PART D: MEASURING AND EVALUATING PLATE TECTONICS

Hot spots are centers of volcanic activity that persist in a stationary location for tens-of-millions of years. Geologists think they are either: a) the result of long-lived narrow *plumes* of hot rock rising rapidly from Earth's mantle and forming magma by decompression melting (like a stream of heated lava rising in a lava lamp), or b) the slow decompression melting of a large mass of hot mantle rock in the upper mantle that persists for a long interval of geologic time.

As a lithospheric plate migrates across a stationary hot spot, a volcano develops directly above the hot spot. When the plate slides on, the volcano that was over the hot spot becomes dormant, and over time it migrates many kilometers from the hot spot. Meanwhile, a new volcano arises as new lithosphere passes over the hot spot. The result is a string of volcanoes, with one end of the line located over the hot spot and quite active, and the other end distant and inactive. In between is a succession of volcanoes that are progressively older with distance from the hot spot. The Hawaiian Islands and Emperor Seamount chain are thought to represent such a line of volcanoes that formed over the Hawaiian hot spot (Figure 10).

Question

15. Figure 10 shows the distribution of the Hawaiian Island chain and Emperor Seamount chain. The numbers indicate the age of each island in millions of years (m.y.), obtained from the basaltic igneous rock of which each island is composed.

a. What was the rate in centimeters per year (cm/yr) and direction of plate motion in the Hawaiian region from 4.7 to 1.6 million years (m.y.) ago?

b. What was the rate in centimeters per year (cm/yr) and direction of plate motion from 1.6 million years ago to the present time?

c. How does the rate and direction of Pacific plate movement during the past 1.6 million years differ from the older rate and direction (4.7–1.6 m.y.) of plate motion?

d. Locate the Hawaiian Island chain and the Emperor Seamount chain (submerged volcanic islands) in the top part of Figure 10. How are the two island chains related?

e. Based on the distribution of the Hawaiian Islands and Emperor Seamount chains, suggest how the direction of Pacific plate movement has generally changed over the past 60 million years.

