Lecture 9: Faint Young Sun Paradox

- Carbon Cycle As a Thermostat for Earth
- Chemical Weathering and Continental Drift
- Why No Similar Thermostat on Venus and Mars

Faint Young Sun Paradox

- Solar luminosity was much weaker (~30%) in the early part of Earth’s history (a faint young Sun).
- If Earth’s albedo and greenhouse effect remained unchanged at that time, Earth’s mean surface temperature would be well below the freezing point of water during a large portion of its 4.5 Byr history.
- That would result in a “snowball” Earth, which was not evident in geologic record.

Earth’s Thermostat – Chemical Weathering

- Chemical weathering acts as Earth’s thermostat and regulate its long-term climate.
- This thermostat mechanism lies in two facts: (1) the average global rate of chemical weathering depends on the state of Earth’s climate, (2) weathering also has the capacity to alter that state by regulating the rate which CO$_2$ is removed from the atmosphere.

Negative Feedback From Chemical Weathering

- The chemical weathering works as a negative feedback that moderates long-term climate change.
- This negative feedback mechanism links CO$_2$ level in the atmosphere to the temperature and precipitation of the atmosphere.
- A warm and moist climate produces stronger chemical weathering to remove CO$_2$ out of the atmosphere smaller greenhouse effect and colder climate.
Plate Tectonics

- **Continental Drifting Theory**
  Alfred Wegener proposed that all the continents were once assembled into a supercontinent (Pangea) and then broke and slowly drifted to their current positions.

- **Plate Tectonics**
  The branch of tectonics that deals with the processes by which the lithosphere plates move and interact with each other is called plate tectonics.

Circulation of the Solid Earth

- The rising hot rocks and slid-away flows are thought to be the factor that control the positions of ocean basins and continents.
- The convection determines the shape of the Earth.

Twenty Rigid Plates

- What can happen to the cold boundary?
- The lithosphere has broken into a number of rocky pieces, called plates.
- There are six large plates plus a number of smaller one comprise the Earth’s surface (a total of 20 plates).
- The plates range from several hundred to several thousand kilometers in width.
The Theory of Plate Tectonics

- A major problem of the continent drifting theory is: How could the continents drift through the rigid sea floor?

- This problem is answered by the seafloor spreading hypothesis: Continents do not plow through the sea floor. Continents and segments of ocean floor are connected into plates that continuously move away from one another at mid-ocean ridges.

Plate Margins

- Interactions between plates occur along their edges. There are three types of plate margins:
  
  1. Divergent margins
     - form mid-ocean ridges (over oceans) and rift valleys (over lands)
  2. Convergent margins
     - form deep-sea trenches (two oceanic plates or ocean+continental plates) or high mountains (such as Tibetan Plateau) (two continental plates).
  3. Transform fault margins
     - form earthquake faults

Seafloor Spreading

- (from The earth System)

Tectonic Control of CO₂ Input – The Seafloor Spreading Rate Hypothesis

- During active plate tectonic processes, carbon cycles constantly between Earth’s interior and its surface.
- The carbon moves from deep rock reservoirs to the surface mainly as CO₂ gas associated with volcanic activity along the margins of Earth’s tectonic plates.
- The centerpiece of the seafloor spreading hypothesis is the concept that changes in the rate of seafloor spreading over millions of years control the rate of delivery of CO₂ to the atmosphere from the large rock reservoir of carbon, with the resulting changes in atmospheric CO₂ concentrations controlling Earth’s climate.

- (from Earth’s Climate: Past and Future)
Why No Thermostat on Mars?

- Mars is too small in size
  - Mars had no large internal heat
  - Mars lost all the internal heat quickly
  - No tectonic activity on Mars
  - Carbon can not be injected back to the atmosphere
  - Little greenhouse effect
  - A very cold Mars!!

Why No Thermostat On Venus?

- Venus is too close to the Sun
  - Venus temperature is very high
  - Very difficult for Venus’s atmosphere to get saturated
  - Evaporation keep on bringing water vapor into Venus’s atmosphere
  - Greenhouse effect is very large
  - A “run away” greenhouse happened on Venus
  - Water vapor is dissociated into hydrogen and oxygen
  - Hydrogen then escaped to space and oxygen reacted with carbon to form carbon dioxide
  - No water left on Venus (and no more chemical weathering)