TWO

Midway, Mazama, and a Great Cup of Coffee

Background

Living *near* a potentially destructive volcano can provide a certain, usually unwelcome, sense of adventure. Living *on* an active volcano can make one's day-to-day existence precarious to say the least. Yet millions of Americans do both. Volcanoes are associated with all manner of geologic phenomena considered incompatible with the human life form: earthquakes, lava flows, pyroclasts, mudflows, landslides, and *nueé ardentes*. Like many geologic agents considered destructive, however, volcanic eruptions have a positive side: New materials added to the earth's surface by eruption created the fertile soils that attracted inhabitants to the area in the first place. For instance, such soils, combined with local weather characteristics, allow the area around Kona, Hawaii, to produce the only coffee in the fifty states. Minerals are often mobilized into ores by the heat and pressure associated with volcanism. Copper deposits in the Keweenaw Peninsula of Michigan and some gold deposits of Colorado can be traced to volcanic origins. Pumice is used as a building material and abrasive, and weathered volcanic material, such as bentonite, is used as a drilling lubricant and sealer. Interestingly, in certain areas of the country where bentonite is abundant in the soils, building construction is adversely affected by bentonite's ability to swell dramatically when wet.

Volcanic island chains of the United States played a significant role during World War II in the battle plans of both the United States and Japan. The United States's involvement in the Pacific began with Japanese attacks on Pearl Harbor and Midway in the central part of the ocean. In the early 1940s aviation technology had not yet developed an airplane that could fly nonstop across the Pacific. Thus the strategic value of the Aleutian Islands was recognized early in World War II, and the islands were fortified by military forces of the United States. The Aleutian Islands provided a made-to-order series of stepping stones eastward from Japan to the northwestern United States. Shortly after the attack on Pearl Harbor the Japanese established bases on the islands of Kiska, Aggatu, and Attu. The first enemy air attack on North America occurred when bombers from Japanese aircraft carriers attacked U.S. naval facilities at Dutch Harbor, on the island of Unalasaka, in the Aleutians on 3 June 1942 (Miller 1947, 510). The defense of those islands by military forces of both the United States and Canada against the Japanese was exacerbated by the rugged terrain created by the volcanoes and the horrendous weather of the high northern latitudes. By August 1943 the Japanese recognized their positions were untenable, and the first American territory captured by the Japanese was reclaimed (Miller 1947, 613).

At times in the geologic past volcanoes affected broad areas of what is now the United States. Many areas, such as Maine, South Carolina, New York, Virginia, Missouri, and Nebraska are not associated with active volcanoes today, but were affected in the past. Some of the most unique scenery in the country is a result of volcanism: the Cascade Mountains of Washington and Oregon; the Aleutian Islands, Alaska; Devils Tower, Wyoming; Capulin Mountain National Monument, New Mexico; Devils Postpile, California; Crater Lake, Oregon; Shiprock, New Mexico; Craters of the Moon, Idaho; and the Hawaiian Islands.

Approximately 10 percent of the world's 1,500 geologically recent volcanoes are located in the United States. The United States ranks third in number of volcanoes with a history of recent (past 10,000 years) eruptions (behind Indonesia and Japan). Recent activity has been located only west of the Rocky Mountains and, as Steinbrugge (1982) writes, "Most of . . . [those] . . . have the potential to erupt in the future" (259). Areas of recent volcanism in the United States can be separated as follows:

The Cascade Range of Oregon and Washington. Sixteen volcanoes, all potentially active

The Aleutian Arc of southwestern Alaska. More than 70 active volcanoes, 36 eruptions since 1760

The Hawaiian Islands. Five volcanoes active on Hawaii, one on Maui

The Mono Basin of California. More than 20 explosive eruptions in the past 10,000 years

The Basin and Range Volcanic Field of California, Nevada, and New Mexico. Scattered eruptions; last one in 1850

