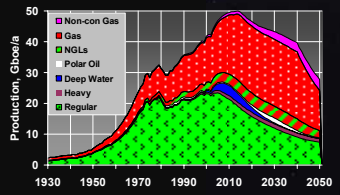
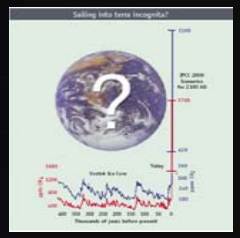


The Paleoclimate record and Anthropogenic Global Warming

December, 2008

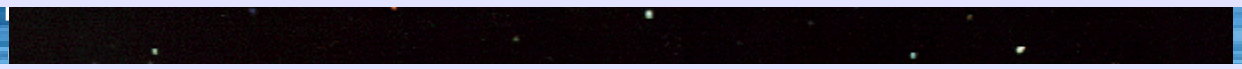


Conclusion

- Paleoclimate science reveals that carbon dioxide were not a greenhouse gas responsible for maintaining the Earth's climate, then the evolution of complex eukaryotic life would not be possible.
  - In other words, if Anthropogenic Global Warming isn't real then "AGW deniers" do not exist.
- In addition to AGW, other energy, environment and economy problems we face can be addressed by conservation and investment in alternative energy sources, in particular solar.

Drake's calculations

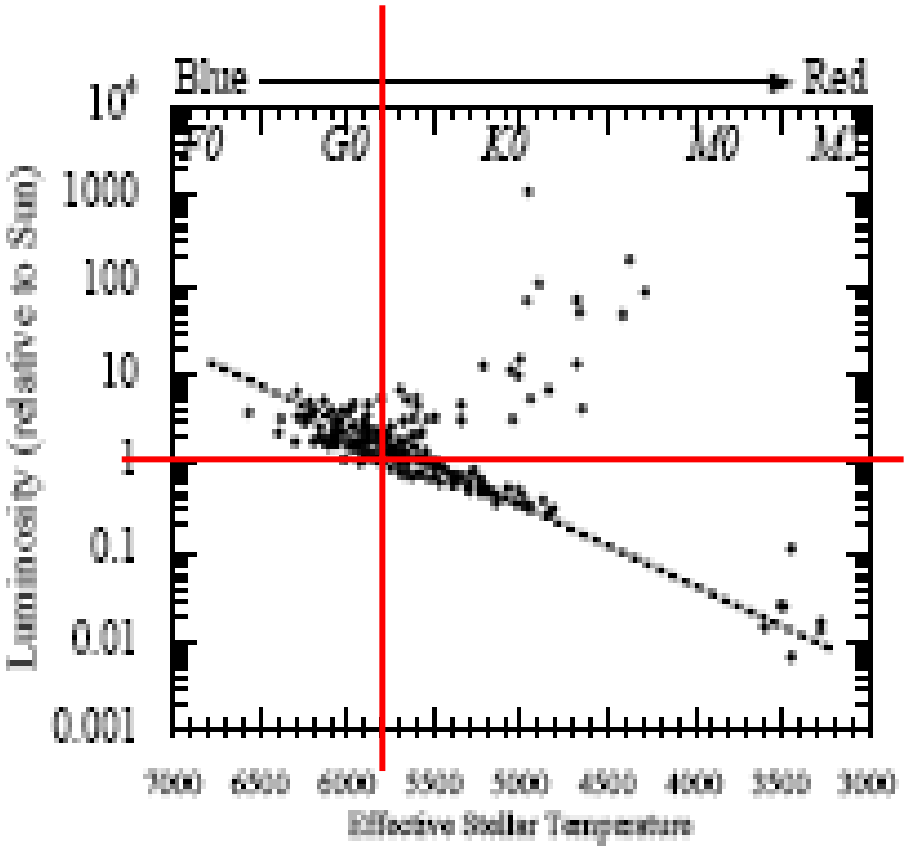
- Type of star that can support life ?
- Stars with planets
- Is the star too close to the galactic center ?
- Habitable planets with life
  - 90%
- How many planets in habitable zone are large enough, have plate techtonics, a large moon ?
- [illegible]
  - 10
- Circular orbit, diurnal rotation, axis tilt ?



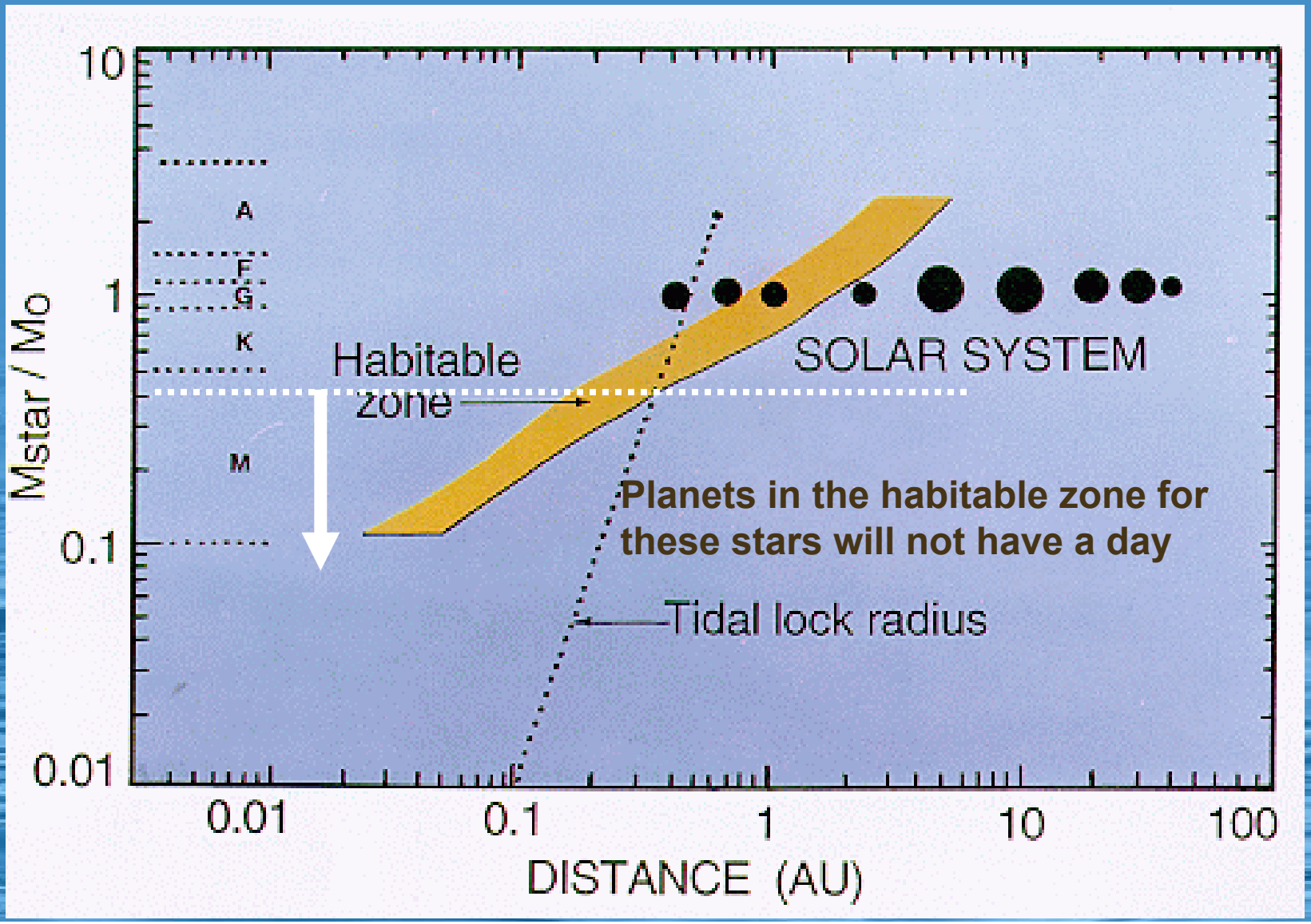
[illegible]ons

What properties determine the probability of the evolution of complex life

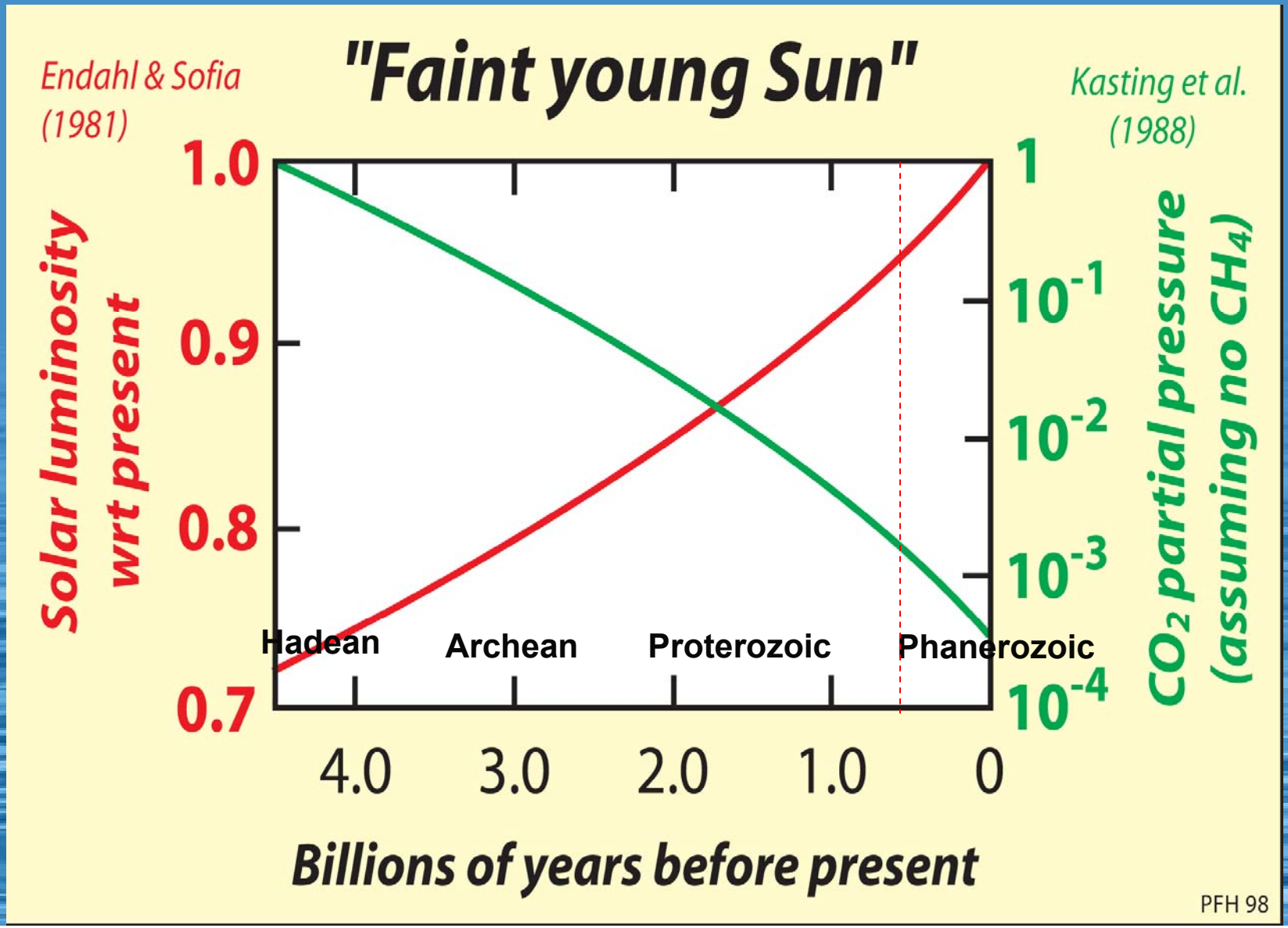
- Type of star – Our star is a class G2 star on the main sequence