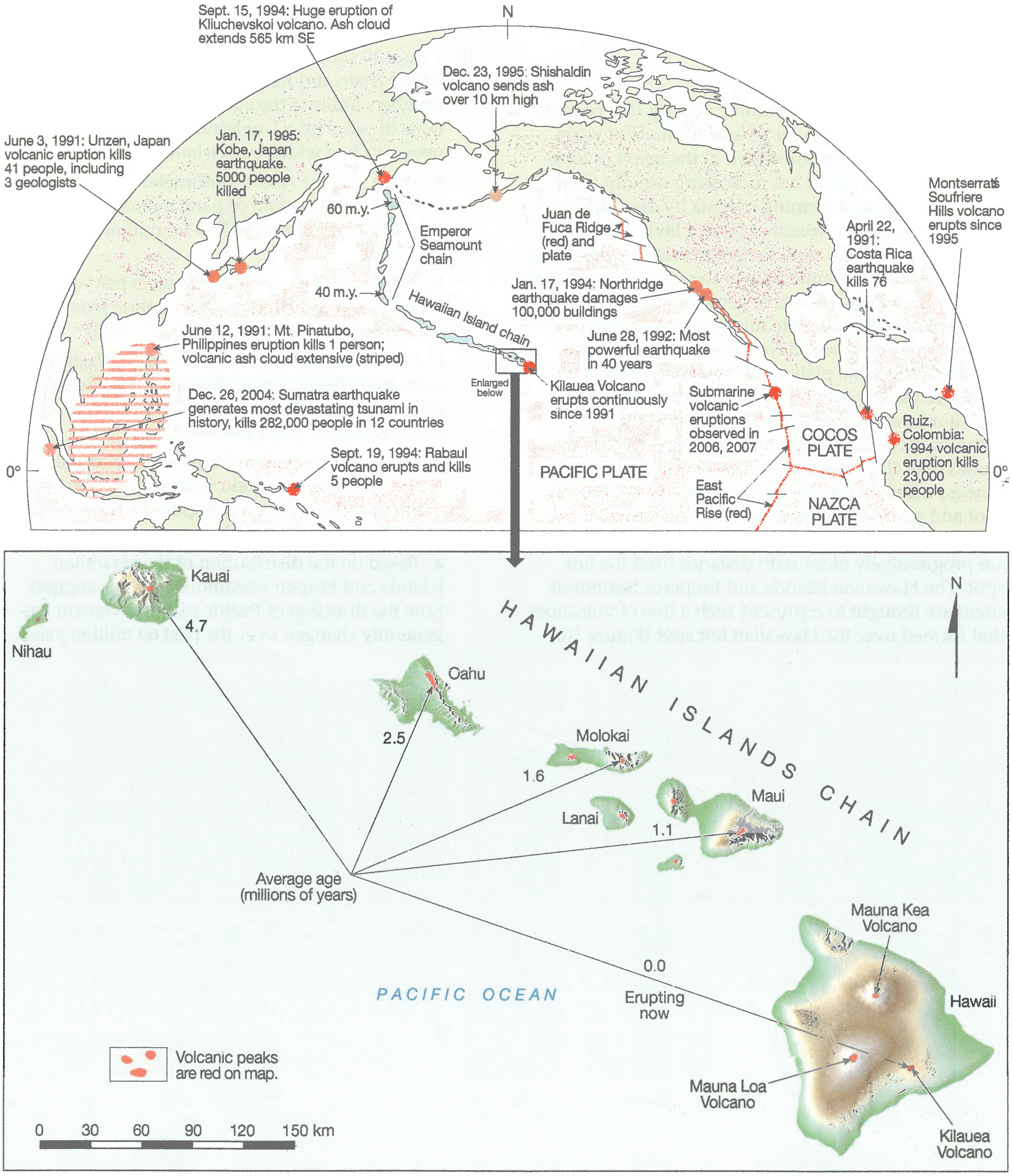

FIGURE 10 Map of the northern Pacific Ocean (top) and adjacent land masses showing some notable geologic hazards (natural disasters) from the 1990s, the Hawaiian Islands Chain, and the Emperor Seamount Chain. Lower map shows details of the Hawaiian Islands Chain, including locations of volcanic peaks.

Another hot spot is beneath Yellowstone National Park in the United States (Figure 11). There are no erupting volcanoes on the Yellowstone hot spot today, but there are hot springs and geysers. The high heat flow also causes buckling and faulting of Earth's crust.

Geologist Mark Anders has observed that as the North American Plate slides over this hot spot, it causes development of a U-shaped set of faults (with the closed end of the U pointing northeast). Also, as layers of volcanic ash and lava flows accumulate on deforming crust, they tilt. By dating the layers of tilted rocks, and mapping the U-shaped fault systems that moved beneath them, Anders has been able to compose a map of circular regions that were once centered over the hot spot at specific times. This line of deformation circles and their ages are shown in Figure 11.

Questions

16. Examine the part of Figure 11 showing the distribution of circular areas that were centers of crustal faulting and buckling when they were located over the Yellowstone hot spot. The numbers indicate the ages of deformation, as determined by Mark Anders.

a. What direction is the North American Plate moving, according to Anders' data? Explain your reasoning.

b. What was the average rate in centimeters per year (cm/yr) that the North American Plate has moved over the past 11 million years?

c. Beside the Yellowstone hot spot in Figure 11, place an arrow and rate of motion (from items 16a and 16b above) to indicate the velocity of the North American Plate.

17. Notice the ages of seafloor volcanic rocks in Figure 11. The modern seafloor rocks of this region (located at 0 million years old) are forming along a divergent plate boundary called the Juan de Fuca Ridge. The farther one moves away from the plate boundary (B in Figure 11), the older are the seafloor rocks.

a. What has been the average rate of seafloor spreading in centimeters per year (cm/yr) east of the Juan de Fuca Ridge (along line B–D) over the past 8 million years?

b. What has been the average rate of seafloor spreading in centimeters per year (cm/yr) west of the Juan de Fuca Ridge (along line A–B) over the past 8 million years?

c. Notice that seafloor rocks older than 8 million years are present west of the Juan de Fuca Ridge but not east of the ridge. What could be happening to the seafloor rocks along line C–D that would explain their absence from the map?

d. Based on your reasoning in item 17c, what kind of plate boundary is represented by the red line running through location C on Figure 11?

e. Notice the line of volcanoes in the Cascade Range located at the center of the map. How could magma form beneath these volcanoes? (Be as specific as you can.)

18. Draw a geologic cross section that shows all of the plate tectonic features developed along line A–D. Be sure that your sketch shows ocean lithosphere (Juan de Fuca Plate), continental lithosphere (North American Plate), and a volcano of the Cascade Range. Add labels, arrows, rates, and brief descriptions for all.

a. Be sure to draw and label all of the processes described in Questions 17c and 17e.

b. Add arrows and rates for the motions of the plates (from Questions 16a, 16b, 17a, and 17b) to your geologic cross section.