The Snake River Plain of Idaho and Wyoming. Occasional fissure eruptions

Two types of active volcanoes are found in the western United States. Volcanoes of the Aleutian Islands and Cascade Mountains, along the Pacific Rim, are completely different from those of the Hawaiian Islands, in the central Pacific. Both the Aleutian and Cascade volcanoes are formed as the North American Plate overrides an oceanic plate. The volcanoes created are called composite volcanoes (or stratovolcanoes) because they form in alternating layers of ash, lava, and other ejected materials fused by the heat. Rock types associated with such volcanoes include andesites and rhyolites. The mountain itself is steep-sided and is the classic type of most well-known volcanoes such as Mount Etna in Sicily, Mount Vesuvius in Sicily, Mount Fuji in Japan, and Mount Rainier in Washington (Coch and Ludman 1991, 116). Eruptions are often explosive, sending ejected materials high into the atmosphere, affecting areas hundreds and thousands of miles away.

By contrast, the volcanoes of Hawaii have broad, relatively flat slopes. They are formed completely of lava from eruptions and, because of their shape, are called shield volcanoes. Shield volcanoes are the largest volcanoes on Earth. The Island of Hawaii is formed of five shield volcanoes reaching from the ocean floor 19,680 feet (6,000 meters) below sea level to more than 13,120 feet (4,000 meters) above sea level, a total height exceeding Mount Everest. As opposed to the large amounts of explosively ejected materials from composite volcanoes, shield volcanoes are characterized by large volumes of lava. Shield volcanoes are associated with the ocean basins and oceanic plates, and the associated rock type is almost exclusively basalt.

In the short term the Mount St. Helens eruptions were certainly a disaster. Over the long term, however, the eruptions and destruction became a working research laboratory for Cascade volcanoes, alerted residents to a geologic hazard, enriched soils over a large area, and became a new and unique tourist attraction for Washington, attracting more than 2 million visitors each year. The eruptions of Mount St. Helens provided important information about future eruptions— and there will be more, based on the intermittent eruptive history of volcanoes in the Cascades. As Foxworthy and Hill (1982, 116) state, "The question of greatest interest concerning the future of Mount St. Helens probably is, 'Will Mount St. Helens continue to erupt?' The answer is, 'Yes.' " Next time there should be more accurate predictions, fewer surprises, and, it is hoped, no victims.

Half an ocean away from Mount St. Helens, another type of volcano has attracted interest for hundreds of years. The Pearl Harbor of early Hawaii consisted of three large saltwater lakes protected from the sea by a narrow, shallow entry built up naturally by coral. It was known to the Hawaiians as *wai momi*, or water of pearl (Albright 1988, 57). Although the Hawaiian island of Oahu was a large volcano projecting above the sea, its last eruption was approximately 3.5 million years earlier, and thus it was considered safe. The British Navy became the first European visitors to Pearl Harbor in 1786. By 1825, a naturalist aboard the HMS *Blonde* recognized the military potential of the area: "It would form a most excellent harbor as inside there is plenty of water to float the largest ship and room enough for the whole Navy of England" (Lott and Sumrall 1977, 3). In 1840, a worldwide naval expedition performed the first technical work by the U.S. Navy: the preparation of a survey and chart of Pearl Harbor. In the 1860s, United States naval officers saw excellent potential on the site for a coaling station needed to refuel military ships in an area devoid of coal for thousands of miles in any direction. In addition, the narrow entrance and shallow draft of the harbor provided excellent natural protection both from the sea and enemies. The rights to establish a coaling station were awarded to the United States in 1887. After dredging and other site preparations, the harbor was officially opened on 14 December 1911. Unfortunately, in December 1941 the harbor's shallow draft provided a false sense of security to the ensconced U.S. Pacific Fleet. The Japanese military knew what the American military did not: A channel with a 40-foot depth would not stop aerial torpedoes (Albright 1988, 44).

