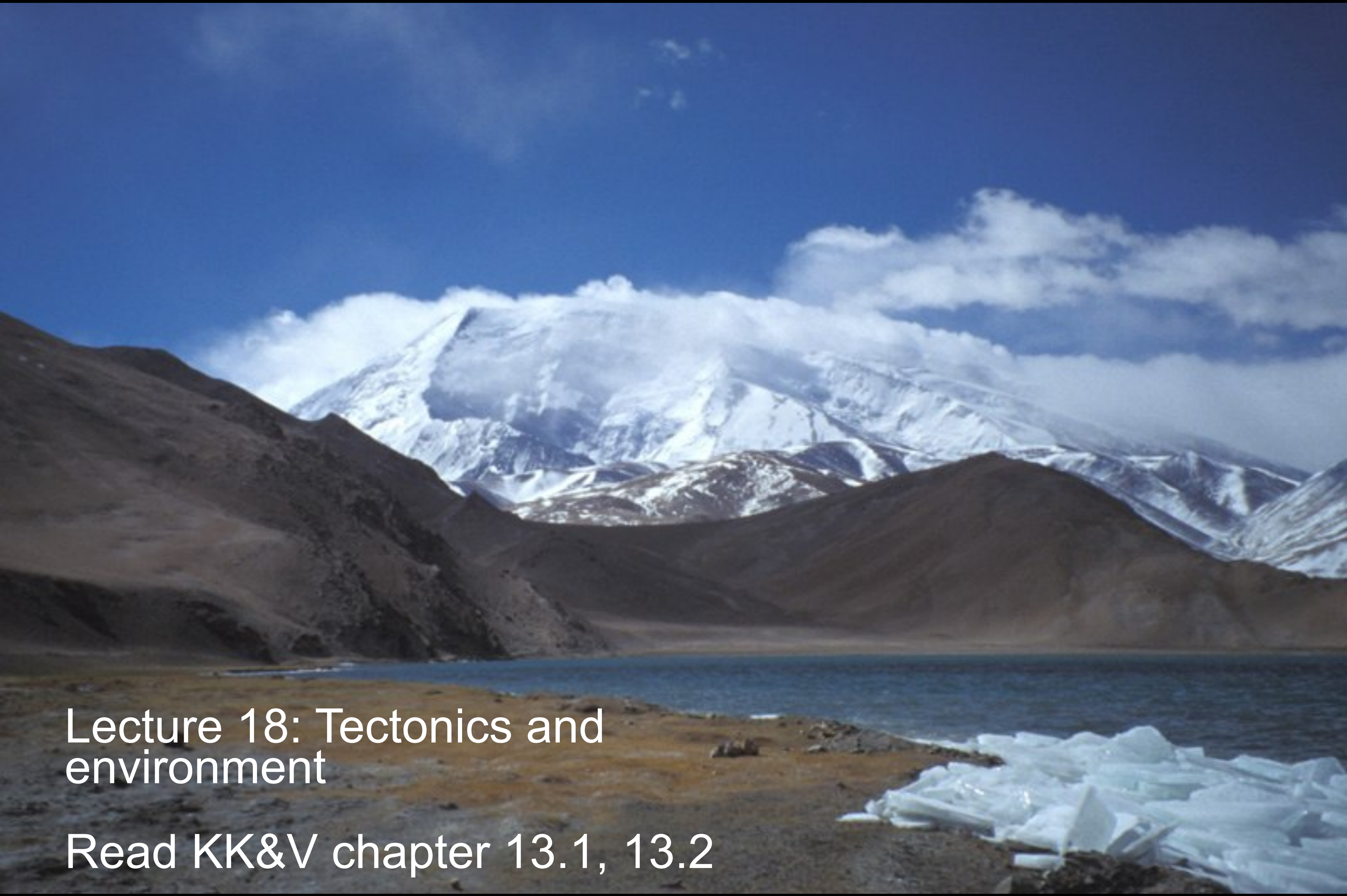
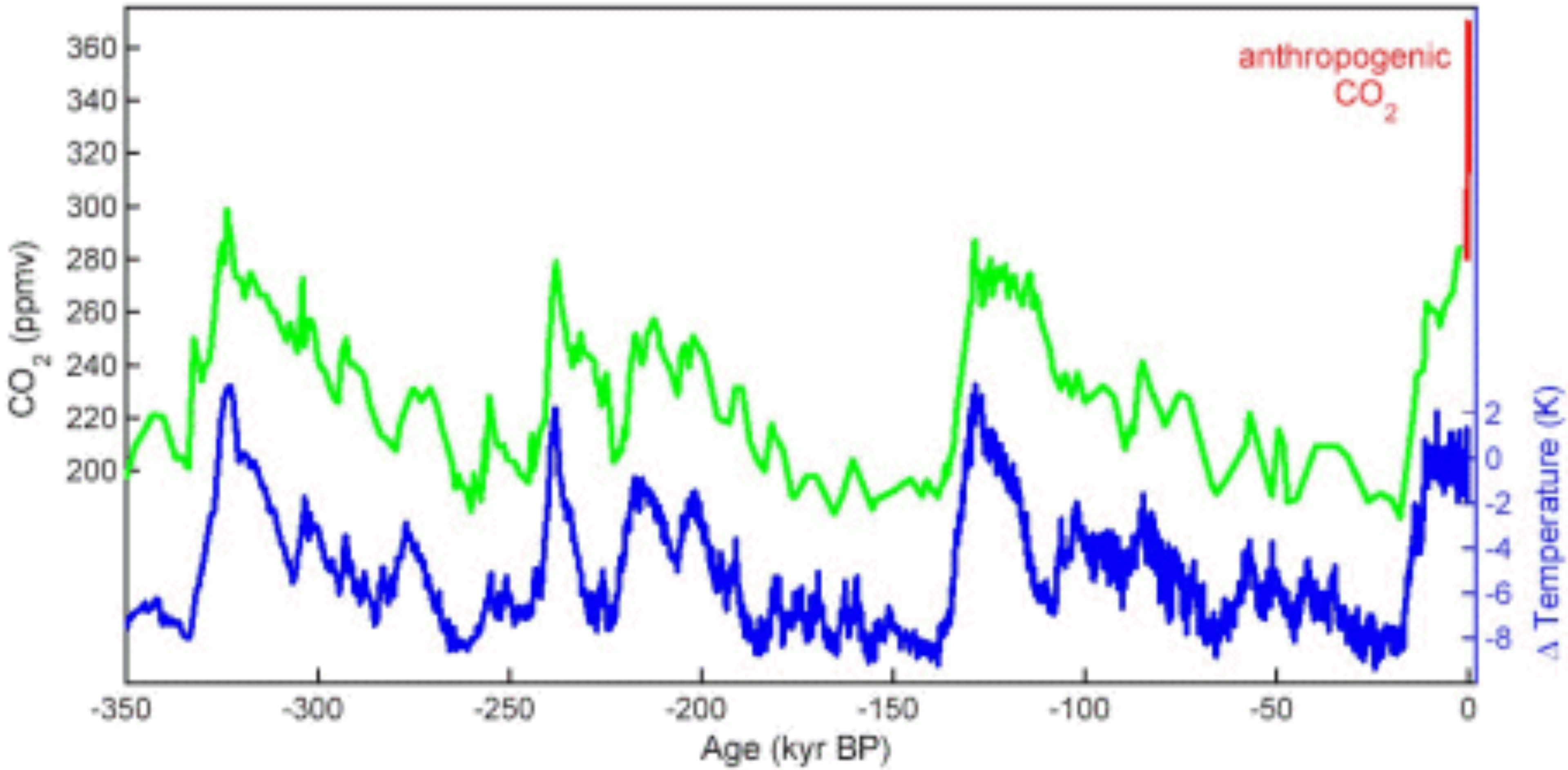
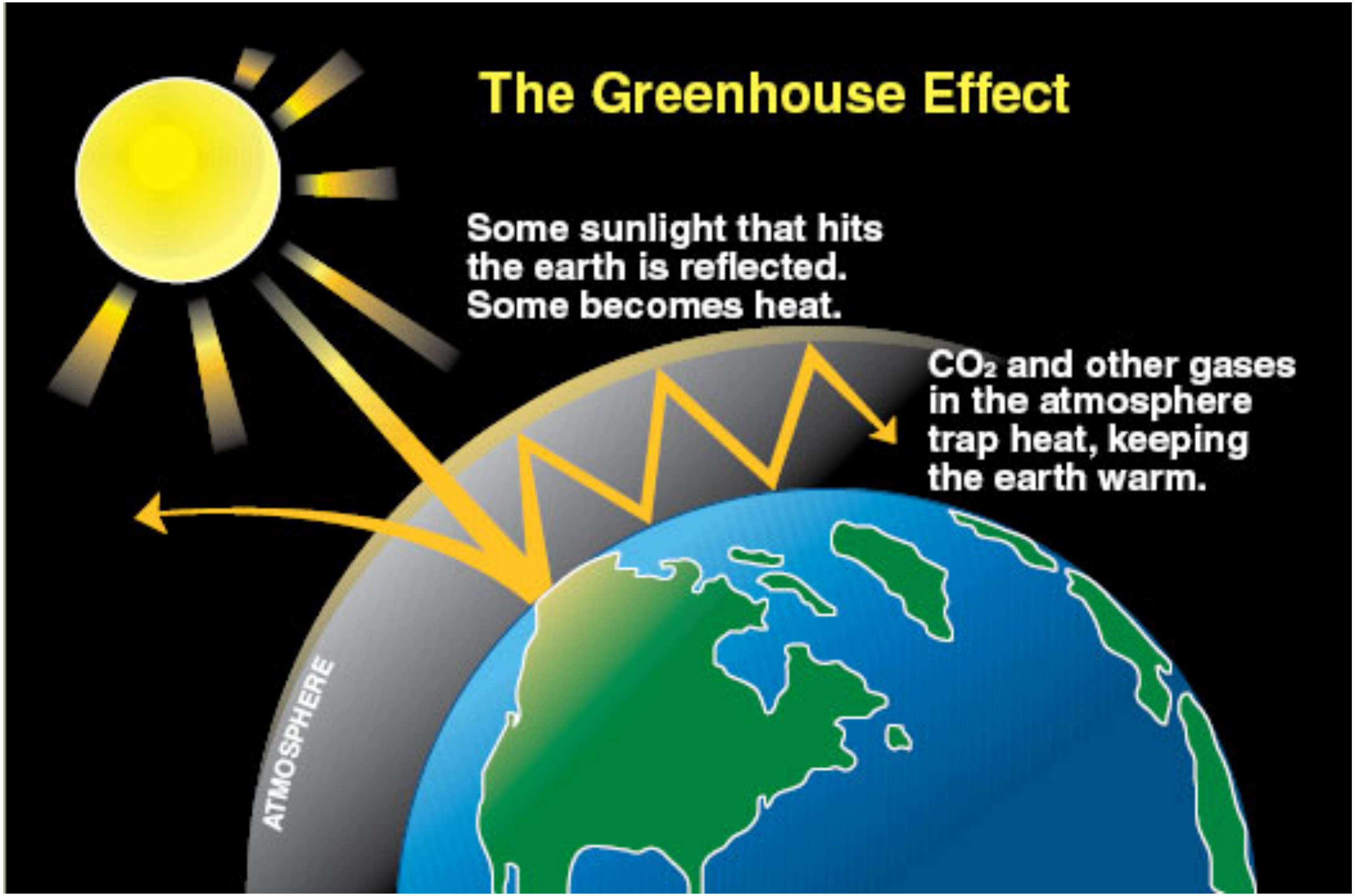


