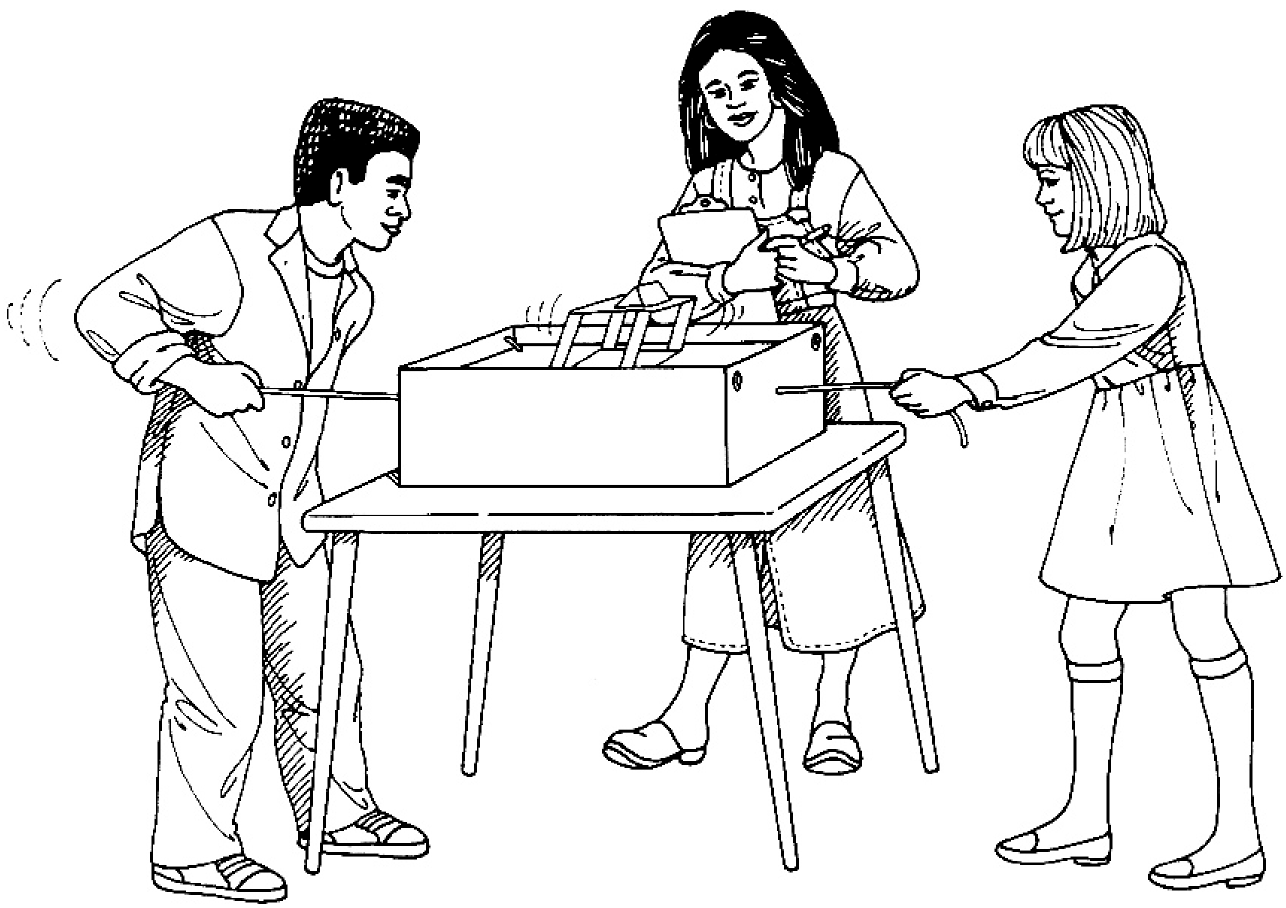
UNIT TWO



What Happens When the EARTH QUAKES?

In this unit students will move beyond their own personal survival and that of their community, the focus of Unit 1, to the big picture of earthquakes in space and time. Since the Seismic Sleuths curriculum is intended to supplement, and not to replace, your school's own syllabus, it sketches this big picture without filling in all the basic earth science background. Your preparation to teach these lessons must begin with an assessment of your students' readiness. If they have no familiarity with rocks and minerals or with faulting and other processes that form landscapes, you may need to provide a brief introduction from the first few chapters of a high school geology or earth science textbook.

Unit 2 begins with a hands-on activity that models what happens when the stresses accumulated at a fault are released in an earthquake. Using a box, a board, sandpaper, and other simple materials, students apply scientific method and basic math skills to measure movement, calculate averages, and plot their information on a graph.

The second lesson includes three activities and an overview of what is now known about Earth's ever-shifting surface and its layered inner structure. In the first activity, students will reproduce the magnetic evidence for the migration of Earth's poles in the course of tectonic movement. In the second, they see how this record is written in the rocks at mid-ocean ridges. In the third, they create a map showing the arrangement of the continents 120 million years ago, and compare it with the map of the world today. As students consider several alternative explanations for tectonic plate movement, remind them that earth science, like the Earth it studies, is constantly in motion. Scientific knowledge moves forward through questioning and the development of hypotheses into theories; its goal is never to provide dogmatic answers.

