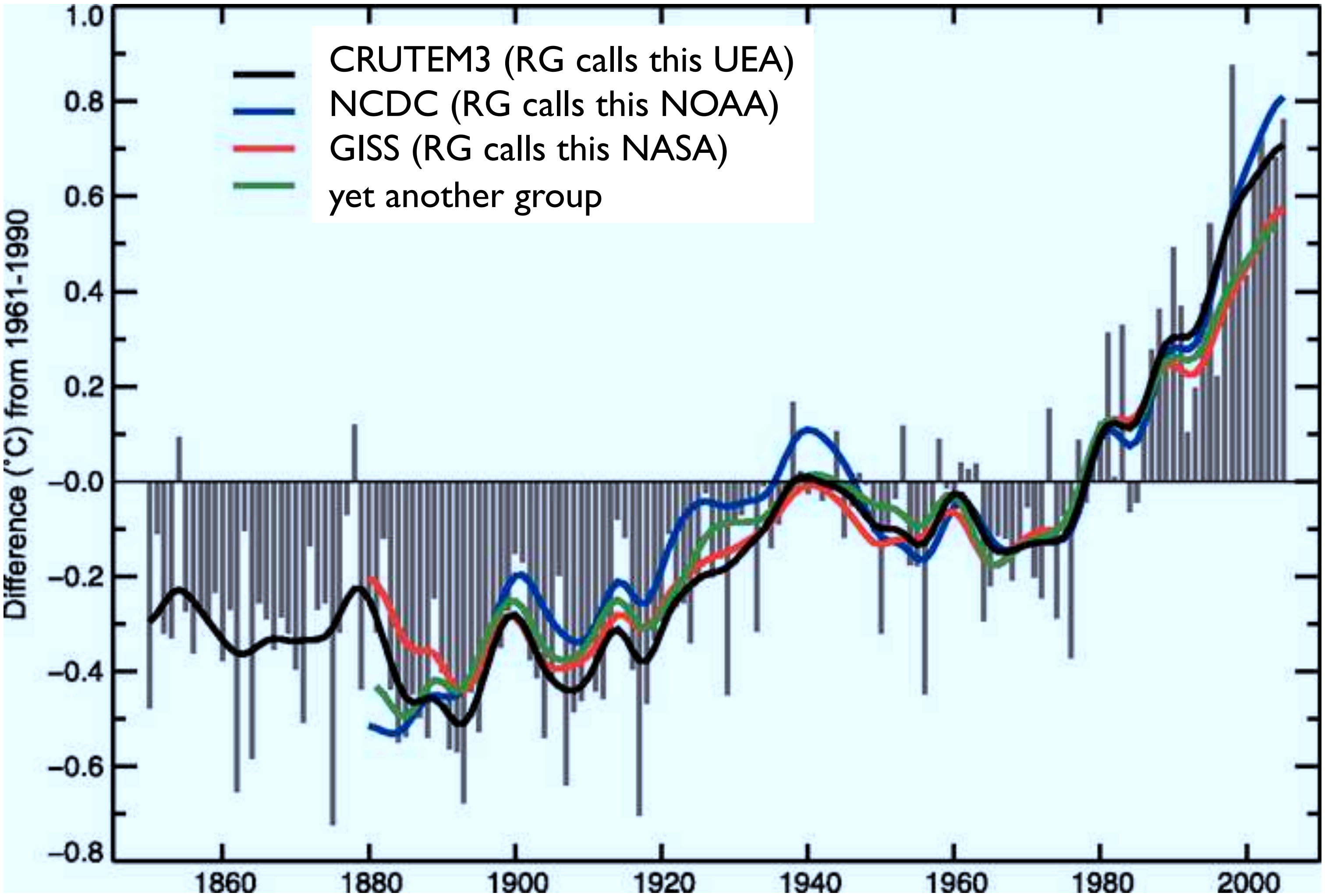
Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111

Ice-skating was not only a tradition on the lake but also provided a different social atmosphere for the neighborhood—the delight of winter twilight bursting with bonfires, music, and clamp-on skates. This was a time when new friends were introduced in chilly, huddled circles, and couples shared their first enchanted moment hand-in-hand with the cold wind in their faces. In this 1902 depiction, one can tell from the strange chunk of clear-cutting to the right that urbanization was undergoing a rapid transition from initial to intermediate status. Each year, skating visitors would see a noticeably different Green Lake. (Courtesy MOHAI, SHS1760.)



CRUTEM3 (RG calls this UEA)
NCDC (RG calls this NOAA)
GISS (RG calls this NASA)
yet another group
Difference (°C) from 1961-1990
1.0
0.8
0.6
0.4
0.2
−0.0
−0.2
−0.4
−0.6
−0.8
1860
1880
1900
1920
1940
1960
1980
2000

History of the Earth - RG p 193-226

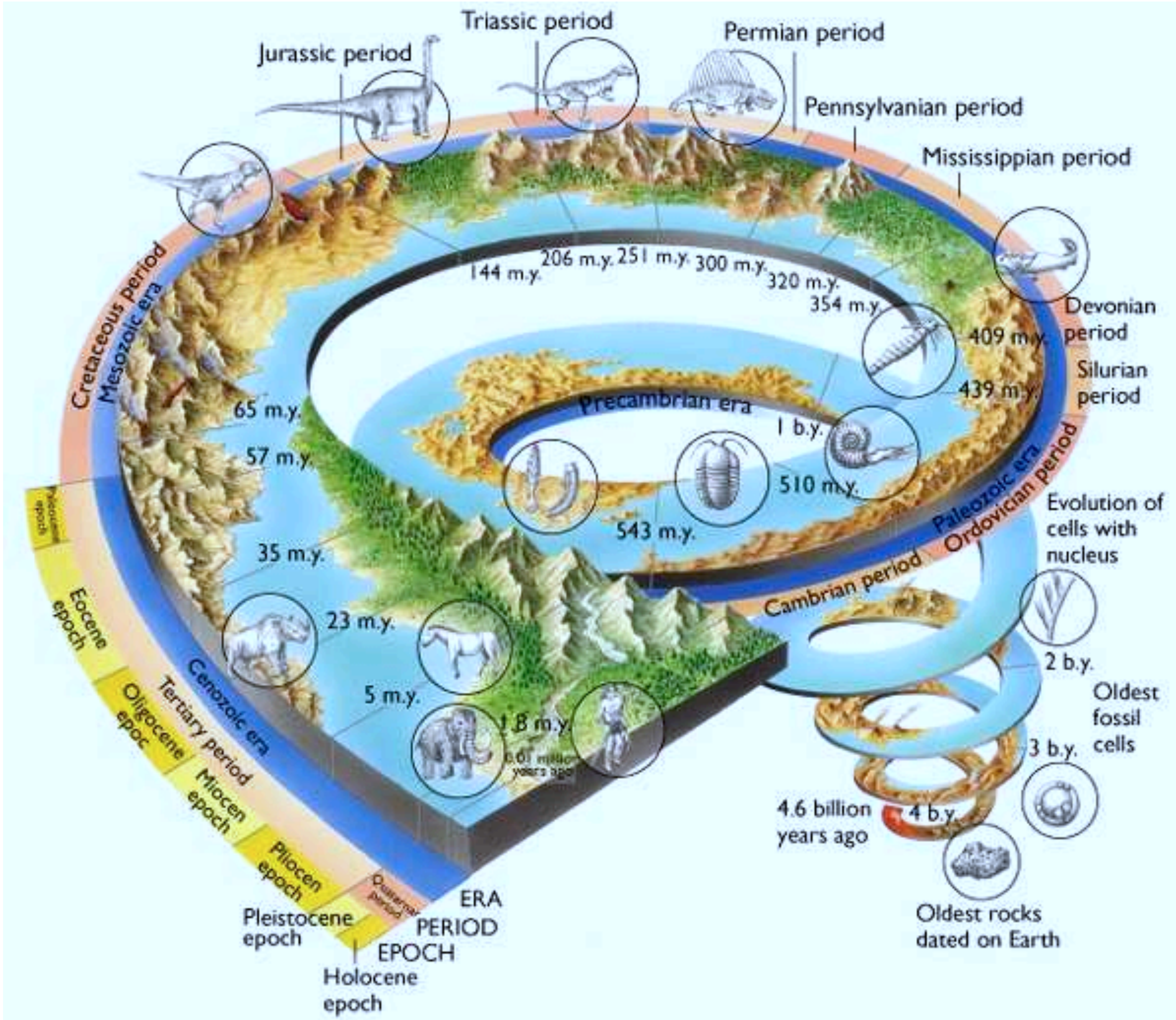
The first three eons, including the rise of oxygen

Snowball Earth

Continental drift

Onset of the current series of ice ages

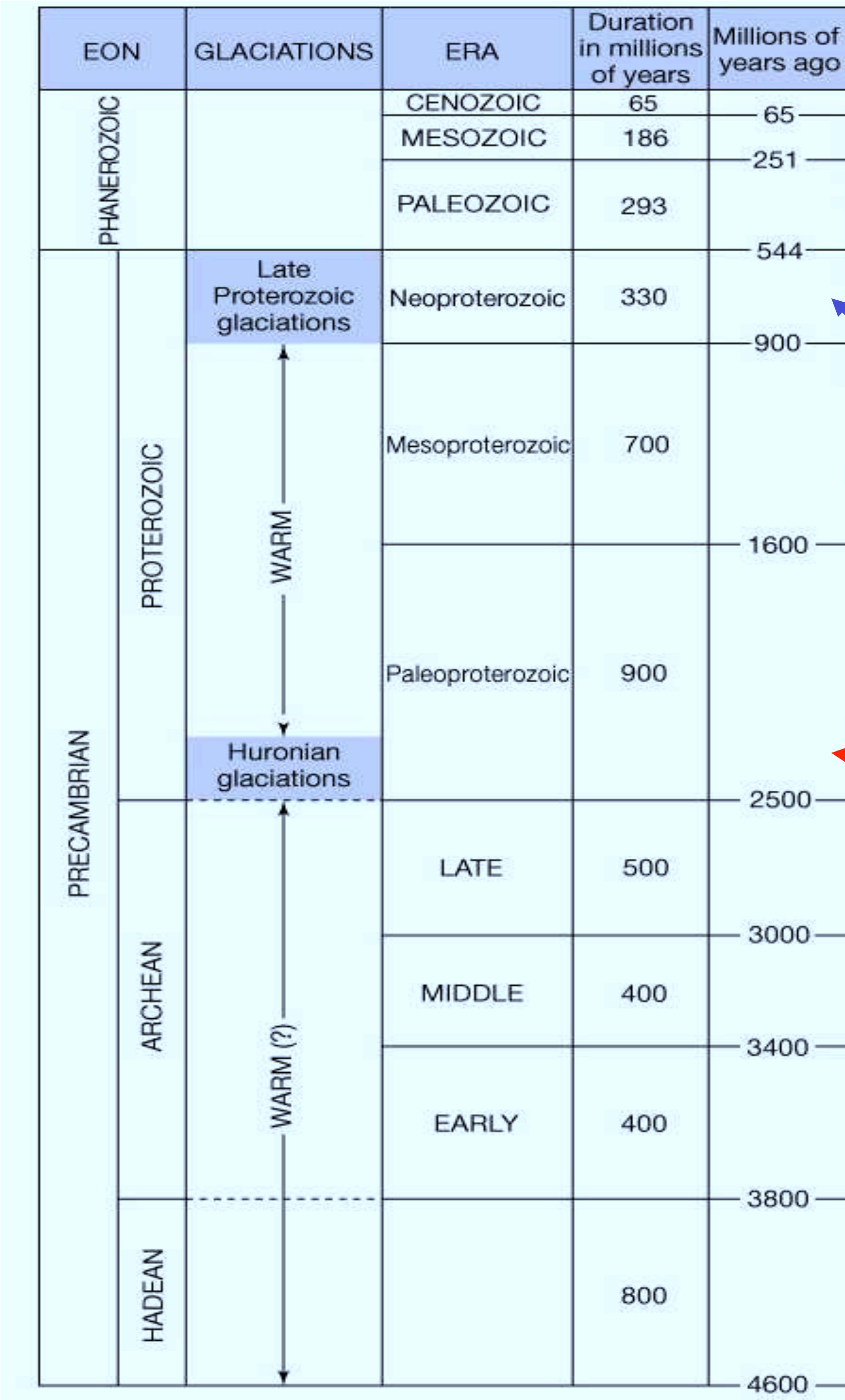
What does this have to do with global warming?


Jurassic period
Triassic period
Permian period
Pennsylvanian period
Mississippian period
Cretaceous period
Mesozoic era
144 m.y.
206 m.y.
251 m.y.
300 m.y.
320 m.y.
354 m.y.
Devonian period
409 m.y.
Silurian period
439 m.y.
65 m.y.
Precambrian era
1 b.y.
57 m.y.
510 m.y.
Paleozoic era
Ordovician period
Evolution of cells with nucleus
543 m.y.
35 m.y.
Cambrian period
Eocene epoch
23 m.y.
2 b.y.
Cenozoic era
Tertiary period
Oligocene epoc
5 m.y.
Oldest fossil cells
1.8 m.y.
3 b.y.
Miocen epoch
4.6 billion years ago
4 b.y.
Pliocen epoch
Oldest rocks dated on Earth
ERA
PERIOD
EPOCH
Pleistocene epoch
Holocene epoch

Eight Memorable Events in Earth History

Birth of Planet (4.6 Byr BP)
Formation of Oceans (~4.2 Byr BP)
Bacterial Life (3.5 Byr BP)
Rise of Oxygen (2.3 Byr BP)
Earth Freezes over (750 Myr BP)
Explosion of Multicellular Life (500 Myr BP)
Asteroid Hit (65 Myr BP)
Beginning of Ice ages (3 Myr BP)

End of Ice Ages (10 kyr BP)
Beginning of Agriculture & Civilization



EON	GLACIATIONS	ERA	Duration in millions of years	Millions of years ago
PHANEROZOIC		CENOZOIC	65	65
		MESOZOIC	186	251
		PALEOZOIC	293	544
PRECAMBRIAN – PROTEROZOIC	Late Proterozoic glaciations	Neoproterozoic	330	900
	WARM	Mesoproterozoic	700	1600
	Huronian glaciations	Paleoproterozoic	900	2500
ARCHEAN	WARM (?)	LATE	500	3000
		MIDDLE	400	3400
		EARLY	400	3800
HADEAN			800	4600

end of last ice-age; begin civilization

beginning of modern era of ice-ages

asteroid impact; end of dinosaurs

Cambrian explosion of life;
beginning of fossil record

Earth freezes over; life survives
in pockets

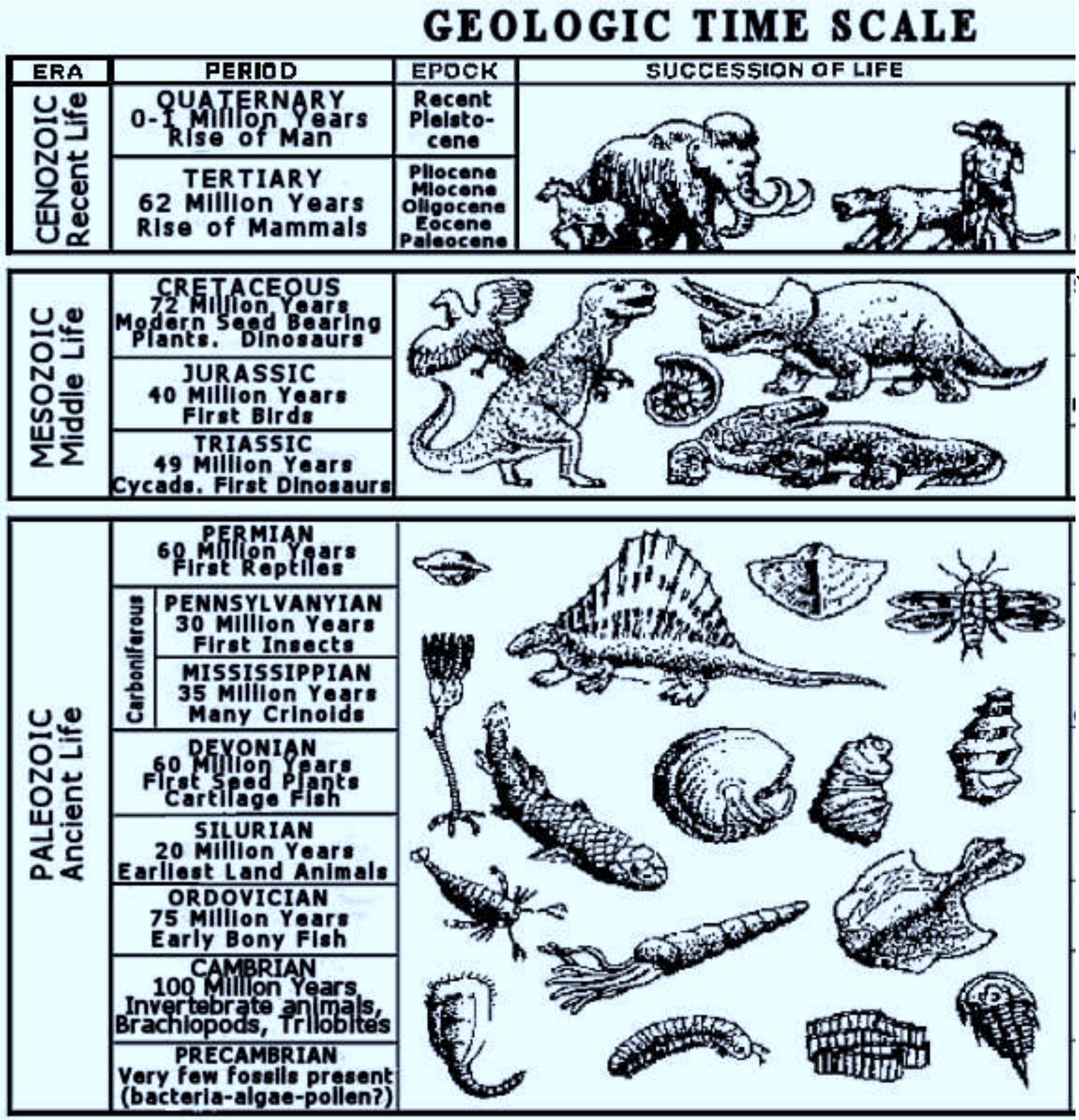
rise of atmospheric oxygen
(greatest global pollution event;
deadly to nearly all existing life)

life! (prokaryotic bacteria)

formation of Earth

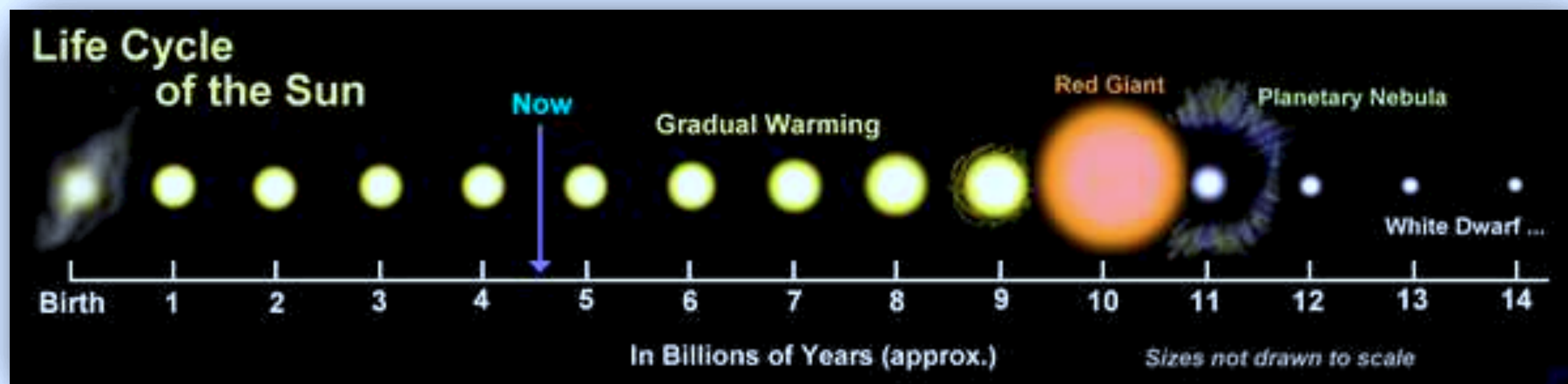
Earth is unfathomably old
most of Earth history is very alien