Lecture 18: Tectonics and environment

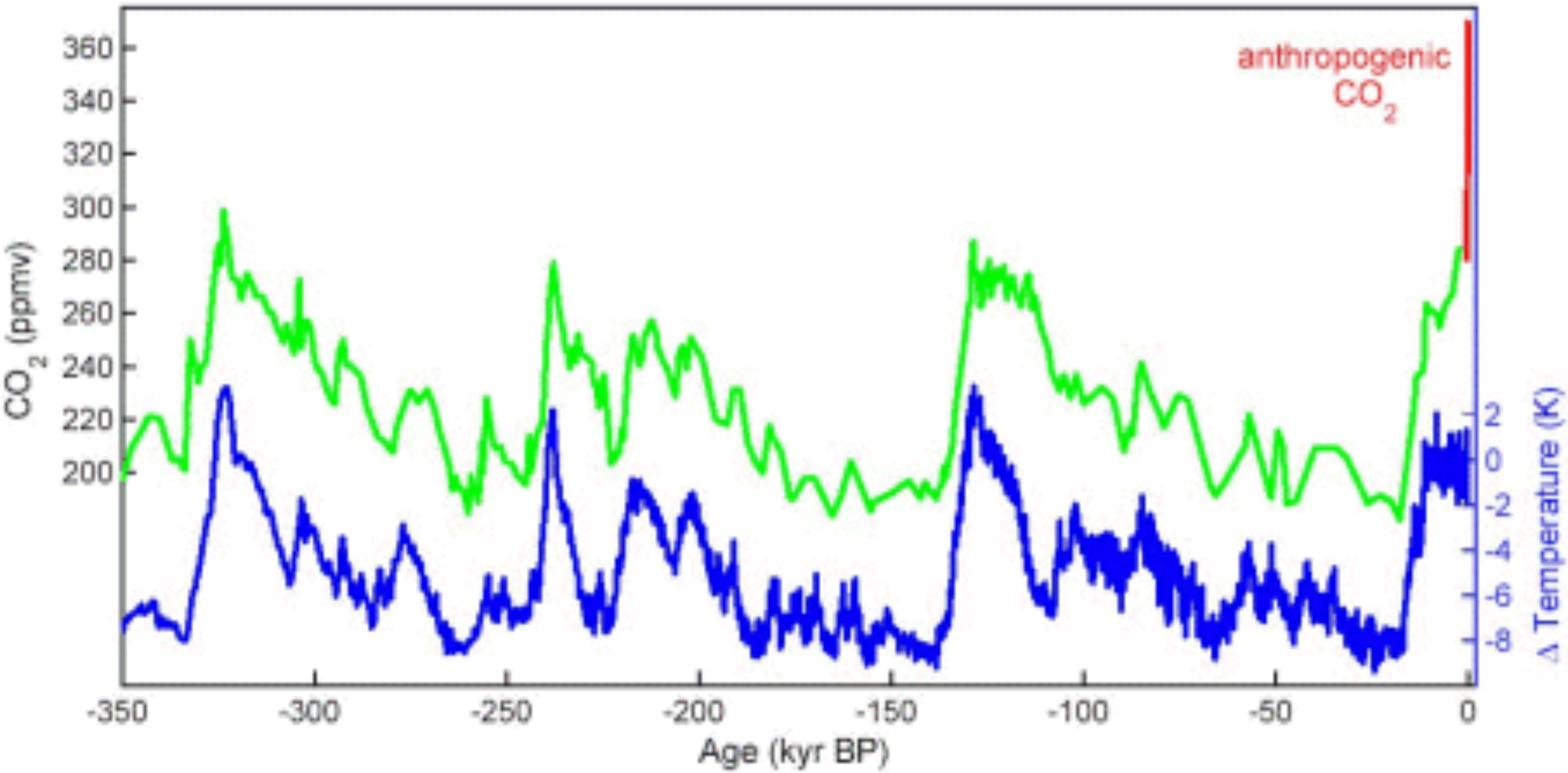
Read KK&V chapter 13.1, 13.2

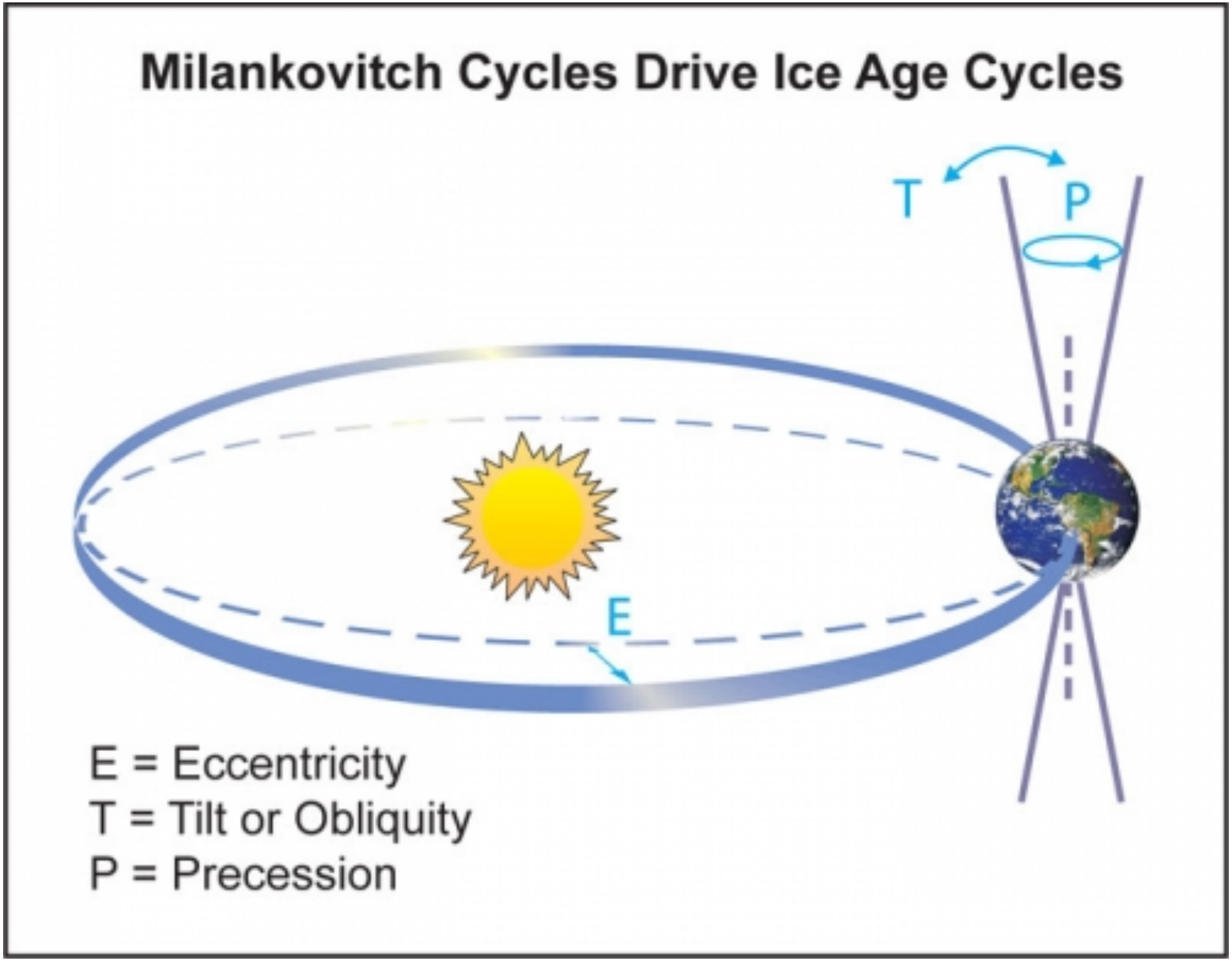
Climate variability: the last 0.5 My




The Greenhouse Effect
Some sunlight that hits the earth is reflected. Some becomes heat.
CO_2 and other gases in the atmosphere trap heat, keeping the earth warm.
ATMOSPHERE

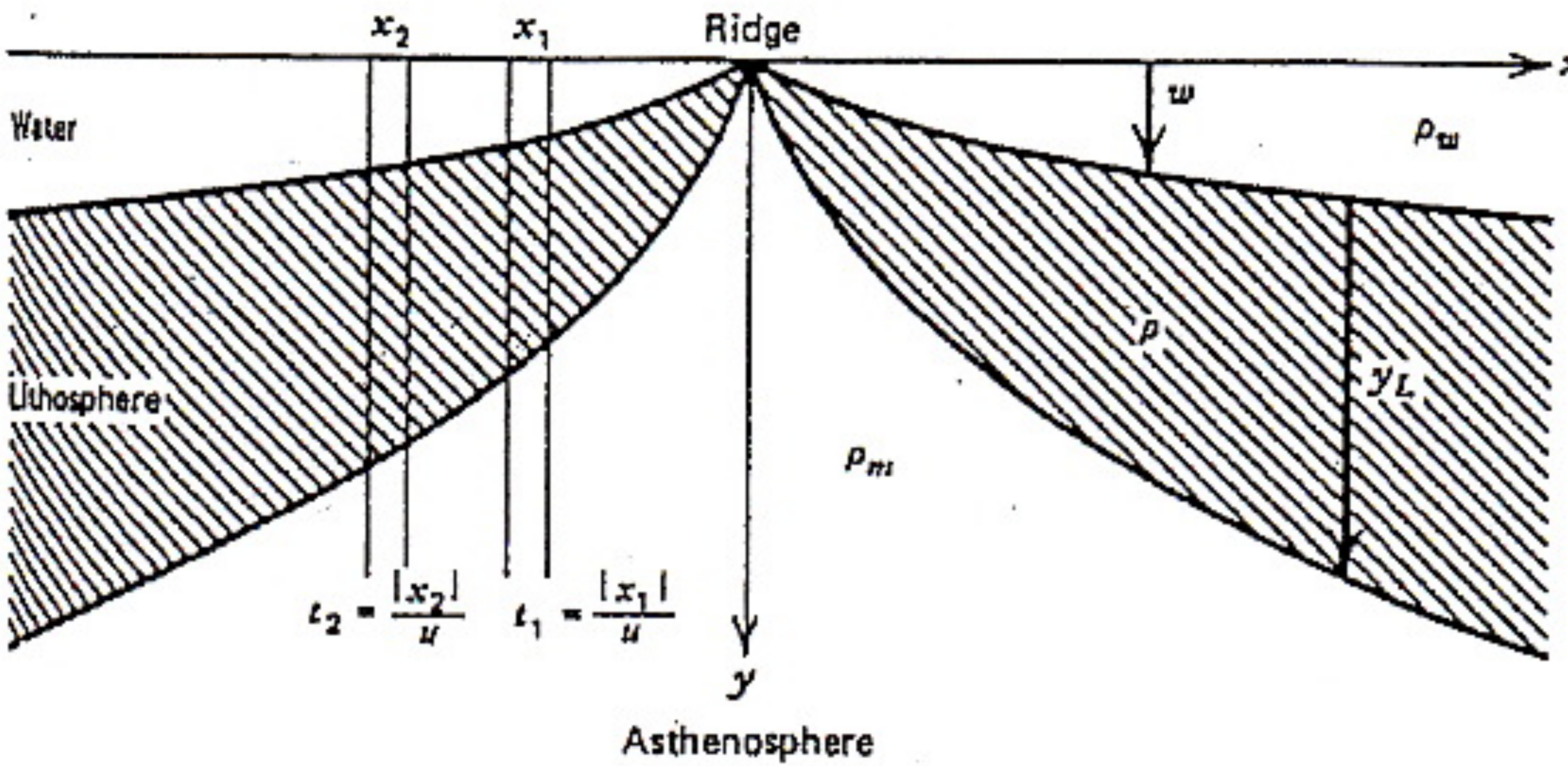
Climate variability: the last 0.5 My




Milankovitch Cycles Drive Ice Age Cycles
T
P
E
E = Eccentricity
T = Tilt or Obliquity
P = Precession

- The mean temperature is correlated with the sea level: during periods of low temperature (“Ice Ages”), the sea level drops because some water is tied in glaciers. During warm periods, glaciers melt and the sea level rises

- However, there were periods in the past when the Earth had no polar ice caps, and yet the sea level was still changing. Why?

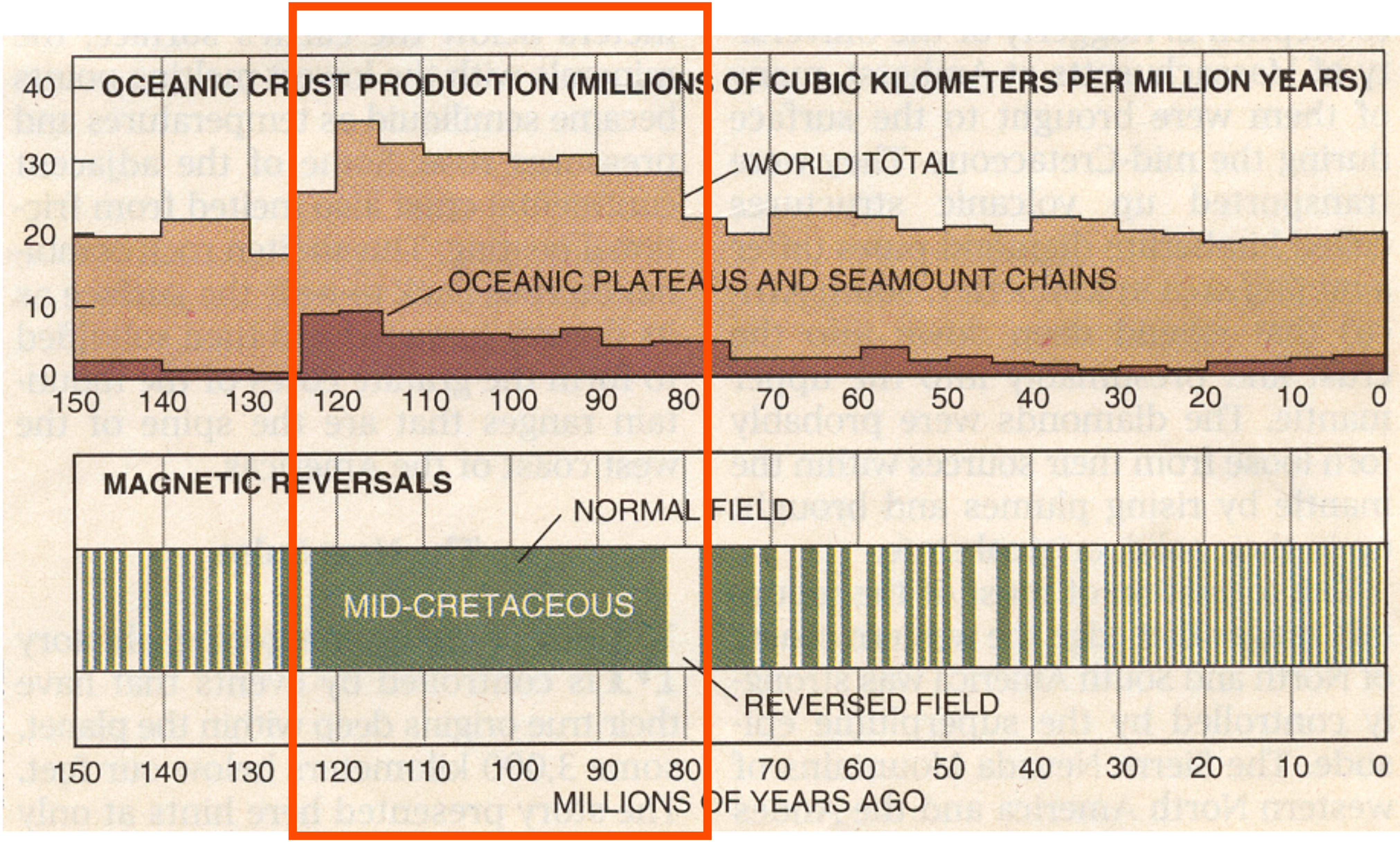


*from Turcotte and Schubert, 2002, Geodynamics

The seafloor depth follows the "square root of age";

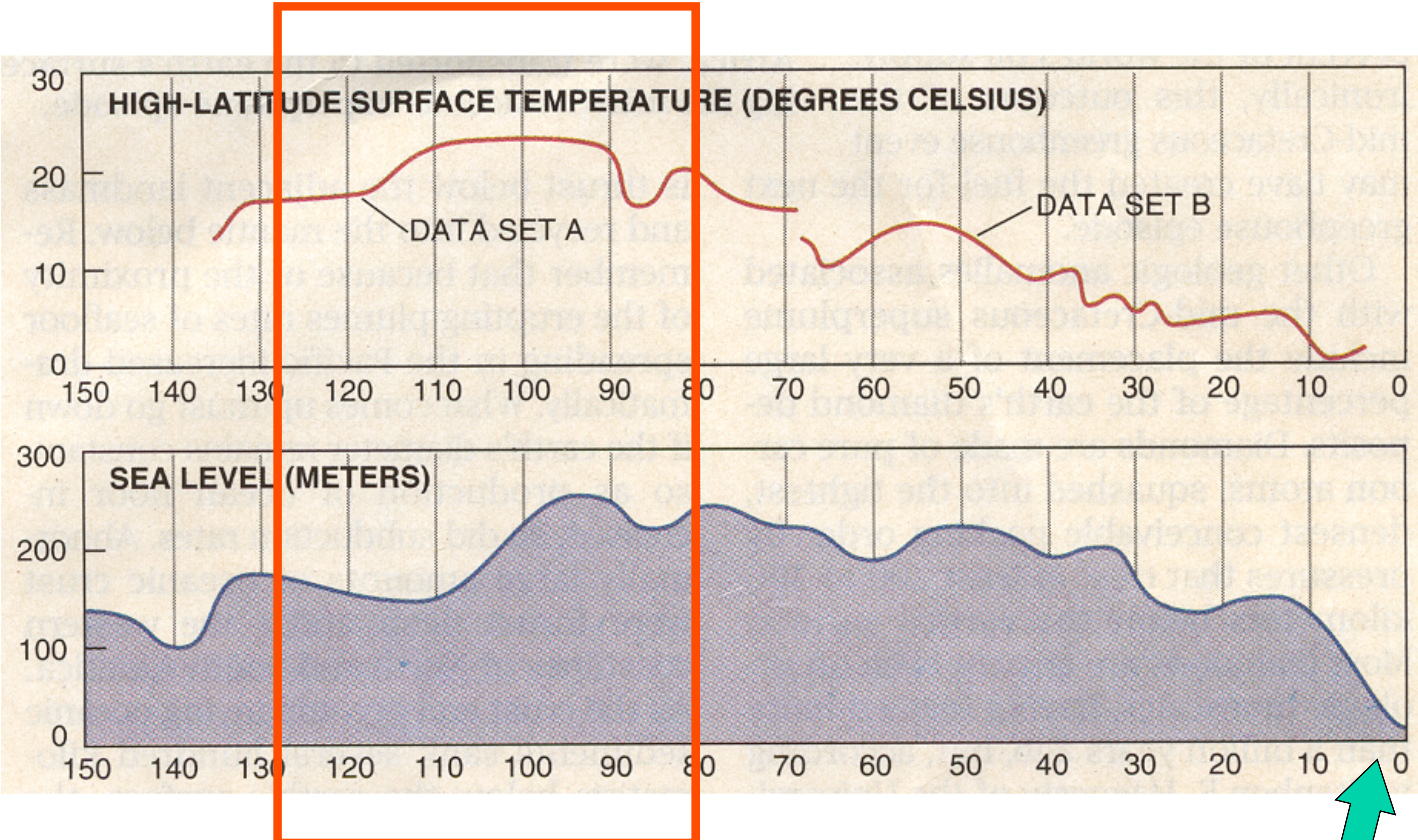
higher spreading rates give rise to shallower ocean basins

The mid-Cretaceous superplume event



- Increase in the world-wide rate of oceanic crust production
- Shutdown in reversals of the earth's magnetic field