By the 1840s geologist James Dwight Dana, while traveling with the worldwide U. S. Exploring Expedition, recognized the chronological sequencing of islands in many of the linear Pacific island chains: older to the northwest, younger to the southeast (Appleman 1985, 106). Although the Hawaiian Islands may be the best known, they are not the only Pacific island chain to share a linear, parallel west-northwest and south-southeast trend, resulting from motions of the Pacific Plate. Thousands of miles to the south-southeast lay the Marquesas Chain, Society Chain, Gambier Chain, and Cook Austral Chain, all with the youngest island on the southeastern end, parallel to one another and to the Hawaiian Island Chain (Morgan 1973, 659; Appleman 1985, 110-11).

Many of these chains were critical to human migration east across the Pacific Ocean. The human and wild animal migrations from Asia to North America traversed the Bering Land Bridge approximately 50,000 years ago. A similar migration from southeast Asia began more than 70,000 years ago, arriving 20,000 years later in Australia. By 2000 B.C.E. migrations east from Australia extended past the Solomon Islands, by 1500 B.C.E to Fiji, by 1000 B.C.E. to Tonga, by 1 P.E. to Samoa, by 500 P.E. to the Marquesas Island Chain, and by 1000 P.E. to the Hawaiian Island Chain (McEvedy and Jones 1979, 322).

Two incidents in the central Pacific dramatically affected the history of the United States. Both involved the Empire of Japan and the Republic of the United States. Both involved the attempted destruction of the capital ships of the U.S. Pacific Fleet. Both involved a linear chain of volcanic islands in the Pacific Ocean— the Hawaiian Islands. The attack on Pearl Harbor and the attack on Midway Island were the Japanese attempts to eliminate a potential threat to their expansion plans. The Americans were there because the island chain offered a defensive outpost and fueling station for the ships of the fleet. But why were the islands there?

Traditionally, the origin of these island chains is considered one of the many separate pieces of evidence that helps confirm the theory of plate tectonics. Consider a steam locomotive generating puffs of smoke as it moves along a straight section of track. If those puffs could somehow be frozen in the sky they would form a straight line, with puffs separated by a certain distance; the slower the train, the closer the puffs. Now imagine a spot in the upper portion of the earth's mantle that periodically squirts magma up into the Pacific Plate as that plate moves toward the west-northwest. Those squirts become frozen on the plate as a series of volcanic islands in a line, forming island chains. The spots that squirt the material are called hot spots or mantle plumes. More than thirty years ago Morgan (1973, 661) suggested that such plumes were the driving force for plate motions. For explanatory purposes, this is an oversimplification of a complex process, the details of which are poorly understood. As early as 1849, the Hawaiian Island Chain was considered a composite of two, parallel trends of volcanic eruptions (Ihinger 1995, 1038). Recent studies suggest the islands are the result of a complex interaction between hot material in the mantle and the overlying plate.

The process continues as you read this chapter. Just as older islands are found to the northwest of the Hawaiian Island Chain, newer islands are being formed to the southeast. Loihi Seamount, 17 miles (28 kilometers) southeast of the Island of Hawaii and 3178 feet (969 meters) below the Pacific Ocean surface, will likely be the next Hawaiian Island (Malahoff 1987, 133).

Activity: Midway Is Midway

Approximately six months after naval forces of Japan destroyed the warships of the U.S. navy at Pearl Harbor, naval forces of the United States destroyed four aircraft carriers of the Japanese navy at the Battle of Midway (Keegan 1989, 210). The two battles occurred 1,240 miles (2,000 kilometers) apart along an island chain with a coherent geologic history. Enough data are available to study the progressive formation of the Hawaiian Island Chain in detail. By examining the dates of the last known eruptions of the islands it is possible to

a. determine the direction of motion of the Pacific Plate over the hot spot,

b. determine the velocity of the plate as it moves over the hot spot, and

c. make a prediction about when the next island may appear at the southeast end of the chain.

