

Plate Tectonics and Continental Drift

Tectonics is the study of the origin and arrangement of Earth's structural features which include not only folds and faults but also continents, mountains, and earthquake regions. The basic idea of tectonic theory is that Earth's *lithosphere* (the crust and the rigid upper mantle) is divided into several large, thick plates that slowly move and change in size and shape. Plate boundaries are the sites of intense geologic activity (e.g., earthquakes and volcanoes).

The boundaries between plates are of three general types. At *divergent* boundaries plates move apart while *convergent* boundaries are where plates collide. A *transform* boundary is found where two plates are moving horizontally past one another.

Plate tectonics combines two previous theories, *continental drift* and *seafloor spreading*. Continental drift is the idea that continents move freely, changing their positions relative to one another. Seafloor spreading is the hypothesis that seafloor forms at the crust of the mid-oceanic ridge and moves horizontally away from the ridge crest towards an oceanic trench.

The theory of plate tectonics is important in inferring past climates and possible changes in the future. It's possible to infer past periods of glaciation on continents that drifted across cold polar regions. Climate models indicate that changes in atmospheric carbon dioxide levels are needed to explain the sequence of icehouse/greenhouse changes over the last million years. Several hypothesis link carbon dioxide changes to plate tectonics. So understanding plate tectonics plays an integral part in understanding past climates.

Part A: Identification of Plate Boundaries

Using the *Tectonic Plate Map* (Map 2), identify each of the plate boundaries listed in Table 1 shown below. Place a check in the appropriate box identifying the type of plate boundary. [Note that the arrows on the *Tectonic Plate* map represent relative motion of the plates with respect to one another. In *most* cases this is also the real motion.]

Table 1

Location	TYPE OF PLATE BOUNDARY		
	Divergent	Convergent	Transform
Mid-Atlantic Ridge			
Aleutian Trench			
Nazca Plate and South American Plate			
Southwest Indian Ridge			
Southeast Indian Ridge			
Boundary between the Pacific Plate and the Australian Plate			
West Coast of Southern California			
Philippine Plate and Pacific Plate			
Indian-Australian Plate and the Eurasian Plate			

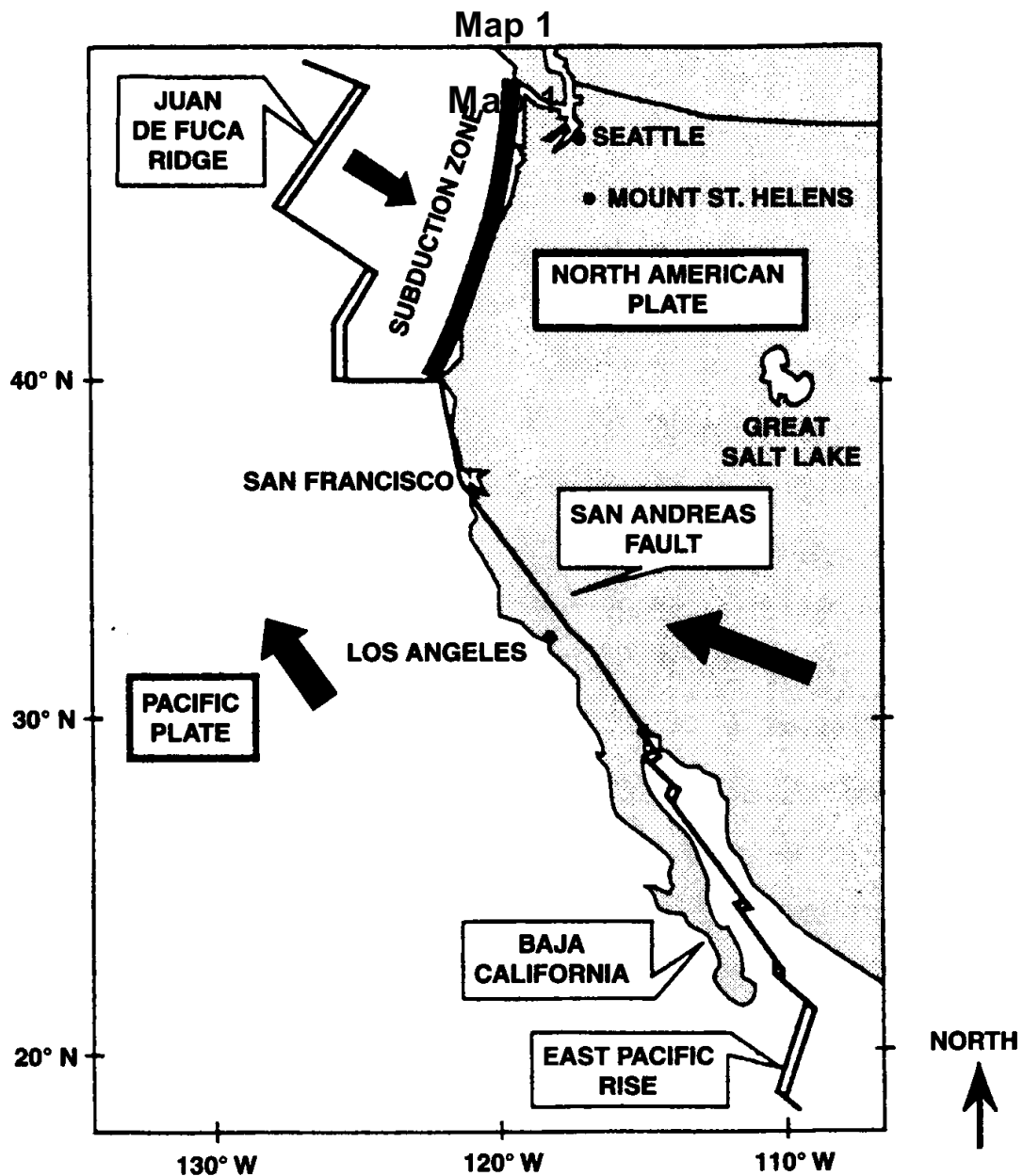
Questions:

1. At what type of boundary are ocean trenches found? _____
2. Which boundaries shows continent-continent collision? _____

Part B: The San Andreas Fault

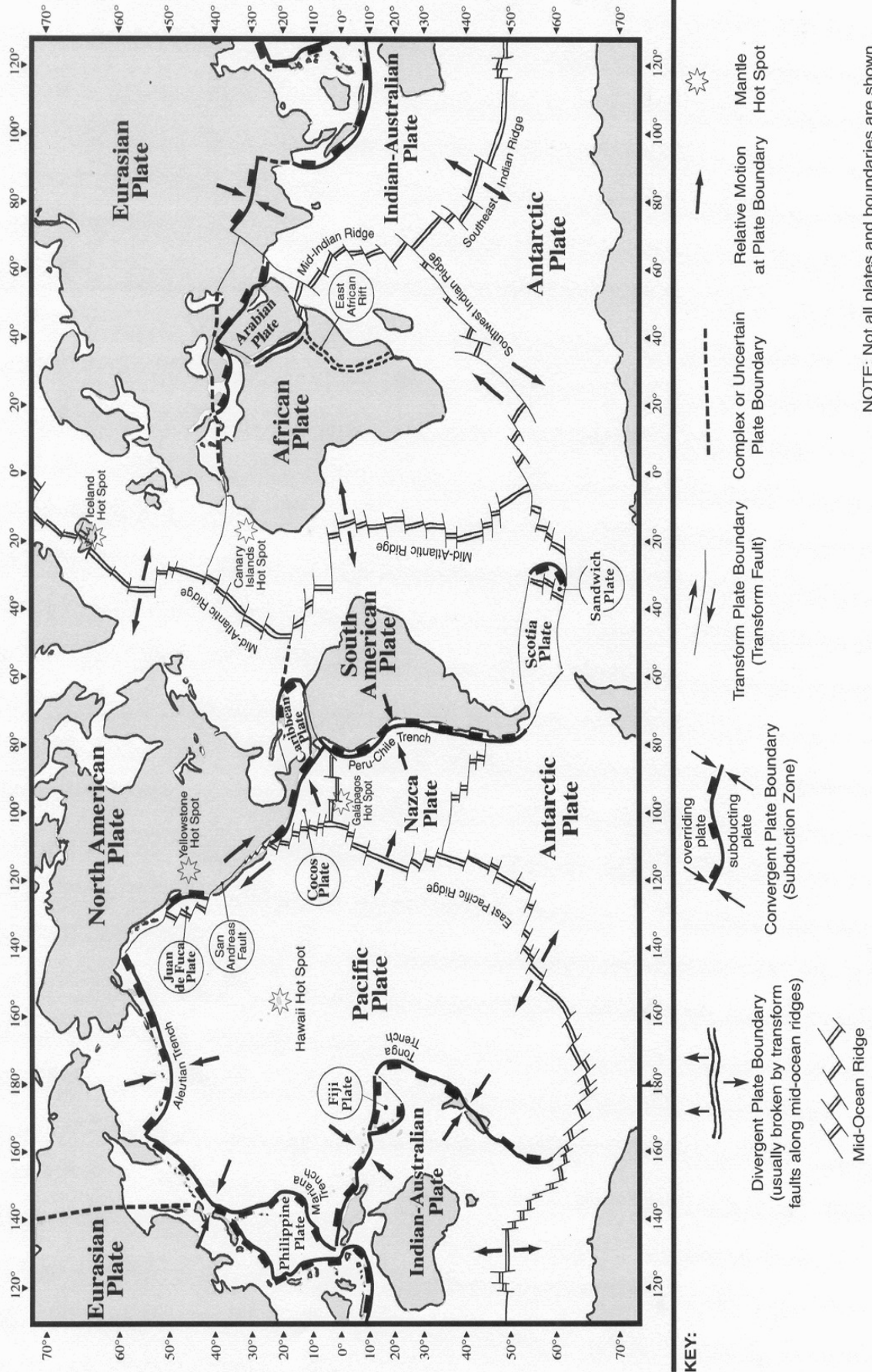
Map 1 shows the Pacific Coastline of the United States. The thick arrows show the actual directions of plate movement.