Effects on temperature and sea level



- rising global surface temperature
- rising global sea level

At present plume activity is low

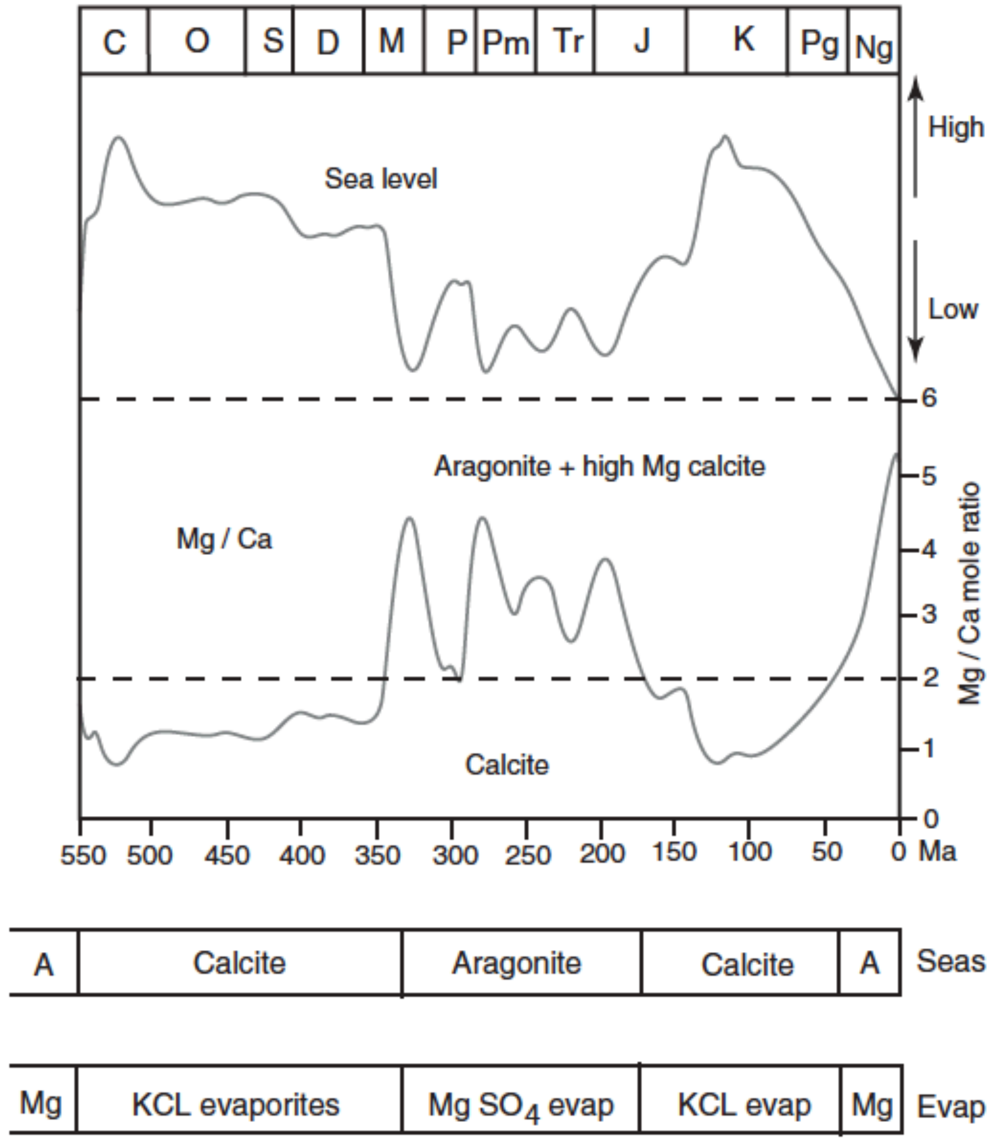
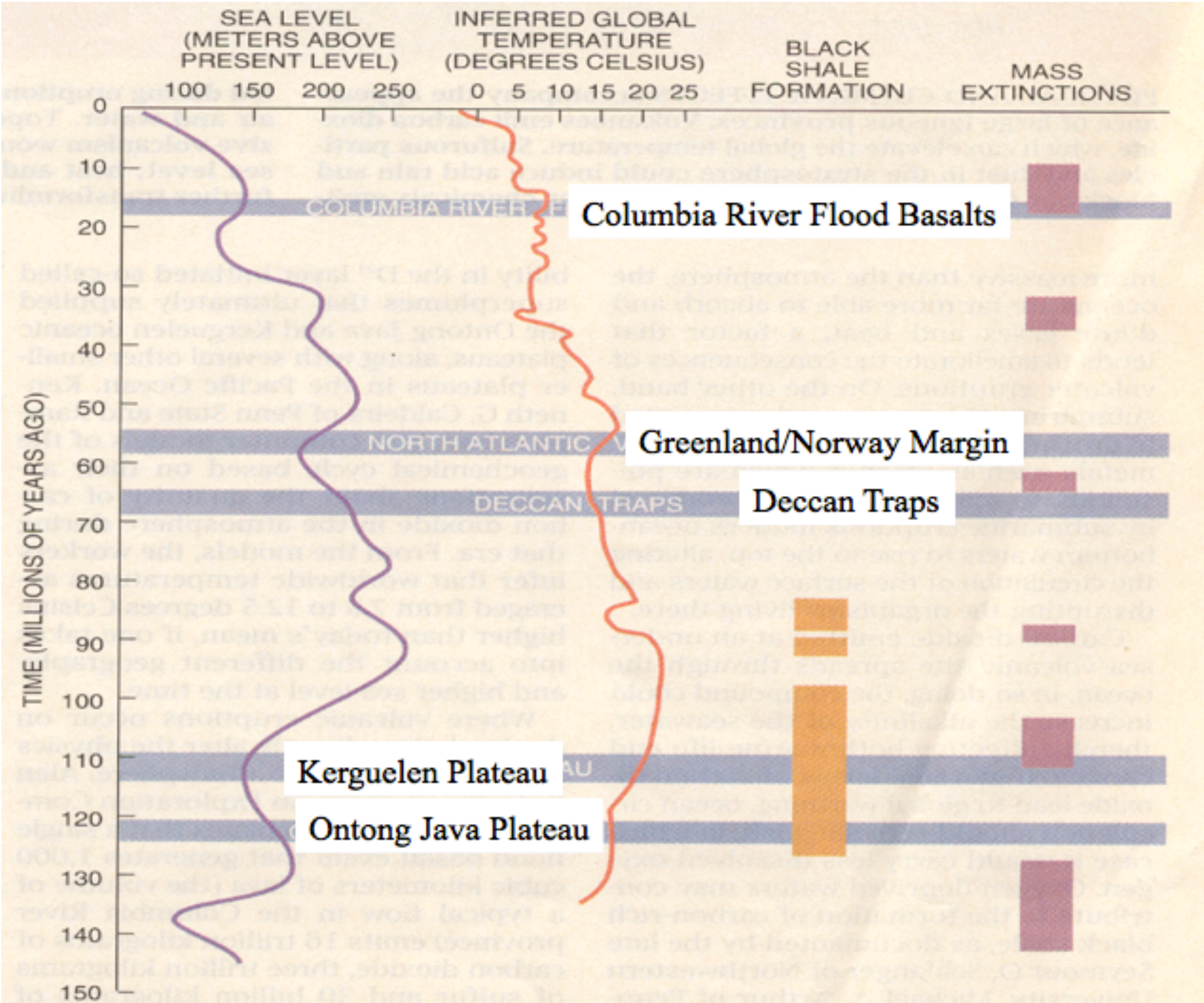
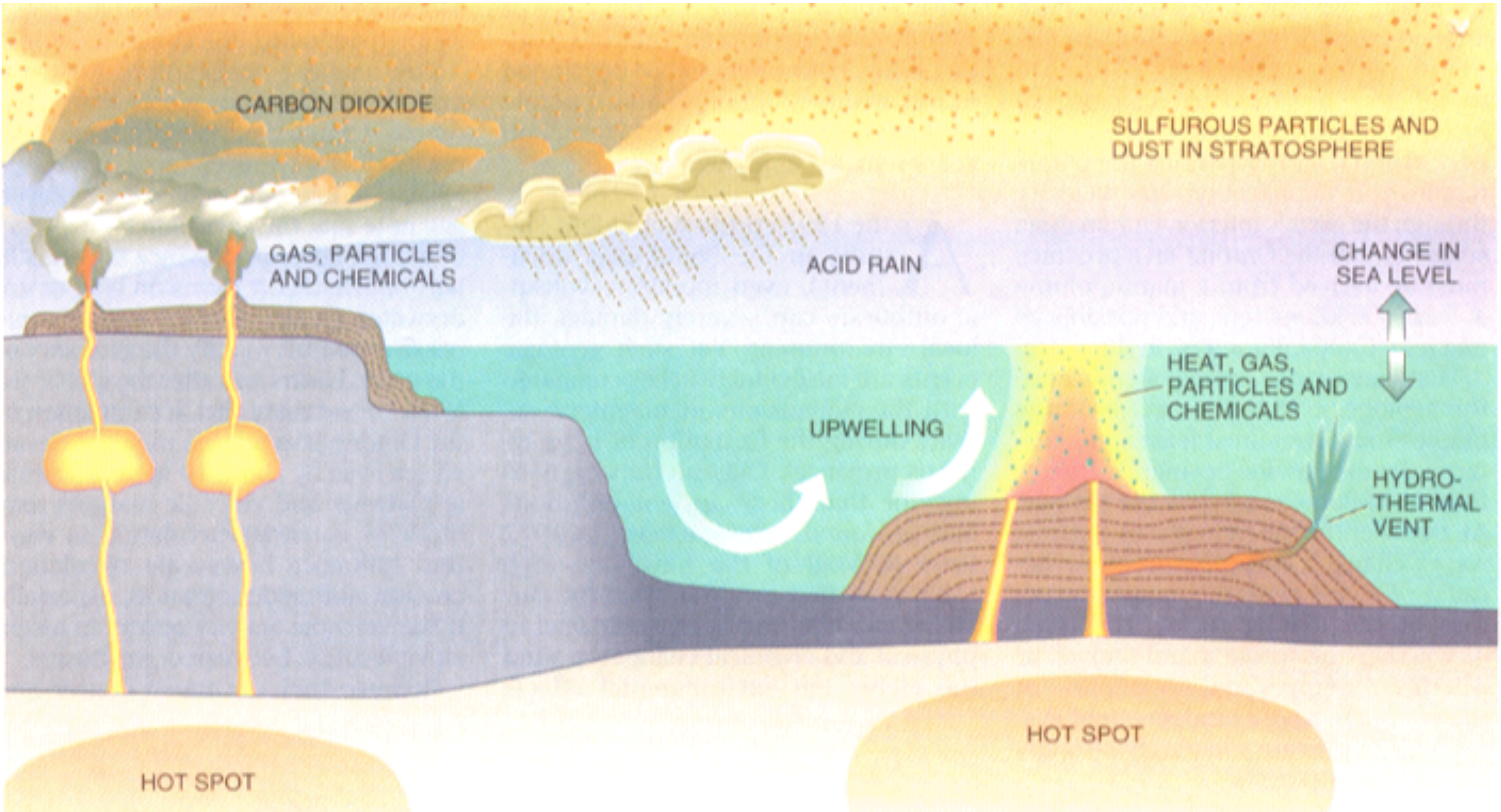


Fig. 13.1 *Variation in the Mg/Ca ratio in seawater, calculated by Hardie, 1996, from an assumed curve of long term changes in sea level, and (below) summaries of the mineralogy of nonskeletal carbonates, and marine evaporites, illustrating the correlation with the predicted changes in the Mg/Ca ratio in seawater during the past 550 Ma (based on figure 2 in Stanley & Hardie, 1999).*


SEA LEVEL (METERS ABOVE PRESENT LEVEL)
100 150 200 250
INFERRED GLOBAL TEMPERATURE (DEGREES CELSIUS)
0 5 10 15 20 25
BLACK SHALE FORMATION
MASS EXTINCTIONS
TIME (MILLIONS OF YEARS AGO)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Columbia River Flood Basalts
Greenland/Norway Margin
Deccan Traps
Kerguelen Plateau
Ontong Java Plateau

• The Mid-Cretaceous super-plumes delivered increasing amounts of carbon dioxide to the atmosphere contributing to increased alkalinity in the ocean and elevated global warming from the “greenhouse effect”.

• Computer models suggest global, annual mid-Cretaceous temperatures 8 to 12 degrees centigrade warmer than today.



Volcanoes emitting carbon dioxide and sulfuric acid droplets which in the short term causes global cooling by blocking sunlight and in the long term sustained greenhouse warming.

- Warm waters hold less dissolved oxygen leading to widespread anoxia in the mid-Cretaceous oceans and the deposition of organic-rich black shales.

- Some super-plume episodes such as those that formed Kerguelen Plateau, Broken Ridge and the Deccan Traps coincided with mass extinctions.

- Both LIPs and increased spreading rates contributed to warming

Two main factors affecting the global climate:

- CO_2 (and other greenhouse gases) in the atmosphere
- Ocean circulation (landmass distribution, seaways, roughness of the seafloor)

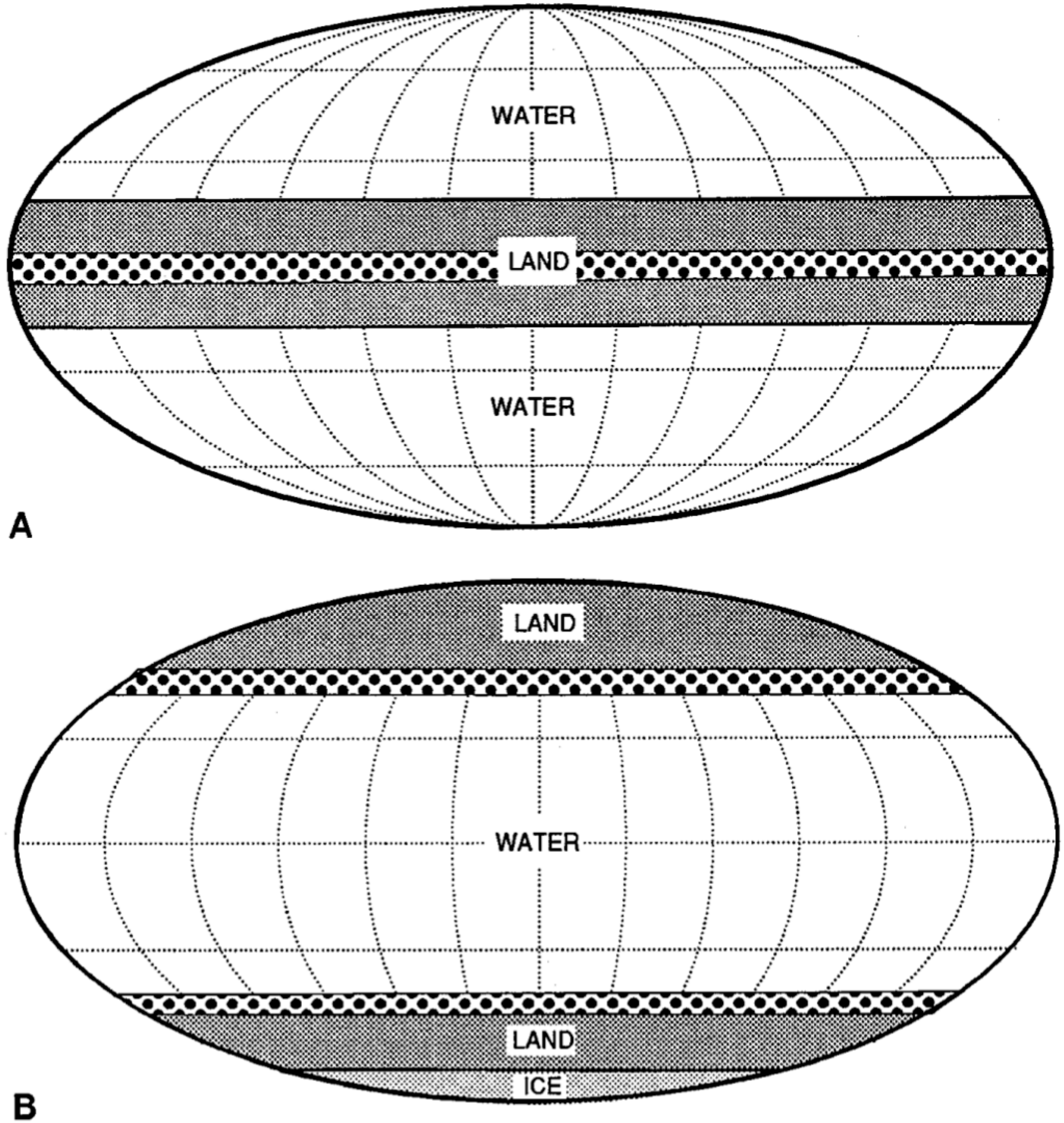
- Surface ocean currents are driven by wind (amospheric circulation

