What Forces Drive Plate Tectonics?

The tectonic plates are moving, but with varying rates and directions.

What hypotheses have been proposed to explain the plate motion?

– Convection Cells in the Mantle
– Ridge-Push and Slab-Pull Model
– Thermal Plumes
Convection Cells in the Mantle

• Large-scale thermal convection cells in the mantle may move tectonic plates.

• Convection cells transfer heat in a circular pattern. Hot material rises; cool material sinks.

• Mantle heat probably results from radioactive decay.
Convection Cells in the Mantle

Movement of the convection cell (red arrows) drives the divergence of continents.
Crust is heated and expands over a mid-ocean ridge spreading center. Crust tends to slide off the thermal bulge, pushing the rest of the oceanic plate ahead of it.

This is called **ridge-push**.
Near subduction zones, oceanic crust is cold and dense, and tends to sink into the mantle, pulling the rest of the oceanic plate behind it. This is referred to as **slab-pull**.
Thermal Plumes

- Thermal plumes are concentrated areas of heat rising from near the core-mantle boundary. **Hot spots** are present on the Earth's surface above a thermal plume.

- The lithosphere expands and domes upward, above a thermal plume. The uplifted area splits into three radiating fractures and the three plates move outward away from the hot spot.
A triple junction over a thermal plume. Afar Triangle.
Thermal Plumes

- Thermal plumes do not all produce triple junctions.
- Hot spots are present across the globe. If the lava from the thermal plume makes its way to the surface, volcanic activity may result.
- As a tectonic plate moves over a hot spot (at a rate as high as 10 cm per year), a chain of volcanoes is formed.
Paleomagnetic Evidence

• Magnetic reversals have occurred relatively frequently through geologic time.

• Recently magnetized rocks show alignment of magnetic field consistent with Earth's current magnetic field.

• Magnetization in older rocks has different orientations (as determined by magnetometer towed by a ship).
Paleomagnetic Evidence

Magnetic stripes on the sea floor are symmetrical about the mid-ocean ridges.
Paleomagnetic Evidence

Normal (+) and reversed (-) magnetization of the seafloor about the mid-ocean ridge. Note the symmetry on either side of the ridge.
Reversals in sea floor basalts match the reversal time scale determined from rocks exposed on land.

Continental basalts were dated radiometrically and correlated with the oceanic basalts. Using this method, magnetic reversals on the sea floor were dated.
Calculating Rates of Seafloor Spreading

• Width of magnetic stripes on sea floor is related to time.
• Wide stripes = long time
• Narrow stripes = short time
• Knowing the age of individual magnetic stripes, it is possible to calculate rates of seafloor spreading and former positions of continents.
Rates of Seafloor Spreading

The velocity of plate movement varies around the world.

- Plates with large continents tend to move more slowly (up to 2 cm per year).
- Oceanic plates move more rapidly (averaging 6-9 cm per year).
Youth of Ocean Basins and Sea Floor

- Only a thin layer of sediment covers the sea floor basalt.
- Sea floor rocks date to less than 200 million years (most less than 150 million years).
- No seafloor rocks are older than 200 million years.
Drilling ocean cores shows that sediment is older away from ridges (spreading centers).
Measurement of Plate Tectonics from Space

- Lasers
- Man-made satellites in orbit around Earth - Global Positioning System
- By measuring distances between specific points on adjacent tectonic plates over time, rates of plate movement can be determined.
Seismic Evidence for Plate Tectonics

• Inclined zones of earthquake foci dip at about a 45° angle, near a deep-sea trench. Benioff Zones, (or Wadati-Benioff Zones).

• The zone of earthquake foci marks the movement of the subducting plate as it slides into the mantle.

• The Benioff Zone provides evidence for subduction where one plate is sliding beneath another, causing earthquakes.
Gravity Evidence

• A gravity anomaly is the difference between the calculated theoretical value of gravity and the actual measured gravity at a location.

• Strong negative gravity anomalies occur where there is a large amount of low-density rock beneath the surface.

• Strong negative gravity anomalies associated with deep sea trenches indicate the location of less dense oceanic crust rocks being subducted into the denser mantle.
Negative gravity anomaly associated with a deep sea trench. Sediments and lower density rocks are subducted into an area that would otherwise be filled with denser rocks. As a result, the force of gravity over the subduction zone is weaker than normal.
Thermal Plumes, Hot Spots, and Hawaii

- **Volcanoes** develop over hot spots or thermal plumes.
- As the plate moves across the hot spot, a chain of volcanoes forms.
- The youngest volcano is over the hot spot.
- The volcanoes become older away from the site of volcanic activity.
- Chains of volcanic islands and underwater sea mounts extend for thousands of km in the Pacific Ocean.
A new volcano, Lo'ihi, is forming above the hot spot, SE of the island of Hawaii. The Hawaiian islands are youngest near the hot spot, and become older to the NW.
Thermal Plumes, Hot Spots, and Hawaii

This chain of volcanoes extends NW past Midway Island, and then northward as the Emperor Seamount Chain. The volcanic trail of the Hawaiian hot spot is 6000 km long. A sharp bend in the chain indicates a change in the direction of plate motion about 43 million years ago.
Exotic Terrains

• Small pieces of continental crust surrounded by oceanic crust are called **microcontinents**.

• *Examples*: Greenland, Madagascar, the Seychelles Bank in the Indian Ocean, Crete, New Zealand, New Guinea.
Exotic Terrains

Microcontinents are moved by seafloor spreading, and may eventually arrive at a subduction zone.

They are too low in density and too buoyant to be subducted into the mantle, so they collide with (and become incorporated into the margin of) a larger continent as an exotic terrain.
Exotic Terrains

Exotic terrains are present along the margins of every continent.

They are fault-bounded areas with different structure, age, fossils, and rock type, compared with the surrounding rocks.
Exotic Terrains

- Green terrains probably originated as parts of other continents.
- Pink terrains may be displaced parts of North America.
- The terrains are composed of Paleozoic or older rocks accreted during Mesozoic and Cenozoic.