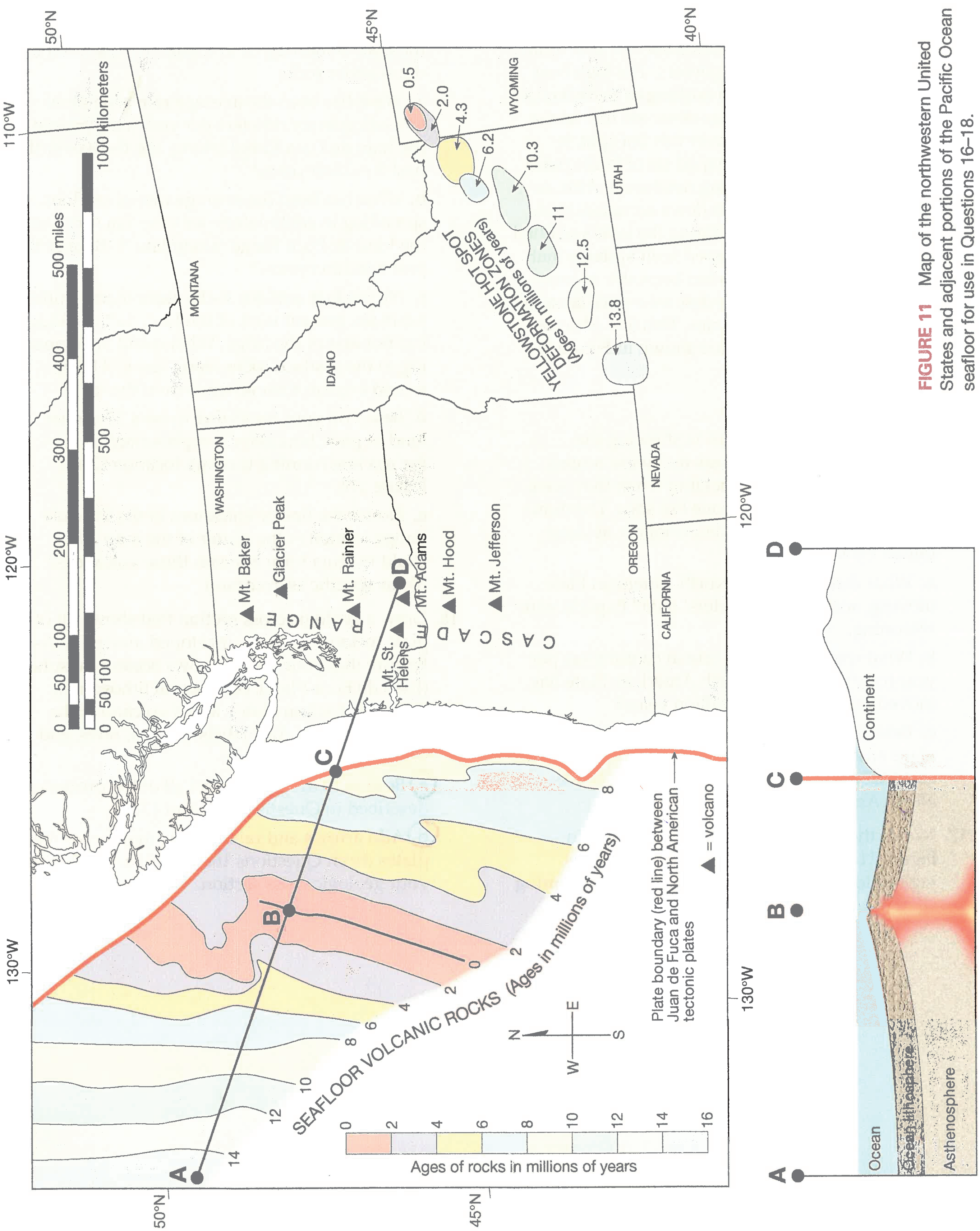

FIGURE 11 Map of the northwestern United States and adjacent portions of the Pacific Ocean seafloor for use in Questions 16–18.

