Mon Nov 10

Announcements:

9.0 earthquake in Puget Sound! (in 1700)

TALK TODAY: Monday 10 Nov **3:30 310 ATG**

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Prof Lyatt Jaegle, UW, "Space-based observations of
biomass-burning emissions of NOx" [a pollutant gas]
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Where we're going:

This week:

KKC Chaps 8,9 (selected) and Snowball Earth article (web)

Solid Earth Circulation (wrap-up last week)

Ancient Climates (or "History of Planet Earth in 3 Easy Lessons")

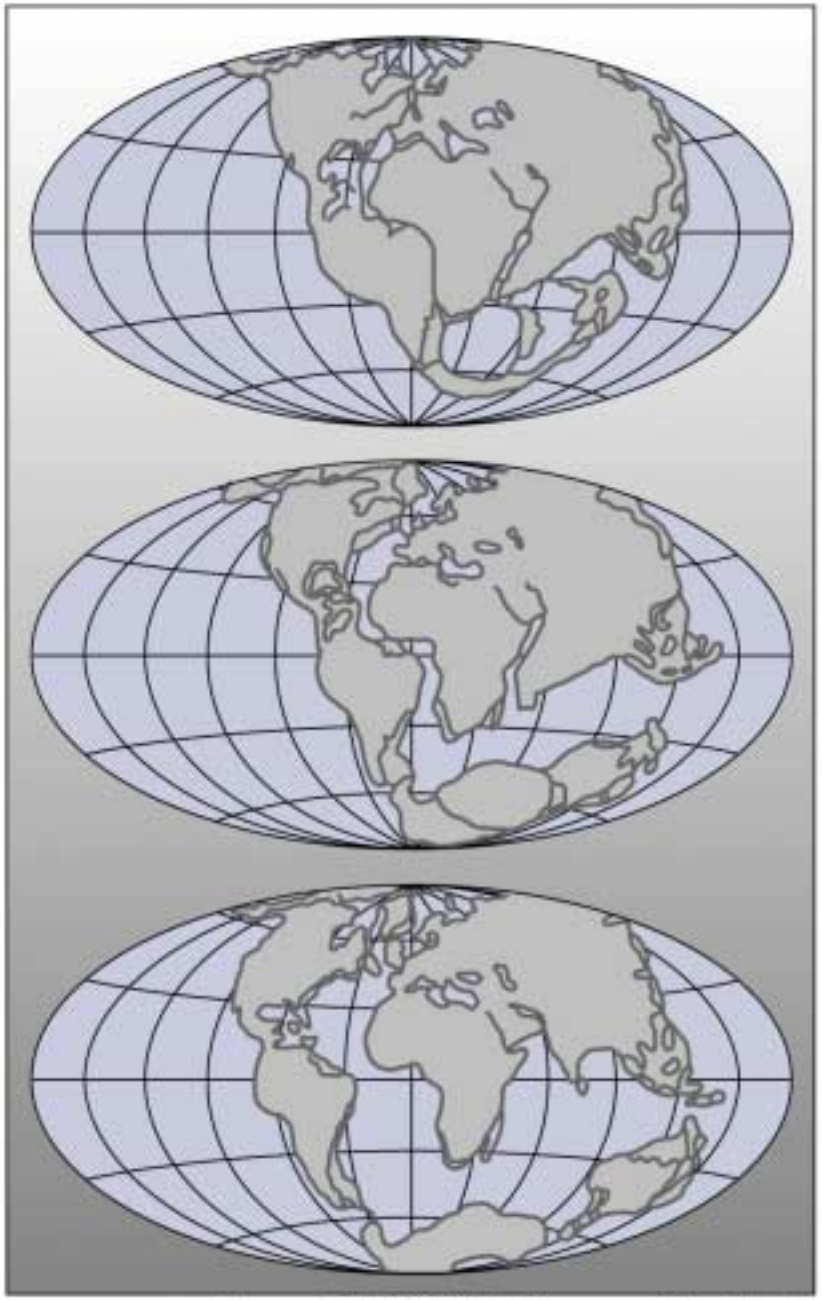
Tues: HOLIDAY (free talk by veteran in Kane 120, 7pm)

Wed: HW#4 DUE

Fri: *review*, *tutorial*

but first, some first-grade wisdom...

Continental drift: Fig 6-1



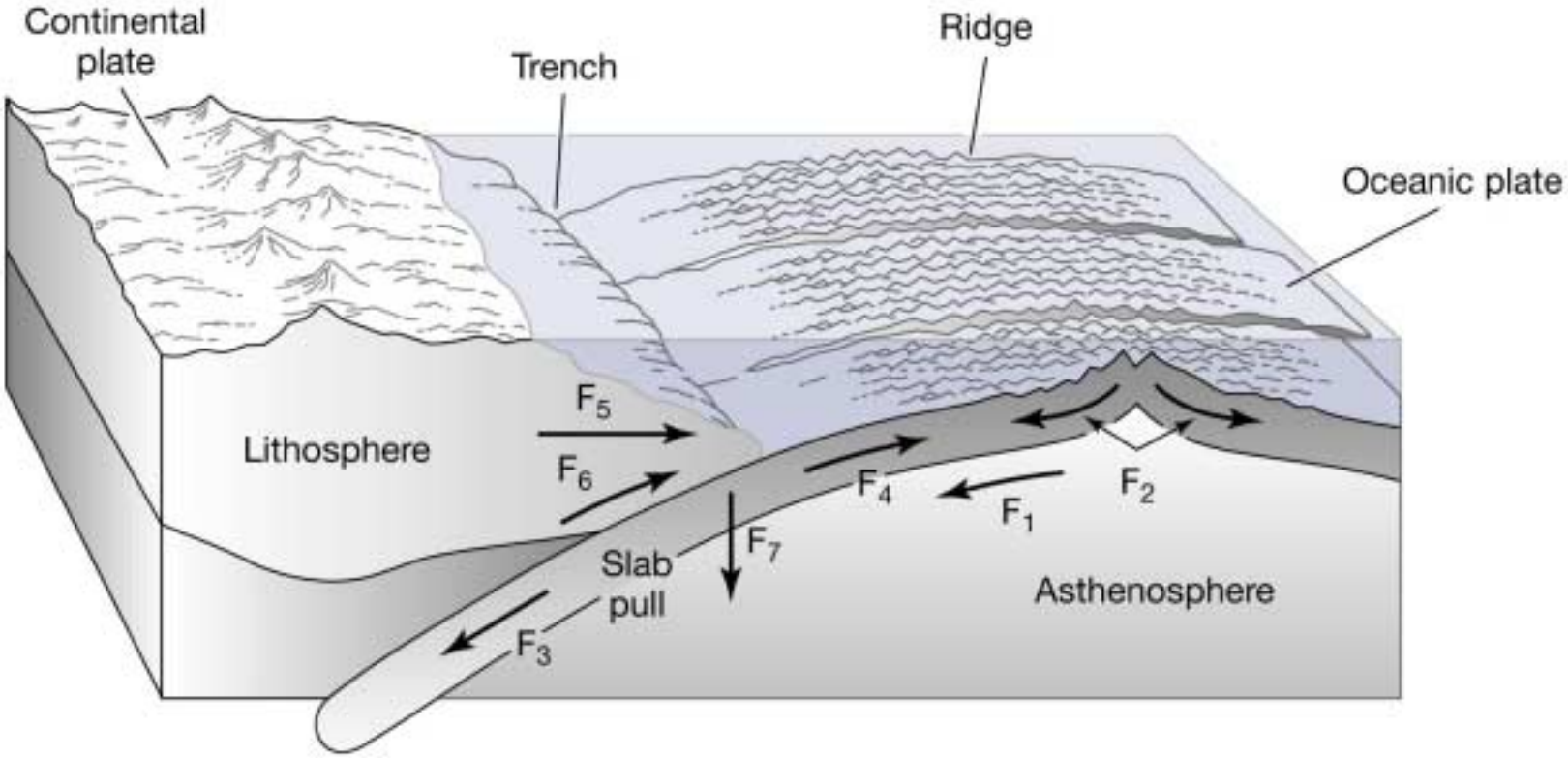
Late Carboniferous
(about 300 million
years ago)

Eocene
(about 50 million
years ago)

Pleistocene Glacial
(about 1 million
years ago)

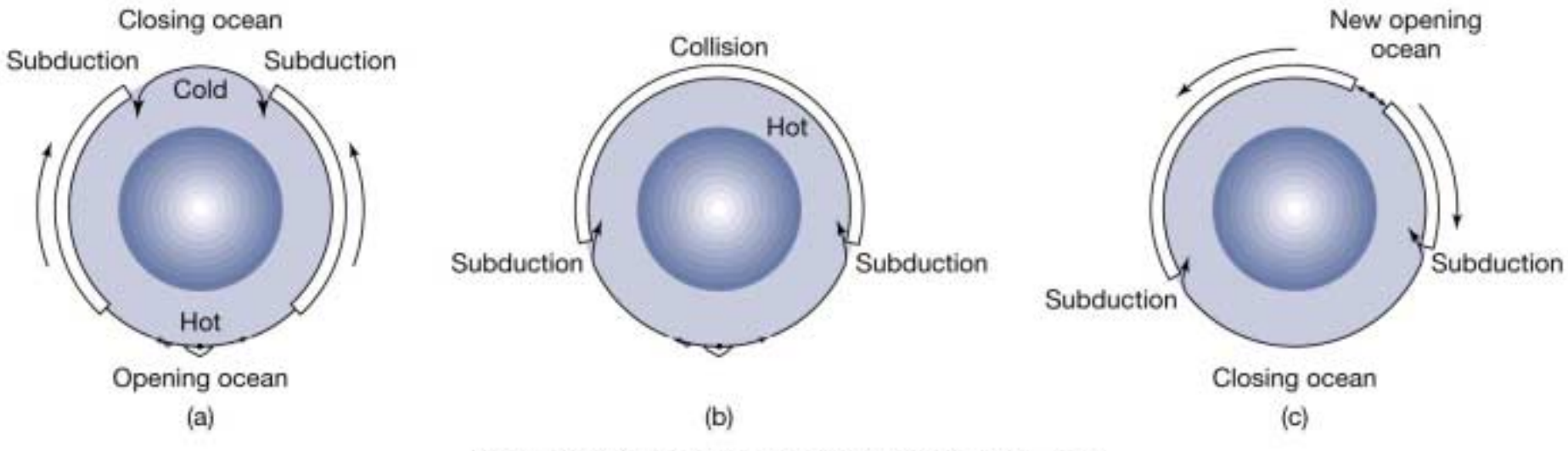
Plate tectonics: Fig 6-21

• the third of our three BIG pumps
• driven by circulations in the upper mantle; ultimately, by radioactive decay, releasing heat within the Earth's interior
• recycles key substances like mineralized carbon



Wilson Cycle: Fig 6-27

- continents group together then spread apart
- timescale is ~500 million years
- major climatic consequences (location of continents affects atmos/ocean currents; ice-albedo feedback, etc)



Circulation Summary

Three BIG Pumps

- Atmosphere/Surface Ocean
  - distributes heat poleward
  - cause of regional and seasonal climates
  - mixing timescale is ~1 week
- Thermo-haline circulation (THC)
  - mixes deep ocean
  - timescale of mixing is about 1000 years
  - may shut on and off as conditions change in N. Atlantic
  - possible "trigger" for global climate
- Solid Earth circulation: Wilson Cycle
  - continents group and then spread
  - cycle timescale is ~500 million years
  - major climatic effects (e.g. sets boundaries for the other two circulations)
  - mixes key elements like carbon and recycles them from rocks back to the atmosphere

Ancient Climates: Readings
(info on website)

