GLOBAL PLATE TECTONICS

I. Introduction
- “Tectonics” comes from the Greek, *Tektonikos*, which means “to construct”
- This concept revolutionized all of geology, and especially the discipline of Geological Oceanography
- Our planet is constantly changing, due to volcanoes, earthquakes, etc. and these are all due to the release of massive amounts of energy that drive plate tectonic processes
- As far as we know, Earth is the only planet to (still) have plate tectonics!

II. Terms and Concepts (Review)
- Our planet is composed of layers:
  1) Crust
  2) Mantle
  3) Outer/Inner Core

- We can also divide the outer part (excluding the core and lower mantle) into 2 broad categories:
  1) **Lithosphere (rocky sphere)**—outermost layer, including the crust and upper mantle
     - This layer is rigid (it’s a shell), and cool
     - It overlies (“floats on”) the hotter, inner layer
  2) **Asthenosphere (weak sphere)**—inner layer, including the rest of the upper mantle (it doesn’t include the lower mantle or core!)
     - Hotter than the lithosphere
     - very close to the melting point, so it’s very plastic (viscous), flows slowly—it’s also more dense

- The lithosphere “floats” on the Asthenosphere because of **Isostasy:**
  - the relative elevation of one object within another object of differing densities—in other words, how high one object “floats” in another object based on the pull of gravity and their relative densities
  - Basalt: product of the melting of the earth’s interior which then flows to the surface as lava. ~3 g/cm³ density
  - Granite: same as basalt, but forms more slowly ; 2.7 g/cm³
  - Mantle: viscous, internal material; 3.3 g/cm³ density
  - Isostatic Adjustment: if the mantle is particularly hot (buoyant) under a section of continent, it can rise up higher than we would expect based solely on densities—San Gabriel Mountains are a good example

III. History of Plate Tectonics
A. Suspected long before the 20th Century:
- 1596, Dutch map maker Abraham Ortelius – *Thesaurus Geographicus*
  - Ortelius suggested that the Americas were "torn away from Europe and Africa . . . by earthquakes and floods" and went on to say: "The vestiges of the rupture reveal themselves, if someone brings forward a map of the world and considers carefully the coasts of the three [continents]."
- 1858, Idea resurfaced in the work of geographer Antonio Snider-Pellegrini

B. Wegener and the theory of Continental Drift
- Alfred Lothar Wegener was a 32 year old German meteorologist
- 1912 Published two articles describing a supercontinent called “Pangaea”
  - Explained evidence for dramatic climate shifts (for example, coal deposits in Antarctica)
  - Also explained why S. America and Africa look like they fit together
  - Finally, some fossils are found on the edges of both S. America/Africa
  - Fatal weakness—no explanation for what the force was that caused this movement (we still don’t know for certain!)

IV. Evidence for Continental Drift from the Land
A. Jigsaw Puzzle
- 1965, Sir Edward Bullard used a computer model to fit the continents together…but instead of using the modern boundaries, he used the edges at 2000 m depth

B. Continental Geology:
- As described by Wegener, there are puzzling inconsistencies in both the fossil record (relative dating technique) and the apparent climate…it appeared that some areas were much warmer than they are today!
- We find coral reef fossils in the Himalayas, Western Europe, and North America…and yet we can assume that the earth’s climate is a function of latitude, and always has been
  - Corals only grow in clear, warm water (>18°C)
  - 250-350 mya, two super-continents:
    - Laurasia and Gondwana
    - Panthalassa ocean surrounded everything
  - 200 mya, formed Pangaea, with Tethys Sea—allowed the formation of corals!

C. Paleomagnetism—The study of magnetism in rocks
- Mantle has lots of iron in it…therefore, basalt rock has lots of magnetite and ilmenite, which record the direction and intensity of magnetic fields when they form
- Curie Temperature: As magma cools, oxides of minerals form. Below 600°C, these minerals line up with the magnetic field, and get set—similar to striking a steel screwdriver while it’s pointing towards the magnetic pole
- It also records the **Magnetic Dip**, which tells you where the rock formed—at the equator, there’s no dip. At the poles, the dip is at its maximum.

- **Apparent Polar Wandering**—the magnetic poles aren’t always at the “North Pole”, but on average are relatively close. There can only be one magnetic North at a time!
  - Looking at ancient rocks from different continents, they point to different magnetic poles—these are too far from the North Pole! There’s no way that the magnetic pole wandered that much.
  - So, one explanation is that the **continents drifted!**

- **Magnetic Pole Reversals**—Ancient rocks appear to change the magnetic North pole from North (current direction) to South, 1-2 times every few million years for the last 76 million years.
  - Right now, magnetic North is weakening (for the past 150 years or so)...in the next few thousand years, it will probably reverse again.

D. Summary
- By the 1960’s, there was a lot of evidence that the continents weren’t always where they are today...but it was still a hotly debated topic because it seemed so far-fetched. What could drive these changes?

