Continental Drift – an idea before its time

- **Alfred Wegener**
  - First proposed his continental drift hypothesis in 1915
  - Published *The Origin of Continents and Oceans*
  - Some ideas in the publication were:
    1. The supercontinent was named **Pangaea**
    2. Southern section was named **Gondwana** or **Gondwanaland** and northern section, **Laurasia**
    3. The supercontinent broke in pieces about 200 million years ago
Pangaea approximately 200 million years ago

Continental Drift – an idea before its time

- Continental drift hypothesis
  - Continents “drifted” to present positions
- Evidence used in support of continental drift hypothesis:
  - Fit of the continents
  - Fossil evidence
  - Rock type and structural similarities
  - Paleoclimatic evidence
Evidence for Continental Drift

- Continental fit
  - Continental crust matches oceanic crust at the continental slope

Fossil evidence

- The same fossils are found in both South America and Africa
- Fresh water fish cannot migrate through oceans
- Swamp evidence is found in Antarctica
Similarity of Rock Sequences and Mountain Ranges

- If you close the continents of North America, Greenland, the UK, and Northern Europe, you find one continuous mountain range

Now: 200 million years ago:

Paleoclimatic evidence

- Glaciers tend to move from land to sea, but in the rock record they appear to move from sea to land
Paleoclimatic evidence

- If all the Gondwanaland continents are fitted together, then the glaciers moved from the continents to the sea.

The great debate

- Objections to the continental drift hypothesis
  - Inability to provide a mechanism capable of moving continents across the globe
  - Wegener suggested that continents broke through the ocean crust, much like ice breakers cut through ice.
The great debate

• Continental drift and the scientific method
  – Wegner’s hypothesis was correct in principle, but contained incorrect details
  – For any scientific viewpoint to gain wide acceptance, supporting evidence from all realms of science must be found
  – A few scientists considered Wegner’s ideas plausible and continued the search

Continental drift and paleomagnetism

• Initial impetus for the renewed interest in continental drift came from rock magnetism
• Magnetized minerals in rocks
  – Show the direction to Earth’s magnetic poles
  – Provide a means of determining their latitude of origin
Continental drift and paleomagnetism

- Polar wandering
  - The apparent movement of the magnetic poles illustrated in magnetized rocks indicates that the continents have moved
  - Shows that Europe was much closer to the equator when coal-producing swamps existed

- Polar wandering curves for North America and Europe have similar paths but are separated by about 24° of longitude
  - Different paths can be reconciled if the continents are placed next to one another
Apparent polar-wandering paths for Eurasia and North America

The scientific revolution begins

- During the 1950’s and 1960’s technological strides permitted extensive mapping of the ocean floor
- Seafloor spreading hypothesis was proposed by Harry Hess in the early 1960’s
The scientific revolution begins

• Geomagnetic reversals
  – Earth's magnetic field periodically reverses polarity
    • the north magnetic pole becomes the south magnetic pole, and vice versa
  – Dates when the polarity of Earth’s magnetism changed were determined from lava flows

• Geomagnetic reversals
  – Geomagnetic reversals are recorded in the ocean crust
  – In 1963 Fred Vine and D. Matthews tied the discovery of magnetic stripes in the ocean crust near ridge crests to Hess’ concept of seafloor spreading
Paleomagnetic reversals recorded by basalt at mid-ocean ridges

The scientific revolution begins

- Geomagnetic reversals
  - *Paleomagnetism* (evidence of past magnetism recorded in the rocks) was the most convincing evidence set forth to support the concept of seafloor spreading
Plate tectonics: The new paradigm

- Much more encompassing theory than continental drift
- The composite of a variety of ideas that explain the observed motion of Earth’s lithosphere through the mechanisms of subduction and seafloor spreading

Plate tectonics: The new paradigm

- Earth’s major plates
  - Associated with Earth's strong, rigid outer layer
    - Known as the *lithosphere*
    - Consists of uppermost mantle and overlying crust
    - Overlies a weaker region in the mantle called the *asthenosphere*
Plate tectonics: The new paradigm

- Earth’s major plates
  - Seven major lithospheric plates
  - Plates are in motion and continually changing in shape and size
  - Largest plate is the Pacific plate
  - Several plates include an entire continent plus a large area of seafloor
Plate tectonics: The new paradigm

- Earth’s major plates
  - Plates move relative to each other at a very slow but continuous rate
    - Average about 5 centimeters (2 inches) per year
    - Cooler, denser slabs of oceanic lithosphere descend into the mantle
Plate tectonics: The new paradigm

• Plate boundaries
  – All major interactions among individual plates occur along their boundaries
  – Types of plate boundaries
    • Divergent plate boundaries
      – (constructive margins)
    • Convergent plate boundaries
      – (destructive margins)
    • Transform fault boundaries
      – (conservative margins)
Plate tectonics: The new paradigm

• Plate boundaries
  – Each plate is bounded by a combination of the three types of boundaries
  – New plate boundaries can be created in response to changes in the forces acting on these rigid slabs

Divergent plate boundaries

• Most are located along the crests of oceanic ridges and can be thought of as constructive plate margins
• Oceanic ridges and seafloor spreading
  – Along well-developed divergent plate boundaries, the seafloor is elevated forming oceanic ridges
Divergent plate boundaries