The third lesson begins with an exercise in which students contrast the small scope of historic time with the vastness of geologic time. In the second activity, Paleoseismology, they simulate the techniques seismologists use to read the record of relatively recent earthquakes.

The amount of damage an earthquake causes depends on the strength and duration of the earthquake, on population density, on methods of construction (to be dealt with in Unit 4), and on the geophysical/geological characteristics of the impacted area. Lesson 4 progresses to three of the most potentially destructive earthquake effects: liquefaction, landslides, and tsunami. Each occurs when a seismic shock impacts an area with certain physical characteristics. Lesson 5 underlines the importance of site, as students interpret maps highlighting different features of the landscape. They will draw on their new knowledge to make additions to the local map they began in Unit 1.

2.1

Stick-Slip Movement

RATIONALE

Students will operate a model to observe the type of motion that occurs at a fault during an earthquake and explore the effects of several variables.

FOCUS QUESTIONS

How much energy will a fault store before it fails?

Is this quantity constant for all faults?

OBJECTIVES

Students will:

1. Model the frictional forces involved in the movements of a fault.
2. Measure movement, calculate averages, and plot this information on a graph.
3. Explore the variables of fault strength vs. energy stored.

MATERIALS

for each small group

- 1 copy of Master 2.1a, Stick-Slip Data Sheet
- 4 sandpaper sheets, 23 cm x 28 cm (9 in. x 11 in.), in 60, 120, and 400 grit (12 sheets)
- Scissors
- Strapping tape
- 1-1b box of sugar cubes
- 8 thumbtacks
- A box of rubber bands
- 2 large paper clips
- Yardstick or meter stick
- At least 2 m of string
- Large dowel or empty tube from a roll of paper towels

- Marking pen
- Scales
- Pine board, approx. 2.5 cm x 30 cm x 1.8 m (1 in. x 12 in. x 6 ft.)
- Several books to support one end of the board
- Protractor for measuring angles
- 1 brick (optional)

PROCEDURE

Teacher Preparation

To assure success, construct the model ahead of time and rehearse the activity. Then arrange materials for student models in a convenient place.

A. Introduction

Elicit a definition of *fault* from the class, supplementing students' information as necessary until the essential elements have been covered.

Explain to students that when an earthquake occurs and movement begins on a fault plane, the movement will not proceed smoothly away from the focus. Any change in the amount of friction along the fault will cause the fault movement to be irregular. This includes changes along the length of the fault and with depth, changes in rock type and strength along the fault, and natural barriers to movement, such as changes in the direction of the fault or roughness over the surface of the fault plane.

Rupture along a fault typically occurs by fits and starts, in a type of sporadic motion that geologists call *stick-slip*. As energy builds up, the rock on either side of the fault will store the energy until its force exceeds the strength of the fault. When the residual strength of the fault is exceeded, an earthquake will occur. Movement on the fault will continue until the failure reaches an area where the strength of the rock is great enough to prevent further rupture. In this manner, some of the energy stored in the rock, but not all of it, will be released by frictional heating on the fault, the crushing of rock, and the propagation of earthquake waves.

B. Lesson Development

1. Divide the class into working groups of at least four students each. Distribute one copy of Master 2.1a, Stick-Slip Data Sheet, to each group. Tell students that they are going to model a process, record data for each trial, and then vary the process, changing only one variable at a time.

2. Allow groups to assemble their materials, then give these directions:

a. Fold each piece of 120-grit sandpaper in half lengthwise and cut, to produce eight strips of sandpaper, each 11.5 cm x 28 cm (4.5 in. x 11 in.) in size.

b. Wrap one of the strips around the box and secure it around the sides (not the top and bottom) with two rubber bands. (See diagram.) Weigh and record box mass.

VOCABULARY

Fault: a break or fracture in Earth's crust along which movement has taken place.

Friction: mechanical resistance to the motion of objects or bodies that touch.

Stick-slip movement: a jerky, sliding movement along a surface. It occurs when friction between the two sides of a fault keeps them from sliding smoothly, so that stress is built up over time and then suddenly released.

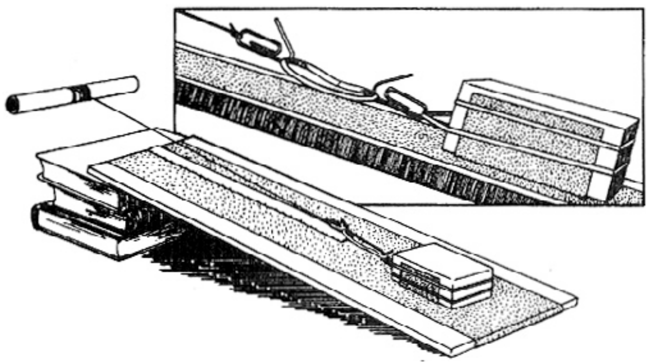
Variable: in a scientific experiment, the one element that is altered to test the effect on the rest of the system.

c. Tape the seven remaining strips of 120-grit sandpaper into one long strip. (Be sure to use tape only on the back of the sandpaper.) Now attach the sandpaper lengthwise down the center of the pine board, using two thumbtacks at each end and being sure the sandpaper is drawn tight.

d. Attach one paper clip to one of the rubber bands around the box.