V. Evidence for Plate Tectonics from the Oceans
A. Chronology
- 1947: Maurice Ewing determined the existence of a vast “abyssal plain”
- 1947: Based on that, Oceanographers admitted that the ocean floor wasn’t flat, started proposing the theory of Continental Drift
- 1947: Not enough sediment on the sea-floor if the ocean is 4 billion years old
- 1950’s: Paleomagnetism applied to the sea floor
- 1956: Ewing and Bruce Heezen propose that there’s a Mid-Oceanic Ridge system, and accompanying Rifts (trenches)
- 1960: US Geologist Harry Hess proposes the concept of sea-floor spreading—the basis for modern plate tectonics—based on depth records from WW II.
- 1963: Vine and Matthews (Cambridge) prove the existence of magnetic reversals which are **mirror images** of each other at the oceanic spreading centers
- 1963: Deep Sea Drilling Project Started

B. Deep Sea Drilling Project
- To prove (or disprove) the concept of sea-floor spreading, the DSDP went looking for evidence:
  1. There should be more sediment accumulation in older sections of the ocean basins
  2. Fossils immediately over the basaltic crust should be older as you move away from the spreading centers
3. Radio-isotope dating of the crustal material should confirm these dates

VI. Sea-Floor Spreading—Mechanisms
- To understand how sea-floor spreading works, we have to understand the geology of the planet
  - Lithosphere: the rigid, cool crust is broken up into a series of “plates”
  - Asthenosphere: much hotter, and capable of slow movement (like liquid glass, or molasses)
  - We don’t really know what the mechanism is, but the patterns are consistent with the formation of convection cells, which allow the escape of heat from the deep earth.
- Where does the heat source come from? Mostly from the decay of radio-isotopes in the earth’s interior.
  - About 94% of the heat comes from the Mantle, and about 6% from the core material
  - The release of heat (=energy) from the mantle causes volcanoes
  - Core heat causes the formation of hot spots, and is much more localized to one region—we can tell because the basalts formed have different mineral composition (core has more K, Ru, Cs, U, Th)
    - Hot spots include Iceland, Hawaii, Yellowstone
  - There are about 41 hot spots that we know of right now
- Evidence for convection:
  - The mid-ocean ridges are hotter than average (about 10x), while the trenches are colder than average (about 1/10)
  - The “excess energy” may explain why trench areas violate isostasy—higher than they should be
  - Depth of oceans (shallowest at ridges) is consistent with sea-floor spreading…as the rock cools, it contracts, making the oceans deeper
  - Also consistent with oldest rocks in trenches, youngest at ocean ridges
  - Lastly, explains both the “ring of fire” and the worldwide distribution of earthquakes

VII. Plate Boundaries
- After the DSDP results, scientists accepted the idea of Plate Tectonics, or the idea that the continents move around because there are a series of plates.
- Where Plates meet each other, there are 3 types of boundaries:
  1. Divergent (constructive): new lithosphere is being added
  2. Convergent (destructive): plates collide and one is subducted
  3. Transform (shear): plates slide past each other, no gain or loss of material
- ALL of these interactions cause earthquakes!
- At any boundary, we can describe it by looking at its fault strike and fault dip.
  - Fault Strike—the direction of its surface orientation
  - Fault Dip—the direction of its vertical orientation
- We can describe an earthquake by looking at its 3-D structure:
- P Waves (pressure, or primary, or compressional)
- S Waves (secondary, or shear)—liquids don’t allow S waves

A. Divergent Boundaries
- Oceanic ridges known as oceanic ridges or rises, located at deep ocean spreading centers
- The spreading rate determines the morphology of the ridge:
  - East Pacific Rise is gently sloping, b/c it spreads rapidly (16 cm/yr)
  - Mid-Atlantic Ridge is very steep, b/c it spreads slowly (2-3 cm/yr)
    - MAR has more violent earthquakes, probably because the lithosphere is stiffer, and also thicker

B. Convergent Boundaries
- Commonly known as trenches or subduction zones
- Very common locations of strong earthquakes
- A plate with a continent near the edge almost always rides over an oceanic plate—as the material is subducted, it heats up and releases excess volatiles and water vapor—forms volcanoes
  1. Island Arc Systems—about 100 km landward of the trench, the volcanoes form a series of islands—Aleutian Islands, Japan—forms shallow sea between islands and continent
  2. Continental arc trench systems—volcanic rock mixes with the granitic material as it surfaces, forms mountain ranges (Peru-Chile Trench)
  3. Continental Mountain Systems—himalayas, formed by the smashing together of india and Asia

C. Transform Boundaries
- Plates slide past each other
- If they’re associated with magma chambers, they’re transform faults
- If there’s no magma chamber, they’re fracture zones (old transform fault)
  - form sharp cliffs, because one side is much older than the other side
- San Andreas Fault is a good example of a transform fault

VIII. Growth of the Ocean Basins
- **Paleogeography** is the study of the historical changes in the shapes and positions of the oceans and continents
- **Paleoceanography** is the study of the changes in the physical and biological character of the oceans resulting from paleogeography
- The age of the ocean floor is highly variable…the Atlantic is the most symmetric, while the Pacific is least symmetric.
  - Atlantic spreading is the slowest
  - Pacific basin is fastest, and surrounded by many subduction zones
- Oldest ocean crust is about 175 Ma—anything older than that was subducted a long time ago, even though the earth is 4.6 Bya