The Habitable Zone for different star classes

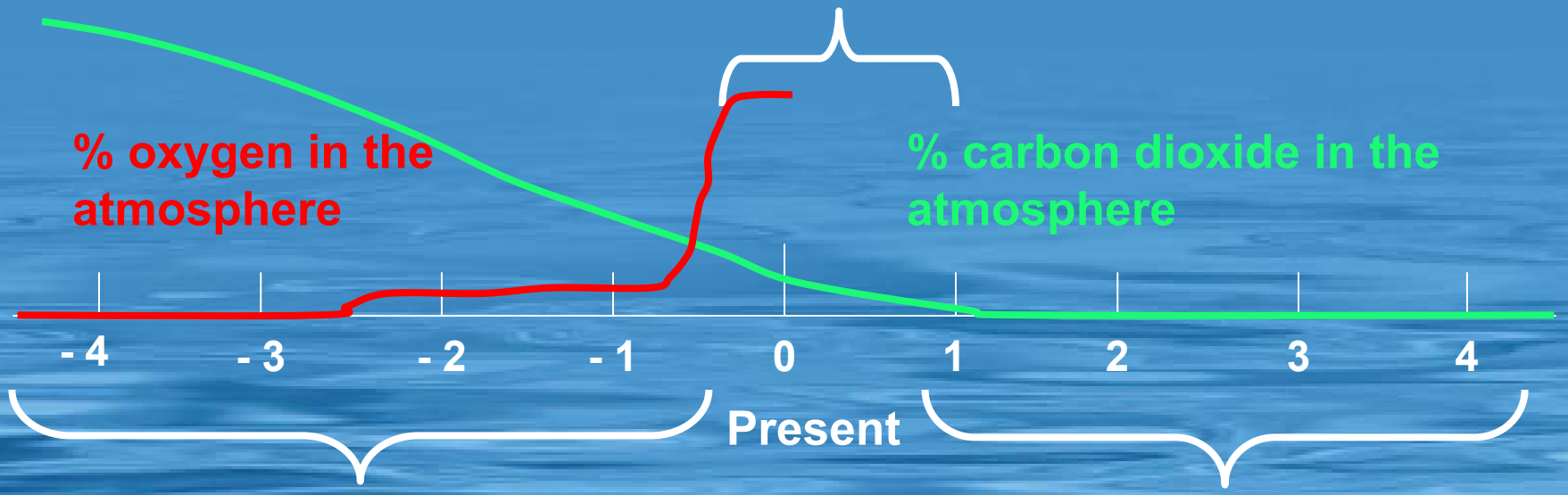


Solar luminosity and atmospheric carbon



Limit on complex life on Earth

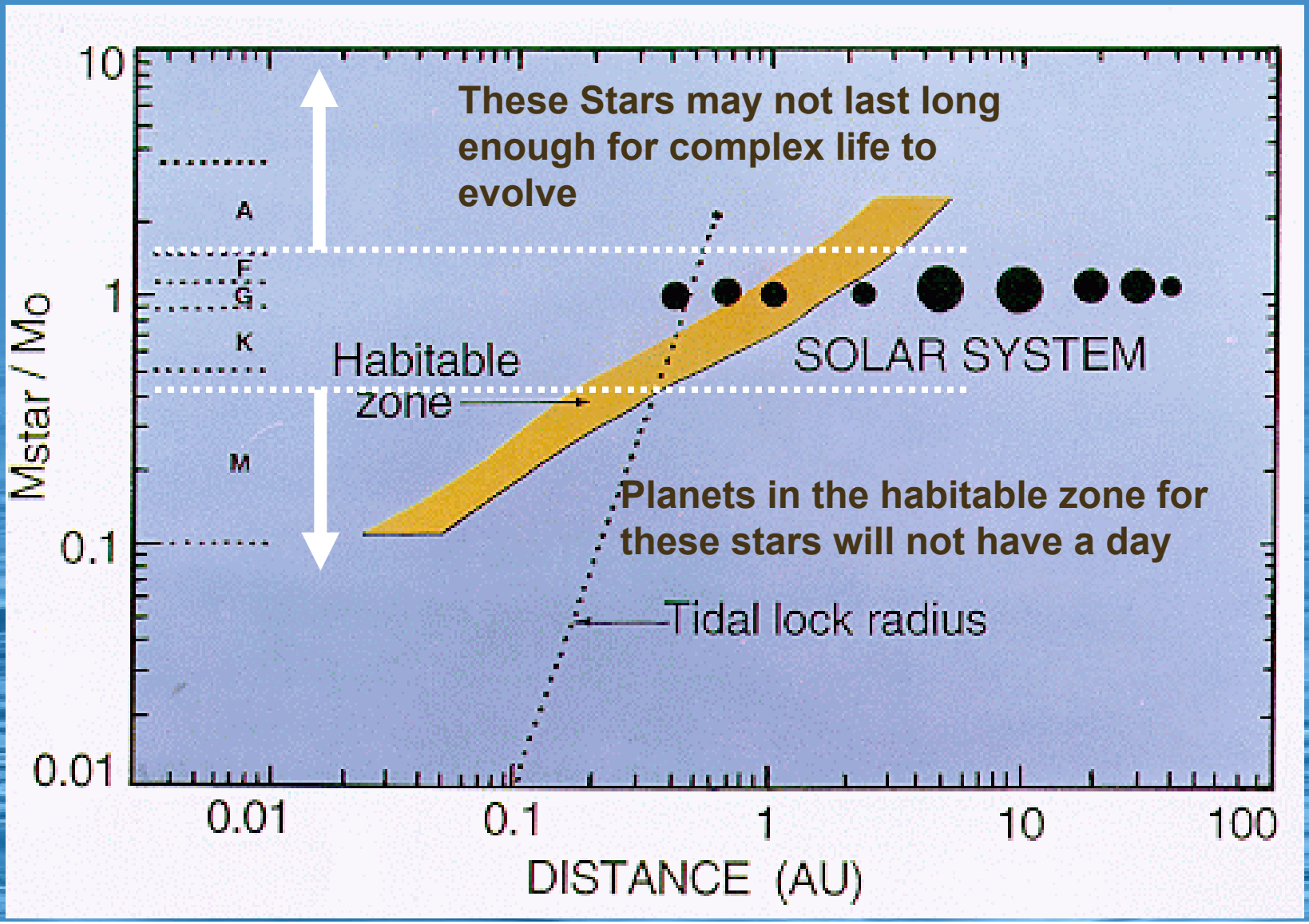
Complex life has a window of about 1.5 billion years on Earth out of the 10 billion years of the sun's existence



There was not enough oxygen on Earth to support Human life for the first 4 billion years of the Earth's existence

There will not be enough carbon dioxide to support oxi-photosynthesis within 500 million to 1 billion years

The Habitable Zone for different star classes



What are necessary requirements for complex life to evolve on a planet?

- A cooperative star and a fortunate orbit
- Chemical composition must include a rich set of elements (in no particular order): carbon, hydrogen, oxygen, nitrogen, phosphorus, magnesium, iron, potassium, calcium, sodium, sulfur, copper, uranium, etc.
- The planet climate over any time scale must be constrained within limits that support liquid water for at least a few billion years.

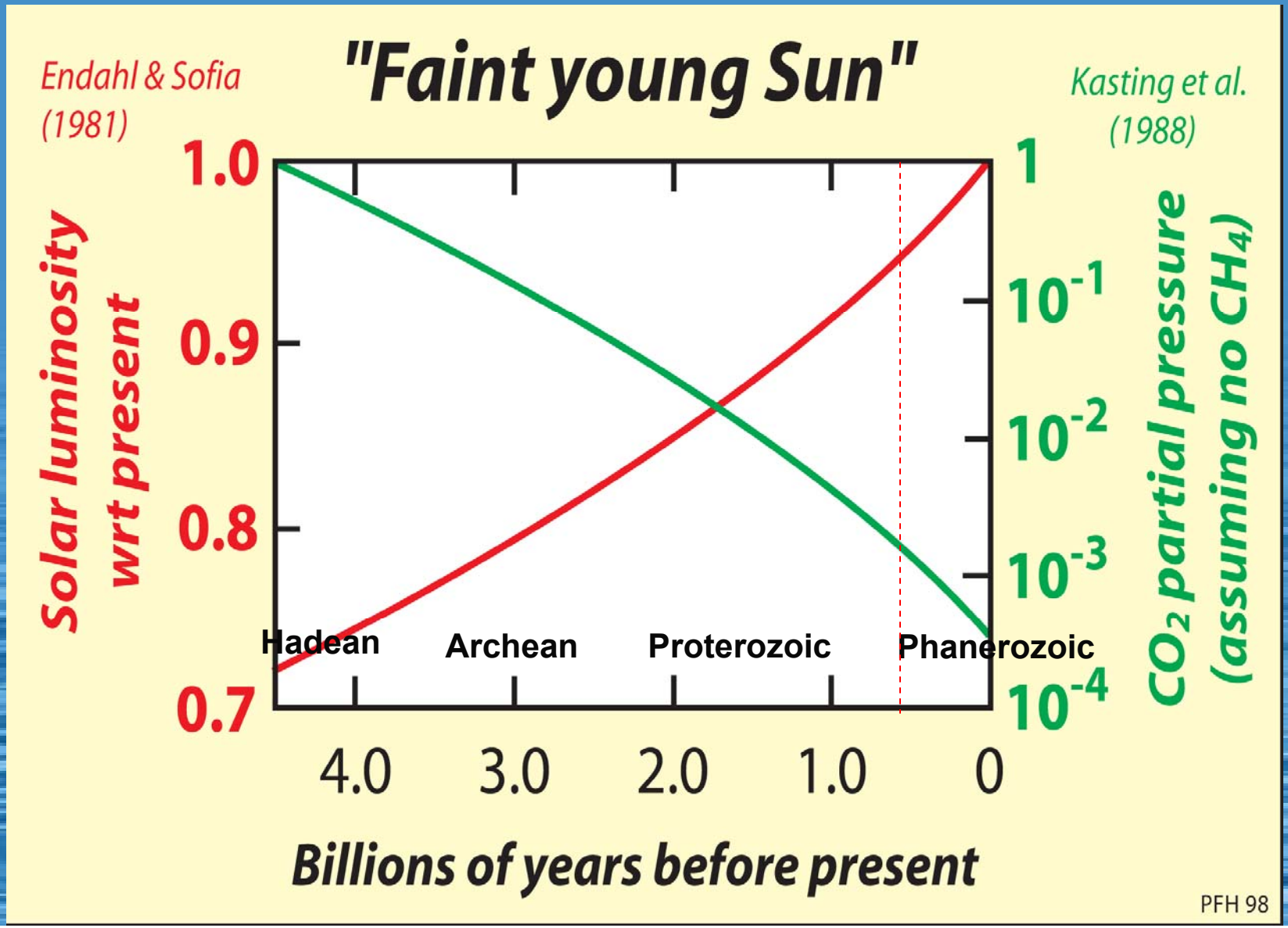
Happy Birthday Charles Darwin

February 2009 sees the 200th anniversary of the birth of Charles Robert Darwin and November 2009 the 150th anniversary of the publication of his great work, *On the Origin of Species*.

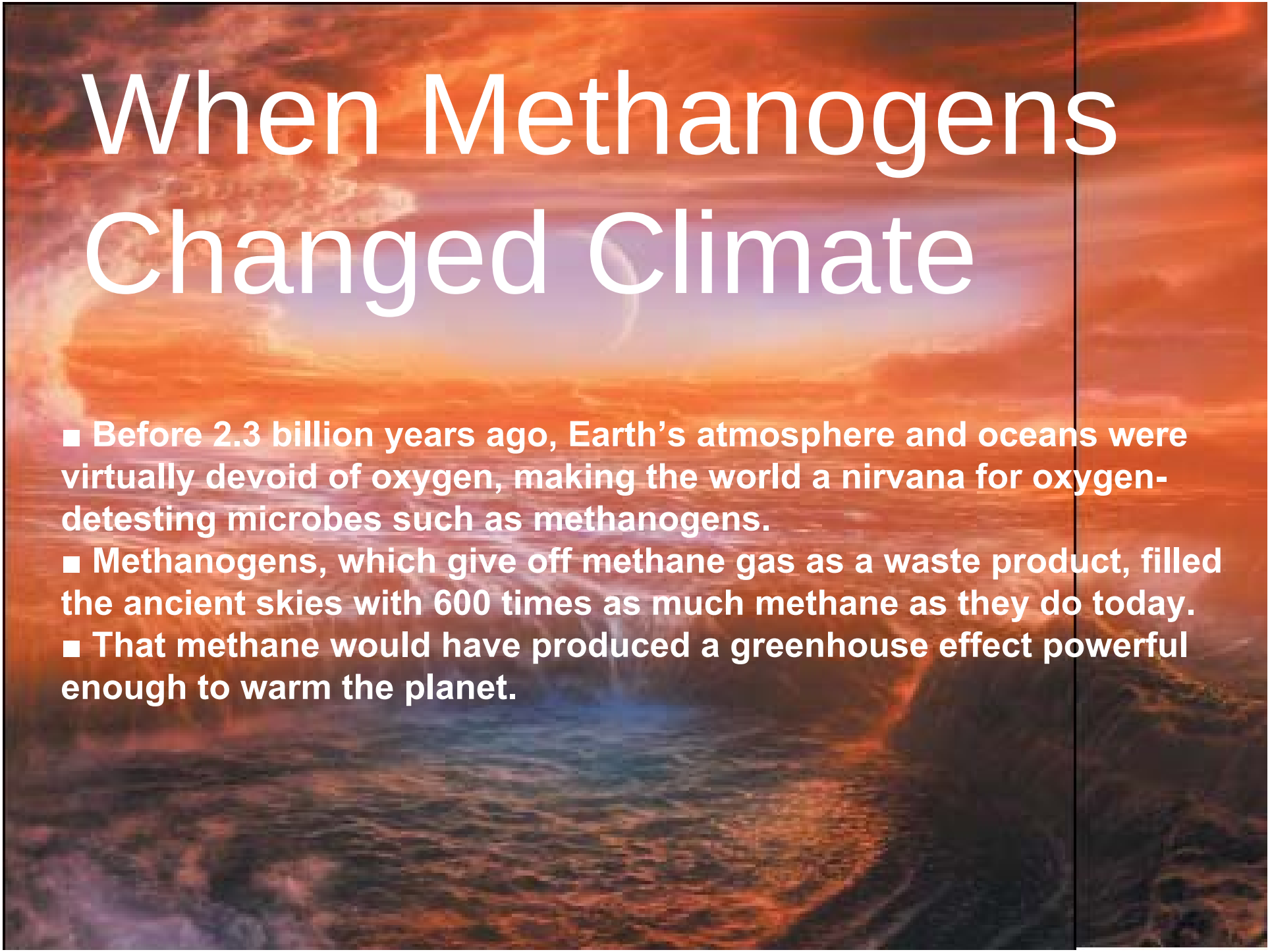
What caused the Earth's climate to vary in the past?

- Solar luminosity
- Atmospheric carbon greenhouse effect
- Earth orbital variation
- Plate tectonics
  - Position of continents and oceans
  - High mountains (long term weathering and winds)
  - Ocean circulation
  - Subduction and regeneration of CO_2
- Volcanism contributes CO_2 (carbon cycle)
- Plant and bacterial life via photosynthesis
- Burial of organic matter in oceans
- Mountain weathering and deposition as carbonate layers in oceans
- Surface and cloud Albedo
- Water vapor