Geological Time Scale



Asteroid impact;
end of dinosaurs

Cambrian explosion
of life;
beginning of fossil
record

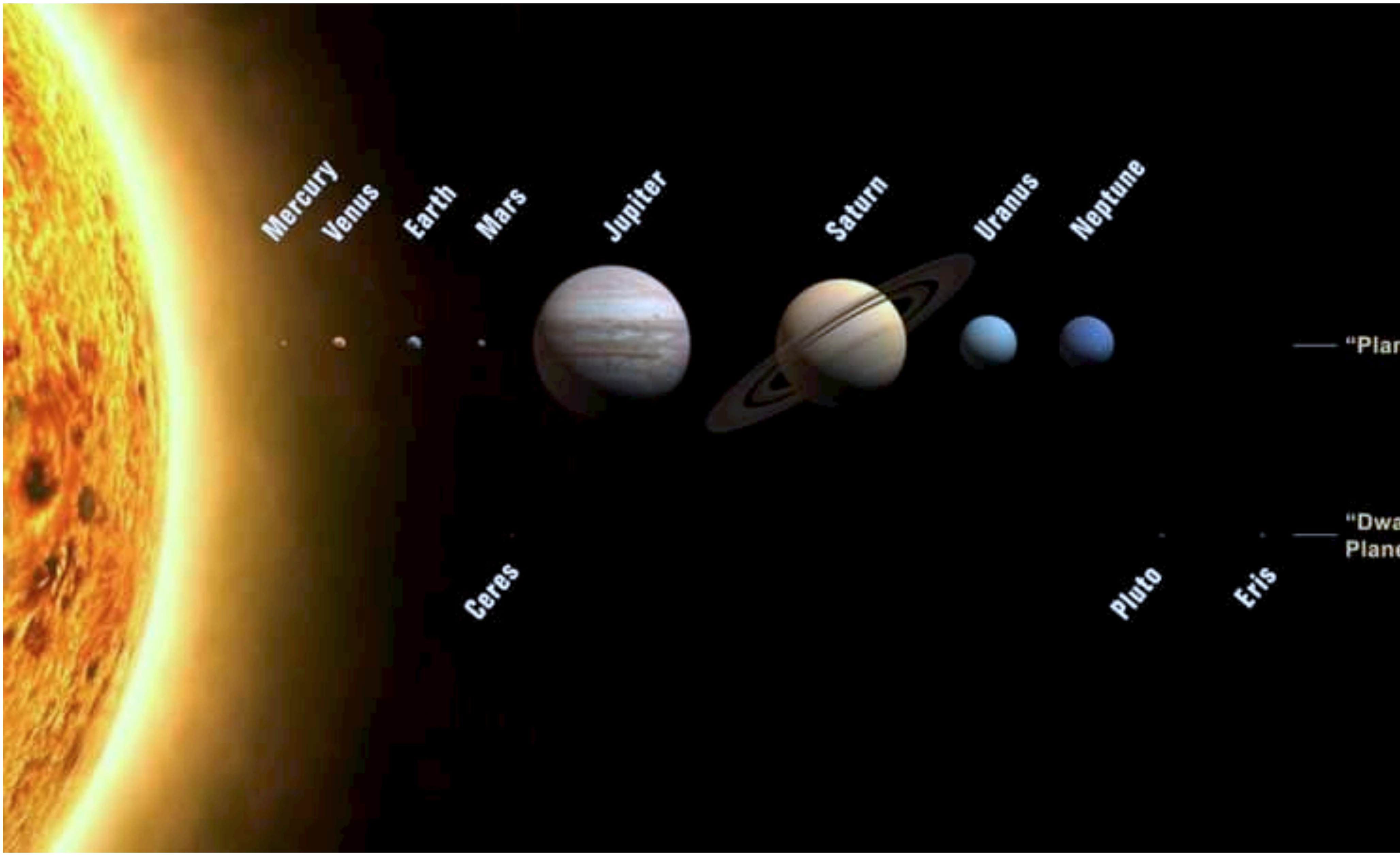


It is believed that the sun's emission has increased by ~30% over the lifetime of the Earth

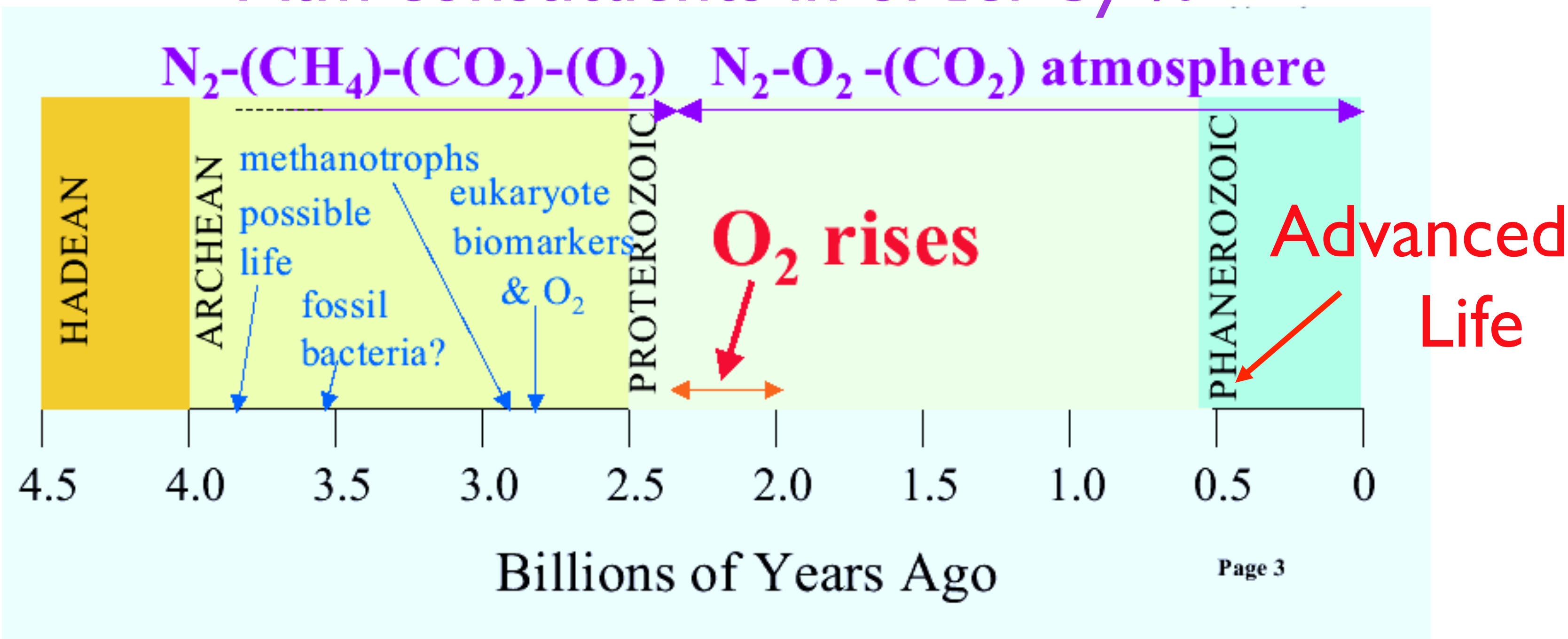
The sun isn't much older than Earth

Evolution of the sun

In the region of the Earth less than a million years after the sun formed. Small grains of dust are aggregating into "planetesimals." Planets grew by collisional aggregation of these objects.


Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Ceres
Pluto
Eris

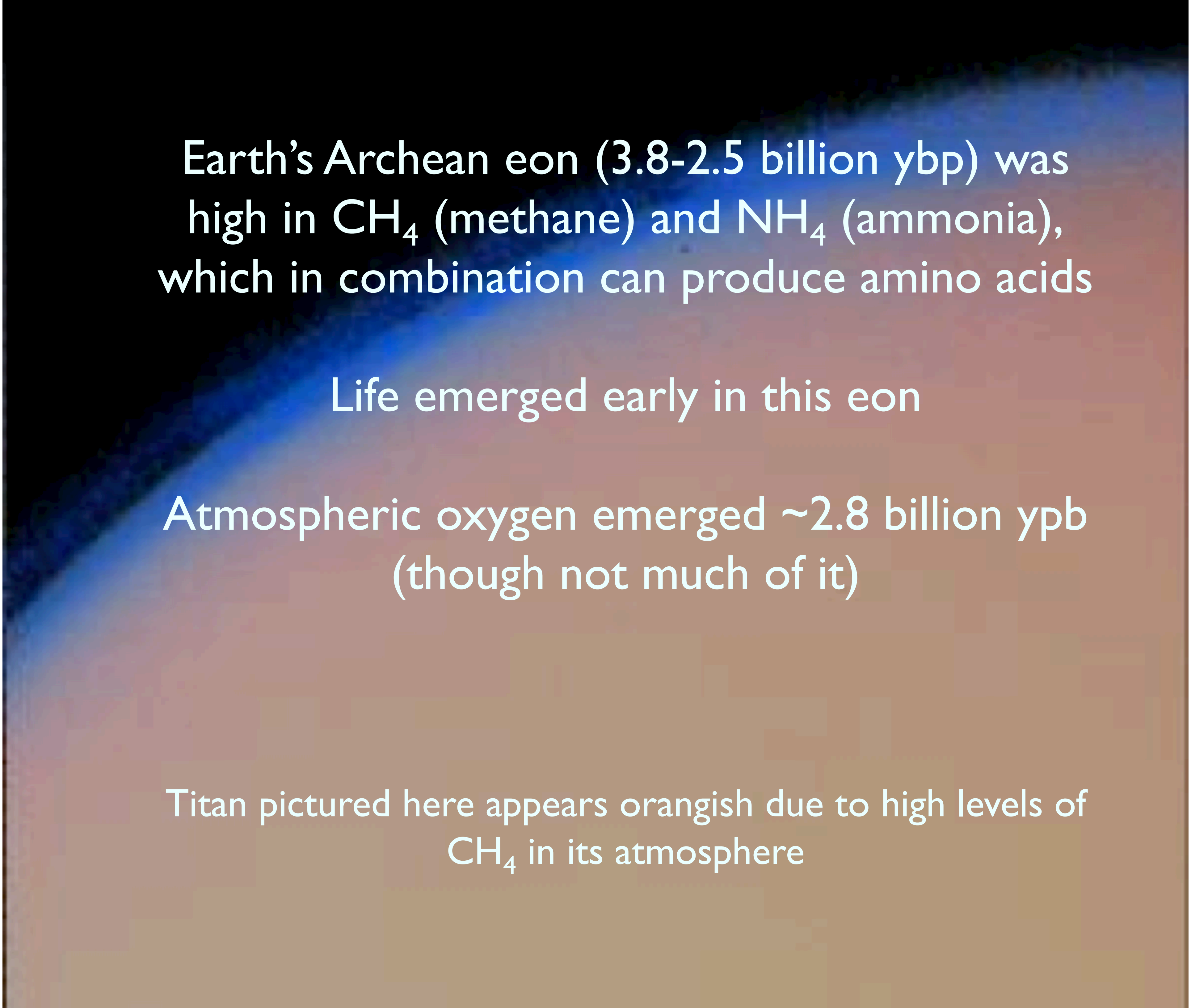
Atm constituents in order by %



Hadean eon (4.6-3.8 billion ybp)

One catastrophe after another

The sky was not yet blue



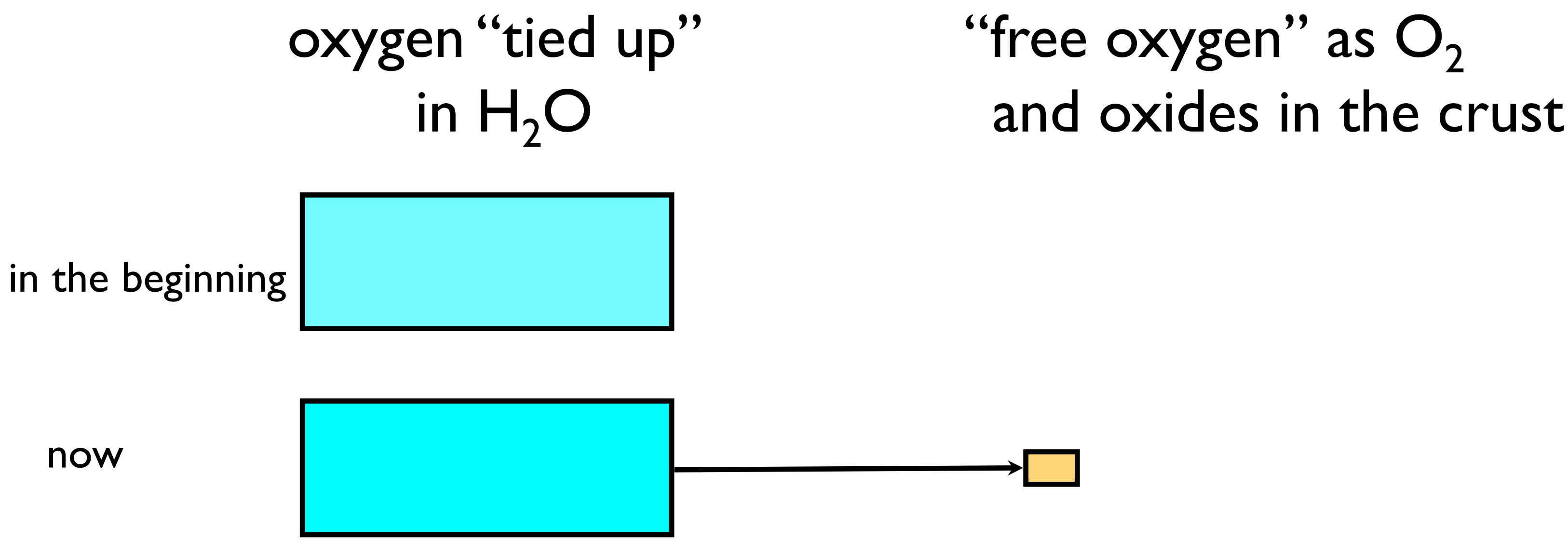
Earth's Archean eon (3.8-2.5 billion ybp) was high in CH_4 (methane) and NH_4 (ammonia), which in combination can produce amino acids

Life emerged early in this eon

Atmospheric oxygen emerged ~2.8 billion ypb (though not much of it)

Titan pictured here appears orangish due to high levels of CH_4 in its atmosphere

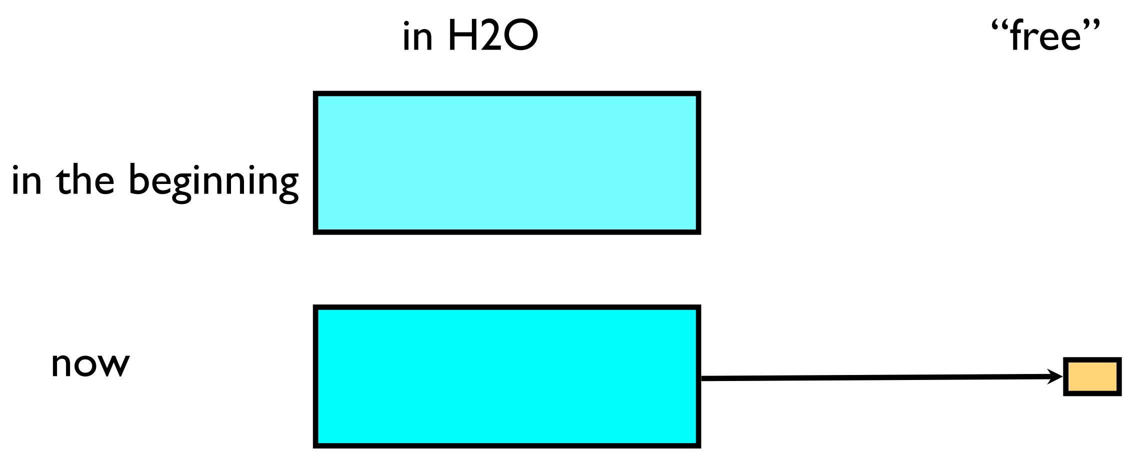
Proterozoic Eon (2.5-0.5 billion byp)
A catastrophe at the start: The rise of oxygen



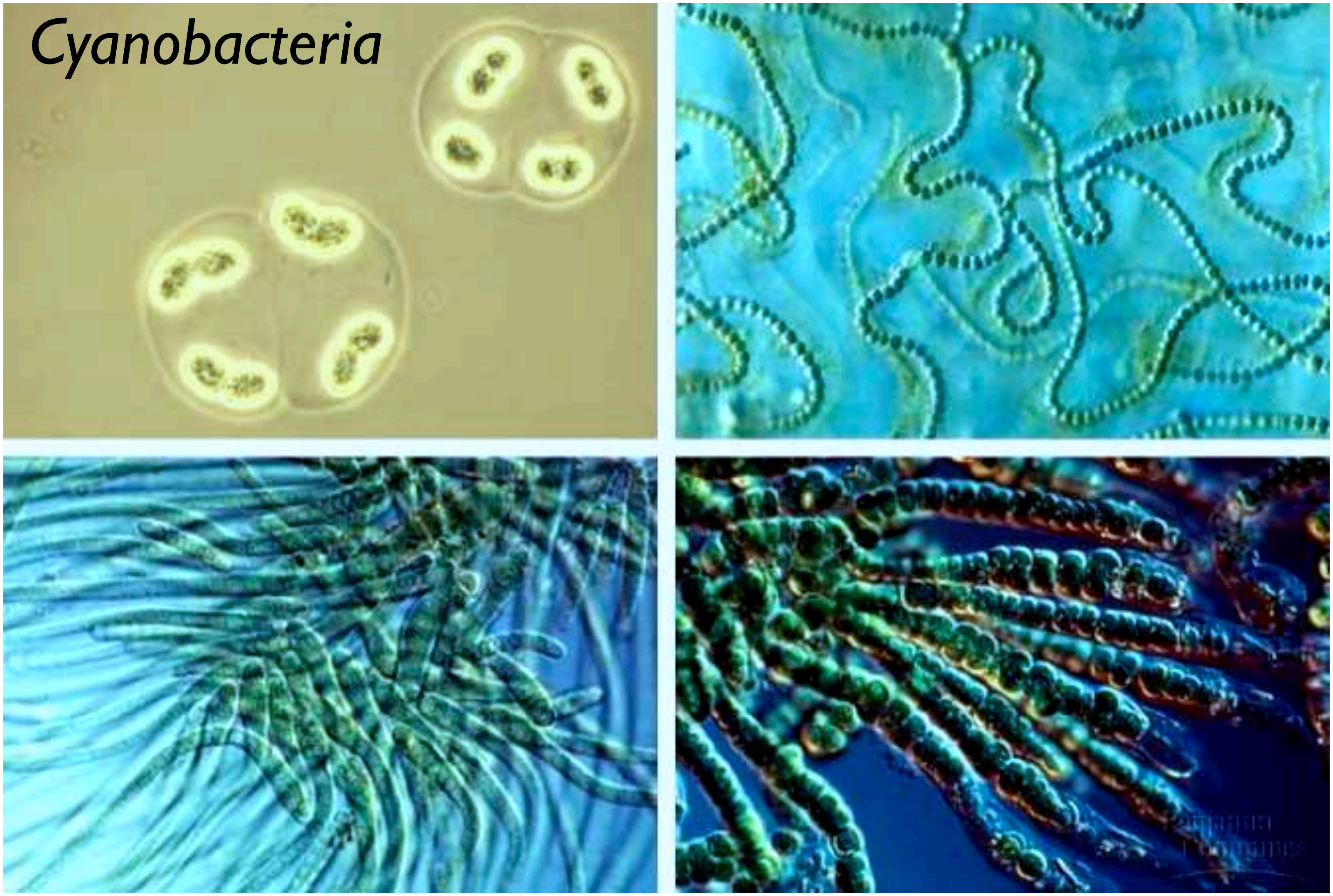
To liberate oxygen, two things need to happen

