Long-Term Climate Regulation (Ch. 12)

• The Faint Young Sun Paradox Revisited (continued)
Silicate weathering: Atmospheric CO2 dissolves in raindrops, making them naturally acidic. Rocks (carbonate, silicate) exposed at Earth’s surface under chemical attack from this rain, a process known as chemical weathering, which consume CO2. Silicate weathering consumes twice as much dissolved CO2 as does carbonate weathering.
Chemical Weathering: Earth’s Thermostat?

- Chemical weathering can provide negative feedback that reduces the intensity of climate warming.
Chemical Weathering: Earth’s Thermostat?

- Chemical weathering can provide negative feedback that reduces the intensity of climate cooling.
So?

• Weathering stabilizes climate - cooler earth could work to increase concentration of CO2
• Increase in CO2 => increase in H2O and greenhouse effect
• Warmer planet
Greenhouse vs. Faint Young Sun

- Cold surface temperatures created by the faint young Sun compensated by stronger atmospheric CO$_2$ greenhouse effect
Negative Feedback Loops (Stabilizing)

The carbonate-silicate cycle feedback

CO₂ emitted from volcano would have accumulated in the atmosphere until the global rate of silicate weathering balanced the volcanic outgasing rate. The Earth system has a natural way of recovering from global glaciation!
Required $CO_2$ vs. time if no other greenhouse gases (besides $H_2O$)

$1 \text{ bar} = 1000 \text{ mb}$

Current atmospheric pressure = 1013 mb

$\sim 1000xco2$ (today) to keep the early ocean from freezing!
But ...

• There is some evidence that suggests CO2 abundance on the early earth was not that high
• Can we think of another greenhouse gas?
• Well, how about CH$_4$ (methane)?
• CH$_4$ produced by bacteria that like warm conditions (evidence for such bacteria in fossil record)
Effect of Methane on Archean Climate

- The oxygen is produced by photosynthesis and hence, would not have been present prior to the origin of photosynthetic life. Photosynthesis originated at or before 2.3 b.y. ago, the time when atmospheric O2 level first rose.

- CH4 could have been abundant prior to 2.3 b.y. ago, when O2 levels were low. \( \text{CO}_2+4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \) through biological and abiotic processes.

- ~1000 ppm CH4 (likely) 3.8-2.3 b.y. ago.

- If atmospheric CH4 was indeed present at these concentrations, it would have had a strong warming effect on the Ts.

- CH4 was an important greenhouse gas in Archean atmosphere.
$\text{CH}_4$-Climate Positive Feedback Loop

- Surface temperature
- $\text{CH}_4$ production rate
- Greenhouse effect

$(+)$
But

• If $CH_4$ becomes more abundant than $CO_2$, organic haze begins to form...
Titan’s Organic Haze Layer

Haze is thought to form from photolysis (and charged particle irradiation) of CH$_4$

(Picture from Voyager 2)
Views of Titan
Summary

- Higher $CO_2$ concentrations are a good way of compensating for faint early sun.

- But other greenhouse gases ($CH_4$) could also have been important.

- Early $CH_4$ cycle contained feedback loops that might have worked to stabilize the Archean climate (organic haze).
Earth history

- Age of earth is ~4.5 billion years
  - How do we know? Lead isotope dating of meteorites and moon rocks, among other things (p189)

- This is really old – climate over most of earth history is very different from today
  - Early earth was an extremely hostile environment (from our perspective)
  - Very different plant and animal life than today
Earth history

- How do we know climate over earth history?
  - Deep sea cores (last 200 m. y. – no older sea floor)
  - Fossil record (last 550 m. y. – species of plants and animals can be related to climate)
  - Geologic evidence of glaciation
- What does this tell us?
Evidence for glaciations

Brooks Range,
Northern Alaska
(From Skinner & Porter, The Blue Planet, p. 294)

Glacial till—pieces of rock picked up by glaciers as they move across the landscape
Moraine—piles of glacial till deposited at the terminus (terminal moraine) or sides (lateral moraine) of a glacier
Cirque—a steeply walled canyon carved into a mountain by a glacier
Evidence for glaciations

Diamictite—a rock containing unconsolidated smaller fragments
Tillite—a diamictite produced by burial of glacial till
glacial marine tills, Ghaub Fm, Namibia
Evidence for glaciations

Striations—parallel scratchings on rock surfaces caused by the passage of glaciers (bearing rocks)
Scratched pebble from Jbéliat tillite, Mauritania
Evidence for glaciations

Dropstones—Isolated rocks found in smoothly laminated marine sediments that are interpreted as having fallen from melting icebergs
Ice-rafted dropstone, Ghaub Fm, Namibia
Ice-rafted dropstone in proglacial marine strata, Ghaub Fm lower member, Otavi Group, Namibia
Crash course in earth history
Age of the Earth
How do we know?

- Radiocarbon dating of earth rocks
  - Rocks are “re-cycled” – planet must be older than oldest rocks
  - Oldest rocks are about 4 Billion years
  - Some crystals in rocks dated to 4.3 Billion years

- Radiocarbon dating of meteorites and moon rocks
  - “Best age” of 4.54 Billion years from iron meteorites
  - Consistent with age of universe of 10 to 15 Billion years from astronomical evidence