Solar luminosity and atmospheric carbon

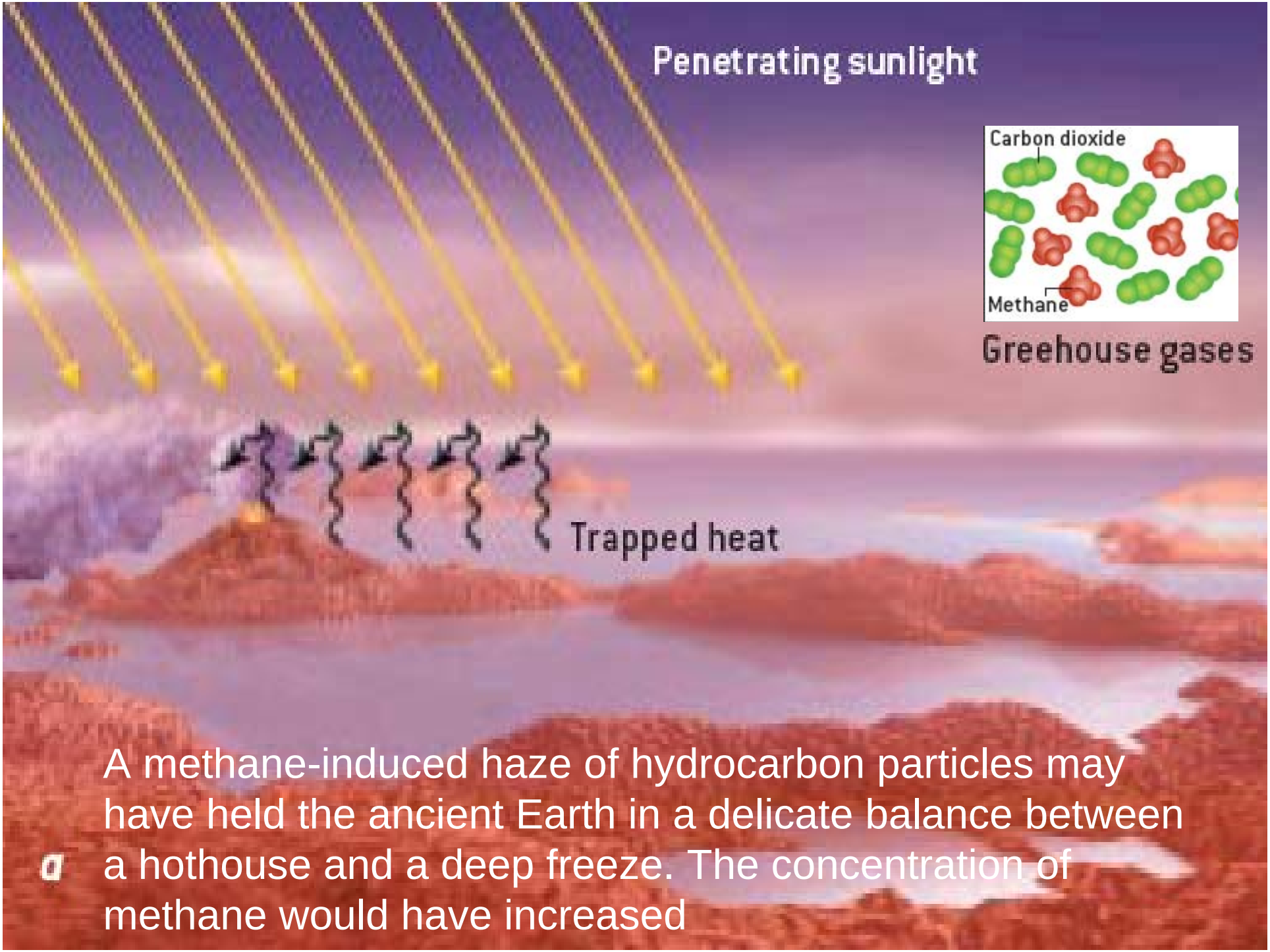



When Collision Kinetic Energy Made Climate
During the Hadean

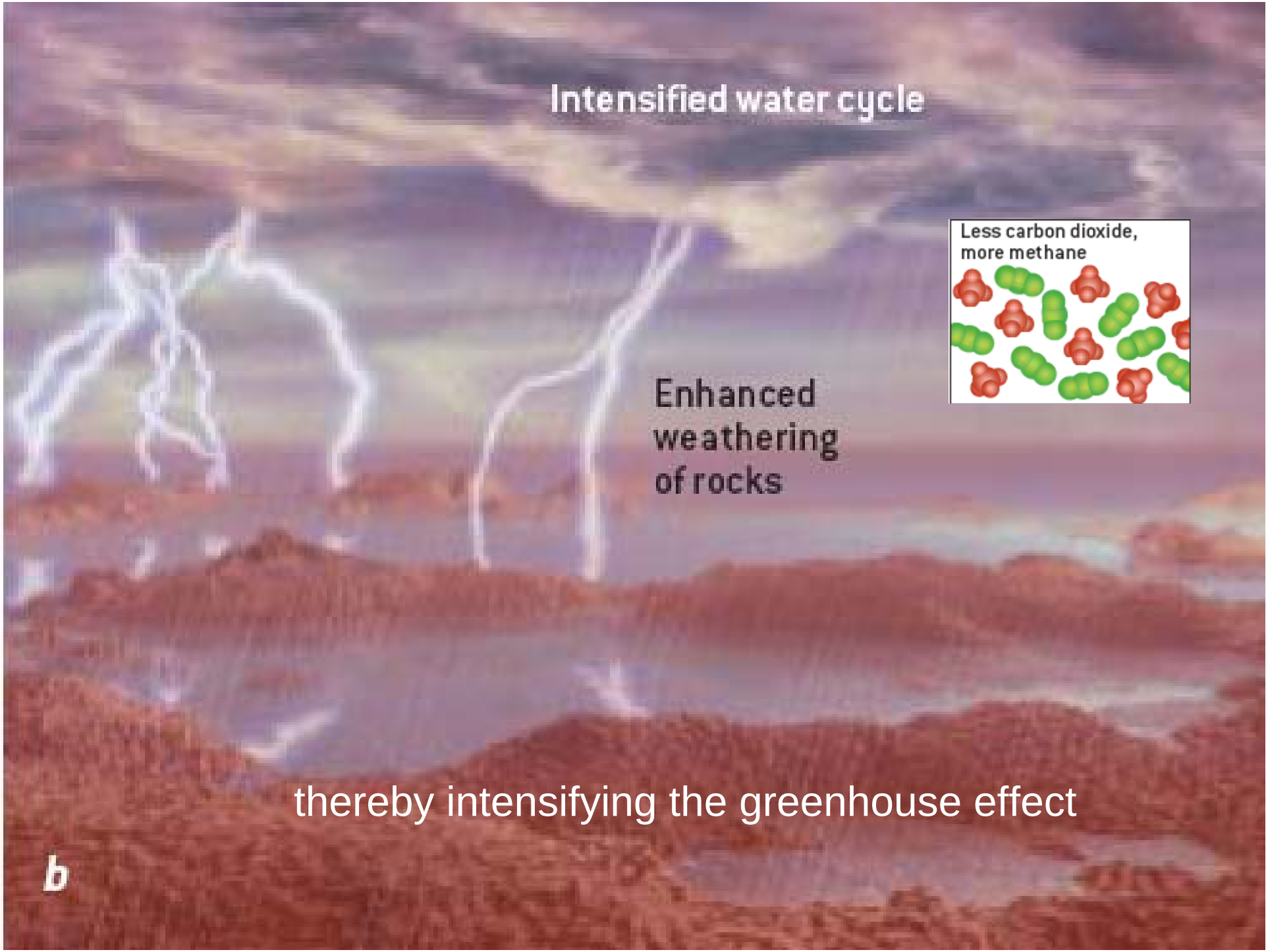


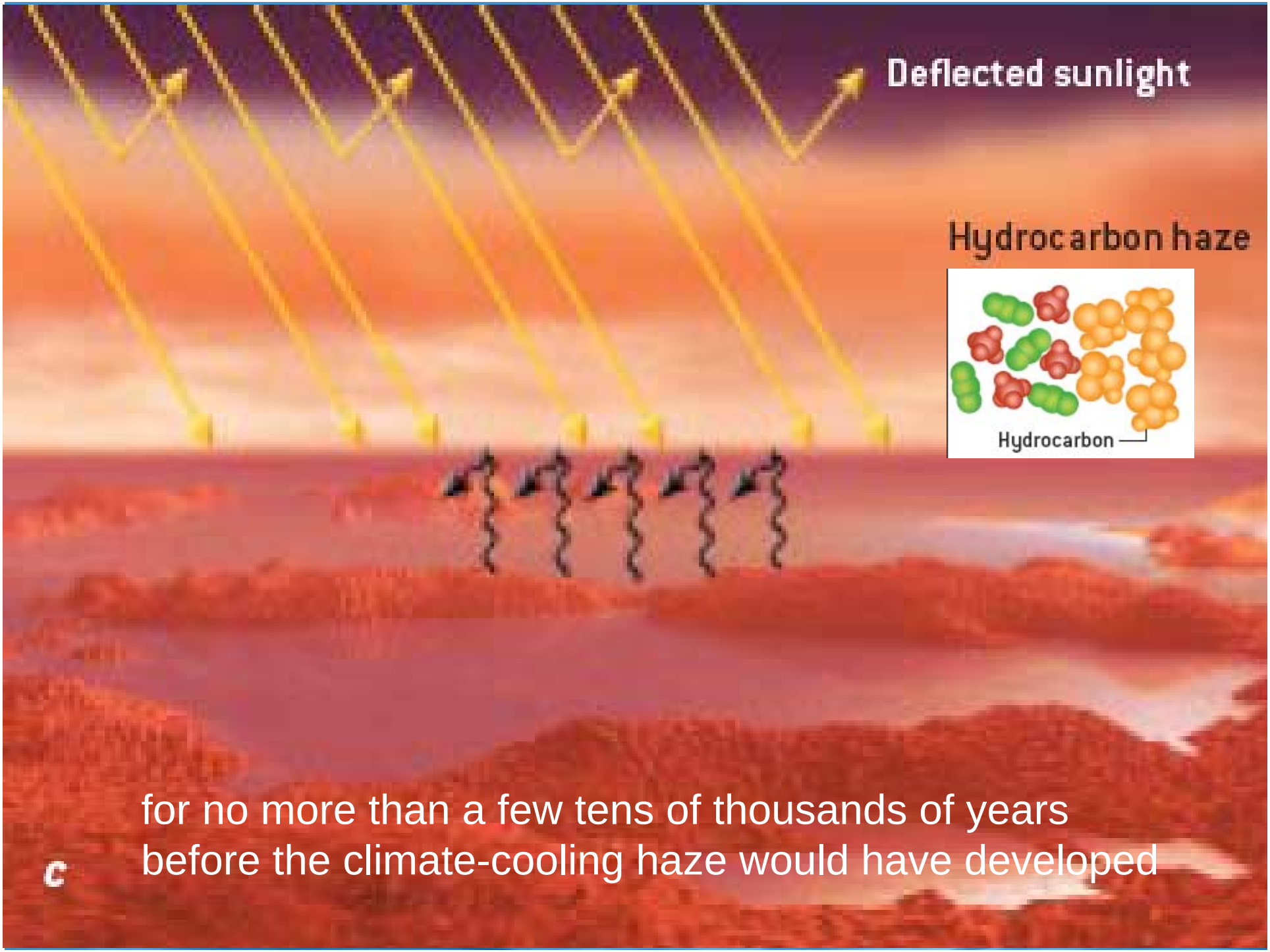
When Methanogens Changed Climate

- Before 2.3 billion years ago, Earth's atmosphere and oceans were virtually devoid of oxygen, making the world a nirvana for oxygen-detesting microbes such as methanogens.
- Methanogens, which give off methane gas as a waste product, filled the ancient skies with 600 times as much methane as they do today.
- That methane would have produced a greenhouse effect powerful enough to warm the planet.



- A methane-induced haze of hydrocarbon particles may have held the ancient Earth in a delicate balance between a hothouse and a deep freeze. The concentration of methane would have increased


Intensified water cycle
Less carbon dioxide, more methane
Enhanced weathering of rocks
thereby intensifying the greenhouse effect
b



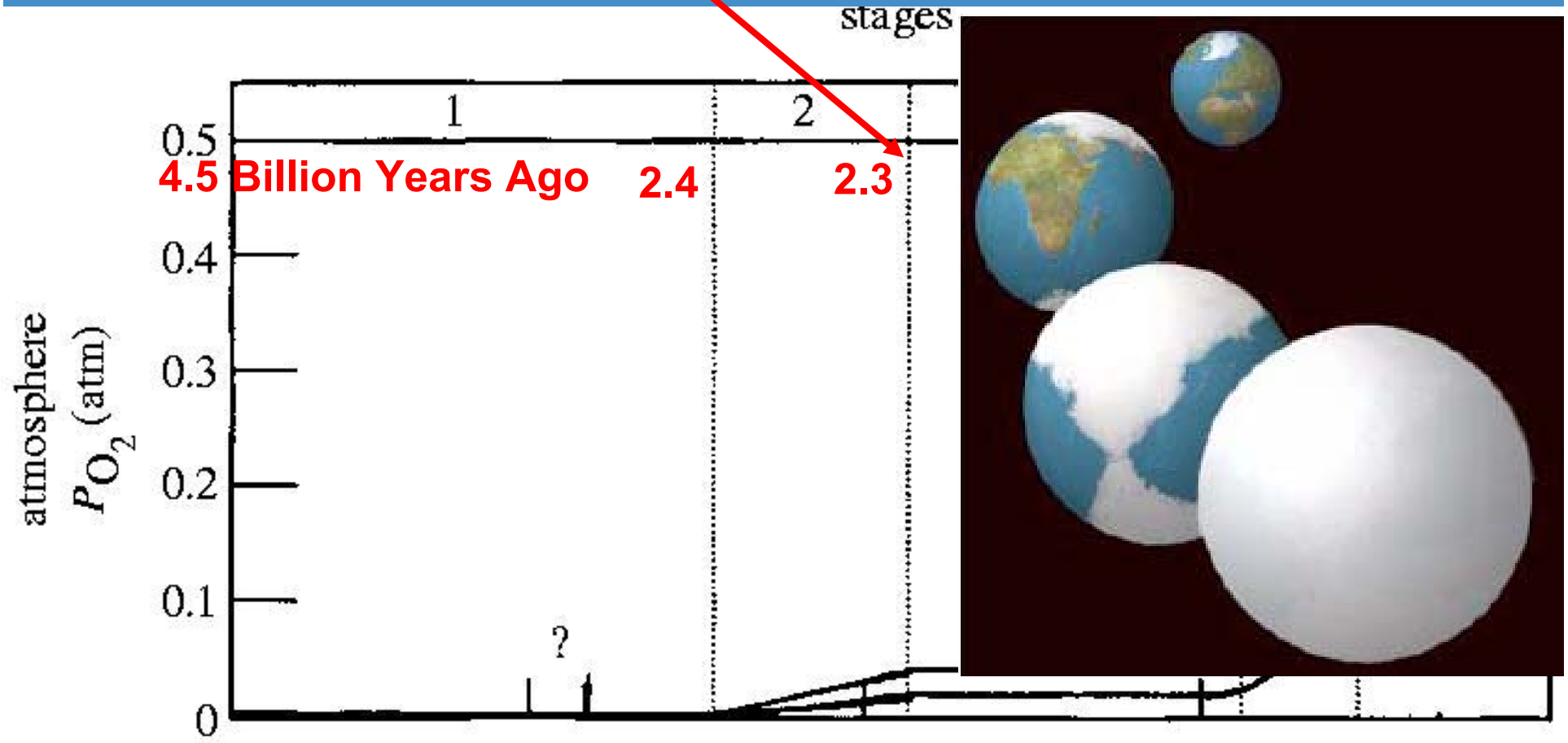
for no more than a few tens of thousands of years
before the climate-cooling haze would have developed

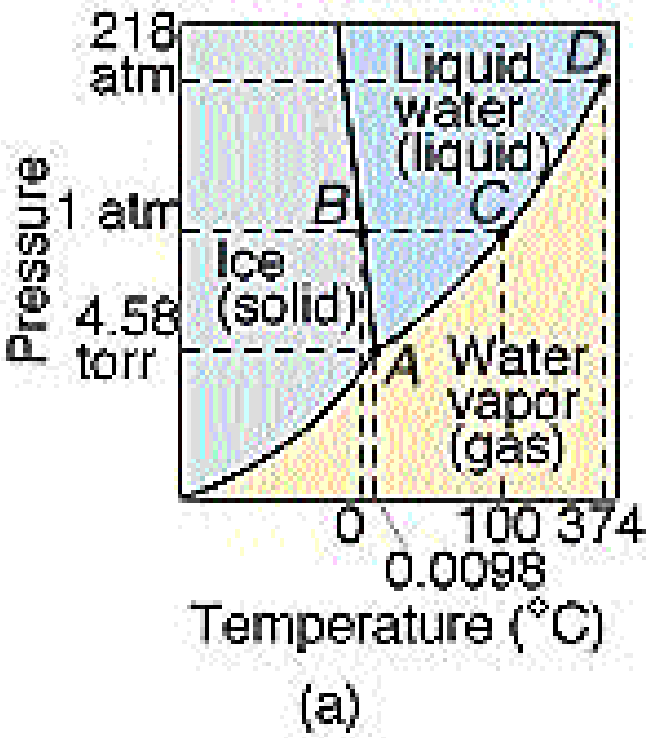
When Cyanobacteria changed climate

Cyanobacteria are both nitrogen fixers and photoautotrophs. Emerged about 2.4 billion years ago

