Plate Boundaries, evidence to support Plate Tectonics, Mechanisms of Motion

I. Divergent Boundaries
  A. Moving apart
  B. Sea Floor spreading at Oceanic Ridges
    1. Ridge is a relative term
      a. 2000-3000 m higher than surrounding sea floor
      b. 1000-4000 km wide
      c. often contain central ‘rift valley’
    2. ridge exists because of newly created lithosphere
      a. made from upwelling, hot melt from mantle
      b. hotter things are less dense
      c. as sea floor moves away from ridge, it cools
        1) contracts as it cools, becomes more dense
        2) increase in lithosphere thickness because cooling strengthens underlying mantle
    3. spreading occurs from 2 to 15 cm/yr: average ~5 cm/yr
      a. could have created all ocean basins in existence in 200 million years
      b. no oceanic crust has been discovered that is over 180 million years old
  C. divergent boundaries can occur on continents also
    1. examples
      a. East African Rift Valley
      b. Rio Grande Rift
    2. Characterized by volcanism, faulting, down-dropped areas within uplifted area
    3. Continued rifting results in splitting of continent
      a. fill with mantle-derived material—dense
      b. new lithosphere created becomes oceanic
        1) floats at level below ocean surface
        2) Red Sea, for example, or Gulf of California

II. Transform fault boundaries
    1. Plates slide past one another
      a. No new crust is created
      b. No crust is destroyed
    2. Transform faults
      a. Most join two segments of a mid-ocean ridge
      b. At time of formation, roughly parallel the direction of plate movement
      c. Aid the movement of oceanic crustal material
    3. San Andreas Fault

III. Convergent plate boundaries (destructive margins) (colliding plates)
   A. Plates collide, an ocean trench forms, lithosphere is subducted into the mantle
   B. Types of convergence—three general classes, created by two types of plates
      1. —denser oceanic plate subsides into mantle SUBDUCTION
         --oceanic trench present where this occurs
         -- Plate descends angle average 45^o
      2. Oceanic-continental convergence
   C. Denser oceanic slab sinks into the asthenosphere—continental plate floats
   D. Pockets of magma develop and rise—
      1. due to water added to lower part of
      2. overriding crust—100-150 km depth
   E. Continental volcanic arcs form
      1. e.g., Andes Low angle, strong coupling, strong earthquakes
         a. Nazca plate Seaward migration of Peru-Chile trench
         b. e.g., Cascades
         c. e.g., Sierra Nevada system example of previous subduction
   F. Oceanic-oceanic convergence
      1. Two oceanic slabs converge—
         a. one descends beneath the other
         b. the older, colder one
      2. Often forms volcanoes on the ocean floor
      3. Volcanic island arcs forms as volcanoes emerge from the sea
         a. 200-300 km from subduction trench
            1) Philippine Arc
            2) e.g., Aleutian islands
            3) e.g., Mariana islands
            4) e.g., Tonga islands
         b. all are young volcanic arcs, 20 km thick crust
         c. Japan more complex and thicker crust 20-35 km thick
   G. Continental-continental convergence—
      1. all oceanic crust is destroyed at convergence, and continental crust remains
      2. continental crust does not subside—too buoyant
      3. two continents collide—become ‘sutured’ together
      4. Can produce new mountain ranges such as the Himalayas
IV. Summary of plate boundaries—Juan de Fuca Plate example
      1. Divergent margin on west—spreading from Pacific Plate
      2. Convergent boundary on east—
         a. subducted below North American Plate,
         b. creating Cascade Range,
      3. Transform boundary on southwest, south and nortth

