

EXERCISE 32

Plate Tectonics

Objective: To study the tectonic processes and topographic features associated with plate boundaries and hot spots.

Reference: Hess, Darrel. *McKnight's Physical Geography*, 11th ed., pp. 402-418.

PLATE TECTONICS

The model of **plate tectonics** is the starting point for understanding the distribution and formation of many collections of landforms around the world. Figure 32-1 is a map showing the principal plates and plate boundaries. These **lithospheric plates** are 65 to 100 kilometers (40 to 60 miles) thick and consist of the crust and upper mantle. The plates move over the layer of the mantle known as the **asthenosphere** at speeds averaging from 2.5 to 10 centimeters (1 to 4 inches) per year.

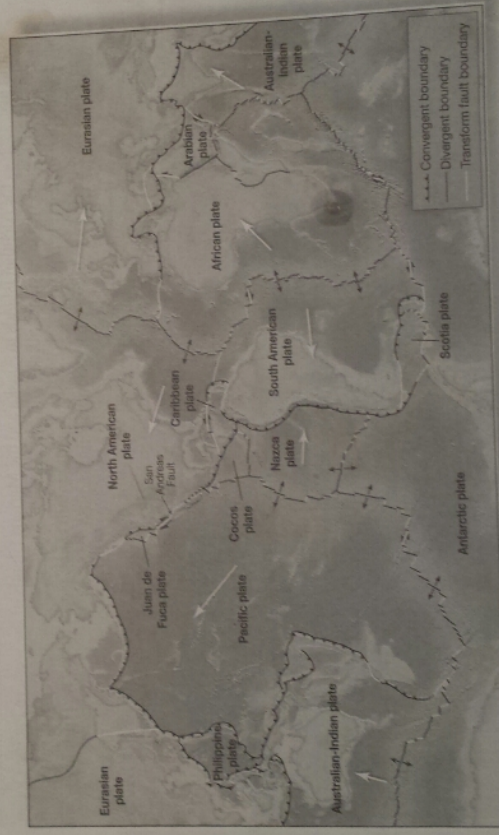


Figure 32-1: Major lithosphere plates. Barbed lines show collision; dark gray lines with offsets show spreading; single white lines show transform boundaries; arrows indicate generalized direction of plate movement. (From Hess, *McKnight's Physical Geography*, 11th ed.)

PLATE BOUNDARIES

The three different kinds of plate boundaries are associated with different kinds of topographic features and tectonic activity.

Divergent Boundaries: At divergent boundaries (also called "spreading centers"), plates are moving apart. The most common kind of spreading center is the **midocean ridge** where new basaltic ocean floor is created (Figure 32-2). Spreading may also take place within a continental rift valley (such as the Great East African Rift Valley).

Convergent Boundaries: At convergent boundaries, where plates collide, three circumstances are possible:

1. If the edge of an oceanic plate collides with the edge of a continental plate a **subduction zone** is formed. The denser oceanic plate is subducted below the continent, producing an **oceanic trench**. As the oceanic lithosphere descends, water and other volatile materials are driven out of the ocean rocks, leading to the partial melting of the mantle. The **magma** that is generated rises, producing intrusions of **plutonic rock** such as granite and a chain of andesitic **volcanoes**, such as the Andes in South America or the Cascades in North America (Figure 32-2).
2. If the edge of an oceanic plate collides with the edge of another oceanic plate, subduction also takes place. An oceanic trench forms, along with a chain of andesitic volcanic islands known as an **island arc**, such as the Aleutian Islands in Alaska and the Mariana Islands of the western Pacific Ocean.
3. If the edge of a continent collides with the edge of another continent, the relatively buoyant continental material is not subducted. Instead, a mountain range is uplifted. The Himalayas are a dramatic example of this kind of plate boundary interaction.

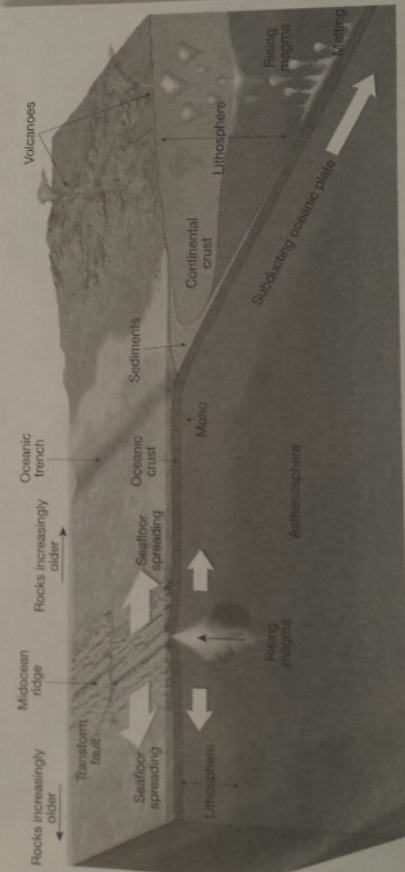


Figure 32-2: Plates move apart at spreading centers such as midocean ridges, collide at convergent boundaries such as subduction zones, and slide past each other along transform faults. (From Hess, *McKnight's Physical Geography*, 11th ed.)

