Chapter 2  Plate Tectonics: A Scientific Revolution

• Until the 1960’s scientists thought
  – mountains formed due to compression as the earth cooled and shrank.
  – That continents were in fixed positions since the formation of earth.

• Today we know Earth’s major mountains are produced by collision of lithospheric plates
Continental Drift was proposed by Alfred Wegener in 1915, but it was rejected (you are not responsible for his name or this date)

- He proposed the supercontinent called **Pangaea** began breaking apart about **200 million years ago**

  He died on a Greenland expedition trying to prove his theory.
Wegener’s original evidence of Continental Drift

- Based on correlations across the Atlantic ocean.
  - Continental coastlines across the Atlantic Ocean are mirror images
  - Rocks of mountain ranges continue across oceans
  - Identical land-based fossils found on both sides of the Atlantic Ocean
  - Climate and glacial movement

- Continental Drift was rejected because there was no evidence of a reasonable mechanism for the great forces needed to move large masses of solid rock long distances.
Wegner’s Evidence of Continental Drift:
1. Continents across the Atlantic Ocean fit together as a mirror image

- Con: it was not a perfect fit.
- We now know the continental slope is the edge of continent so the fit is better fit.
Wegner’s Evidence of Continental Drift:
2. Mountain Ranges correlate across the Atlantic Ocean

Appalachian mountains of the U.S. are of comparable age and structure to those across the Atlantic Ocean.

As Pangaea these mountain ranges fit together like a puzzle.
Wegner’s Evidence of Continental Drift:
3. Fossils Match across the ocean

Identical fossils of land-based plants and animals are found on continents now separated by vast ocean. (You do not need to memorize the names of these fossils)
Wegner’s Evidence of Continental Drift:
4. Paleoclimatic evidence correlated across the oceans.

Glacial striations provide evidence glaciers occurred in a certain area and the direction of glacial movement.

Evidence of occurrence of ancient glaciers at the equator and coal swamps in cold regions.

Reconstructed into Pangaea, ancient glaciers occur at the south pole and coal swamps at the equator.
Theory of Plate Tectonics is now proven (which includes proof that continental drift)

- **Theory of Plate Tectonics**: Earth’s outer rigid shell called the **lithosphere** consists of individual plates that move on the underlying weaker partially-molten **asthenosphere**
Lithospheric Plates
Some Features of Lithospheric Plates

- They change shape, size and location through time
- Larger plates contain both continental and oceanic crust
- No single plate is defined by the margins of a single continent
- They move about 2 to 20 cm per year
- Most major deformation occurs at plate boundaries
Lithospheric Plate Movement
Types of Plate Boundaries

**Divergent boundary**
- product of extension

**Convergent boundary**
- product of compression

**Transform-fault boundary**
- no compression or extension
- plates slip past one another
Divergent Plate Boundary
Also named: Sea Floor Spreading, Spreading Center, Oceanic Ridge.

- Divergent-plate boundary is located where two plates move apart, resulting in upwelling of magma from the mantle to create **new basaltic-composition oceanic crust** on the sea floor.
Divergent Plate Boundary Features

- Form **oceanic ridges** with narrow canyons down the center called **rift valleys**
Divergent Plate Boundaries

Examples

- East Pacific Rise
- Mid-Atlantic Ridge
- Iceland
Divergent Plate Boundaries
Example: Mid-Atlantic Ridge in Iceland
Divergent Plate Boundaries

Continental rift zone - New Divergent Plate Boundary

- Where a new divergent plate boundary starts forming within a continent
  - First crust warps
  - then a rift valley forms
  - then a linear sea and
  - finally a new ocean forms splitting the continent apart

- Present day examples
  - East African rift valley and Red Sea
Divergent Plate Boundaries
Examples: Continental Rift Zones

East African Rift and the Red Sea
Divergent Plate Boundaries
Summary

• Other names for divergent-plate boundary: Sea-Floor Spreading, Spreading Center, Oceanic Ridge
• Extensional feature (pulling apart)
• Basaltic composition magma pours out forming new oceanic crust
  – Large amounts of basaltic composition magma generally pour out along the same ridge margin for hundreds of millions of years creating ocean basins in the process.
  – This is how the Atlantic Ocean formed.
• Examples: Mid-Atlantic Ridge, East Pacific Rise, Iceland
• Features: oceanic ridges, rift valleys
• Early Divergent margin: Continental Rift Zone
  – Examples: East African Rift Valley, Red Sea
Convergent Plate Boundary
Other names: Subduction Zone, Ocean Trench

- Where two plates move toward each other and the leading edge of the denser plate is bent downward and slides beneath the less dense plate.
  - Oceanic crust is destroyed
  - **New** continental crust is formed
    - As volcanic emanations
      - Forms a **Continental Volcanic Arc**
      or a **Island Volcanic Arc**
    - As sediment accumulations
      - Form the **accretionary wedge**
  - Deep Ocean Trench forms
Convergent Plate Boundary

Earth’s diameter remains constant, so as oceanic crust is created at divergent boundaries, oceanic crust is destroyed at convergent plate boundaries.
Convergent Plate Boundary

3 Types

Ocean-Continental

Ocean-Ocean

Continent-Continental
Convergent Plate Boundary
Examples of convergent plate boundaries (in blue)

