Lecture 18: Tectonics and environment

Read KK&V chapter 13.1, 13.2
Climate variability: the last 0.5 My
The Greenhouse Effect

Some sunlight that hits the earth is reflected. Some becomes heat.

CO₂ and other gases in the atmosphere trap heat, keeping the earth warm.
Climate variability: the last 0.5 My
Milankovitch Cycles Drive Ice Age Cycles

\[ E = \text{Eccentricity} \]
\[ T = \text{Tilt or Obliquity} \]
\[ P = \text{Precession} \]
• The mean temperature is correlated with the sea level: during periods of low temperature ("Ice Ages"), the sea level drops because some water is tied in glaciers. During warm periods, glaciers melt and the sea level rises.

• However, there were periods in the past when the Earth had no polar ice caps, and yet the sea level was still changing. Why?
The seafloor depth follows the “square root of age”;

higher spreading rates give rise to shallower ocean basins
The mid-Cretaceous superplume event

- Increase in the world-wide rate of oceanic crust production
- Shutdown in reversals of the earth’s magnetic field
Effects on temperature and sea level

- rising global surface temperature
- rising global sea level

At present plume activity is low
Fig. 13.1 Variation in the Mg/Ca ratio in seawater, calculated by Hardie, 1996, from an assumed curve of long term changes in sea level, and (below) summaries of the mineralogy of nonskeletal carbonates, and marine evaporites, illustrating the correlation with the predicted changes in the Mg/Ca ratio in seawater during the past 550 Ma (based on figure 2 in Stanley & Hardie, 1999).
• The Mid-Cretaceous super-plumes delivered increasing amounts of carbon dioxide to the atmosphere contributing to increased alkalinity in the ocean and elevated global warming from the “greenhouse effect”.

• Computer models suggest global, annual mid-Cretaceous temperatures 8 to 12 degrees centigrade warmer than today.
Volcanoes emitting carbon dioxide and sulfuric acid droplets which in the short term causes global cooling by blocking sunlight and in the long term sustained greenhouse warming.
• Warm waters hold less dissolved oxygen leading to widespread anoxia in the mid-Cretaceous oceans and the deposition of organic-rich black shales.

• Some super-plume episodes such as those that formed Kerguelen Plateau, Broken Ridge and the Deccan Traps coincided with mass extinctions.

• Both LIPs and increased spreading rates contributed to warming
Two main factors affecting the global climate:

- CO₂ (and other greenhouse gases) in the atmosphere
- Ocean circulation (landmass distribution, seaways, roughness of the seafloor)
• Surface ocean currents are driven by wind (atmospheric circulation).

• Deep currents depend on surface currents, rotation of the Earth, and incoming solar radiation.

• In the absence of continents, the world-encircling equatorial and circumpolar currents would inhibit the heat transfer from low to high latitudes (favoring the formation of ice polar caps).

• North-South trending land masses deflect the currents (to the right in the Northern hemisphere, and to the left in the Southern hemisphere), thereby transferring the heat from the tropics to the polar regions, and reducing the temperature gradients (current example: Gulfstream).
Climate simulation models with (A) equatorial and (B) polar continents
Polar ice caps are not permanent

The climate was much warmer >40 mln years ago than it is today

...was it ever much colder?
Snownball Earth
750 mln years ago

Namibia, South Africa
Lowered reflectivity causes further cooling, ending in "snowball Earth."

CO₂ cycle in ocean stops; CO₂ outgassed by volcanoes builds up.

Strong greenhouse effect melts "snowball Earth," results in "hothouse Earth."

Because of an extended cold spell, oceans start freezing.

CO₂ cycle restarts, pulling CO₂ back into oceans, reducing greenhouse effect to normal.

growing polar caps
volcanic outgassing
“Cambrian explosion”
The effect of orogeny

- **Tectonics**
  - Uplift and Surface Motion
- **Erosion**
  - Fluvial incision
  - Mass Wasting
  - Glacial Processes
- **Climate**
  - Precipitation
  - Surface Temperature
  - Global Circulation
  - Enhanced Precipitation
- **Alpine Glaciation**
- Enhanced Elevation
- Enhanced Relief
  - Enhanced Basin Size
- Reduction of Orogen Mass
- Reduction of Gravitational Stresses

Cycle:
1. Tectonics → Erosion
2. Climate → Enhanced Precipitation
3. Enhanced Precipitation → Alpine Glaciation
Long-term carbon cycle

• Carbon added to atmosphere through metamorphic outgassing and outgassing of volcanoes and mid-ocean ridges

• Hydrolysis-weathering of silicate minerals in continental crust:
  \[ \text{CaSiO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2 + \text{H}_2\text{O} \]

• The products of continental weathering are transported to the oceans by rivers, where they are used to make CaCO3 and SiO2 shells of marine organisms. When these organisms die, many of them are deposited and buried on the seafloor. The carbon cycle is completed upon subduction and melting of these sediments. The melt may rise as magma, providing volcanoes and MORs with a source of recycled CO2.
BLAG hypothesis:
Plate tectonics influence global climate by moderating atmospheric CO$_2$ concentrations.
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Plate tectonics influence global climate by moderating atmospheric CO\textsubscript{2} concentrations
Uplift weathering hypothesis: Uplift accelerates chemical weathering, drawing down CO$_2$, and cooling the global climate.
• Chemical weathering – a CO$_2$ sink

CaSiO$_3$ + H$_2$CO$_3$ → CaCO$_3$ + SiO$_2$
The End

Enjoy the Summer!