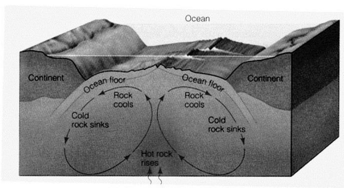
Lecture 6: Solid Earth (Outline)



From *The Blue Planet*

- ❑ Climate Role of the Solid Earth
- ❑ Internal Structure of the Solid Earth
- ❑ Theory of Plate Tectonics
- ❑ History of Plate Tectonics

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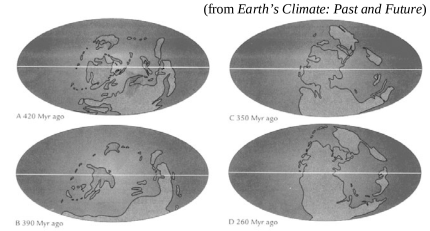
Plate Tectonics and Climate

(from *Earth's Climate: Past and Future*)



- ❑ How can one account for the alternating periods of climatic warmth and coolness observed in the geologic record?
- ➔ Part of the answer must lie in the tectonic activity and the positions of the continents.

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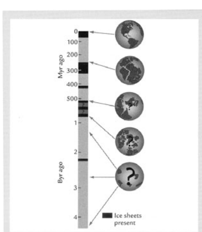
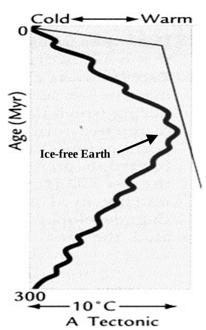
Tectonic-Scale Climate Change



Past glaciations and continental positions. During Earth's 4.55-billion-year history, intervals when large continental ice sheets were present alternated with times when they were not (left). The earliest history of these changes is poorly defined because few ancient records are preserved. The movements of continents in relation to ocean basins are well known only for the last several hundred million years (right). (Globes adapted from D. Merritts et al., *Environmental Geology*, © 1997 by W. H. Freeman and Company.)



(from *Earth's Climate: Past and Future*)

- ❑ The faint young Sun paradox and its possible explanation.
- ❑ Why was Earth ice-free even at the poles 100 Myr ago (the Mesozoic Era)?
- ❑ What caused Earth's climate to cool over the last 55 Myr (the Cenozoic Era)?

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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.

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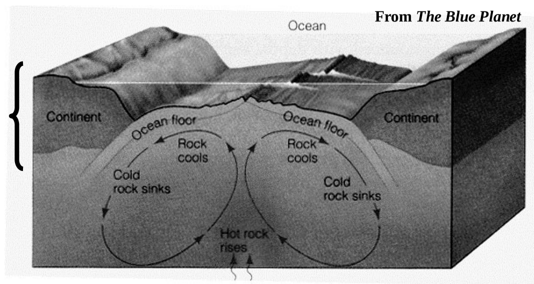
Circulation of the Solid Earth

From *The Blue Planet*

Cold Lithosphere



❑ 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.

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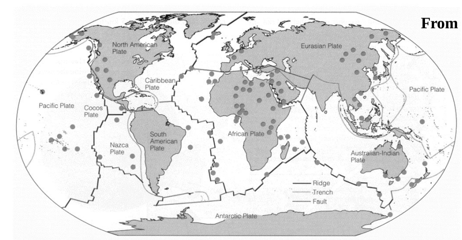
Twenty Rigid Plates

From *The Blue Planet*



❑ What can happen to the cold boundary?

➔ The lithosphere has broken into a number of rocky pieces, called plates.

❑ There are a few 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.

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Continental and Oceanic Crusts

❑ Some lithospheric plates are composed primarily of oceanic crustal material, whereas others are composed primarily of continental materials.

❑ The continents stand, on average, about 4.5 km above the floor of the ocean basins.

❑ Continental crust is relatively light (density 2.7 g/cm3), whereas oceanic crust is relatively heavy (density close to 3.2 g/cm3).

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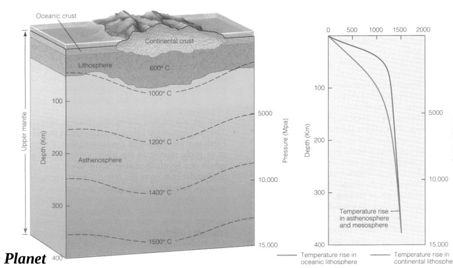
Temperature Structures in the Solid Earth



From *The Blue Planet*

❑ The lithospheric plates are riding on top of a layer of hot, ductile, easily deformed material called the asthenosphere, or "weak layer".