Time

+ 1 class period

Materials

+ copies of figure 2.9 (A-C) (one for each student)
+ calculator (recommended)
+ copies of table 2.6 (one for each student)
+ protractor
+ transparent tape

Grouping

+ individuals

Directions

1. Discuss the concept of hot spots with students, using the information on page 49 as a guide.

2. Distribute figure 2.9 (A-C) to the students. Before proceeding have the students tape all three sections together to make a continuous map. This is a map of the Hawaiian Island Chain, from Loihi Seamount southeast of the Island of Hawaii, west-northwest to the Kanmu Seamount (also the southern end of the Emperor Seamounts).

3. Distribute table 2.6 to students. Table 2.6 lists the locations and names of various islands and seamounts in the Hawaiian Island Chain, and times of the last known eruptions in millions of years. Discuss the difference between islands and seamounts. Imagine that a volcanic eruption starts on the seafloor, more than 15,000 feet (4,573 meters) below the sea surface. As the lava erupts it builds up to create a mound, then a hill, then a mountain. If that mountain does not reach the sea surface it is called a seamount. If it extends above the sea surface it is an island. The mountain of Mauna Loa on Hawaii rises more than 32,000 feet (9,756 meters) above the seafloor, making it higher than Mount Everest; however, only 14,000 feet (4,268 meters) of its total height projects above the ocean.

4. Discuss the numbers on the table with the class. What kinds of conclusions can you draw from these numbers? In which direction do the islands get younger? Are the eruptions over, or are they likely to continue? If so, where and when? Some of the students may have been to Hawaii and may be familiar with the newer islands that tourists usually visit (Hawaii, Oahu, Maui, Kauai), but most people are unaware of how far the chain extends to the west-northwest. If students have visited the islands ask them to describe the differences between Kauai and Hawaii; the former is the Garden Isle and the latter has active volcanic eruptions. Why?

Text continues on page 49.

