HW4 due on Friday!

Great oxidation

Snowball Earth
  - Faculty Teaching Excellence program

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(Office hours: Mondays 2:30 – 3:30 in X590 and Wednesdays 11-12 in D230)
The great oxidation event (GOE)

- Oxygen catastrophe
- Mass extinctions

**Atmosphere & ocean anoxic, except for small pockets**

**Stage 1**: 
- Atmospheric $O_2$ starts toxic to anaerobic organisms

**Stage 2**: 
- $O_2$ starts to gas out of oceans

**Stage 3**: 
- O$_2$ sinks filled and accumulation

**Stage 4** and **Stage 5**: 
- charcoal
Rooted Tree
Phylogenetic Tree of Life

Bacteria
- Spirochetes
- Proteobacteria
- Cyanobacteria
- Planctomyces
- Bacteroides
- Cytophaga
- Thermotoga
- Aquifex

Archaea
- Green Filamentous bacteria
- Gram positives
- Methanobacterium
- Methanococcus
- Thermoproteus
- Pyrodictium
- Methanosarcina
- T. celer

Eukaryota
- Entamoebae
- Slime molds
- Animals
- Fungi
- Plants
- Ciliates
- Flagellates
- Trichomonads
- Microsporidia
- Diplomonads

2.5 Gyr ago?
An anoxic environment

- Oceans dissolve iron
  - Comes from hydrothermal vents
  - In the form of ferrous iron (FeO)
- Early cyanobacteria (phytoplankton)
  - Gradual oxidation
  - Rust (hematite or Fe$_2$O$_3$) $\rightarrow$ insoluble
  - Banded Iron Formation (BIF)
BIFs: layers of $\text{Fe}_2\text{O}_3$ deposits
• Earliest one: already 3.8 Gyr ago!
• Long lag time to 2.5 Gyr when O$_2$ levels rose. Why?
Why atmospheric $O_2$ much later?

A. No animal life available yet?
B. All used up by microbes
C. All used up by BIFs
D. Atmosphere still too warm
E. Not yet enough nutrients for phytoplankton
Why atmospheric $O_2$ much later?

A. No animal life available yet?  
   wrong logic

B. All used up by microbes  
   Possible, but too inefficient

C. All used up by BIFs  
   Possible, but big enough?

D. Atmosphere still too warm  
   not possible

E. Not yet enough nutrients for phytoplankton  
   Fe rich oceans $\rightarrow$ nutrient-rich
Why atmospheric $O_2$ much later?

A. No animal life available yet?
B. All used up by microbes
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D. Atmosphere still too warm
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New feedback cycle

- Cyanobacteria + $\rightarrow$ $O_2$ + $\rightarrow$ less Fe
- Cyanobacteria − $\rightarrow$ $O_2$ + $\rightarrow$ more Fe
Another feedback cycle

- Cyanobacteria + $\rightarrow$ CO$_2$ $-$ $\rightarrow$ cooler
- Cyanobacteria $-$ $\rightarrow$ CO$_2$ + $\rightarrow$ warmer
Snowball Earth events

- Geological record $\rightarrow$ global events
  - Dramatic climate changes
- 2.45 Gyr ago (extreme event)
- 0.75 – 0.58 Gyr ago (up to 4)
  - Global glaciation (snowball Earth)
  - Mass extinction ($\text{CO}_2$ sinks cease)
  - Oceans become Fe-rich
Effects of snowball Earth on CO₂ sinks

• Photosynthetic life
• Acid rain: \( H_2O + CO_2 \rightarrow H_2CO_3 \)
• \( CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2 \)
• Snowball Earth would halt this process
Escaping Snowball Earth

- Volcanoes
- More O$_2$ production
  - BIFs
  - Explains Fe-rich betw glacial deposits
- Similar events earlier in history!
Snowball Earth & evolution

- Eukaria & Archea only after 2.5 Gyr
- Multicellular diverse life after 0.6 Gyr
- Coincidence?
- Greenhouse ↔ Icehouse
- Evolutionary pressure
- Oxygen spikes could have sparked early animal evolution
Oxygen catastrophe

• Oxygen spikes
  – BIFs
  – Oceans Fe poor

• Phytoplanktons starve
  – Global disaster for most life

• Antioxidant enzymes (Vitamin E & C)
  – Reengineer life in iron-poor environments
  – Archea have such enzymes
Rooted Tree

Phylogenetic Tree of Life

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2.5 Gyr ago?
Ice ages are different

• Temperature drops by a few degrees
  – More snowfall, down to low latitudes
  – Last one 10,000 yr ago
  – Duration: 35 Myr

• One contributor: cyclic changes in Earth rotation (tilt 22°-25°) & orbit
  – Milankovich cycles
Snowball Earth refers to

A. One in a series of deep ice ages that occurred >0.5 Gyr ago
B. The idea that Earth would be frozen without greenhouse effect
C. Any of the ice ages that occurred in the past few million years
**Snowball Earth refers to**

A. One in a series of deep ice ages that occurred >0.5 Gyr ago

B. The idea that Earth would be frozen without greenhouse effect

C. Any of the ice ages that occurred in the past few million years
The boring billion: 1.8 – 0.8 Gyr

• After: atmos. O₂, glaciation, GOE, prokaryotic life, UV-blocking ozone

• O₂ remained at 1% PAL (present atmospheric level)
More evidence for early life
Accumulation of organics

• Photosynthesizing cyanobacteria
• Grow on top of each other
• Layered structure
Στρώμα λίθος
Modern stromatolites
Early Faint Sun Paradox

The Early Faint Sun Paradox: Organic Shielding of Ultraviolet-Labile Greenhouse Gases
Carl Sagan and Christopher Chyba

No climate paradox under the faint early Sun
Minik T. Rosing¹,²,⁴, Dennis K. Bird¹,⁴, Norman H. Sleep⁵ & Christian J. Bjerrum¹,³

- Early Sun 30% fainter
  - Yet liquid water!? 
  - Greenhouse gases?
- Geol record: no!
  - Less continents
  - Less albedo
Next week

• Evidence for early life on Earth
• Oceans 4.4 Gyr ago
• Different rock types
• pp. 65 – 71 in RGS
  – After that
    • Significance of $^{13}$C isotope
    • Cambrian explosion of life