–trona
60
50
40
30
20
10
0
Time (Myr ago)

Proxy data: stable isotopes



Wikipedia

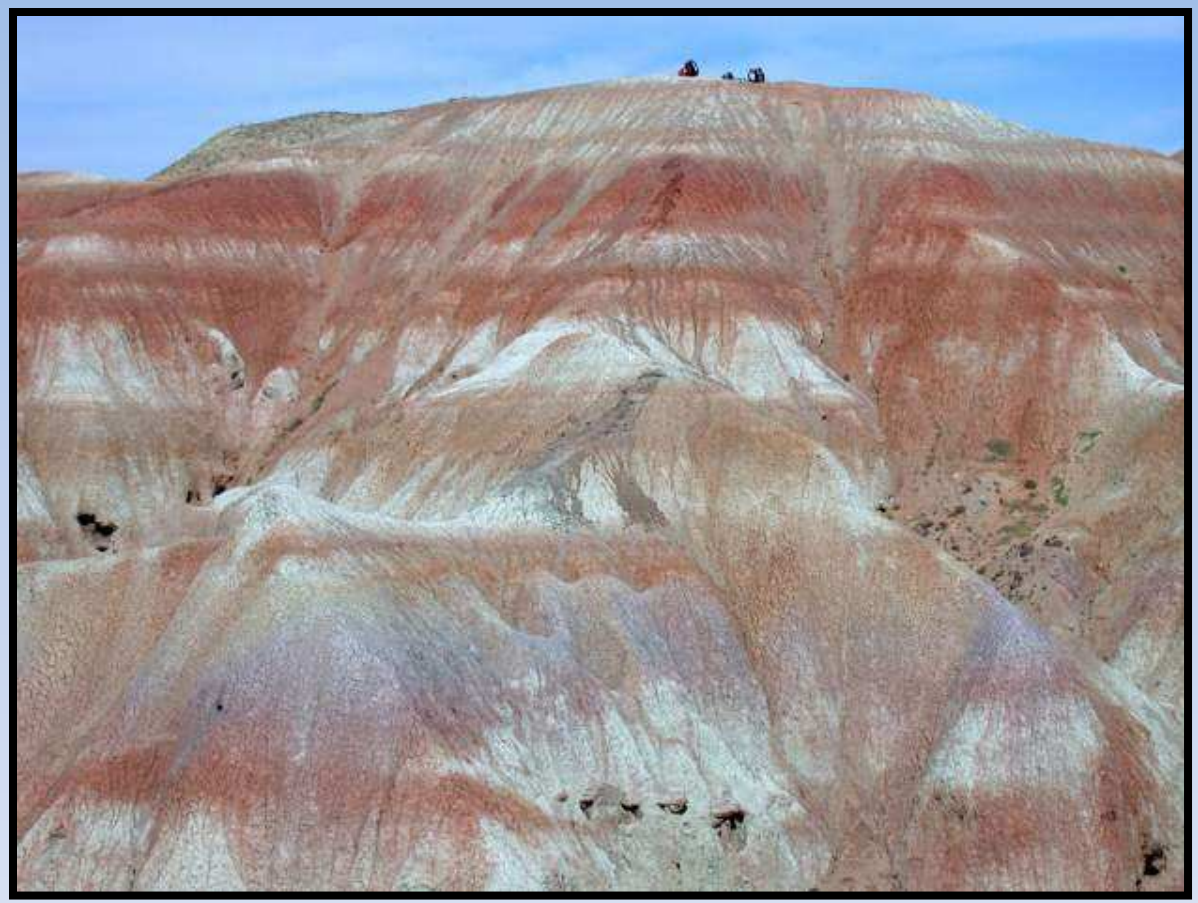

4 45 46 47 48 49 50 51 52 4 55 56 5
PMAG


1263
2717 m water depth
1265
3060 m water depth
1266
3738 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

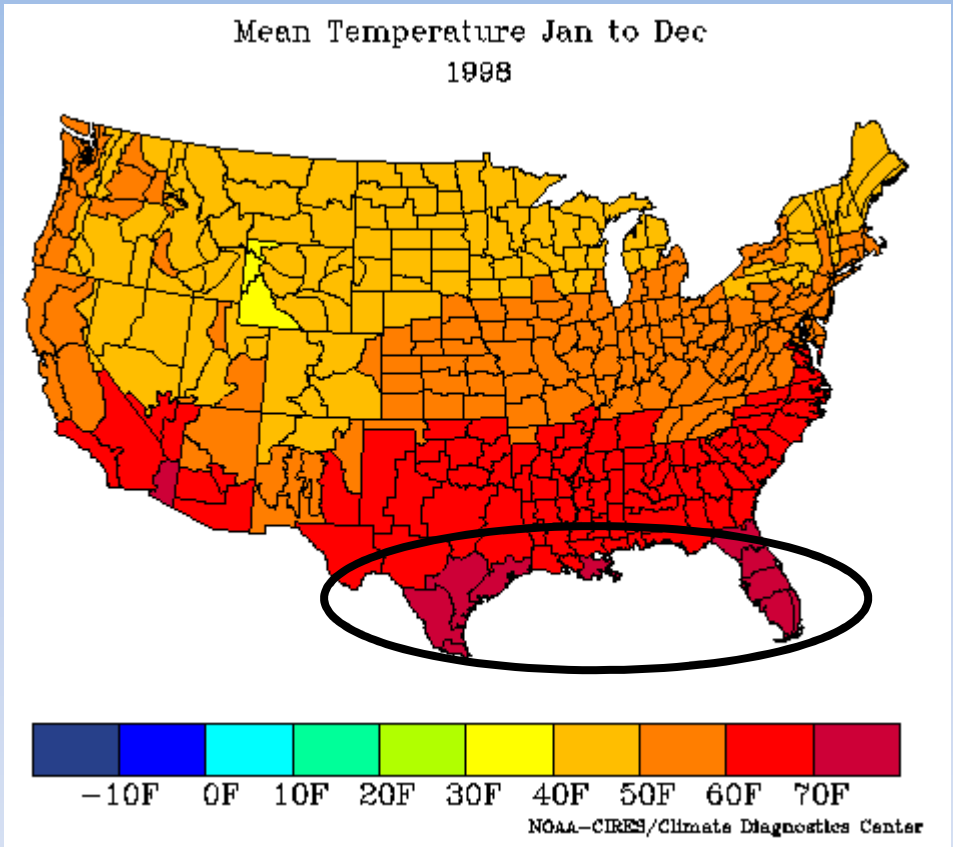


Paleosol Density

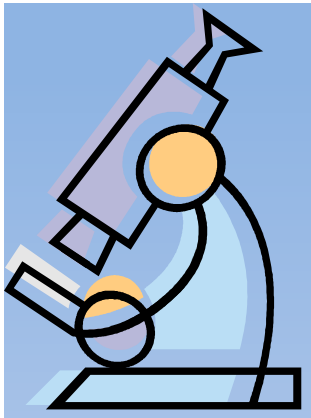
Bighorn Basin Climate

- Plant fossils and isotopes show Mean Annual Temperature of 20° to 25° C or 68 to 77° F

- Similar to Gulf Coast region today

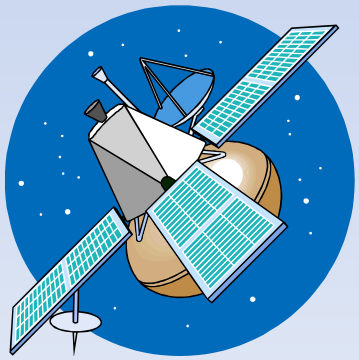


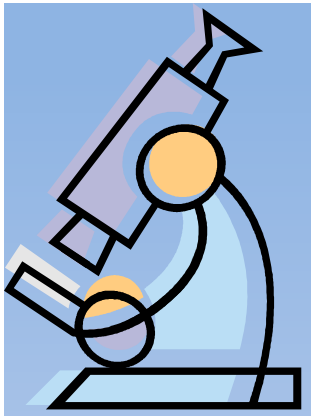
PROXY DATA-EXTRAS



FROM CSI TO GSI: GEOLOGICAL SAMPLE INVESTIGATION

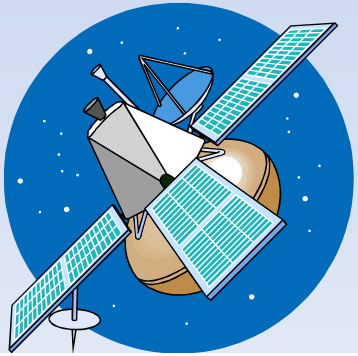
LET THE EVIDENCE SPEAK FOR ITSELF





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

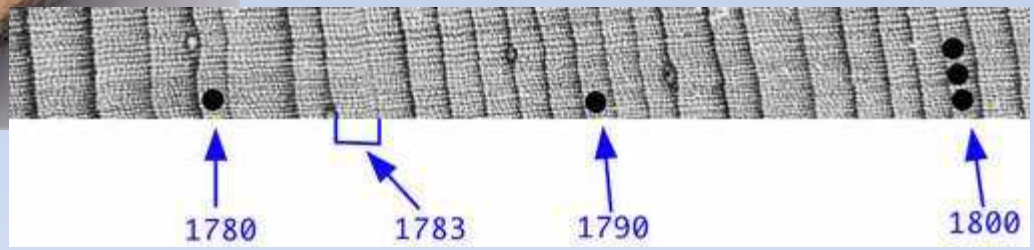
Born	May 28, 1807 Haut-Vully, Switzerland
Died	December 14, 1873 (aged 66) Cambridge, Massachusetts
Fields	Paleontology, Glaciology, Geology, Natural History
Alma mater	University of Erlangen-Nuremberg