1. A chemical reaction has to make O_2 from CO_2

2. Something has to prevent the liberated O from recombining with H to make water

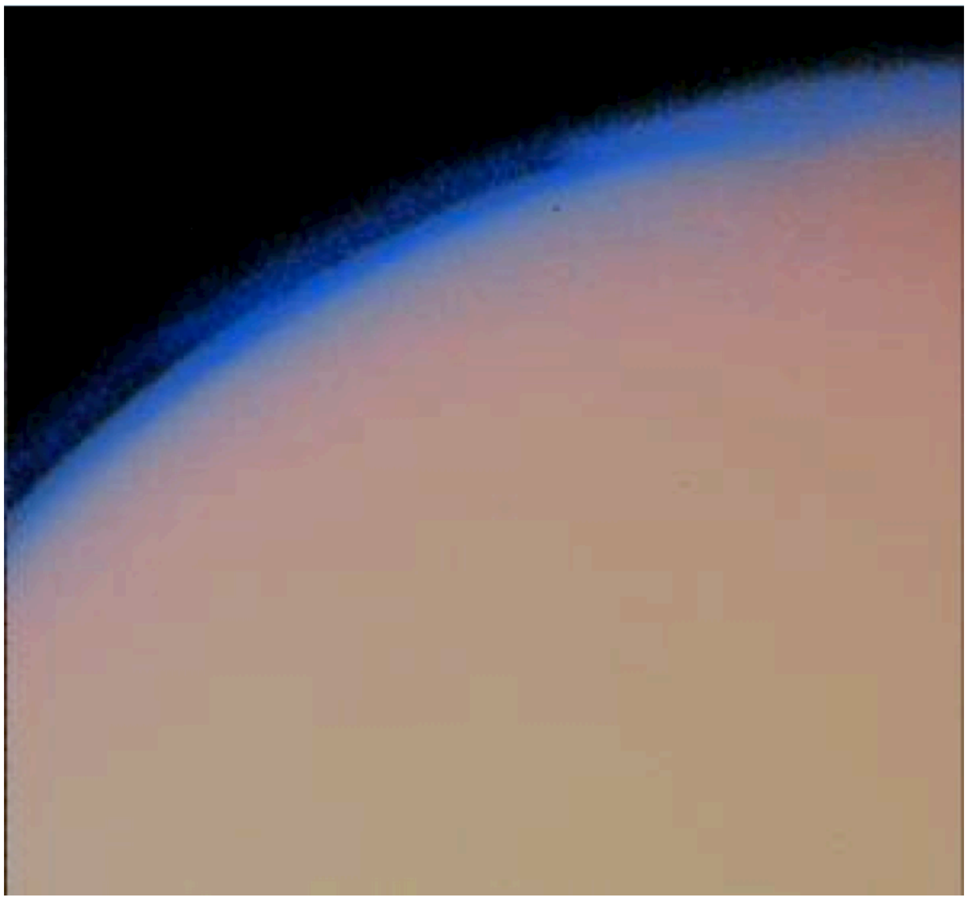


1) The reaction: Photosynthesis $CO_2 + H_2O \rightarrow CH_2O + O_2$

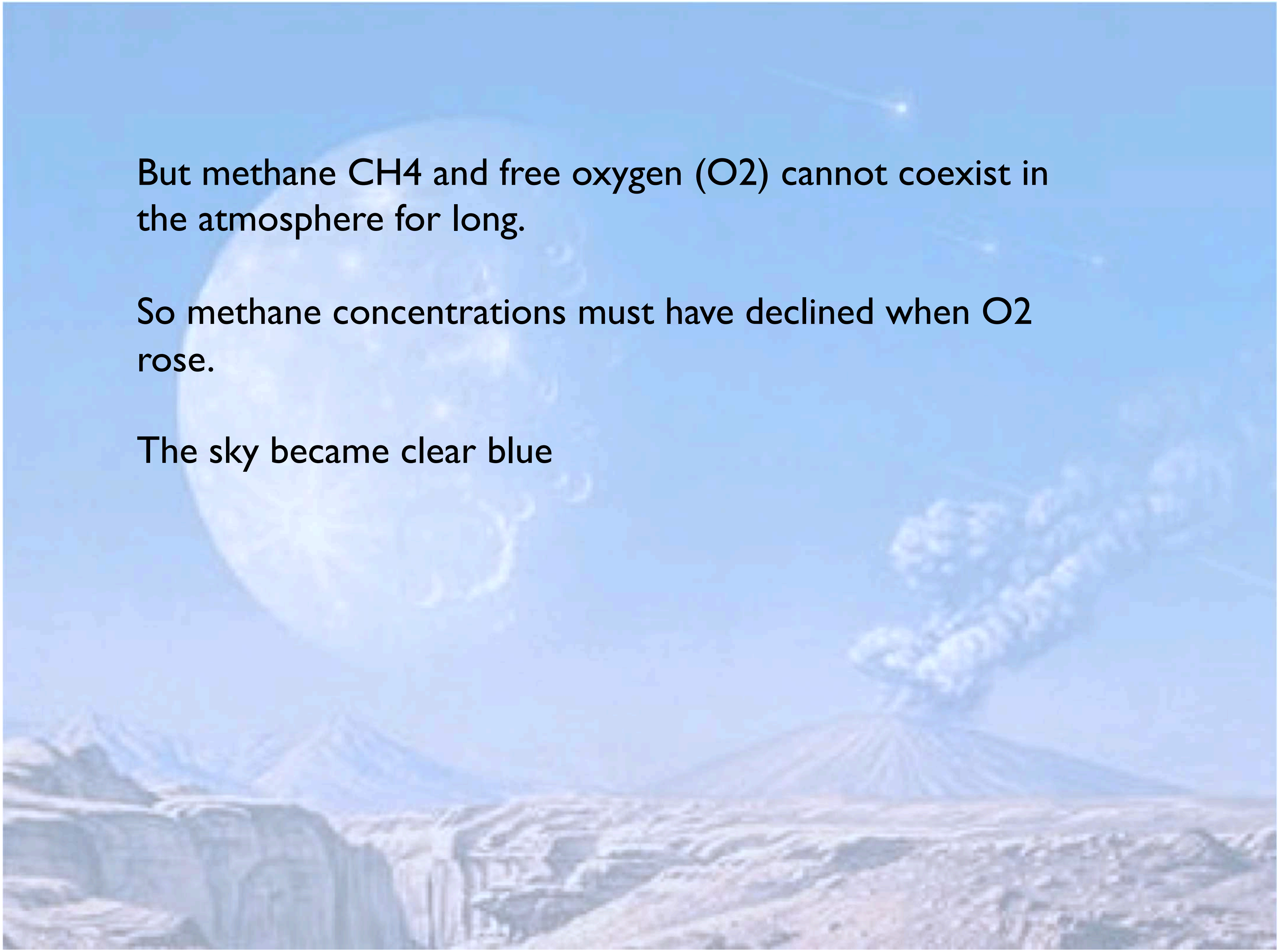


2) Prevent free O from recombining with 2 H via

$$2H_2+O_2 \rightarrow 2H_2O$$
$$CH_4+2O_2 \rightarrow CO_2 + 2H_2O \quad ?$$



Methane, CH4, breaks down when exposed to ultraviolet solar radiation in the upper atmosphere, liberating H atoms, which can escape to space



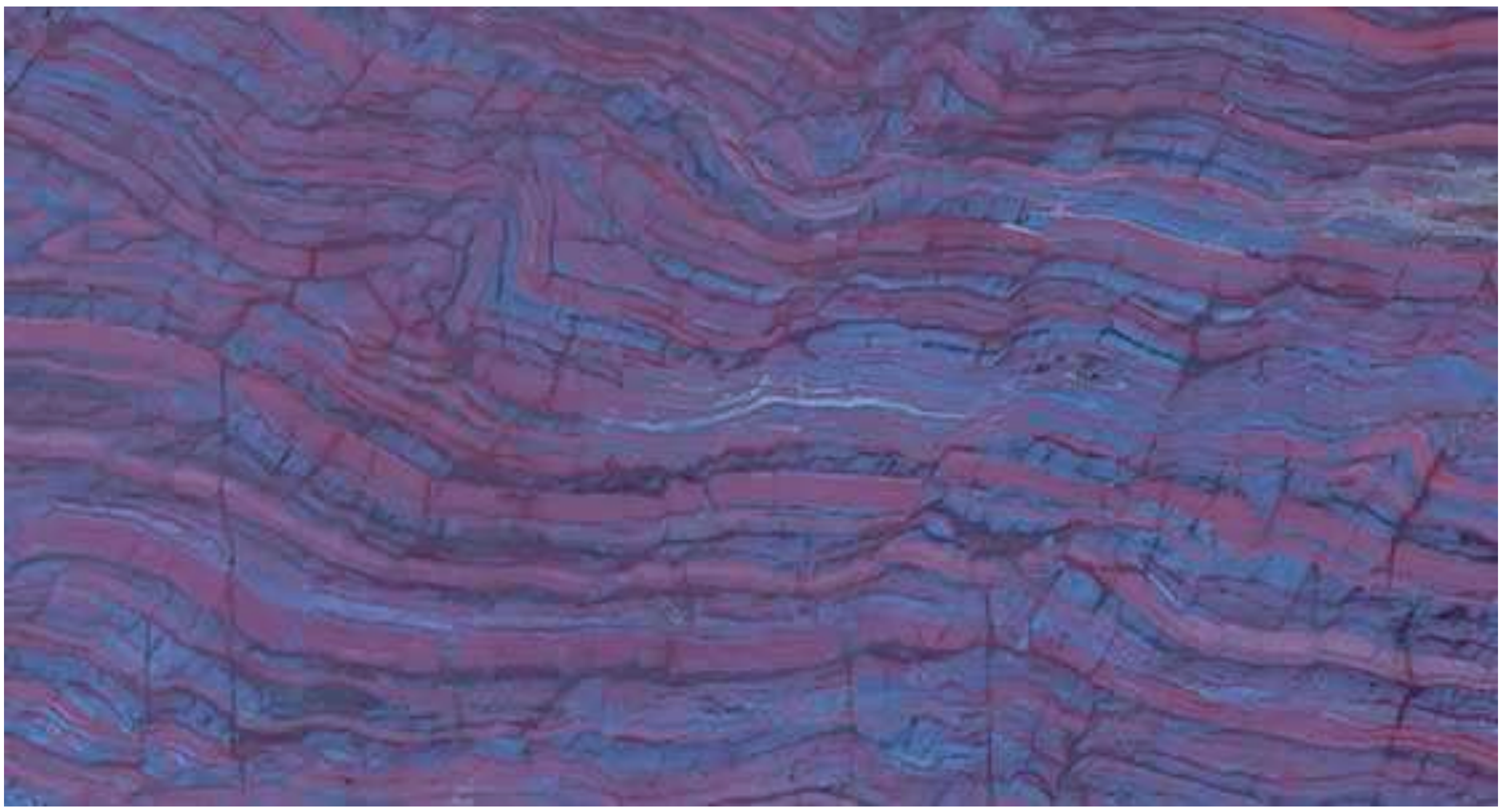
But methane CH4 and free oxygen (O2) cannot coexist in the atmosphere for long.

So methane concentrations must have declined when O2 rose.

The sky became clear blue

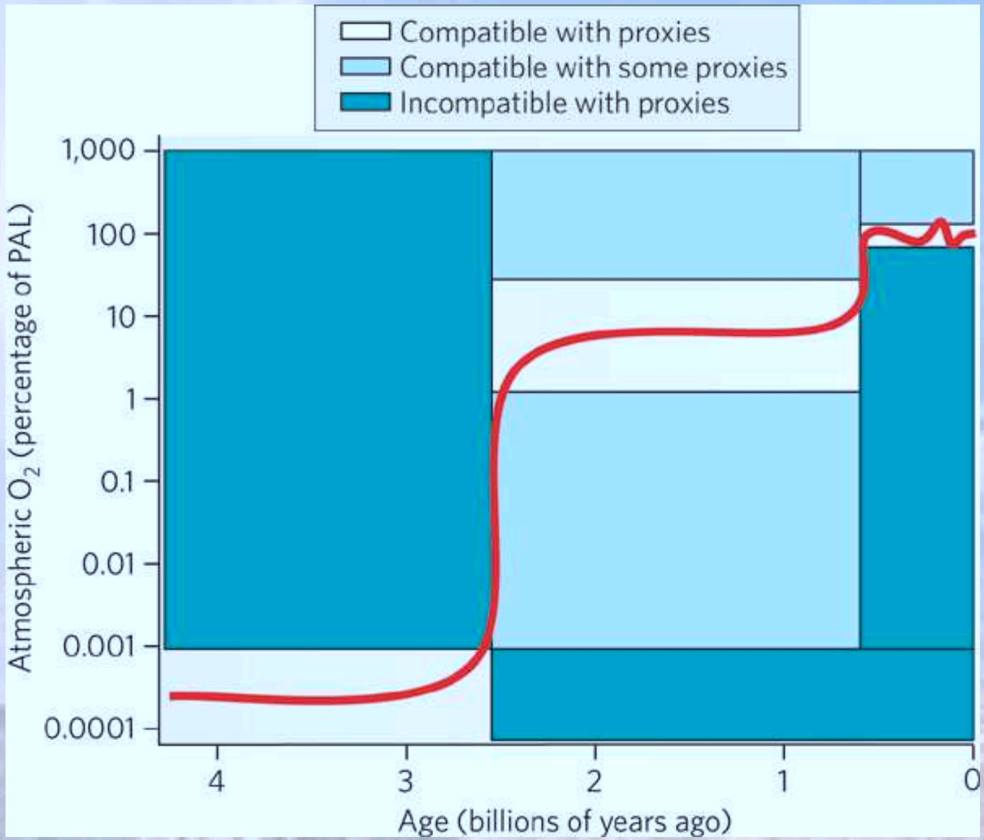
The Great Oxidation

Before free oxygen was in the atmosphere, metals like iron were dissolved in their pure elemental form in the ocean. After ~2.0 billion years ago, all iron oxides were in the fully oxidized form Fe2O3. After that the dissolved iron concentration was too depleted.

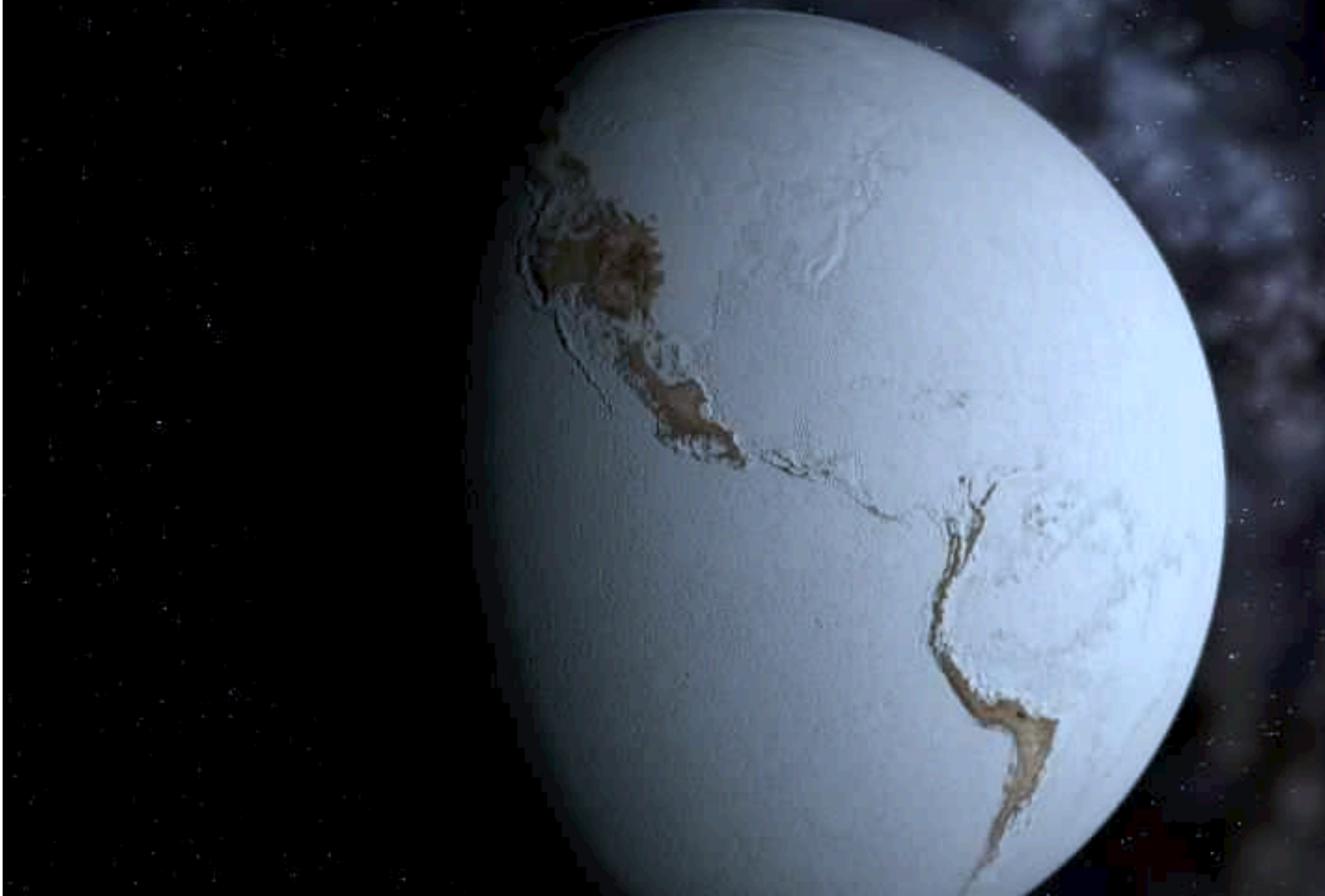


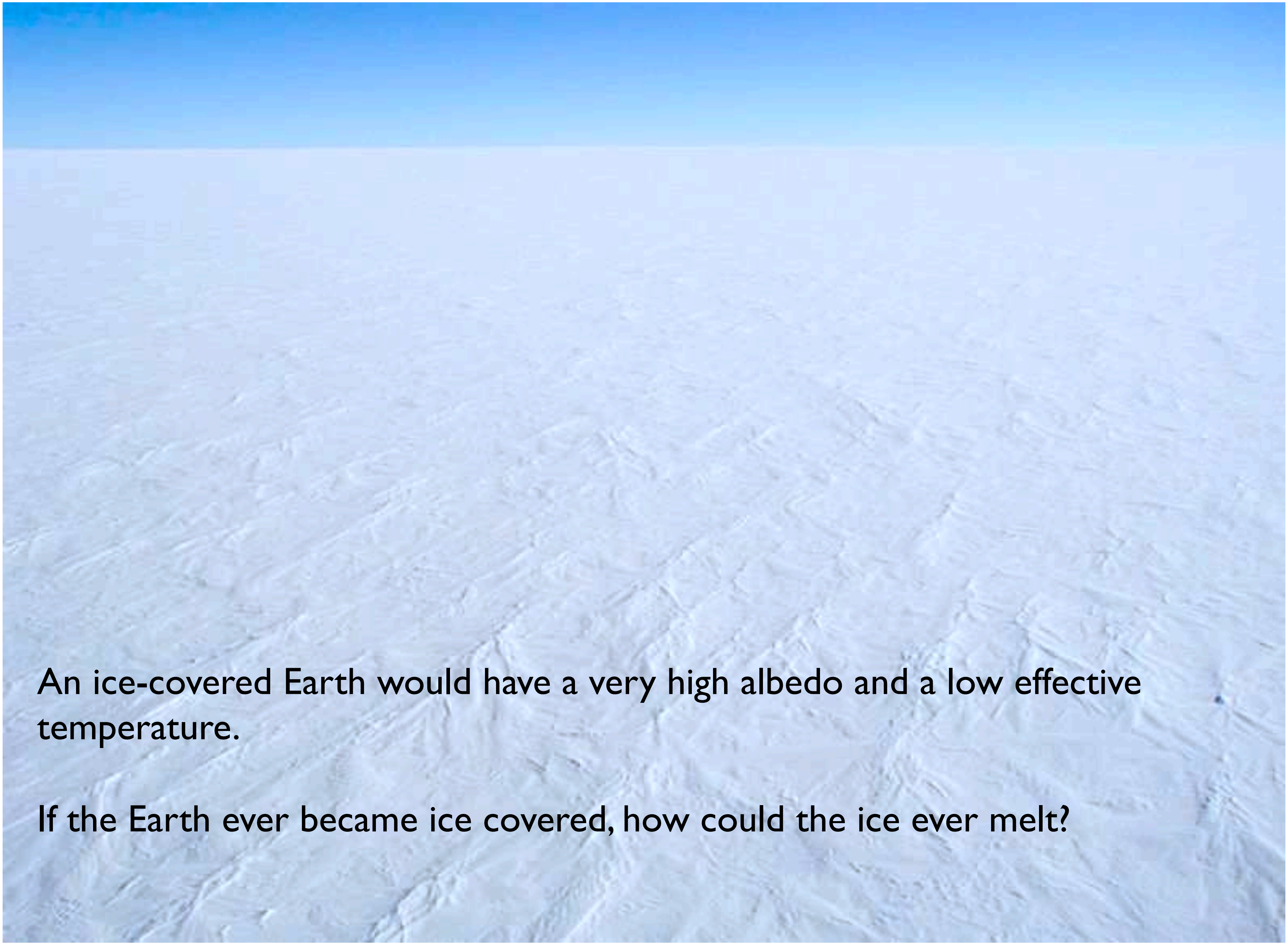
The geological evidence indicates that O2 levels in the atmosphere rose abruptly once the minerals in the Earth's crust were fully oxidized.