e. Tie one end of the string onto another paper clip and place a mark on the string about 1 cm from the clip. Use one rubber band to join the paper clip on the box with the paper clip on the string. Tie the free end of the string around the dowel or paper towel roll.

f. Tape the meter stick onto the sandpaper strip on the board.



g. Position the box at one end of the board so it is centered on the sandpaper. Use books to raise the other end of the board approximately 10 cm (4 in.). Measure and record the height.

h. Gently roll the string onto the dowel until the string lifts off the paper and becomes taut. Note the location of the mark on the string relative to the meter stick. Take care to keep the dowel in the same position during rolling and measurement.

i. Continue to roll the string onto the dowel until the box moves. The box should move with a quick, jumping motion. Record the new location of the mark on the string (the distance the box moved) on the data table. Continue rolling up the string and recording jump distance until the box hits the meter stick. The meter stick can be pulled upwards to allow the box to continue to be pulled.

j. Subtract the beginning measurement from the ending measurement or add up the jump measurements to find out how far the box moved. Divide by the number of jumps to calculate an average jump distance.

3. Instruct other students in the same group to change one variable, repeat the procedure, and average the distance of the jumps. Students may vary the model by adding one or more rubber bands, adding more books to change the angle of the board, substituting the brick for the box, or using sandpaper of a different grit. If time allows, give every student a chance to operate the model with each of the variations.

4. Ask students to complete their data sheets.

C. Conclusion

Ask the class:

- What might the different variables represent in terms of earthquakes and landscape conditions? (Number of rubber bands—different amounts of energy released; angle of the board—steepness of the fault; sandpaper grit size—differences in the amount of force

TEACHING CLUES AND CUES

This part of the activity requires a very steady hand.

Controlling the tension on the string works best if the string is rolled onto the dowel until the dowel rests on the books and is against the edge of the board.

required for a fault to move—the amount of friction.) Emphasize that different faults can store different amounts of energy before they fail. Some faults have the potential for generating larger earthquakes than others.

■ Do the rubber band and string go totally slack after each movement? (No.) What does this tell you about the release of stored energy on a fault when an earthquake occurs? (No earthquake ever releases all the energy stored in the Earth at a particular point. It is because some stored energy always remains that one quake may have numerous foreshocks and aftershocks, and earthquakes recur frequently in some active areas.) ▲

Stick-Slip Data Sheet

Name ____

Date _______________________________

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Box Weight					
Board Height					
Sandpaper Grit					
Beginning Distance					
Jump 1					
Jump 2					
Jump 3					
Jump 4					
Jump 5					
Jump 6					
Jump 7					
Jump 8					
Jump 9					
Jump 10					
Jump 11					
Jump 12					
Jump 13					
Jump 14					
Jump 15					
Total					

Stick-Slip Data Sheet

Distance					
Average Distance					

2.2

Shifting Plates & Wandering Poles

RATIONALE

To understand earthquakes students need to understand the structure of the Earth. The theory of plate tectonics has contributed to an understanding of how the Earth's plates move and how that movement can cause earthquakes.

FOCUS QUESTIONS

How does the shape of the continents indicate that they were once joined?

What are some of the ways to tell the continents are moving?

OBJECTIVES

Students will:

1. Model magnetic reversal patterns.
2. Use paleomagnetic data to demonstrate plate motion.

MATERIALS

- Master 2.2a, Tectonics Background
- Transparency of Master 2.2b, Earth Cross Section
- Overhead projector
- Master 2.2c, Reading the Patterns
- Master 2.2d, Continental Pieces, two copies for each small group
- Master 2.2e, World Map Grid
- Master 2.2f, World Map Grid, 120 MYA
- Classroom world map

for each small group

- Bar or cow magnet
- Large nail
- Paper clips or staples
- Clamp with a handle

VOCABULARY

Paleomagnetism: the natural magnetic traces that reveal the intensity and direction of Earth's magnetic field in the geologic past.

- Bunsen burner, cigarette lighter, or other direct heat source
- One 3 x 5 file card and sheets of blank paper
- Twenty 9 can (3-4 in.) lengths of audiocassette tape (Use an old tape.)
- A roll of clear tape
- Scissors and a ruler
- Pens or pencils
- Maps of South America and Africa (*optional*, but desirable)
- Map of the Pacific Ocean floor (*optional*, but desirable)

PROCEDURE

Teacher Preparation

Practice the magnetizing demonstration before class. Prepare the nail by stroking it with a magnet until it will pick up paper clips or staples on one end. Place the nail in a clamp and heat it in the middle until the clips drop off.

Read Master 2.2a, Tectonics Background, and decide how much time you will need to spend presenting this information to your students. If they are already familiar with its outlines, you may just want to connect the illustrations with the stick-slip movement students saw in the previous activity.

PART ONE

POLES AT PLAY

A. Introduction

Pass out copies of Master 2.2a, Tectonics Background. Project Master 2.2b, Earth Cross Section, and review the first two major sections of Master 2.2a with the students. Point out to students that on a world map continental land masses seem to have a jigsaw fit. Early mapmakers noted this long ago when drawing the first maps of the new world.