V. Evidence for the plate tectonics model
   A. Paleomagnetism—Probably the most persuasive evidence
      1. poles align closely with geographic poles
      2. migrate over time: North pole has been in northern Canada since 1600s
      3. Ancient magnetism preserved in rocks
         a. bar magnet of Earth create by dynamic metallic core
         b. magnetic minerals become aligned like millions of bar magnets
            1) iron-rich minerals: pyroxene, hornblende—in basalt lava
            2) cool below 580^{o} C (Curie point) become aligned with field
            3) Paleomagnetic records show
      4. “Polar wandering” showed that 500 million years ago,
         a. there were two north poles—didn’t seem too likely
         b. North America and Europe drawn backward
            1) through time show same pole position
            2) was evidence that continents moved
      5. Earth's magnetic field reverses at irregular intervals
         a. studies of lava flows in 1950s revealed direction of
         b. pole from rock that recorded the magnetism varied widely over time.
         c. volcanoes are big magnetic tapes recording Earth’s magnetism
            1) distinct and unique sequence of reversed and normal rock
            2) sea floor shows distinct magnetic banding
         d. Recorded in rocks as they form at oceanic ridges
            1) Record across ocean ridges confirms seafloor spreading
            2) new basalt added to ocean floor, equal amounts to edges of plates
            3) Paleomagnetic time scale shows rates of spreading
               a) North Atlantic Ridge is spreading about 2 cm/year
               b) East Pacific Rise spreading more than 15 cm/year in places
   B. Earthquake patterns
      1. Associated with plate boundaries:
      2. in fact the plate boundaries are defined by earthquakes
      3. Deep-focus earthquakes only occur along trenches
         a. pattern shows depth increases with distance from trench to volcanic arc
         b. provide a method for tracking the plate's descent
         c. few quakes below 700 km are recorded:
            1) perhaps plate loses rigidity to have quakes below this depth
            2) perhaps plate become assimilated into underlying material at this depth

C. Ocean drilling

1. Deep Sea Drilling Project
2. ship: Glomar Challenger, replaced by Joides Resolutioncould lower drill pipe to sea floor (1000s of meters) and drill into sediment
3. Character of sediment
    a. thinnest on axis of ridges, thickest near trenches
    b. Dated by fossils contained within it:
        basalt altered by sea water so can't be dated by radiometric methods
    c. Age of deepest sediments in any area (those upon basalt sea floor)
        1) Youngest are near the ridges
        2) Older are at a distance from the ridge
4. Supports tectonic hypothesis prediction that ocean basins are geologically young
    a. oldest sea floor sediments found are 180 m.a.
    b. continental crust, by comparison, has been found up to 3,900 m.a.

D. Hot spots—explanation of the data, within framework of plate tectonics model

1. The data: there are chains of seamounts and guyots increasing
    regularly in age Hawaii → Midway → Suiko → Aleutian Trench
2. The explanation in the model
    a. Rising plumes of mantle material
    b. Volcanoes can form over them, upon moving plate above the plume
        e.g., Hawaiian Island chain
    c. Chains of volcanoes mark plate movement
    d. Tracks direction and rate of plate movement
3. rate of movement over hotspot compares well with rate of divergence at rise
4. This allows us to infer that hotspot does not move

VI. Measuring plate motion

A. By using hot spot "tracks" like those of theHawaiian Island- Emperor Seamount chain

1. 3000 miles long
2. 65 million years old
3. 9 cm/year!

B. Using space-age technology to directly measure motion of plates

a. Very Long Baseline Interferometry (VLBI)
    1) radio telescopes measure to far object from two places
    2) measure again at a later date and compare distances
    3) good for places separated by long distances (i.e. North America and Europe)
b. Global Positioning System (GPS)
    1) satellite triangulation
    2) precise to fractions of cm in a local area
    3) Good for across active faults
    4) Confirms plate movement
        a) Hawaii moving toward Japan at 8.3 cm/year
        b) England separating from Maryland at 1.7 cm/year

VII. Driving mechanism of plate tectonics

A. No one model explains all facets of plate tectonics
   1. Earth's heat is the driving force
   2. convective overturn in mantle does move plates
   3. Unequal heat distribution within Earth’s interior is equalizing

B. Several models have been proposed
   1. Slab-pull vs. ridge-push models
      a. Descending oceanic crust pulls the plate by gravity
      b. slope of spreading ridge allows plate to slide off of it
      c. May work in tandem
   2. Mantle plumes may contribute to the push off the ridge
      a. some originate at core-mantle boundary
      b. some upward flow of heat not related to plumes
   3. Convection hypotheses
      a. data to account for
         1) boundaries within Earth’s interior mapped by seismic waves
         2) heat flow within Earth’s interior mapped by seismic waves
         3) chemistry of lava at plumes is different from lava at ridge
      b. the models
         1) 660 km boundary
            a) matches differences of lava chemistry
               i. ridge lava comes from high in mantle
               ii. plume lava comes from core-mantle boundary
            b) seismic mapping shows oceanic slabs descend into lower mantle
         2) whole mantle convection
            a) matches the interior structure of Earth’s interior
            b) does not match lava chemistry
         3) Deep layer that does not mix (like a ‘lava lamp’)
            a) accounts for chemical differences of ridges vs. plumes
            b) allows cold oceanic slabs to convect down to core-mantle boundary
            c) no actual evidence to support this idea, although it cannot be discarded due to lack of evidence