1. Refer to the Map 2 (*Tectonic Map*) to determine the *relative motion* of the land on either side of the San Andreas Fault. Draw arrows on the east and west sides of the fault to indicate this relative motion.
2. Describe how the *relative movement* on either side of the San Andreas Fault differs from the actual movement of the Pacific Plate and the North American Plate.
3. What is the reason for the discrepancy identified in question 2.



Map 2

Tectonic Plates



NOTE: Not all plates and boundaries are shown.

Part C: The Hawaiian Islands

The Hawaiian islands were created as the Pacific Plate traveled over a hot spot in the mantle. A mantle plume is believed to be the center of vertically rising convection cells, assumed to be deep below Earth's surface. Their effect upon the surface is the production of a *hot spot* which is the site of volcanic activity.

By graphically comparing the age of the islands of the Hawaiian Islands and seamounts and studying a map of the Hawaiian Islands, you will be able to infer the location of the hot spot and the direction and rate of movement of the Pacific Plate.

1. Using the information in Table 2, plot a graph (Graph 1) that compares the age of the Hawaiian Islands and seamounts to their longitude.
2. Next to each point label the name of the island.
3. Connect the points with a smooth “best-fit” line.
4. Estimate the age of Nihoa and plot its position on the graph.

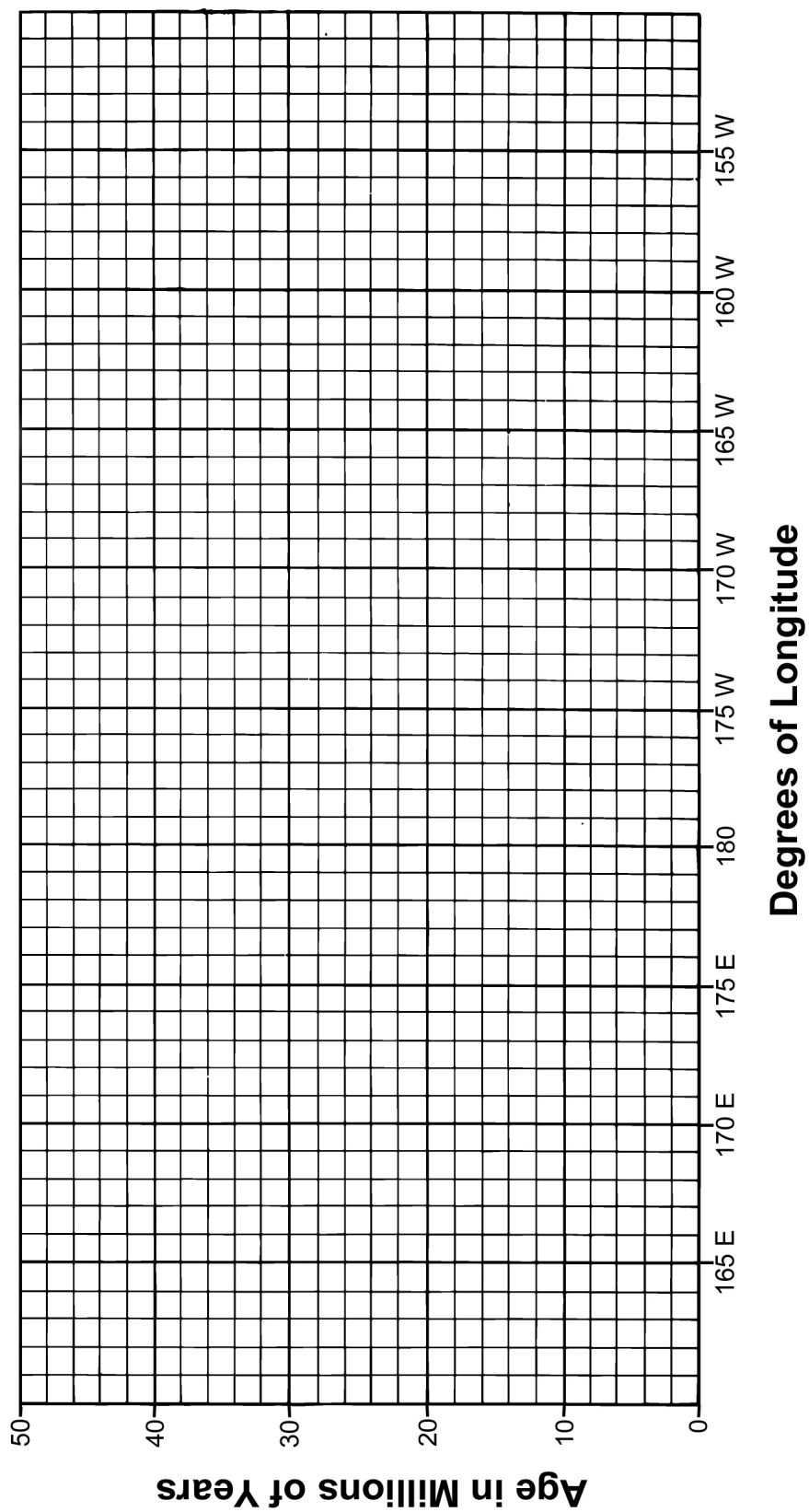
Table 2

Island (or reef)	Approximate age (in millions of years)	Longitude (in degrees & minutes)
Hawaii	0.5	155° 30' W
Kanum	39.0	170° E
Kauai	4.7	158° 30' W
Maui	1.1	156° 15' W
Midway	18.0	177° 30' W
Molokai	1.6	157° W
Necker	10.1	164° 30' W
Nihoa	no data provided	162° W
Oahu	2.5	158° W
Pearl	20.1	176° W
Yuruaku	42.3	168° 30' E