Introduction/Overview	8:152-153,	Fig 8-1
Formation of Early Atmosphere	8:158-159,	Fig 8-7
Faint Young Sun paradox	8:159-161,	Figs 8-8, 8-9
Long Term Climate Record	8:161-164,	Fig 8-10, 8-11
Low Latitude Glaciation BOX	8:165	
"Snowball Earth" article	available on web	
Warm Mesozoic Era	8:167-169,	Fig 8-15
Cooling During Cenozoic Era	8:169-170,	Fig 8-17
Modern Controls on Atmos. O2	9:188-189,	Fig 9-17

Ancient Climates: Stories

Paleoclimate record

fossils, clues and mysteries

Grand Sweep of Earth History

4.6 billion years (so far)

marker events (to memorize)

Faint Young Sun paradox

good illustration of scientific method

Rise of Atmospheric Oxygen

greatest global pollution event ever

but made life on land possible

oxygen and fire

Snowball Earth >>>read from article

something new in ancient history

Failure of planetary life support

Venus and Mars

Snowball Earth

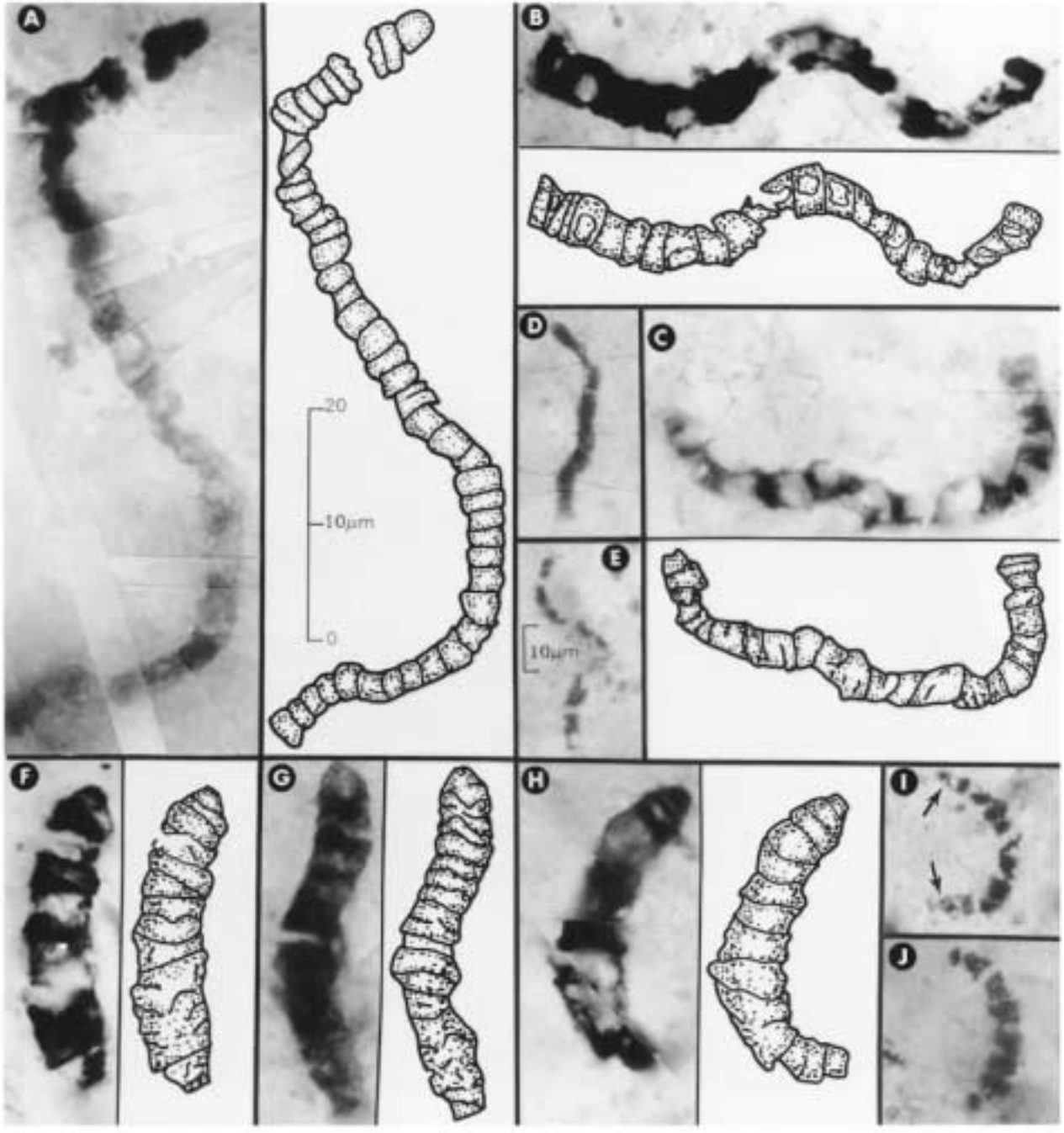
asteroids

Fig 9-5: microfossils, 3.5 billion yr old, Australia

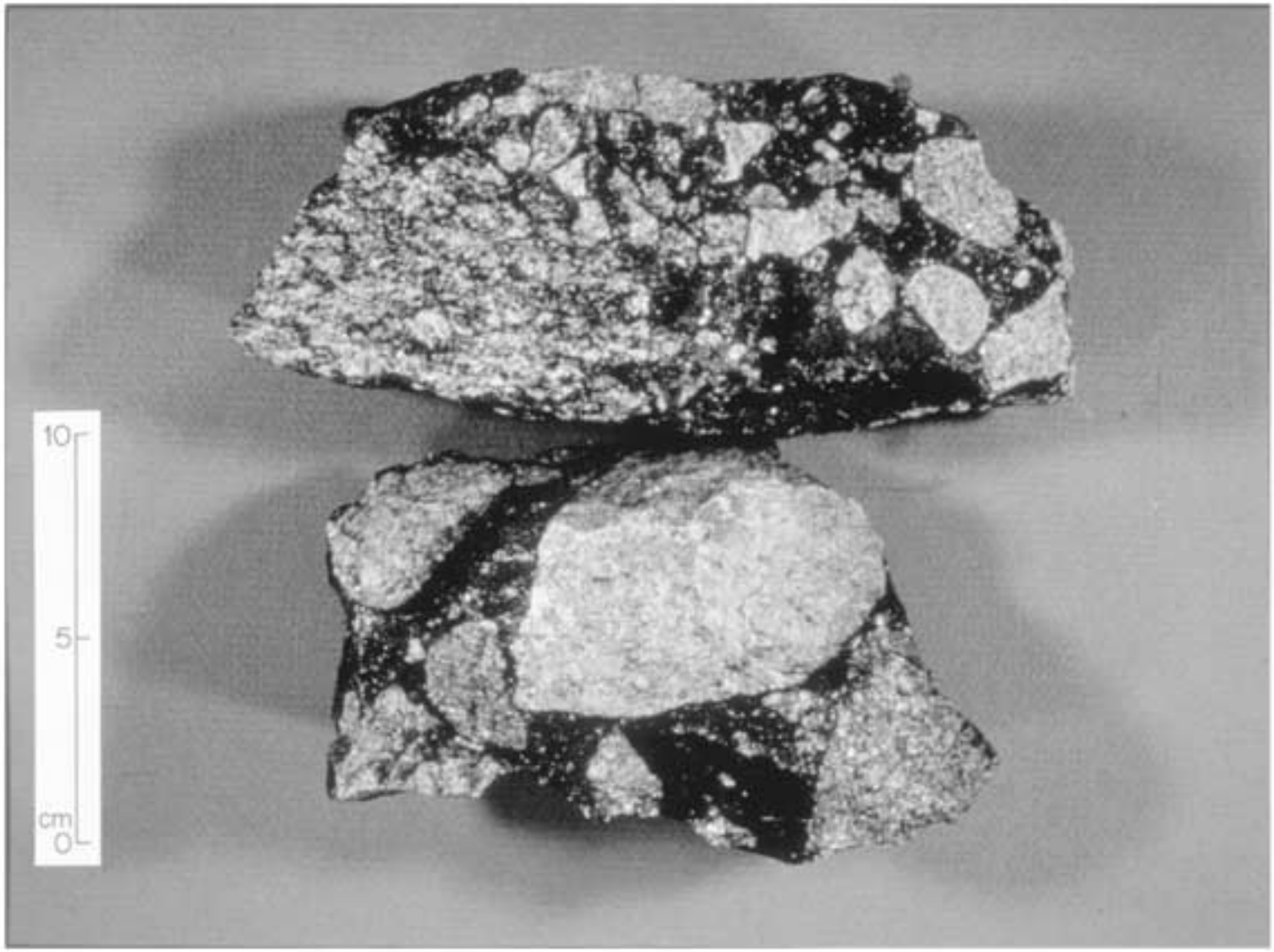
Origin of life:
~4 billion yrs ago

prokaryote (bacteria):
single-celled organisms
with no cell nucleus
- only form of life for most of Earth history
- still dominates

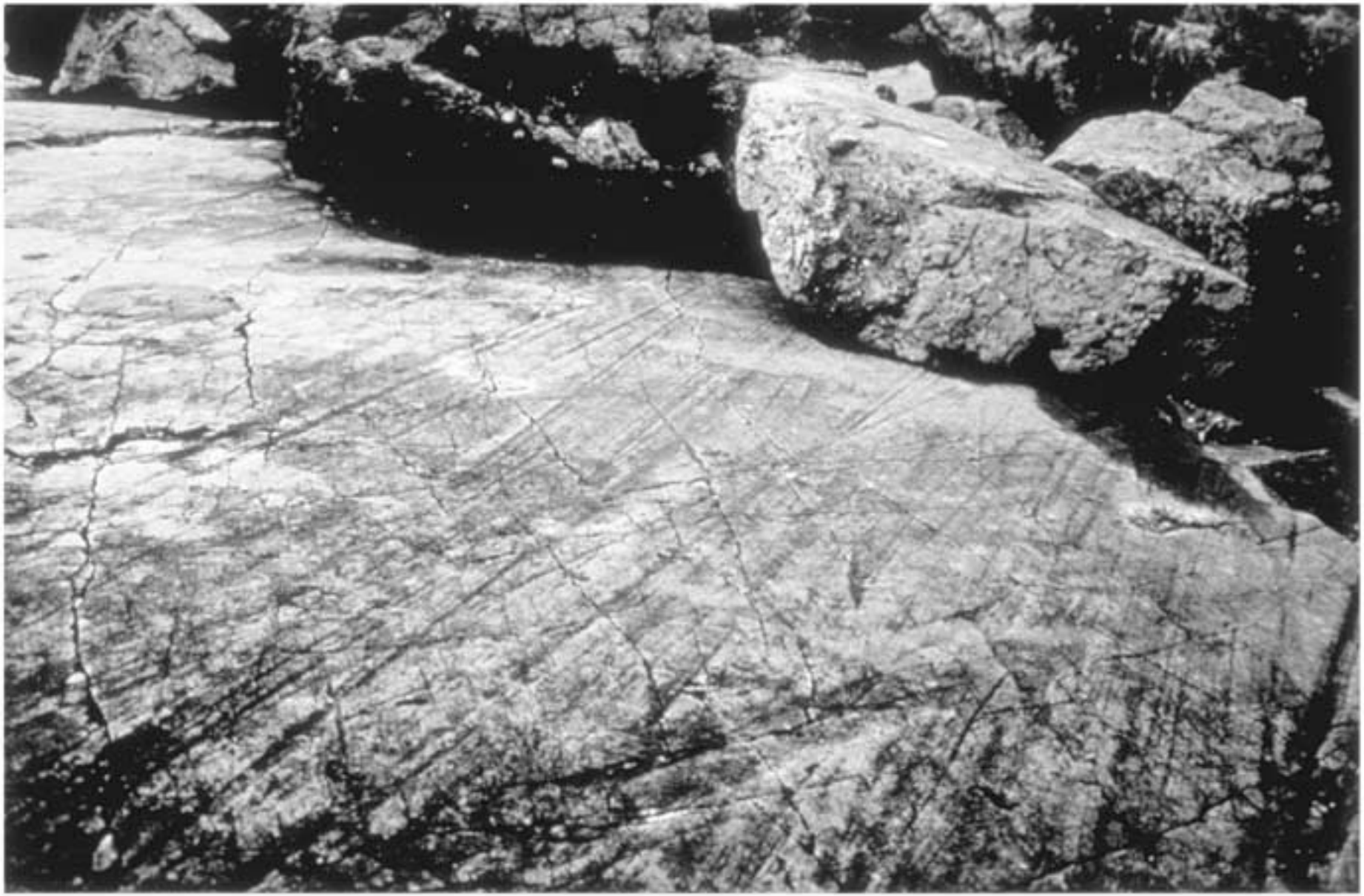
eukaryote:
organism whose cells
have a nucleus
- includes all multicellular organisms
- came much later