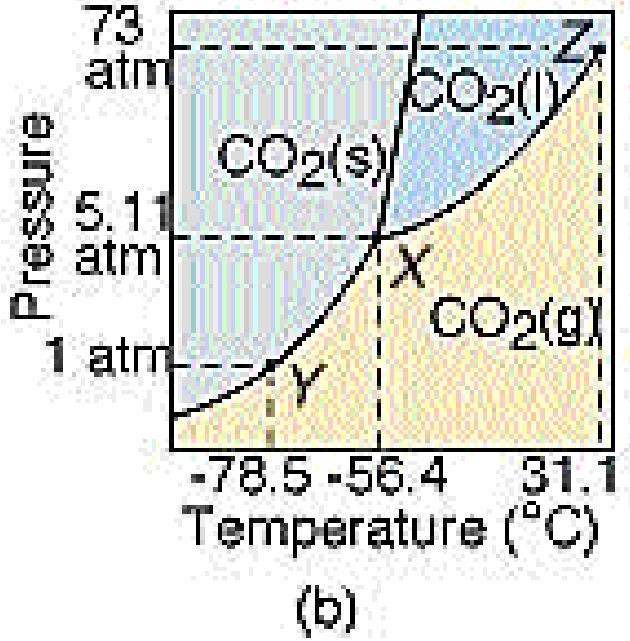
Makganyene Snowball Earth

Makganyene Snowball Earth 2.32 to 2.22 Ga



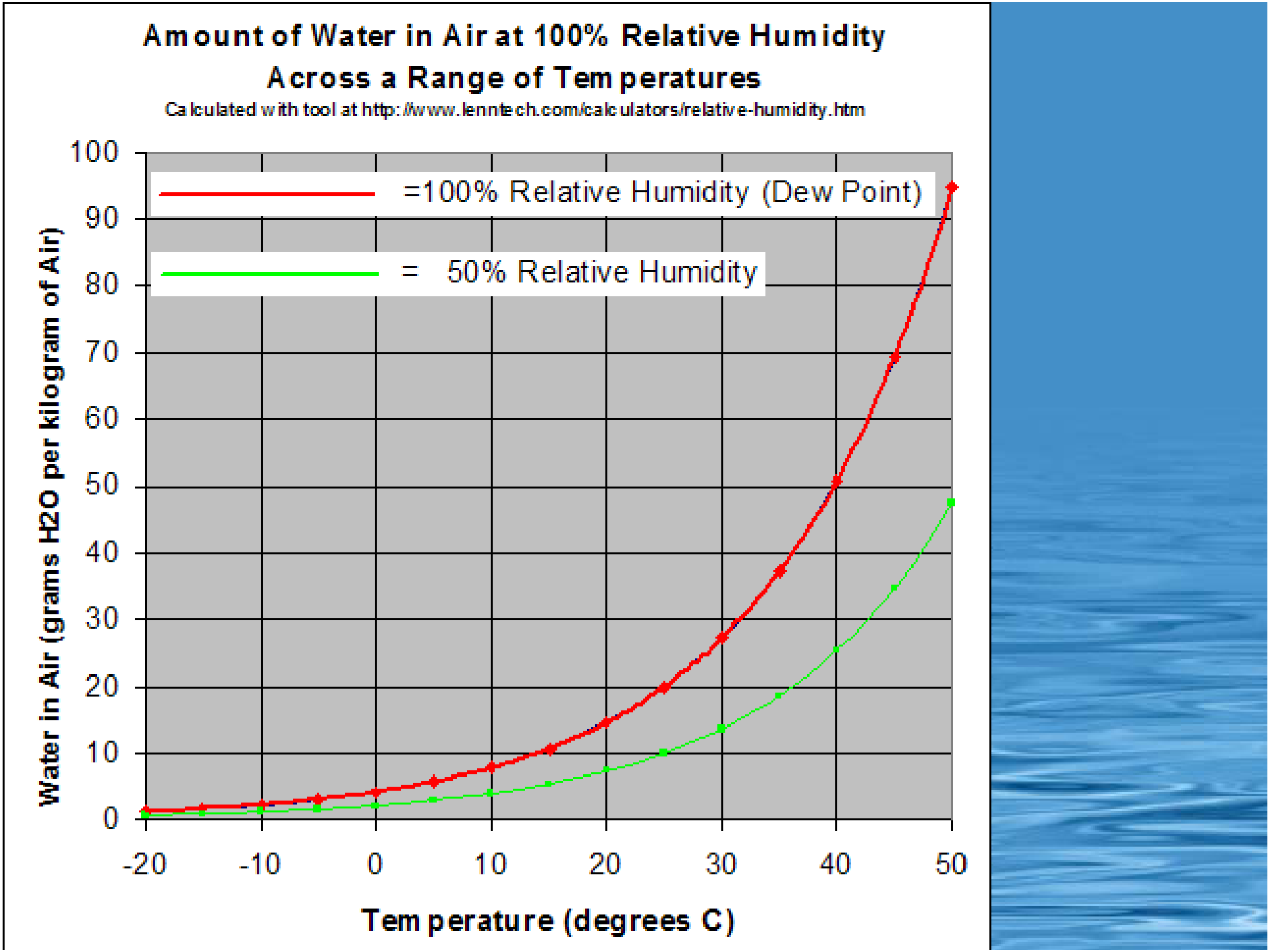

218 atm
1 atm
4.58 torr
Pressure
Liquid water (liquid)
D
B
C
Ice (solid)
A
Water vapor (gas)
0
100
374
0.0098
Temperature (°C)

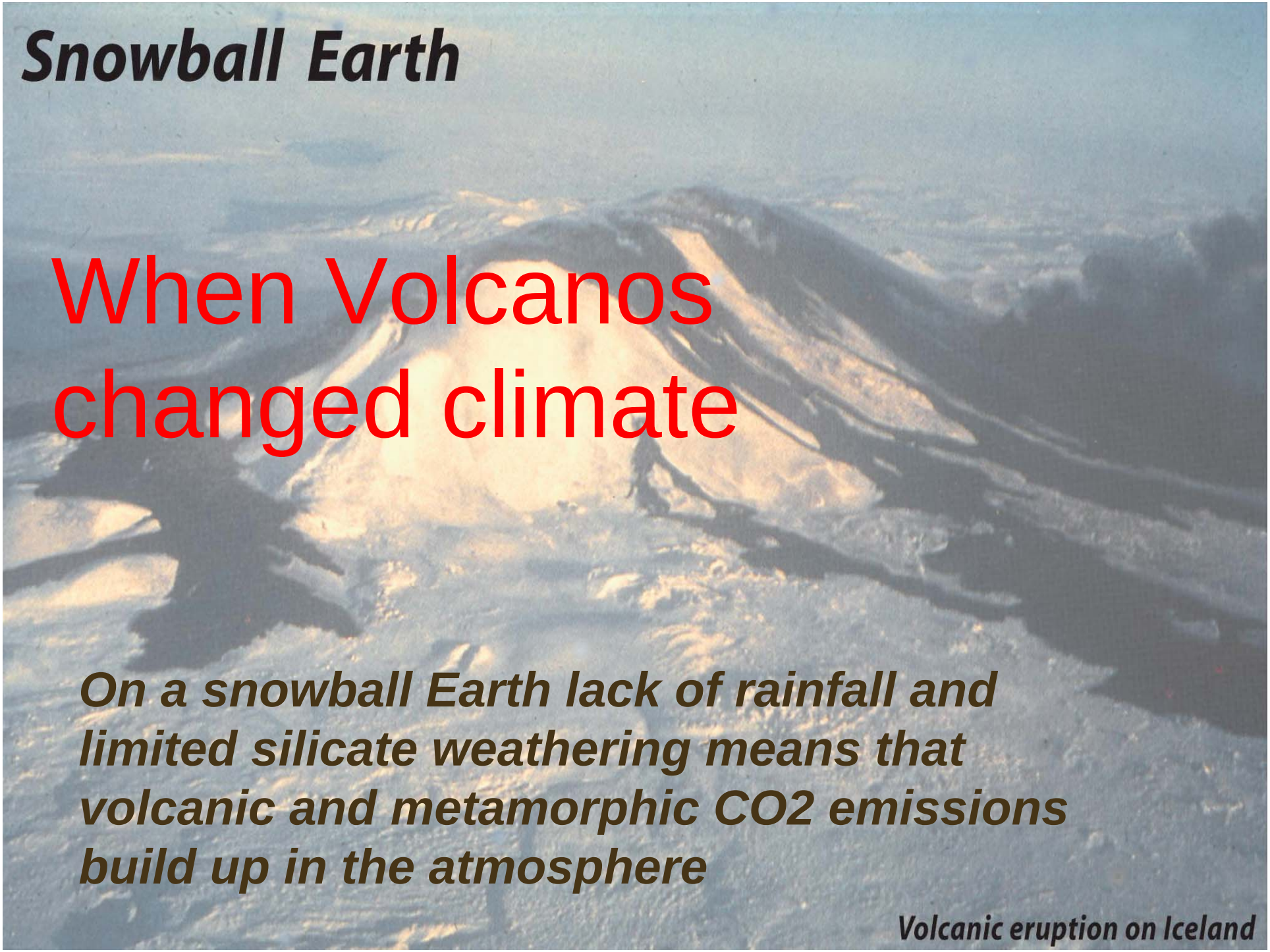
(a)

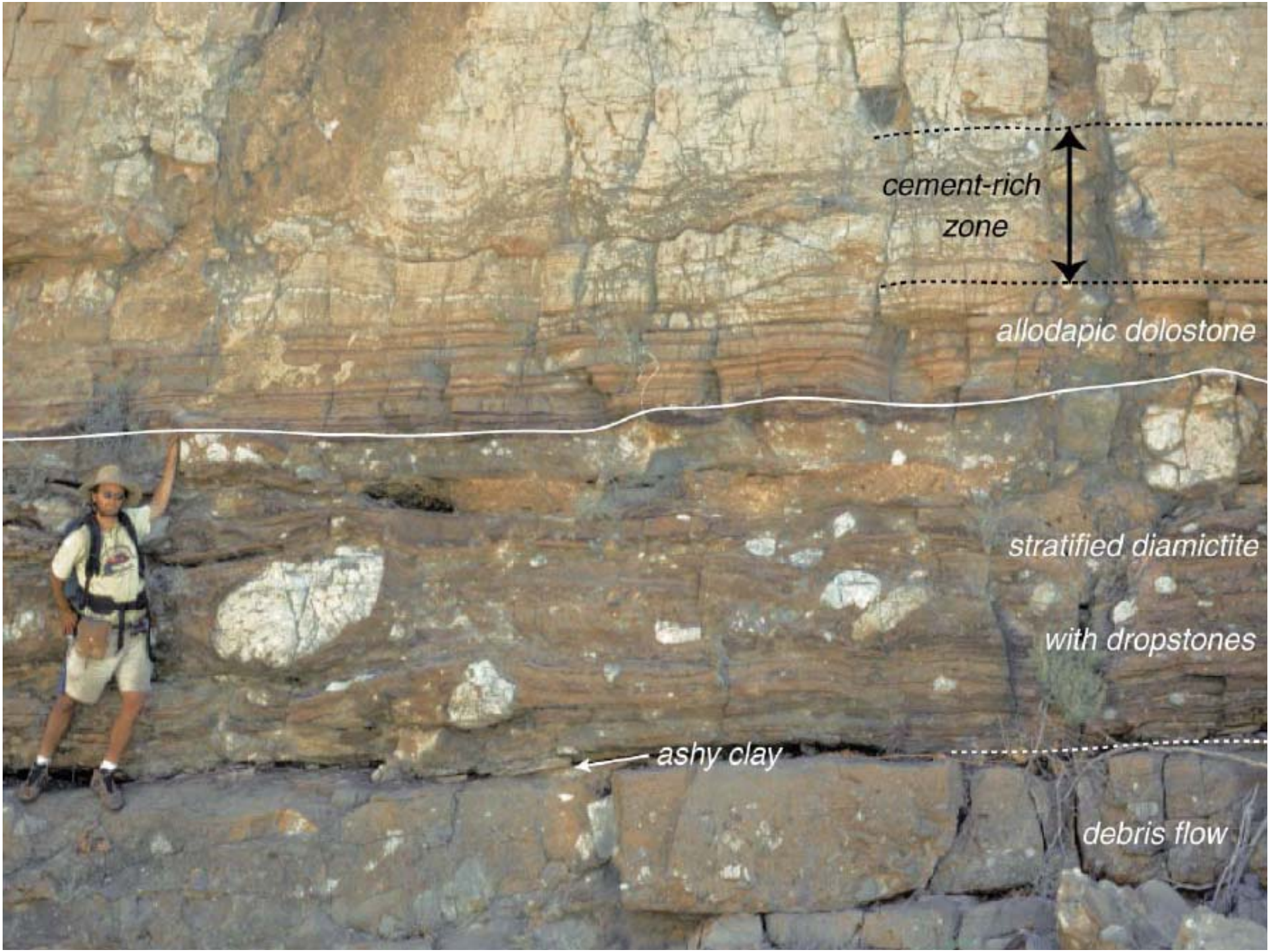

73 atm
5.11 atm
1 atm
Pressure
Z
CO_2(l)
CO_2(s)
X
CO_2(g)
Y
-78.5
-56.4
31.1
Temperature (°C)

(b)

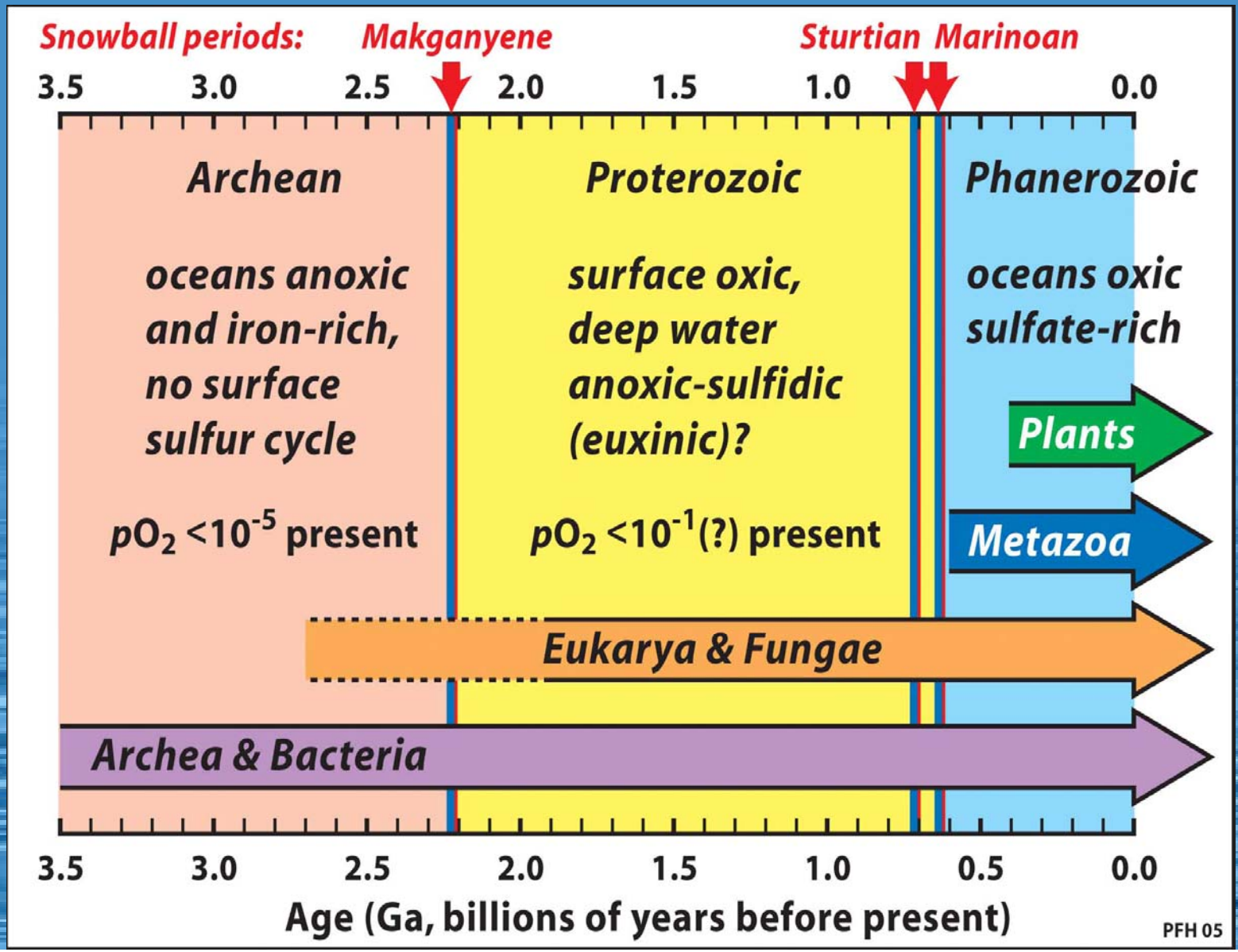

Oxygen from oxi-photosynthesis depletes the atmosphere of the greenhouse gas, methane. It also draws down atmospheric carbon dioxide, leads to the first great oxidation event and snowball earth.

