Chapter 4
Plate Tectonics

One of the first steps in performing a scientific investigation is to understand what is already known. The investigation could be posed in a number of ways, but I have settled on asking students to find evidence for the theory of plate tectonics, as explained in their textbook. This approach has worked well in a class of general education majors. With more class time it might be possible to lead students to the discovery that the earth's surface must actually be moving around. The seafloor age data requires it, as do the existence of earthquakes in well defined patterns. Nevertheless, the search for this evidence provides rich investigative opportunities. Furthermore, the real earth is uncooperative enough to provide many complications for deeper investigation.

The first step is to familiarize students with the theory as described in the simplistic cartoons that depict spreading centers, transform faults and subduction zones. A clear understanding of the basic theory is essential if students are to successfully find data in support of it. The "Plate Tectonics Lecture" does an excellent job of animating these cartoons to aid in visualization. In some instances, clay models might also prove useful.

The following discussion reviews some of the most important ideas of Plate Tectonics. Later, examples of interesting studies are shown and discussed.

The theory of plate tectonics states that the earth’s surface has a number of rigid, brittle segments that move around. The outlines of these plates are easy to see on a world map of earthquakes. Earthquakes occur where brittle pieces of the earth are slipping past one another. When you break a dish, a "crack" occurs and there is a separation of two or more pieces. The noise is analogous to the earthquake and the crack is where relative motion between two pieces takes place. The plate is called of “Lithosphere” (C in figure 4.1). Within the lithosphere is the crust and upper portion of the mantle. There are three kinds of boundaries between plates. These will each be discussed below.

Divergent boundaries

These are called “spreading centers” and often occur at “mid-ocean ridges”. Two plates are separating, or diverging. Location A in figure 4.1 is the location of the spreading center in the middle of the Atlantic Ocean. Notice that the spreading center (A) is higher in elevation (shallower water). Even before plate tectonics, this long linear feature was described as a “mid-ocean ridge”. This is because the lithosphere is hottest at a spreading center, so thermal expansion makes its elevation higher. Hot mantle rocks rise into the space left by the separating plates and form the new oceanic crust. The Mid-Atlantic ridge has many large volcanoes on its flanks. The region is characterized by few earthquakes, most of which are on short “transform” segments (discussed next). The diagram of figure 4.2 shows how a spreading center would be illustrated in “Map” view (looking straight down from an airplane).

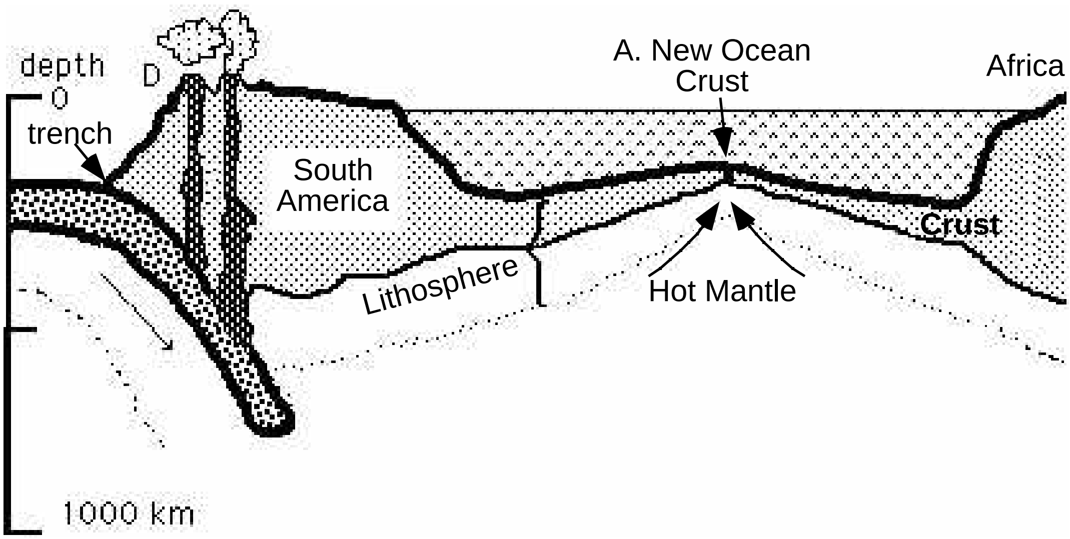


Figure 4.1. Cross section diagram of the Eastern Pacific and Atlantic Ocean basins.

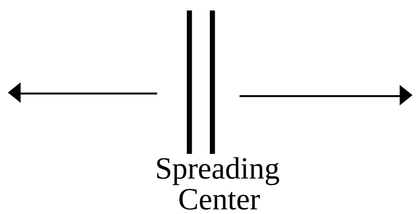


Figure 4.2. Diagram of a spreading center, map view.