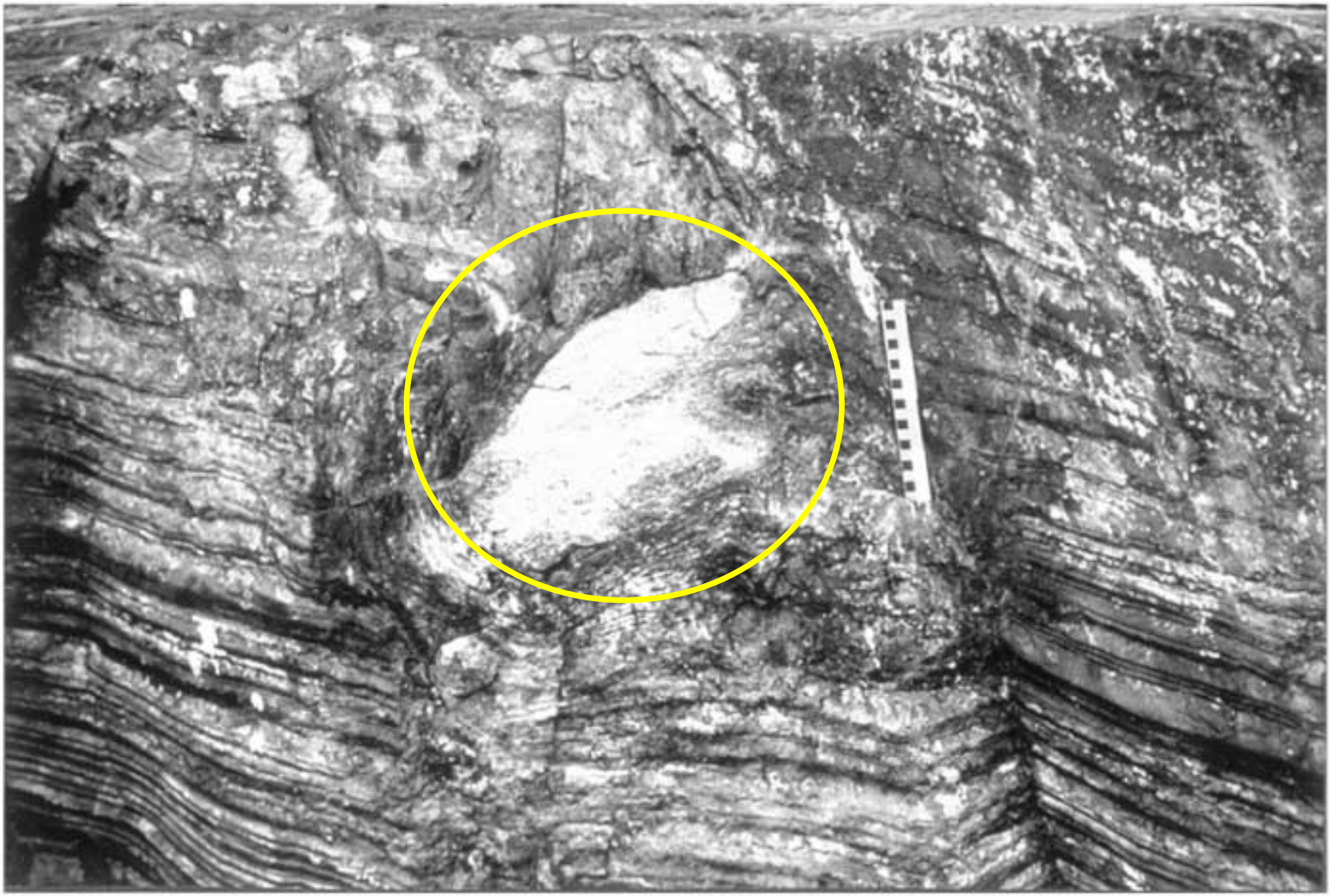
Evidence of glaciations: tillite, 2.4 billion yrs old, Fig 8-10a



Evidence of glaciations: striations, 650 million yr old, Fig 8-10b



Evidence of glaciations: dropstone, Fig 8-10c

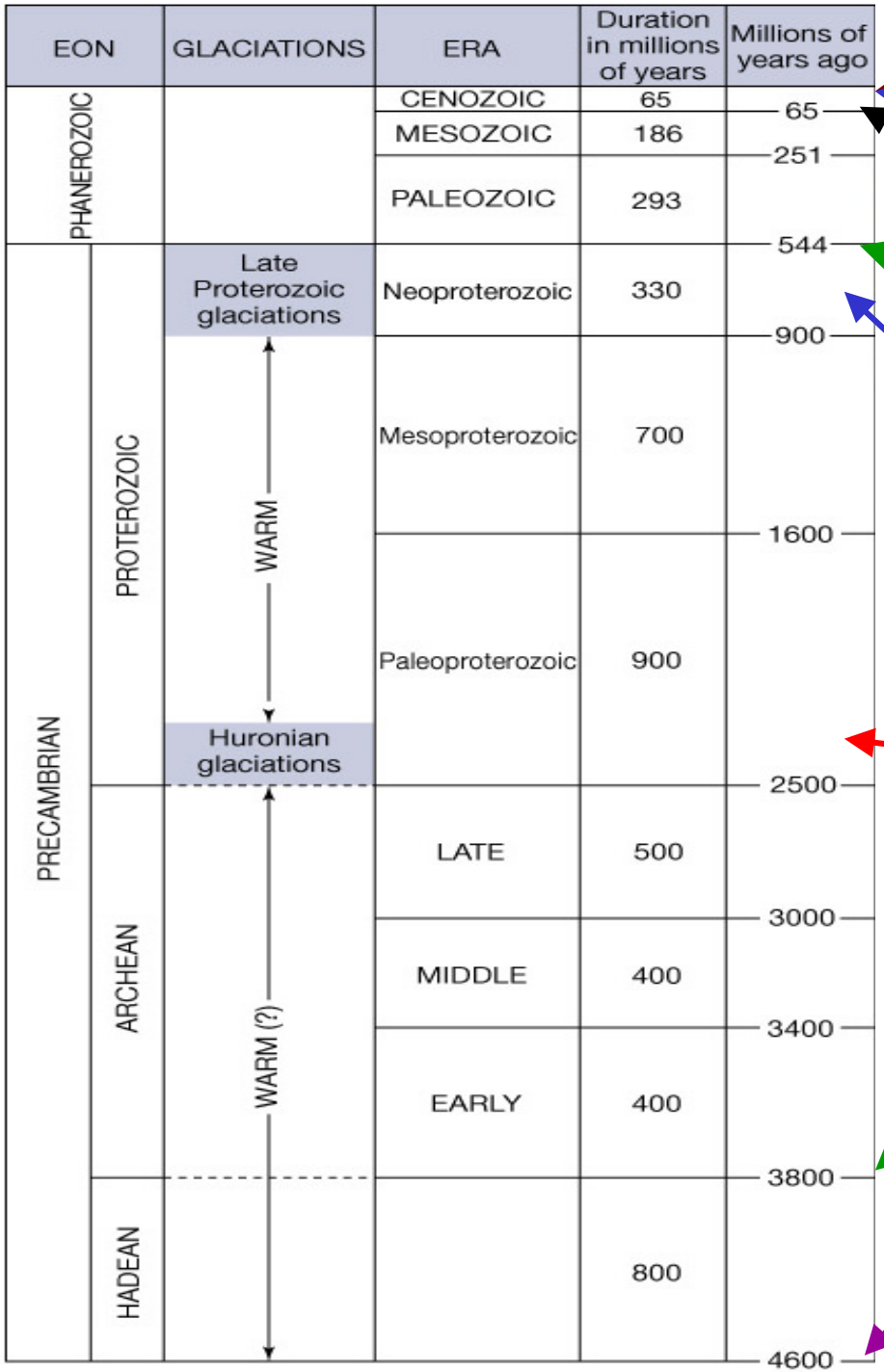


Wed Nov 12

Announcements:
- grades on web
- HW#4 due today; HW#5 due next thursday
- Tad gone Tues-Thurs next week

Today:
- marker events in Earth history
- Faint Young Sun paradox

but first, tribute to a life of self-sacrifice...



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)

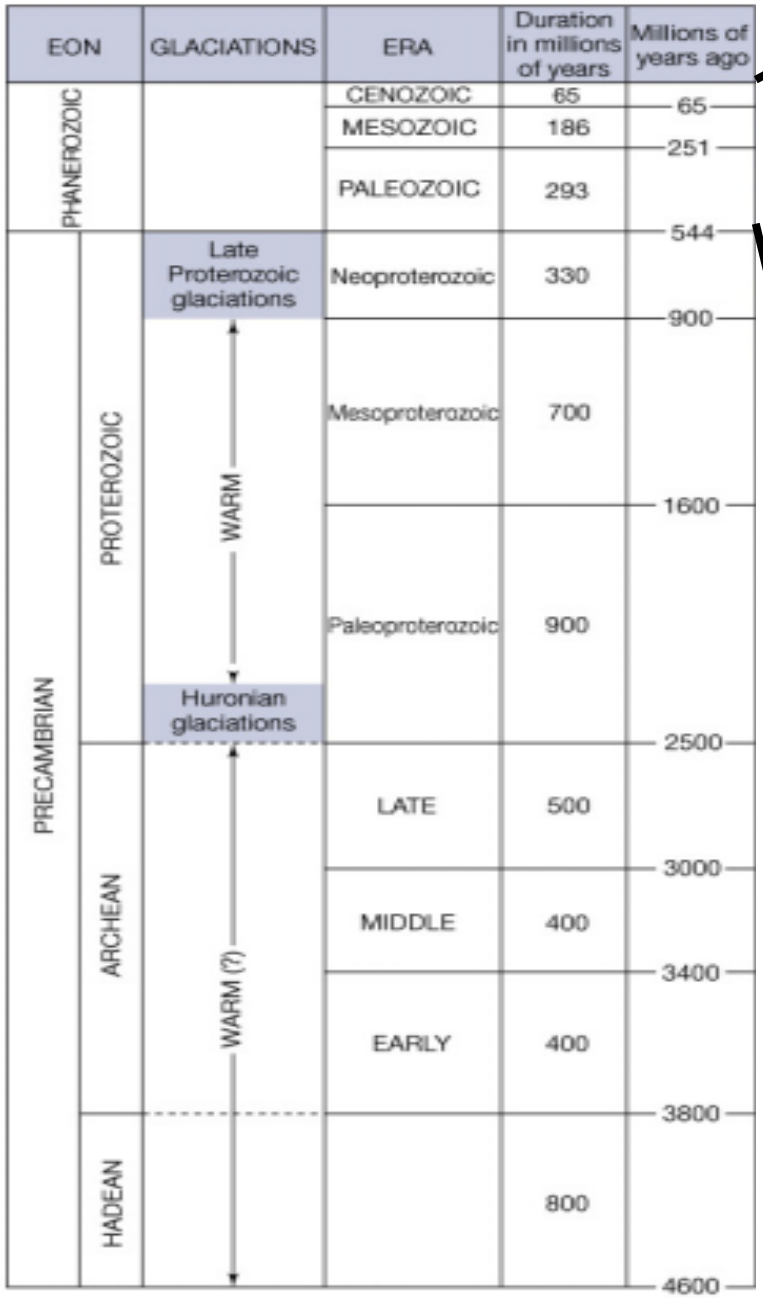
life! (prokaryotic bacteria)