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

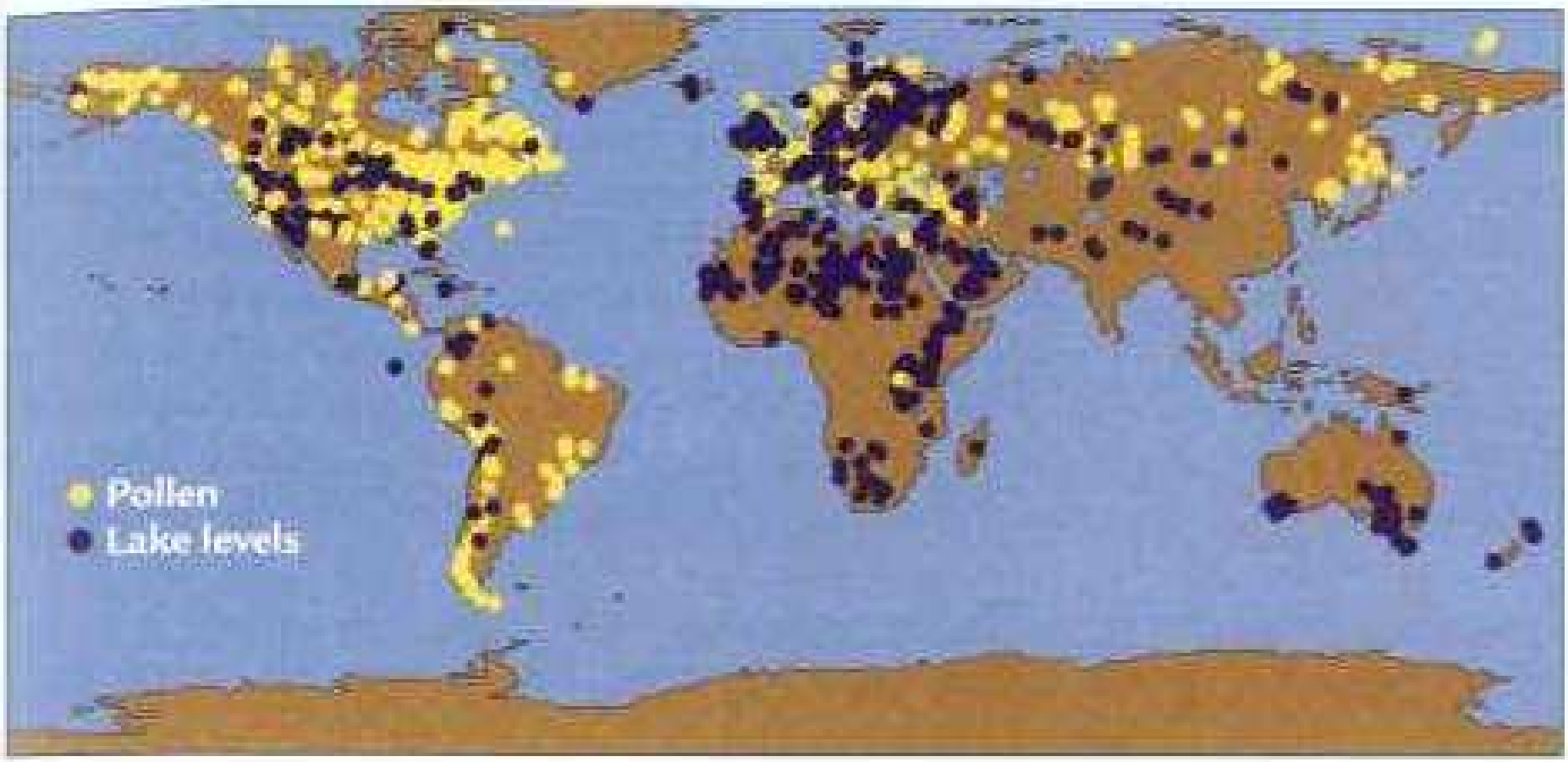
Photographic proxy data/evidence

Ruddiman, 2008

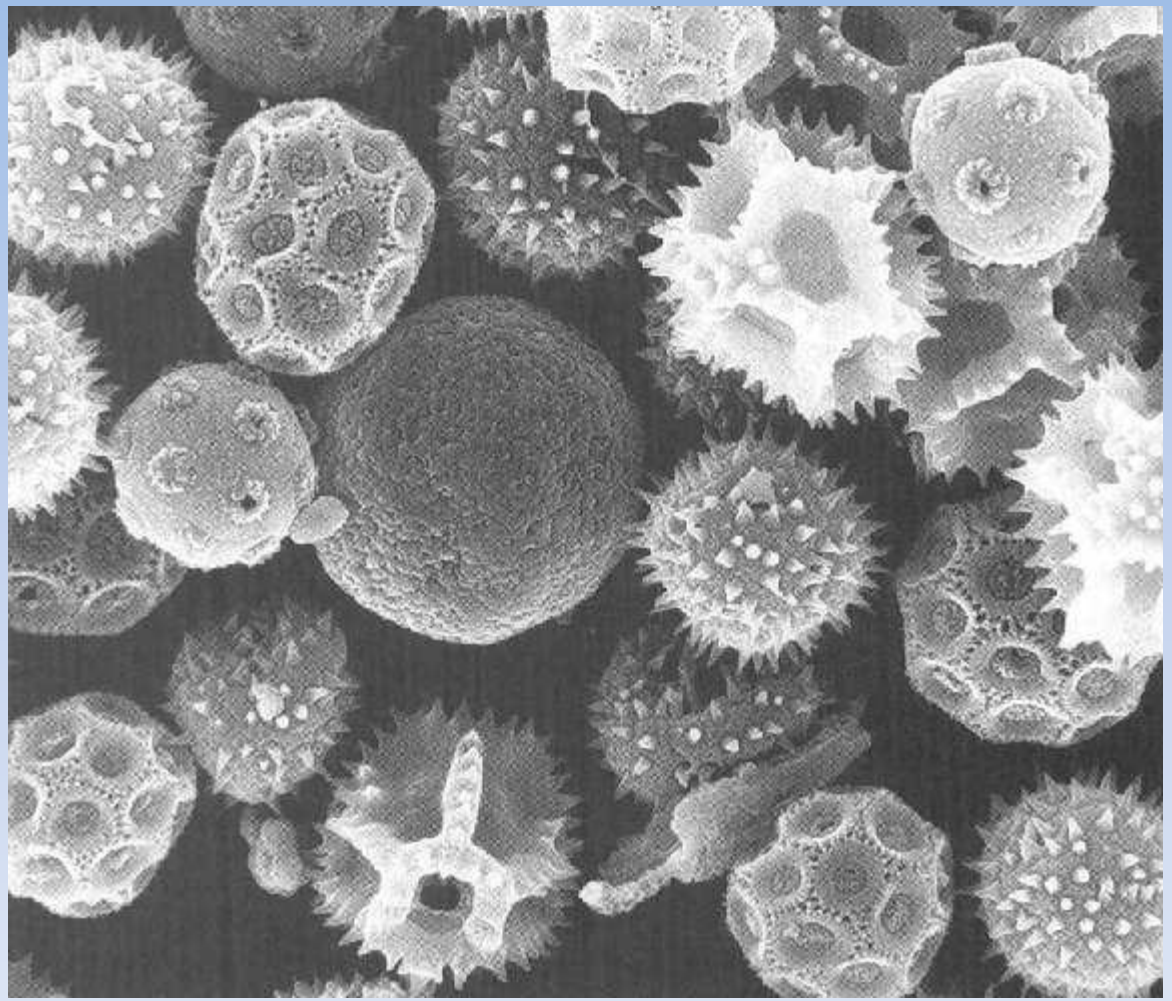
EARLY PROXY DATA: TREE RINGS



Pollen & Lake core data

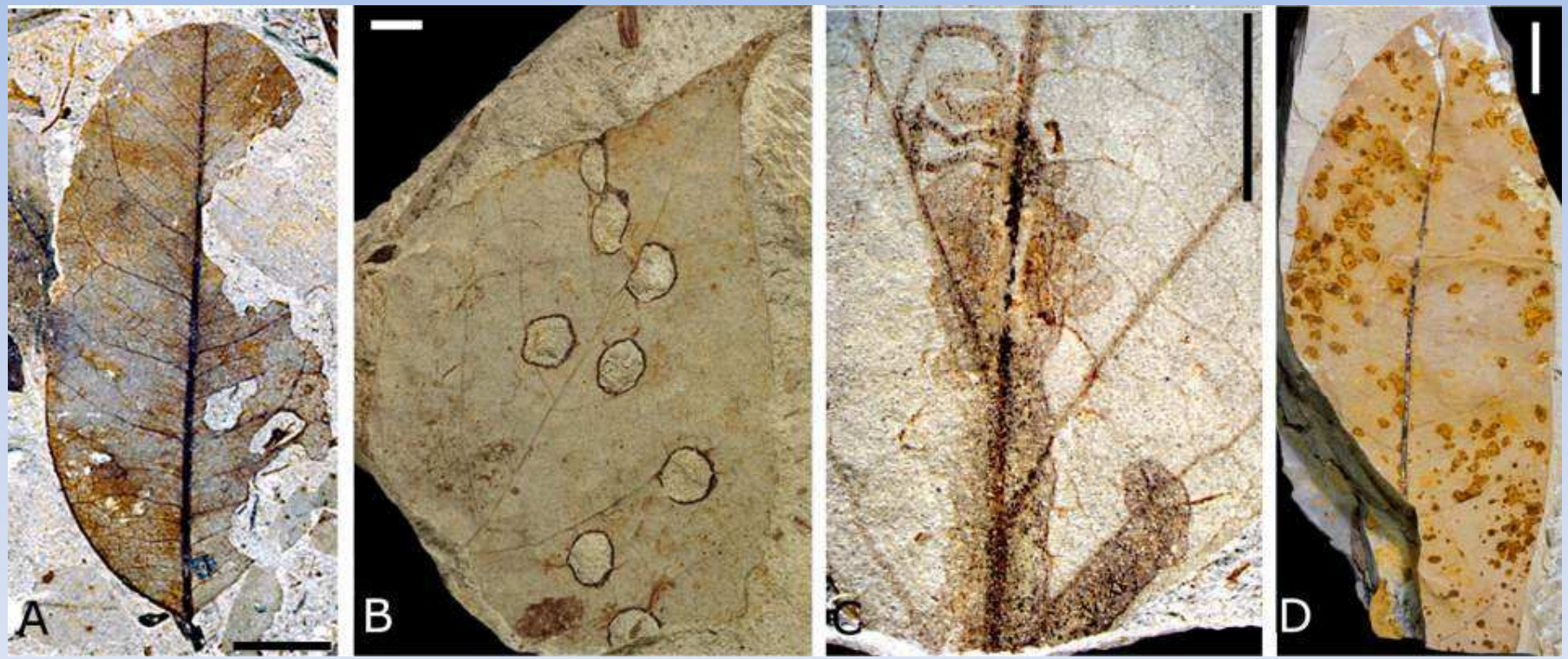