Transform Boundaries

Transform boundaries are where the plates slide past one another. The San Andreas Fault is a transform boundary between the Pacific and North American Plates. Transform boundaries are characterized by many earthquakes at relatively shallow depths (less that 50 km deep).

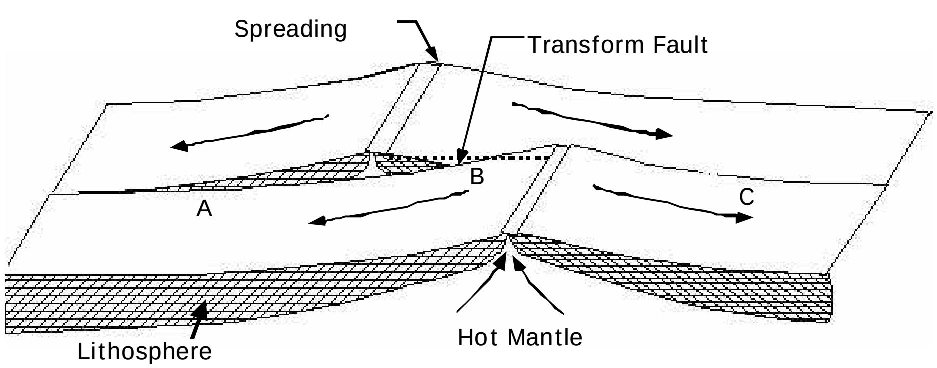
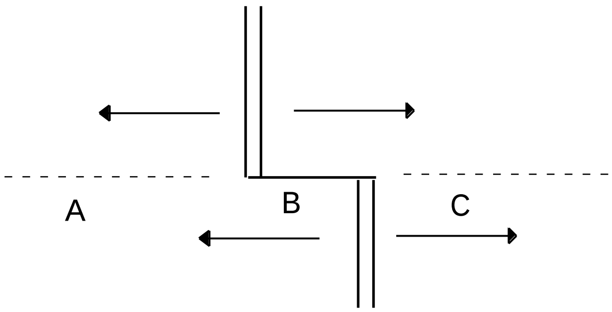


Figure 4.3. Offset spreading centers, joined by a transform fault.

Figure 4.3, shows a transform fault between two spreading centers. Notice the location between the two spreading centers (marked by the "B"), which is the transform fault. This is the only region where there is relative sliding motion. Each of the offset spreading centers is at a higher elevation, so when the offset spreading centers are joined by a transform fault, there are elevation differences at the boundary. . Boundary segments marked by A and C do not have relative motion across the "fault" (dotted line segment). Yet the original elevation differences caused by the offset are still present. These segments are called "Fracture Zones", and can be observed in the Map elevation data in the eastern Pacific Ocean, where they may persist for thousands of kilometers.



In map view, the representation of offset spreading centers, joined by a transform fault (fig. 4.4), is shown to the left. The transform fault is indicated by the B, and A and C are the fracture zones, which carry the scar of the old transform fault along as the plate spreads away from the spreading center.

Figure 4.4. Map view of two offset spreading centers joined by a transform fault.

Where do you think the earthquake activity will be most intense in figures 4.4 and 4.5?

There are several rules that these structures obey.

1) The transform fault is at a right angle to the spreading center
2) Both spreading centers are spreading at the same rate, unless there is relative rotation between the two plates.
3) Over time, spreading centers can move. This happens if one side spreads faster than the other and since the spreading center must be in the center of the two spreading plates, it moves in the direction of the faster spreading plate.
4) Over time, spreading centers can become longer or shorter. When this happens, they are often called "propagating rifts". The length of the spreading center increases in the direction of the propagation. This means that the transform fault that connects a propagating spreading center to another spreading center must move too (B in fig 4.4).

Convergent Boundaries

Figure 4.5 diagrams a boundary where plates are coming together, or "converging". There are a number of important variations to converging boundaries. Figure 4.1 shows a collision between an oceanic plate and a continent (e.g. the west coast of South America). The collision between India and Eurasia is an example of a plate convergent boundary where two continents collide. The continents are both too buoyant to sink, so their collision causes a thickening of the lithosphere, which is manifested in the Himalayan Mountains and Tibetan Plateau. When an oceanic plate collides and subducts beneath another oceanic plate, an island arc forms. The islands are caused by the volcanoes created by the subduction process (figure 4.5). Behind the island arc, a basin is formed. Often, a small spreading center occurs, caused by the pull of the subducting slab. This is called “back-arc spreading”.