formation of Earth

Earth is unfathomably old
most of Earth history is very alien

Geological Time: Fig 8-11

Geological Time: Fig 8-11



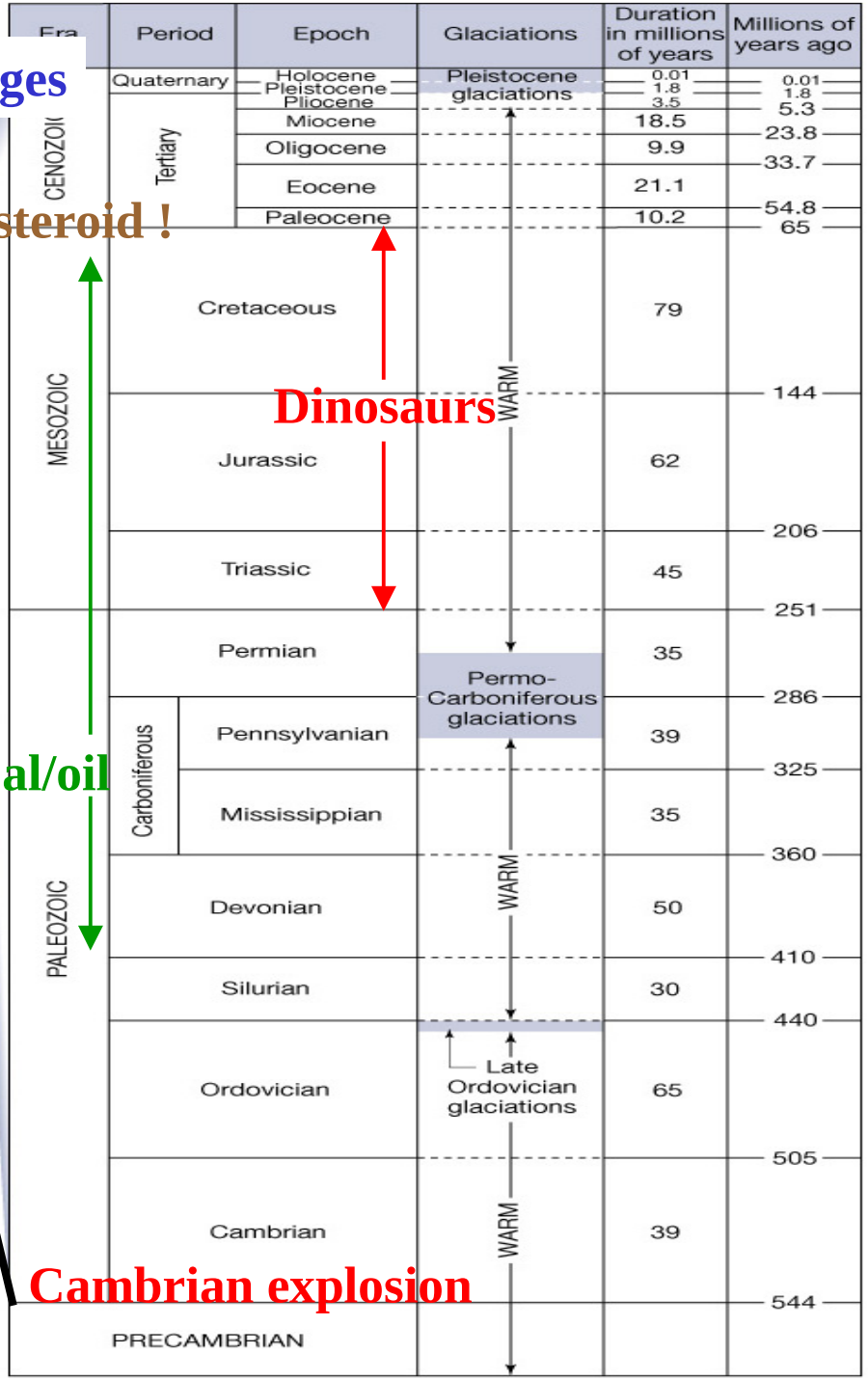
Ice-ages

asteroid !

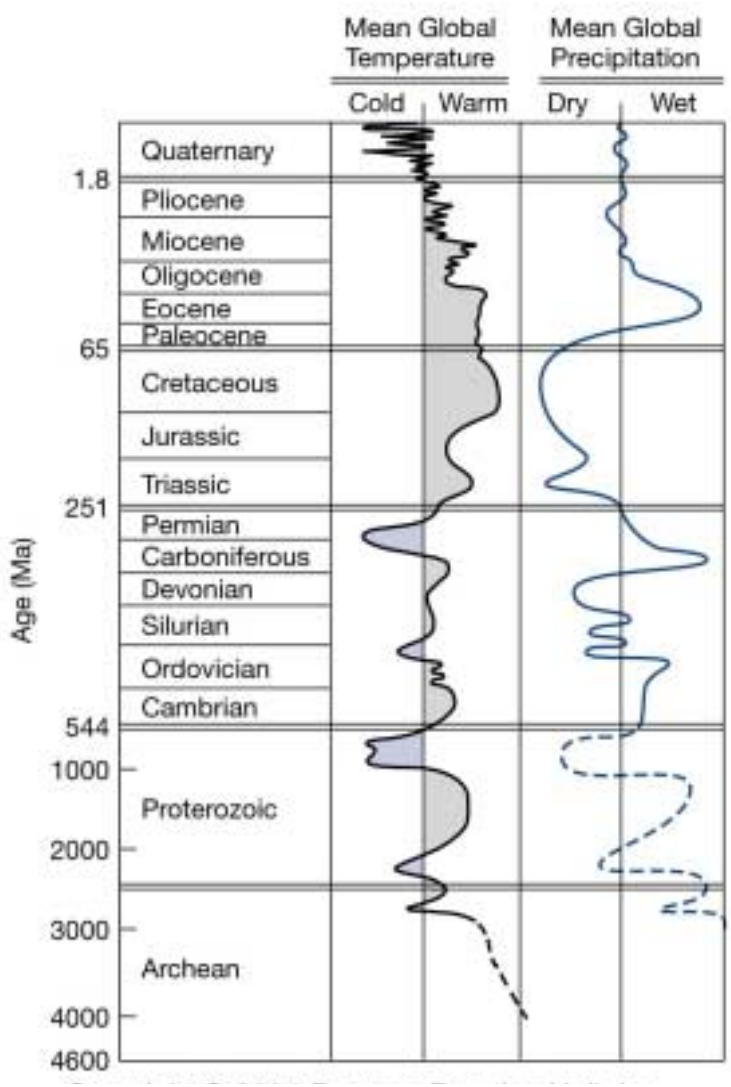
Dinosaurs

coal/oil

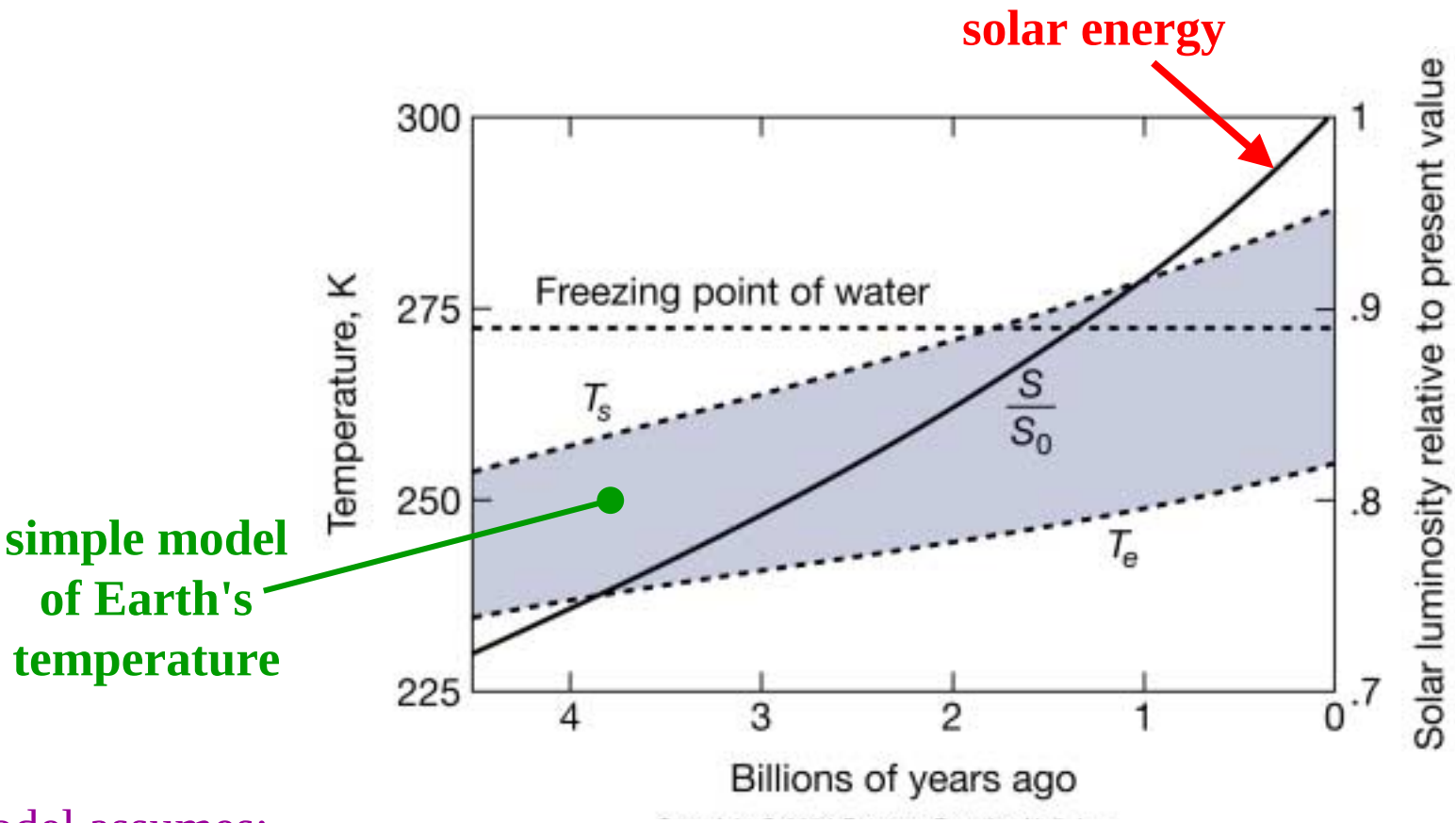
Cambrian explosion



Temperature/Precipitation History



Faint Young Sun paradox: Fig 8-8



model assumes:

