Plate Tectonics
Chapter 19
Plate Tectonics

- **Plate tectonics** - Earth’s surface composed thick plates that move
- Intense geologic activity is concentrated at *plate boundaries*
- Combination of *continental drift* and *seafloor spreading* hypotheses proposed in late 1960s
Review: Three Types of Plate Boundaries

- Transform (strike-slip)
- Convergent (subduction)
- Divergent (spreading)

But how do we know that plates move at all?
Early Case for Continental Drift

- Puzzle-piece fit of coastlines of Africa and South America has long been known
Early Case for Continental Drift

• In early 1900s, Alfred Wegner noted South America, Africa, India, Antarctica, and Australia have almost identical rocks and fossils.

- *Glossopteris* (plant), *Lystrosaurus* and *Cynognathus* (animals) fossils found on all five continents.

- *Mesosaurus* (reptile) fossils found in Brazil and South Africa only.
Most of the Earth's ice is found in Antarctic continental glacier. Where are some other continental glaciers?
• *Glacial striations* on a rock from stones grinding at the base of a heavy ice sheet leave these shiny linear marks on the bedrock below.
• Glaciers flow downhill as a solid mass that creates channels, and walls made of ground up rock debris known as a merraine.
Erosional Landscapes

- Erosional landforms produced by valley glaciers include:
  - *U-shaped valleys*
  - *Hanging valleys*
    - Smaller tributary glacial valleys left stranded above more quickly eroded central valleys
Early Case for Continental Drift

- Wegner reassembled continents into the supercontinent *Pangaea*

- Late Paleozoic glaciation patterns on southern continents best explained by their reconstruction into (Pangaea) Gondwanaland
Early Case for Continental Drift

- *Coal beds* of North America and Europe indicate Laurasia super continent

- Continental Drift hypothesis initially rejected
  - Wegener could not come up with viable *driving force*
  - continents should not be able to “plow through” sea floor rocks
The Earth's Magnetic Field Can Give Us Clues
Paleomagnetism and Continental Drift Revived

- Studies of *rock magnetism* allowed determination of magnetic pole locations (close to geographic poles)

- **Paleomagnetism** uses mineral magnetic alignment and dip angle to determine the distance to the magnetic pole when rocks formed
  - Steeper dip angles indicate rocks formed closer to the magnetic poles

- Rocks with increasing age point to pole locations increasingly far from present magnetic pole positions
Paleomagnetism and Continental Drift Revived

- **Apparent polar wander** curves for different continents suggested plate movement!

- Wegner was right!
Earthquakes don't occur randomly – but in patterns

Friction and motion at plate boundaries seem to produce earthquakes
Early Case for Continental Drift

- Puzzle-piece fit of coastlines of Africa and South America has long been known
Plate Tectonics and the Scientific Method

How does an idea become a theory?

* **When** Wegner first suggest the idea of Plate tectonic what was it?
  a) theory  b) hypothesis  c) data  d) proof

* **What** data was later acquired to test this?

* **When** did plate tectonics become an accepted theory?
  (What discovery proved the original predictions?)
The Scientific Method

Step 1: A question is asked

Step 2: Gather data

Step 3: Use data to propose a hypothesis
(Has this hypothesis been tested yet? NO!

Step 4: Make a prediction (based on hypothesis)

Step 5: Test prediction (with new data)

Step 6: Hypothesis becomes a theory! Yeah!
(if predictions and tests are good)
Let's Use the Scientific Method!

You are Captain Kirk on the USS Enterprise. You have traveled unexpectedly to a parallel universe. You come upon a planet that looks like Earth.

Use the Scientific Method to:
1) Make a hypothesis about your discovery
2) Design a way to testing your hypothesis
3) Determine whether your hypothesis is correct and whether it can be transformed into a theory.
Banded rocks on the seafloor

Mid-Atlantic Ridge

Millions of years ago

9.6  33.0  83.0  141.9
Seafloor spreading
Evidence of Plate Motion

- **Marine magnetic anomalies** - bands of stronger and weaker than average magnetic field strength
  - Parallel to mid-oceanic ridges
  - Field strength related to basalts magnetized with current magnetic field
  - Symmetric “bar-code” anomaly
  - Matches pattern of reversals seen in continental rocks
* Symmetric “bar-code” pattern reflects plate motion away from central ridge

* Matches pattern of reversals seen in continental rocks (*Vine and Matthews*)
Seafloor Magnetic Anomalies

Which plates are moving fastest, which move the slowest?
Divergent Plate Boundary
Atlantic Spreading Center – Iceland

DIVERGENT BOUNDARY
At divergent margins, earthquakes tend to be fairly weak and shallow. Earthquakes can only occur in rock that is cold and brittle enough to break; at a midocean ridge, this means they cannot be very deep.
Seafloor Spreading

• Seafloor rocks, and mantle rocks beneath them, cool and become more dense with distance from mid-oceanic ridge
• When sufficiently cool and dense, these rocks may sink back into the mantle at subduction zones
  – Downward plunge of cold rocks gives rise to oceanic trenches
• Overall young age for sea floor rocks (everywhere <200 million years) is explained by this model
Transform Plate Boundaries

- Plates slide past one another
- Fault zones, earthquakes mark plate boundaries
- San Andreas fault in California