Ruddiman, 2008

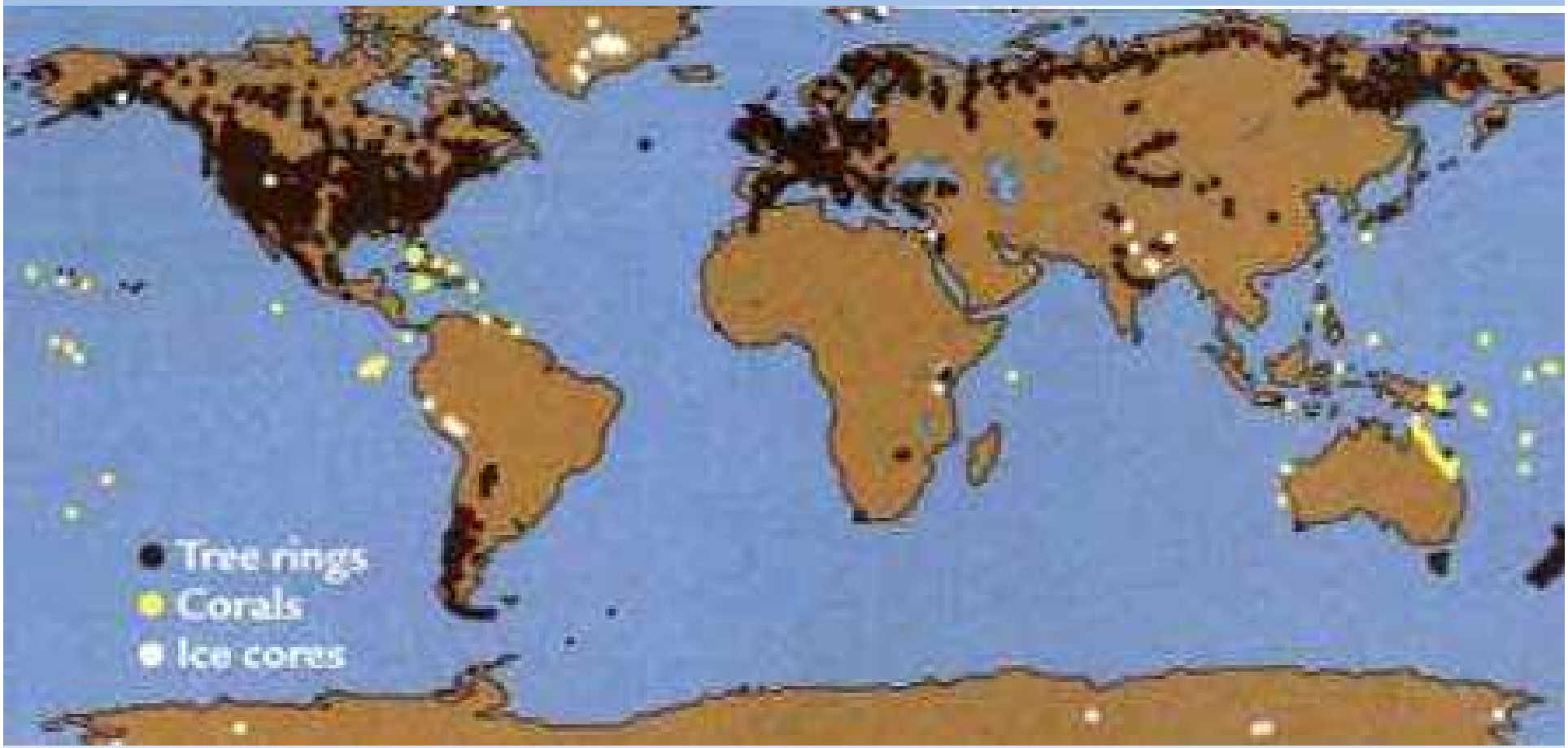


PROXY DATA: POLLEN DATA

PROXY DATA: LEAVES

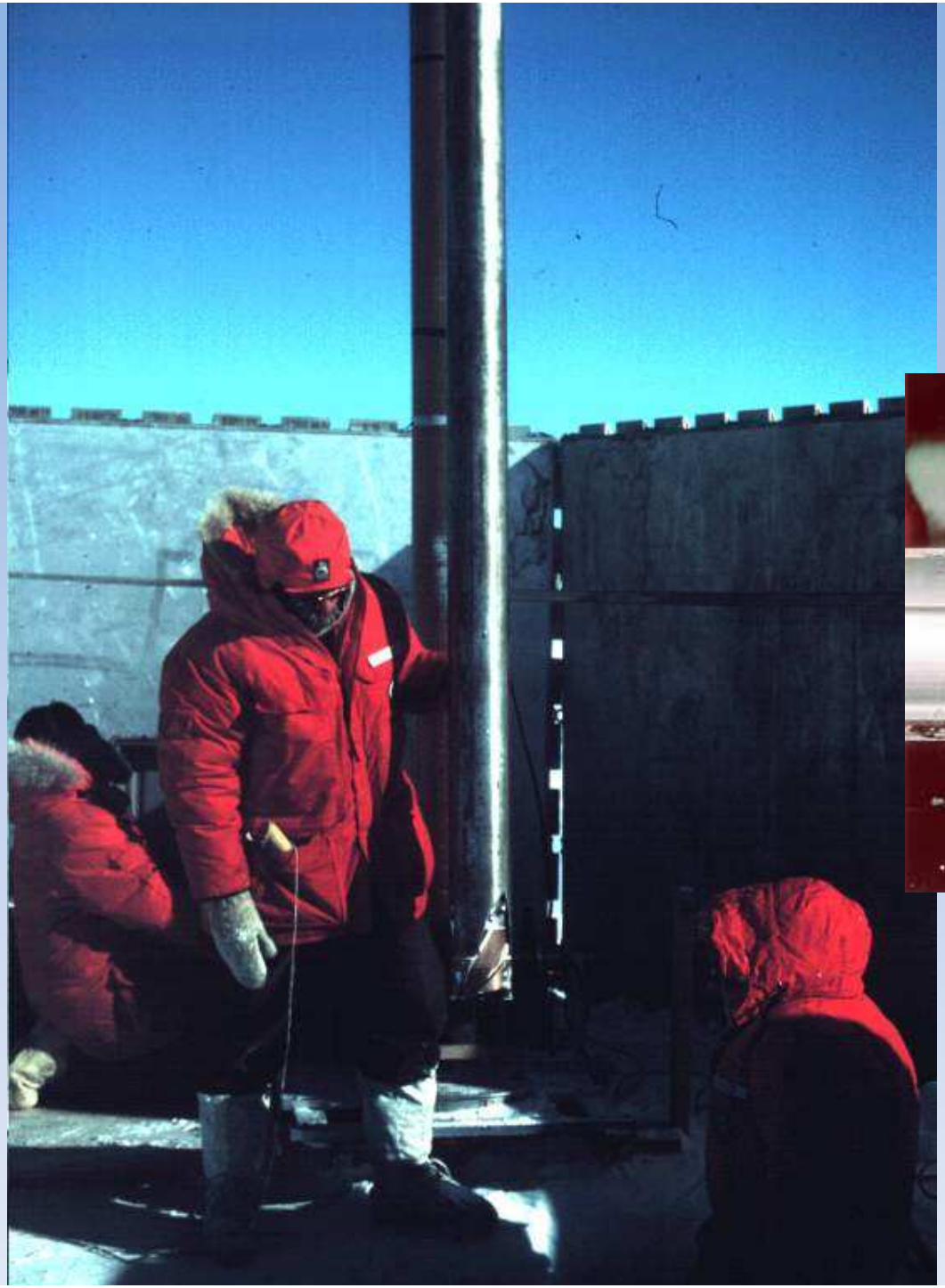


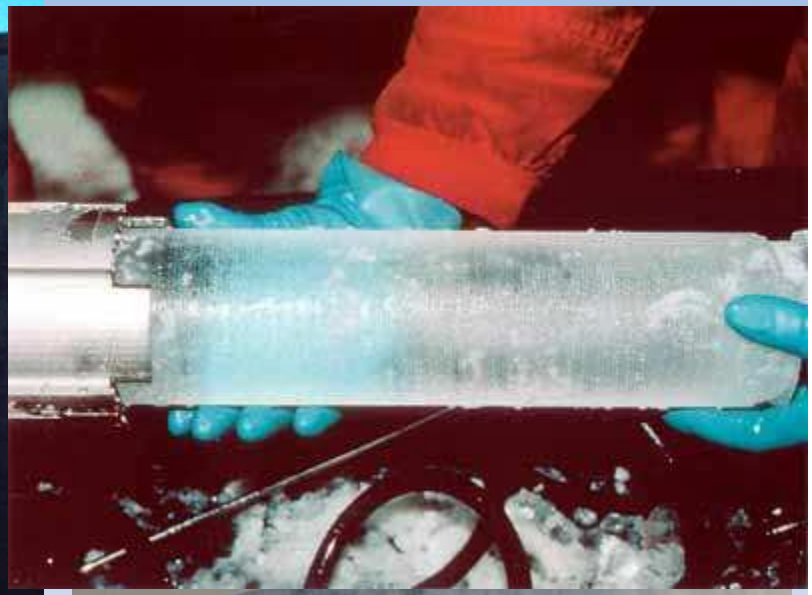
Tree rings, corals, ice cores



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).