- Deep currents depend on surface currents, rotation of the Earth, and incoming solar radiation

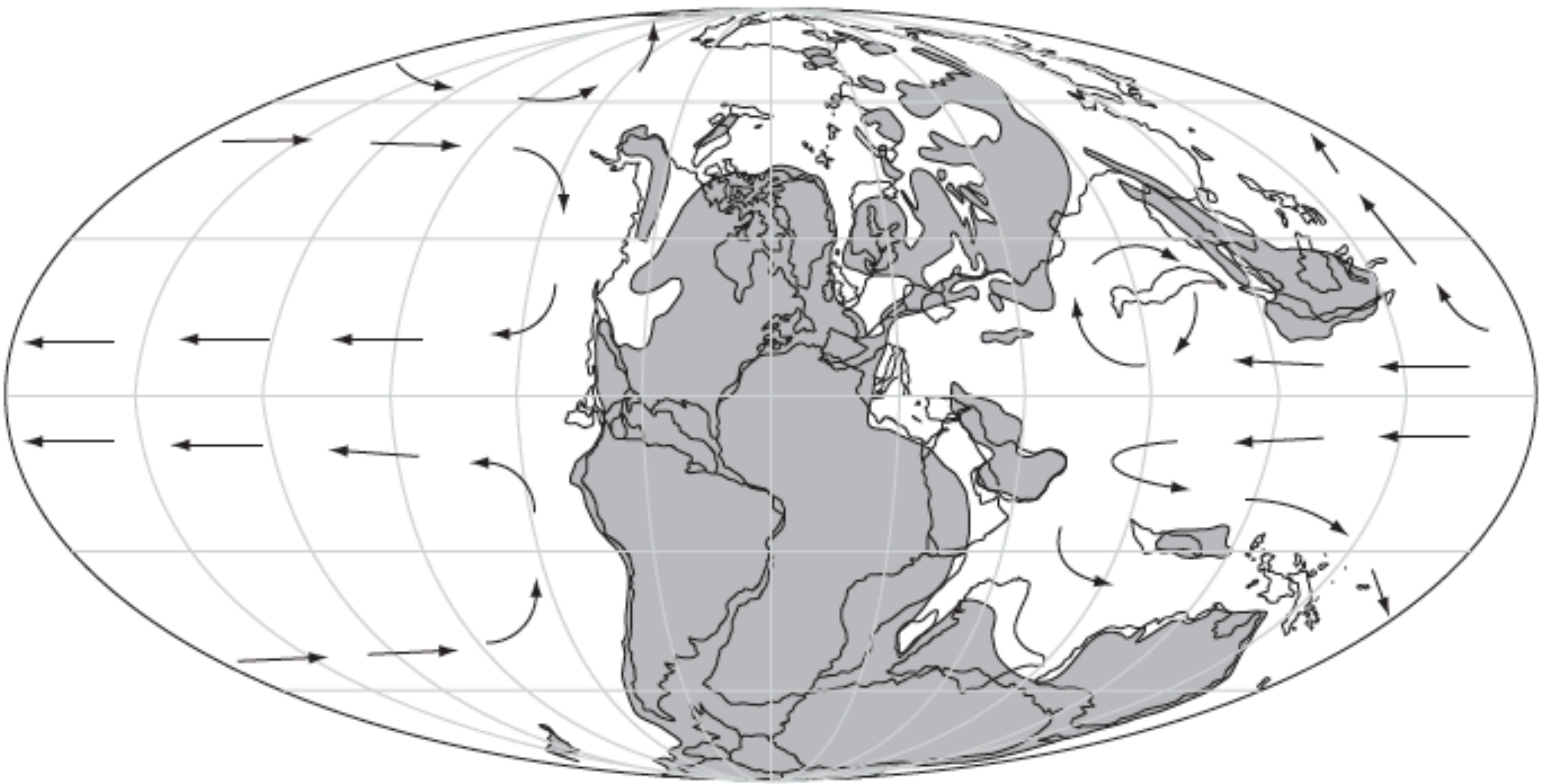
- In the absense of continents, the world-encircling equatorial and circumpolar currents would inhibit the heat transfer from low to high latitudes (favoring the formation of ice polar caps)

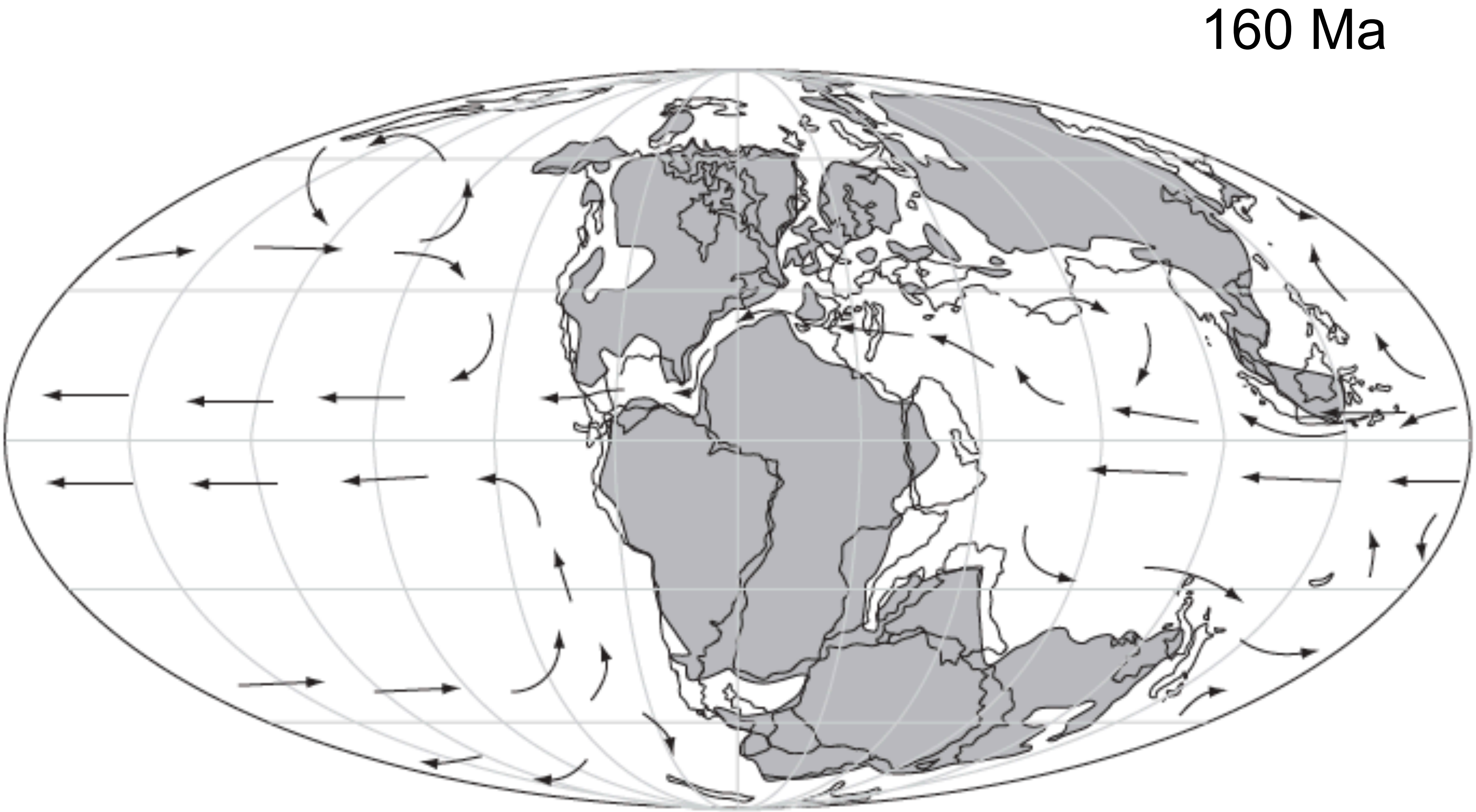
- North-South trending land masses deflect the currents (to the right in the Northern hemisphere, and to the left in the Southern hemispere), thereby transferring the heat from the tropics to the polar regions, and reducing the temperature gradients (current example: Gulfstream)