B. Procedure

1. Ask the students how magnets work. Some may already know that alignment of atomic forces creates the magnetic “pull,” or force field. Tell students that when a magnet is heated it loses its magnetic force, and when it cools down it again picks up the faint trace of the Earth’s magnetic field. Demonstrate this with a nail by stroking it with a magnet and then heating it, as explained above. Ask students where rocks are heated (in volcanoes and deep within the Earth). Tell them that in the next two activities they are going to simulate the process of using paleomagnetism to study plate tectonics.

2. Tell students that in 1963, two English geophysicists, Vine and Matthews, were using extremely sensitive magnetometers to make measurements of the seafloor across the Mid-Atlantic Ridge. Scientists already knew that over the 4.6 billion years of Earth’s history, its magnetic poles have changed directions more than once, so that the south pole and the north pole have actually switched

TEACHING CLUES AND CUES

You may want to take students through a quick review of magnetic properties and the rule of attraction and repulsion of poles.

TEACHING CLUES AND CUES

Be sure students understand that it is the magnetic poles that have changed, not the physical ends of the Earth.

places. When a volcano erupts, the volcanic rocks record the direction of the poles at that time. The rocks are magnetized in somewhat the same way as the nail was by the magnet in your demonstration. What Vine and Matthews discovered was a pattern of polar reversal stripes on both sides of the ridge. The purpose of this activity is to simulate those patterns.

3. For each group of two or three students, pass out 20 audiotape strips, one 3 by 5 card, glue or tape, and a magnet.

4. Give these instructions:

a. Tape 6 or 7 strips of audiotape to the card by one end, so they are parallel to each other and about 1 cm apart. One end will be loose, as shown on the illustration.

b. Stroke one of the strips with one pole of the magnet. Then stroke the next strip with the other pole of the magnet.

When the magnet is passed over the loose, ends of the tape, the strips will move. Their direction will depend on which end of the magnet they were stroked with.

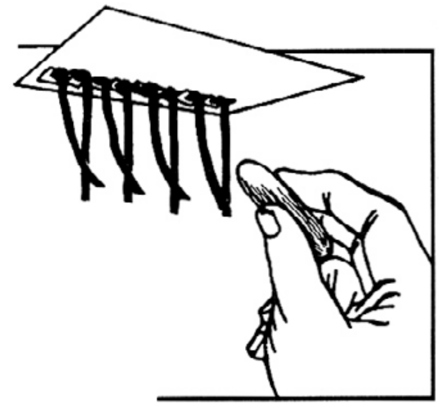
c. Create patterns of magnetism by mixing up the order in which you stroke the strips of tape, then give the cards to other groups to interpret.

C. Conclusion

After they have had a chance to create patterns and share them with other groups, ask students if they were able to interpret the other

groups' patterns. How did the tape strips record the direction of the magnetism? (Magnetic particles are embedded in the tape.)

This activity was adapted from a workshop on earth science activities presented at the Exploratorium in San Francisco, CA.



TEACHING CLUES AND CUES

This activity works best if the card is held upside down with the tape hanging down.

Be sure all strokes on the individual strips are in the some direction. Do not touch again when testing polarity.

PART TWO

RECORDS IN THE ROCK

A. Introduction

Review the structure of the Earth's interior with the class, drawing on Master 2.2a. Remind students that in the last activity they saw how patterns of magnetic polarity can be recorded. What Vine and Matthews saw, as they explored the Mid-Atlantic Ridge with their instruments, was a similar pattern recorded in volcanic rocks. Looking at these patterns on one side of the ridge, they noticed that the opposite side showed a mirror image of reversals. Their next step was to collect rock samples from the sea floor and determine the age of the rocks, to find out when the volcanoes that formed the rocks erupted. They discovered not only that the patterns of ages were mirrored on the two sides, but also that the rocks on both sides were progressively older as they moved away from the ridge. The next activity will help students understand the process Vine and Matthews followed.

B. Procedure

l. Give each group a copy of Master 2.2c, Reading the Patterns, and a pair of scissors. Give these instructions:

a. Cut the reversal pattern off the bottom of the sheet and trim away everything outside the dotted outline.

b. Cut the reversal pattern along the dashed horizontal line in the center to form two strips. Place the two strips together with the patterned bands facing in, making sure that the arrows on both strips face the same way. Tape ends together.

c. Insert the scissors at one of the black dots on the map and carefully cut a slit along the axis of the mid-ocean ridge, following the broken line between the two dots. Insert the open end of the folded reversal pattern into the slit from underneath, holding onto the stub, and carefully pull the first several centimeters of paper through (up to the first dark line). Crease the strip along the dark line so the first pattern is showing, bend it flush with the paper on one side of the ridge, and label it with a 1 in red ink. Do the same thing on the other side of the ridge.

Tell students that this represents a volcanic eruption during which the rocks adopt the magnetic field of the Earth at that time. Then, announce that a reversal of the poles has occurred.

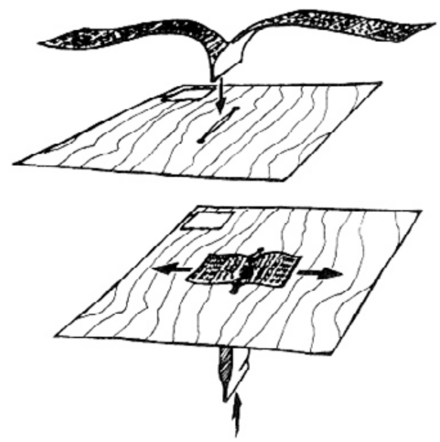
d. Pull up the second pattern on the strip, bend it over, and label it 2. Repeat with the other side. Continue this process until all the patterns have been pulled up and labeled.