5. Using the information in Table 2, plot the ages of the following islands on the map of the Hawaiian Islands: Kauai, Oahu, Molokai, Maui, Hawaii (at Kilauea Volcano).
6. Using the map scale, calculate the distance from each island to Kilauea Volcano by measuring from the center of each volcanic peak at the end of the long pointer line. Using the map scale, determine the actual distance in kilometers. (Record this information in Table 3).
7. Convert the actual distance in kilometers from each island to Kilauea Volcano to centimeters (1 km - 100,000 cm) and record in Data Table 3.
9. Using the distance and approximate age (in millions of years) calculate the average rate of movement for each island in centimeters per year (cm/yr).
10. Show all calculations for distance and rate on separate paper.

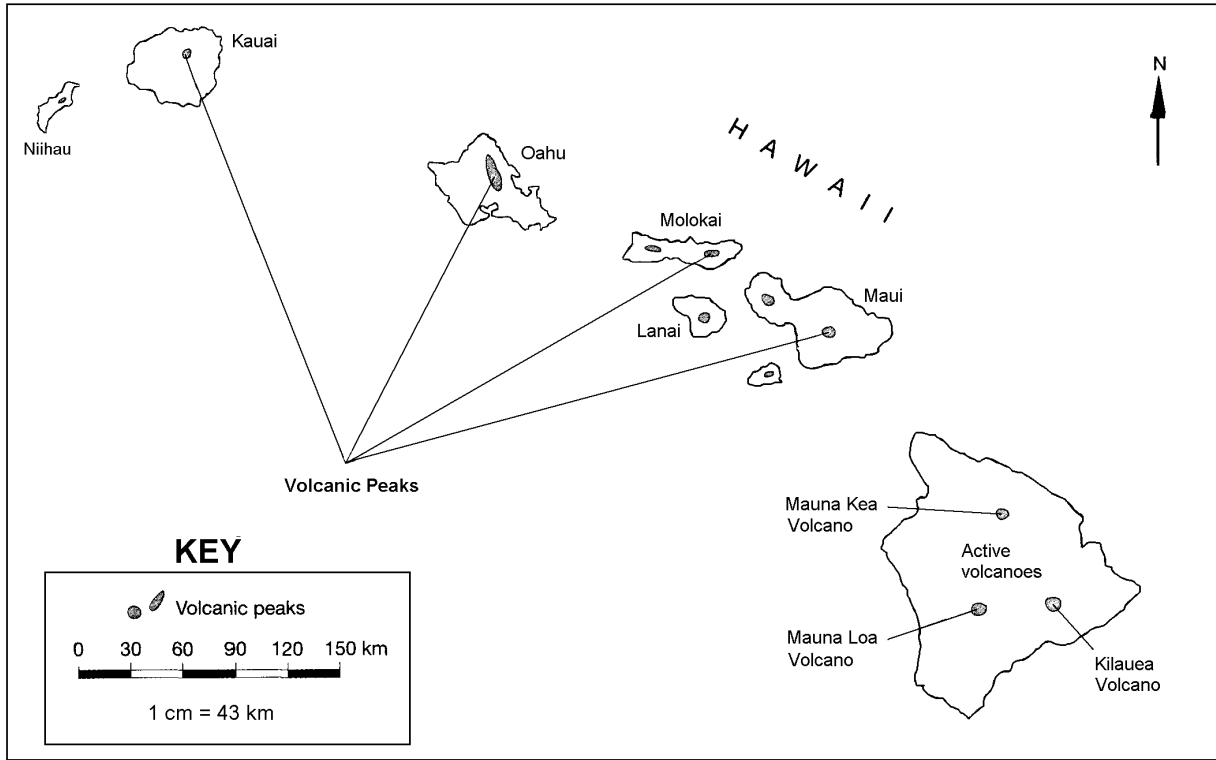
Graph 1

AGE OF THE HAWAIIAN ISLANDS



Map 3: HAWAII

Adapted from *Laboratory Manual In Physical Geology, 3rd Edition* (AGI/NAGT, 1993) in *Explorations in Earth Science*, UPCO, (Osmun, Vorwald, and Wegner, 2006)



Map of the Hawaiian Islands, showing volcanic peaks. Absolute ages were determined from basalts that form the islands.

Table 3

Island	Measured Distance (cm)	Actual Distance (km)	Actual Distance (converted to cm)	Approximate Age in Years	Average Rate (cm/year)
Kauai					
Oahu					
Molakai					
Maui					

Questions

- Which Hawaiian island is the youngest? _____
- Which Hawaiian island is the oldest? _____
- Referring to the Hawaii map and your graph, what is the relationship between the age of the islands and their longitude?