Climate simulation models with (A) equatorial and (B) polar continents

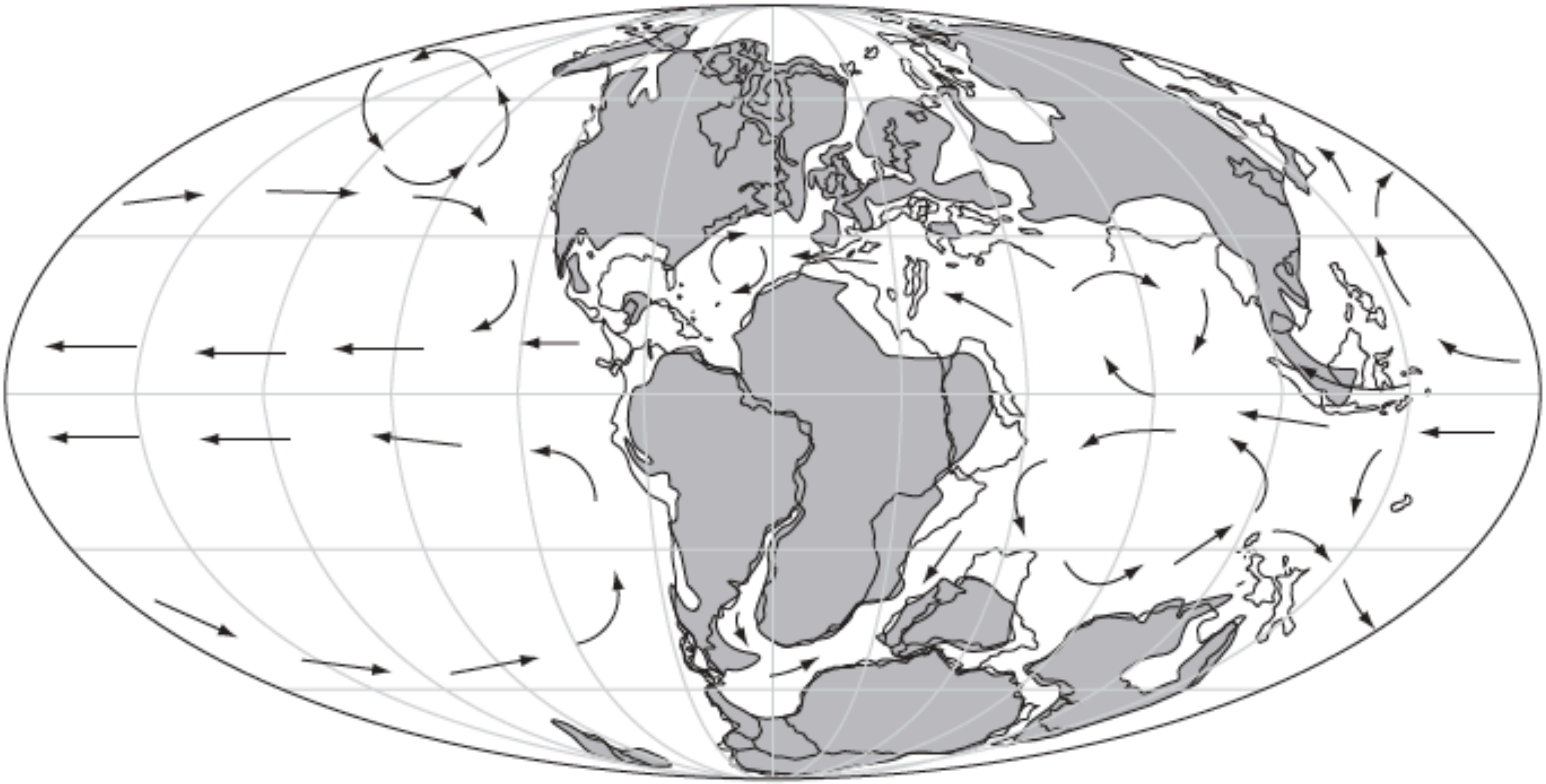


245 Ma

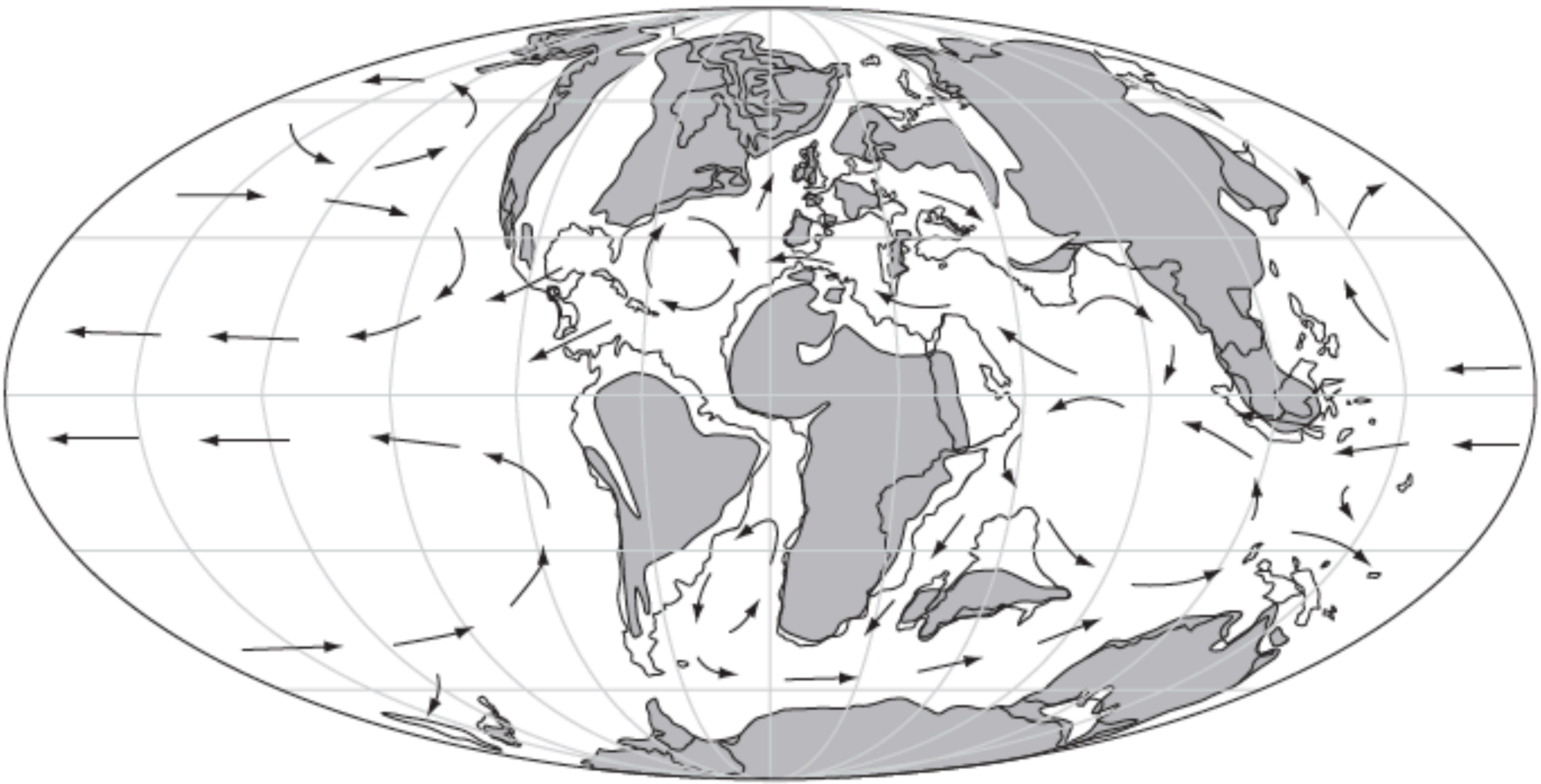



160 Ma

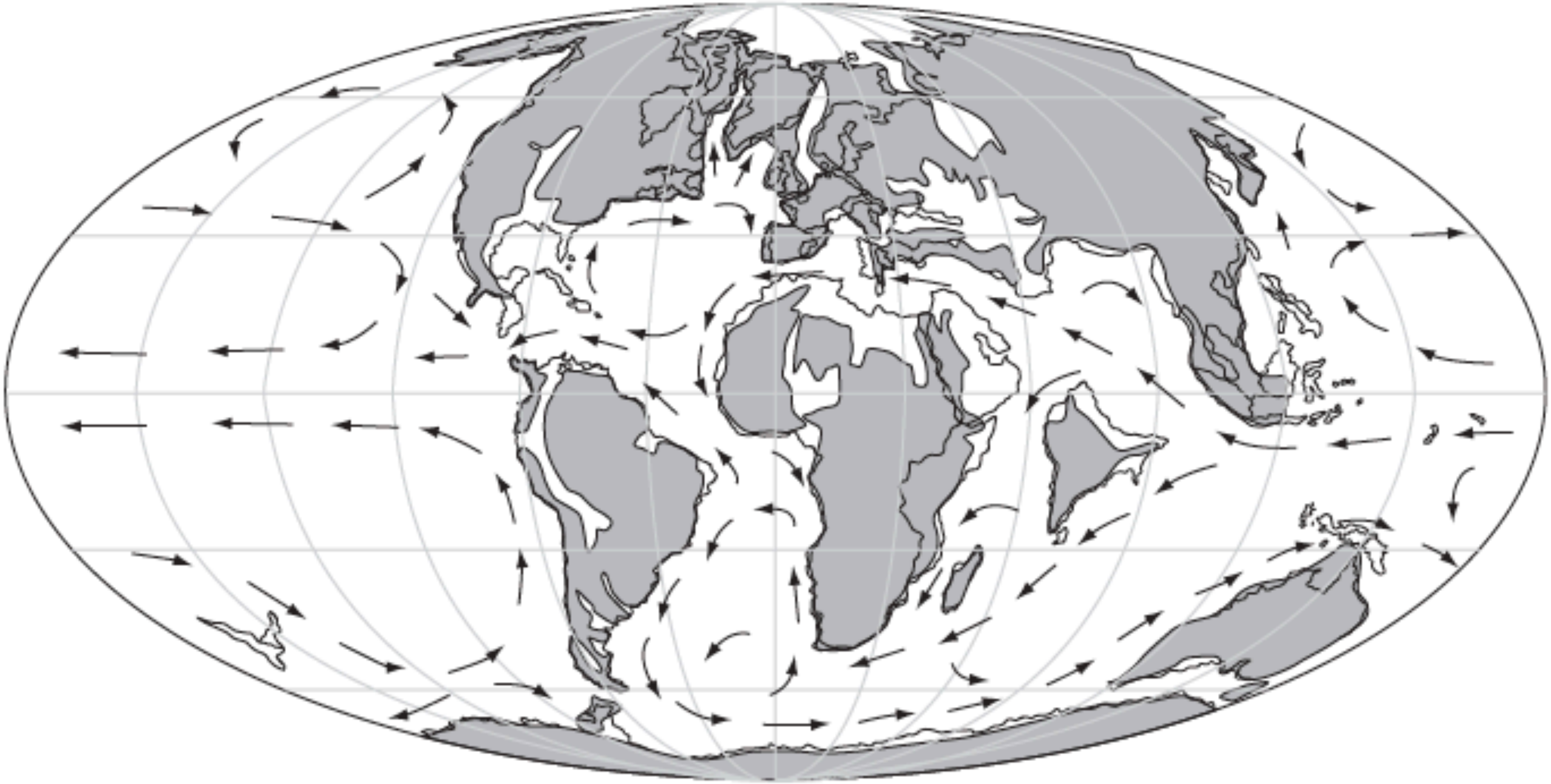
130 Ma



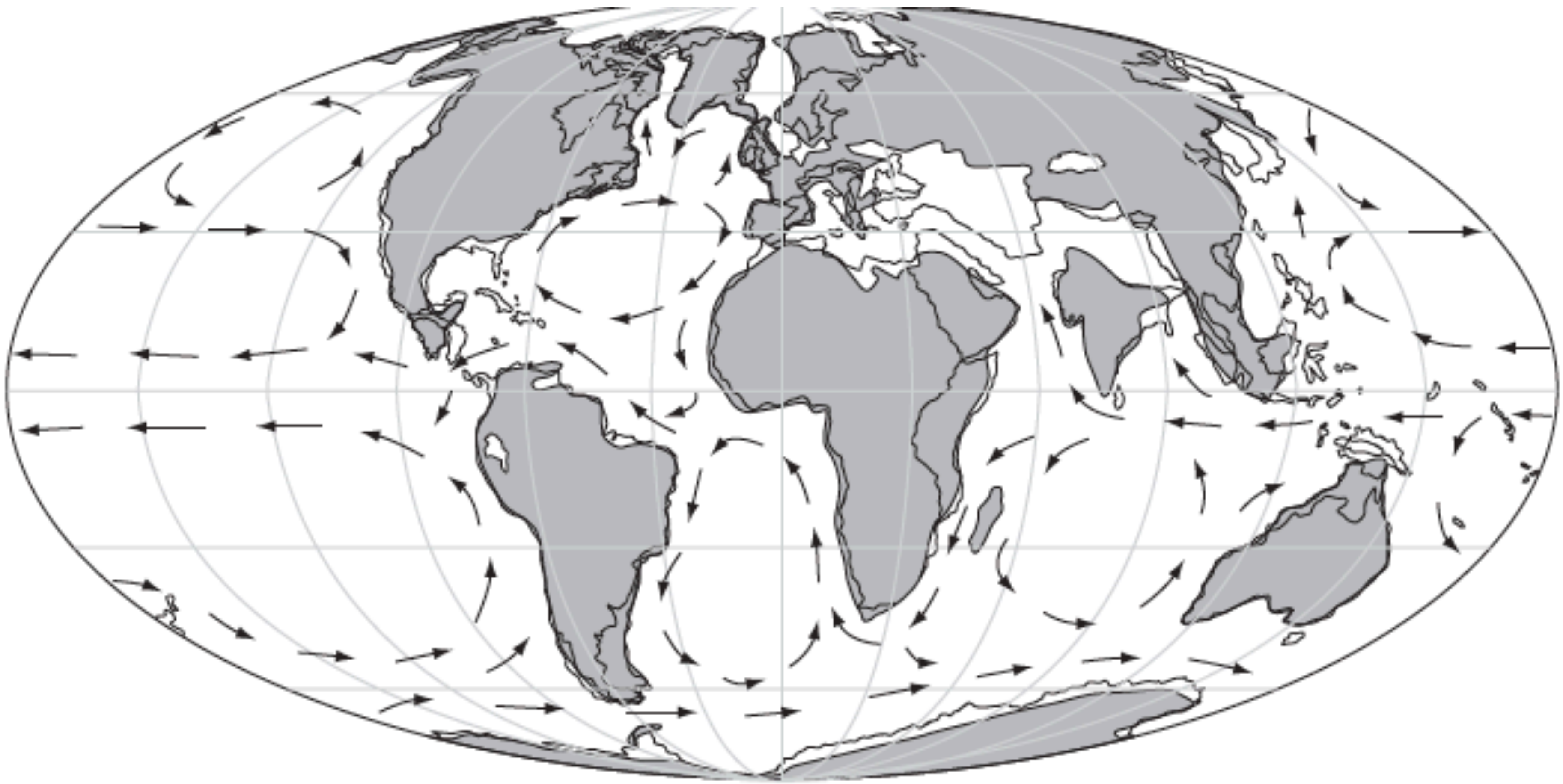
95 Ma

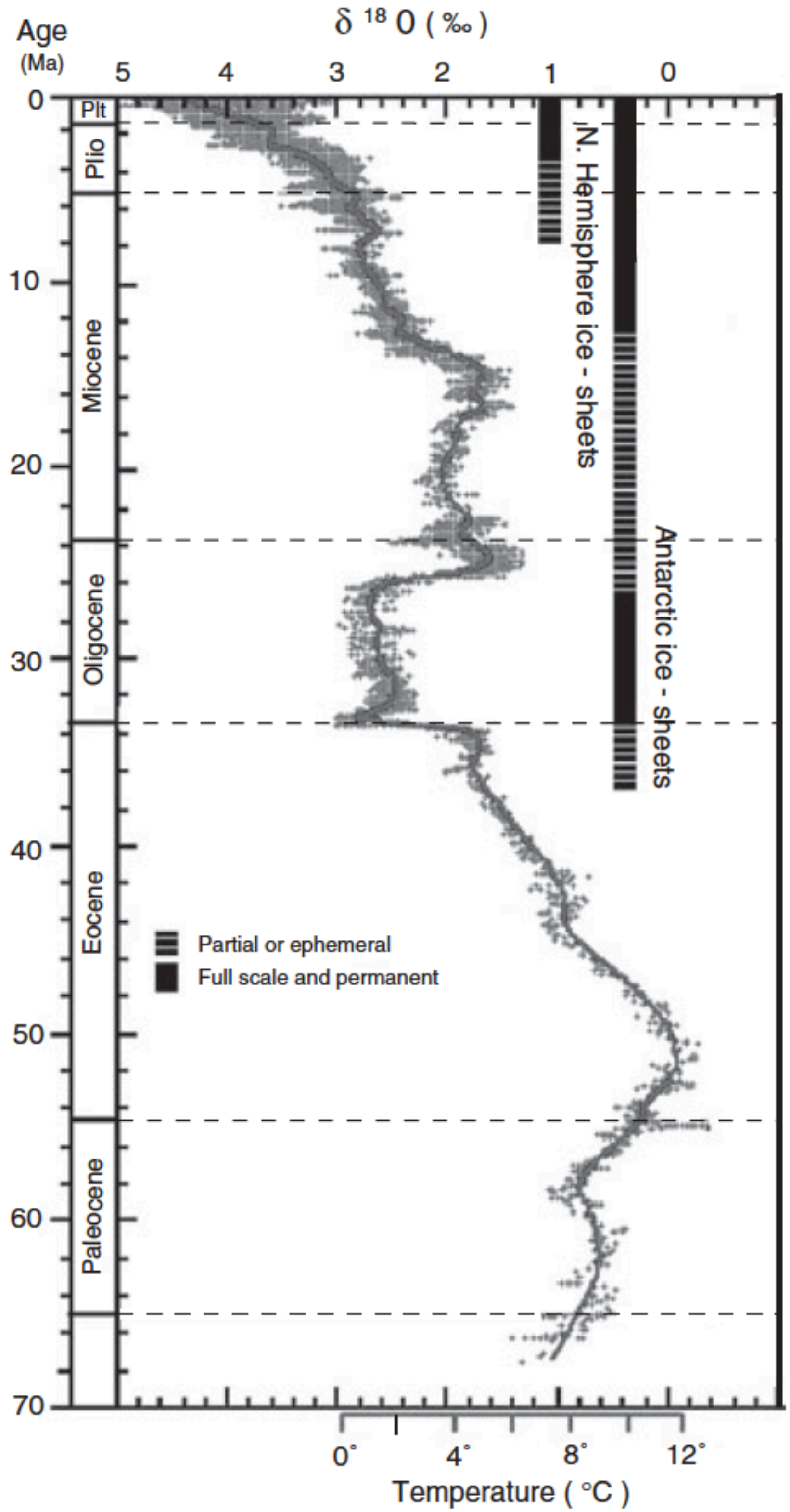


60 Ma



30 Ma



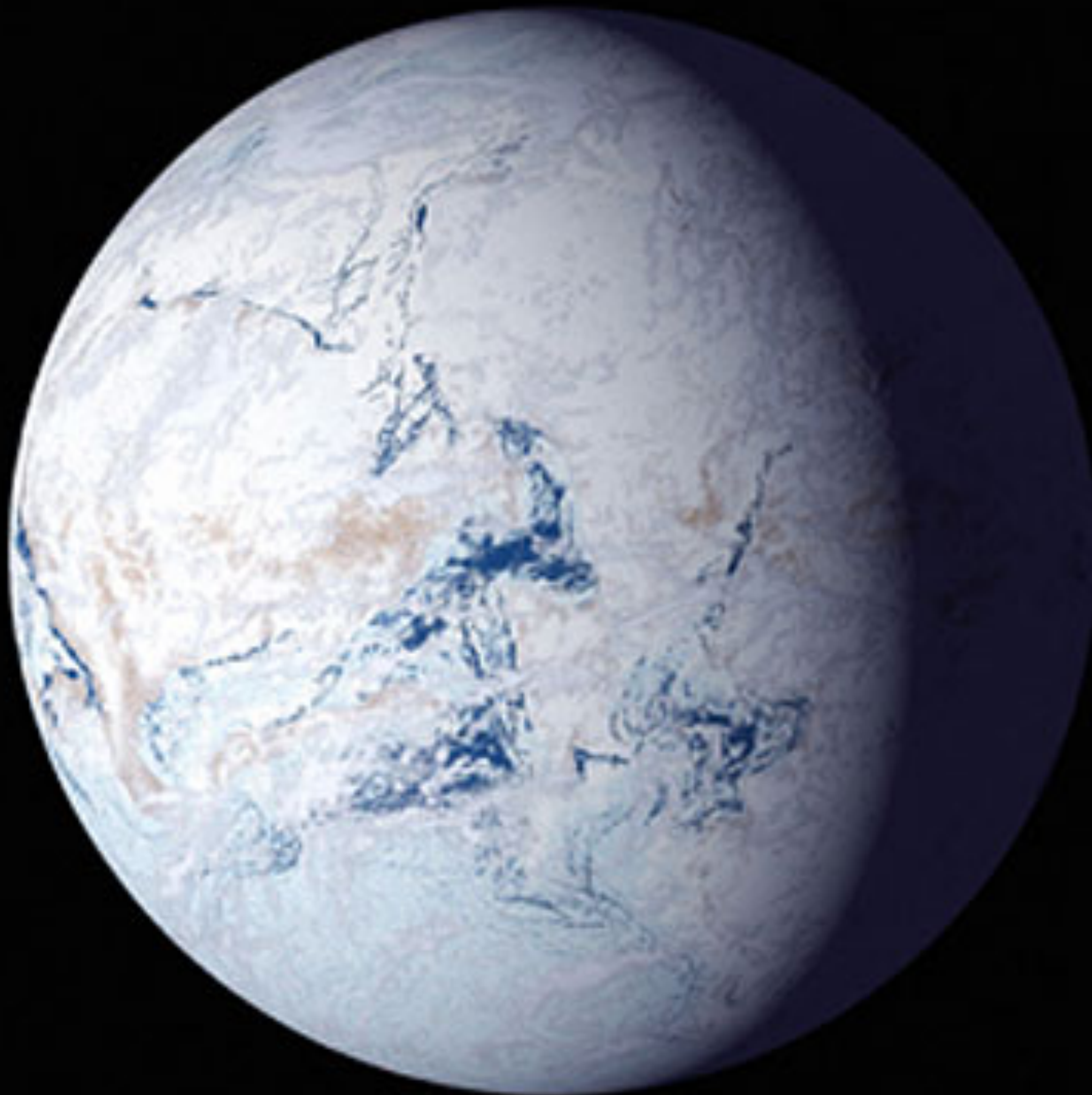


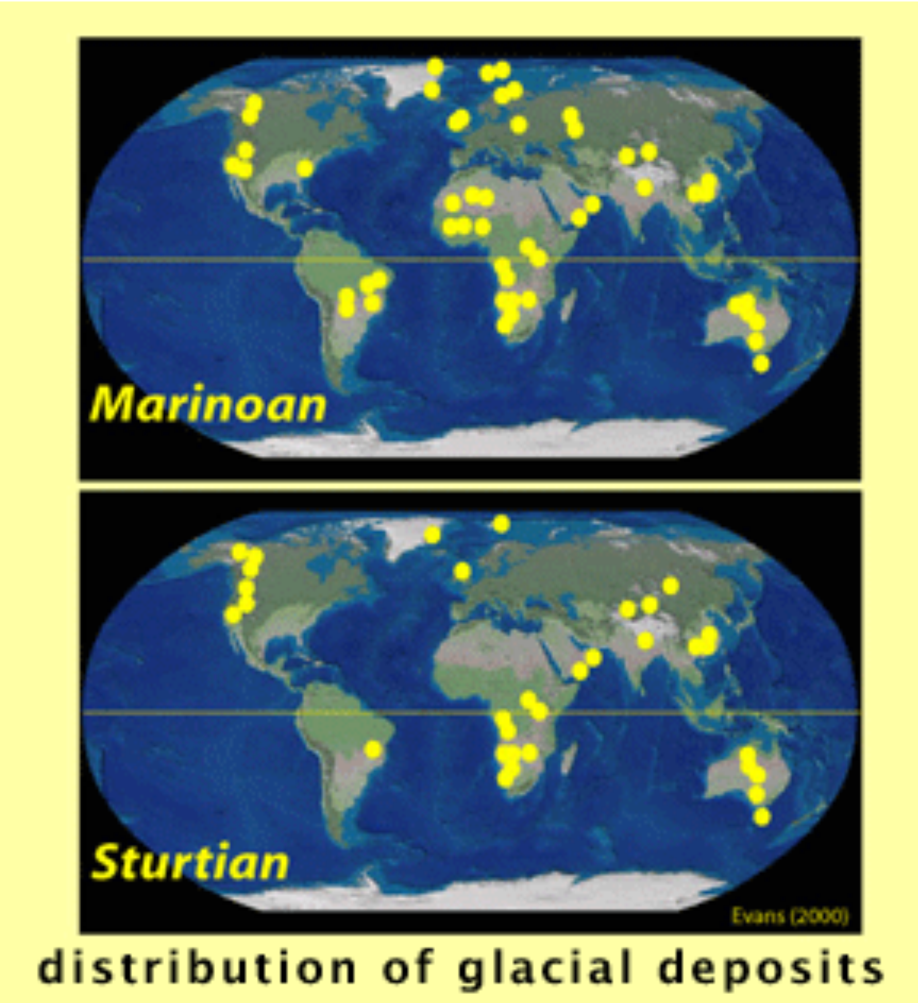
Polar ice caps are not permanent

The climate was much warmer >40 mln years ago than it is today

…was it ever much colder?