❑ Heat moves by conduction above 100 km and by convection below 100 km.

❑ Temperature at the center of the earth is believed to close to 5000ºC.

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Heat In Earth's Interior

- There are two major sources of the heat in Earth's interior:

(1) Radioactive decay: of potassium, uranium, and thorium.

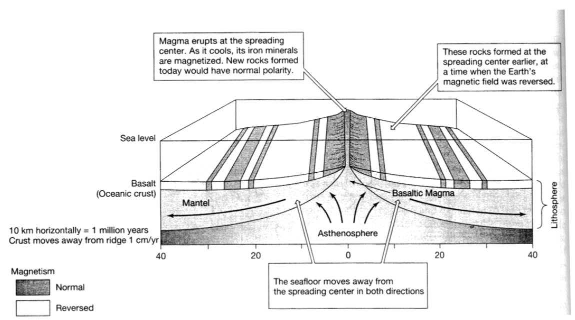
(2) Residual heat from Earth's formation: A tremendous amount of energy was transferred to Earth during the accretion of the planet by collisions with planetesimals.

The Theory of Plate Tectonics

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

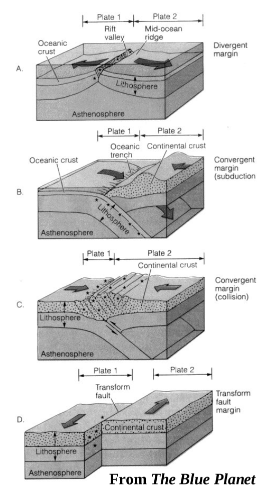
- This problem is answered by the seafloor spreading hypothesis: Continents do not plow through the sea floor. *Continents and segments of ocean floor are connected into plates that continuously move away from one another at mid-ocean ridges.*

Seafloor Spreading



(from *The earth System*)

Plate Margins



From *The Blue Planet*

- 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

Three Ways for Solid Earth to Affect Climate

- Polar position hypothesis
- Chemical Weathering Hypothesis
- Seafloor Spreading Hypothesis

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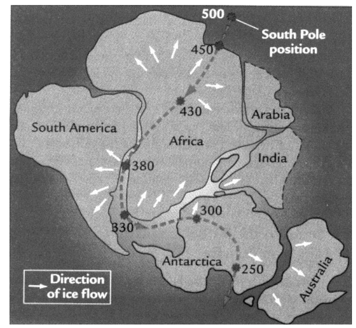
The Polar Position Hypothesis



(from *Earth's Climate: Past and Future*)

- The polar position hypothesis focused on latitudinal position as a cause of glaciation of continents.
- This hypothesis suggested that ice sheets should appear on continents when they are located at polar or near-polar latitudes.
- To explain the occurrence of icehouse intervals, this hypothesis calls not on worldwide climate changes but simply on the movements of continents on tectonic plates.
- This hypothesis can not explain the climate of the Late Proterozoic Era, when both continents and glaciers appear to have been situated at relatively low latitudes.
- It can not explain the warm Mesozoic Era when high-latitude continents were present but were almost completely ice-free.

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Climate Changes in the Last 500 Myr

(from *Earth's Climate: Past and Future*)

TABLE 5-1 Evaluation of the Polar Position Hypothesis of Glaciation

Time (Myr ago)	Ice sheets present?	Continents in polar position?	Hypothesis supported?
430	Yes	Yes	Yes
425–325	No	Yes	No
325–240	Yes	Yes	Yes
240–125	No	No	Yes
125–35	No	Yes	No
35–0	Yes	Yes	Yes

- Climate in the past 500 million years have alternated between long periods of warm climate and short periods of cold climate.
- During the last 500 million years, major continent-size ice sheets existed on Earth during three icehouse ear: (1) a brief interval near 430 Myr ago, (2) a much longer interval from 325 to 240 Myr ago, and (3) the current icehouse era of the last 35 million year.

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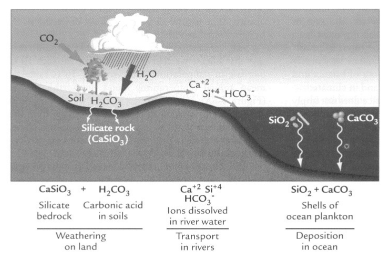
Chemical Weathering



(from *Earth's Climate: Past and Future*)

- The precipitation process in the atmosphere dissolve and remove CO_2 from the atmosphere.
- Rocks exposed at Earth's surface undergo chemical attack from this rain of dilute acid.
- This whole process is known as ***chemical weathering***.
- The rate of chemical weathering tend to increase as temperature increases.
- Weathering requires water as a medium both for the dissolution of minerals and for the transport of the dissolved materials to the ocean

  ➔ The rate of chemical weathering increases as precipitation increases.