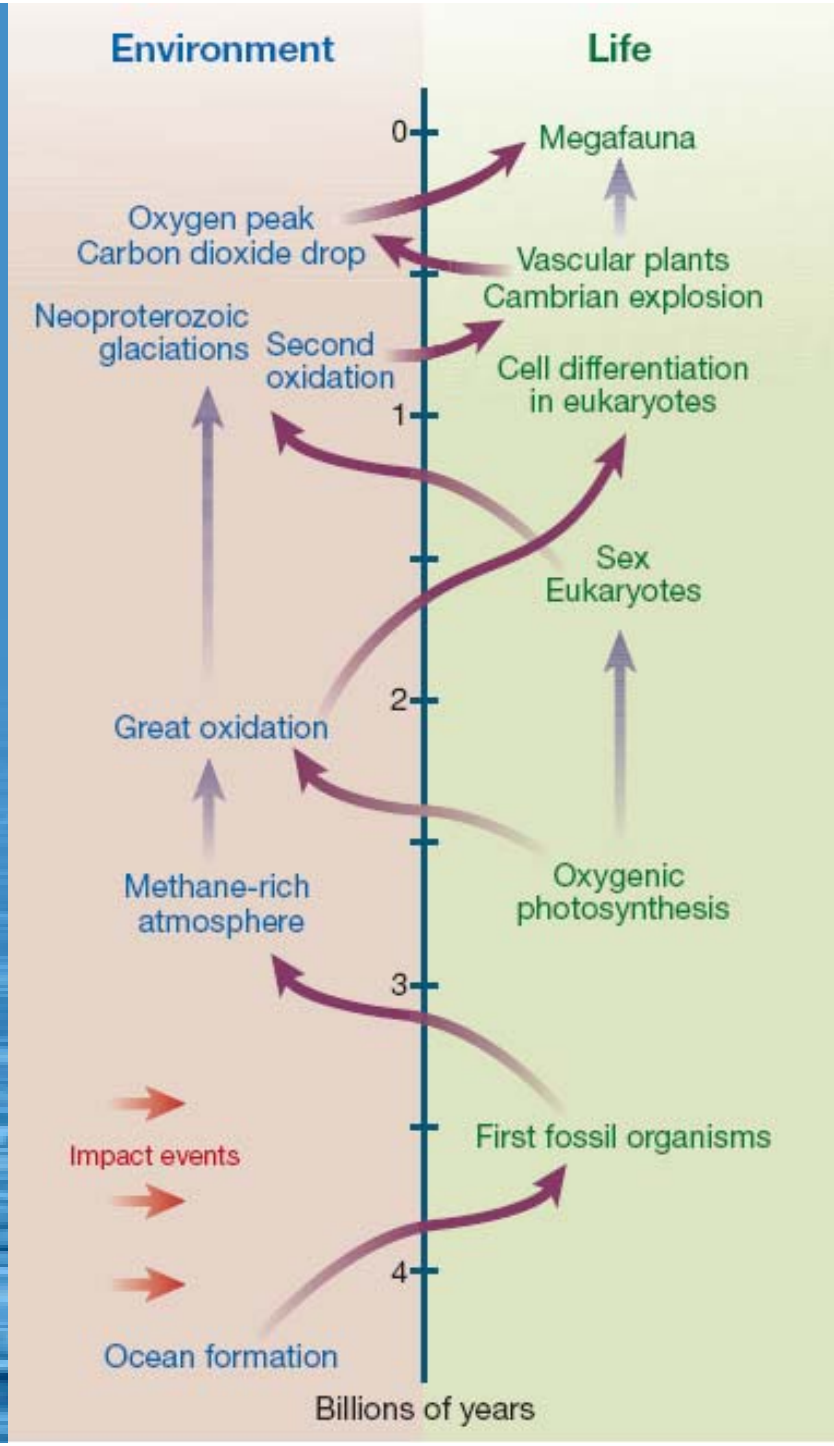

Amount of Water in Air at 100% Relative Humidity
Across a Range of Temperatures
Calculated with tool at http://www.lenntech.com/calculators/relative-humidity.htm
=100% Relative Humidity (Dew Point)
= 50% Relative Humidity
Water in Air (grams H2O per kilogram of Air)
100
90
80
70
60
50
40
30
20
10
0
-20
-10
0
10
20
30
40
50
Temperature (degrees C)


Snowball Earth
When Volcanos changed climate
On a snowball Earth lack of rainfall and limited silicate weathering means that volcanic and metamorphic CO2 emissions build up in the atmosphere
Volcanic eruption on Iceland

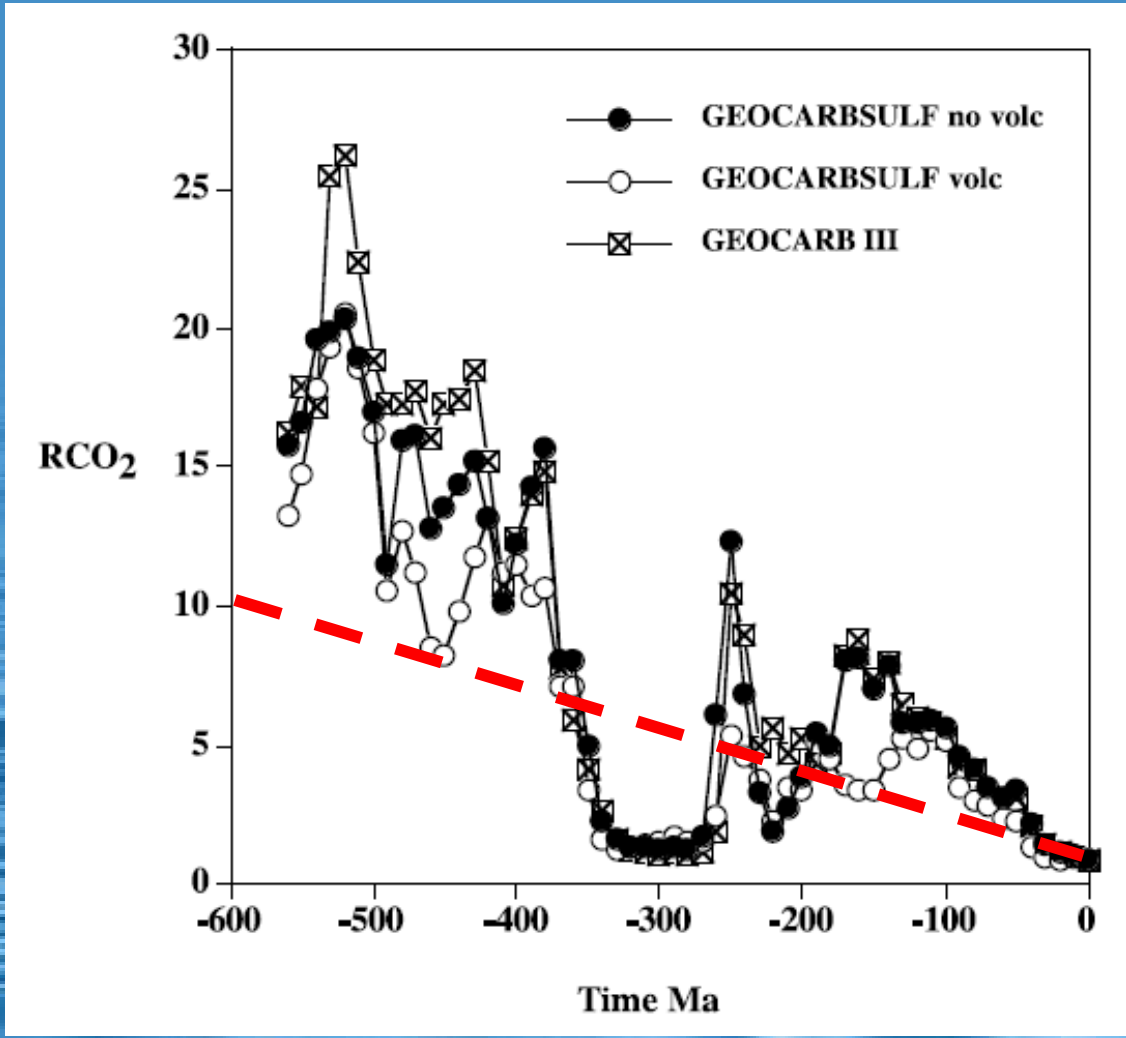

cement-rich
zone
allodapic dolostone
stratified diamictite
with dropstones
ashy clay
debris flow

Snowball Earth

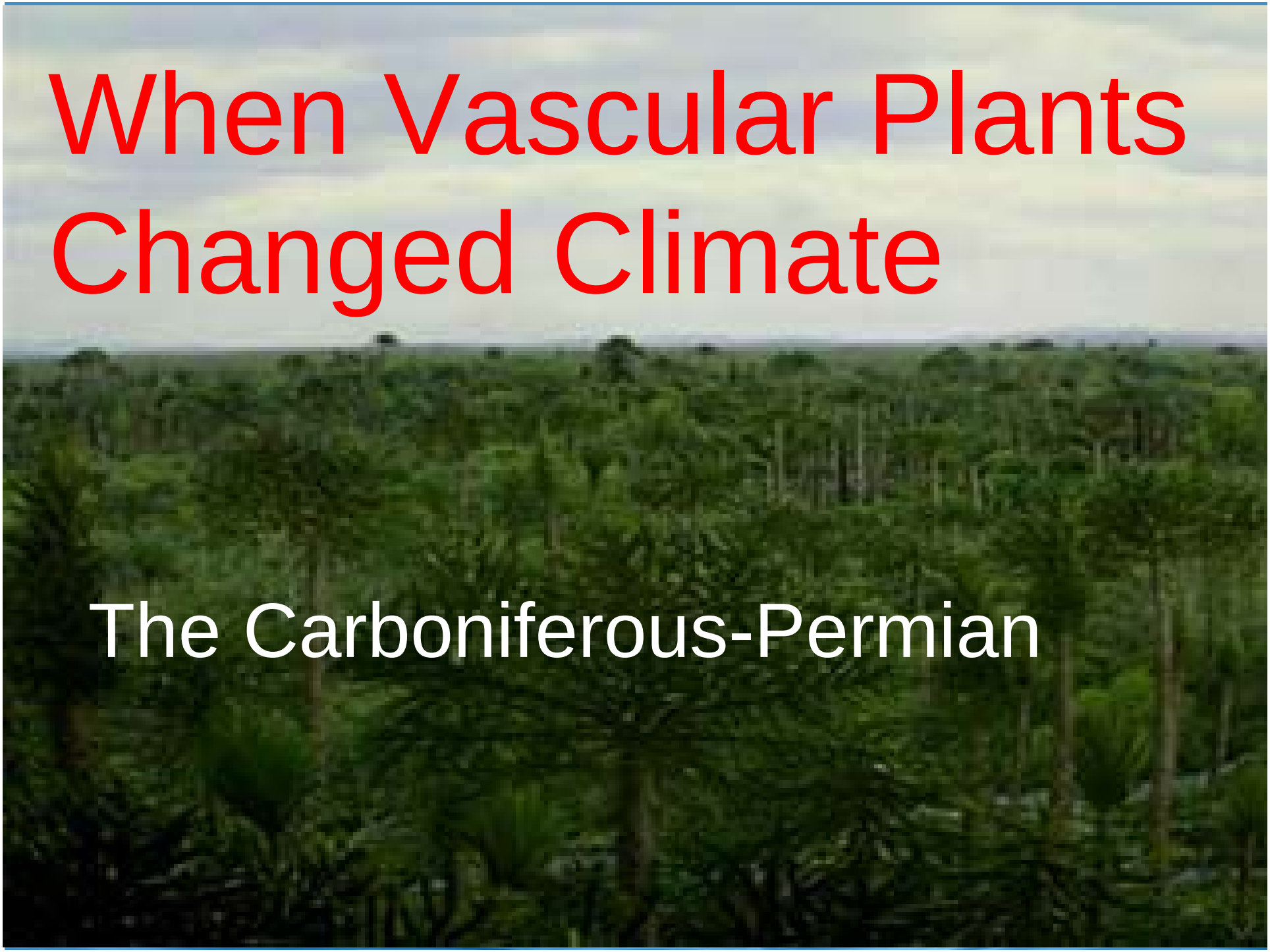



Environment
Life
0
Megafauna
Oxygen peak
Carbon dioxide drop
Vascular plants
Cambrian explosion
Neoproterozoic glaciations
Second oxidation
Cell differentiation in eukaryotes
1
Sex
Eukaryotes
2
Great oxidation
Methane-rich atmosphere
Oxygenic photosynthesis
3
First fossil organisms
Impact events
4
Ocean formation
Billions of years

CO2 in the Phanerozoic



Carbon dioxide level required to achieve today's climate . (Berner The Phanerozoic Carbon Cycle)