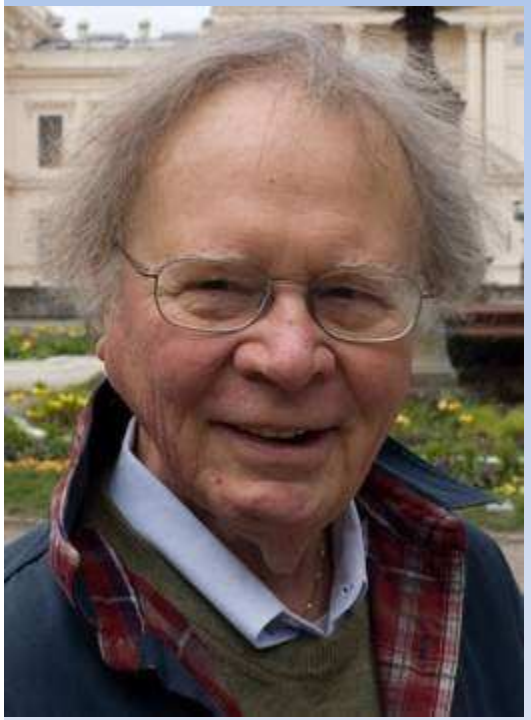
Cesare Emilani:

Paleontologist, Chemist

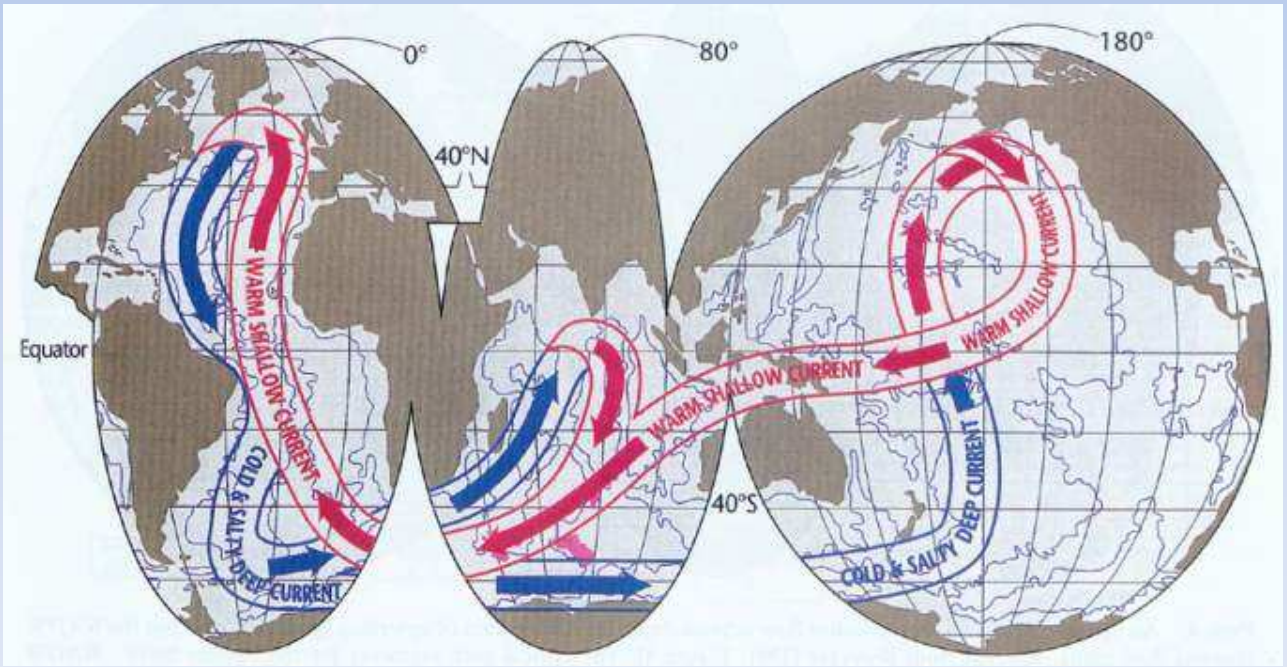
Father of Paleoceanography

Other Paleoceanographers

Wally Broecker

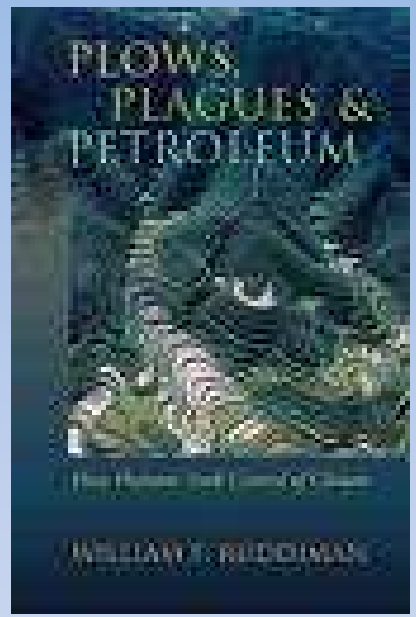


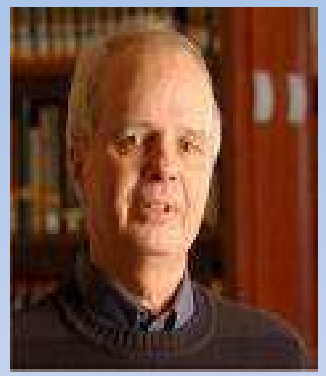
Thermal-haline "conveyor" belt of circulation