4. What is the inferred age of Nihoa? _____
5. Which island does not seem to fit the pattern of the others? _____
6. As distance west of Kilauea increases the size of the islands generally appears to decrease. What is the likely reason for this trend?
8. Predict where the next volcanic Hawaiian island will form.
9. Based on Procedure B, describe the change in the rate of movement of the Pacific Plate during the last 4.7 million years.
10. In which direction is the Pacific Plate moving? _____

Part D: Converging Boundaries and Subduction Zones

Adapted from "Historical Geology - Interpretations and Applications, 5th Edition (Poort and Carlson, 1998)

Deep ocean trenches represent zones of subduction where ocean-floor rock sinks into the mantle. Evidence for this is the distribution of intermediate and deep focus earthquakes. Earthquakes occur only in rigid rock material and not in plastic (solid material capable of flowing under great pressure) or molten rock in the mantle or core.

It has been observed that most earthquakes occur at shallow focal depths within the lithosphere. Earthquakes of intermediate focal depths occur only near trenches. This is evidence that solid and rigid material is being forced down into the mantle at these locations. These earthquakes occur within the subducting plate. Therefore, plotting earthquakes and their focal depths relative to a trench provides a profile of the subducting plate.

1. Using the data table of earthquake focal depths (Table 4), Map 4 "Trenches of the Western Pacific", and the Graph 2 provided, you will construct a cross-section of a subducting plate along line A-A' on the map.
 - a. The focal depth of each earthquake event is listed along with its distance from a seismic monitoring station on Bonin Island. (Bonin Island is at 0 km on the horizontal axis.)
 - b. On the graph paper construct the cross-section by plotting the focal depth of each earthquake at its distance from the Bonin Island monitoring station.
 - c. Use the appropriate symbol for each earthquake depth category as shown on the map and graph paper.
 - d. Draw a "best fit" line through the graph plots. This will identify the boundary between the two plates. The slope of the boundary will be different for the shallow portion of the plate.
2. Based on the pattern of graph plots, determine the approximate angle for the subducting plate. Note that based on the plots and best fit line that the angle changes with depth. Measure the two angular trends you can identify and record both values in the box at the top of the graph that is labeled "*subduction angle*."
3. Based on the map and the graph plots, label the *upper plate* and the *lower plate* on the cross-section.
4. On the cross-section draw an arrow on the subducting plate showing the direction in which it's moving.
5. Which plates are involved in this converging boundary?

6. Which of the plates you identified is the subducting plate? _____

Table 4

Earthquake	Distance from Station (km)	Depth (km)	Earthquake	Distance from Station (km)	Depth (km)
1	400	390	13	80	13
2	120	32	14	580	680
3	350	295	15	390	335
4	290	190	16	460	460
5	530	540	17	190	70
6	200	54	18	50	10
7	220	90	19	440	400
8	340	215	20	480	530
9	150	32	21	260	110
10	520	630	22	165	55
11	310	230	23	190	58
12	240	150	24	520	605

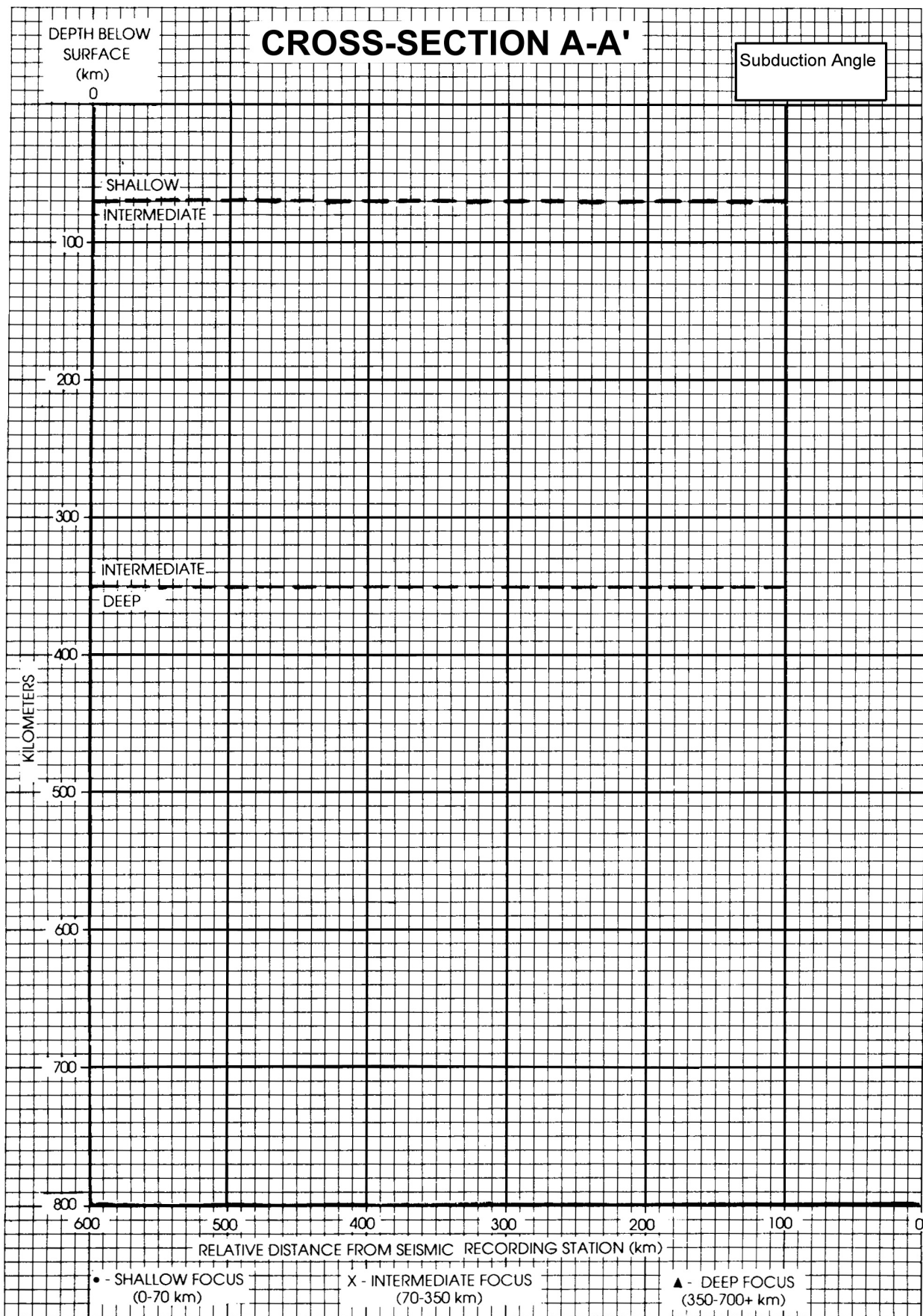
Use Map 4 the following information to answer questions 7 and 8.