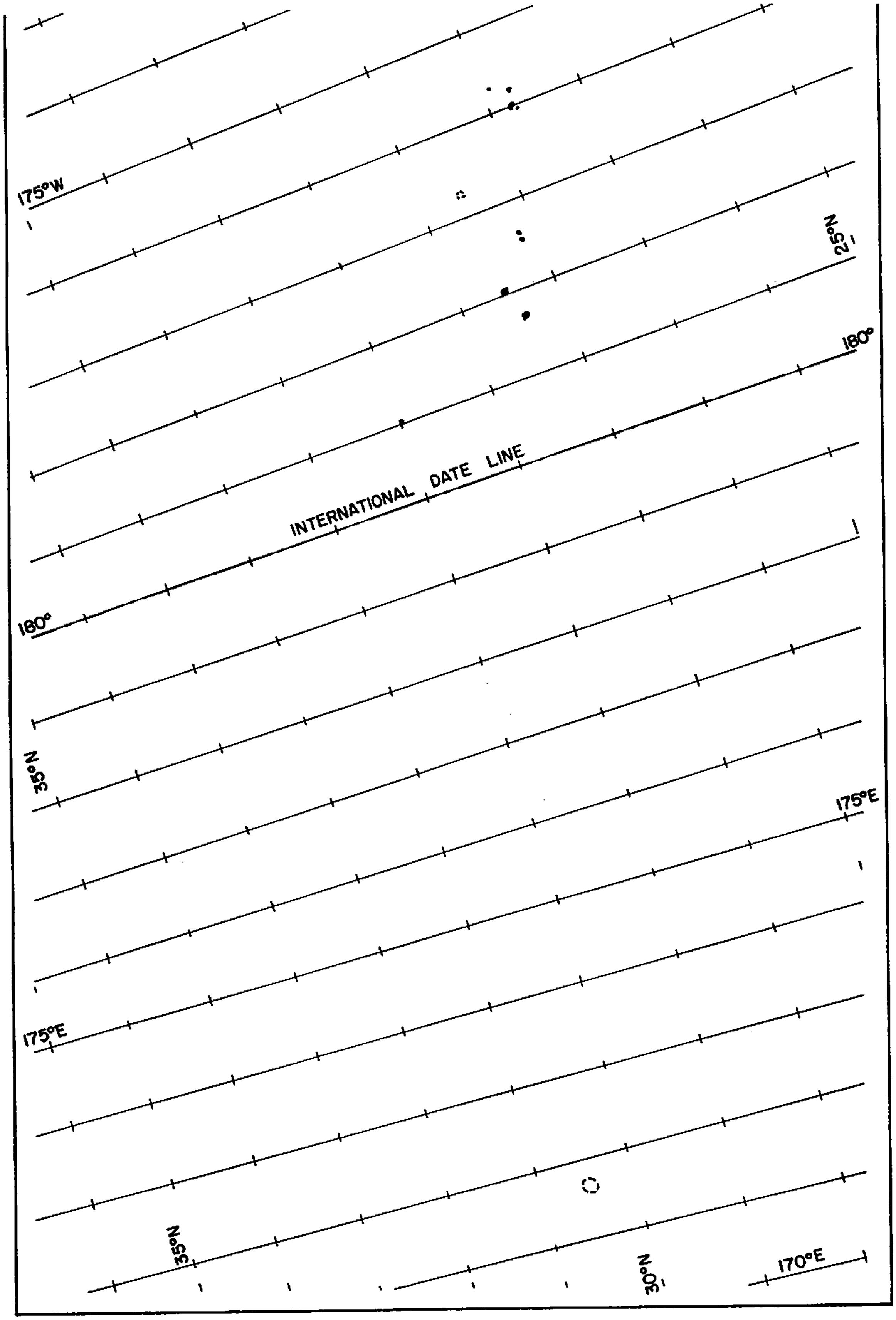

Fig. 2.9A. Base Map for "Activity: Midway Is Midway" (Parts A-C). Western section.