- **Ocean-Ocean**: Japan trench
- **Ocean-Continente**: NW United States, Cascade Range
- **Continente- CONTinent**: Himalayan Mountains
Convergent Plate Boundary
Example: Ocean-Ocean Convergent Boundary

The Japanese Islands are a Volcanic Island Arc
Convergent Plate Boundary

Example: Ocean-Continent Convergent Boundary

- Volcanoes of the Cascade Range of the Northwestern United States form a Continental Volcanic Arc. (this includes Mt St. Helens)
Convergent Plate Boundary
Example: Continent-Continent Convergent Boundary

- Produced the Himalaya Mountains which are a Continental Volcanic Arc

(these are the worlds tallest mountains, and occur on the Tibet-India Boarder)
Convergent Plate Boundary

Summary

• Other names for convergent plate boundary: Subduction Zone, Oceanic Trench
• Compressional feature (pushed together)
• Oceanic crust is destroyed
• New Continental Crust forms:
  • Granitic to intermediate composition magma forms new continental crust as either continental or volcanic island arcs
  • Sediment accumulation in the accretionary wedge
• Three types of convergent plate boundaries:
  • Ocean-ocean collision: Japan
  • Ocean-continent collision: Cascade Range of Northwestern U.S.
  • Continent-continent collision: Himalaya Mountains (Tibet-India border)
Transform Plate Boundaries
(also called transform faults)

- Occur where lithospheric plates slide horizontally past one another where oceanic-ridge segments are offset.
- No oceanic or continental crust is produced or destroyed
Transform-Fault Plate Boundary
Transform Plate Boundary
Example

• San Andreas Fault of California of the southwestern United States -
Proof of Plate Tectonics

• Evidence of Plate Motion
  – Ocean Drilling Cores
  – Mantle Plumes and Hot Spots
  – Paleomagnetism
  – Apparent Polar Wandering - Paleomagnetism
  – Magnetic Reversals and Seafloor Spreading - Paleomagnetism
Ocean Drilling Evidence

Core samples of ocean sediments show they increase in thickness and age with increased distance from the ocean ridge crest.
Mantle Plumes and Hot Spot Evidence

- Linear chains of volcanic islands increase in age with distance from a mantle plume (Hot Spot)
- Example: Hawaiian Islands
Numerous Hot Spots and associated Volcanic Chains
Yellowstone National Park (Wyoming) is a hot spot
The last in a series of ancient volcanoes.

The ancient volcano collapsed in forming a caldera

Hot springs at Yellowstone are evidence of magma below

Paleomagnetic Evidence

- Earth has a magnetic field with the lines of force shown on this figure.
- Iron atoms are magnetic with negative and positive poles.
- Iron in magma moves freely so it aligns with the magnetic poles of the earth, based on the location of the magma.
Paleomagnetism (fossil magnetism) of rocks

- When magma cools to below its Curie point (580°C), the iron is “frozen” into the rock pointing to Earth’s poles.
- Because of this iron minerals in igneous rock act as “fossil compasses”. The dip angle of iron atoms gives the location of the rock relative to Earth’s poles at the time it formed from the magma.

http://earthsci.org/education/teacher/basicgeol/platec/platec.html
Paleomagnetic evidence of Apparent Polar Wondering

- Paleomagnetic (Fossil compass) direction measured on rock collected from volcanic rocks from around the world, show the rock have moved since they formed.
How Apparent Polar Wandering works.

- Magnetic minerals in rocks from the same location but different ages suggest the N pole moved with time.
  - Poles cannot move so concluded the rocks moved
  - Paths of poles fit Pangaea model
Paleomagnetic Evidence of Seafloor Spreading – Magnetic Reversals on the Sea Floor

- Over periods of hundreds of thousands of years the north and south poles reverse.
- Iron in ocean basalt “freezes” in this change in polarity.
- Results in reversal bands centered on ocean spreading centers.
Age of the Ocean Floor is controlled by Plate Motion

- All the ocean crust present before the breakup of Pangaea has now been destroyed.
- Since the breakup of Pangaea began approximately 200 million years ago, the ocean crust is less than 200 million years old.
Age of the Ocean Crust is controlled by Plate Motion

• All the ocean crust present before the breakup of Pangaea has now been destroyed, it ranges in age from 0 years to 180 million years.
• The oceanic crust is youngest at the divergent margins and oldest at tectonically inactive continental margins.
Forces that Drive Plate Motion
(in order of importance)

- Mantle convection
  - **Slab Pull**: subducting ocean slab is cold and dense so it sinks and pulls the plate down.
  - **Ridge Push**: the oceanic ridge material “slides” down the flanks.
1. Divergent margin
2. Convergent margin (continent-continent collision)
3. Convergent margin (subduction zone)
4. Transform fault margin
5. Mid-ocean ridge
6. Oceanic trench
7. Rift valley
8. Transform fault
9. Lithosphere
10. Asthenosphere
11. Continental crust
12. Oceanic crust
What type of motion? ______________
What type of plate margin is this? ______________

Where is new continental crust forming (2 locations)?
Where is oceanic crust destroyed?

Not all will be used
Oceanic plate
Continental plate
Deep-sea trench
Volcanic Arc
Mantle melting

**Convergent**
Divergent

**Subduction zone**
Spreading center
Accretionary Wedge
Earthquake zone

http://hays.outcrop.org/images/tectonics/subduction.jpg
End of Lecture Chapter 2

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