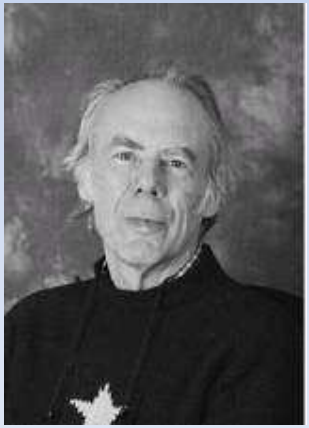
Other Paleoceanographers

Bill Ruddiman





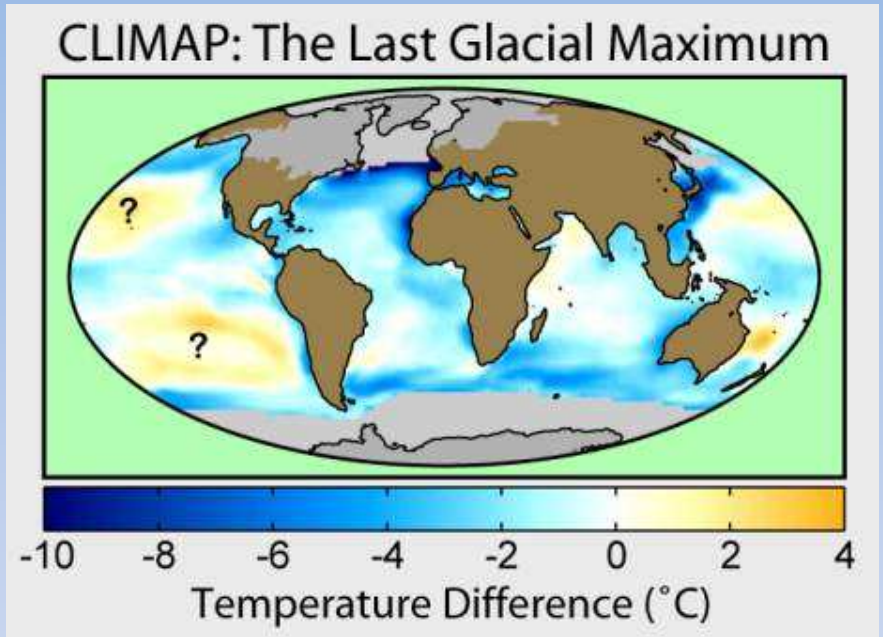
Nick Shackleton

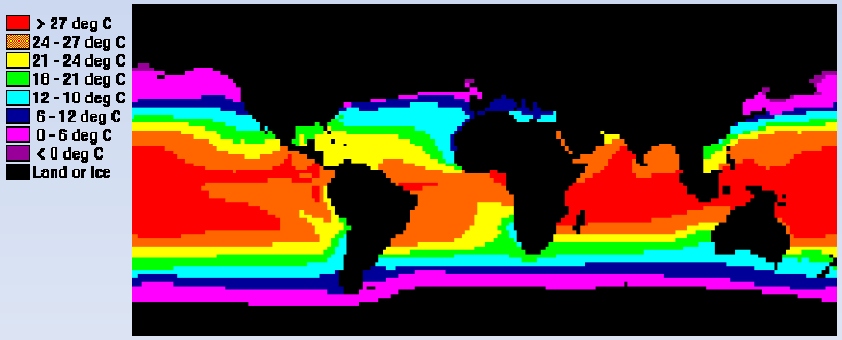


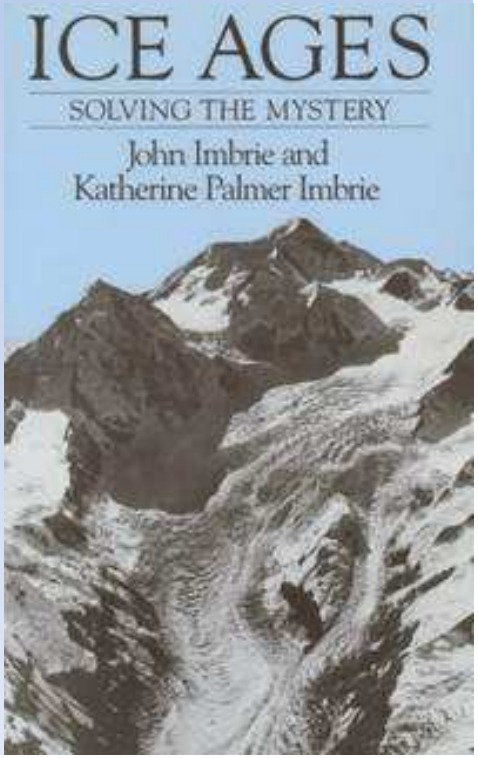
Other Paleoceanographers

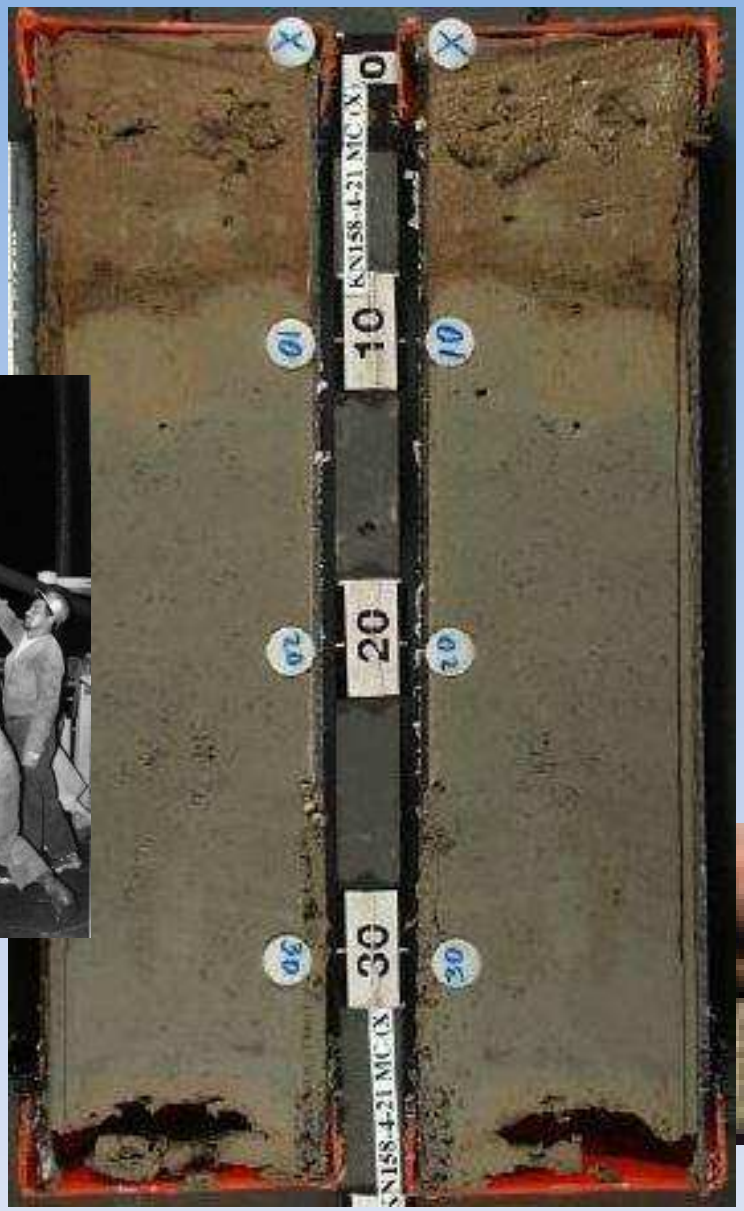
John Imbrie:

CLIMAP



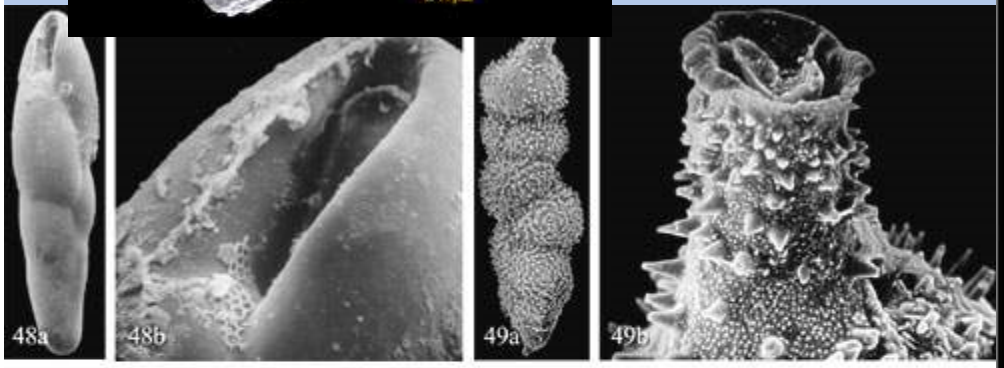


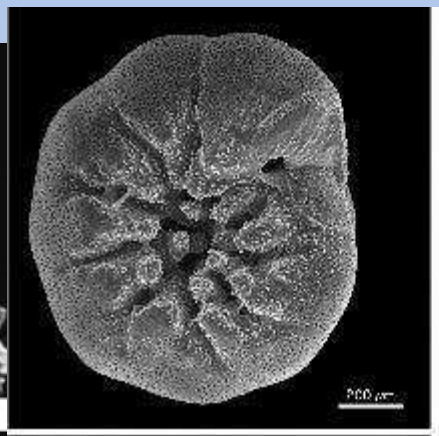


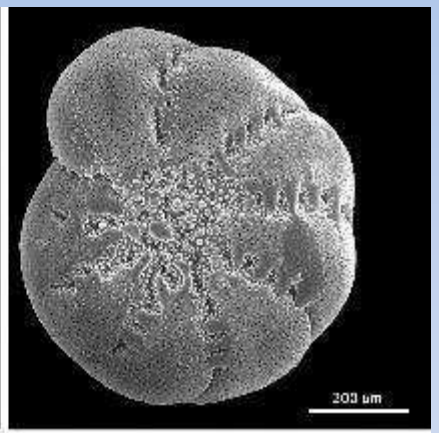


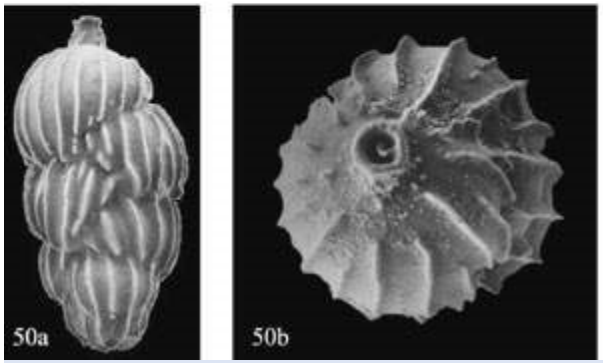
PROXY DATA:
CORE DATA

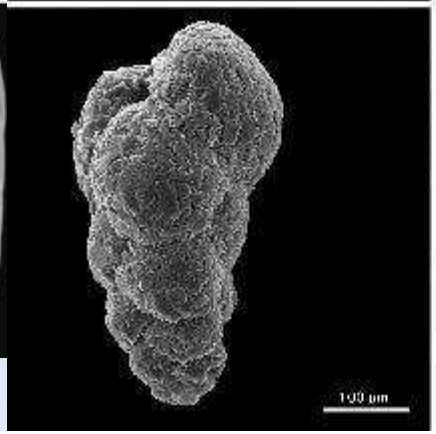
PROXY DATA: BENTHIC FORAMS

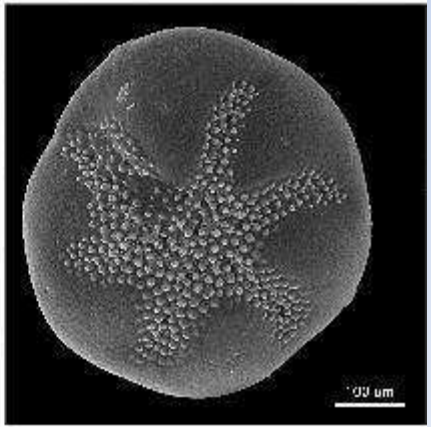


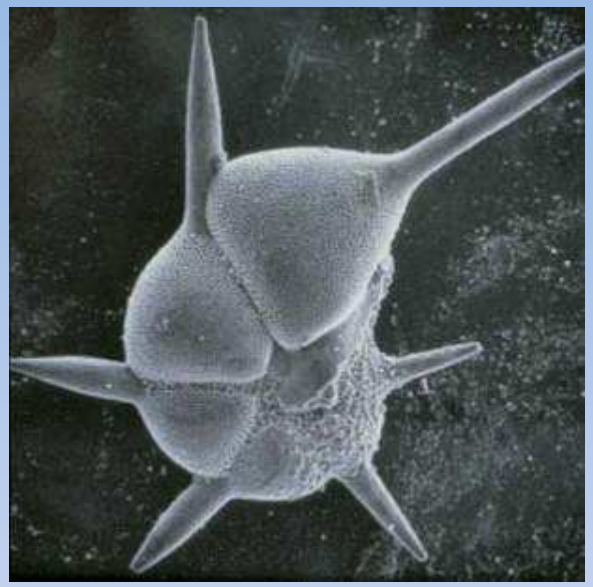




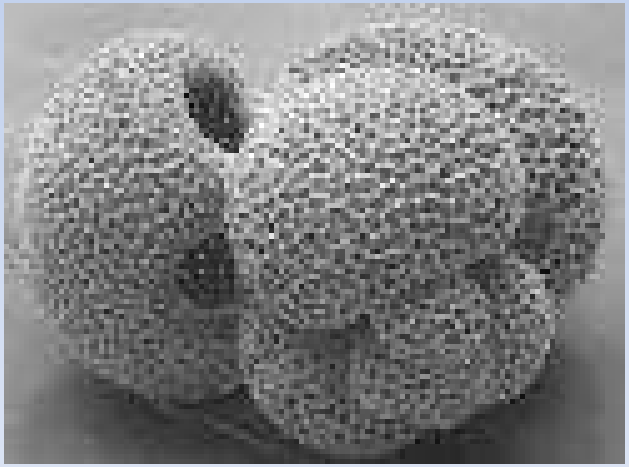




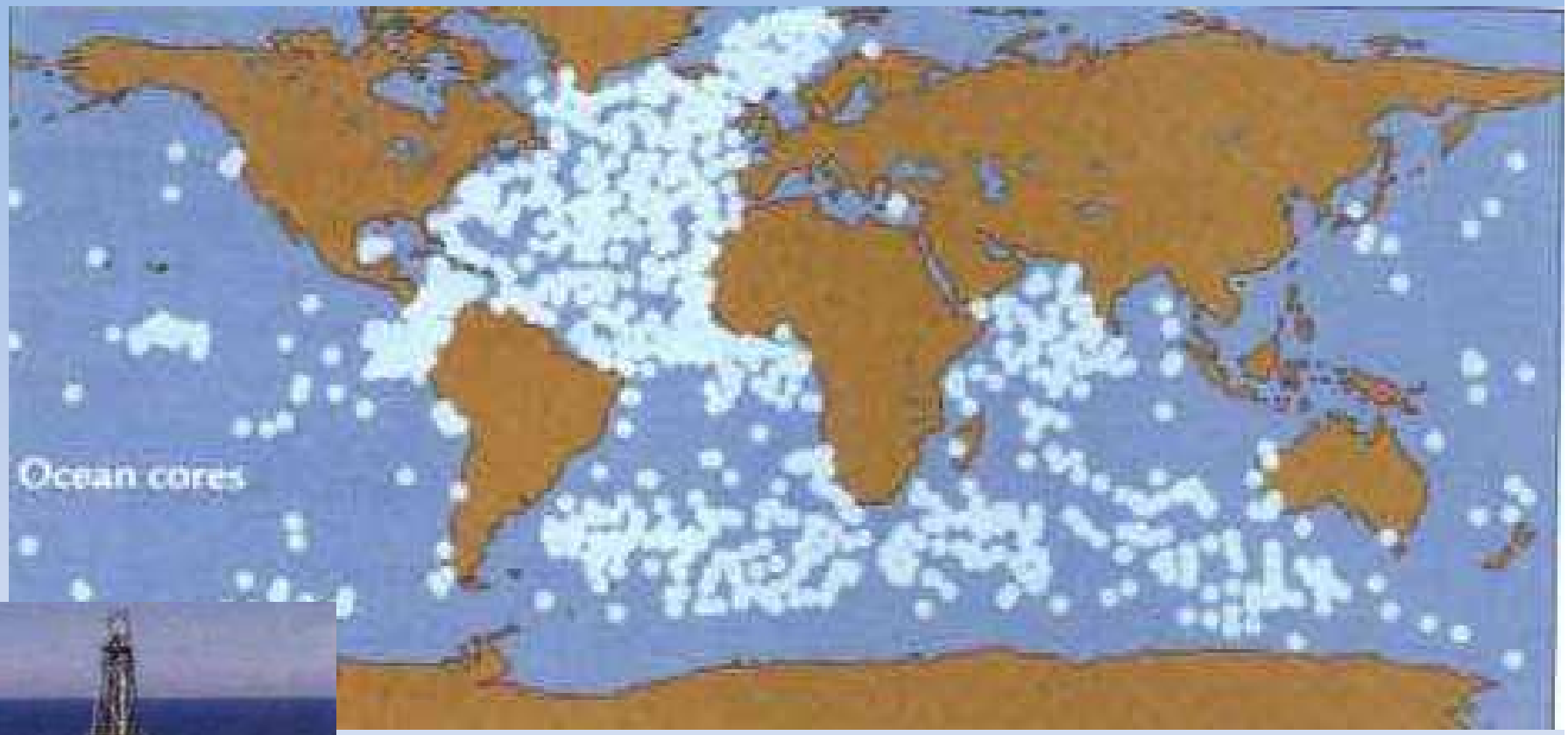




PROXY DATA: PLANKTONIC FORAMS



Deep Sea Coring



Ruddiman, 2008

The Azolla event

Precipitation (sink):

$$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$$

GUESS WHAT:

AS CONTINENTS DRIFT TO HIGH LATITUDES AND HIGHER ELEVATIONS AND BECOME GLACIATED IT LEADS TO:

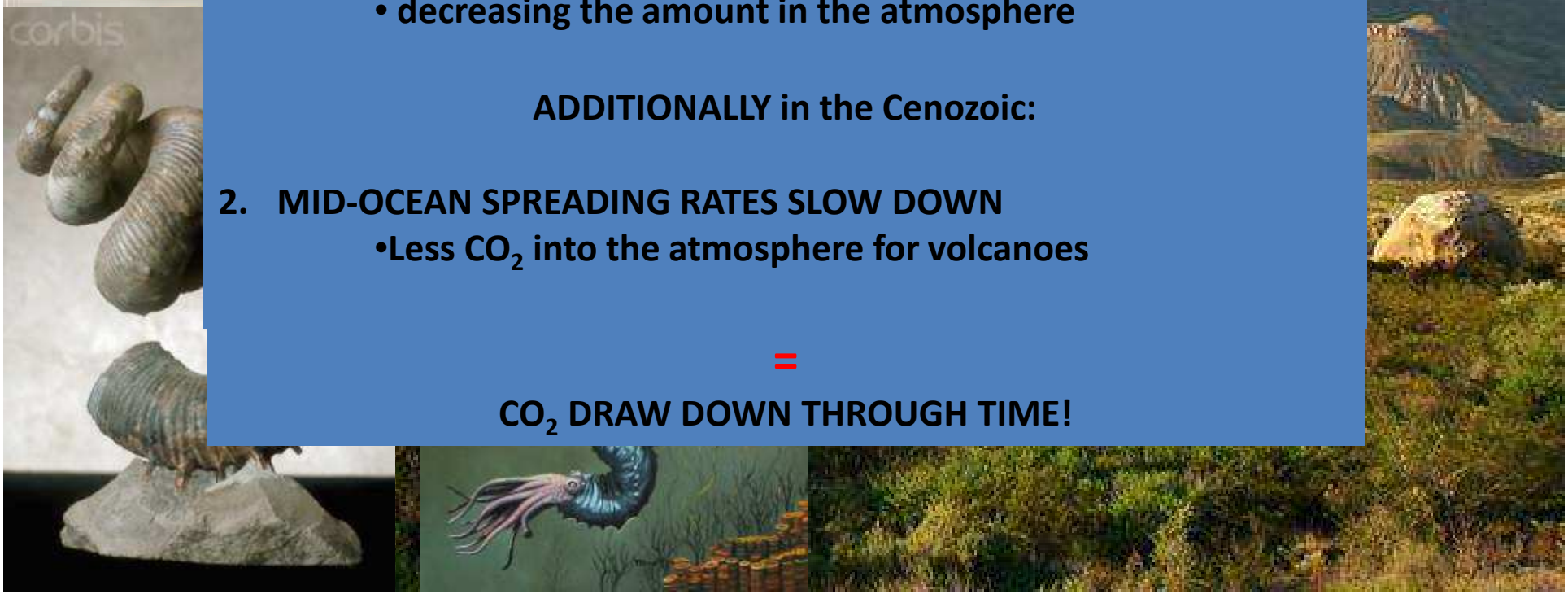
1. **GREATER MECHANICAL WEATHERING OF SILICATES:**
   - **increasing sequestration of CO_2 in sediments**
   - **decreasing the amount in the atmosphere**

ADDITIONALLY in the Cenozoic:

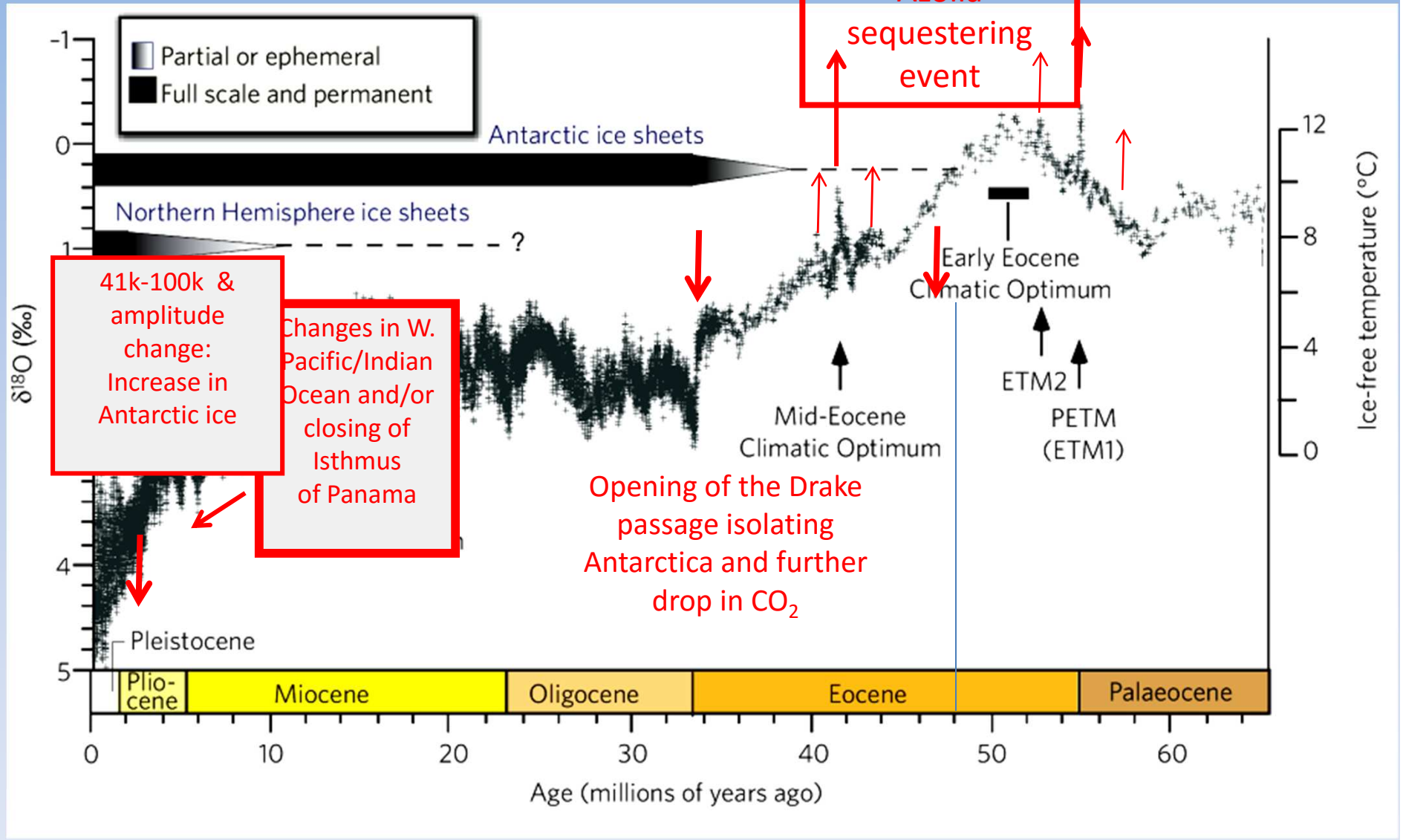
2. **MID-OCEAN SPREADING RATES SLOW DOWN**
   - **Less CO_2 into the atmosphere for volcanoes**

=

CO_2 DRAW DOWN THROUGH TIME!