The closer the spacing between shallow, intermediate, and deep focus earthquakes, the steeper the slope of the plate (or angle of descent).

7. Assuming that the depth relationships across the three trenches are similar, which of the three trenches has the *steepest* subduction angle?

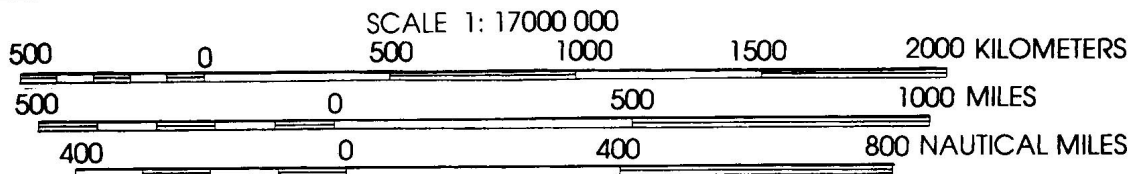
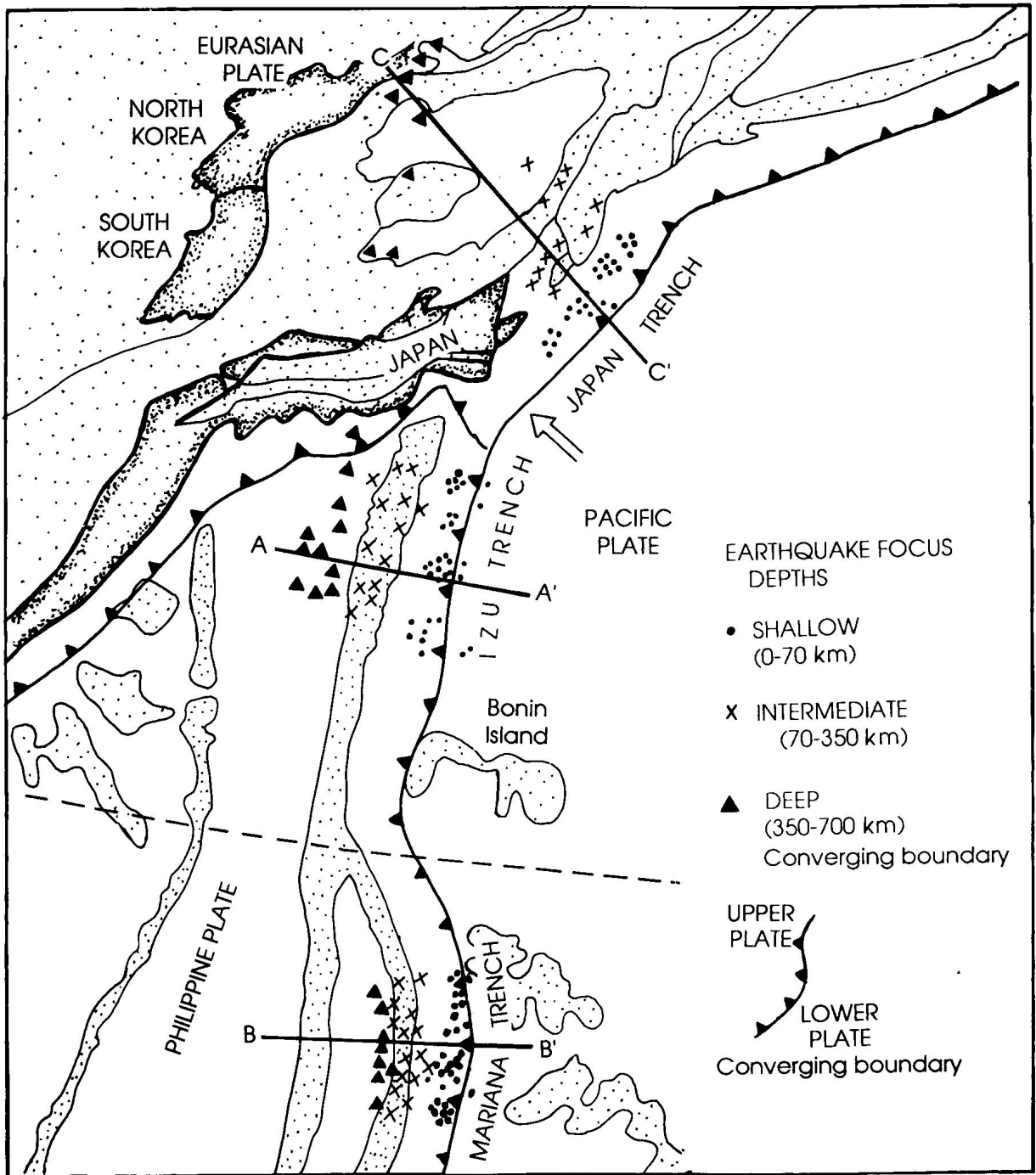
8. Assuming that the depth relationships across the three trenches are similar, which of the three trenches has the *shallowest* subduction angle?