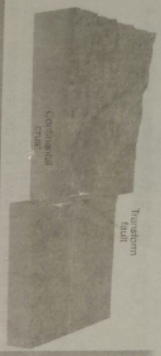


Figure 32-3: Along a transform plate boundary, such as the San Andreas Fault system of California, the movement is lateral. (from Hess, *McKnight's Physical Geography*, 11th ed.)

Transform Boundaries: Plates slide past each other at transform boundaries, such as along the San Andreas Fault system in California (Figure 32-3).

EVIDENCE SUPPORTING PLATE TECTONICS

Evidence supporting the theory of plate tectonics comes from global patterns of landforms and tectonic activity. In addition to the matching shape of the continental margins on both sides of the Atlantic Ocean (which spread apart from the Mid-Atlantic Ridge), the age of the ocean floor provides evidence of movement. The ocean floors are youngest at midocean ridges, where new lithosphere is being formed, and become progressively older away from a ridge in both directions. This was verified through ocean core samples, as well as paleomagnetic evidence (changes in Earth's magnetic field that have been recorded in the volcanic rocks of the ocean floor).

Plate boundaries are often the sites of significant volcanic activity. At spreading centers, magma is moving up to the surface, creating new lithosphere as the plates spread apart. Magma generated in subduction zones can produce a chain of continental volcanoes or a volcanic island arc.

The distribution of **earthquakes** also provides clues to plate activity. Most earthquakes around the world occur in association with plate boundaries. Shallow-focus earthquakes, within about 70 kilometers (45 miles) of the surface, occur at all plate boundaries. However, in subduction zones, bands of progressively deeper earthquakes are observed, produced when an oceanic plate is thrust deep down into the asthenosphere.

HOT SPOTS

One of the important modifications of basic plate tectonic theory is the concept of the **hot spot**. These are locations where a fairly narrow plume of magma is rising from the asthenosphere to the surface, producing volcanoes. Many hot spots apparently develop from **mantle plumes** that originate deep within the mantle.

Hot spots may occur well away from plate boundaries, often in the middle of a plate. It is not yet completely understood why these hot spots occur where they do, but the existence of hot spots has been helpful in verifying plate motion.

Evidently, hot spots can remain active in the same location for millions of years. While the hot spot remains in the same place, the plate above continues to move over it. Currently active volcanoes are found directly over the hot spot, while the moving plate carries older volcanoes off the plume, at which time they become inactive. Ongoing plate motion carries these old volcanoes

farther and farther away from the hot spot, resulting in a chain of extinct volcanoes known as a "hot spot trail."¹

THE HAWAIIAN HOT SPOT

The Hawaiian Islands are the best-known example of an island chain produced by a hot spot. The only currently active volcanoes are found on the island of Hawai'i in the southeast part of the island chain. It is believed that this island is currently over the hot spot.

Figure 32-4 is a map showing the ages of volcanic rocks in the Hawaiian chain. Notice that the age of the volcanic rocks becomes progressively older as we follow the islands to the northwest. The pattern of islands in the Hawaiian chain shows the general direction of movement of the Pacific Plate, and from the ages of the rocks, we can infer the rate of plate movement.

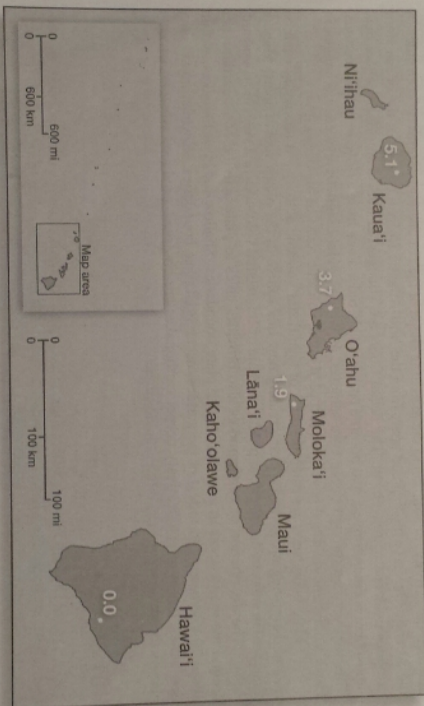


Figure 32-4: The Hawaiian Islands. The ages of the basalt from the Hawaiian volcanoes are shown in millions of years; map scale 1:4,200,000. (Adapted from McKnight, *Physical Geography*, 4th ed.)