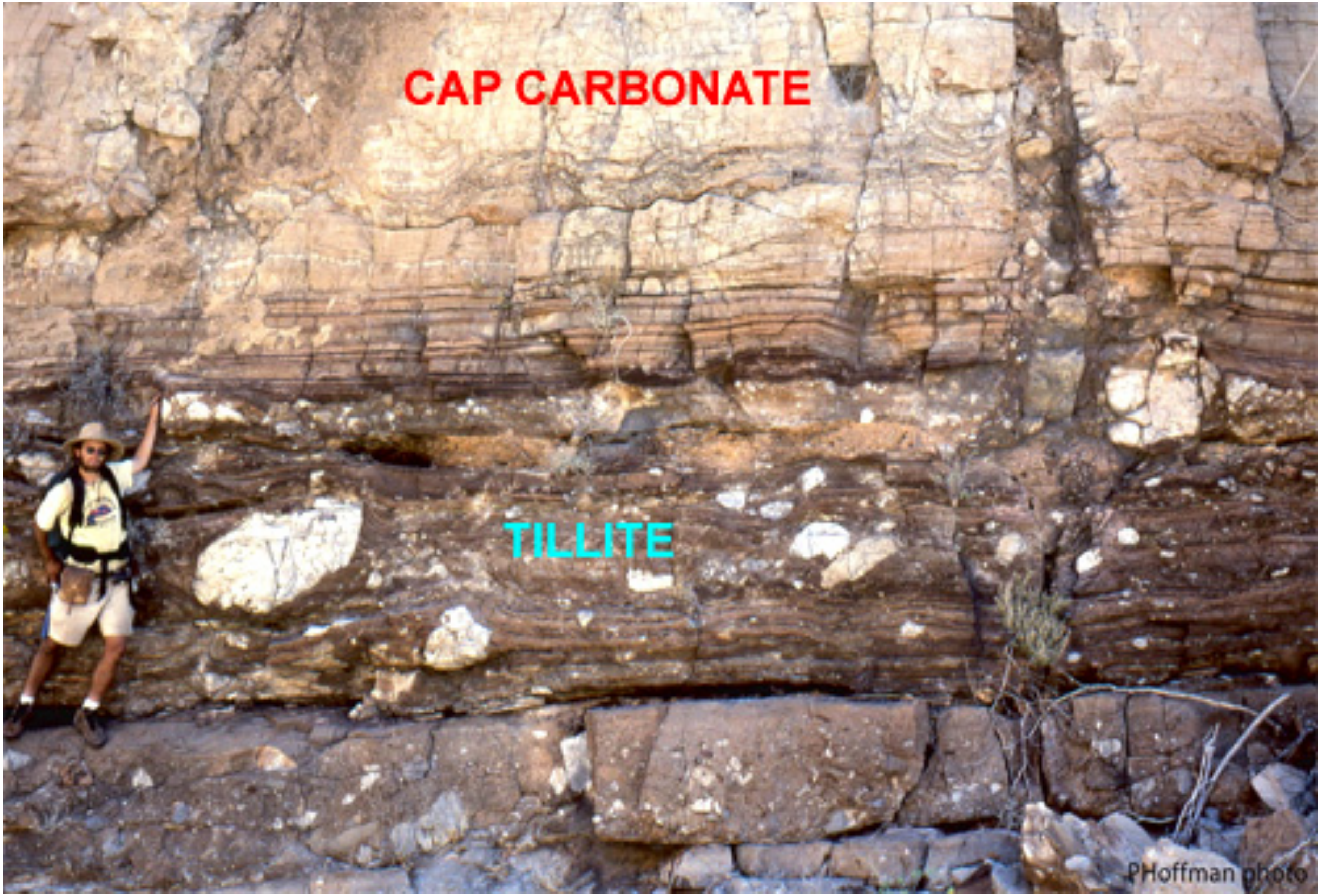
Snownball Earth

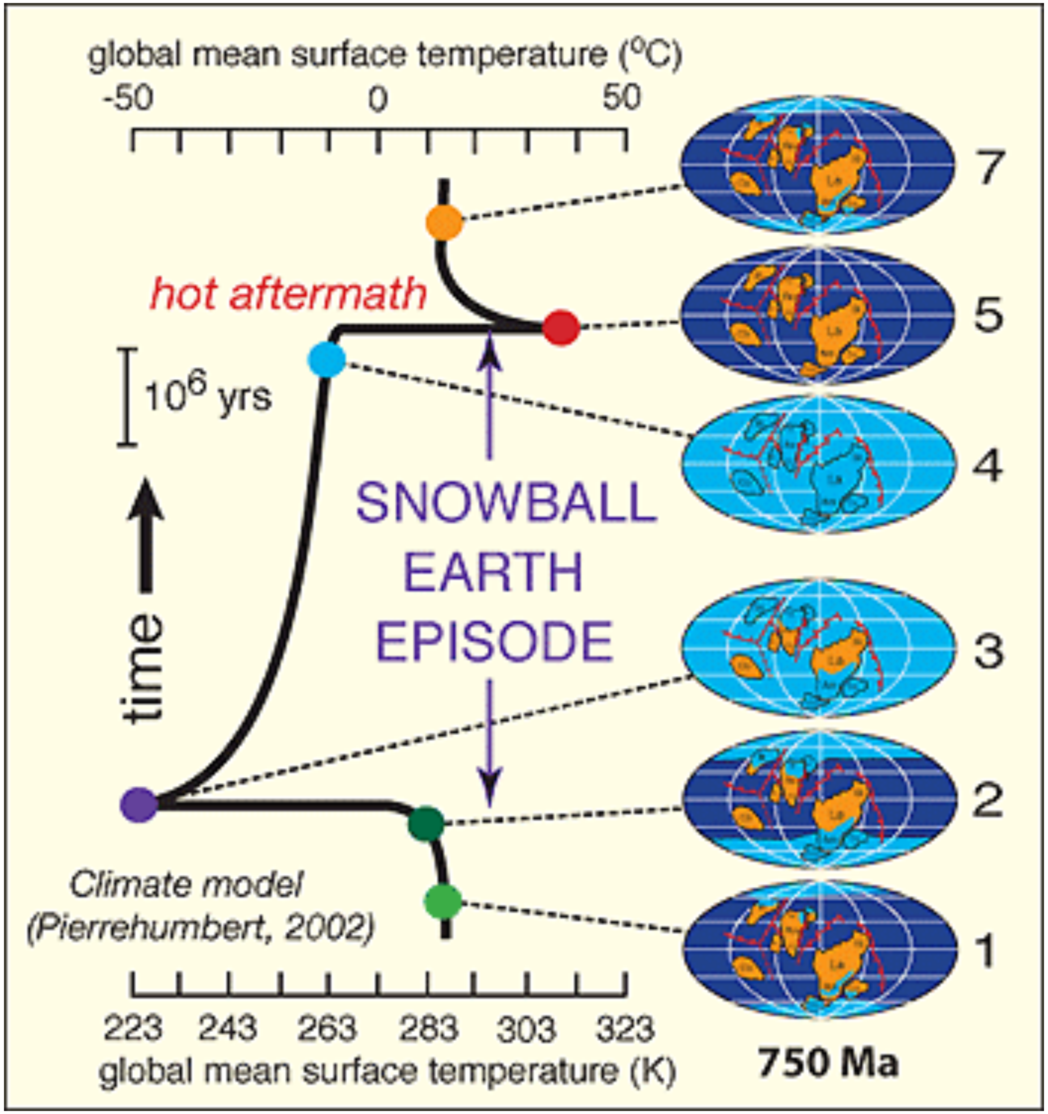


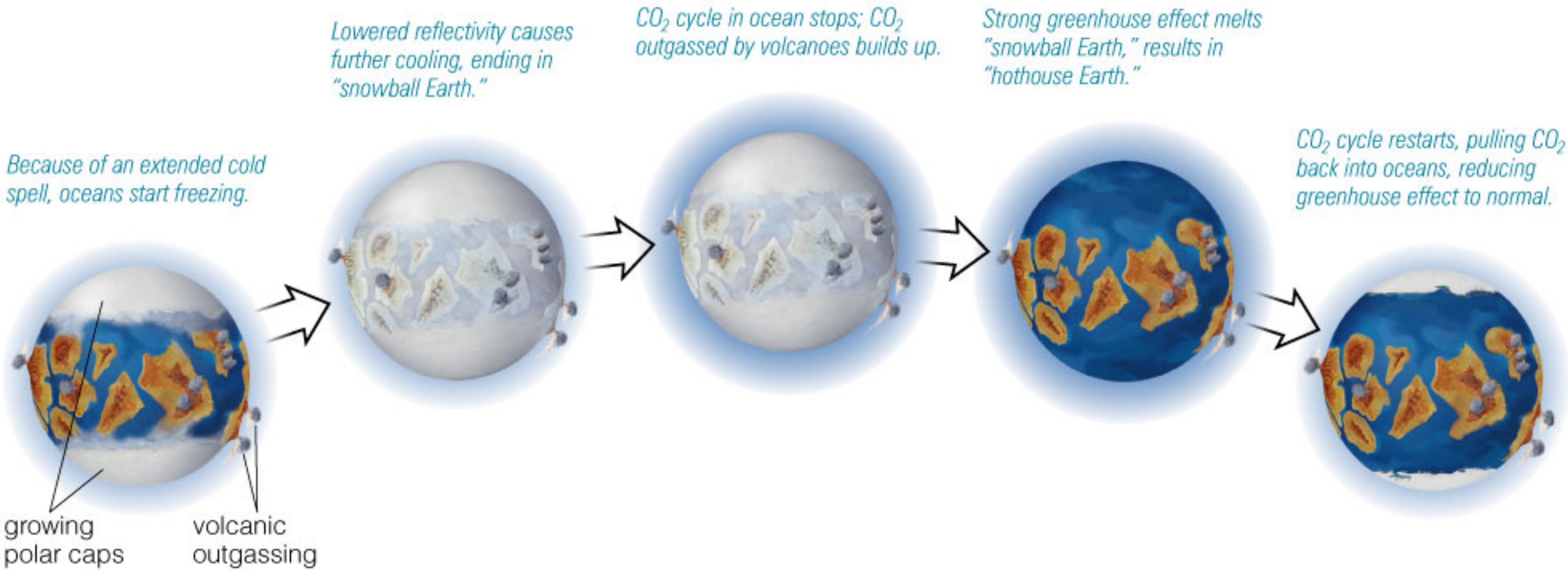


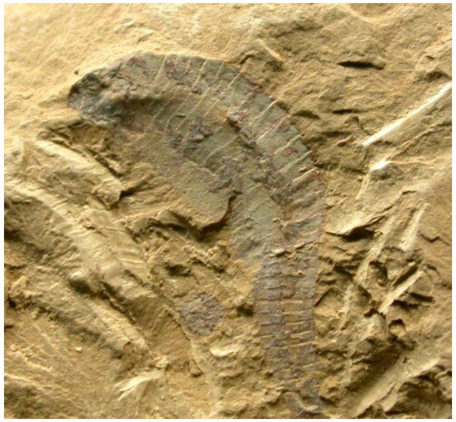
750 mln years ago

Namibia, South Africa

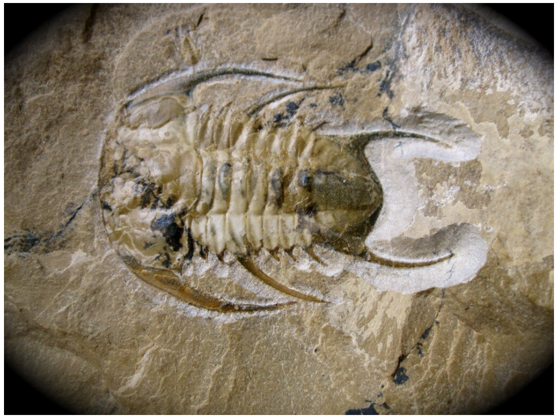

CAP CARBONATE
TILLITE
PHoffman photo


global mean surface temperature (°C)
-50
0
50
hot aftermath
10^6 yrs
time
SNOWBALL
EARTH
EPISODE
Climate model
(Pierrehumbert, 2002)
223
243
263
283
303
323
global mean surface temperature (K)
7
5
4
3
2
1
750 Ma