9. Is the horizontal scale on the cross-section the same as the vertical scale? _____
10. Based on your answer to question 9, is the cross-section vertically exaggerated? _____
11. How does the type of convergent boundary shown by this cross-section differ from the convergent boundary where the Nazca Plate is colliding with the South American Plate?
13. What *surface* feature has formed on along the west coast of South American as a result of the collision of the Nazca Plate with the South American Plate? _____



Graph 2

Map 4: Trenches of the Western Pacific



Lambert Azimuthal Equal-Area Projection
 (Map center point: Equator, 160° W.)

Part E: Seafloor Spreading

One test for the sea-floor-spreading hypothesis involves magnetic patterns on the seafloor. In the late 1950's, scientists mapped the present-day magnetic field generated by rocks on the floor of the Pacific Ocean. The volcanic rocks which make up the sea floor have magnetization because, as they cool, magnetic minerals within the rock align to Earth's magnetic field. The intensity of the magnetic field they measured was very different from the intensity they had calculated. Thus, the scientists detected magnetic anomalies, or differences in the magnetic field from place to place. They found positive and negative magnetic anomalies. *Positive* magnetic anomalies are places where the magnetic field is *stronger* than expected. Positive magnetic anomalies are induced when the rock cools and solidifies with the Earth's north magnetic pole in the *northern* geographic hemisphere. The Earth's magnetic field is enhanced by the magnetic field of the rock. *Negative* magnetic anomalies are magnetic anomalies that are *weaker* than expected. Negative magnetic anomalies are induced when the rock cools and solidifies with the Earth's north magnetic pole in the *southern* geographic hemisphere. The resultant magnetic field is less than expected because the Earth's magnetic field is reduced by the magnetic field of the rock. Figure 1 illustrates the pattern of magnetic anomalies observed in seafloor rocks along a mid-ocean ridge.

When mapped, the anomalies produce a zebra-striped pattern of parallel positive and negative bands (Figure 2). The pattern was centered along, and symmetrical to, the mid-ocean ridge. A hypothesis was presented in 1963 by Fred Vine and Drummond Matthews to explain this pattern. They proposed that lava erupted at different times along the rift at the crest of the mid-ocean ridges preserved different magnetic anomalies