- Oceanic ridges and seafloor spreading
  - Seafloor spreading occurs along the oceanic ridge system
- Spreading rates and ridge topography
  - Ridge systems exhibit topographic differences
  - Topographic differences are controlled by spreading rates

Divergent plate boundaries are located mainly along oceanic ridges
Divergent plate boundaries

- Spreading rates and ridge topography
  - Topographic differences are controlled by spreading rates
    - Slow spreading rates (1-5 centimeters per year)
      - a prominent rift valley develops along the ridge crest that is wide (30 to 50 km) and deep (1500-3000 meters)
    - Intermediate spreading rates (5-9 centimeters per year)
      - rift valleys that develop are shallow with subdued topography

Divergent plate boundaries

- Spreading rates and ridge topography
  - Topographic differences are controlled by spreading rates
    - At spreading rates greater than 9 centimeters per year no median rift valley develops and these areas are usually narrow and extensively faulted
- Continental rifts
  - Split landmasses into two or more smaller segments
Divergent plate boundaries

• Continental rifts
  – Examples include the East African rift valleys and the Rhine Valley in northern Europe
  – Produced by extensional forces acting on the lithospheric plates
  – Not all rift valleys develop into full-fledged spreading centers

The East African rift: a divergent boundary on land
Convergent plate boundaries

• Older portions of oceanic plates are returned to the mantle in these destructive plate margins
  – Surface expression of the descending plate is an ocean trench
  – Called subduction zones
  – Average angle at which oceanic lithosphere descends into the mantle is about 45°

Convergent plate boundaries

• Although all have the same basic characteristics, they are highly variable features
• Types of convergent boundaries:
  – Oceanic-continental convergence
  – Denser oceanic slab sinks into the asthenosphere
Convergent plate boundaries

• Types of convergent boundaries
  – Oceanic-continental convergence
    • As the plate descends, partial melting of mantle rock generates magmas having a basaltic or andesitic composition
    • Mountains produced in part by volcanic activity associated with subduction of oceanic lithosphere are called continental volcanic arcs (Andes and Cascades)

An oceanic - continental convergent plate boundary
Convergent plate boundaries

• Types of convergent boundaries
  – **Oceanic-oceanic convergence**
    • When two oceanic slabs converge, one descends beneath the other
    • Often forms volcanoes on the ocean floor
    • If the volcanoes emerge as islands, a *volcanic island arc* is formed (Japan, Aleutian islands, Tonga islands)
Convergent plate boundaries

• Types of convergent boundaries
  – **Continental - continental convergence**
    • Continued subduction can bring two continents together
    • Less dense, buoyant continental lithosphere does not subduct
    • Result is a collision between two continental blocks
    • Process produces mountains
      – (Himalayas, Alps, Appalachians)
Collision of India and Asia produced the Himalayas
Transform fault boundaries

- The third type of plate boundary
- Plates slide past one another and no new lithosphere is created or destroyed
- **Transform faults**
  - Most join two segments of a mid-ocean ridge as parts of prominent linear breaks in the oceanic crust known as *fracture zones*
Transform fault boundaries

- Transform faults
  - A few cut through continental crust
    - San Andreas fault
    - Alpine fault (New Zealand)
Parkfield, California

San Andreas Fault

ENTERING Pacific Plate

Sag-pond on SAF at south end Of Carrizo Plain Nat. Mon.
Testing the plate tectonics model

• Plate tectonics and earthquakes
  – Plate tectonics model accounts for the global distribution of earthquakes
    • Absence of deep-focus earthquakes along the oceanic ridge is consistent with plate tectonics theory
    • Deep-focus earthquakes are closely associated with subduction zones
    • The pattern of earthquakes along a trench provides a method for tracking the plate's descent
Deep-focus earthquakes occur along convergent boundaries

Earthquake foci in the vicinity of the Japan trench
Testing the plate tectonics model

- Evidence from ocean drilling
  - Some of the most convincing evidence confirming seafloor spreading has come from drilling directly into ocean-floor sediment
    - Age of deepest sediments
    - Thickness of ocean-floor sediments verifies seafloor spreading

Age of ocean floor
Testing the plate tectonics model

• Hot spots
  – Caused by rising plumes of mantle material
  – Volcanoes can form over them (Hawaiian Island chain)
  – Most mantle plumes are long-lived structures and at least some originate at great depth, perhaps at the mantle-core boundary
The Hawaiian Islands have formed over a stationary hot spot.
The driving mechanism

- No one driving mechanism accounts for all major facets of plate tectonics
- Most researchers agree that convective flow in the rocky 2,900 kilometer-thick mantle is the basic driving force of plate tectonics
- Several mechanisms generate forces that contribute to plate motion
  - Slab-pull
  - Ridge-push

The driving mechanism

- Models of plate-mantle convection
  - Any model describing mantle convection must explain why basalts that erupt along the oceanic ridge
  - Models:
    - Layering at 660 kilometers
    - Whole-mantle convection
    - Deep-layer model
Importance of plate tectonics

- Theory provides a unified explanation of Earth’s major surface processes
- Within the framework of plate tectonics, geologists have found explanations for the geologic distributions of earthquakes, volcanoes, and mountains
- Plate tectonics also provides explanations for past distributions of plants and animals

End of Chapter