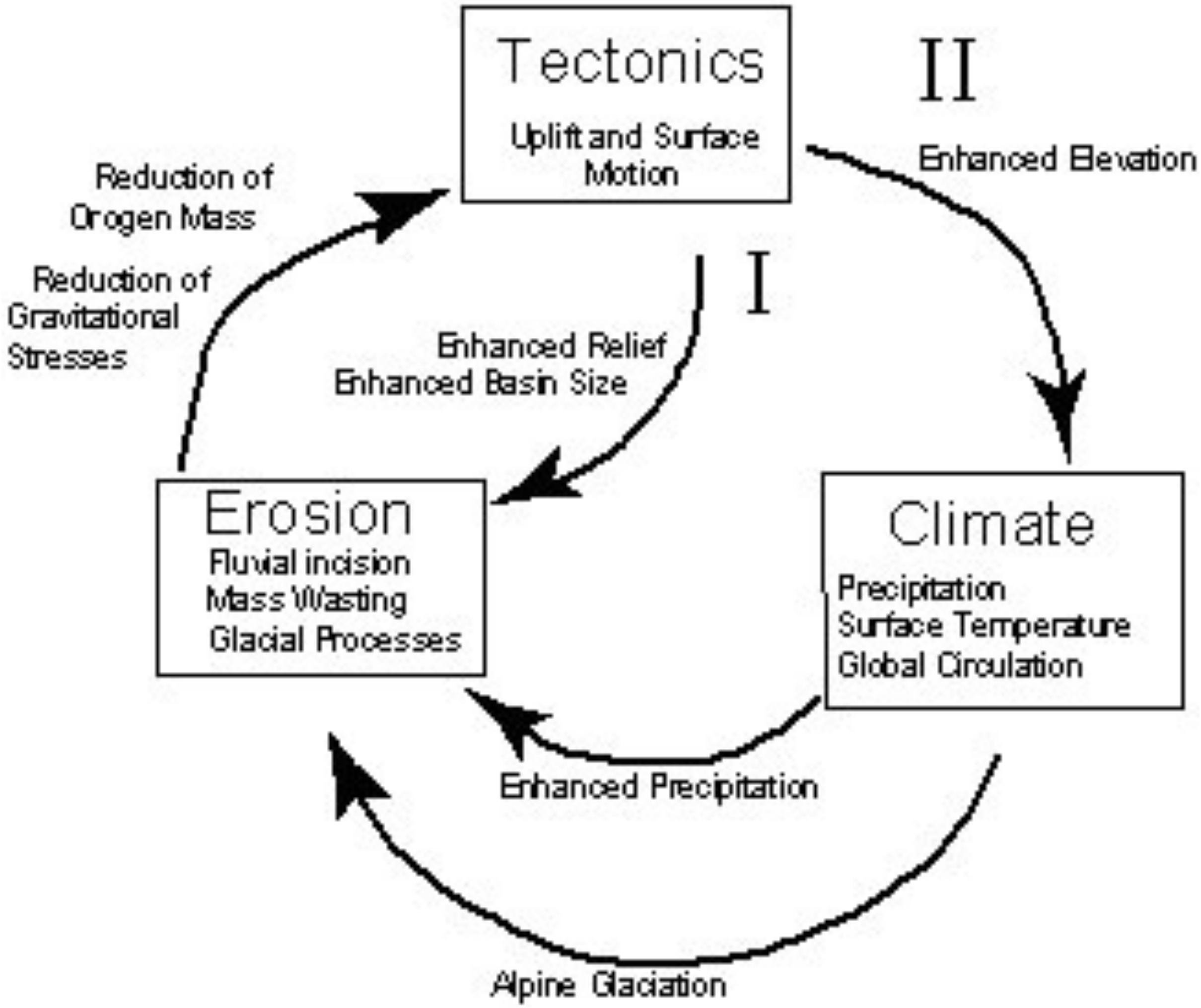

Because of an extended cold spell, oceans start freezing.
growing polar caps
volcanic outgassing
Lowered reflectivity causes further cooling, ending in "snowball Earth."
CO2 cycle in ocean stops; CO2 outgassed by volcanoes builds up.
Strong greenhouse effect melts "snowball Earth," results in "hothouse Earth."
CO2 cycle restarts, pulling CO2 back into oceans, reducing greenhouse effect to normal.

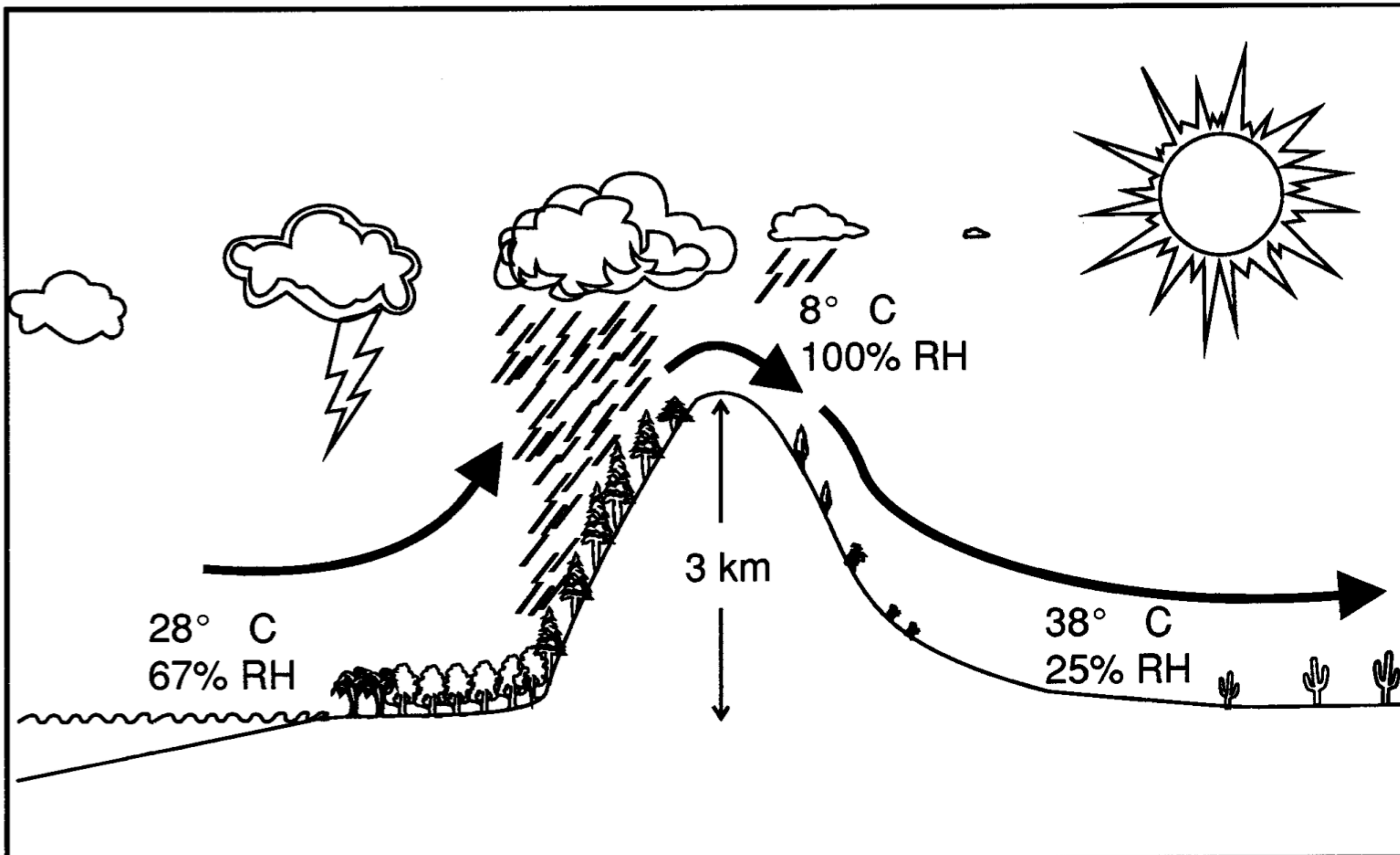


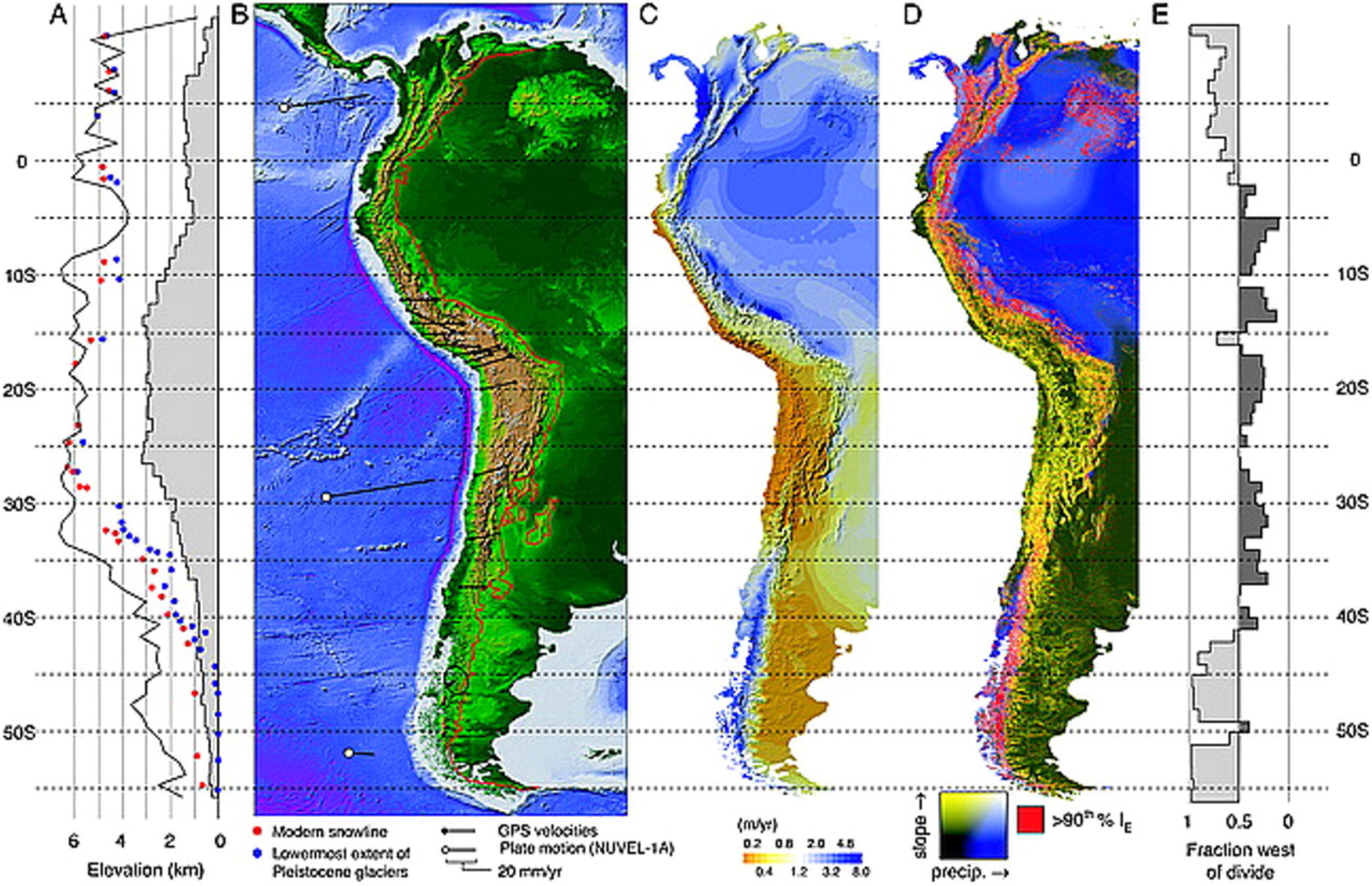
"Cambrian explosion"