¹Recent geophysical evidence suggests that the locations of some mantle plumes may slowly change over time, making a complete explanation of some hot spots more complex than geologists once thought.

EXERCISE 32 PROBLEMS—Part I Introduction

In the Part I problems for this exercise, you will study the tectonic map of a hypothetical ocean basin (shown on page 217). The map shows the location of volcanoes, earthquakes, and the age of ocean floor rocks. From this map, you will determine the probable location of the plate boundaries and the locations of major topographic features in the region.

On the map, the edges of two continents are shown (in the upper right corner and the lower left corner). Six islands are also shown in the ocean basin.

The symbols used on the tectonic map are described below.

Earthquake Epicenter Location and Depth:

The locations of earthquake epicenters are shown with letters. The depth of an earthquake (the distance of the earthquake hypocenter or "focus" below the surface) is indicated with an "S" (shallow focus), "I" (intermediate focus), or "D" (deep focus):

S = Shallow Earthquakes	0–70 kilometers (0–45 miles) deep
I = Intermediate Earthquakes	70–200 kilometers (45–125 miles) deep
D = Deep Earthquakes	200–500 kilometers (125–310 miles) deep

Active Volcano: ▲

Continent or Island: 

Age of Volcanic Ocean Floor Rocks:

The circled numbers represent the age of volcanic ocean floor rocks in millions of years.

For example, (20) indicates the location of 20-million-year-old rocks.

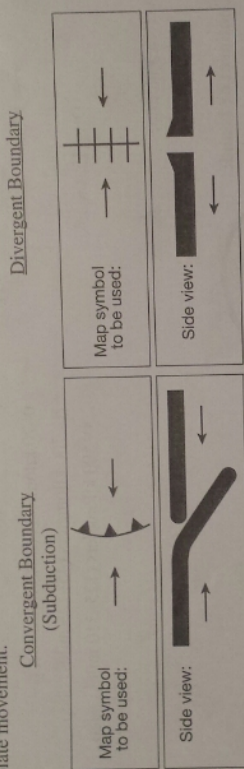
EXERCISE PROCEDURE:

The first step of the exercise is to draw in the approximate plate boundaries as indicated by the tectonic activity on the map.

Clues include:

- (a) The pattern of earthquakes. For example, subduction produces a pattern of deeper and deeper earthquakes as one plate plunges below the other.
- (b) The age pattern of volcanic ocean floor rocks suggests the location where new ocean floor is being created at a midocean ridge.
- (c) Volcanic activity may be associated with subduction, spreading centers, or hot spots.

Use the following symbols to indicate the extent of all plate boundaries. Both the map symbols, and a side view of the circumstance they represent, are shown below. Arrows indicate direction of plate movement.

**Note:**

- No transform boundaries are found on the map.
- Assume that only one of the volcanoes on the map is associated with a hot spot.

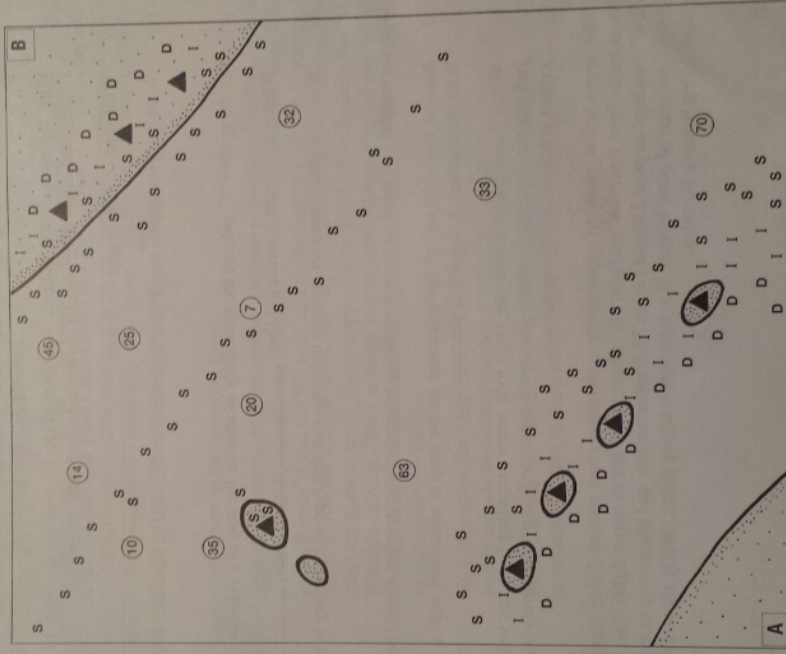
Name _____

Section _____

EXERCISE 32 PROBLEMS—PART I

After drawing in the plate boundaries using the appropriate symbols on the tectonic map below, answer the questions on the following page. When asked to cite evidence to support your answers, only cite evidence *that you can see on this map*.