For life forms adapted to living in an anoxic (O2-free) atmosphere with high methane concentrations, this was a catastrophic event.



Snowball Earth– occurred several times in the last billion years
ice-albedo feedback out of control

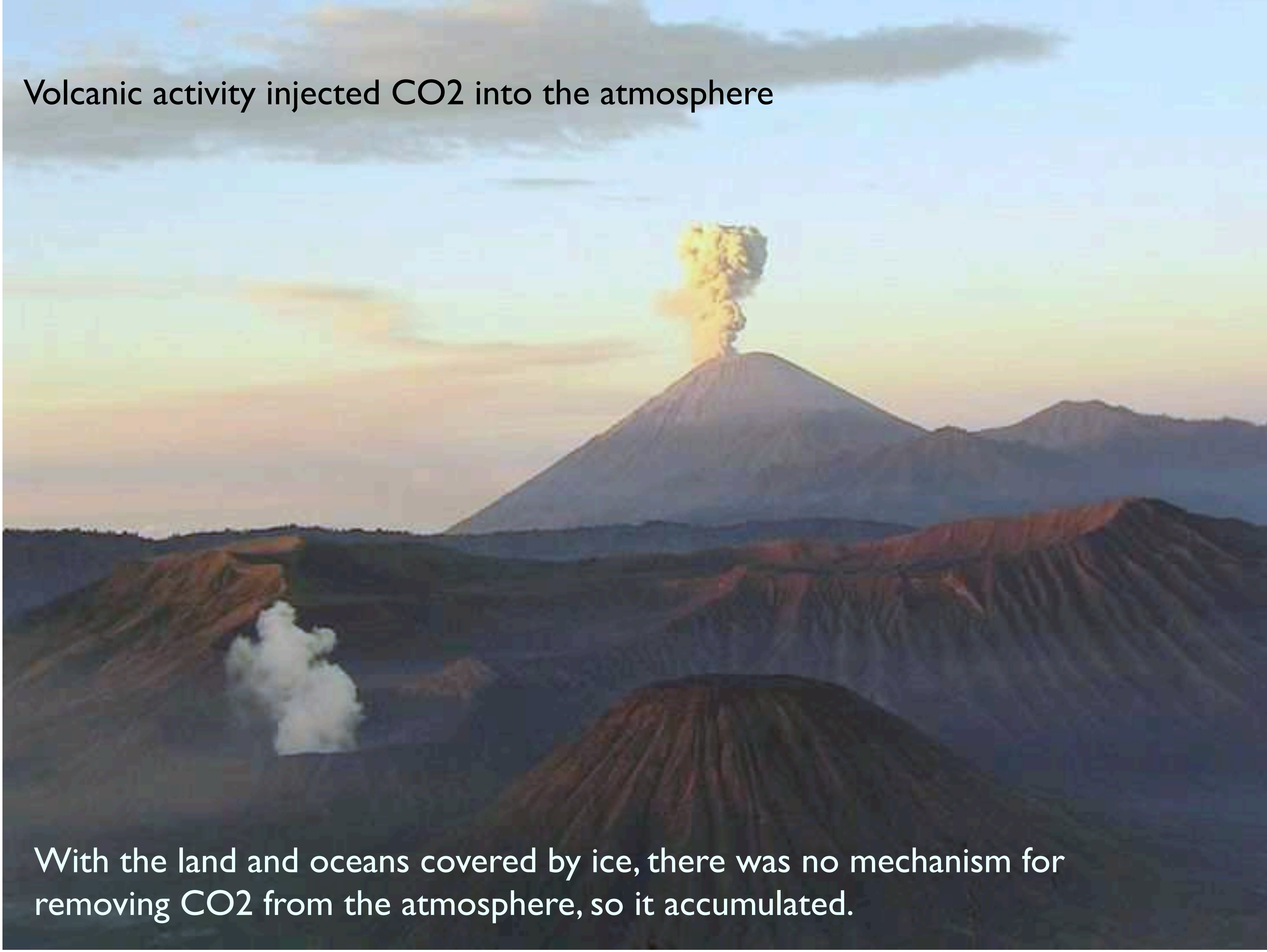




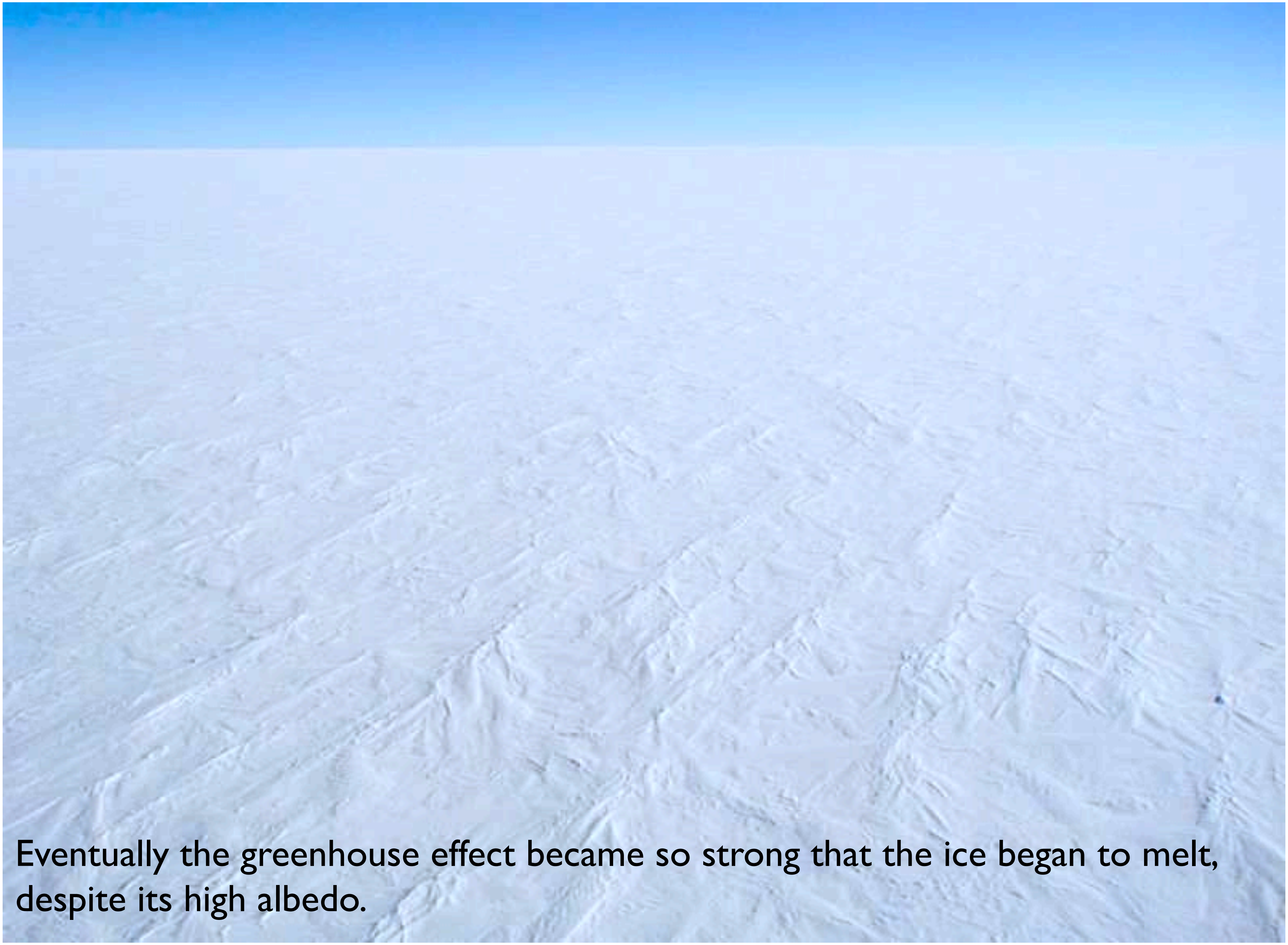
An ice-covered Earth would have a very high albedo and a low effective temperature.

If the Earth ever became ice covered, how could the ice ever melt?

Volcanic activity injected CO_2 into the atmosphere



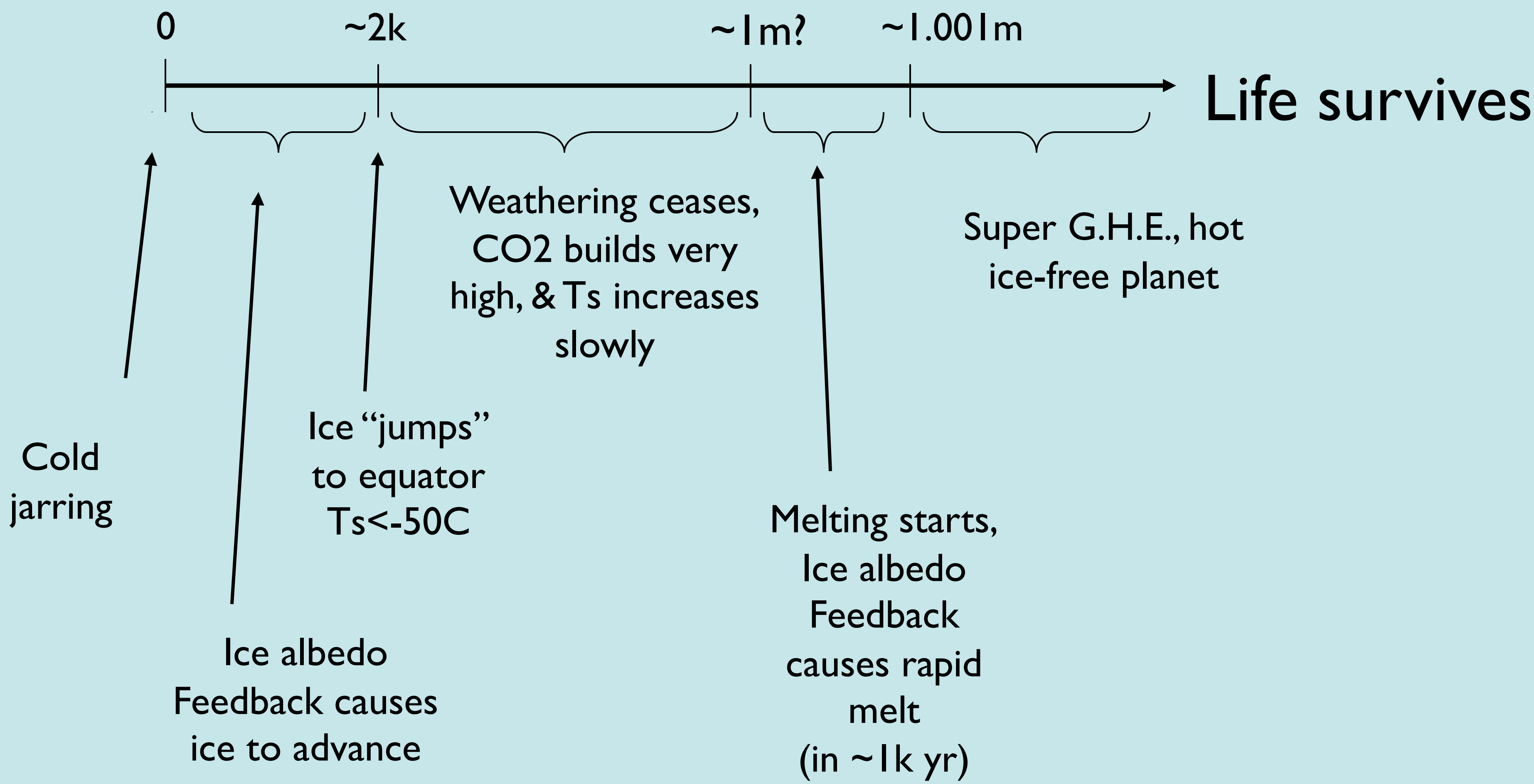
With the land and oceans covered by ice, there was no mechanism for removing CO_2 from the atmosphere, so it accumulated.



Eventually the greenhouse effect became so strong that the ice began to melt, despite its high albedo.

Once initiated, melting would proceed rapidly as the albedo dropped.

Snowball Earth Timeline

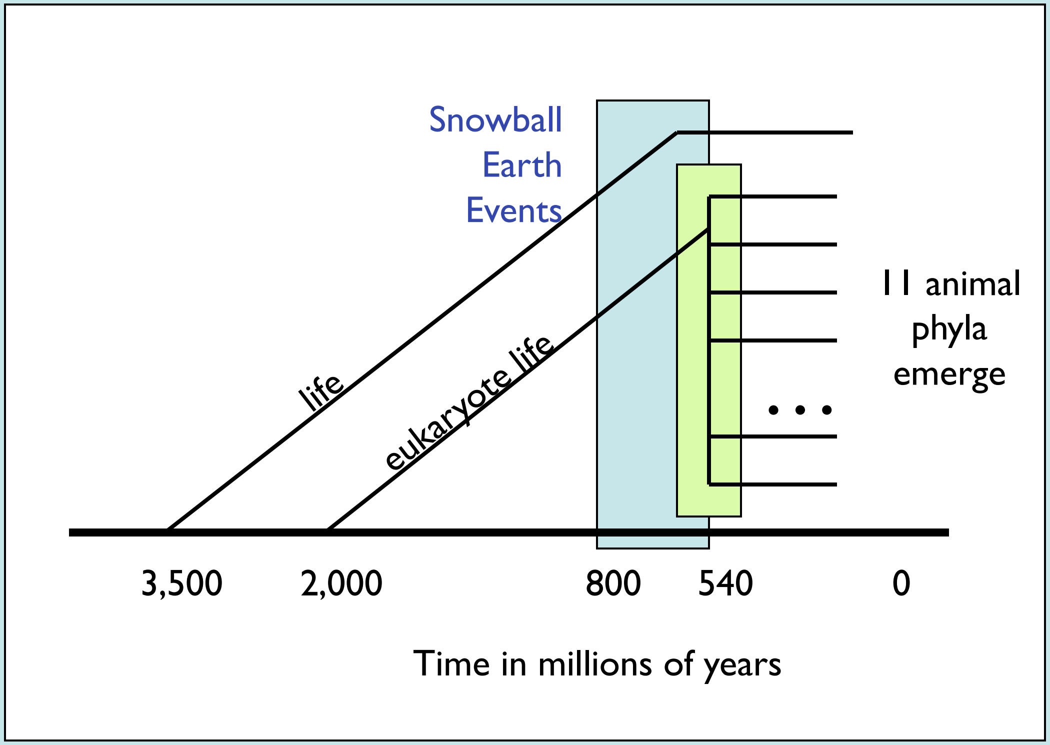


So what?

Ice covering the planet is cool

Rapid melt warmed Earth ~100 C in a thousand years

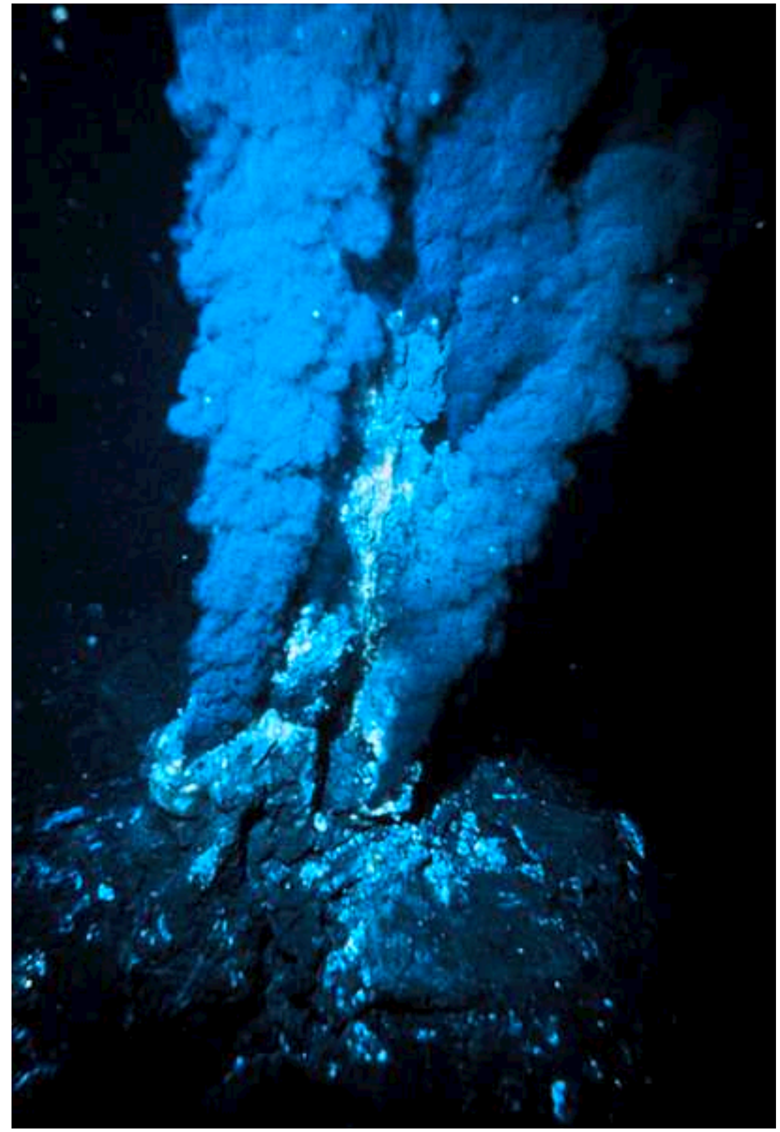
How did life survived these Events?