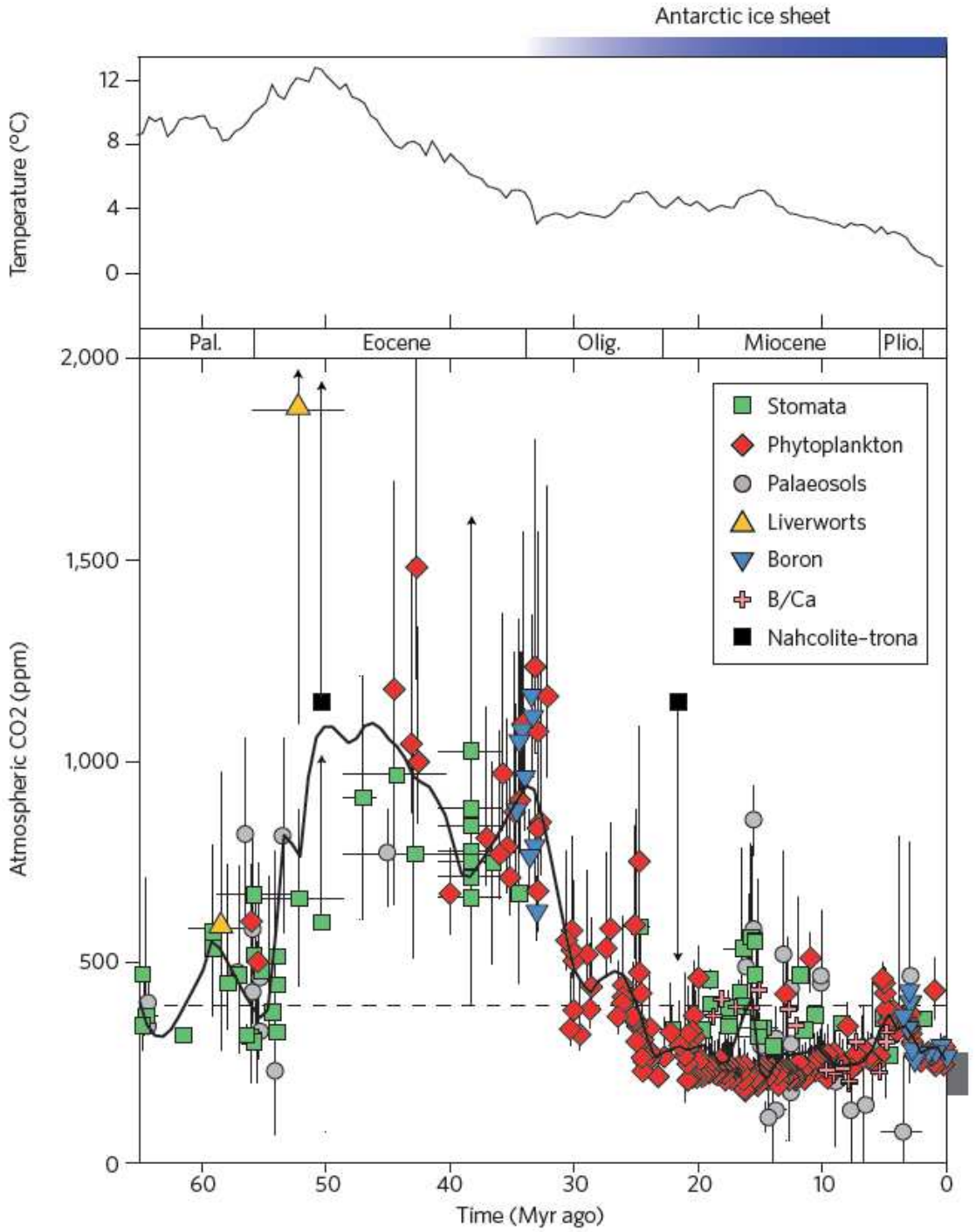


Cenozoic Deep Sea Climate Record



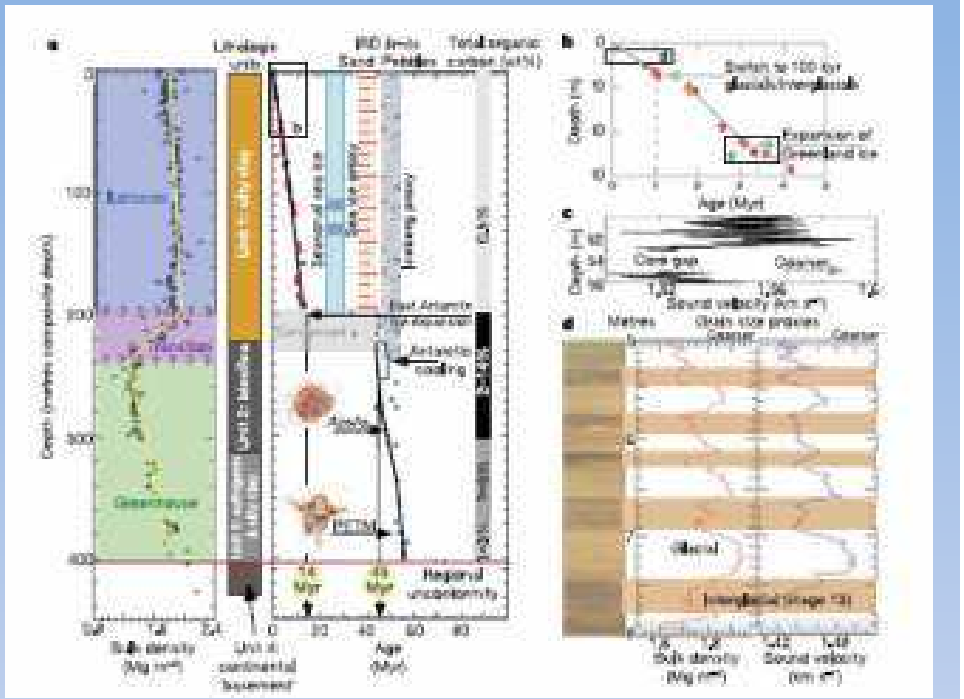
Zachos et al. 2008

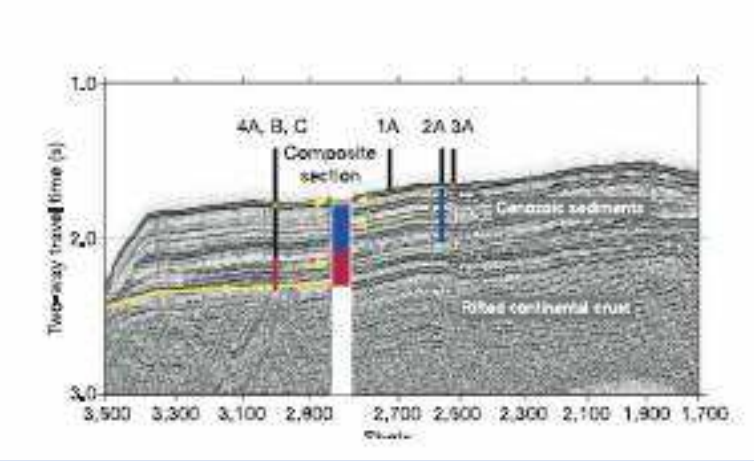
Correlation of CO_2 and temperature over last 65 million years