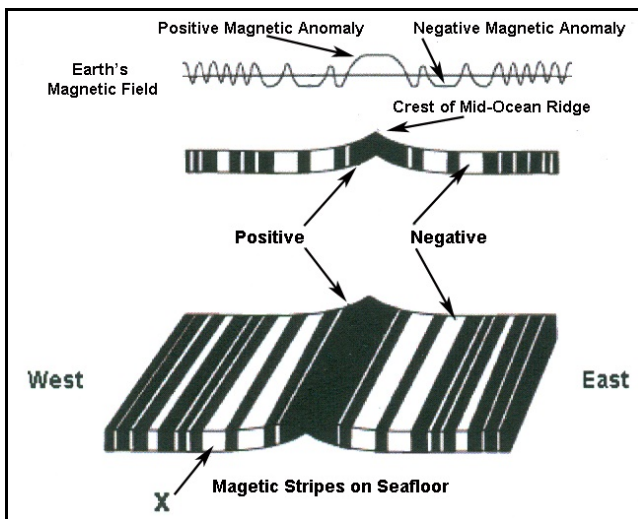


Figure 1

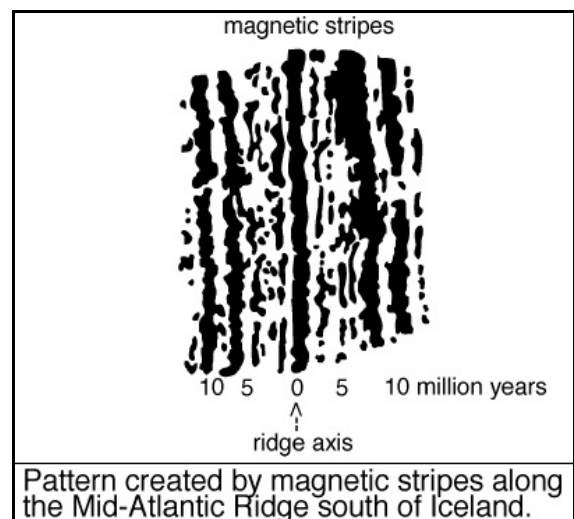


Figure 2

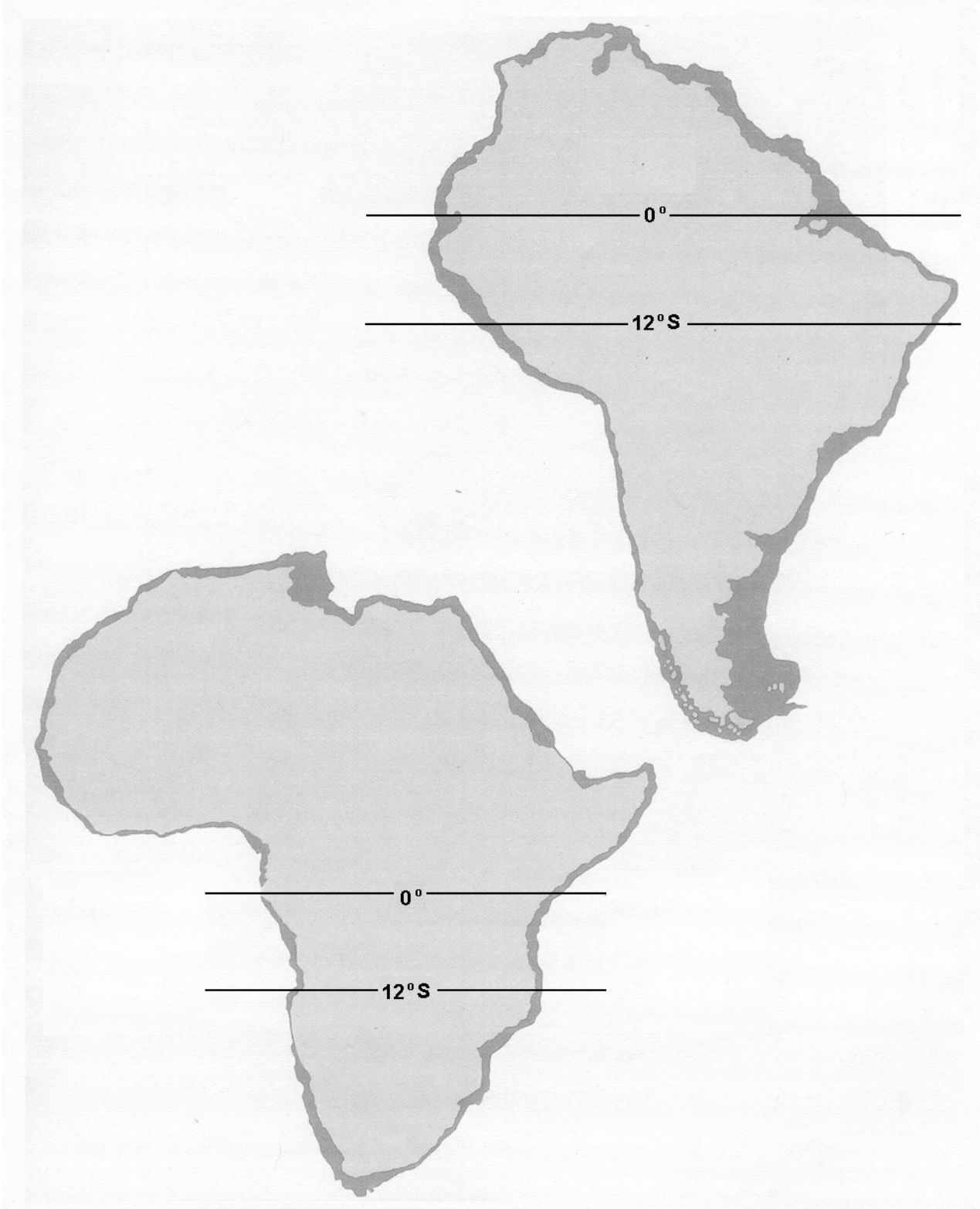
1. In Figure 1 label the rock unit on the east side of the mid-ocean ridge that matches rock unit X on the west side with an X.
2. In Figure 1 draw arrows on the east side and west side of the ridge showing the direction the seafloor is moving.
2. What type of magnetic anomaly would be found in igneous rocks that have recently solidified at the ridge crest?

3. According to Figure 1, how many magnetic reversals are indicated? _____
4. In which hemisphere was Earth's north magnetic pole when the rocks identified by the X in Figure 1 solidified?

5. According to Figure 2 what is the relationship between the age of the seafloor rock as distance increases east and west of the mid-ocean ridge?
6. What does the varying thickness and spacing of the rock units on either side of the ridge indicate about the rate at which the seafloor is moving over time?

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