- CO2 in atmosphere same as today
- Earth albedo same as today

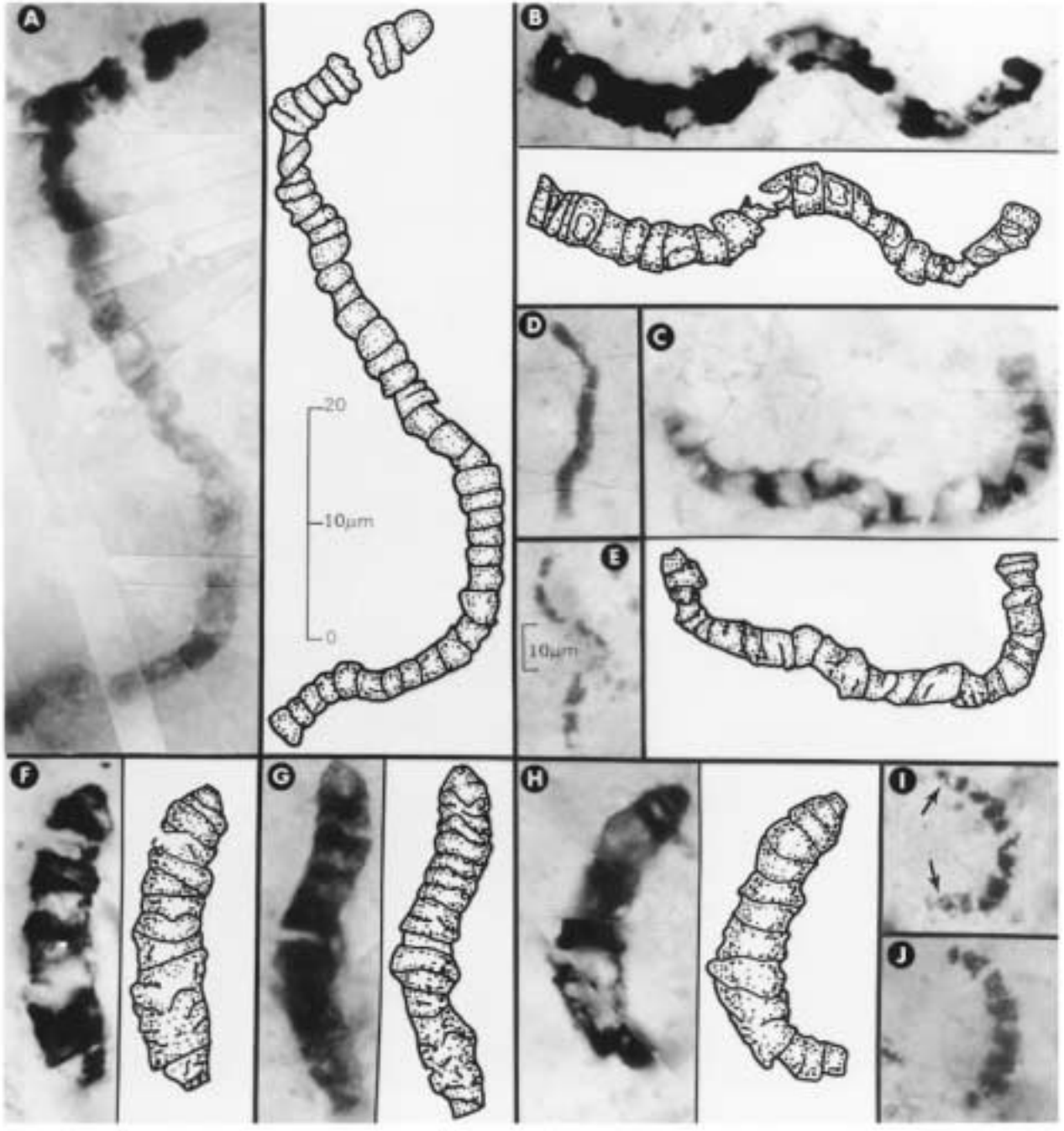
Why do we know this model is wrong?

Fig 9-5: microfossils, 3.5 billion yr old, Australia

Answer:

Archeon life!

Requires liquid water



Faint Young Sun paradox: p159-161

paradox: despite less solar energy, Archean was warm enough to support photosynthetic life

conceptual framework:
$T_s = f(S_o, A, \Delta T_g)$

Possible explanations

- sun... ?
- albedo... no
- geothermal energy... no

> greenhouse...

  - H2O... no
  - NH3... no

  > CO2... [see figure]

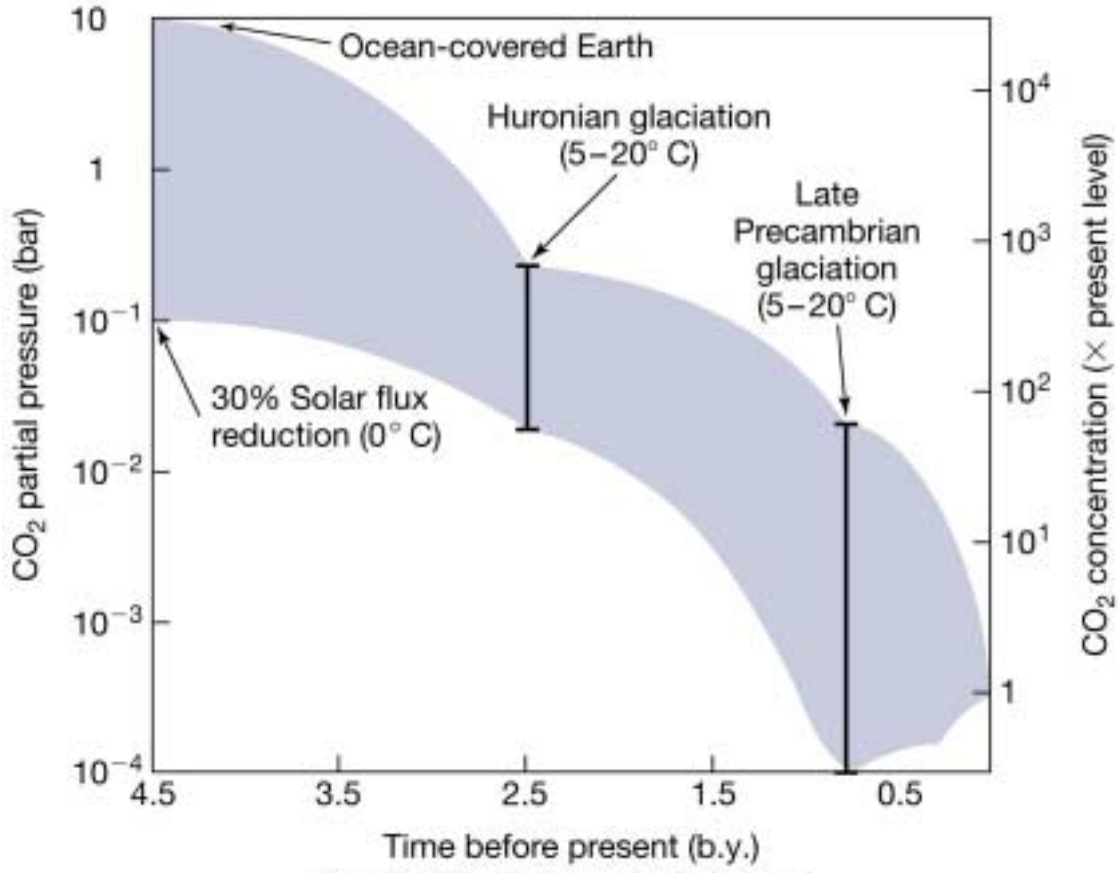
    less land
    more volcanism
    plenty of carbon [see inorganic carbon cycle figure]

  > CH4 methane? (CH4) [recent Kasting proposal]

    early life would have produced it
    far longer atmospheric lifetime than today due to lack of oxygen

Illustrates nature of scientific knowledge/progress (draw figure)

CO2 over Earth History: Fig 8-9



Thurs Nov 13

Announcements:

?

Today:

- marker events in Earth history
- Mesozoic Warmth
- Cenozoic Cooling
- Sister planets
- Snowball science history (and some pretty pictures)

but first, a few late-breaking headlines...

Earth History: Marker Events

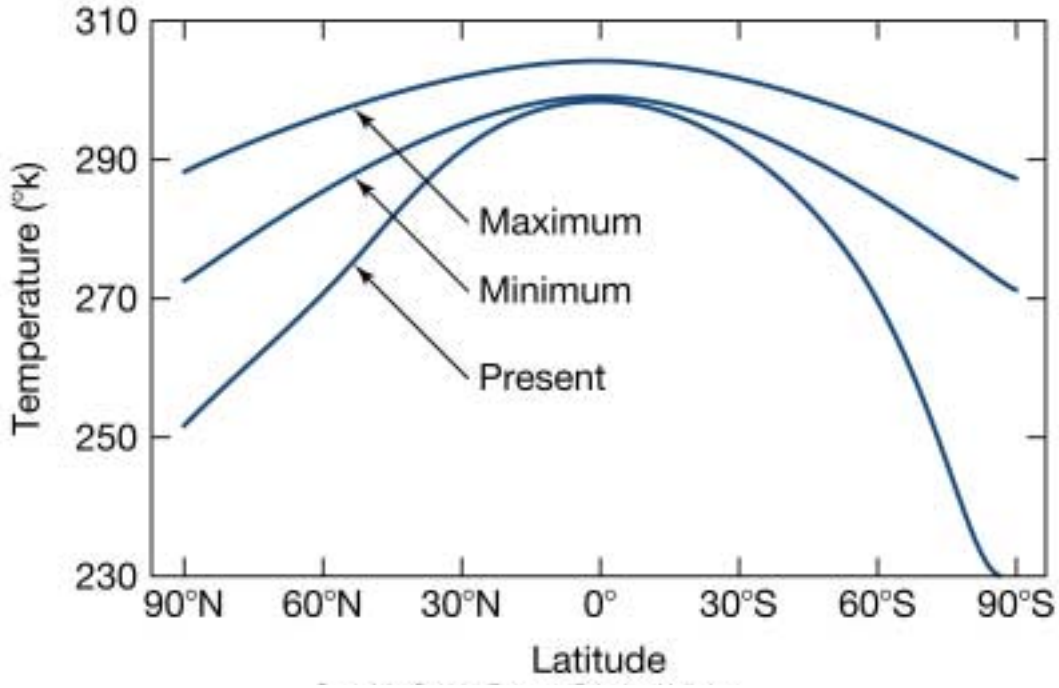
1. Origin of Earth	4.6 billion ybp (years before present)
2. Origin of Life	~4 billion ybp
3. Rise of Oxygen to ~ modern levels	~2 billion ybp
4. Snowball Earth events	600-900 million ybp
5. Beginning of fossil record (Cambrian explosion)	540 million ybp
6. Extinction of Dinosaurs by asteroid	65 million ybp
7. Beginning of modern glaciations	3 million ybp
8. End of last ice-age	10 thousand ybp

Mesozoic Warmth (250-65 million ybp)

<u>What:</u>
- Warmer global-mean temperature.
- <u>Much</u> warmer Polar Regions; no ice-caps.
- Much warmer deep ocean.