2. When all the bands have been labeled, ask students:

- What does each fold of paper represent as it is pulled up from below? (new rock being erupted from inside the Earth by volcanic action)
- Which pattern represents the oldest volcanic rock? (Number 1)
- Is the pattern of the reversals and the ages mirrored on the two sides of the ridge? (Yes.)
- Why do the pattern bands vary in width? (Their width is determined by how much volcanic activity occurred before the reversal and how long the reversal of polarity lasted.)
- Can you tell which way the poles were oriented during any given age on your model? (Yes.)

C. Conclusion

Conduct a quick drill to be sure students understand how the models show what direction the poles were oriented in. Call out a number and ask students to answer with a direction. Go on until students can respond rapidly.



TEACHING CLUES AND CUES

There should be nine bands on each side of the ridge.

PART THREE

MAPPING PREHISTORY

A. Introduction

Tell students that in the last activity they modeled the creation of new ocean floor at a spreading mid-ocean ridge. Project the transparency of Master 2.2b and review the section of Master 2.2a entitled Three Kinds of Plate Movement, Four Kinds of Boundaries, and discuss. Then discuss the driving mechanism for plate tectonics, so students understand some of the complicated forces and that scientists are still exploring how these forces work. Tell the class that in this last activity they will look at one more line of evidence that the continents have been moving. Review the process of magnetism and how rocks pick up the polar orientation during their formation. Explain that sensitive instruments called magnetometers can analyze samples of rock to discover where the north pole was located during their formation. In this next activity, students will use magnetic data collected from several different locations to establish plate motions.

B. Procedure

1. To each small group, pass out scissors, tape, a ruler, two copies of Master 2.2d, Continental Pieces, and one each of Master 2.2e, World Map Grid, and Master 2.2f, World Map Grid, 120 MYA. Point out that there are two north arrows on each of the continental pieces. The N stands for north today and the PN stands for paleonorth, or the approximate location of the north pole 120 million years ago (MYA). The line that lies across the arrow, labeled G, represents grid north, and should always line up so it is parallel to longitude (see example on Master 2.2e, World Map Grid.) The numbers in the tables on the grid masters tell the distance to the north pole from the tip of the arrow point at the time that sample was collected.

2. Give these instructions:

a. Cut out the continents on one copy of Master 2.2d along the dotted continental outlines.

b. To place the continents on Master 2.2e, World Map Grid, begin with any continent. Place the ruler alongside the present day north arrow line (N) on the continent to align it with the intersection of the Prime Meridian (O) and the north edge of the map. Next, align the grid north line (G) so it is parallel to the nearest longitude. When both arrows are aligned, measure the distance from the pole to the point where the two arrows cross. Tape the continent in place.

c. Repeat the process until all the continents are in place. This creates a map of the world as it appears today.

d. Now repeat the process with a new copy of Master 2.2d, Continental Pieces, and a copy of Master 2.2f, World Map Grid l20 MYA, this time lining up the PN arrows. This creates a map of the world as it may have appeared 120 million years ago.

TEACHING CLUES AND CUES

To demonstrate paleomagnetic alignment, make large blowups of the South American and African continents, or draw their outlines on the overhead. Demonstrate the process of alignment and distance measurements.

Be sure to pass out two copies of Master 2.2d to each group.

Make sure that the grid north line remains parallel to the longitude lines while you complete step 2.b.

3. When they have completed both tasks, ask students if they could tell which continent moved the most. (India) Point out that the continents do not fit together perfectly and ask them for some possible reasons. (Students may suggest that the scale could be wrong, the drawings may not be quite accurate, or our measurements may be inaccurate.) Let students discuss the possibilities. If necessary, ask if they think the continents have always had the same outline as they do today. (No. The sliding, colliding, and converging movement of the plates has added new material in some places and worn the edges away in others. Point out western North America and the place where India collided with Asia to form the Himalayas.)

If a wall chart or map of the oceans is available, point out the continental shelves. Explain that geologically each continent extends to the edge of its continental shelf. Does the jigsaw puzzle fit together better if the edges of the shelves are used as continental boundaries? (Yes.)

TEACHING CLUES AND CUES

You may want to project some of the students' completed maps during this discussion.

C. Conclusion

Review the steps in using magnetism to find the ancient location of the continents. Point out to students that this evidence was not available during Wegener's time. In this series of activities they have experienced some of the ways scientists established the theory of plate tectonics. Ask:

- If this information had been available, would it have helped Wegener's case? (Yes.)
- How does the last map differ from a map of today? (Discuss.)
- At the rate of drift (5 to 15 cm, or 2-7 inches in a year), about how long would it take today's continents to join into one supercontinent? (Answers will vary.)

TEACHING CLUES AND CUES

Students will learn more about Alfred Wegener in the next unit, in lesson 3.2.

ADAPTATIONS AND EXTENSIONS

1. Challenge students to find out how magnetometers work and how scientists use them, then report to the class.

2. On a map of the Pacific Ocean floor, locate the Hawaiian Islands and the chain of islands that forms the Emperor Seamounts. Note the sharp bend in the line of seamounts. Ask students:

- What could have caused the bend? (a change in the direction of plate movement)
- What does this bend, and the long pattern of reversals illustrated in the earlier activities, indicate about the possibility of the Pacific Ocean closing? (With plates constantly changing directions, it may not close.)