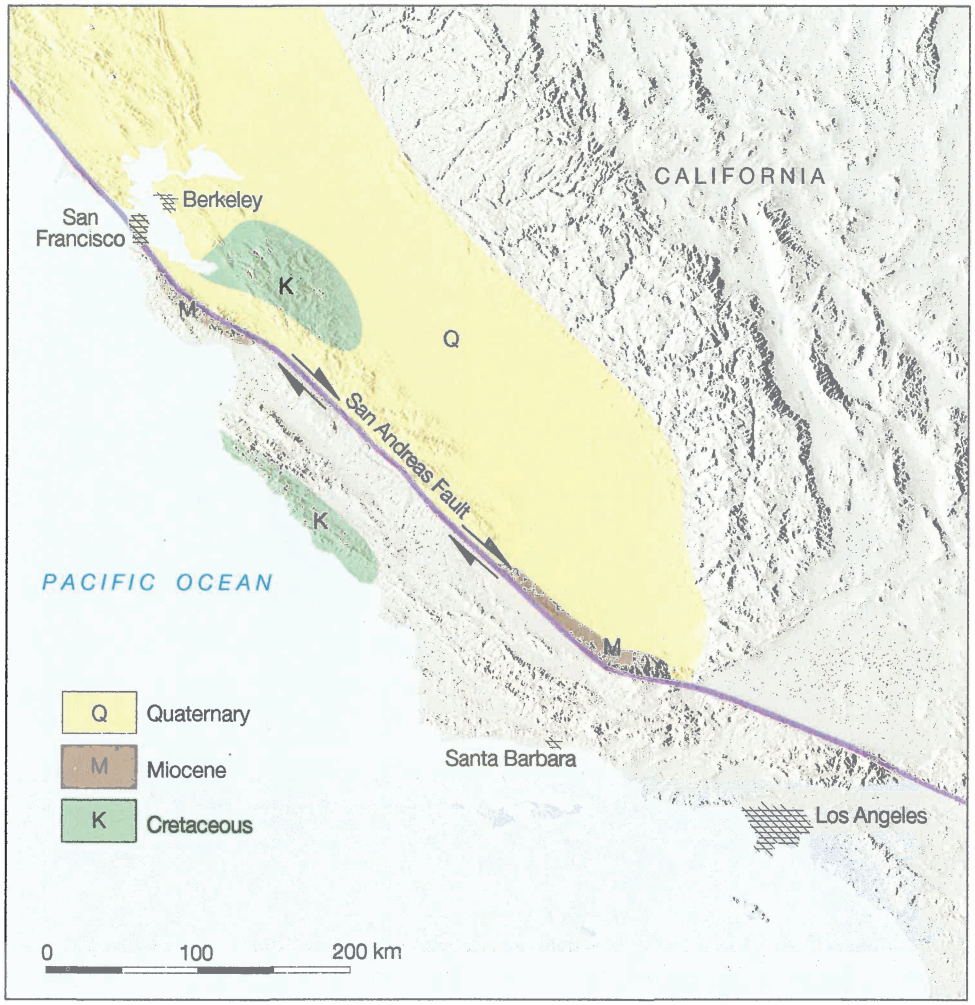

FIGURE 12 Generalized geologic map of southern California. Half-arrows indicate relative motions along the San Andreas Fault. The fault is also a boundary between two of Earth's lithospheric plates. The relative motion of the Pacific Plate (under the Pacific Ocean) is northwest. The North American Plate is located east of the fault and is moving relatively southeast.

San Andreas Fault Hazards

Study the geologic map of southern California in Figure 12, showing the position of the famous San Andreas Fault. The east side of this fault is rocks of the North American lithospheric plate. The west side of the fault is the Pacific lithospheric plate, which is moving northwest. It is well known to all who live in southern California that plate motions along the fault cause frequent earthquakes that place at risk humans and their properties.

Question

19. The two bodies of Late Miocene rocks (about 25 million years old) located along either side of the San Andreas Fault (Figure 12) were one body of rock that has been separated by motions along the fault. Note that arrows have been placed along the sides of the fault to show the relative sense of movement.

a. The San Andreas Fault is what kind of plate boundary?

b. You can estimate the average annual rate of movement along the San Andreas Fault by measuring how much the Late Miocene rocks have been offset by the fault and by assuming that these rocks began separating soon after they formed. What is the average annual rate of fault movement in centimeters per year (cm/yr)?

c. The average yearly rate of movement on the San Andreas Fault is very small. Does this mean that the residents of southern California have nothing to worry about from this fault? Explain.

d. An average movement of about 5 m (16 ft) along the San Andreas Fault was associated with the devastating 1906 San Francisco earthquake that killed people and destroyed properties. Assuming that all displacement along the fault was produced by Earth motions of this magnitude, how often must such earthquakes have occurred in order to account for the total displacement?