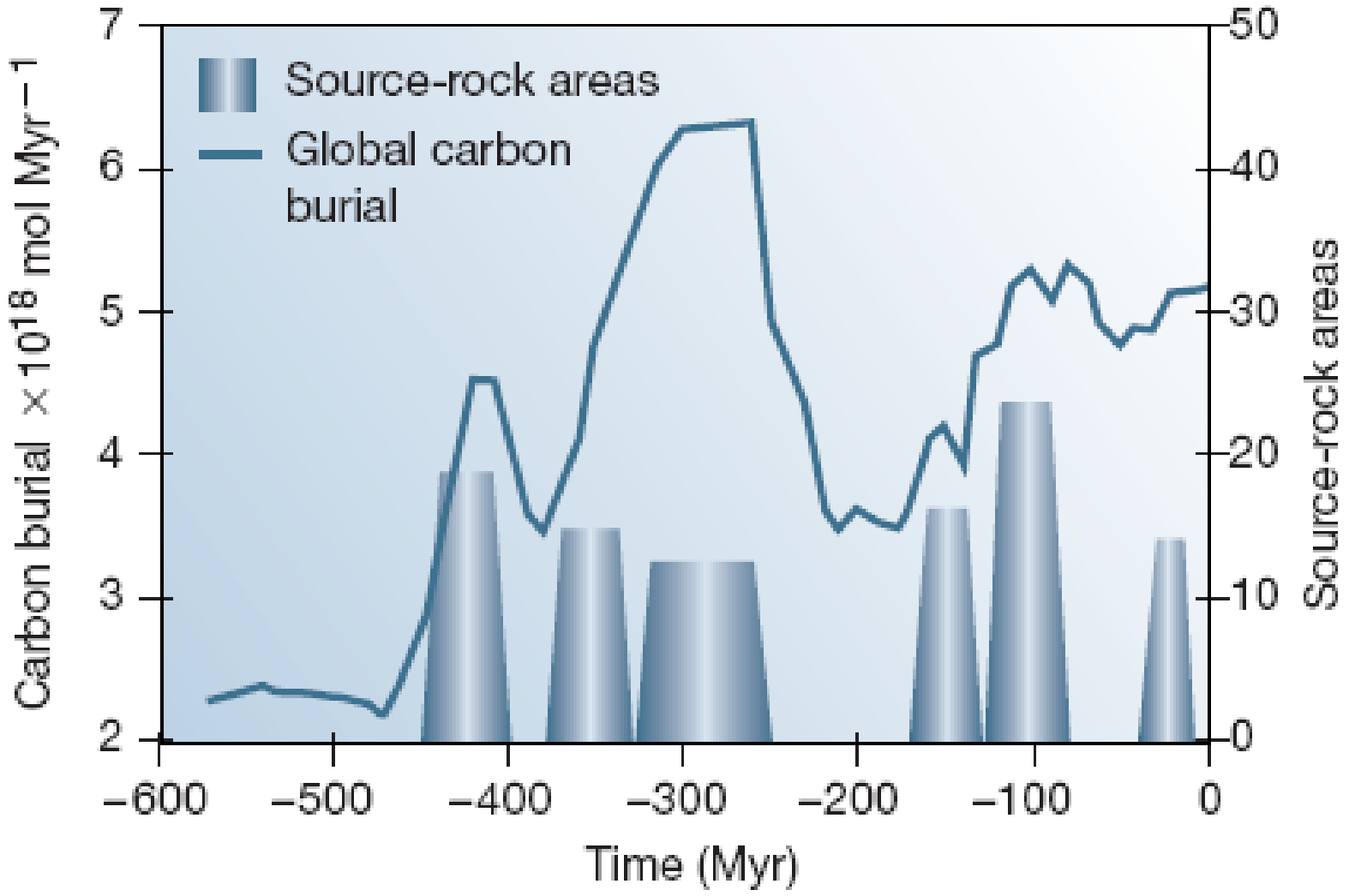


When Vascular Plants Changed Climate

The Carboniferous-Permian


The Carboniferous-Permian

Carboniferous-Permian


Source-rock areas
Global carbon burial
Carbon burial ×10^18 mol Myr−1
Source-rock areas
Time (Myr)
7
6
5
4
3
2
50
40
30
20
10
0
−600
−500
−400
−300
−200
−100
0

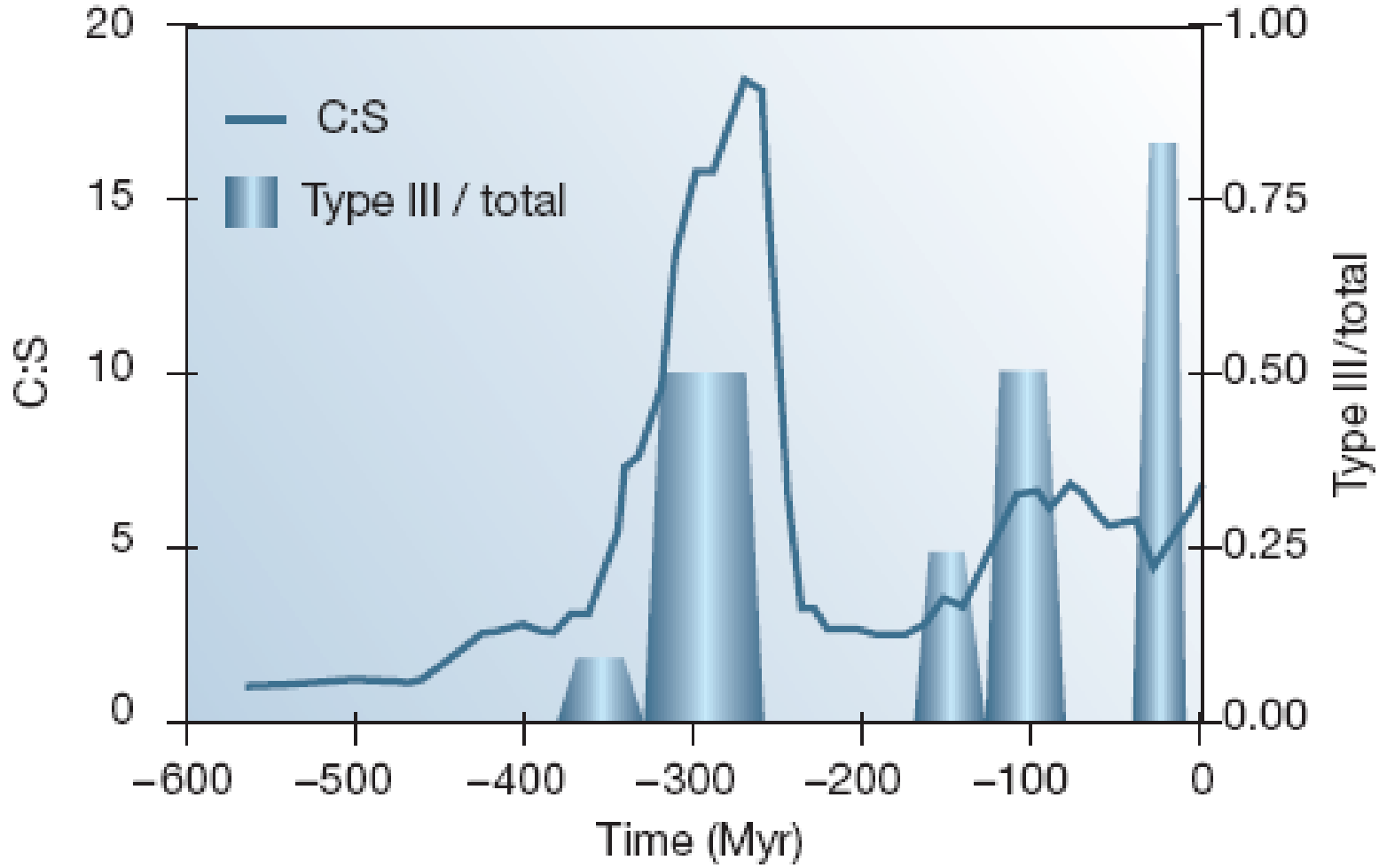
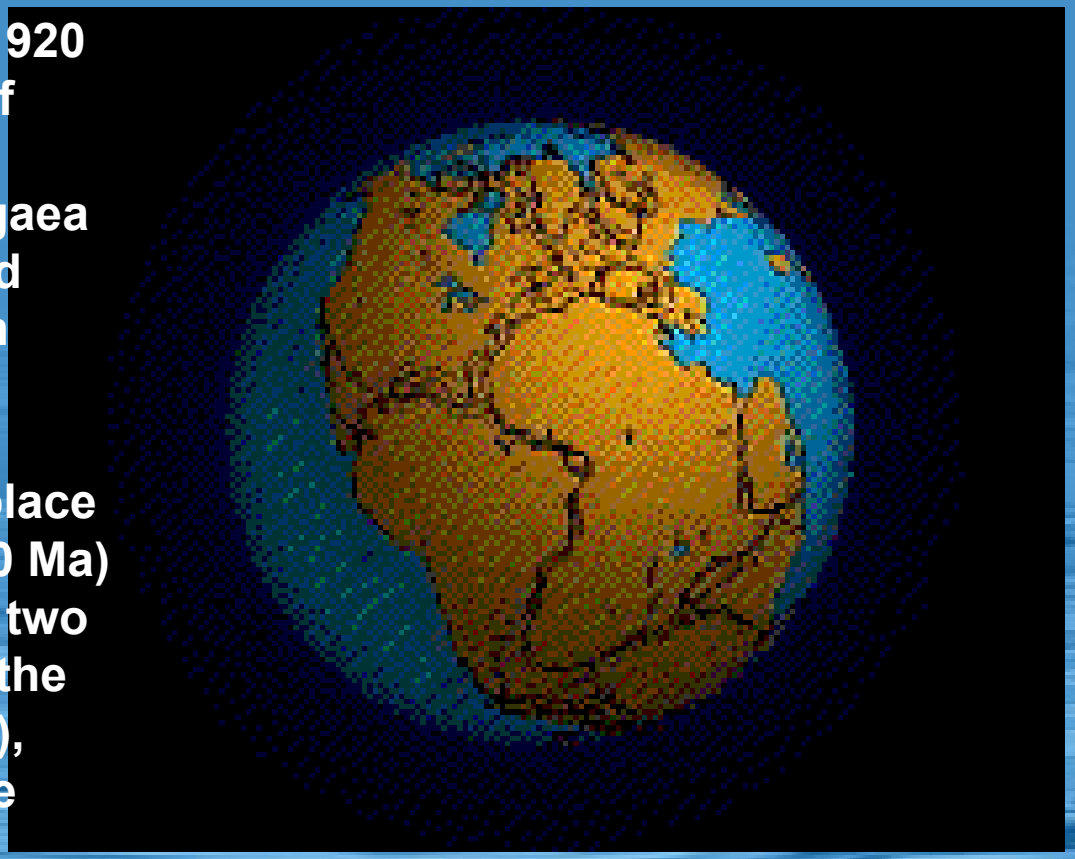

C:S
Type III / total
C:S
Type III/total
20
15
10
5
0
1.00
0.75
0.50
0.25
0.00
−600
−500
−400
−300
−200
−100
0
Time (Myr)

Plate tectonics

Alfred Wegener originated the continental drift theory. In the 1920 edition of his book The Origin of Continents and Oceans, he postulated supercontinent Pangaea existed during the Paleozoic and Mesozoic eras about 250 million years ago.

The break-up of Pangaea took place about 180 million years ago (180 Ma) in the Jurassic Period, first into two supercontinents (Gondwana to the south and Laurasia to the north), thereafter into the continents we have today.



CO_2 emission and consumption are kept n rough balance by a negative feedback esulting from the temperature-depend- ence of silicate weathering. The feedback operates on a million-year time scale.

(weathering)

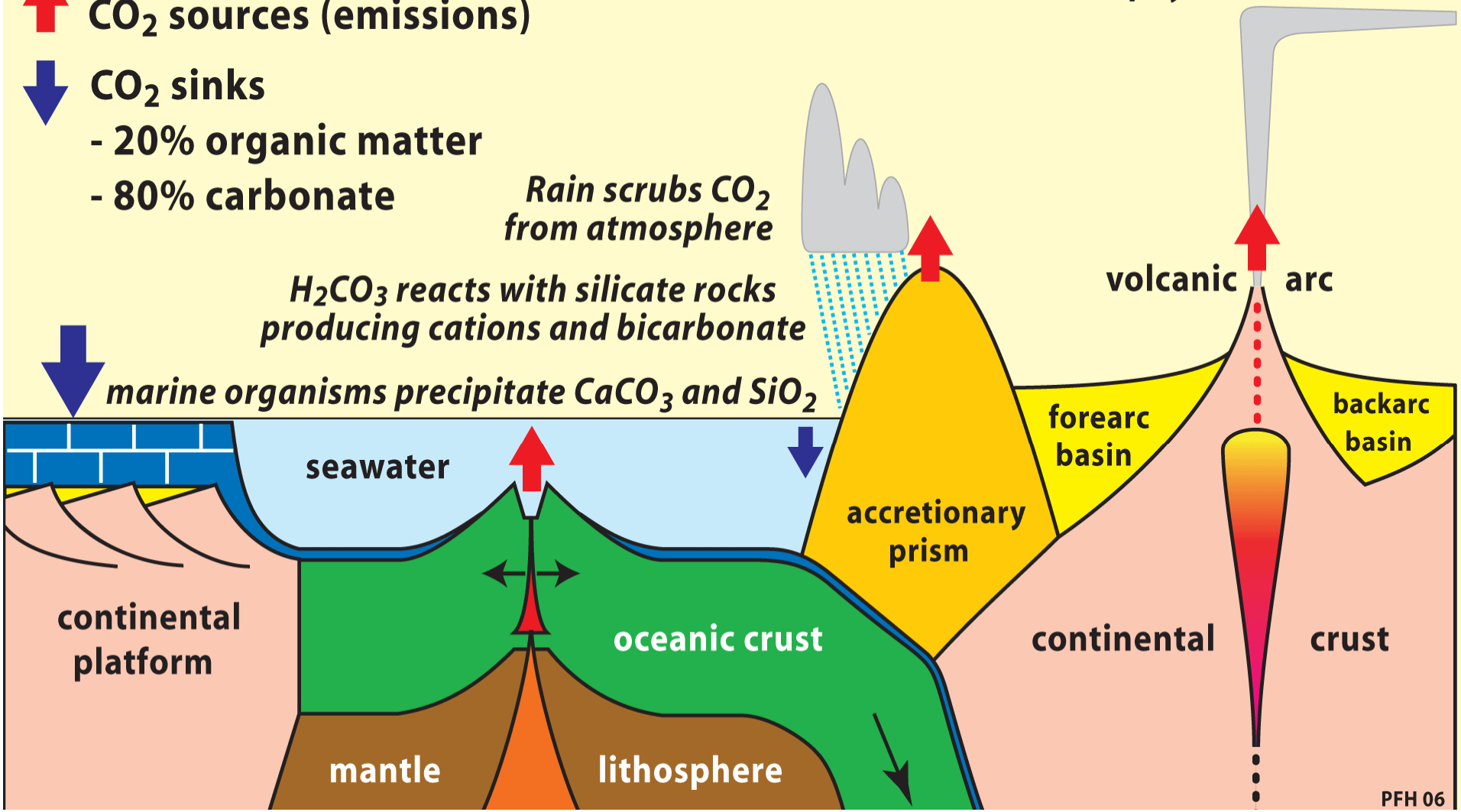
$$CO_2 + CaSiO_3 \rightleftharpoons CaCO_3 + SiO_2$$

(metamorphism)

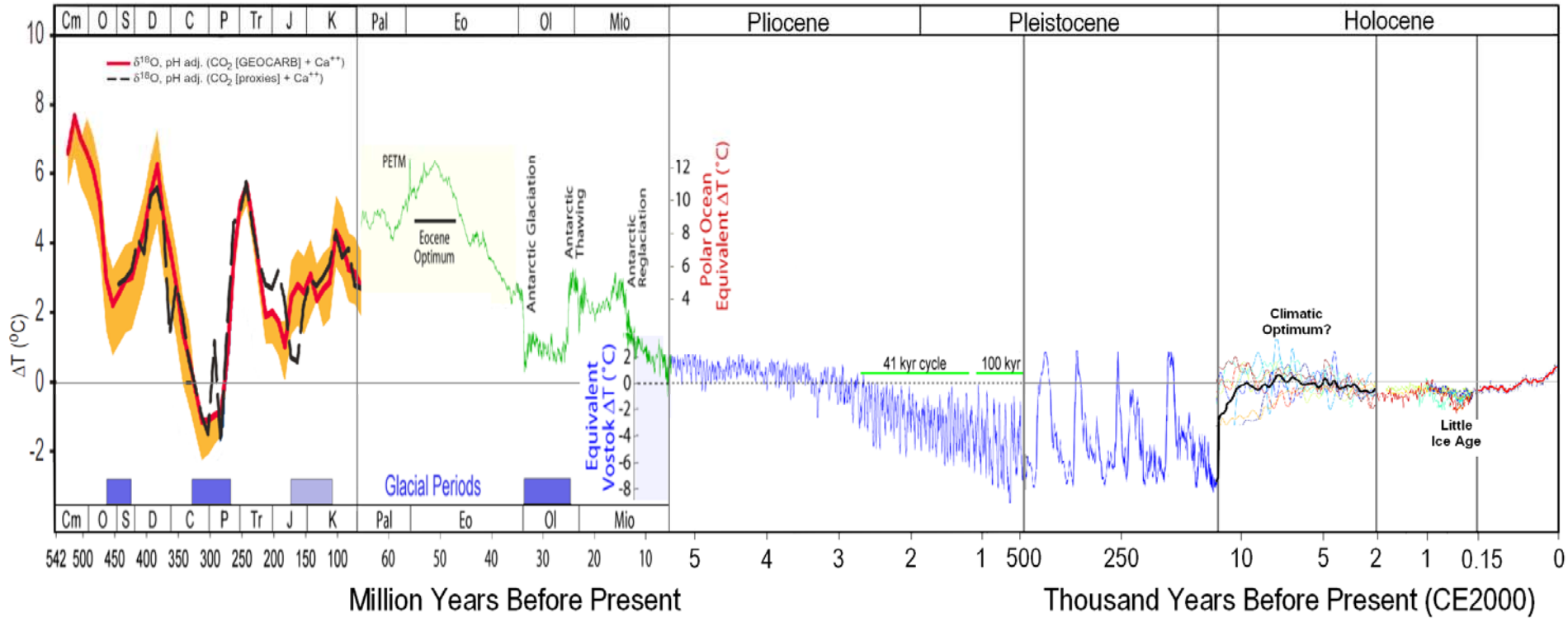
Walker et al. (1981) Jour. Geophys. Res., 86, 9776.