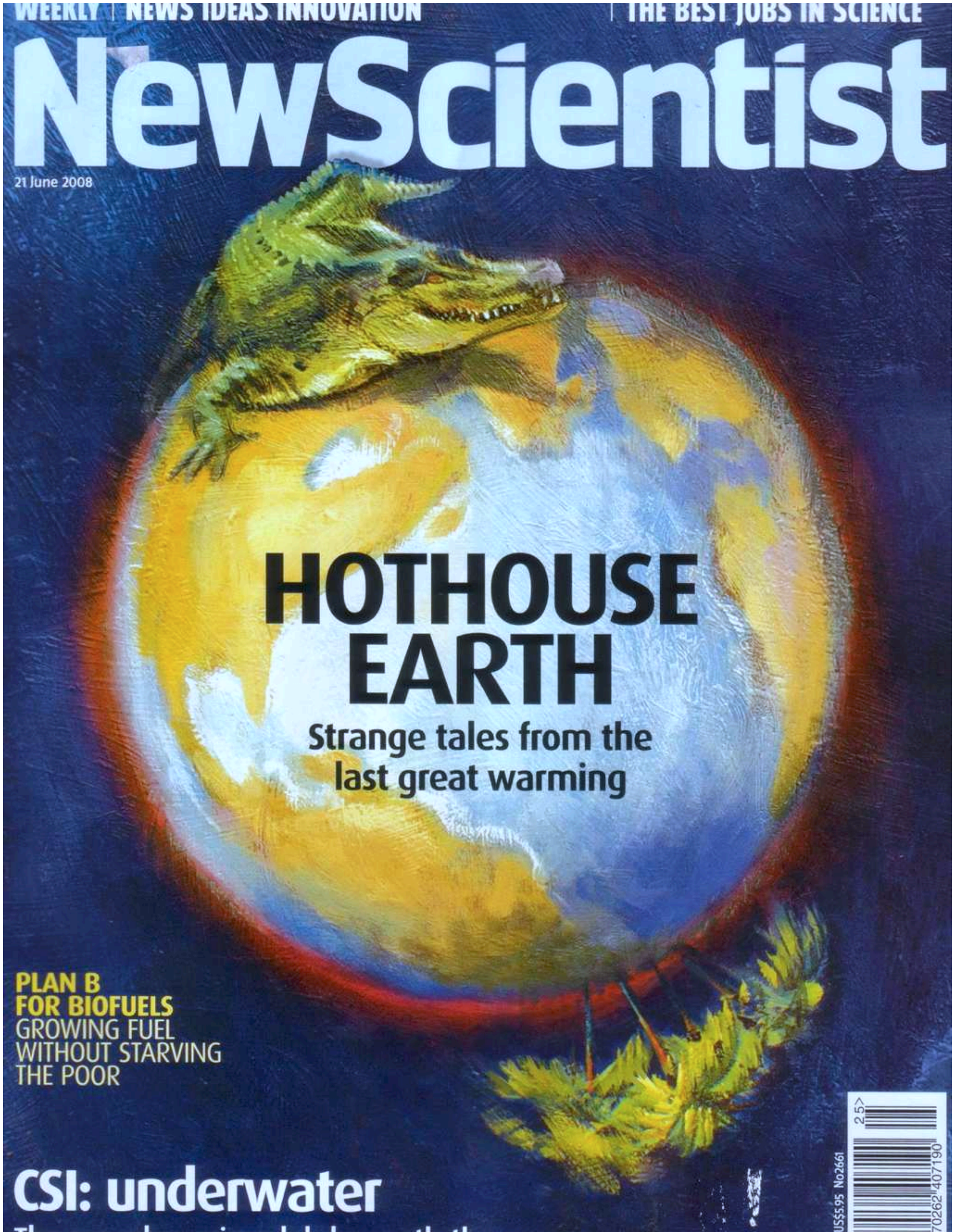
Snowball Earth–

How did life survive snowball Earth?

Cracks in the ice?



Hydrothermal vents?



Once thawed, the Earth would be very warm because of the high atmospheric concentrations of GHG.

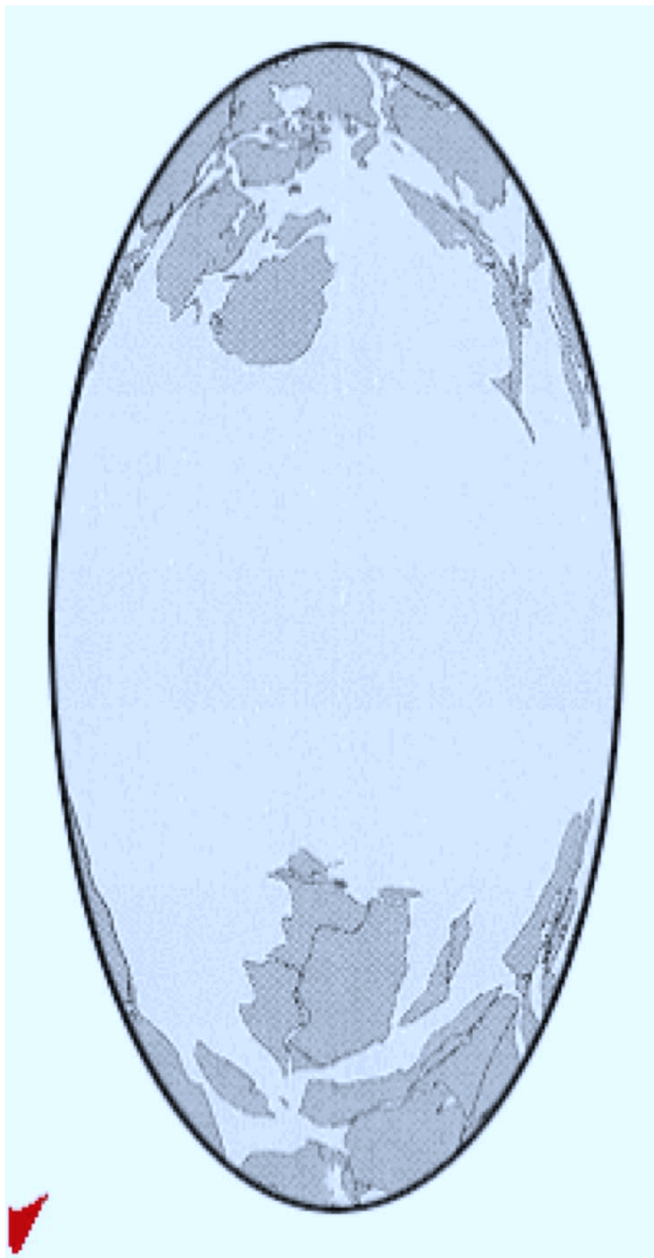
but these high GHG concentrations would gradually decline due to massive weathering

Continental Drift
(Alfred Wegener, 1920s)

Another major factor in the history of climate change

Continental Drift
(Alfred Wegener, 1920s)

Another major factor in the history of climate change



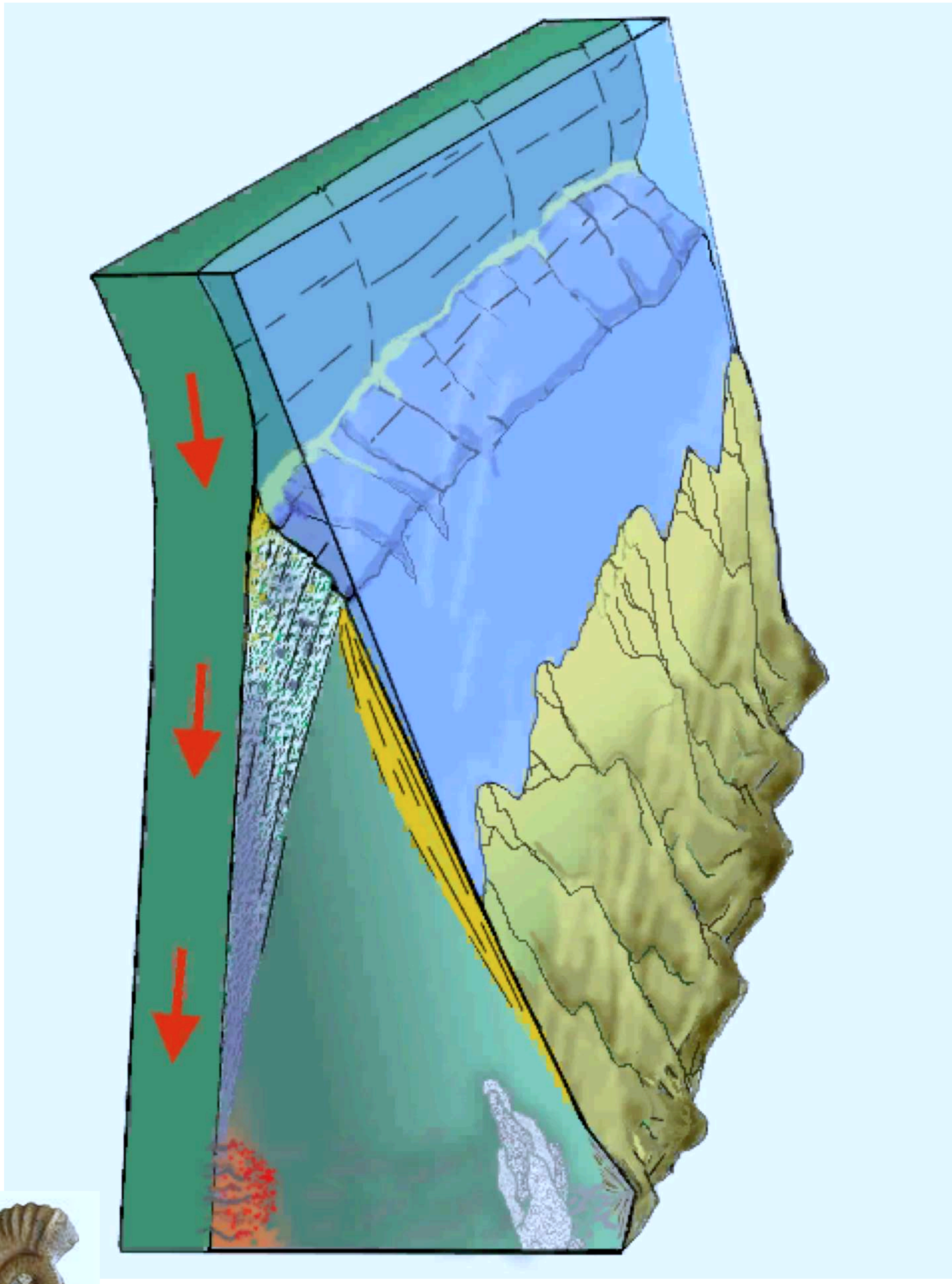


Plate tectonics and climate

Sea floor spreading and volcanoes release CO_2 to the atmosphere. An increase or decrease in their rate can alter atmospheric CO_2 concentrations

The cooling effect of volcanoes from aerosols lasts only a few years, while the CO_2 is slow to disappear, especially at times when the ocean and land carbon reservoirs were already nearly saturated

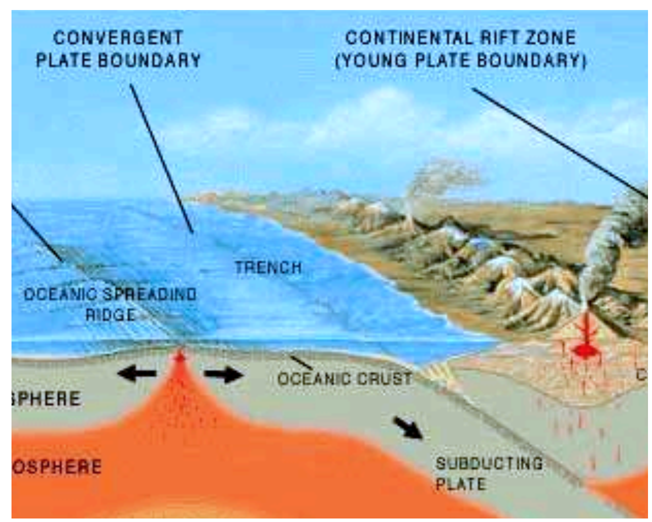


Plate tectonics and climate – some examples

Decline in atmospheric CO_2 starting 60 million years ago

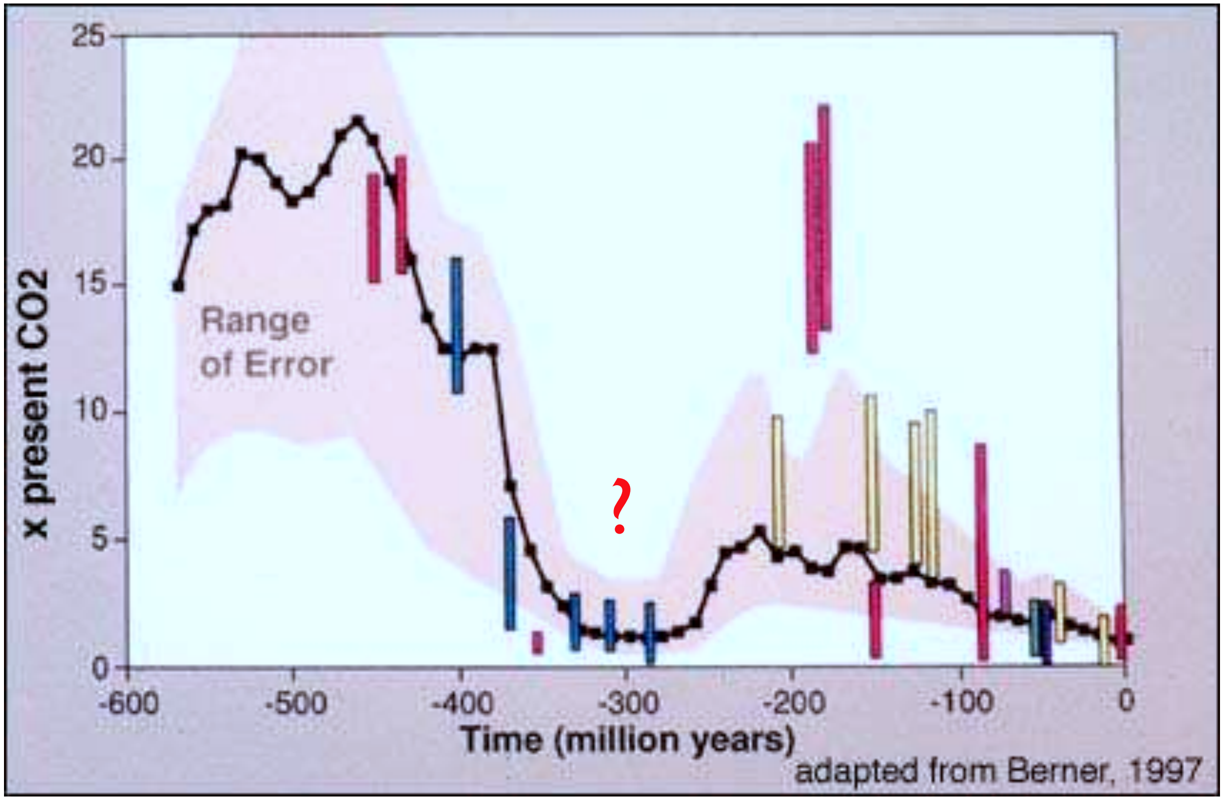
rise of Himalayas and Rockies– more weathering as fresh rock exposed

slowdown in continental drift– less volcanism– less CO_2

Movement of Antarctica over the South Pole– glaciation– higher albedo

Closing of the isthmus of Panama was the last major change to the land distribution (about 4 million years ago)

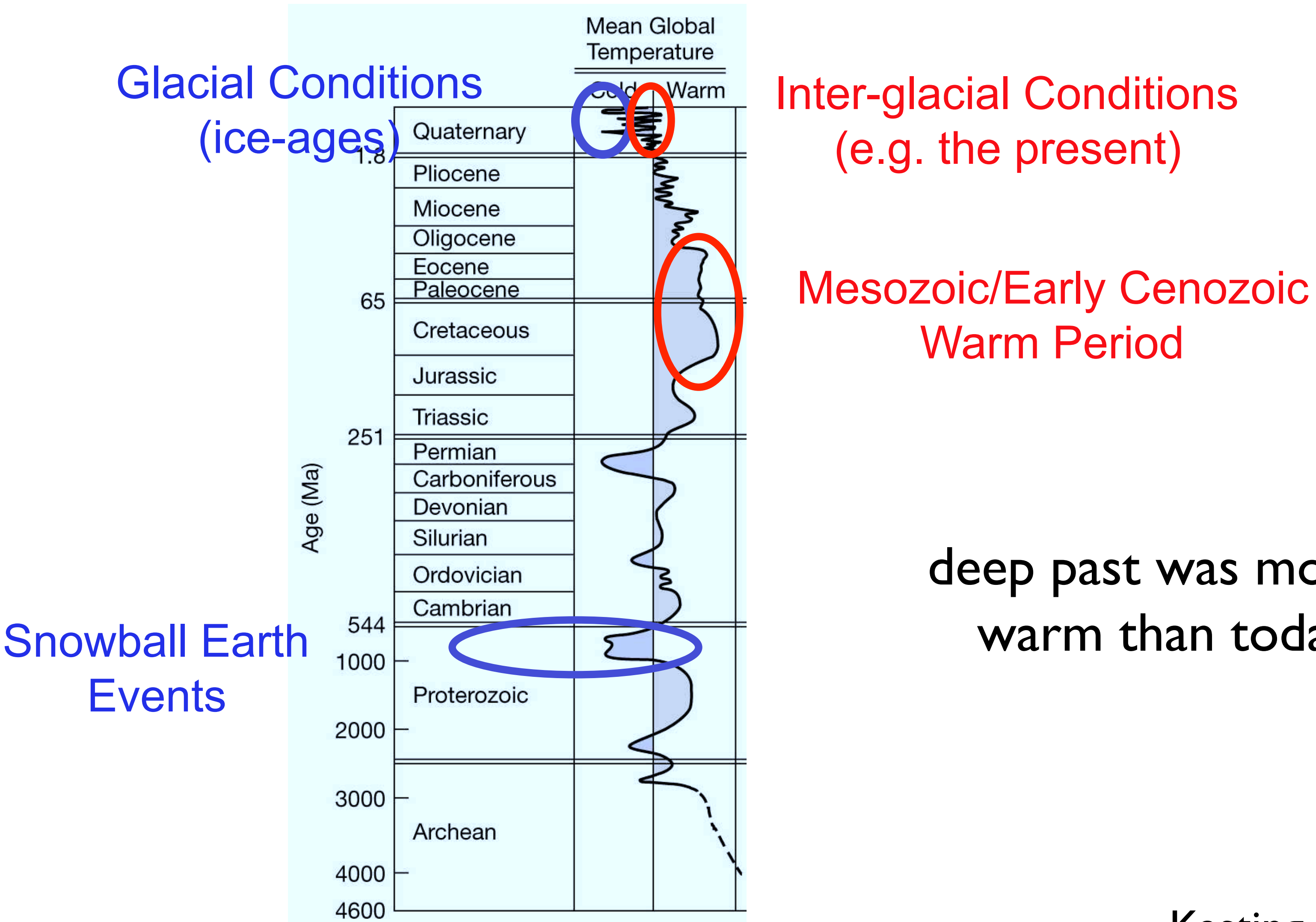
Atmospheric Carbon Dioxide



Not known what caused the dip exactly but its about the time life moved from sea to land and continents were converging on the equator, so weathering was on the rise