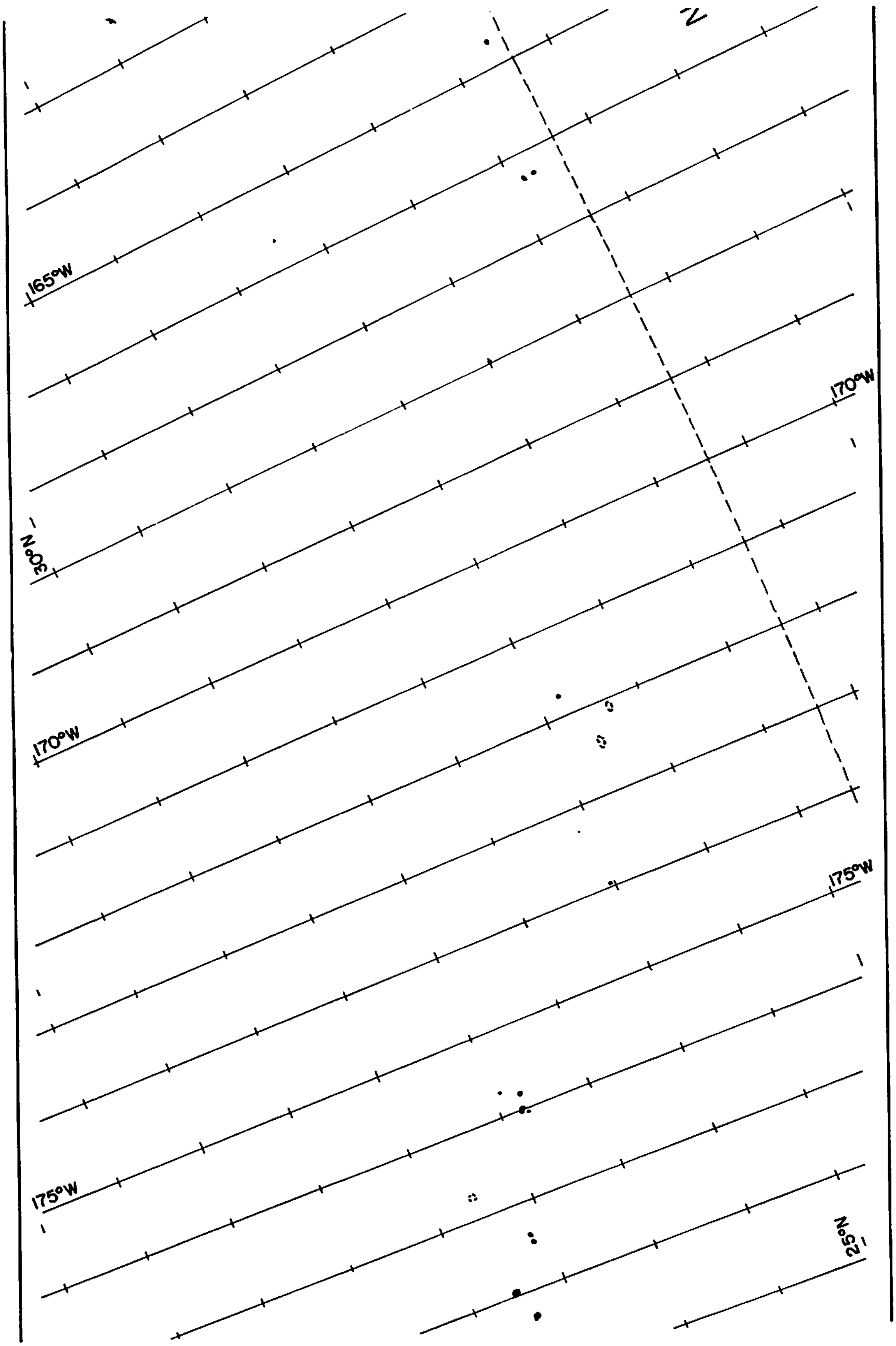

Fig. 2.9B. Center section.