TECTONIC MAP OF HYPOTHETICAL OCEAN BASIN



Scale: 1 cm = 300 km (1 inch = 500 miles)

1. (a) How many different *plates* (not boundaries) are clearly shown on the map? _____
(b) How many of the plates on the map consist entirely of ocean floor (or ocean floor with islands)? _____
2. (a) With the number "2" indicate the most likely location on the map of a midocean ridge (such as the Mid-Atlantic Ridge). _____
(b) What type of plate boundary is this? _____
(c) What evidence *shown on the map* indicates that this type of boundary is present? _____
3. (a) With the number "3" indicate the most likely location on the map of a major volcanic mountain range similar to the Andes in South America. _____
(b) What type of plate boundary is this? _____
(c) What evidence *shown on the map* indicates that this type of boundary is present? _____
4. (a) With the number "4" indicate the most likely location on the map of a volcanic island arc. _____
(b) What type of plate boundary is this? _____
(c) What evidence *shown on the map* indicates that this type of boundary is present? _____
5. With the number "5" label all plate boundaries where oceanic trenches should be found.
6. (a) Assume that only one of the volcanoes on the map is associated with a hot spot. With the number "6" label this volcano. _____
(b) With a 2-centimeter (about one-inch) long arrow extending from this volcano, indicate the direction in which you would expect to find progressively older *extinct* volcanoes left by the hot spot. _____
7. In the space below, draw an approximate continuous cross section ("side view") of the ocean basin from Point "A" to Point "B" (from lower left to upper right). Use the "side view" drawings on page 216 and Figure 32-2 for reference, and use arrows to indicate the relative direction of plate motion. If subduction is taking place, clearly show which plate is subducting beneath the other.

A

Lower Left

B

Upper Right

Name _____

Section _____

EXERCISE 32 PROBLEMS—PART II

Using the map of the Hawaiian Islands and the ages of the basaltic lava (Figure 32-4), compute the approximate rate of movement of the Pacific Plate as it passes over the Hawaiian hot spot.

You will compare the age and distance between several different volcanoes on the islands. The ages of volcanic rocks on the islands are given in millions of years. White dots on the islands mark the location of a volcano. For example, on the island of Hawai'i, the dot next to "0.0" marks the location of the currently active volcano, Kīlauea.

In this exercise, you will compare Hawai'i (0.0 years—currently active volcanoes), Moloka'i (1.9 million years), O'ahu (3.7 million years), and Kaua'i (5.1 million years). For the purposes of this exercise, we will take the position of the Kīlauea volcano to represent the location of the Hawaiian hot spot (keep in mind that this is a simplistic assumption). We also assume that the Hawaiian hot spot is completely stationary over long periods of time.

1. Complete the chart on the following page:

- (a) First, determine the distance between each pair of locations listed on the chart. With a ruler, carefully measure the distance between locations on the map to the nearest millimeter if you use S.I. units and to the nearest 1/16 inch if you use English units. If you use English units, convert fractions of inches to decimals to make other calculations easier (for example, $1/8 = 0.125$). This figure is the "Measured Distance on Map." Then multiply this measured distance on the map by 4,200,000 (the denominator of the fractional map scale) to determine the "Actual Distance" in millimeters (or inches).
- (b) Next, determine the "Age Difference" in years between each pair of locations. (Be sure to include the correct number of zeros in your figure.)
- (c) Finally, divide the "Actual Distance" between locations by the "Age Difference" to estimate the rate of plate movement in millimeters (or inches) per year.

Locations	Measured Distance on Map (in mm or inches)	Actual Distance (in mm or inches)	Age Difference (in years)	Rate of Plate Movement (mm or inches per year)
Kauai to Hawaii				
Oahu to Hawaii				
Molokai to Hawaii				
Kauai to Oahu				
Kauai to Molokai				

- Based on the average of your five answers in problem 1 above, what has been the approximate rate of movement of the Pacific Plate in the area of the Hawaiian Islands over the last 5.1 million years?
- Midway Island, to the northwest of Hawaii, is also part of the Hawaiian chain and is believed to have been produced by the same hot spot. Midway is about 2430 kilometers (1510 miles) from the Kilauea volcano on Hawaii. Use the average rate of plate movement you calculated in problem 2 above to estimate the age of volcanic rocks you would expect to find on Midway Island.
- The actual age of the volcanic rock on Midway is about 27.7 million years. Suggest a reason why your answer for problem 3 above differs noticeably from this.