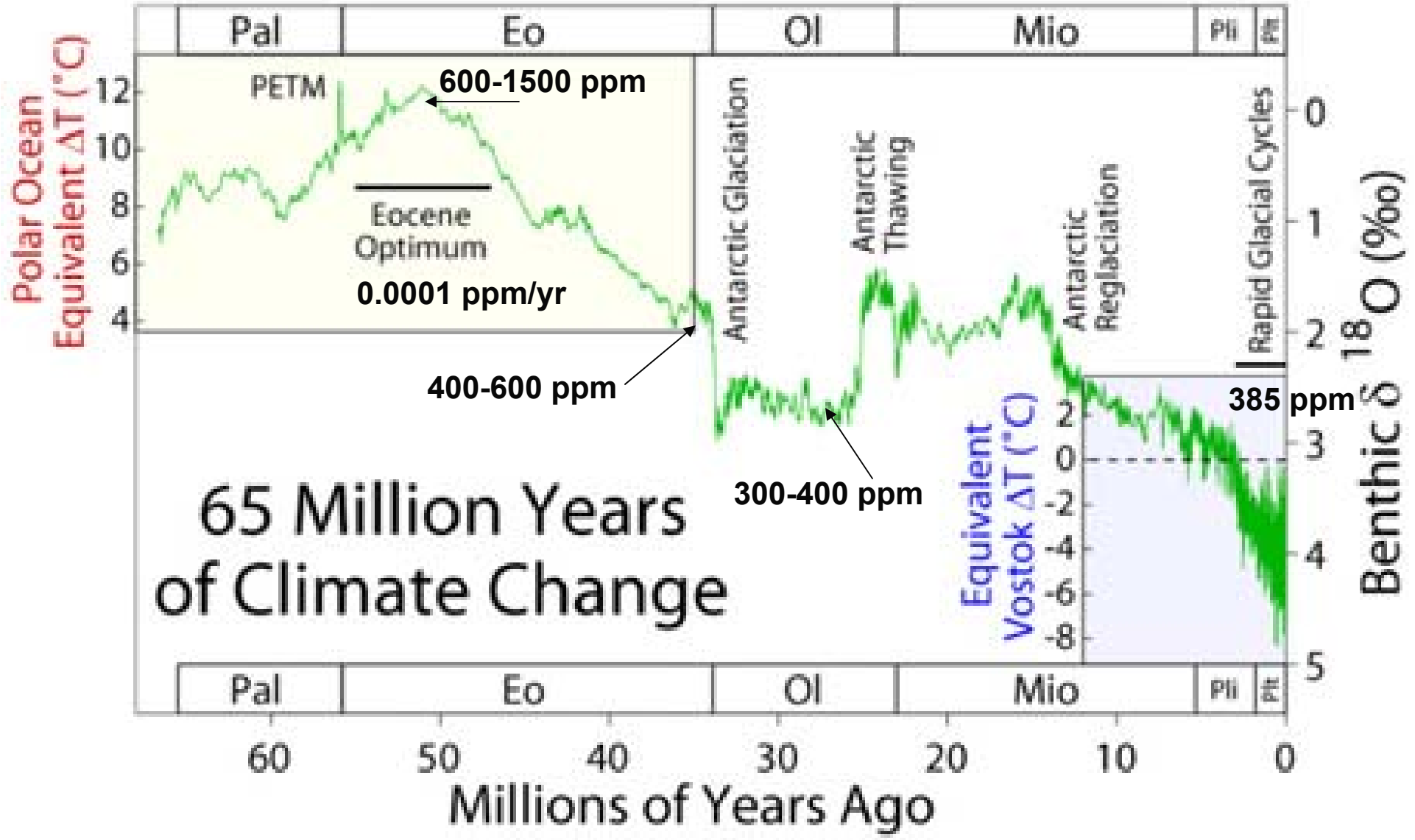
CO_2 sources (emissions)

CO_2 sinks
- 20% organic matter
- 80% carbonate



Temperature of Planet Earth

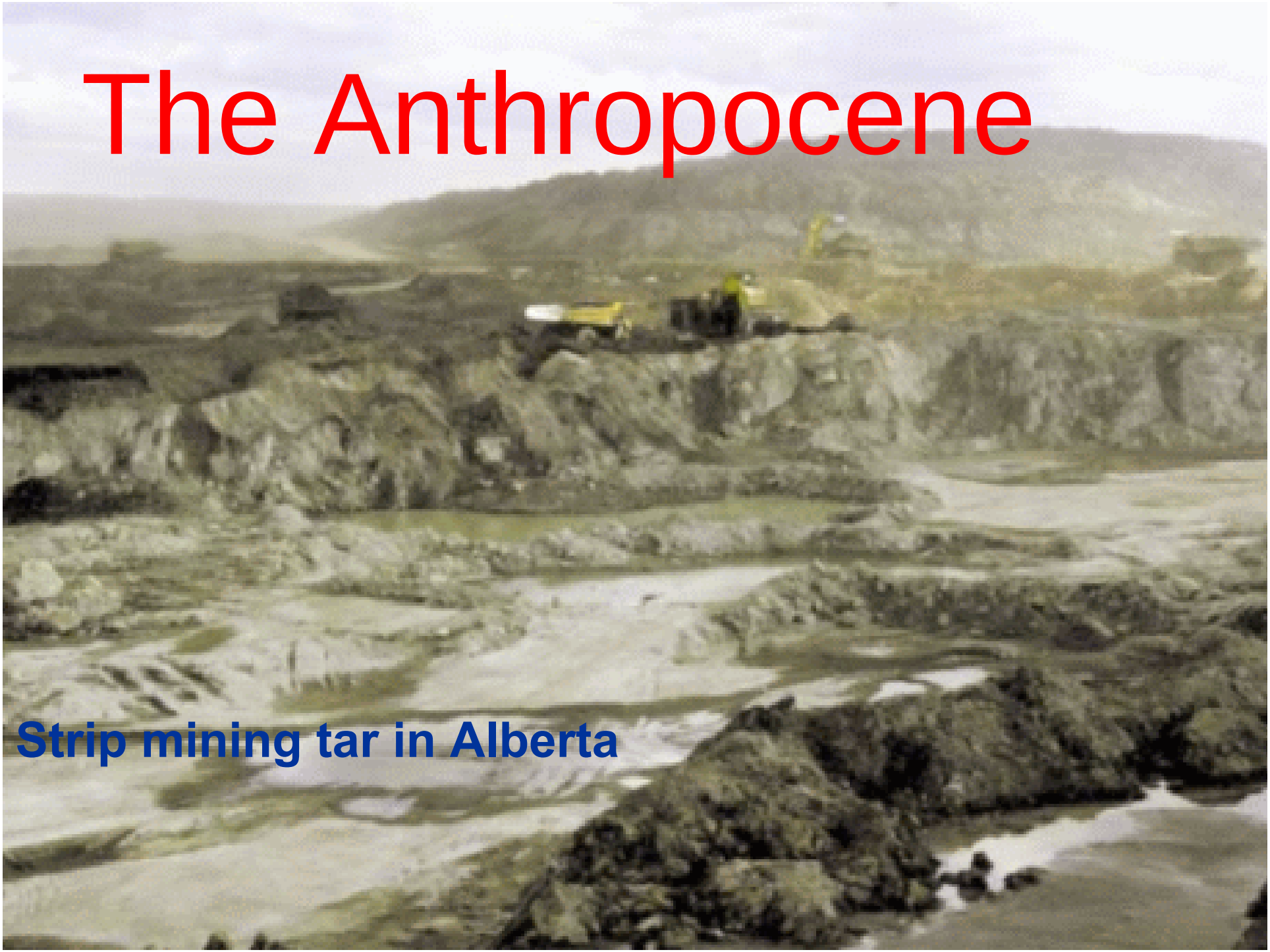



Pal
Eo
Ol
Mio
Pli
Plt
Polar Ocean
Equivalent ΔT (°C)
12
10
8
6
4
PETM
600-1500 ppm
Eocene
Optimum
0.0001 ppm/yr
400-600 ppm
Antarctic Glaciation
Antarctic
Thawing
Antarctic
Reglaciation
Rapid Glacial Cycles
385 ppm
300-400 ppm
Equivalent
Vostok ΔT (°C)
2
0
-2
-4
-6
-8
Benthic δ 18O (‰)
0
1
2
3
4
5
65 Million Years
of Climate Change
60
50
40
30
20
10
0
Millions of Years Ago

When Homo Sapiens Changed Climate

Mountaintop removal for coal in West Virginia

The Anthropocene



Strip mining tar in Alberta

Rate of oil consumption

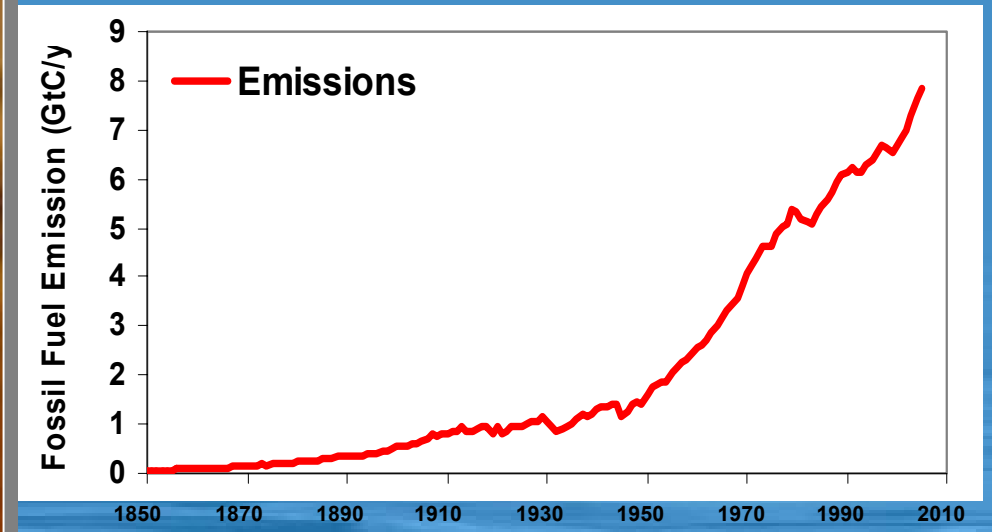
- Ultimate recoverable reserves (URR) oil equals 2.1 trillion barrels of which there may be 800 billion barrels left.
- Assume all oil was formed after the Cambrian explosion 542 million years ago.
- Average rate 2100000/542 = 3900 barrels/yr sequestered
- We use 31.025 billion barrels/yr
- 31025/3900 = 8 million years worth of URR oil sequestration is burned every single year

- Humans have extracted these substances from the ground so quickly, from a geological perspective, that oxidation of carbon occurs at a rate about 100 times faster than what would occur naturally. (Berner, 2007)

Anthropogenic C Emissions: Fossil Fuel

2006 Fossil Fuel: 8.4 Pg C

[2006-Total Anthrop. Emissions:8.4+1.5 = 9.9 Pg]



1990 - 1999: 1.3% y^{-1}

2000 - 2006: 3.3% y^{-1}

Raupach et al. 2007, PNAS; Canadell et al 2007, PNAS

Anthropogenic C Emissions: Land Use Change

Borneo, Courtesy: Viktor Boehm

Tropical deforestation

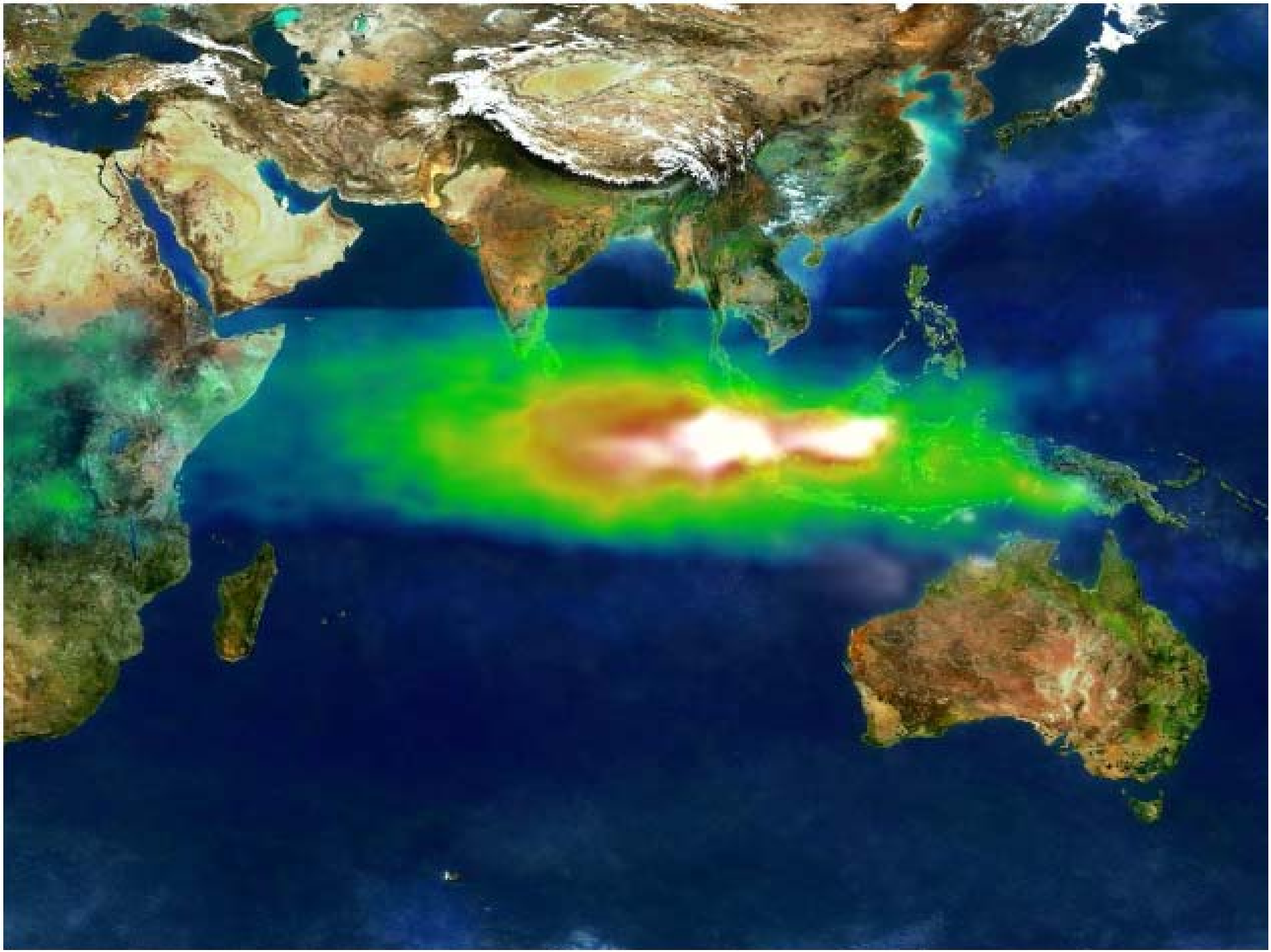
13 Million hectares each year

2000-2005	
Tropical Americas	0.6 Pg C y^{-1}
Tropical Asia	0.6 Pg C y^{-1}
Tropical Africa	0.3 Pg C y^{-1}
	1.5 Pg C y^{-1}