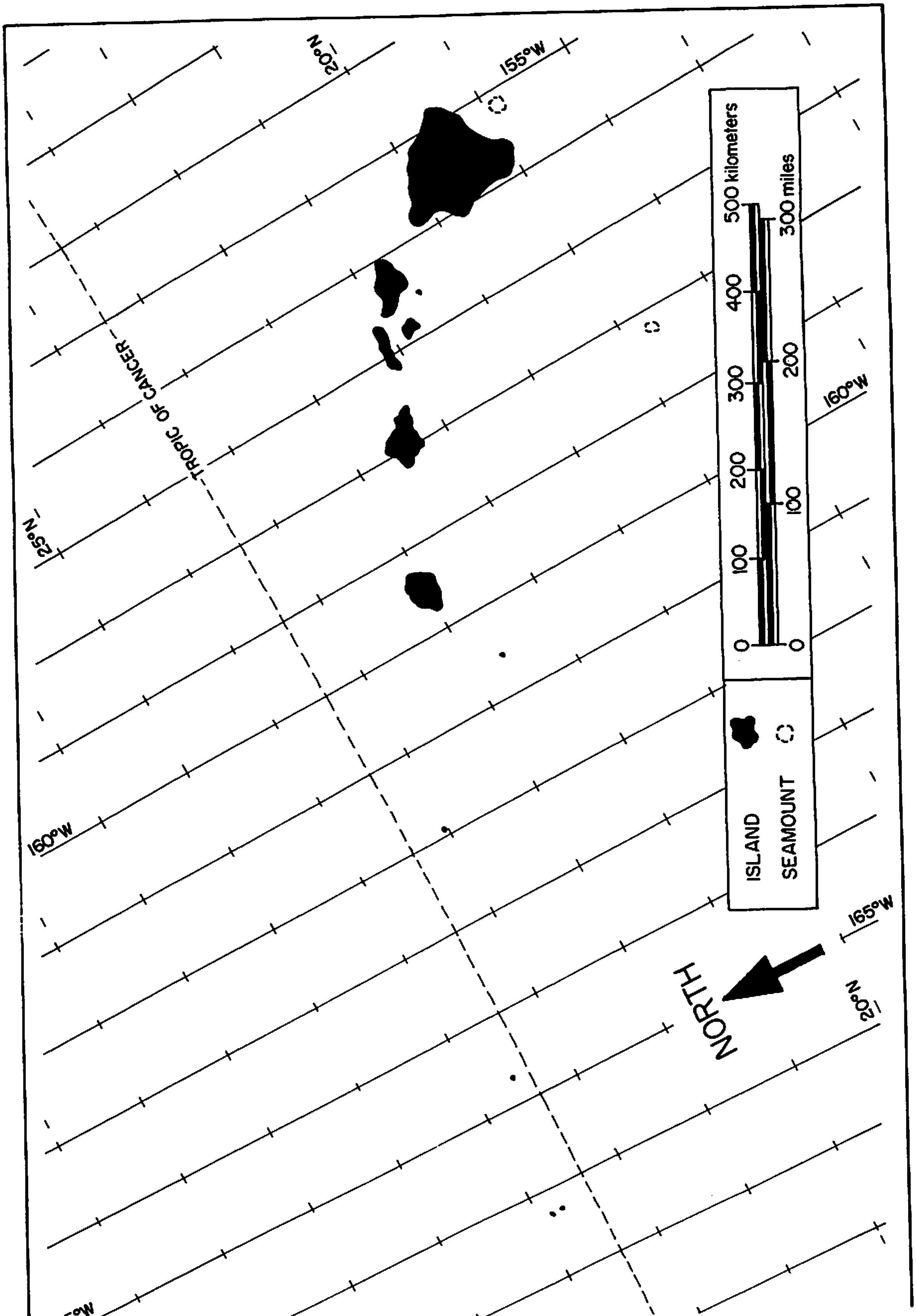

Fig. 2.9C. Eastern section.

Table 2.6. Hawaiian Island Hot Spot Data.

Island Name	Location: longitude	Location: latitude	Distance from Loihi (km)	Most Recent Major Eruption (mya)	Plate Movement in cm per Year
Kanmu Seamount	171°40'E	30°25'N		38.0	
Midway Island	177°25'W	28°08'N		16.2	
Necker Island	164°38'W	23°35'N		10.0	
Nihoa Island	161°55'W	23°02'N		7.2	
Kauai Island	159°28'W	22°02'N		5.1	
Oahu Island	158°02'W	21°28'N		3.7	
Molokai Island	157°00'W	21°06'N		1.8	
Maui Island	156°30'W	20°45'N		1.3	
Hawaii Island (Kilauea)	155°35'W	19°45'N		0 (now)	
Loihi Seamount	155°12'W	18°50'N		0.3	
Average					

5. Using the data in table 2.6 and figure 2.9 students will need to do the following:

   a. Locate and label the islands and seamounts on the map.
   b. Measure the distance between a given island and the Loihi Seamount in kilometers and fill it in on the table.
   c. Calculate the plate movement in centimeters per year using the date of the recent eruption as the time the island was over the hot spot and the measured distance. Use the following formula:

$$\frac{\text{distance from Loihi Seamount (in kilometers)}}{\text{date of more recent eruption (millions of years)}} = \text{velocity of plate movement}$$

Convert the kilometers to centimeters and millions of years to years to determine the answer in centimeters per year. Complete the calculations for all islands and seamounts until table 2.6 is completed. Table 2.7 is the completed version of table 2.6.

6. The Pacific Plate moves northwest between 2 inches (6 centimeters) per year and 15 centimeters (6 inches) per year, most frequently between 3 inches and 4 inches (8 centimeters and 10 centimeters) per year. Compare those rates with the rates obtained by your students. Discuss possible errors with your students— errors in measurement of distance, errors in age dating of last eruption. Perhaps, at the last eruption, the island was not over the hot spot? Perhaps the hot spot theory is incorrect, and there are other factors at work? Perhaps there is more than one hot spot? Ask students to continue the map to the southeast. What will the Hawaiian Island Chain look like 10 million years from now?