San Andreas Fault, Carizzo Plain, Central Ca
Transform Plate Boundaries

- At **transform plate boundaries**, plates slide horizontally past one another
  - Marked by **transform faults**
  - Transform faults may connect:
    - Two offset segments of mid-oceanic ridge
    - A mid-oceanic ridge and a trench
    - Two trenches
  - Transform offsets of mid-oceanic ridges allow series of straight-line segments to approximate curved boundaries required by **spheroidal Earth**
Convergent Plate Boundaries

- Plates move toward each other
- Mountain belts and volcanoes common
- Oceanic plates may sink along a subduction zone,
- Typically marked by a deep ocean trench

India-Eurasia Collision
Continents Grow During the Subduction Process
Convergent Plate Boundaries

• At *convergent plate boundaries*, plates move toward one another
• Nature of boundary depends on plates involved (oceanic vs. continental)
  – *Ocean-ocean plate convergence*
    • Marked by *ocean trench*, *Benioff zone*, and *volcanic island arc*
  – *Ocean-continent plate convergence*
    • Marked by ocean trench, Benioff zone, *volcanic arc*, and *mountain belt*
  – *Continent-Continent plate convergence*
    • Marked by mountain belts and *thrust faults*
Volcanoes originate from subducting plates
Activity:

- Locate Volcanoes on west coast of US
- Find pattern in volcano alignment?
Pacific Ring of Fire

- Mt Vesuvius
- Mt St Helens
- Mt Pinatubo
- Krakatoa
- Hawaii
What Causes Plate Motions?

Causes of plate motion are not yet fully understood, but any proposed mechanism must explain why:

- Mid-oceanic ridges are hot and elevated, while trenches are cold and deep
- Ridge crests have tensional cracks
- The leading edges of some plates are subducting sea floor, while others are continents (which cannot subduct)
Mantle convection may be the cause or an effect of circulation set up by

- slab-pull
- ridge-push and/or
Mantle Plumes and Hot Spots

- **Mantle plumes** - narrow columns of hot mantle rock rise through the mantle
  - Stationary with respect to moving plates
  - Large mantle plumes may spread out and tear apart the overlying plate
    - Flood basalt eruptions
    - *Rifting* apart of continental land masses
  - New *divergent boundaries* may form
Mantle Plumes and Hot Spots

• Mantle plumes may form "hot spots" of active volcanism at Earth’s surface
  – Approximately 45 known hotspots

• Hot spots in the interior of a plate produce *volcanic chains*
  – *Orientation* of the volcanic chain shows *direction* of plate motion over time
  – *Age* of volcanic rocks can be used to determine *rate* of plate movement
  – Hawaiian islands are a good example
The origin of Valles Marineris on Mars — the longest trough system in the solar system — was formed by rifting, strike-slip faulting, and subsurface mass removal (An Yin, 2012).
Valles Marineris on Mars has been compared to the Grand Canyon on Earth.
Magnetic Anomalies on Mars

Global maps obtained using data from Mars Global Surveyor

Southern Highlands of Mars (southern hemisphere) is very old undisturbed crust that is heavily cratered.

Do you see any patterns in the ancient crust?

If so – what do they mean?
• Magnetic anomalies located in Mars southern hemisphere
• Mercator projection stretches poles out to make a square map
• Did Mars have plate tectonics and an active magnetic field?
Plate Tectonics on Other Europa

Fractures in Europa's ice sheet indicate stresses from the moon's interior.
Plate Tectonics on Other Europa?

Phaidra Linea and other, similar bands on Europa (one of Jupiter's moons) can be reconstructed to reunite geologic features, demonstrating that these kinds of bands are "pull-apart" boundaries, where the surface has fractured, opened up, and new crust formed.

This process may be similar to spreading centers on Earth.
Mountain Belts and Earth’s Systems
Chapter 20

- **Mountain belts** are chains of **mountain ranges** that are 1000s of km long
  - Commonly located at or near the edges of continental landmasses

- As mountains grow higher and steeper, erosion rates increase (particularly from running water and ice)
Characteristics of Mountain Belts

- **Mountain belts** are very long compared to their width
  - The *North American Cordillera* runs from southwestern Alaska down to Panama
- Older mountain ranges (Appalachians) tend to be lower than younger ones (Himalayas) due to erosion
- Ancient mountain belts (*billions of years old*) have eroded nearly flat to form the stable cores (*cratons* or *shields*) of the continents
Rock Patterns in Mountain Belts

- **Fold and thrust belts** (composed of many folds and reverse faults) indicate crustal shortening (and thickening) produced by compression
  - Common at convergent boundaries
  - Typically contain large amounts of metamorphic rock
Evolution of Mountain Belts

• Rocks (sedimentary and volcanic) that will later be uplifted into mountains are deposited during accumulation stage at convergent boundaries.

• Mountains are uplifted at convergent boundaries during the orogenic stage. Subsequent gravitational collapse and spreading may bring deep-seated rocks to the surface.
Evolution of Mountain Belts

- After convergence stops, a long period of *erosion*, *uplift* and *block-faulting* occurs
  - As erosion removes overlying rock, the *crustal root* of a mountain range rises by *isostatic adjustment*
Growth of Continents

• Continents grow larger as mountain belts evolve along their margins

• New *accreted terranes* can be added with each episode of convergence adding new continental crust which surrounds older *cratons* that form the cores of the continents
Geologic Time
- Geologic processes occur gradually over millions of years
- Changes imperceptible in our lifetime
- Best estimates for age of Earth is ~ 4.56 billion years

History of Life
- 544 million years ago (Ma): Complex life forms
- 65 Ma: Dinosaurs became extinct
- Only a few Ma: Humans came on the seen

“Nothing hurries geology”
- Mark Twain