<u>Evidence:</u>
- Lush ferns and alligators in Siberia.
- Carbon isotopes in ocean sediments

<u>Cause:</u>
- Higher CO2 is leading suspect.
- sea-floor spreading rate was greater
- higher sea level (no ice caps)



<u>Remaining mysteries:</u>
- Ocean/atmos heat transport must have been much more efficient.
- latitudinal and vertical
- this is not understood

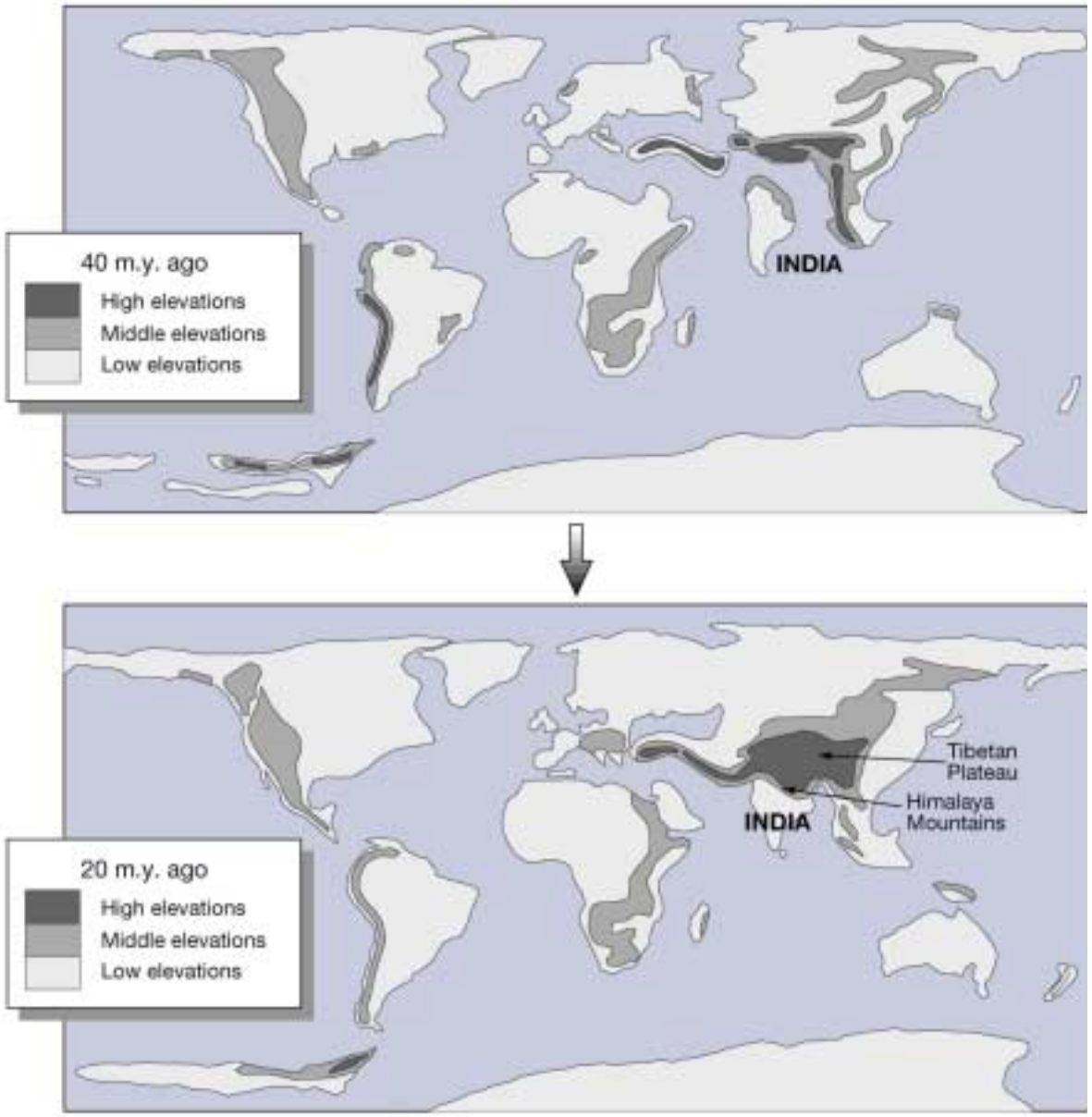
Cenozoic cooling, 65 million ybp to present

What:

- Earth cools, beginning ~60 million ybp.
- Life retreats from Poles.
- Polar ice caps form.
- Eventually, ice-ages begin.

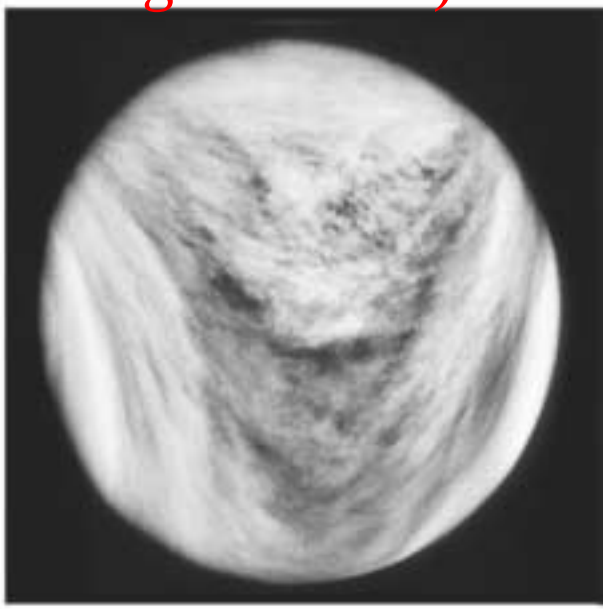
Cause (one leading theory):

- India collides with Asia.
- Himalayas form.
- Silicate weathering increases.
- Atmospheric CO2 goes down.



Sister planets

Venus (runaway greenhouse)



- Oceans boiled away
- No more weathering
- Carbon partitions to atmosphere
- CO2 is ~100,000 times that on Earth
- T_s = 427 C; ΔT_g = 466C

Earth ("just right")

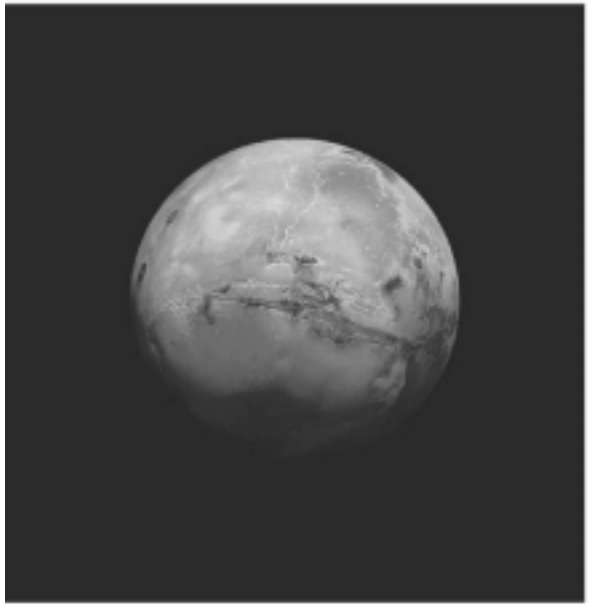
- has oceans
- hydrological cycle
- weathering returns CO2 to lithosphere
- plate tectonics (volcanoes) return carbon to atmos.
- negative feedback

Mars (virtually no greenhouse)

- farther from Sun; too cold for liquid water
- no water vapor greenhouse
- too small for plate tectonics
- no carbon cycle
- CO2 is ~10 times Earth
- T_s = -53C; ΔT_g = ~3C

Mars, CO2 and Greenhouse

Mars
(virtually no
greenhouse)

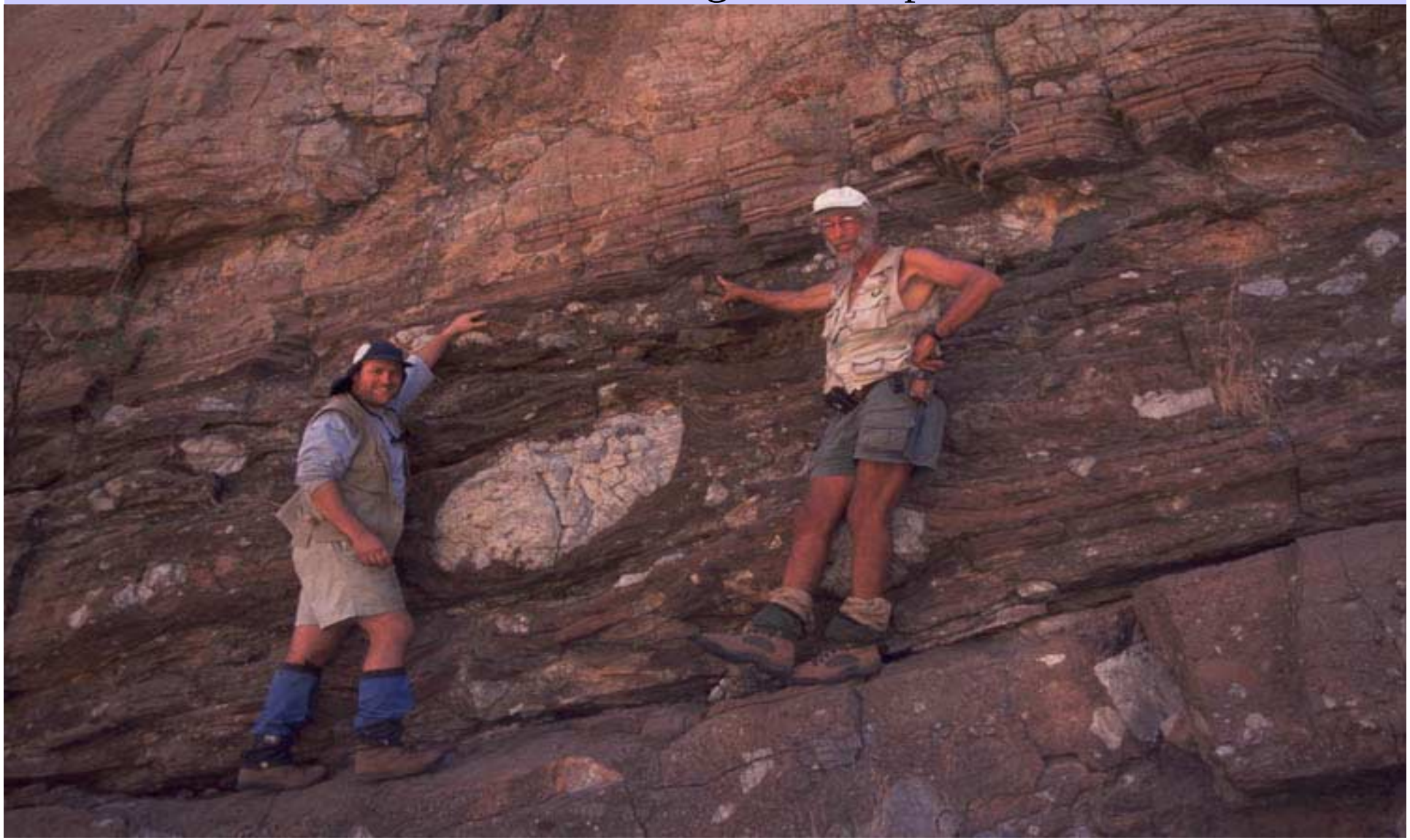


- CO2 is ~10 times Earth
- ΔT_g = ~3C

Do you notice something strange about these facts???

What can we conclude about the cause of the greenhouse effect on Earth???

Hoffmann, Schrag, and Dropstone



http://www-eps.harvard.edu/people/faculty/hoffman/snowball_paper.html

Snowball Science History -1

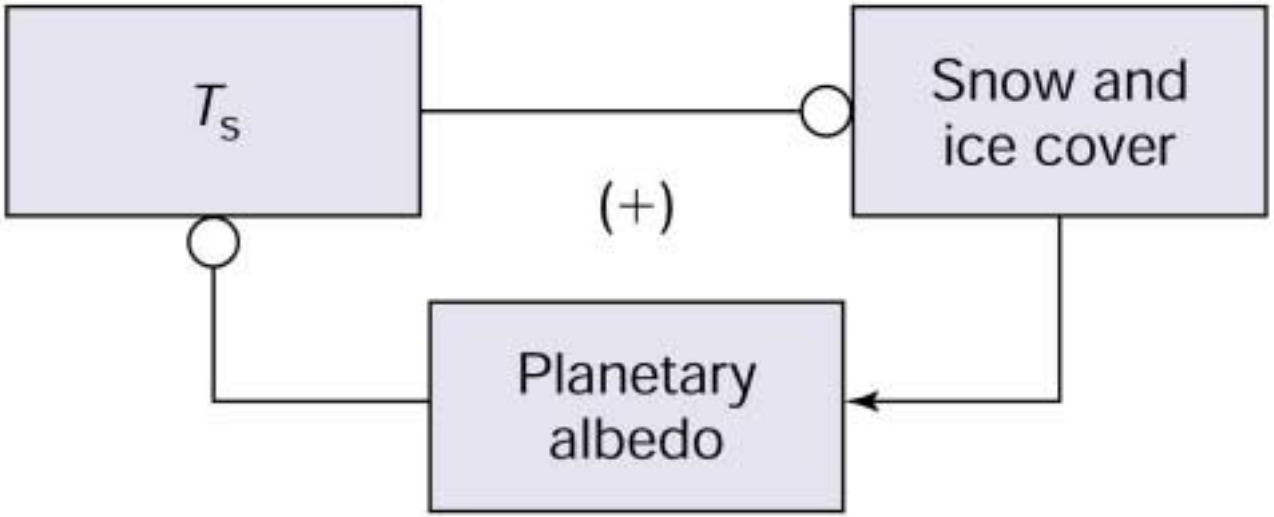
1960's: Mikhail Budyko (theoretical climate modeling)