FAO-Global Resources Assessment 2005; Canadell et al. 2007, PNAS

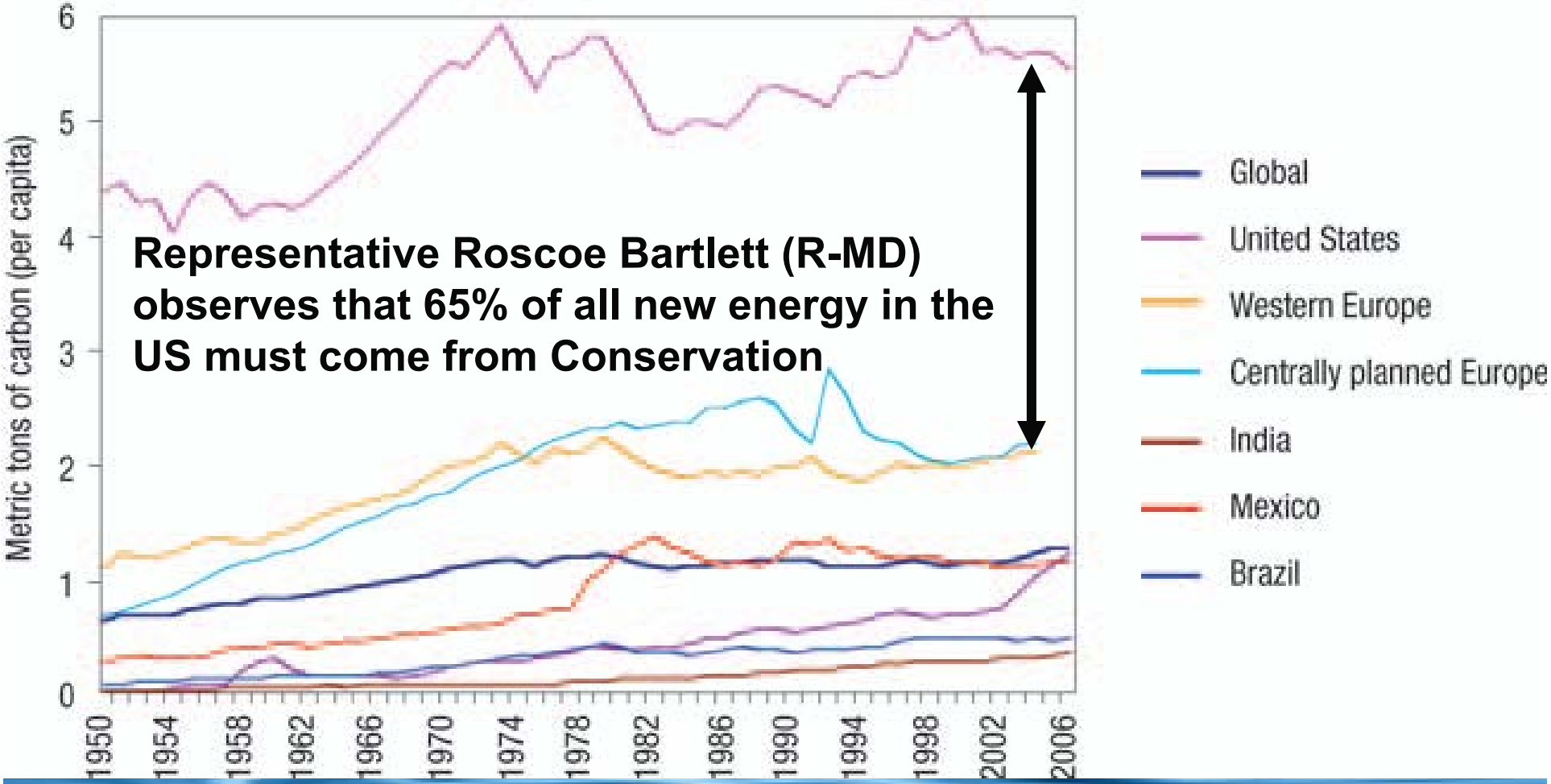
Potential Atmospheric CO2

- Worst case estimate for remaining recoverable fossil fuels is 560 GtC
- Carbon content of remaining forests is 290 GtC
- Cement manufacture 0.5 GtC/yr
- Permafrost carbon content 800 to 1600 GtC
- Methane hydrates 5000 to 10000 GtC
- Carbon stored in soil 1500 GtC
- (560+290+50+900)/4.2 = 430 ppmV
- 430 + 387 = 820 ppmV
- Puts us in the middle of the Eocene with no Antarctic ice sheets => 80 meter sea level rise




Dead Zone

Carbon Emissions per Capita



- Vaclav Smil: “[Nobel Laureate Wilhelm] Ostwald’s energetic imperative – Waste no energy but value it – is relevant as humankind makes the inevitable transition to a permanent economy based exclusively on solar radiation.”
- Dave Rutledge: “My own preference is to fill the Mojave with solar concentrating plants, and save some of this wonderful stuff [oil] for our descendants.”
- Thomas Edison: I'd put my money on solar energy… I hope we don't have to wait til oil and coal run out before we tackle that.”

Nevada Solar One

Photo: Schott Glass

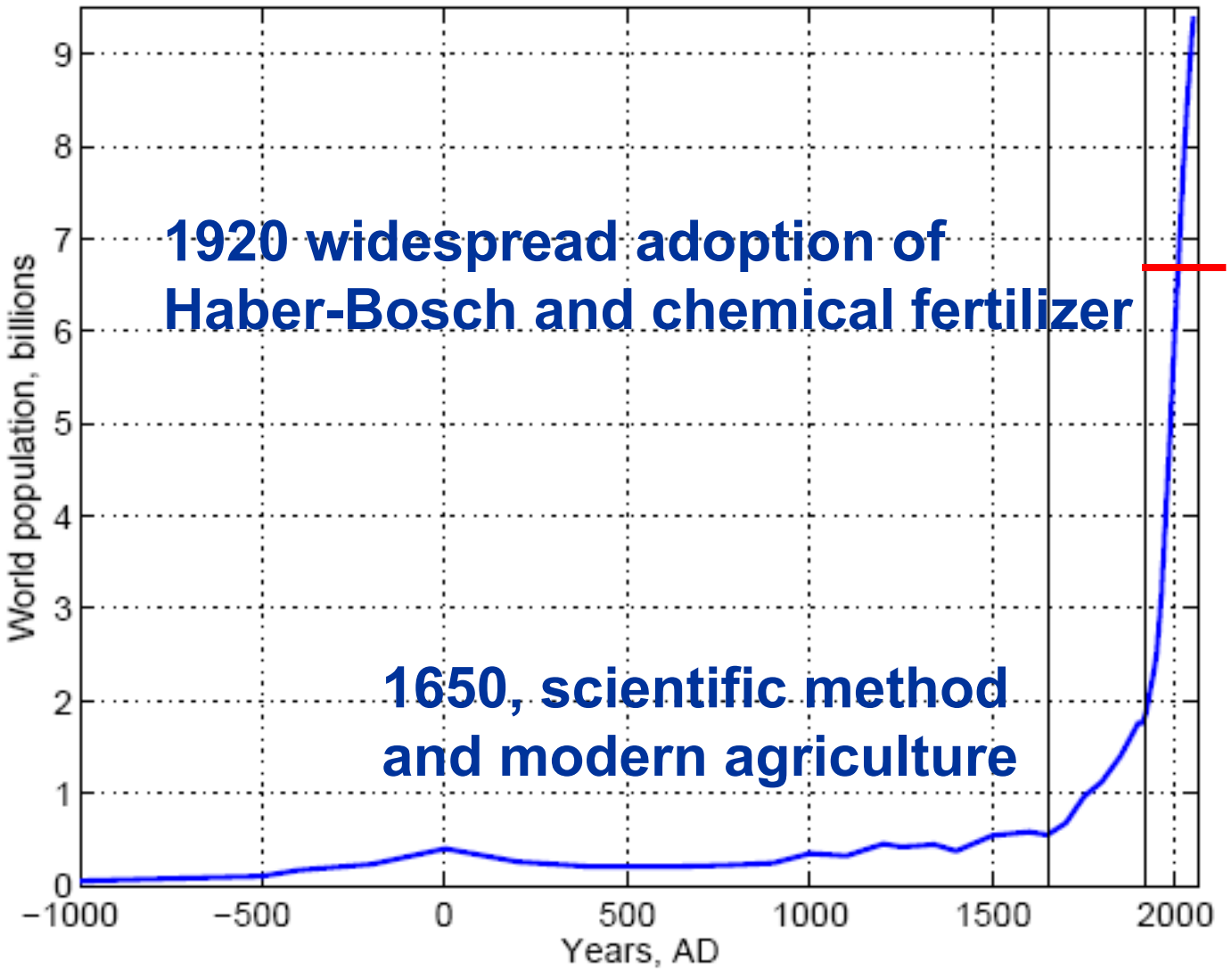
Nevada Solar One

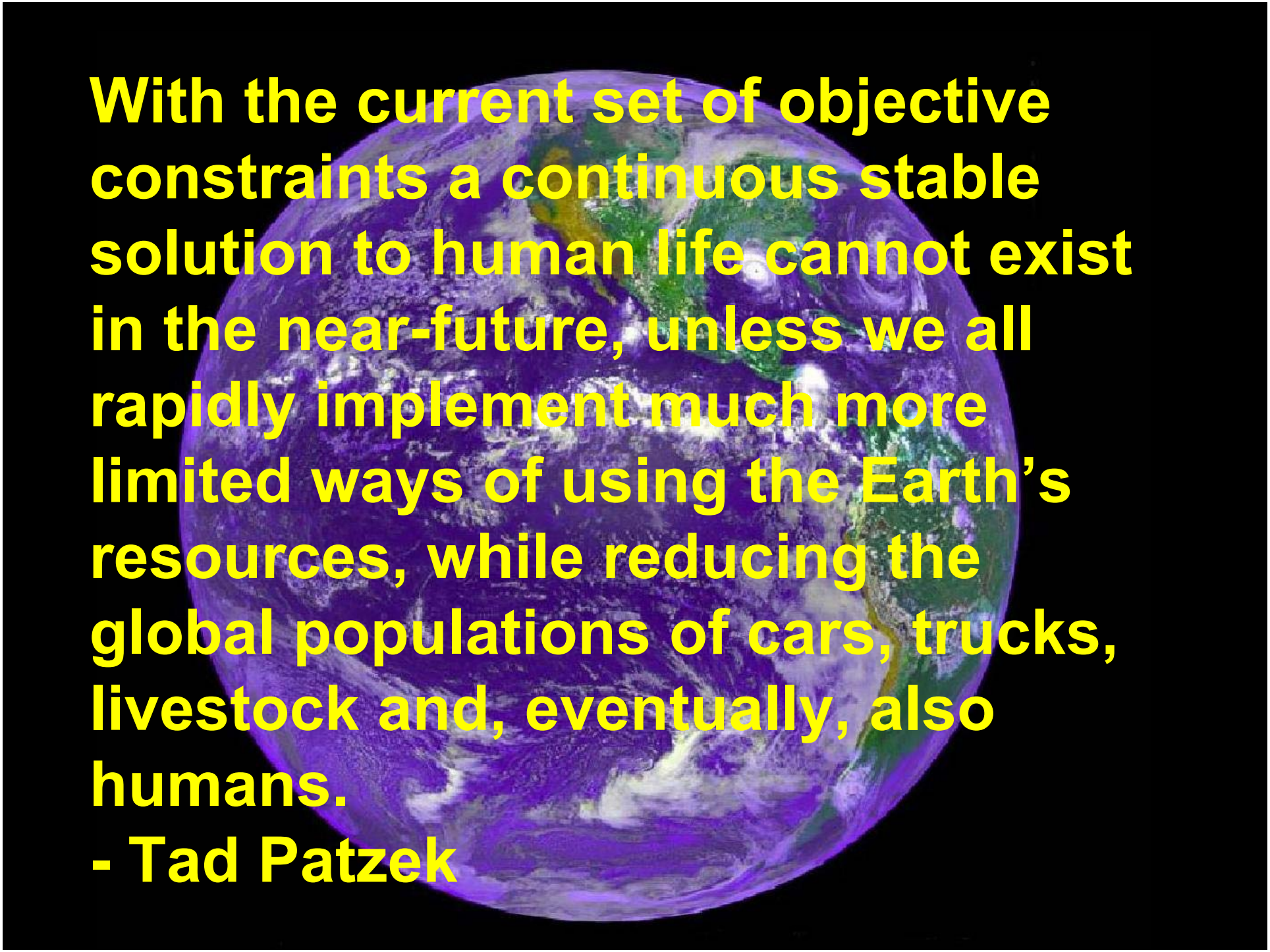
A square 100 miles on a side filled with Nevada Solar One plants would generate as much electricity as the entire US grid (1/5 the area of our lawns)

50 years of operation is the equivalent of mining a 6-foot coal seam under the area of the plant

Photo: Schott Glass

Population Explosion




With the current set of objective constraints a continuous stable solution to human life cannot exist in the near-future, unless we all rapidly implement much more limited ways of using the Earth's resources, while reducing the global populations of cars, trucks, livestock and, eventually, also humans.
- Tad Patzek

Conclusion

- Paleoclimate science reveals that carbon dioxide were not a greenhouse gas responsible for maintaining the Earth's climate, then the evolution of complex eukaryotic life would not be possible.
  - In other words, if Anthropogenic Global Warming isn't real then "AGW deniers" do not exist.
- In addition to AGW, other energy, environment and economy problems we face are addressed by Conservation and investment in alternative energy sources, in particular solar.