

8 Plate Tectonics

I. Intro

- A. Earth forms as a hot body **show figure**
 - 1. initial cooling led to fractionation
- B. heating may have played some role in the early segregation of the earth
 - 1. still plays a role today
- C. radioactive decay of 4 elements still releases heat in the Earth's interior
 - 1. ^{40}K $t_{1/2} = 1.28$ by; ^{235}U $t_{1/2} = 0.72$ by; ^{238}U $t_{1/2} = 4.47$ by; ^{232}Th $t_{1/2} = 14$ by
 - 2. heats the mantle and drives convection cells which allow heat to escape
 - 3. this forms the basis for plate tectonics

II. Basic components

- A. Heat can be moved from the Earth's interior 2 ways **show figure**
 - 1. diffusion (conduction) vs. advection (convection)
- B. convection serves to transport most heat from earth's interior to sfc. **Fig. 7-22**
 - 1. convection cells drive the motion of lithospheric plates
- C. Earth's size and early chemical segregation important in the development of these convective cells
 - 1. smaller planets/moon cool too quickly, never have time to develop these cells
 - 2. Venus is the same size as the Earth but is apparently too hot at the surface
 - a. more later
- D. lithospheric plates consist of a piece of the upper mantle and the crust **Fig. 7-13**
 - 1. below the lithosphere is another part of the upper mantle
 - a. the asthenosphere
 - b. hot and ductile (presumably solid) but can flow
 - 2. at divergent boundaries (ocean ridges) rifting relieves pressure and some of the mantle melts **Fig. 4-22**
 - 3. forms new basaltic oceanic crust
- E. plate motion is driven by a variety of forces **Fig. 7-23**
 - 1. push of the ridges (F_2) and pull of the subduction zone (F_3) appear to dominate today
 - 2. mantle drag (F_1) may have been more important in the past
- F. oceanic lithosphere **back to Fig. 4-22**
 - 1. ~8 km of basalt plus 10's of km of buoyant upper mantle material (olivine rich)
 - 2. as it moves away from ridges it cools and becomes dense
 - 3. depth of ocean basins increases as a result of this cooling **Fig. 4-45**
 - 4. basalt at the base of the lithosphere eventually converted to eclogite
 - a. eclogite - a high pressure form of basalt
 - b. forms from cool basalt at depths $> \sim 50$ km in the upper mantle
 - 5. this transition contributes to the negative buoyancy of old oceanic plates
 - 6. plays a role in their subduction
 - 7. sediment also accumulates on oceanic plate as it moves
 - a. important in many global cycles on long time scales

G. continental lithosphere

1. continental crust is thicker than oceanic crust - averages ~30 km
2. less dense than oceanic crust because of differences in its chemical composition

III. Present day plate tectonics

A. 3 types of plate boundaries

Fig. 4-4

B. divergent boundaries - new oceanic crust forms at mid-ocean ridges

Fig. 4-17A

1. leaves a symmetrical geomagnetic record

Fig. 7-10

C. convergent boundary - plates collide

Fig. 7-19

1. 2 of the 3 possibilities clearly lead to subduction of oceanic crust
 - a. get partial melting of the slab (sinking plate), sediment cover and continental crust as lava moves upwards
 - b. forms either volcanic island arcs or continental arcs

D. continental arc systems

1. collision of a continental/oceanic plate with an oceanic plate
2. here collision occurs near the continental edge
3. oceanic crust sinks because it is denser

Mt St Helens

E. island arc systems

Fig. 4-20

1. collision of 2 oceanic plates far from continental crust
2. plate w/o continent crust will sink

F. formation of new crust at convergent boundaries

1. material can range from being more basaltic to andesitic
2. depends on several factors
 - a. temp. of magma formation
 - b. sediment cover and water content of subducting plate
3. fractional melting of magmas leads to the separation of different minerals

Bowens rxn series

G. collision of two continental plates

1. closing of ocean basins
2. forms the highest mountains on land
3. Himalayas today
4. prior to this some of this sediment also forms a wedge of deformed sediment that is incorporated onto the continental crust
5. processes such as these were important in the early formation of continental crust

Fig. 4.24

H. transform faults - plates slide past one another at

Fig. 7-20

1. this can cleave off bits of continental crust that are eventually plastered onto other continental land masses