Estimate from plant stomata & C^{13}/C^{12} (vertical bars) and the GEOCARB model, based on burial of organic matter in marine sediments

Temperature through Time



deep past was mostly warm than today

Kasting et al

Warm Mesozoic (250 - 65 million years)
Dinosaurs - 2-6 deg C warmer globally
Poles were especially warm - mystery

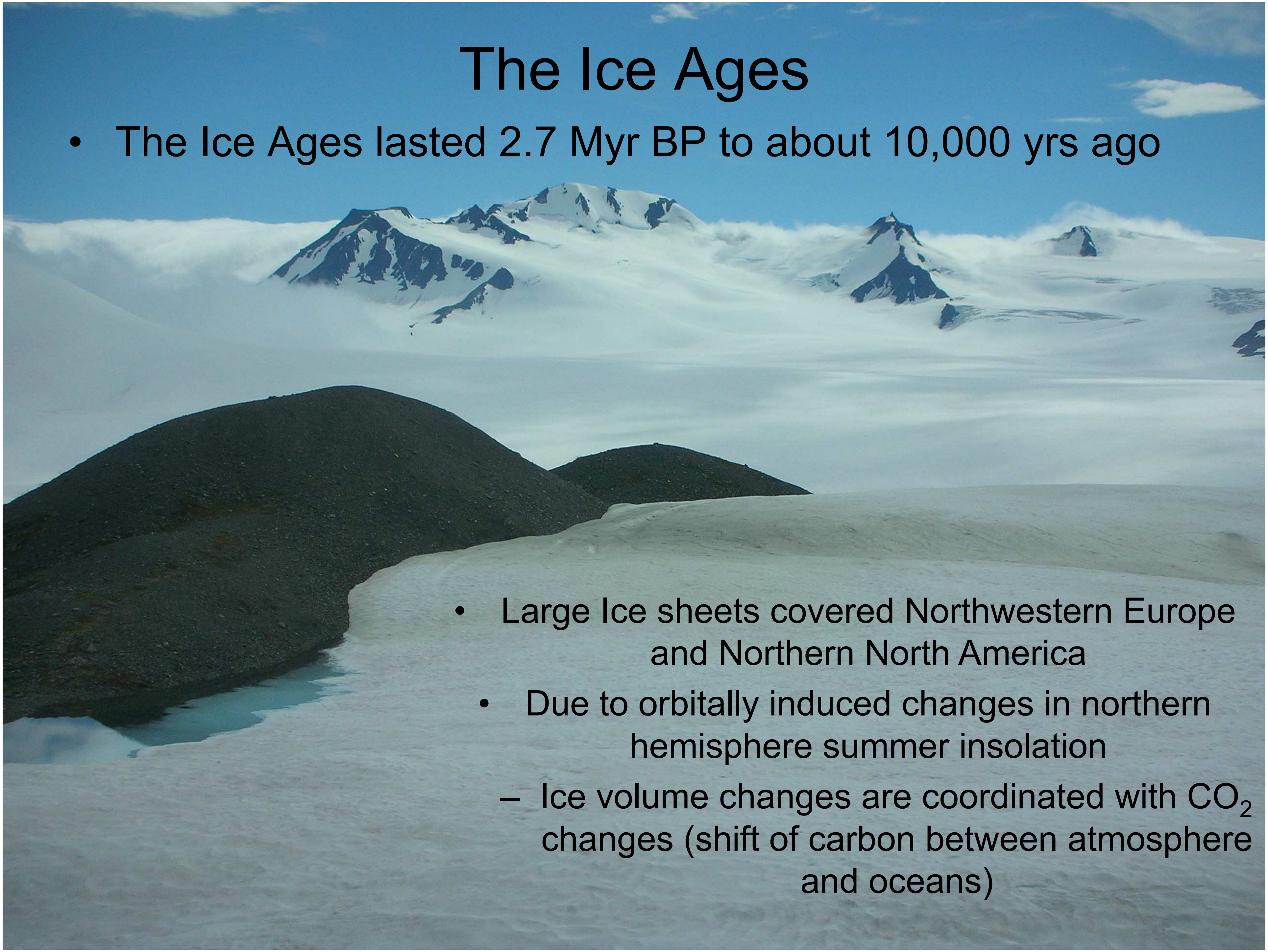
Evidence:
Lush ferns and alligators in Siberia

Cenozoic - 65 million years to present

- Earth slowly cooling
- Life retreats from poles
- Polar ice caps established
- Most recent ice-ages begin ~3 million ybp

Cause of decline in CO_2?

Himalayas form when India collides with Asia and the fresh rock and high precipitation around mountains increased weathering (maybe)



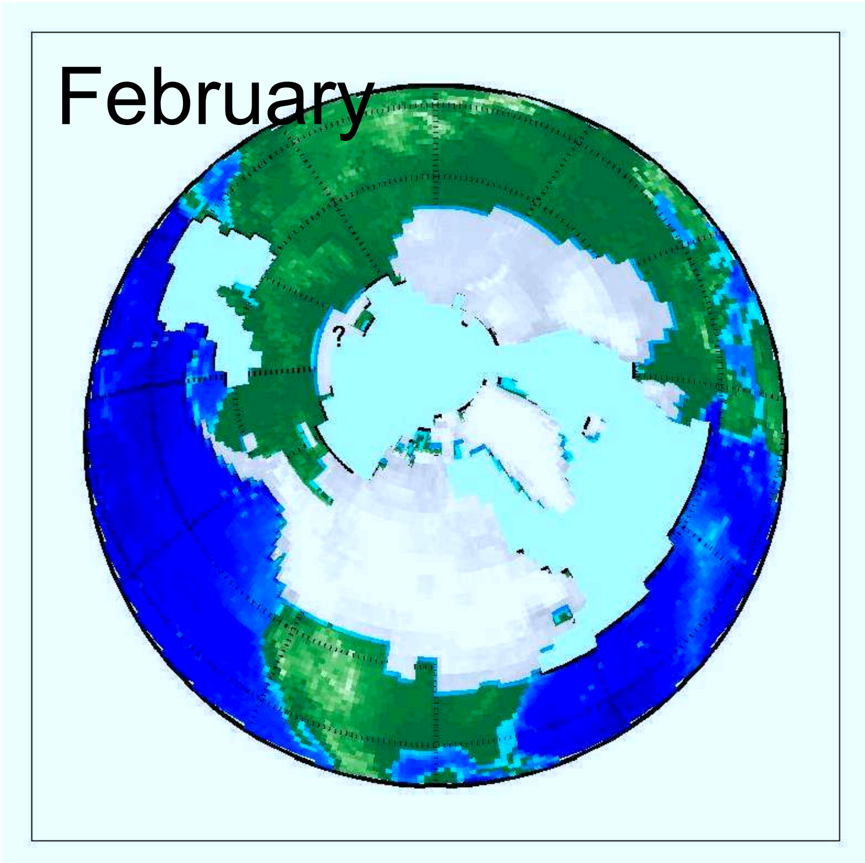
The Ice Ages

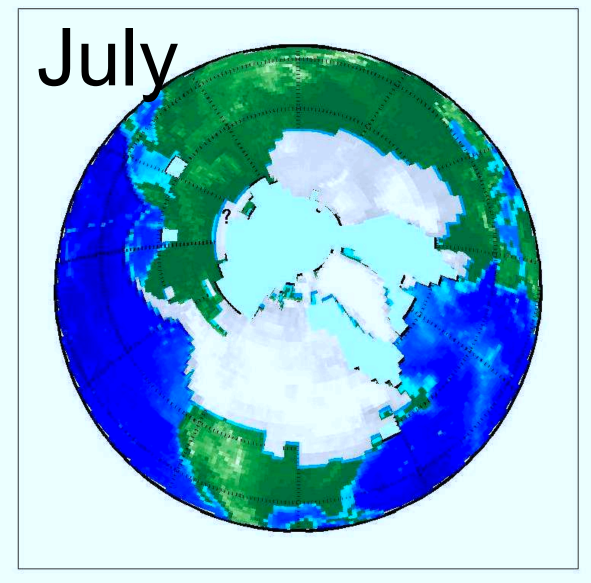
- The Ice Ages lasted 2.7 Myr BP to about 10,000 yrs ago

- Large Ice sheets covered Northwestern Europe and Northern North America
- Due to orbitally induced changes in northern hemisphere summer insolation
  – Ice volume changes are coordinated with CO_2 changes (shift of carbon between atmosphere and oceans)

What does an ice age look like?

- Reconstruction of land and sea ice 21,000 years ago

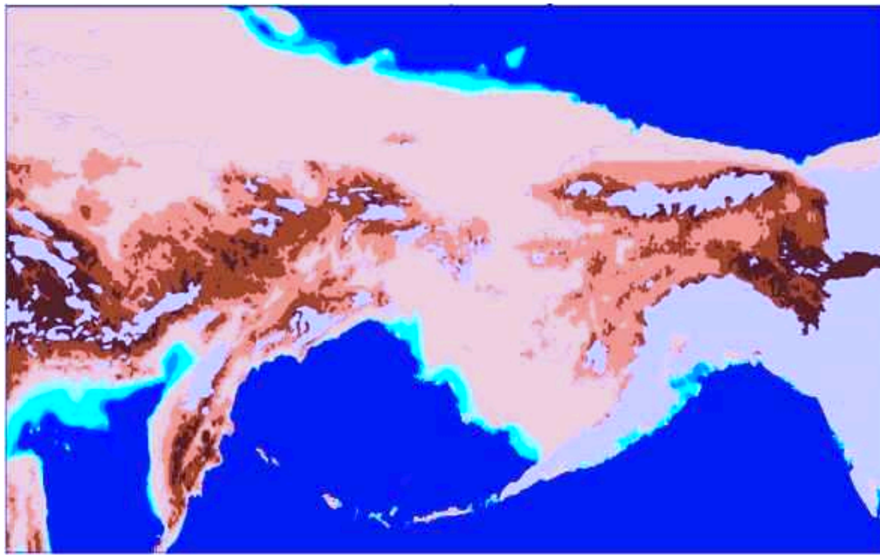




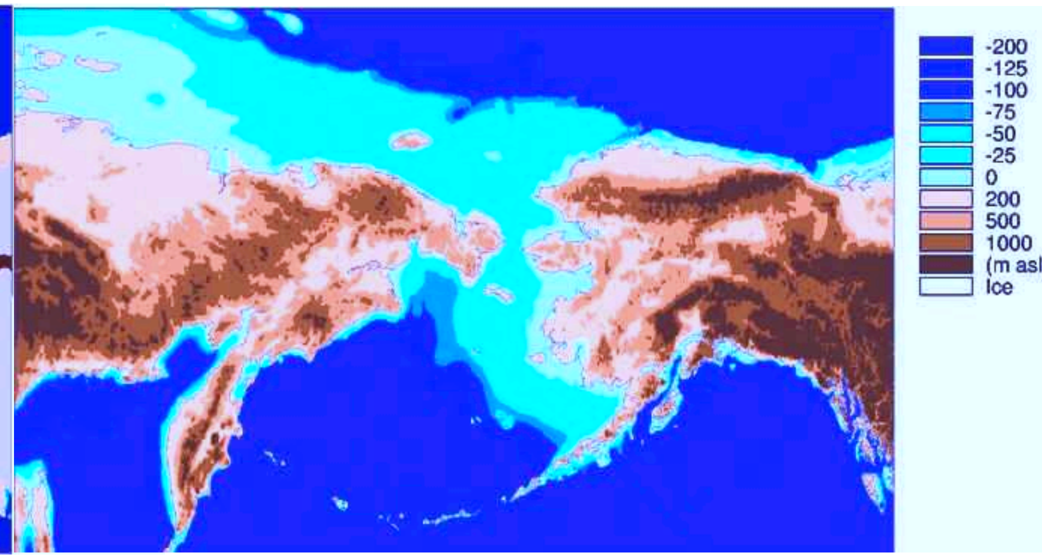
CLIMAP reconstruction

The last glacial maximum (LGM) occurred around 20,000 years ago.

Sea level was lower by ~120 m at the time of the LGM because of the storage of water in the continental ice sheets



20,000 ybp



today

The land bridge

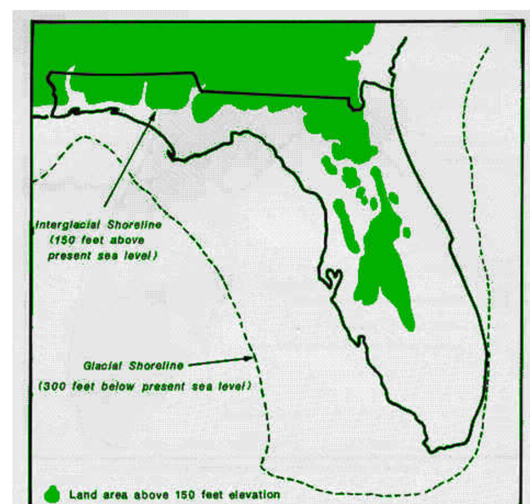


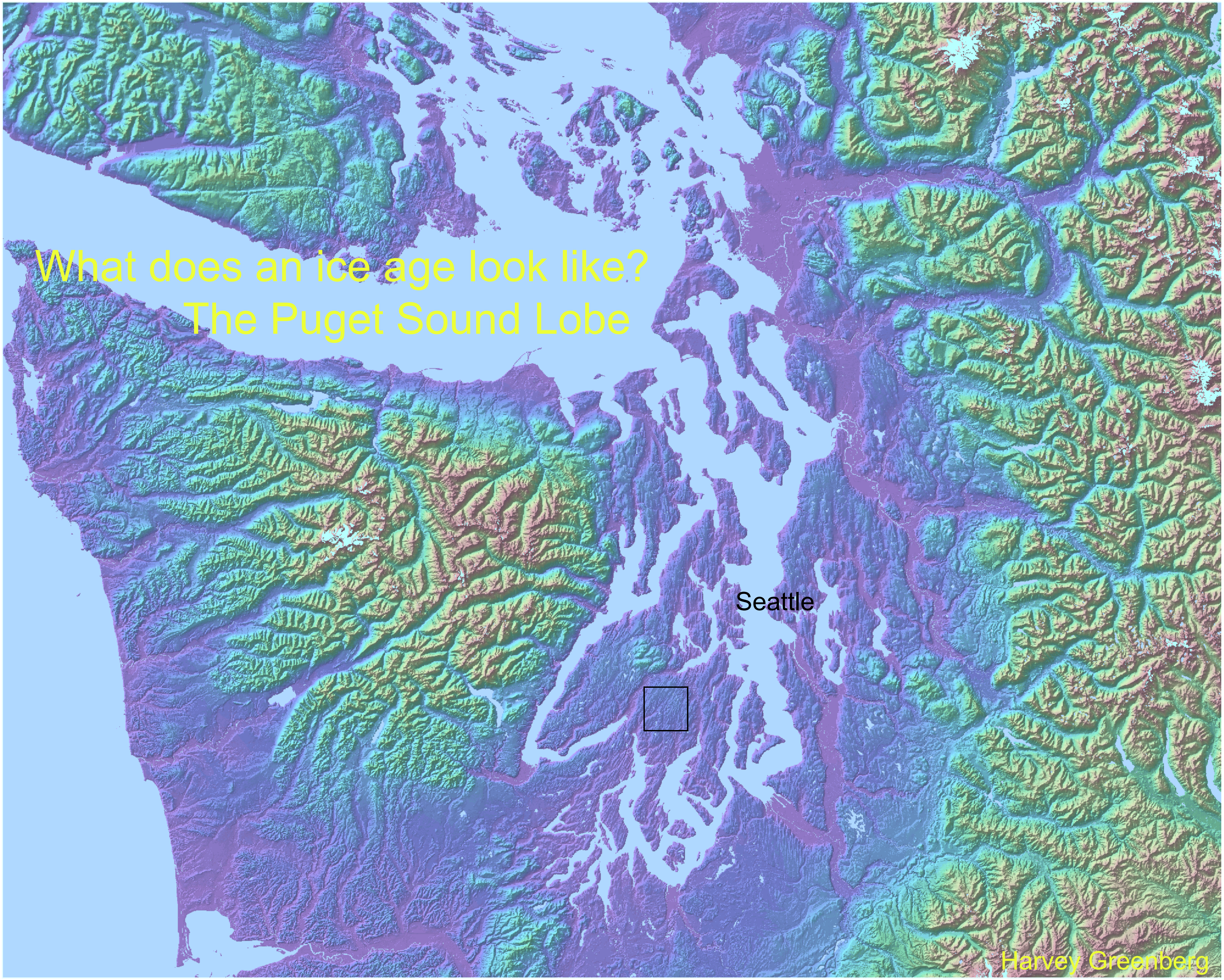
Figure 16. Pleistocene shorelines in Florida. Illustration by Frank R. Rupert.