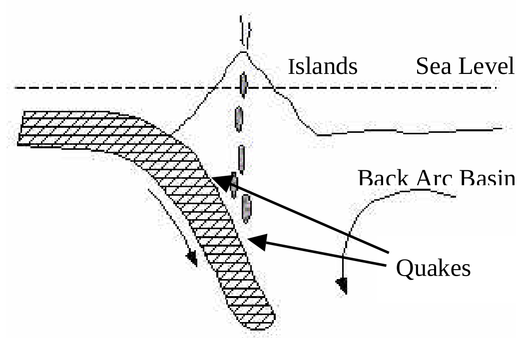
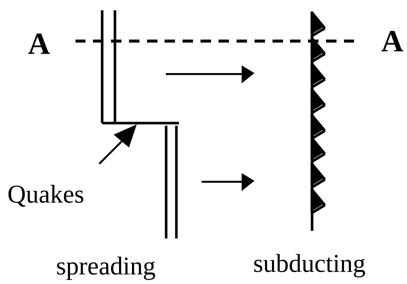


Figure 4.5. Cross section of a convergent margin between two oceanic plates.



A map view of a spreading center, transform fault, and subduction zone is shown in figure 4.6 to the left. The “teeth” in the subducting diagram are in the direction of the downgoing plate.

Figure 4.6. Map view of a plate, from spreading center to subduction zone

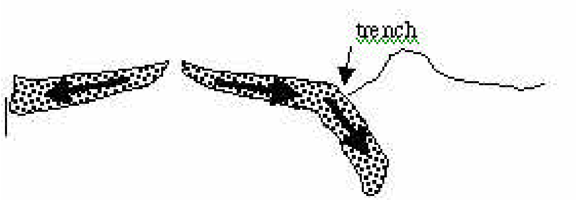


Figure 4.7. Cross section of lithosphere through section A-A of figure 4.6.

Complications

There are many “real world” examples of the simple structures described above. You will be able to find these using the map software. However, there are also many complications, which are beyond the scope of this treatment. One interesting complication occurs at the northern end of the San Andreas Fault. The western margin of North America is a combination of subduction zone and transform fault. North of Mendocino, beneath Northern California, Oregon, Washington, and southern Canada, there is a very slow subduction zone. This subduction zone is responsible for the active volcanoes: Mt. St. Helens, Mt. Ranier, Mt. Hood, Mt. Adams, and others. South of Mendocino is the San Andreas Fault, which veers offshore to the Gorda Rise, which is a spreading center. A diagram of the situation is shown in figure 4.8.

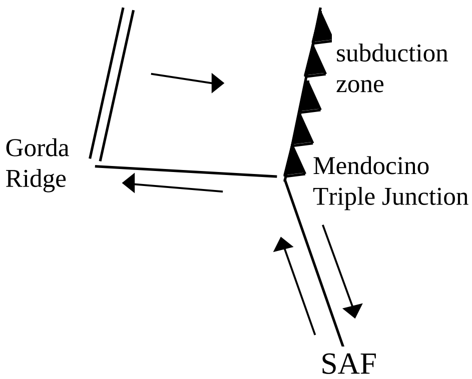


Figure 4.8. Diagram of the Mendocino Triple Junction. SAF - San Andreas Fault.

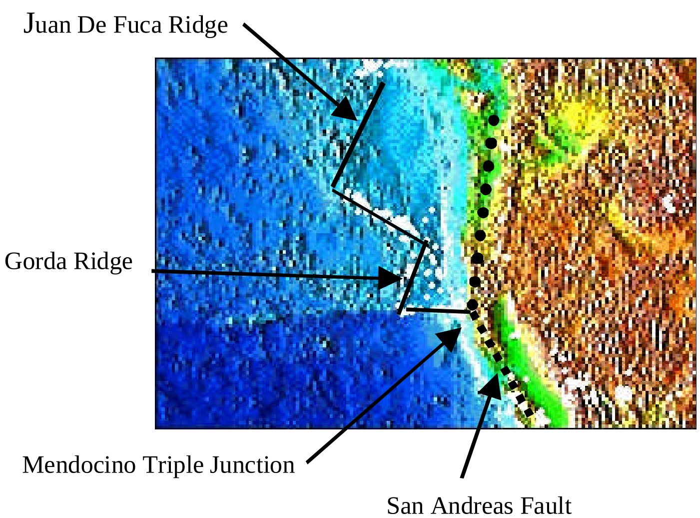


Figure 4.9. Example of a triple junction.

Figure 4.9, at the left, is a map captured from the “Our Dynamic Planet” CD, showing topography and quakes of the Mendocino Triple Junction area.
The dotted line along the Oregon/Washington coast is the subduction zone. Contrary to the previous statement about transform faults always being at right angles to the spreading center, the transform fault that trends east-west from the southern end of the Gorda Ridge is not at a right angle. Notice also that there are many quakes to the east of the Gorda Ridge, indicating that deformation is occurring in a region that, in the ideal case, is fairly quake free. It turns out that this region is deforming and rotating, so the occurrence of quakes within the plate is not surprising.