Plate Tectonics & Long-term Climate (Ch. 5)

- Geologic record → greenhouse - icehouse cycles
- Cycles related to tectonics?
  - Polar position hypothesis- paleogeography
  - Tectonic control on atm CO₂
    - Changes in CO₂ supply
    - Changes in weathering due to uplift (elevation of continents)
- Biological overprint

Supercontinent break-up & fm of ocean basins
Wilson cycle

Stage 1: Embryonic
Motion: Uplift
Feature: Complex system of rift valleys and lakes on continents
Example: East African rift valleys

Stage 2: Juvenile
Motion: Divergence (spreading)
Feature: Narrow sea with matching coasts
Example: Red Sea

Stage 3: Mature
Motion: Divergence (spreading)
Feature: Ocean basin with continental margins
Example: Atlantic Ocean, Arctic Ocean

Stage 4: Declining
Motion: Convergence (subduction)
Feature: Subduction begins, island arcs, and trenches form around basin edge
Example: Pacific Ocean

Stage 5: Terminal
Motion: Convergence, collision, and uplift
Feature: Oceanic ridge subducts, narrow, irregular seas with young mountains
Example: Mediterranean Sea

Stage 6: Suturing
Motion: Convergence and uplift
Feature: Mountains form as two continental crust masses collide, are compressed, and override
Example: India–Eurasia collision, Himalaya Mountains

Supercontinent break-up & formation of ocean basins

- Pannotia 200 million years ago
- Rodinia 750 million years ago
- Nuna 1.4 billion years ago

550 Ma
Polar Position Hypothesis

- Continents move into different climate zones

Does high latitude guarantee glaciation?
Did ice sheets form in portions of Gondwana as it moved across the South Pole?

- Gondwana moved across South Pole for ~200 Myrs
- Evidence of sporadic (not continuous) glaciations
  - some were brief - n. Sahara (~430 Ma) lasted <10 Myrs (& probably < 1 Myrs)
  - s. Gondwana (325 - 240 Ma)
Atm CO$_2$ is also important
- BLAG model 1983
  Atm CO$_2$ driven by $\Delta$sFS rates
- T.C. Chamberlain or Raymo/Ruddiman Model
  Atm CO$_2$ driven by uplift & weathering $\Delta$s

Polar position alone ≠ glaciations (past 500 Myrs)

BLAG has been superseded by Berner’s GEOCARB models (I, II, III, GEOCARBSULF)
All C models now acct for both SFS & weathering
GEOCARB: changes in SFS rate control atm CO$_2$

SFS rates $\rightarrow$ determined from crustal ages & width btwn magnetic reversals $\rightarrow$ used to estimate CO$_2$ outgassing through time
Biological processes have played an important role in transferring C from the atm to the lithosphere.

Sed C $\rightarrow$ delamination/decarbonation $\rightarrow$ melting in subduction zones $\rightarrow$ CO$_2$ outgassing

GEOCARB also uses negative feedback of chemical weathering "thermostat"
Summary of GEOCARB Model

- SFS + chemical weathering control CO₂ over 10s-100s Myrs
- C transported to oceans; some is buried
- Sedimentary C recycled through subduction & outgassing or mtn bldg & erosion

Model Evaluation - works well for extensive ice sheet prediction

<table>
<thead>
<tr>
<th>Time (Myr ago)</th>
<th>Ice sheets present?</th>
<th>Spreading rates</th>
<th>Hypothesis supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>No</td>
<td>Fast</td>
<td>Yes (high CO₂)</td>
</tr>
<tr>
<td>0</td>
<td>Yes</td>
<td>Slow</td>
<td>Yes (low CO₂)</td>
</tr>
</tbody>
</table>
**Uplift Weathering Hypothesis**

- Assumes CO₂ supply is constant
- Rate of CO₂ removal changes
- Controlled by availability of fresh rock/mineral surfaces

Tectonic uplift controls/enhances chem weathering by increasing exposure of fresh rock surfaces through physical weathering.
Exfoliation

Granite

Vertical jointing

Basalts


downward pressure

Exfoliation joints

Sedimentary rock layers

Time

Joints bounded blocks

Vertical joints

Bedding

Soils on glacial moraines

Very old weathered soils

Rate of weathering

Time of moraine exposure (years)
**Uplift Weathering Hypothesis**

- Uplift
- Steep slopes
- Mass wasting
- Mountain glaciers
- Slope precipitation
  - Increased rock fragmentation
    - Increased weathering and CO$_2$ removal
      - Global cooling

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**Table 5-3: Evaluation of the Uplift Weathering (CO$_2$ Removal) Hypothesis**

<table>
<thead>
<tr>
<th>Time (Myr ago)</th>
<th>Ice sheets present?</th>
<th>Continents colliding?</th>
<th>Hypothesis supported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>325–240</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (low CO$_2$)</td>
</tr>
<tr>
<td>240–35</td>
<td>No</td>
<td>No</td>
<td>Yes (high CO$_2$)</td>
</tr>
<tr>
<td>35–0</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (low CO$_2$)</td>
</tr>
</tbody>
</table>
What is the Difference?

Tectonics rule, but key factors differ:

- Uplift weathering – chem weathering drives climate change
  - Uplift → fragmentation & exposure of fresh rocks
    → chemical weathering → CO₂ sink
  - Big problem: run out of atm CO₂

- BLAG – CO₂ outgassing drives climate change;
  chem weathering is a negative feedback
  - GEOCARB takes into acct uplift & different rock types being weathered at different times

  • Polar position helps

Combine them → Greenhouse/Icehouse Fisher cycle

1<sup>st</sup> half of Wilson cycle → Fast SFS → more CO₂ → greenhouse climate

2<sup>nd</sup> half of Wilson cycle - Uplift & mtn bldg → chemical weathering
  → CO₂ drawdown → icehouse climate
What drives long-term (100 myr) ΔSL?

SFS rate affects SL

- Fast spreading
  - "Fat" profile
  - Smaller basin
  - High sea level

- Slow spreading
  - "Thin" profile
  - Larger basin
  - Low sea level
SFS rate affects SL & CO₂

Feedbacks – albedo, thermal expansion, heat capacity

Continental margins affect SL: large volume → displace sw
One supercontinent → less total margin area → lower SL
Many smaller continents, each w/ its own margin → higher SL

more continents + high SFS rate & MOR length = high SL
What drives Greenhouse-Icehouse Cycles?

Continental configuration and position (polar position hypothesis)
Changes in CO₂ supply (SFS)
Changes in CO₂ removal - weathering due to uplift (elevation of continents)
Biosphere mediation of CO₂, C export to lithosphere
Next time

The Greenhouse Climate (Ch. 6, part 1)
Causes of greenhouse climate, 100 Ma
Mechanisms for long-term sea-level change
Sea level - climate interactions