IV. Plate tectonics in the Archaen

A. heat flow during Archean was much higher

1. greater amounts of radioactivity in the Earth's interior

2. the vigorous activity of the early mantle may have discouraged the preservation of early crustal material
 - a. original crust was likely very “oceanic” in origin
 3. other “competing” process led to the evolution of continental crust
 - B. convection cells and plates likely smaller than today
 1. also perhaps more “hot spots” like Hawaii or Iceland
 - C. Archean lithosphere may have been too hot and light to be subducted
 1. would also be thicker
 2. under thicker sections denser oceanic crust melted **back to Bowens rxn. series**
 - a. formed Na-rich TTG rocks **go to Table**
 - b. lighter material that forms the basis of early continental crust
 - D. at microplate boundaries, the plates may only have been compressed and folded
 1. plate collisions add new materials to form continents **Figs. 11-22**
 2. oldest material resides in the continental interiors **Fig. 7-24 and photo**
 - E. when did this all happen? **show time tale w/graphs**
 1. most models suggest much of the crust formed between 3 and 2.5 bybp
 2. not all agree
 3. also later periods of episodic rapid growth
 - F. perhaps related to Wilson cycles/supercontinent formation
 - G. presence of water and moderate surface temps are important for the evolution of modern plate tectonics
 - H. plate tectonics allows heat be removed from the mantle by the subduction of cool oceanic lithosphere and upwelling of new oceanic crust
 1. drives convection cell
 2. also allows basalt-eclogite transition depth to be rel. shallow
 3. subduction leads to fractional melting of oceanic crustal that lead to the formation of light continental crust
 4. on a hotter planet (Venus) the lithosphere is too buoyant
 - a. never gets cold enough to subduct
 - I. presence of water also important
 1. water needed for granite formation
 2. water in subducted sediments acts to “catalyze” fractional melting of mantle material or subducted oceanic crust
 3. on Venus (which lost its water early on) this then inhibits the formation of crustal material that is continental-like in its chemistry
- V. Archaean/Proterozoic transition - why did plate tectonics change? (conventional model)
- A. early plates eventually became bigger and thicker
 1. spanned several small convection cells
 - B. continued recycling of oceanic crust led to the formation of large amounts of buoyant continental crustal material
 1. continued partial melting/distillation of this material

2. separation of Si and other elements (K, O) in this newly formed cont. crust from Mg and other elements that partition into oceanic crust/basalt or mantle material
 3. convert mafic materials to felsic material
 - a. this occurs not only by igneous processes but also by sedimentary and metamorphic processes
 - C. decrease in heat production (due to continual loss of radioactive elements) also slowed mantle convection
 1. drove the system towards larger convection cells
 2. allowed these larger plates to travel farther on the Earth's sfc and therefore cool more
 3. led to subduction (rather than collision) of plates
 4. get the onset of modern plate tectonics
- VI. alternate view on the evolution of plate tectonics - see discussions in Lovelock's book
- A. does life play a role in initiating plate tectonics?
 - B. Earth is also the only planet with life and active plate tectonics
 - C. is there a connection or a cause and effect relationship?
 - D. Lovelock points out the relationship between weathering, calcite deposition in the oceans and plate tectonics
 - E. also notes that life affects/mediates weathering and calcite deposition
 - F. very unorthodox view of things
- VII. Plate tectonics since the Archaean
- A. present-day plate tectonics began roughly 2.5 bybp
 1. end of Archaean, beginning of Proterozoic
 - B. since then the intensity of plate tectonics has varied over time
 1. plates generally move a few cm per year
 - C. Wilson cycles **Fig. 7-26**
 1. approx 500 my cycles in which supercontinents form, break up into smaller continents and then reassemble.
 2. evidence of such a supercontinent 600-900 mybp
 3. supercontinent Pangea formed ~300 mybp **Fig. 7-12**
 4. causes are not well understood **back to Fig. 7-26**
 - a. mantle convection may draw continents to cold regions of the asthenosphere
 - b. continental insulation then allows mantle below to warm up and eventually initiates a new rift **Fig. 8-18**
 - c. initially occurs at hot spots, then grow into a spreading center
 5. Atlantic Ocean has opened and closed over time
 - a. last closed when Pangea formed - has been opening ever since
 - b. compressed sediment formed the Appalachian mountains
 - D. periods of rapid seafloor spreading
 1. sea level rises
 - a. large amts. of hot, shallow basalt form and don't cool much as plates move
 - b. drives sea level up

2. high CO₂ from this tectonic activity
 - a. two reasons
 - b. CO₂ released when new crust forms at spreading centers
 - c. subducted ocean crust also carries marine sediments containing calcite
 - (i) the partial melting of this material releases CO₂ from the calcite
3. reverse is true when spreading slows down
 - a. low CO₂ and deeper ocean basins

VIII. Age of continental vs. oceanic crust

- A. continental crust tends to be older
 1. once buoyant crust is formed it is not subducted – **show figure**
 - a. crustal material lost solely by weathering/erosion
 2. becomes the focus point for additional crust formation
 3. occurs thru island and continental arcs and closing of ocean basins
 - a. collisions that can push up marine sediments and oceanic crust onto continents
- B. oldest rocks on earth are continental crust - ~4.3 – 4.4 by
- C. oceanic crust much younger - none older than ~150 my
 1. recycled at subduction zones
 - ~~2.~~ oldest crust is farthest from spreading centers near subduction zones