The effect of orogeny

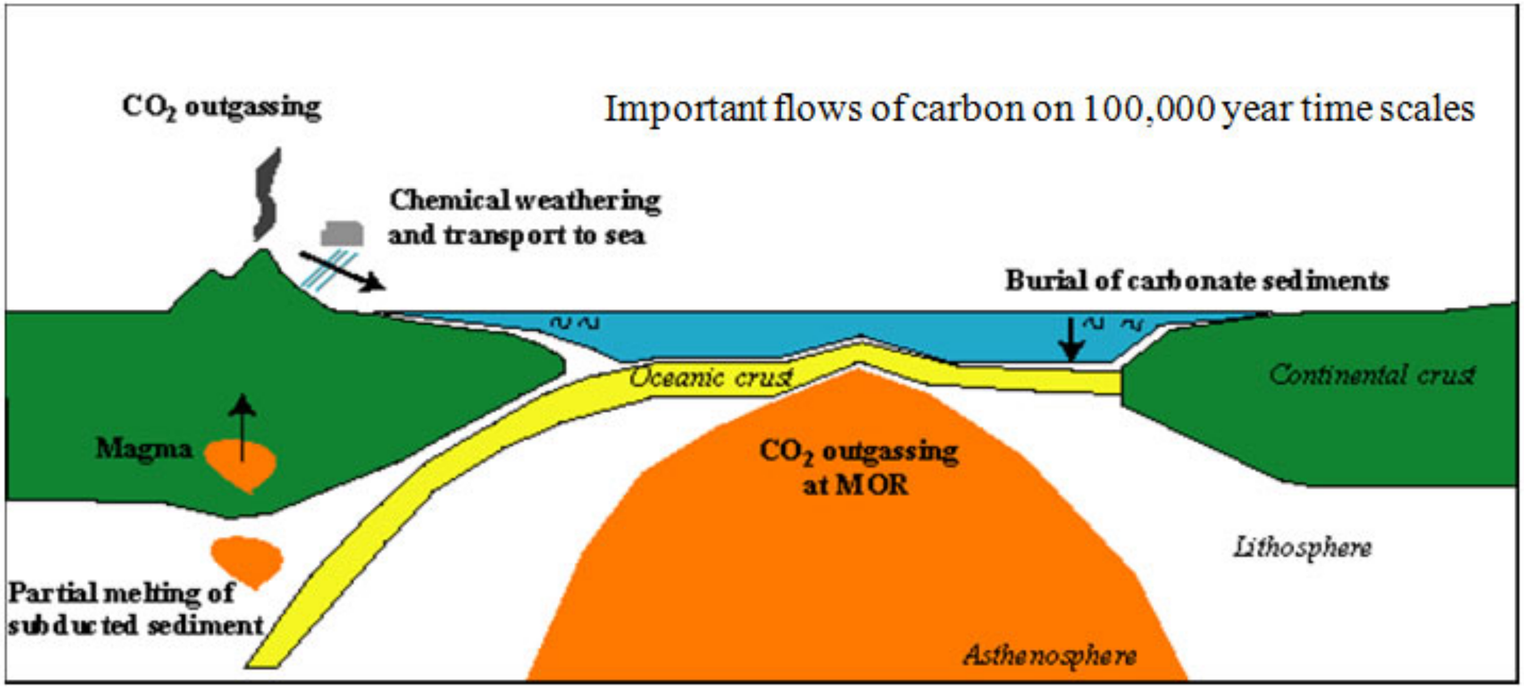


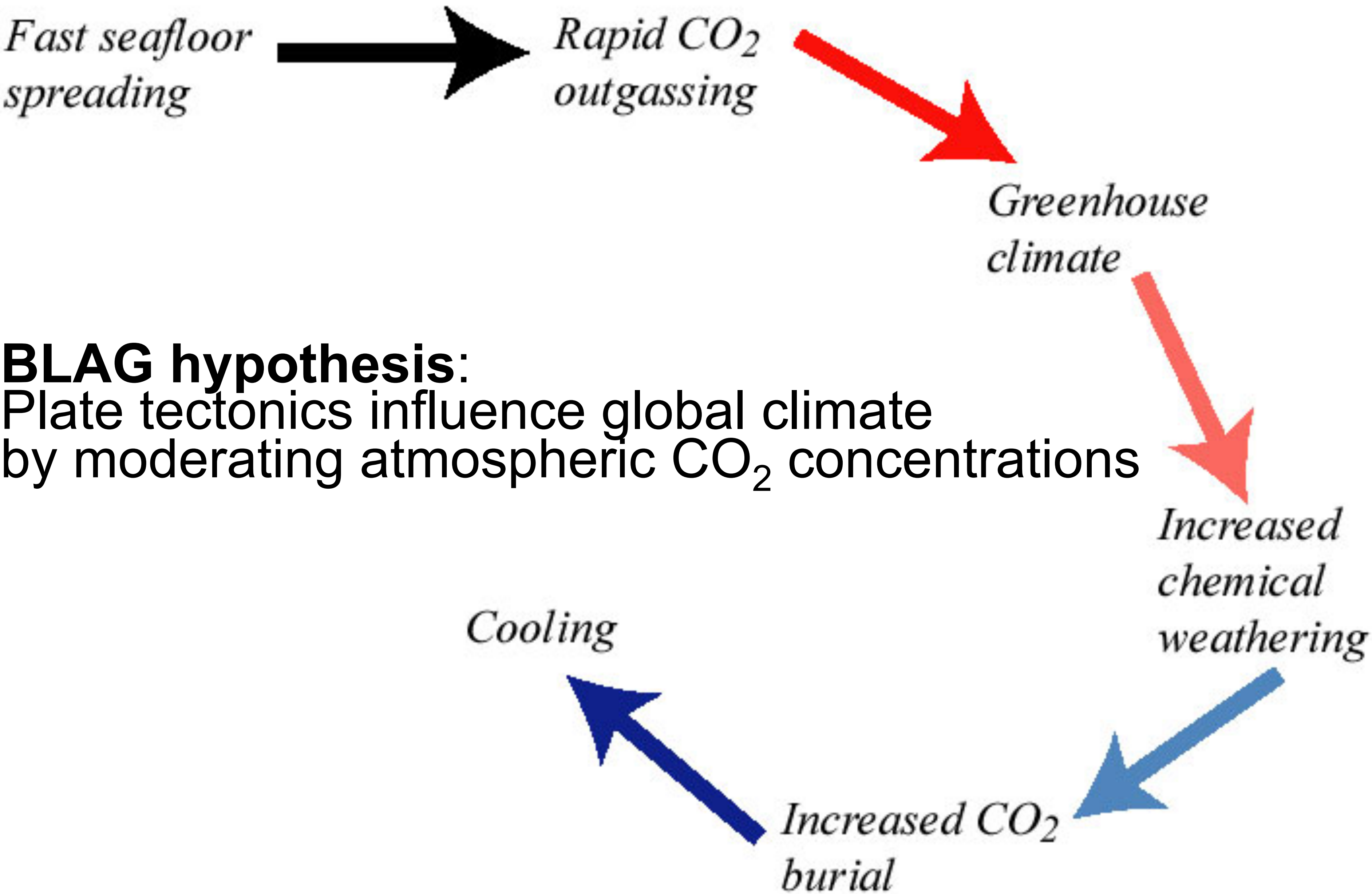

8° C
100% RH
3 km
28° C
67% RH
38° C
25% RH


A
B
C
D
E
0
10S
20S
30S
40S
50S
6
4
2
0
Elevation (km)
Modern snowline
Lowermost extent of Pleistocene glaciers
GPS velocities
Plate motion (NUVEL-1A)
20 mm/yr
(m/yr)
0.2
0.8
2.0
4.8
0.4
1.2
3.2
8.0
slope →
precip. →
>90th % I_E
1
0.5
0
Fraction west of divide

Long-term carbon cycle

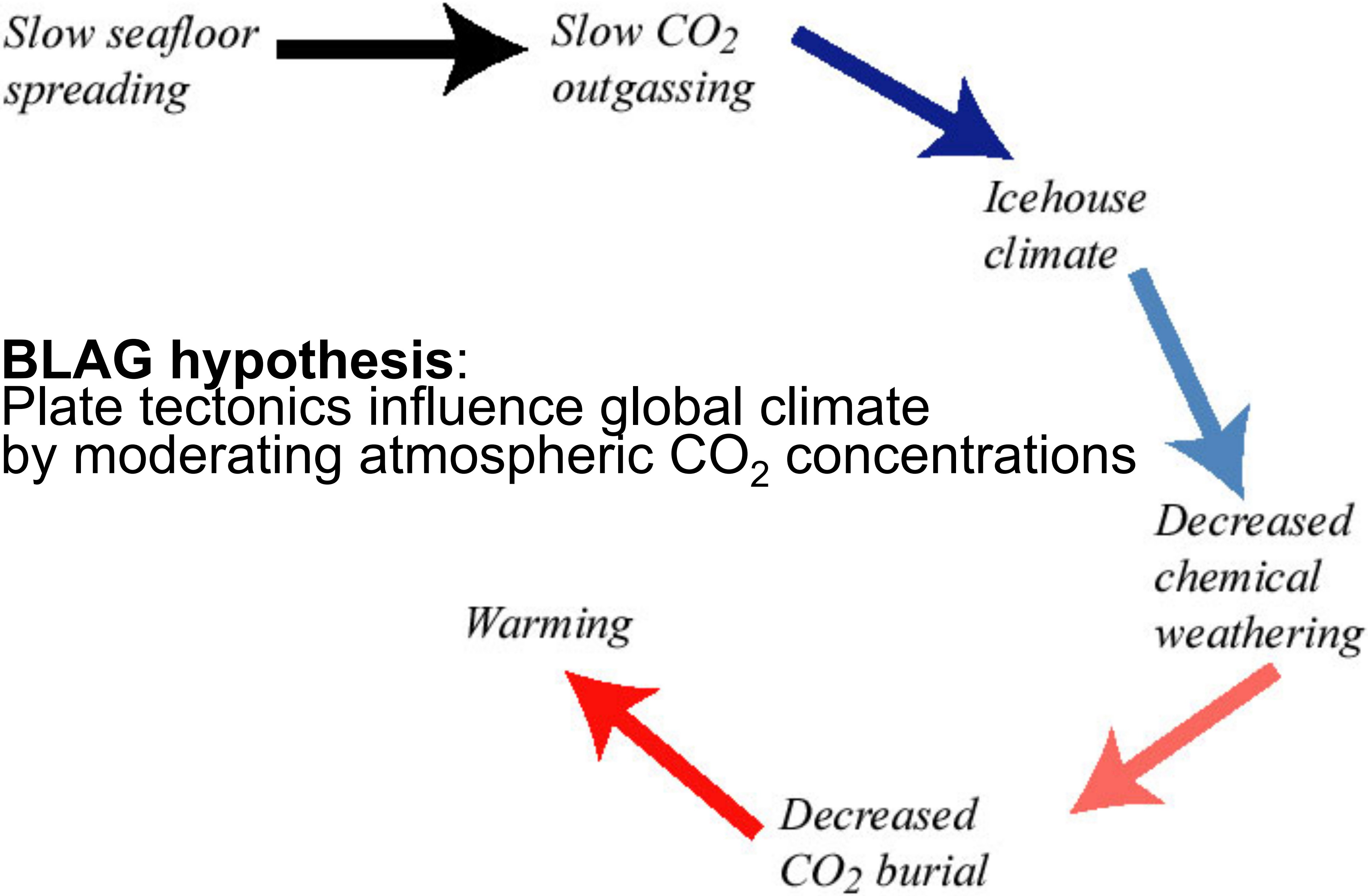
- Carbon added to atmosphere through metamorphic outgassing and outgassing of volcanoes and mid-ocean ridges
- Hydrolysis-weathering of silicate minerals in continental crust:
  $CaSiO_3 + H_2CO_3 >> CaCO_3 + SiO_2 + H_2O$
- The products of continental weathering are transported to the oceans by rivers, where they are used to make $CaCO_3$ and SiO_2 shells of marine organisms. When these organisms die, many of them are deposited and buried on the seafloor. The carbon cycle is completed upon subduction and melting of these sediments. The melt may rise as magma, providing volcanoes and MORs with a source of recycled CO_2.



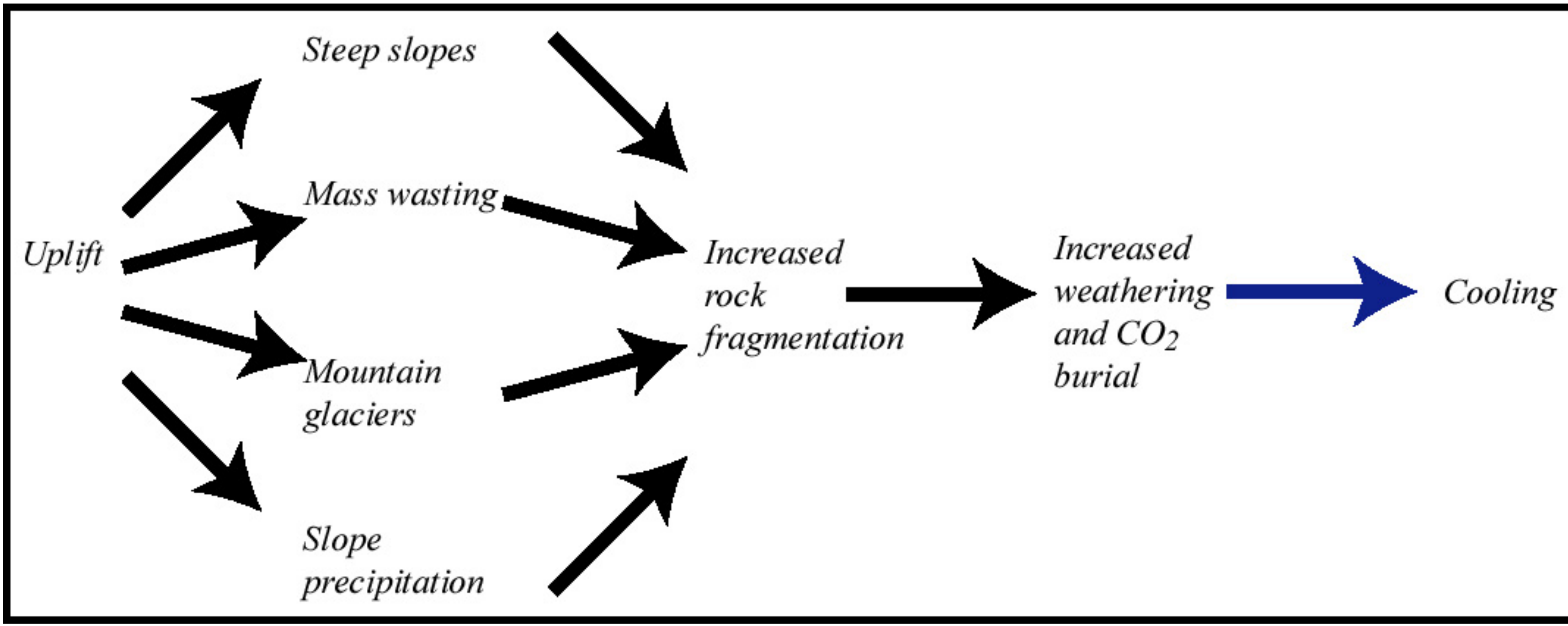


BLAG hypothesis:
Plate tectonics influence global climate
by moderating atmospheric CO_2 concentrations

BLAG hypothesis:
Plate tectonics influence global climate
by moderating atmospheric CO_2 concentrations

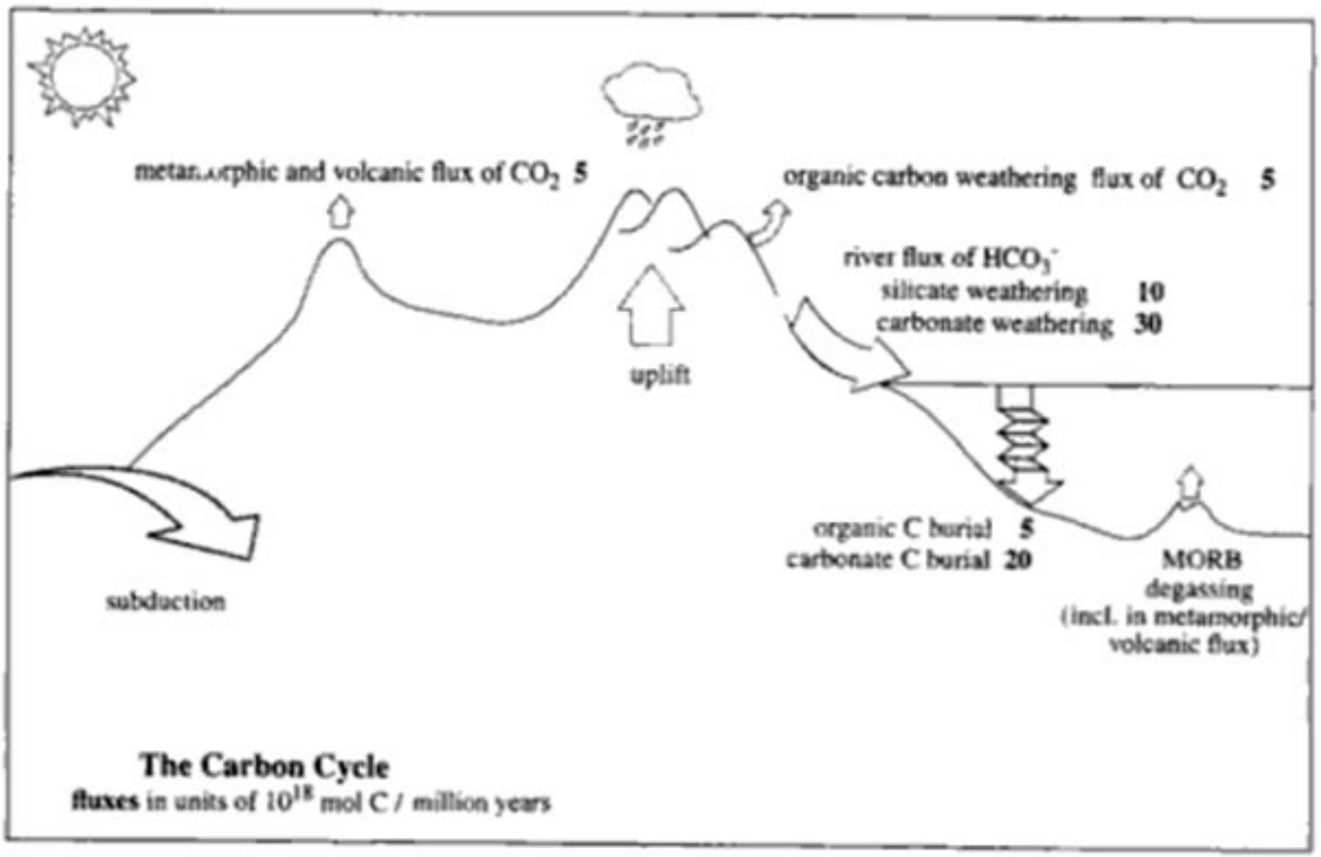


Uplift weathering hypothesis: Uplift accelerates chemical weathering, drawing down CO_2, and cooling the global climate.



- Chemical weathering – a CO_2 sink

$$CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$$



The End

Enjoy the Summer!