Beerling and Royer, Nature 2011

ARCTIC EVENTS





Brinkhuis et al,, 2006
Moran et al., 2006

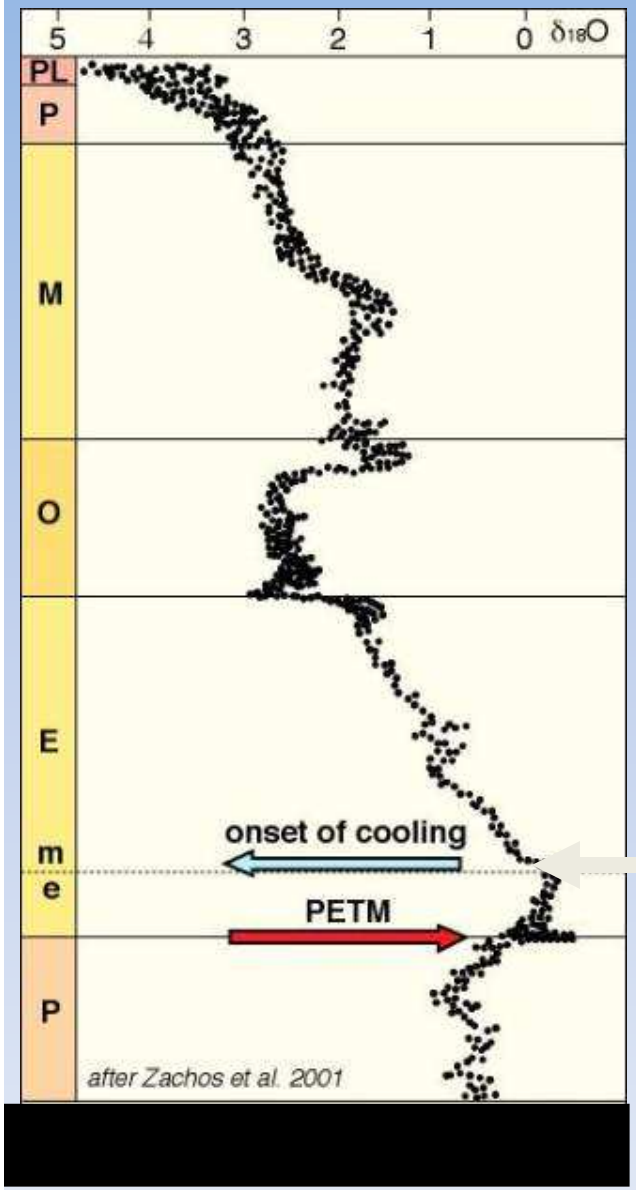
The Arctic Sea 50 million years ago

ACEX Azolla core

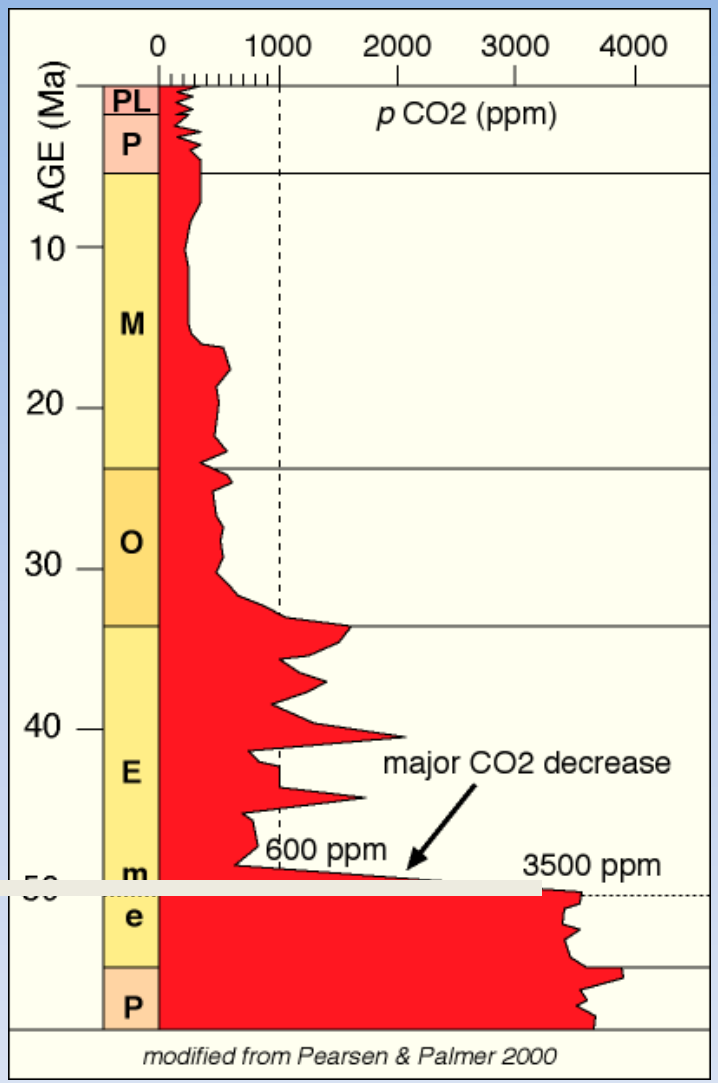
- >8 meter ACEX core with 90% Azolla
- Azolla occurs as laminated layers
- indicates Azolla deposited in situ
- bottom-water anoxia at ACEX site

Bujak, pers. Comm.

UNPRECEDENTED DROP IN CO_2

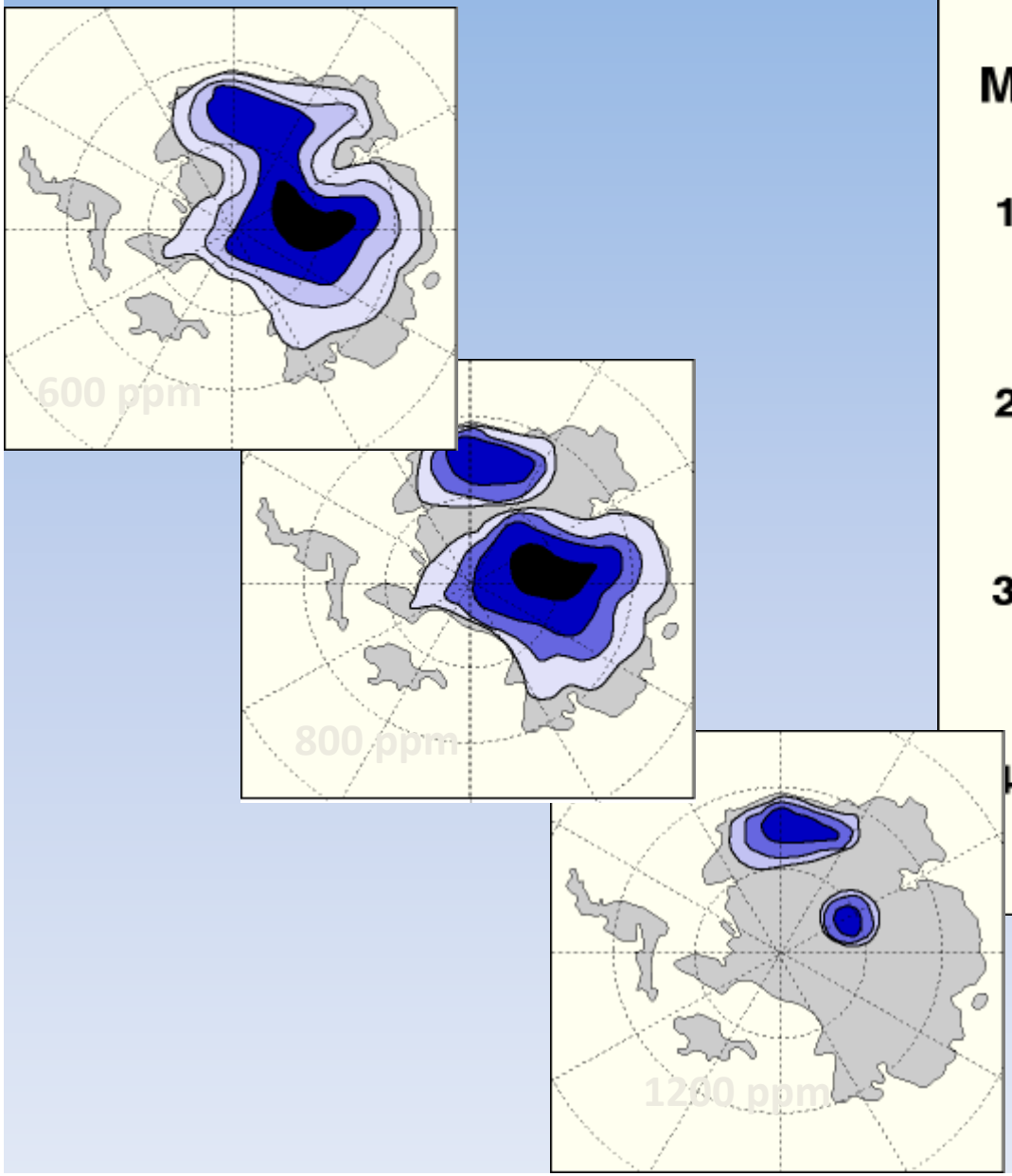


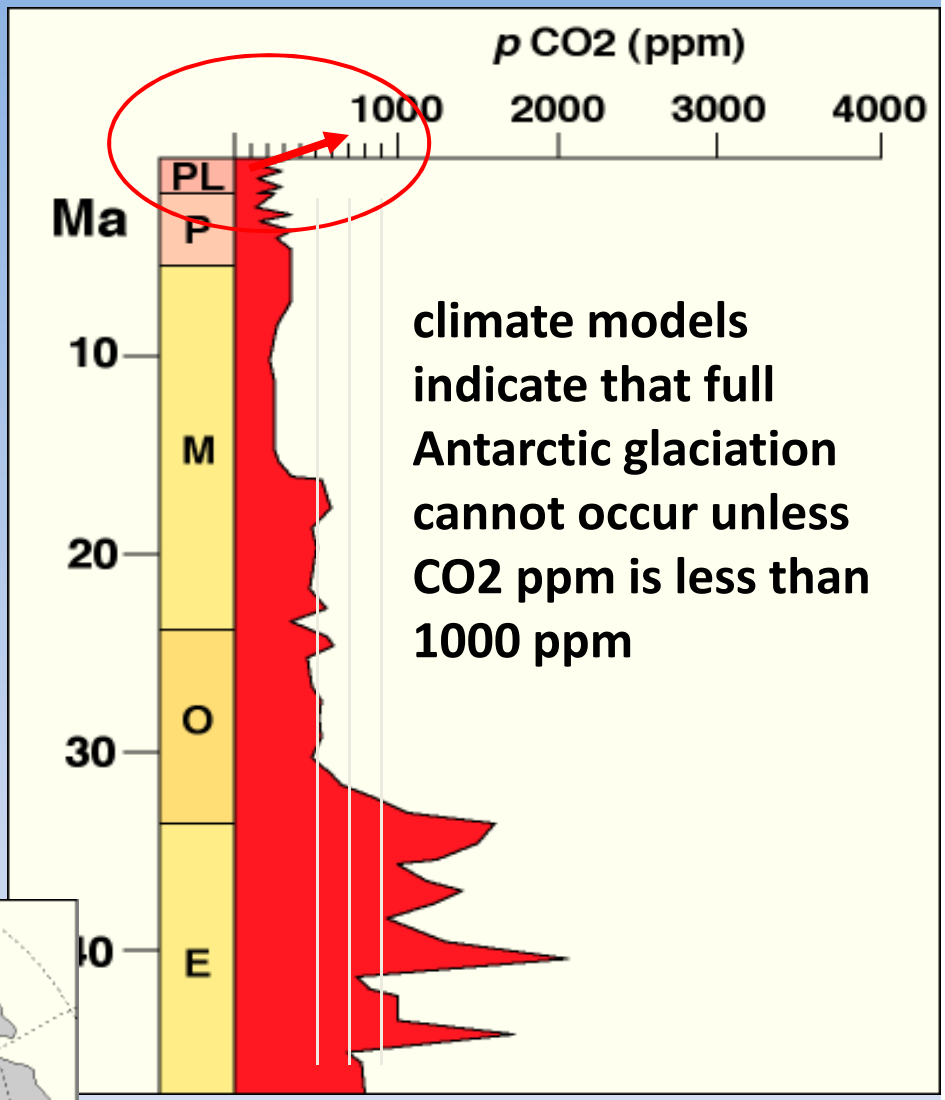
the massive decrease in atmospheric CO_2?



Bujak, pers. Comm.

can this be used to predict the effect of future increases in CO2 ?





climate models indicate that full Antarctic glaciation cannot occur unless CO2 ppm is less than 1000 ppm

Bujak, pers. Comm.