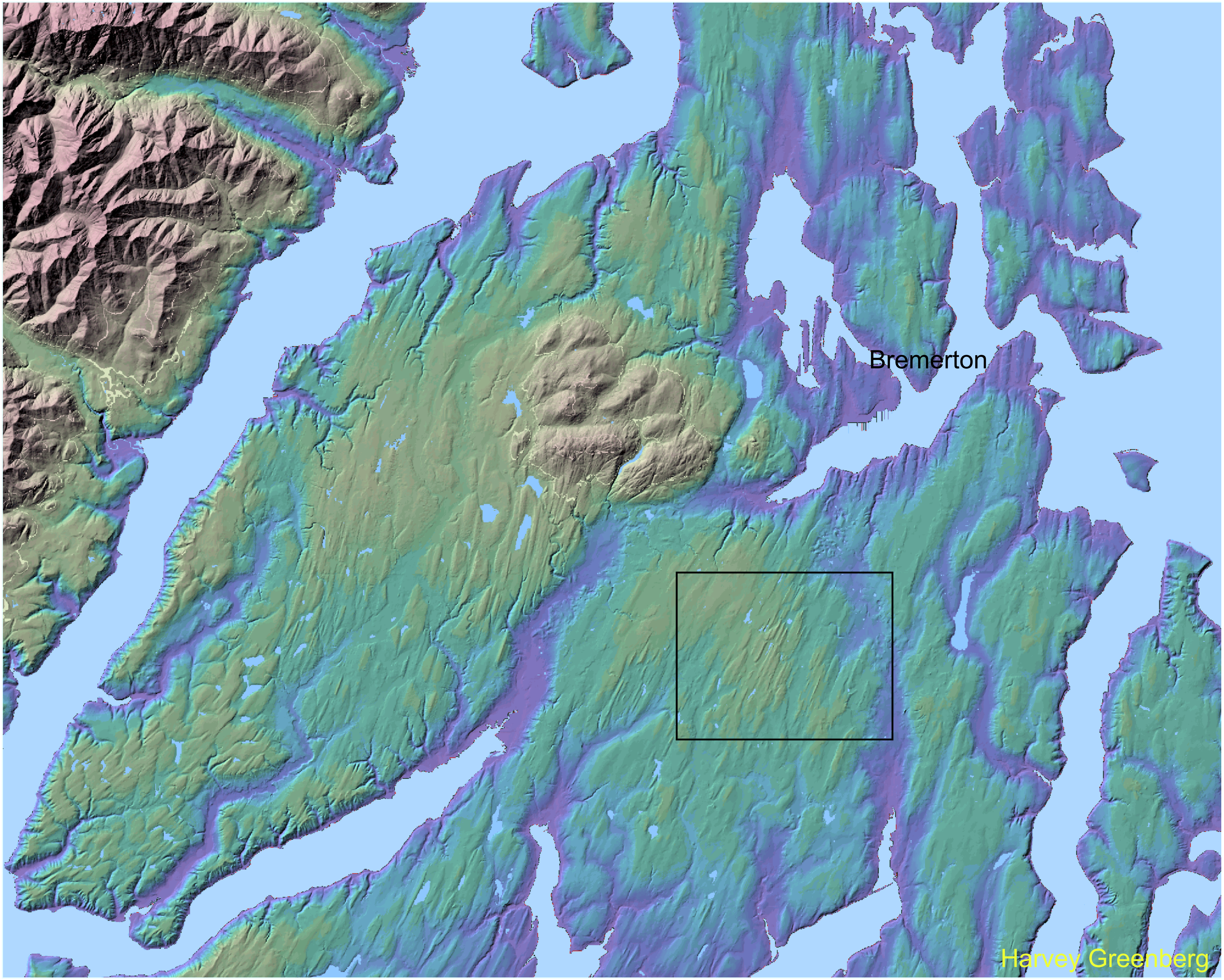
The home ice sheet ~20kbp

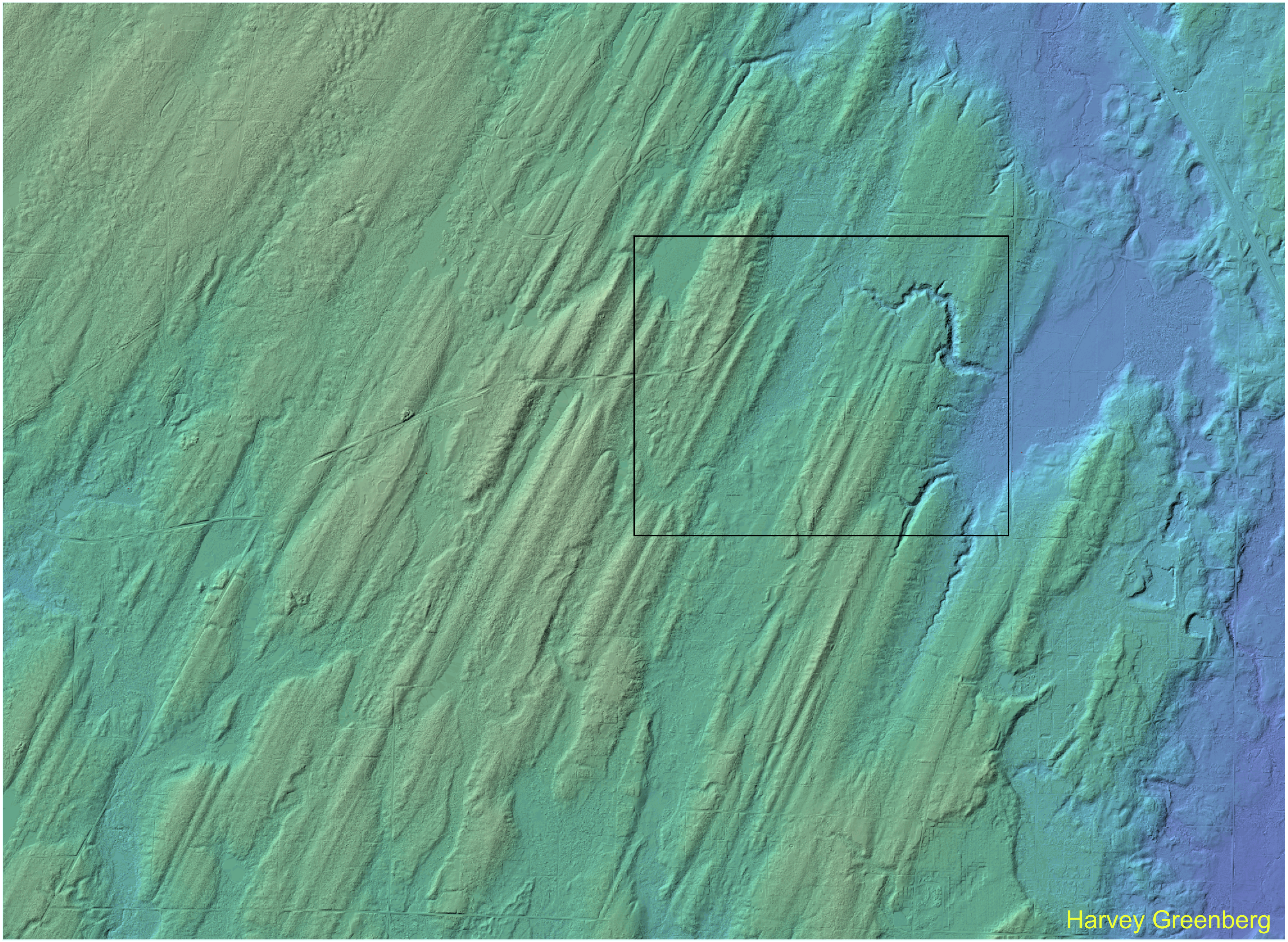
Cordilleran Ice Sheet

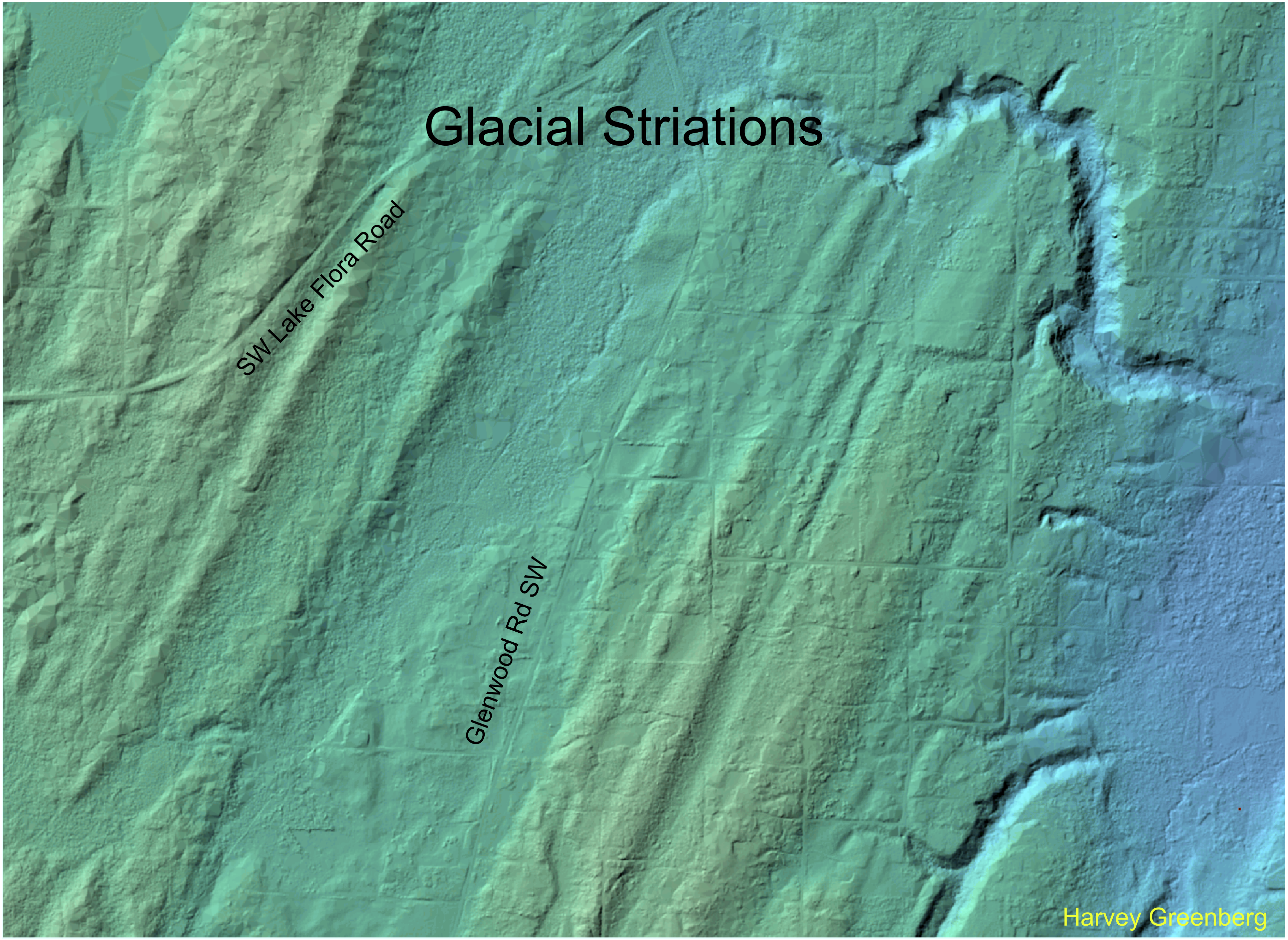
Lake Missoula

Spokane Floods (from Lake Missoula)