- "run-away" ice-albedo feedback if Earth freezes below 30-degree latitude
- this must never have happened for two reasons...
    1. continuous life
    2. Earth could never recover

1964: Brian Harland (geologist)

- Late proterozoic glacial deposits on almost every continent
- magnetic alignment of grains indicate continents were near Equator

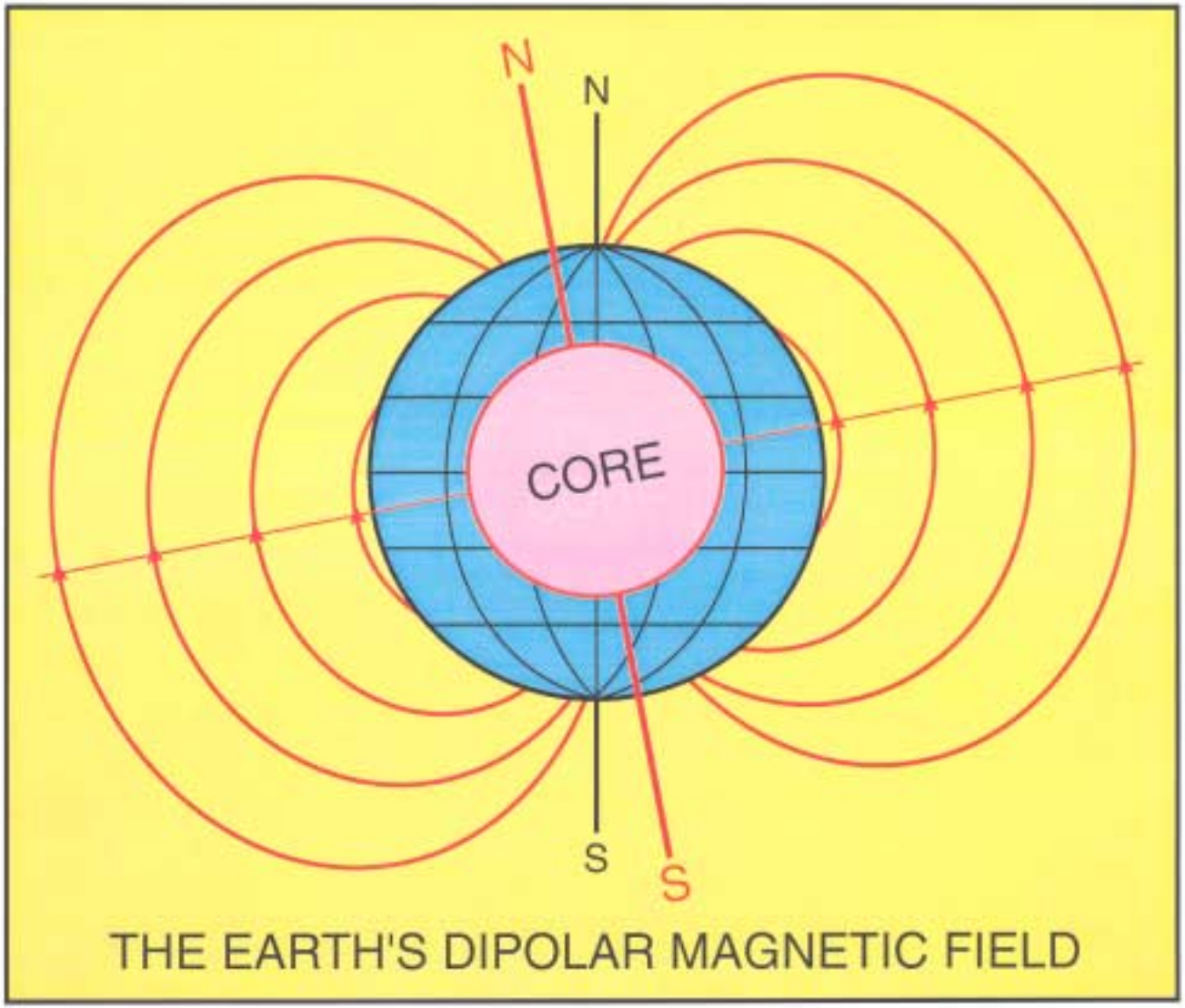
ice-albedo feedback



Positive feedback loop:

- amplifies an initial perturbation
- potentially causes current equilibrium state to be unstable

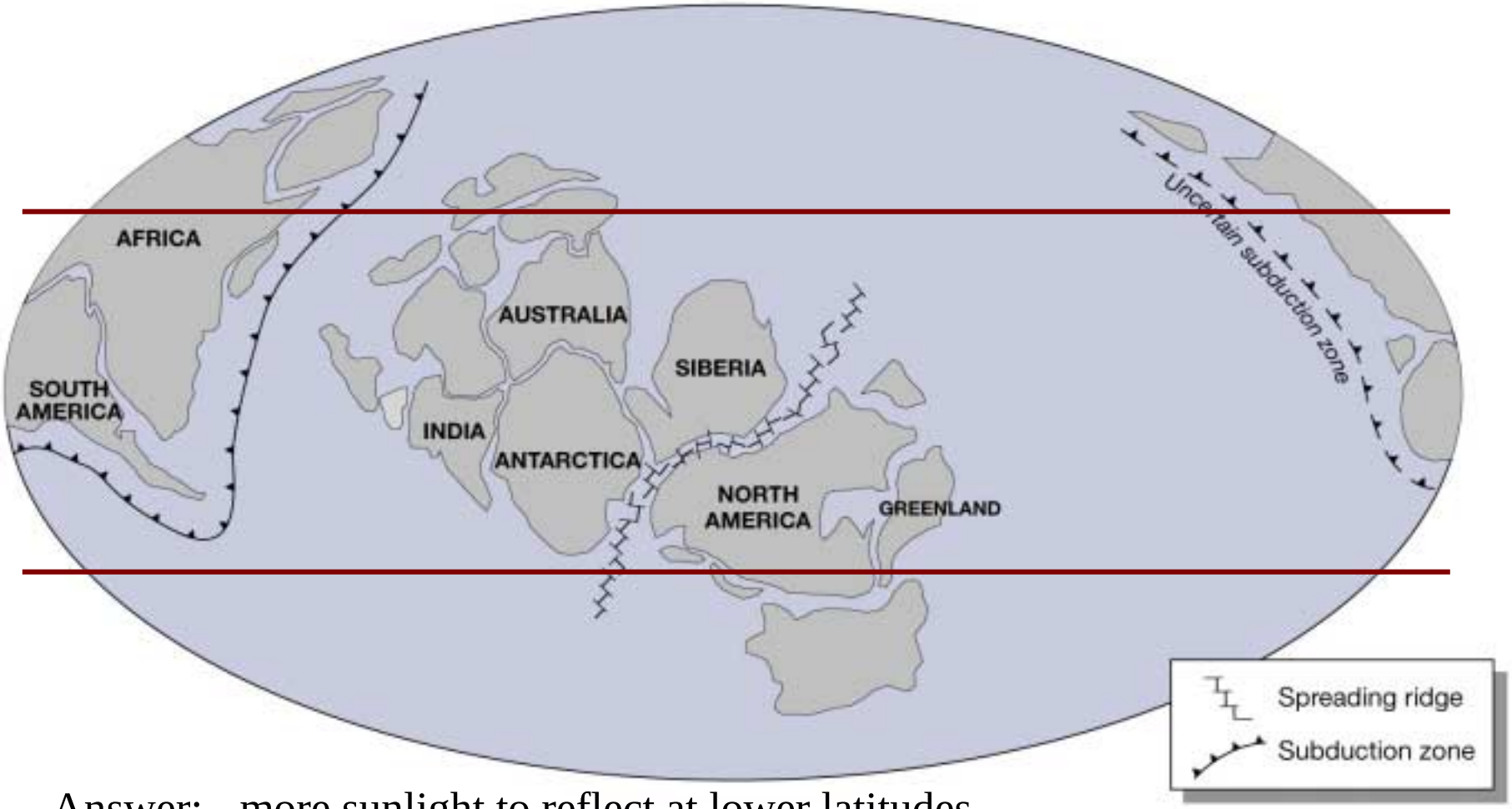
Earth's Magnetic Field



Possible continental positions during Late Proterozoic Glaciations: Fig 8-12

Critical latitude for "runaway" ice-albedo (~30 degrees):

Why would ice-albedo feedback get stronger as the ice-line got to lower and lower latitudes???



Answer: - more sunlight to reflect at lower latitudes

- the amount of area per degree latitude gets much larger (major factor)

Snowball Science History -2

1960's: Martin Rudwick (biologist) with Brian Harland

- Recovery from global glaciation may have spurred Cambrian explosion
- "all 11 animal phyla ever to inhabit the earth emerged within a narrow window of time" after the end of the last glaciation

1970's: more biology

- discovery of life in extreme environments
- organisms near geothermal vents at ocean bottom have no need of sunlight
- bacteria and algea living in snow, ice, and rock pores under extreme cold, heat, and pressure
- overcomes argument (1), above

1992: Joseph Kirschvink (geophysicist)

- Atmospheric CO_2 would build up during a global glaciation
- CO_2 removal by silicate weathering would cease, but
- CO_2 input from volcanoes would continue unabated
- overcomes argument (2), above

Snowball Science History -3

1992: Kenneth Caldeira and James Kasting

- Calculate that CO2 would have to be 350 times current levels to melt a global glaciation
- This would take about 10 million years