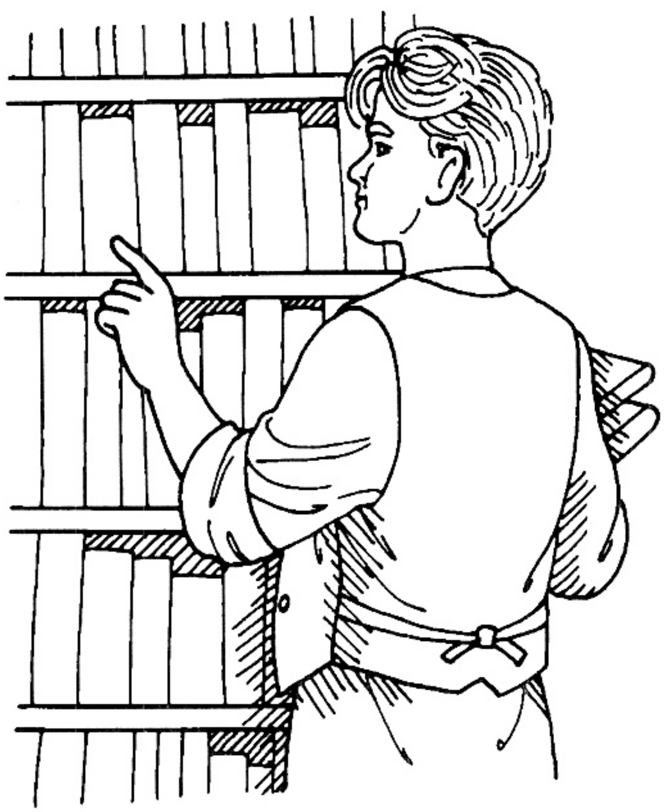
3. *Scientific American* published a series of articles on plate tectonics in the late 1960s which were published as a collection in 1970 (see Wilson, unit resources). Provide students with copies and ask them to prepare a report to the class on the evolution of the theory.

4. Ask volunteers to compare and contrast continental drift, plate tectonics, and sea floor spreading, or to show the relationships among plate boundaries, earthquakes, and volcanoes.

5. Invite students to build models to demonstrate the four types of plate boundaries.

6. A group of students could create giant cardboard models of the continental pieces by enlarging them to scale. They or another group could perform a Drift Dance, moving in various patterns until the pieces lined up more or less as they are today.

7. Ask the class: If earthquakes are only supposed to happen in the vicinity of plate boundaries, why did the 1811 and 1812 New Madrid, Missouri, earthquakes occur? (New Madrid is located on a failed rift zone that tried to split North America apart.) Was it an isolated occurrence, or could the same thing happen in other such areas? (There may be other such rift zones that have not yet been discovered.) ▲



Tectonics Background

To understand why earthquakes happen, we need to understand two basic facts about the planet we live on: that it is made up of layers, and that its surface is broken into irregular pieces called plates. Much of what we know about the composition of Earth has been learned by studying how earthquake waves travel in and through it.

Earth's Layers

Just for a moment, imagine the Earth as if it were a hard-boiled egg. It has a thin crust (the shell); a thick middle layer, or mantle (the white); and a core (the yolk). The crust and the uppermost portion of the mantle together form the lithosphere. The plates are called lithospheric plates because they belong to this region. Scientists divide the mantle into zones and the core into an inner and outer core. (See Master 2.2b.)

Crust and Lithosphere

Earth's crust varies in thickness from about 30 km to between 70 and 80 km on the continents to only 6 km on the ocean floor. Even at its thickest point, the crust is not nearly as thick in relation to the whole bulk of the Earth as the shell of an egg is in relation to the egg. Remember that the crust is 70-80 km thick at its thickest point, and the radius of the Earth is about 6,371 km.

The oldest rocks of the crust found so far have been dated by radioactive decay (isotopic dating) at about 4 billion years. Earth scientists assume that the Earth was much hotter billions of years ago than it is today, and that the lithosphere (crust plus upper mantle) broke into plates as it cooled and hardened.

The lithosphere extends to an average depth of about 100 km. It is deepest under the continents and shallowest at the mid-ocean ridges.

Mantle

The mantle contains several zones, or layers with different properties. Its upper portion is a region with a plastic, semisolid consistency, called the asthenosphere. The thickness of the asthenosphere is still a matter of debate. Estimates of the distance to the base of the asthenosphere range from about 200 km to 700 km. The mantle accounts for approximately 67% of Earth's mass. Information from earthquake waves indicates that this region generally behaves as a plastic; that is, it will bend and flow in response to pressure. Temperature and pressure continue to increase as we move through the mesosphere to approach the core, at a depth of about 2,890 km.

Core

Both layers of the care are thought to be composed primarily of iron, with lesser amounts of nickel and possibly silicon, sulfur, or oxygen. Scientists have measured the velocity of earthquake waves passing through the core, and reason that such movement would be possible through materials with the physical properties of these elements. The liquid outer core, which might be compared to the outer two-thirds of an egg's yolk, reaches from a depth of about 2,890 km to 5,150 km. The solid inner core goes the rest of the way to the center of the Earth.