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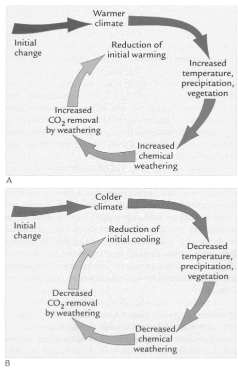
Negative Feedback From Chemical Weathering



(from *Earth's Climate: Past and Future*)

- 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.

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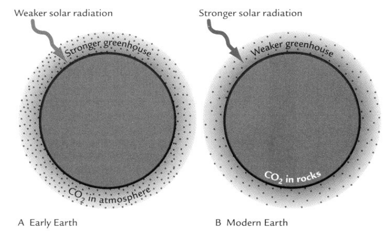
Earth's Thermostat – Chemical Weathering



(from *Earth's Climate: Past and Future*)

- 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.

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Faint Young Sun Paradox

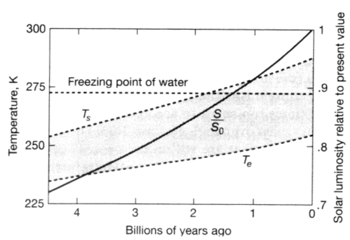

FIGURE 8-8
The faint young Sun paradox. The scale on the right applies to the solar luminosity curve, labeled S/S_0; the scale on the left applies to temperature curves. The shaded area represents the magnitude of the atmospheric greenhouse effect. (From J.F. Kasting et al., How Climate Evolved on the Terrestrial Planets, Scientific American 256(2): 90–97, 1988. Used with permission. © George V. Kelvin/Scientific American.

(from *The Earth System*)

- 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 re[cord].

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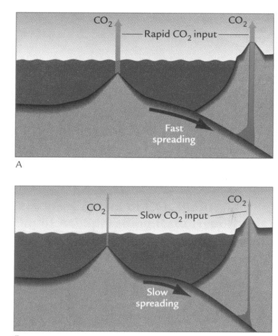
Tectonic Control of CO_2 *Input* – The Seafloor Spreading Rate Hypothesis



(from *Earth's Climate: Past and Future*)

- 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 CO_2 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 CO_2 to the atmosphere from the large rock reservoir of carbon, with the resulting changes in atmospheric CO_2 concentrations controlling Earth's climate.

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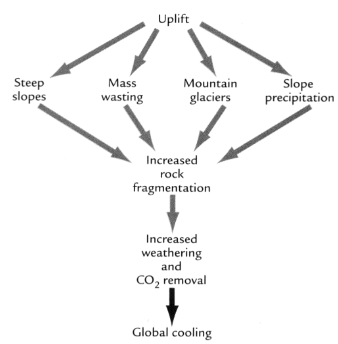
Tectonic Control of CO_2 *Removal* – The Uplift Weathering Hypothesis



(from *Earth's Climate: Past and Future*)

- The uplifting weathering hypothesis asserts that the global mean rate of chemical weathering is heavily affected by the availability of fresh rock and mineral surfaces that the weathering process can attack.
- This hypothesis suggests that tectonic uplifting enhances the exposure of freshly fragmented rock which is an important factor in the intensity of chemical weathering.
- This hypothesis looks at chemical weathering as the active driver of climate change, rather than as a negative feedback that moderates climate changes.

Can These Two Hypotheses Explain Tectonic-Scale Climate Changes?

TABLE 5-2 Evaluation of the BLAG Spreading Rate (CO_2 Input) Hypothesis

Time (Myr ago)	Ice sheets present?	Spreading rates	Hypothesis supported?
100	No	Fast	Yes (high CO_2)
0	Yes	Slow	Yes (low CO_2)

TABLE 5-3 Evaluation of the Uplift Weathering (CO_2 Removal) Hypothesis

Time (Myr ago)	Ice sheets present?	Continents colliding?	Hypothesis supported?
325–240	Yes	Yes	Yes (low CO_2)
240–35	No	No	Yes (high CO_2)
35–0	Yes	Yes	Yes (low CO_2)

(from *Earth's Climate: Past and Future*)