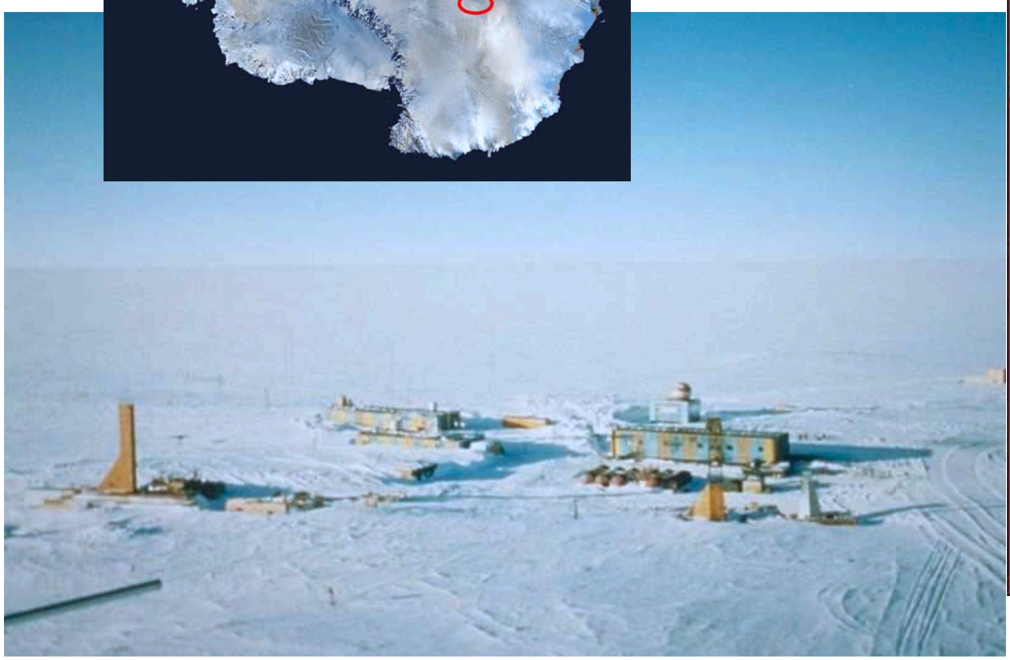

What does an ice age look like?
The Puget Sound Lobe
Seattle
Harvey Greenberg

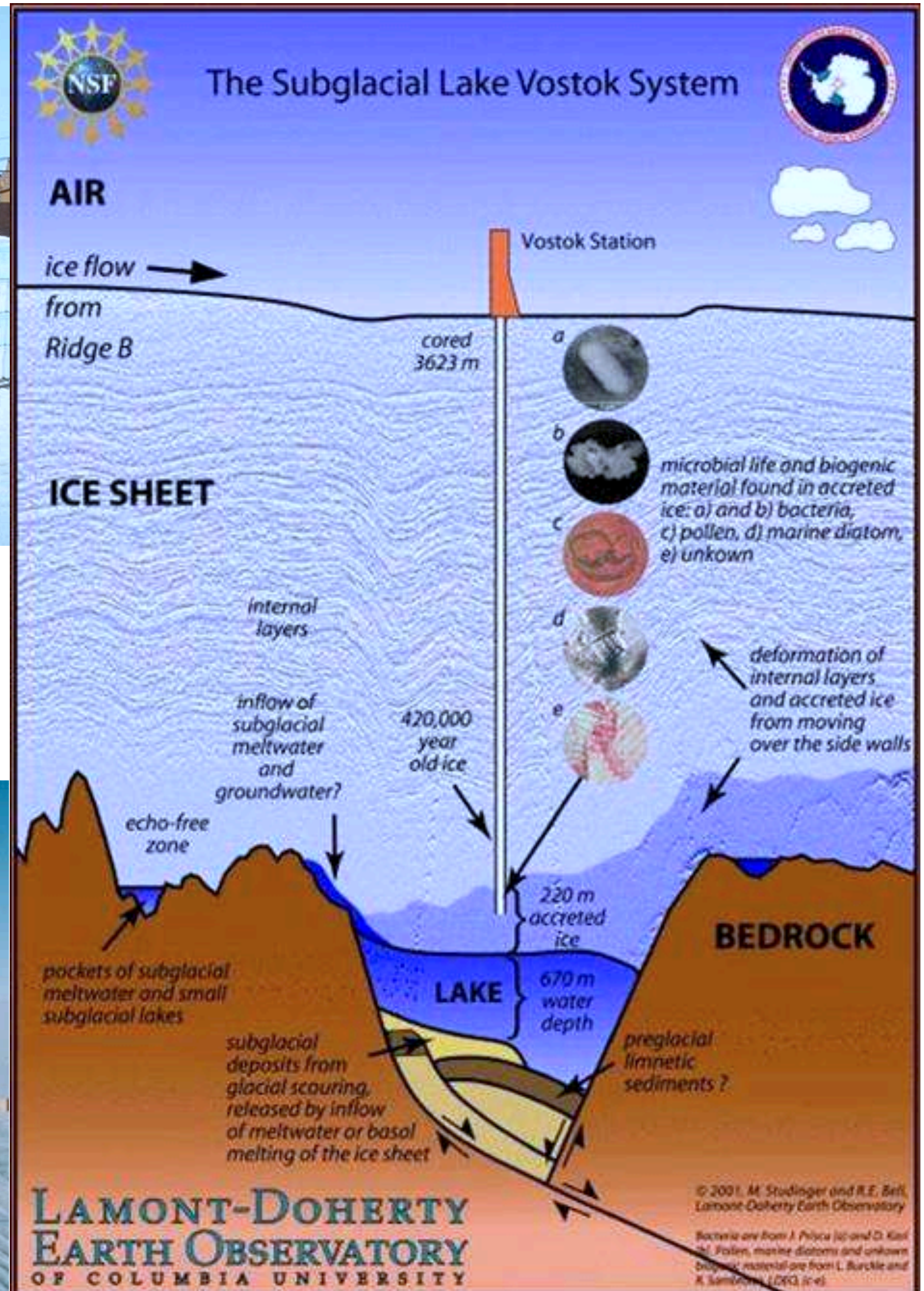

Bremerton
Harvey Greenberg


Harvey Greenberg

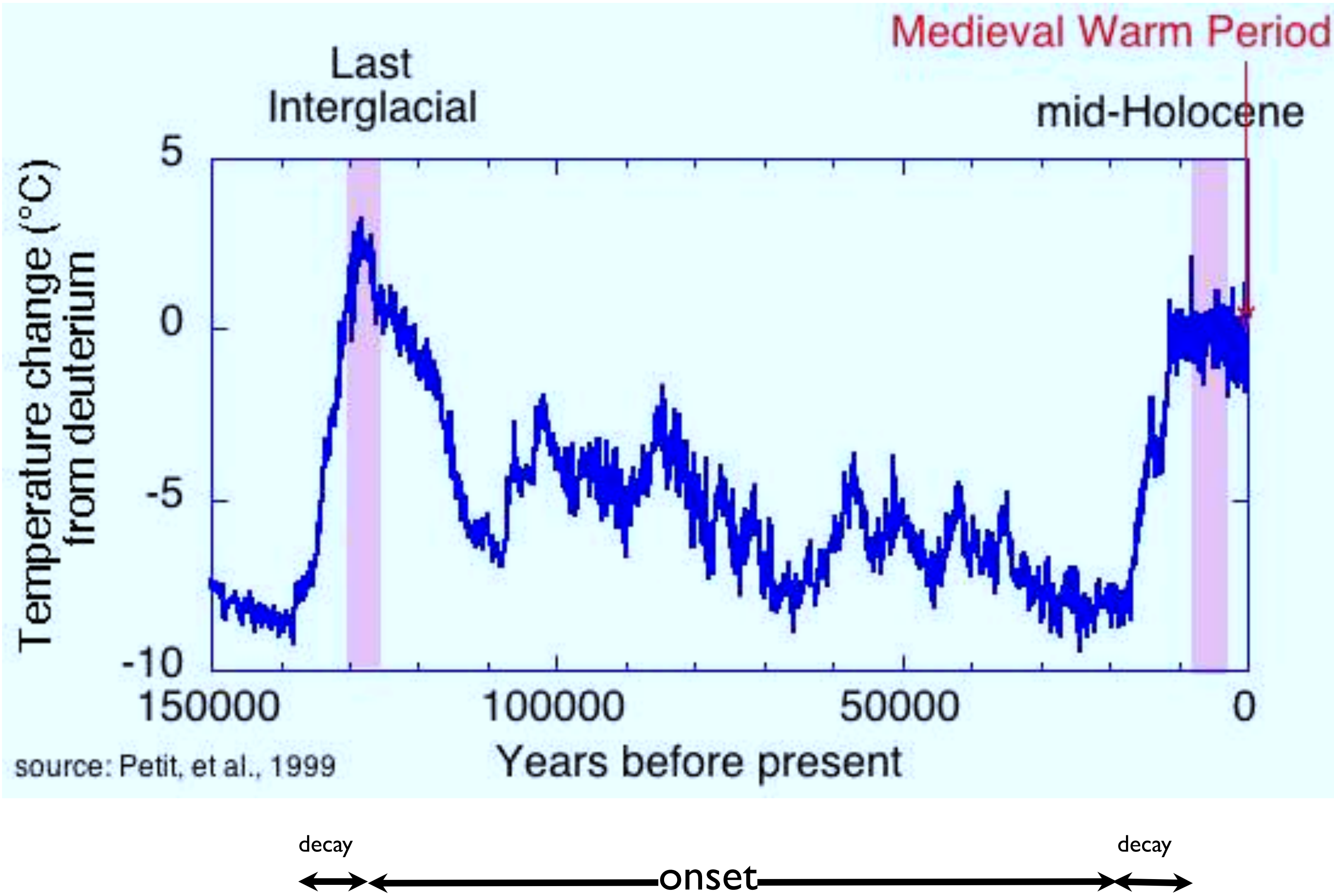

Glacial Striations
SW Lake Flora Road
Glenwood Rd SW
Harvey Greenberg

Vostok Station

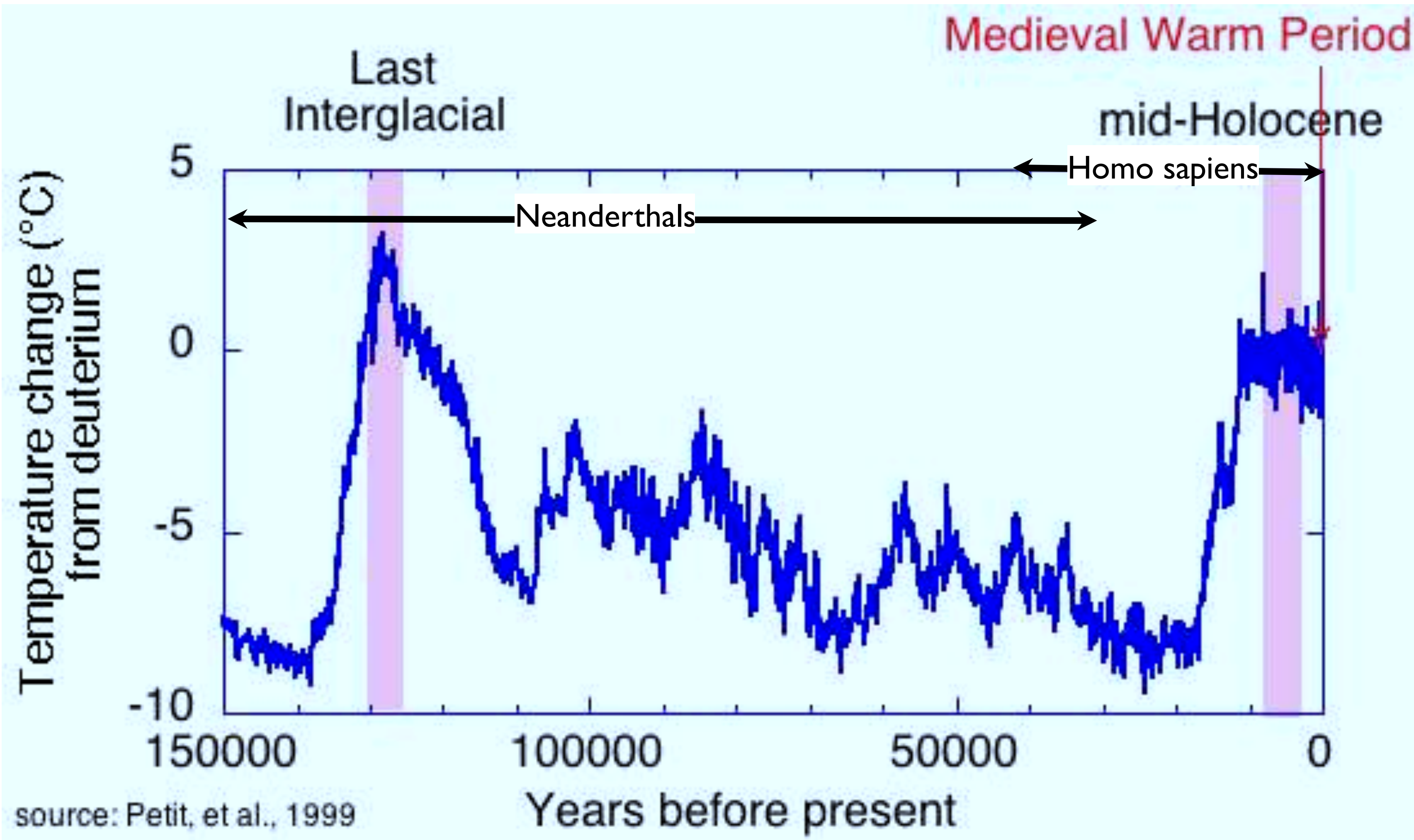




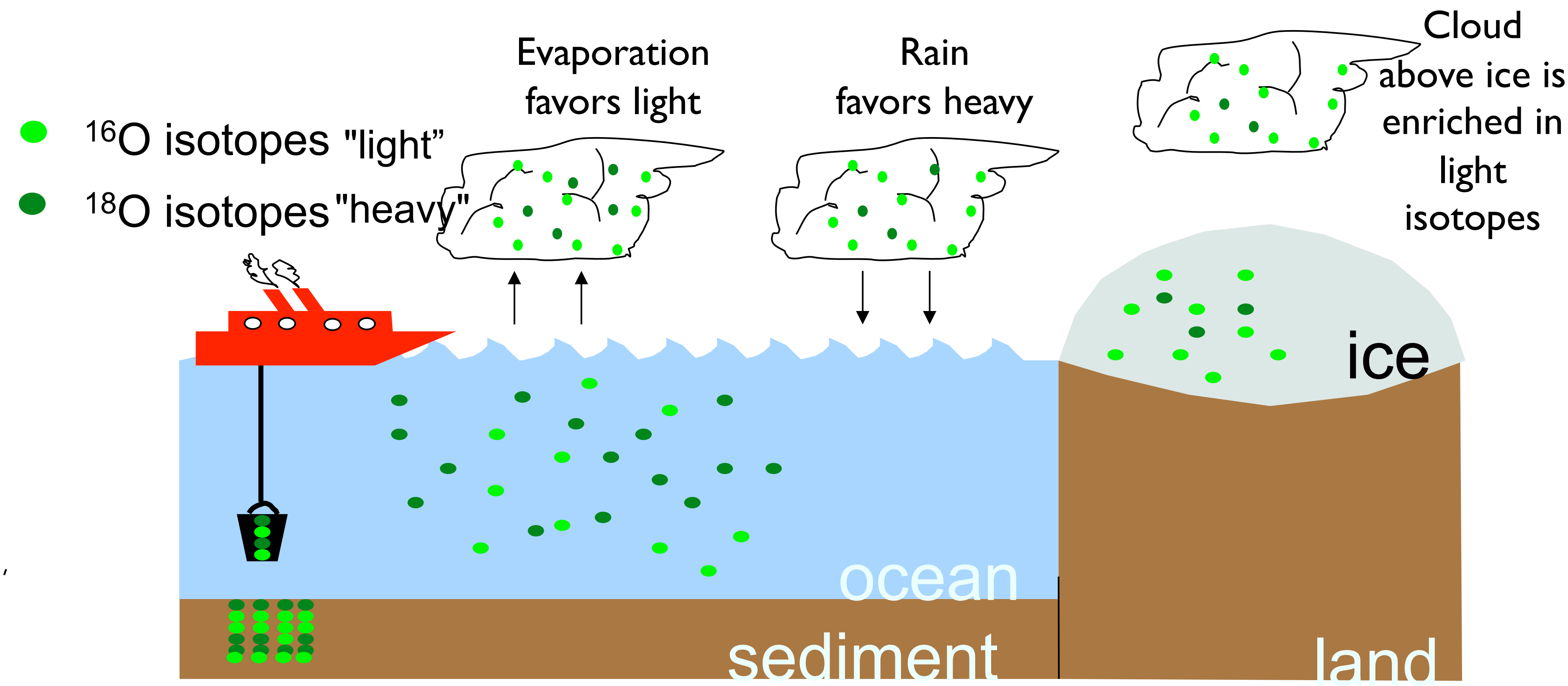
Glacial epochs have a slow onset and a rapid decay, suggesting that ice dynamics may play a role in the decay process. That’s one reason scientists are closely watching the behavior of the Greenland ice sheet



Anasazi ruins
Mesa Verde N.P.,
Colorado



Isotopic Evidence

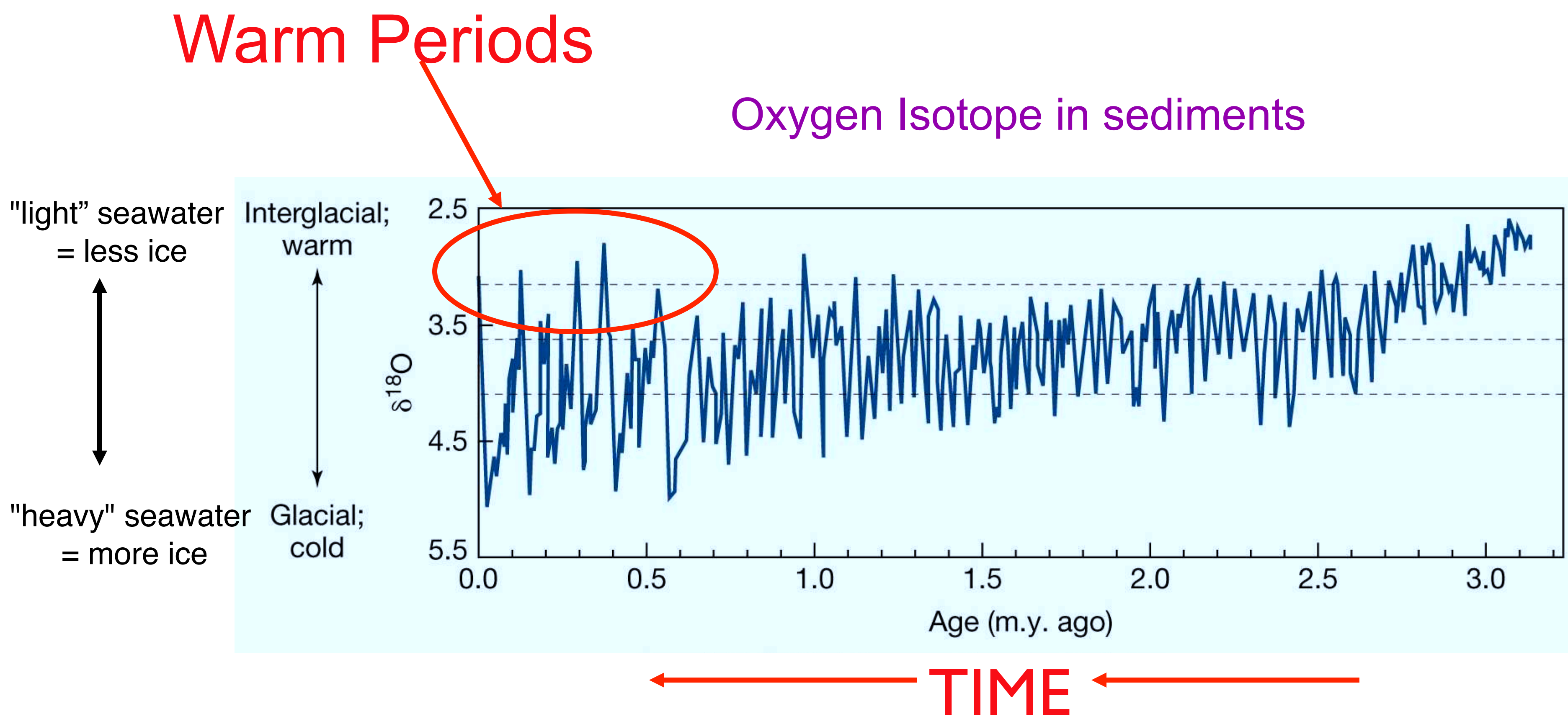


Two immensely valuable consequences:

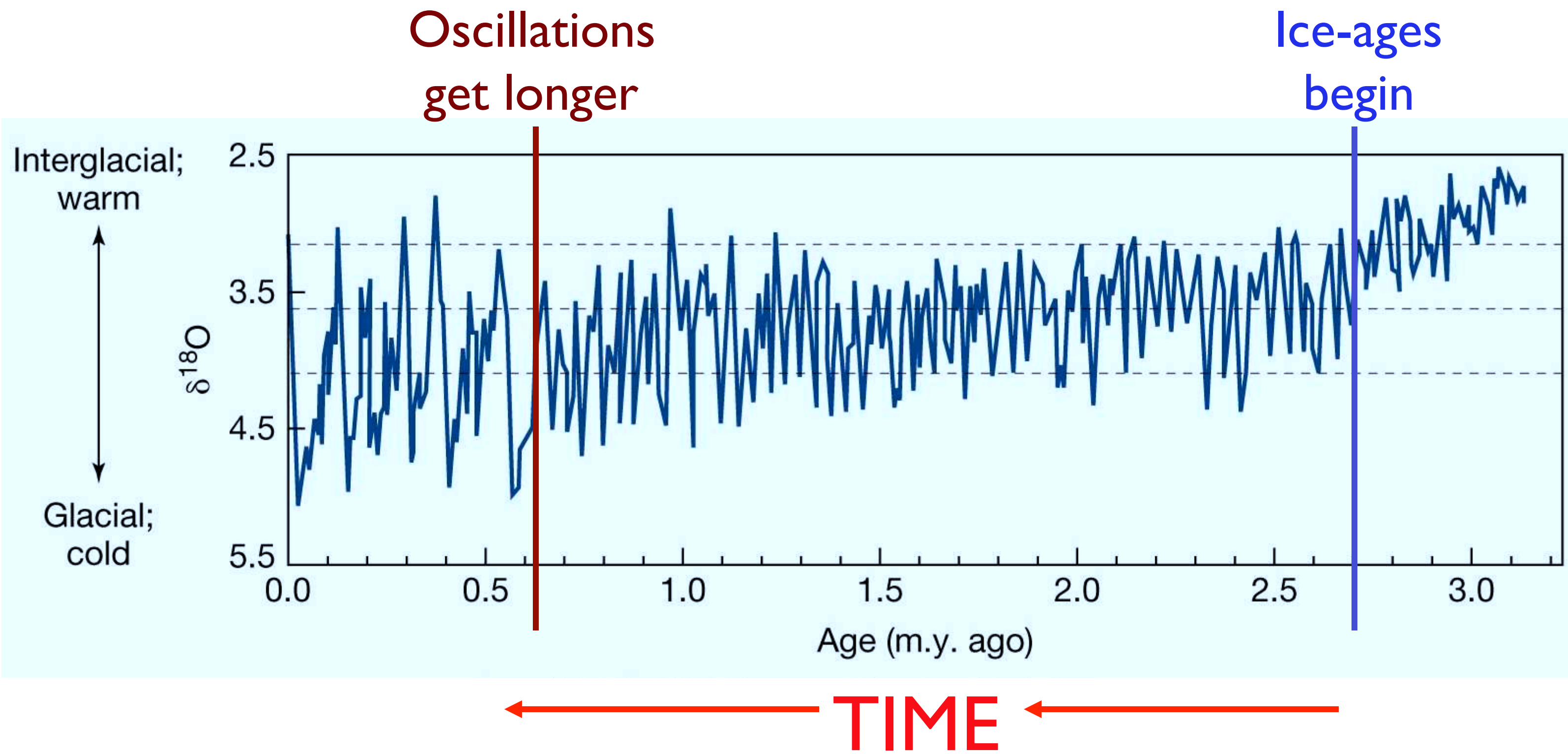
Isotopes in ocean sediments records glacial ice volume

Isotopes in ice-cores indicates local temperature

3 Million Year Record of Global Ice Volume



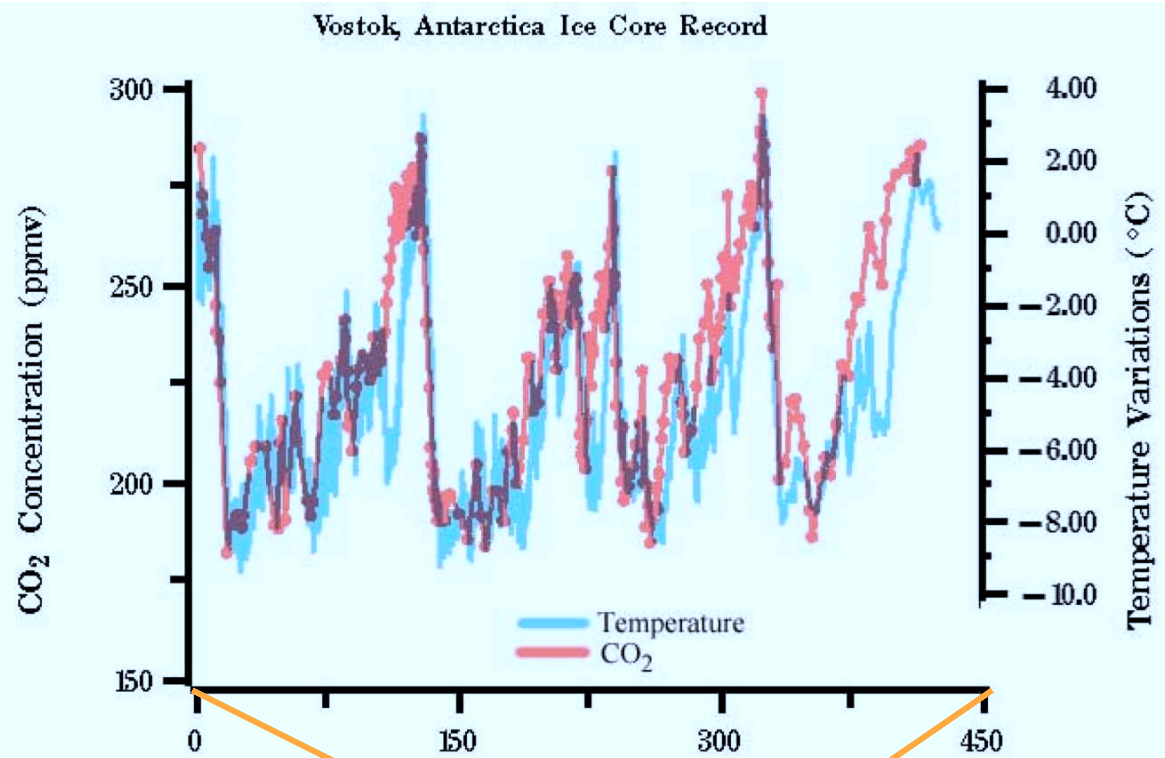
Kasting et al

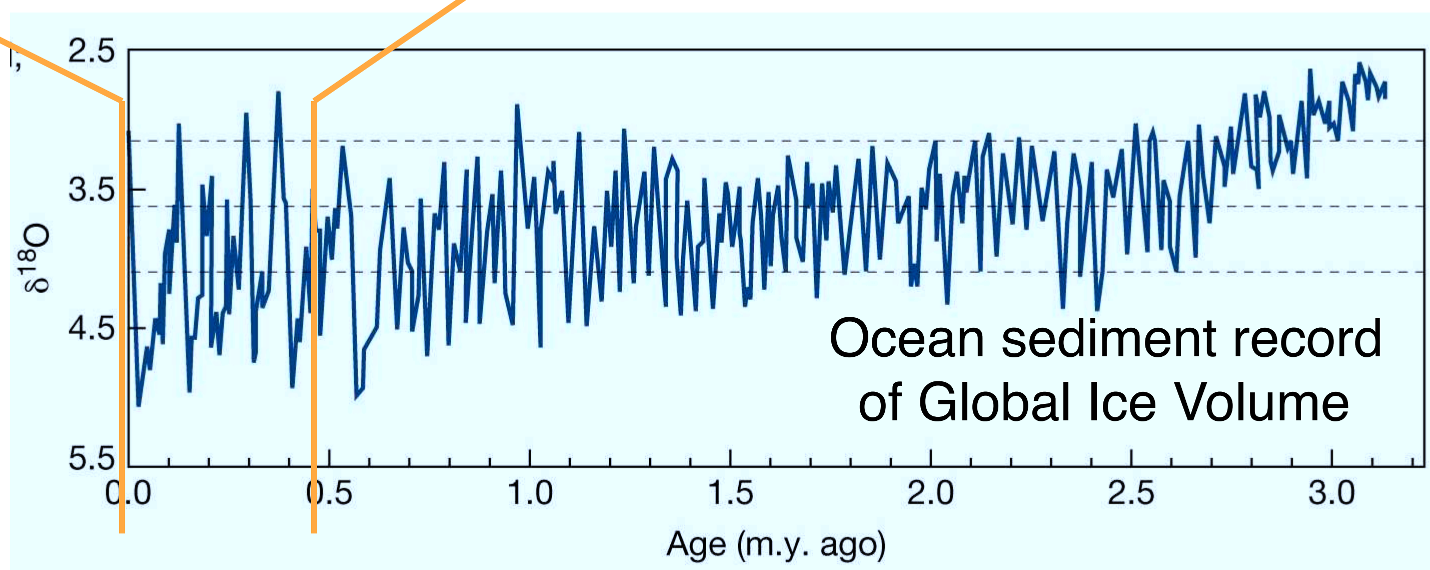


Question:

Was sea-level lower or higher than today during the three most prominent previous interglacial periods?

Kasting et al


Vostok, Antarctica Ice Core Record
300
250
200
150
CO_2 Concentration (ppmv)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.0
Temperature Variations (°C)
Temperature
CO_2
0
150
300
450


2.5
3.5
4.5
5.5
$\delta^{18}O$
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Age (m.y. ago)
Ocean sediment record
of Global Ice Volume