Earth's core is very hot. Its high temperatures are due to the tremendous pressure of the layers above it, heat generated by the impact of other bodies during the formation of the planet, and radioactive decay. Evidence collected from mines and deep wells shows that the average increase in temperature is about 1°C for every 40 meters of depth. If this rate held constant to the center of the Earth, theoretically, the temperature of the core would be about 150,000°C. According to the evidence we have, however, the actual temperature is between 3,000 and 4,000°C at the core-mantle boundary, and about 5,000°C at the boundary of the outer and inner cores—roughly the same temperature as the surface of the Sun!

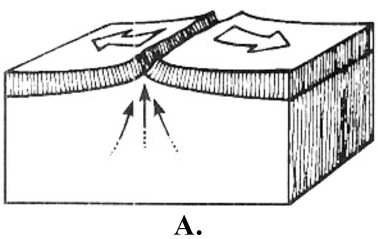
Earth's Plates

Most earthquakes and volcanoes are associated with large-scale movements of Earth's plates, and occur at the boundaries between plates. There are 12 major plates and a number of smaller ones. The plates are named after continents (the North American Plate), oceans (the Pacific Plate), and geographic areas (the Arabian Plate).

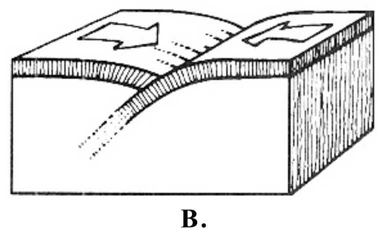
The plates are in very slow but constant motion, so that seen from above by a patient observer, Earth's surface might look like a slowly moving spherical jigsaw puzzle. The plates move at rates of 5 to 15 cm (2-7 inches) in a year—about as fast as our fingernails grow. On a human scale, this is a rate of movement that only the most sophisticated instruments can detect, but on the scale of geological time, it is a dizzying speed. The oldest rocks in the crust, formed 3.8 billion years ago, could have traveled around the Earth 14 times at this rate.

Three Kinds of Plate Movement, Four Kinds of Boundaries

Plate movement is generally one of three kinds: spreading, colliding, or sliding. Earthquakes can accompany all three kinds of movement, but the most forceful quakes generally result from colliding and sliding movements.

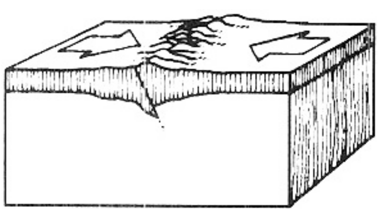


A.

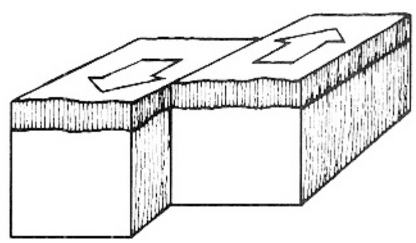


B.

When plates are spreading, or separating from each other, earth scientists call their movement divergent. The type of boundary that results (A) is a ridge, like the Mid-Atlantic ridge system.



C.



D.

When plates are colliding, or pushing against each other, scientists call the movement convergent. If an oceanic plate converges with a continental plate or another oceanic plate, the oceanic plate is forced down into the mantle, creating an ocean trench (B). The Alaskan trench and the Aleutian Islands were formed in this way; so were the Andes Mountains. If two continental plates converge, neither will be forced into the mantle. Instead, their edges will crumple and a large mountain chain may result (C). The Himalayas arose when India collided with Asia.

Movement in which plates slide past each other is called lateral (or transform) plate movement (D). This kind of movement is occurring along the San Andreas Fault in California.

Continental Drift: 1910 to 1960

The theory of continental drift originated early in this century, but it did not gain general acceptance until the late 1960s. Between 1910 and 1912, the German meteorologist, geophysicist, and explorer Alfred L. Wegener formulated the theory called continental drift. He collected evidence from the rocks, fossils, and climatic records of several continents to show that they had once been joined together. Wegener knew little about the oceanic crust, which had not yet been explored, and thought that the continents merely moved horizontally, plowing through the oceanic crust.

Plate Tectonics: 1960 to the Present

In the early 1960s, British geophysicists Fred Vine and Drummond Matthews used magnetic data to show that the ocean floor is spreading apart at the mid-ocean ridges. As they shared the evidence for the process they called sea-floor spreading, scientists began to realize that the continents were also moving. By 1968, a new explanation for the dynamics of Earth's surface had been created, combining Wegener's hypothesis with evidence from the ocean floor. Scientists call it the theory of plate tectonics.

The Mechanism of Plate Tectonics

Although the theory of plate tectonics is generally accepted, no one completely understands how the process works. Wegener thought that centrifugal force, caused by the rotation of the Earth, and tidal forces caused continental drift. Modern scientists have rejected this theory and replaced it with several others. Three mechanisms called convection, ridge push, and slab pull may play a role.

Convection Currents

Convection currents are systems of heat exchange that operate in the mantle as it is heated by the core. The mantle's plastic-like material moves upward as it is heated, and sinks when it cools. You can see this kind of movement if you boil water in a clear glass pot. Even though the heat on the stove is constant, the water on the bottom of the pot is the hottest. As it heats, it becomes less dense and rises, while relatively cooler water from the top of the pot takes its place on the bottom. This continuous exchange creates convection currents in the water.