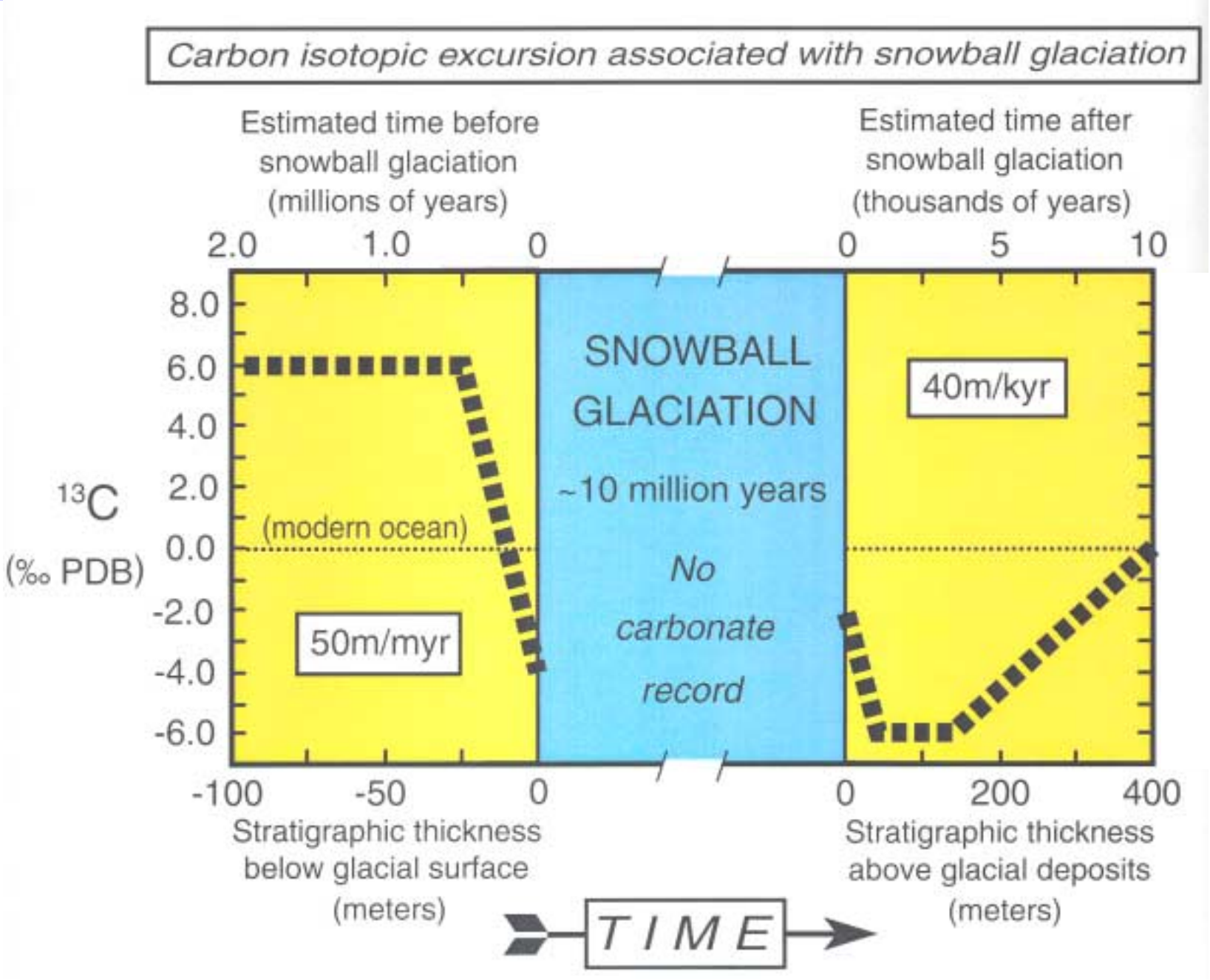
1992: Kirschvink

- Iron deposits mixed with glacial debris indicate ocean lacked oxygen
- This implies ice-covered oceans

1990's: Hoffman and Schrag

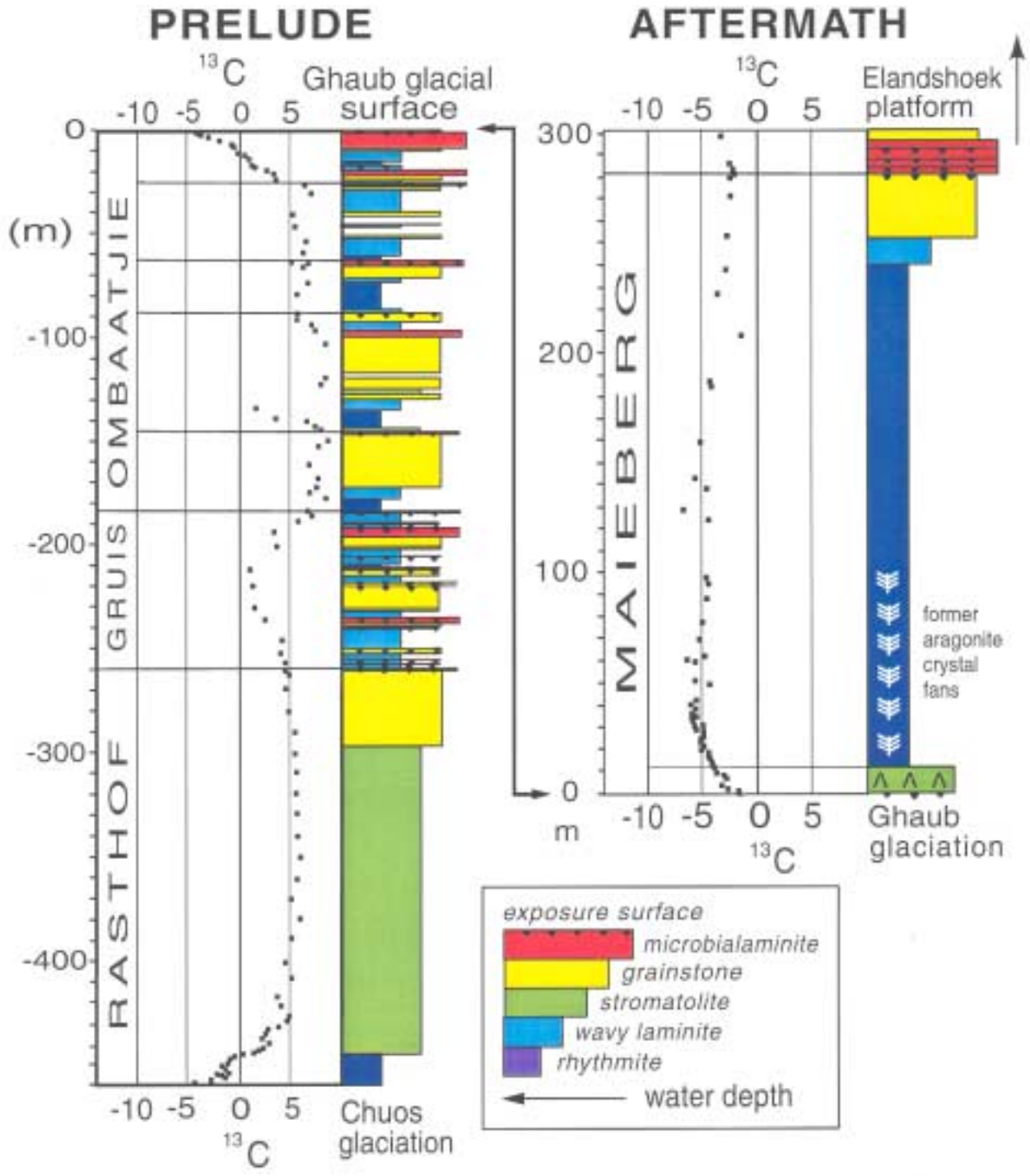
- Carbon isotopes in rocks surrounding glacial deposits indicate a virtual shut-down of biological activity
- Massive carbonate deposits on top of the glacial deposits ("cap carbonates") indicate very warm water and sudden deposition of huge amounts of carbon
- Apparently, the glaciation events were immediately followed by a global hothouse period
- This is consistent with huge buildup of atmospheric CO2.

Idealized carbon isotope record through a Snowball event



Measured carbon isotope record through a Snowball event

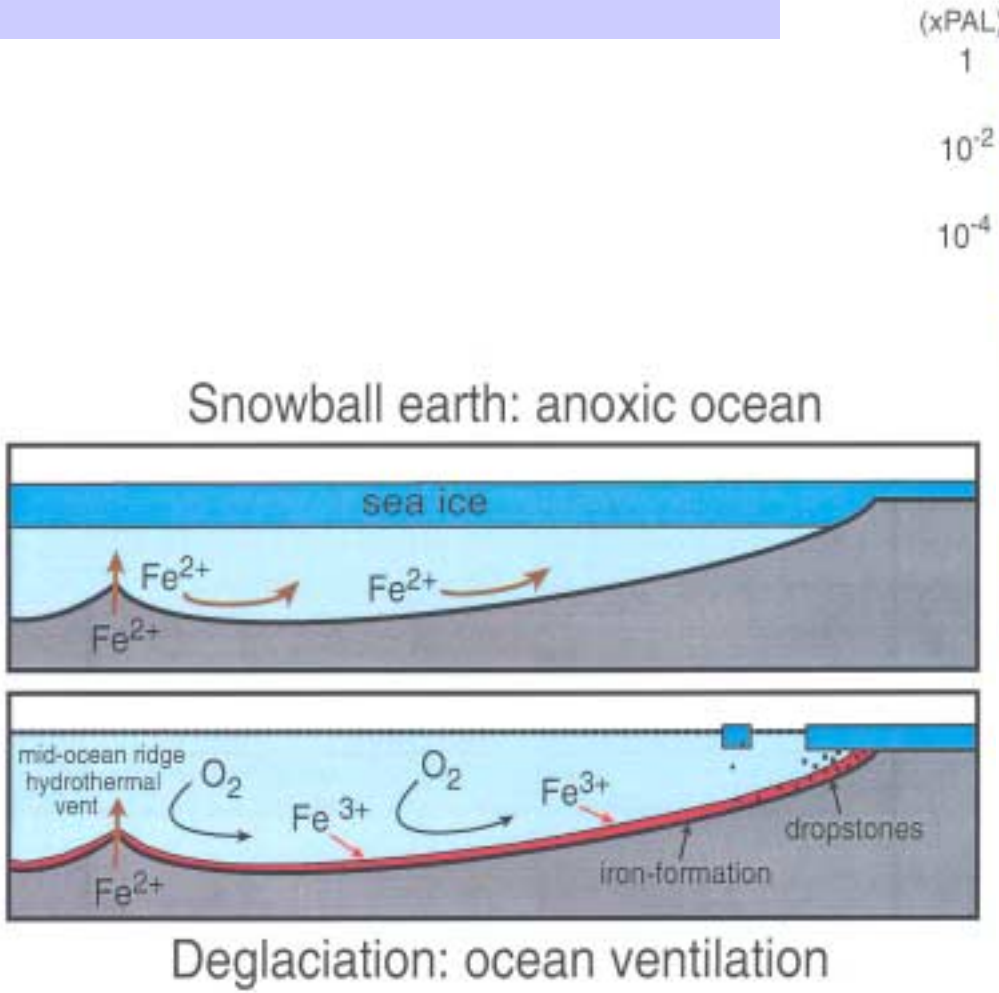
Ghaub Glaciation, Otavi Group, NW Namibia

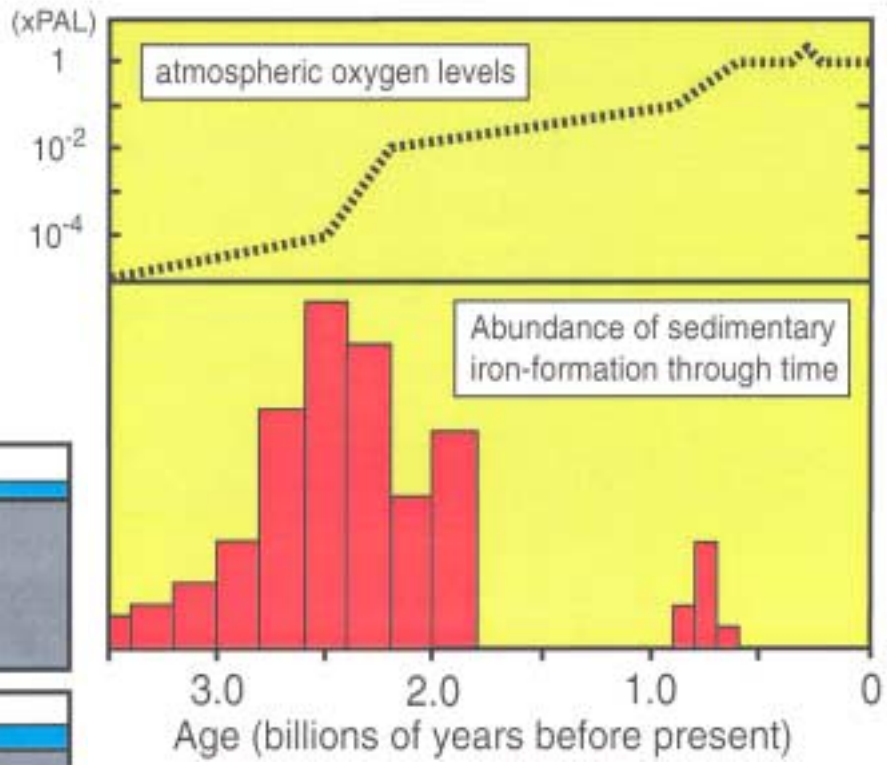


Iron Solubility and Deposition in Relation to a Snowball Event

If O_2 is absent, iron is soluble as ferrous (Fe^{2+}) ion.

If O_2 is present, iron is insoluble as ferric (Fe^{3+}) ion.





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Namibia cliffs, snowball record