Extensions

Northwest of the Hawaiian Islands, a chain of submerged mountains continues toward the north as the Emperor Seamounts. The two chains are separated by a significant directional change, or bend, that occurred approximately 43 million years ago. The Hawaiian Island Chain trends North 68° West; from approximately 32° North Latitude northward, the Emperor Seamounts trend North 10° West. From Kanmu northward, names and ages of some of the seamounts are Koko Seamount, 48 million years; Ojin Seamount, 55 million years; Nintoku Seamount, 56 million years; and Suiko Seamount, 65 million years (Clague and Dalrymple 1987, 5). At the northern end of the Emperor Seamount trend the Meiji Guyot is approximately 73 million years old. As the chain continues toward the north it subducts (dives under) into the Aleutian Trench so that ages exceeding 73 million years are not found. However, by locating the seamounts on a map students can continue this activity toward the north to see if the rate of plate movement has changed. In addition there is a significant change in the line of the two volcanic chains. The Emperor Seamounts are much more north-south than the Hawaiian Islands. What might account for such a change?

Visit the library to research other island chains in the Pacific similar to the Hawaiian Island Chain. Have the students learn more about them to see if they are similar to the Hawaiian Islands in topography, geology, agriculture, and culture.

Table 2.7. Completed Version of Hawaiian Island Hot Spot Data.

Island Name	Location longitude	Location latitude	Distance from Loihi (km)	Most Recent Major Eruption (mya)	Plate Movement in cm per Year
Kanmu Seamount	171°40'E	30°25'N	3700	38.0	9.74
Midway Island	177°25'W	28°08'N	2500	16.2	15.43
Necker Island	164°38'W	23°35'N	1100	10.0	11.00
Nihoa Island	161°55'W	23°02'N	800	7.2	11.11
Kauai Island	159°28'W	22°02'N	600	5.1	11.76
Oahu Island	158°02'W	21°28'N	400	3.7	10.81
Molokai Island	157°00'W	21°06'N	300	1.8	16.77
Maui Island	156°30'W	20°45'N	200	1.3	15.38
Hawaii Island (Kilauea)	155°35'W	19°45'N	0	0 (now)	–
Loihi Seamount	155°12'W	18°50'N	-28	0.3	–
Average					12.60

Encourage students to model the hot spot-island generation process, either as an animation project on the computer or as a physical model using either map or cross-sectional views.

Constant monitoring of active volcanoes may, one day, provide detailed predictions of forthcoming eruptions. Years before it happened scientists knew Mount St. Helens was going to erupt. In 1975 three scientists predicted an eruption before the end of the century. They reinforced that prediction with a subsequent report three years later. Other predictions outline areas of the United States that may be subject to potentially dangerous volcanic activity. Not surprisingly, they are the same areas that have been subject to recent volcanic activity. There is still no way, however, to predict the size, location, duration, or long-term behavior of a volcano (Tilling 1985, 36). Even with more accurate predictions, populations and property would still be at risk. Areas like the Hawaiian Islands would be difficult to evacuate, and property could not be protected. In Vestmannaeyjar, Haimaey, Iceland inhabitants successfully sprayed lava with water to prevent its advance (McPhee 1989, 95). It would be foolhardy, however, to rely routinely on such efforts as protection from the dangers of volcanoes.

RESOURCES

Volcano World on the World Wide Web

http://volcano.und.nodak.edu/

The U.S. Geological Survey publishes several brochures about volcanoes that are of general interest. Some of the titles dealing with volcanoes are *The Interior of the Earth*; *Monitoring Active Volcanoes*; *Natural Steam for Power*; *Volcanic Hazards at Mt. Shasta, California*; *Volcanic Seismic Hazards of Hawaii*; and *Volcanoes of the U.S.* Class sets are sometimes available. Obtain free brochures from the following address:

U.S. Geological Survey
Branch of Distribution
Denver Federal Center
P.O. Box 25286
Denver, CO 80225