According to this theory, convective movement acts as a drag on the underside of the plates. As mantle material moves in large convection cells, the plates are rafted along the top of the cells, being pulled apart where the cell rises and colliding where it sinks.

Ridge Push

The ridge-push mechanism derives from the bulging of the undersea ridge crest as the oceanic lithosphere below it expands. The lithosphere expands because it is heated by mantle material pushing upward from below. As the lithosphere is pushed up at the ridge, a large portion of a plate may come to rest on an inclined plane. Gravity will cause this portion to slide down the inclined plane and push on the rest of the plate.

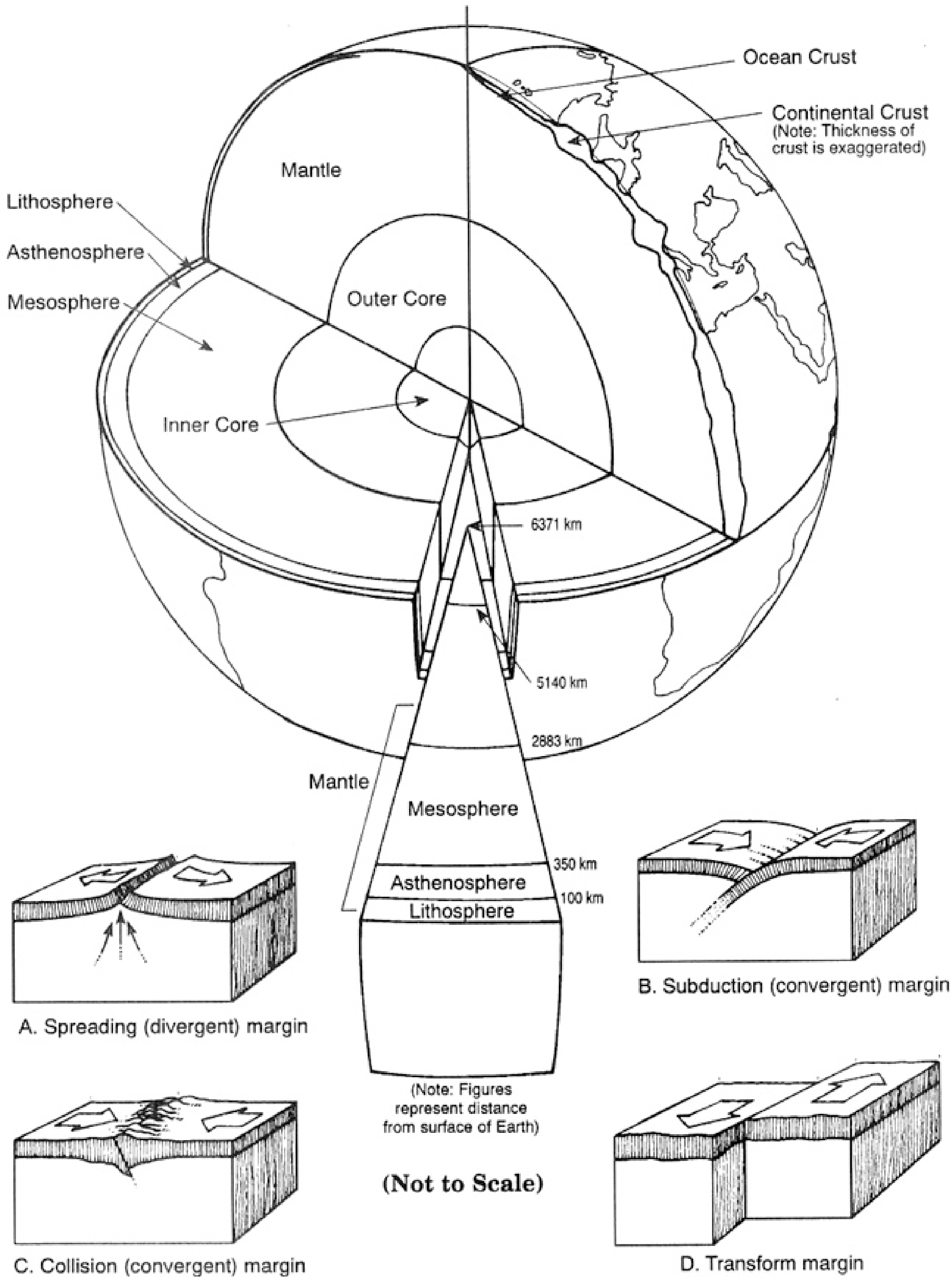
Slab Pull

Once this slab of oceanic lithosphere moves away from the ridge crest (and from the heat that is rising at the ridge), it will cool and contract, increasing in density. It will also thicken as underlying mantle material cools and attaches itself to the bottom of the slab. Eventually, the slab of lithosphere becomes denser than the underlying asthenosphere and sinks into the mantle. As it sinks, it pulls the rest of the plate along with it. At about 200 to 300 km, the difference in density between the descending slab and the mantle is at its greatest, so the slab pull force is also at its greatest. Below this point, the mantle material becomes stronger and the resistance to sinking also becomes stronger.

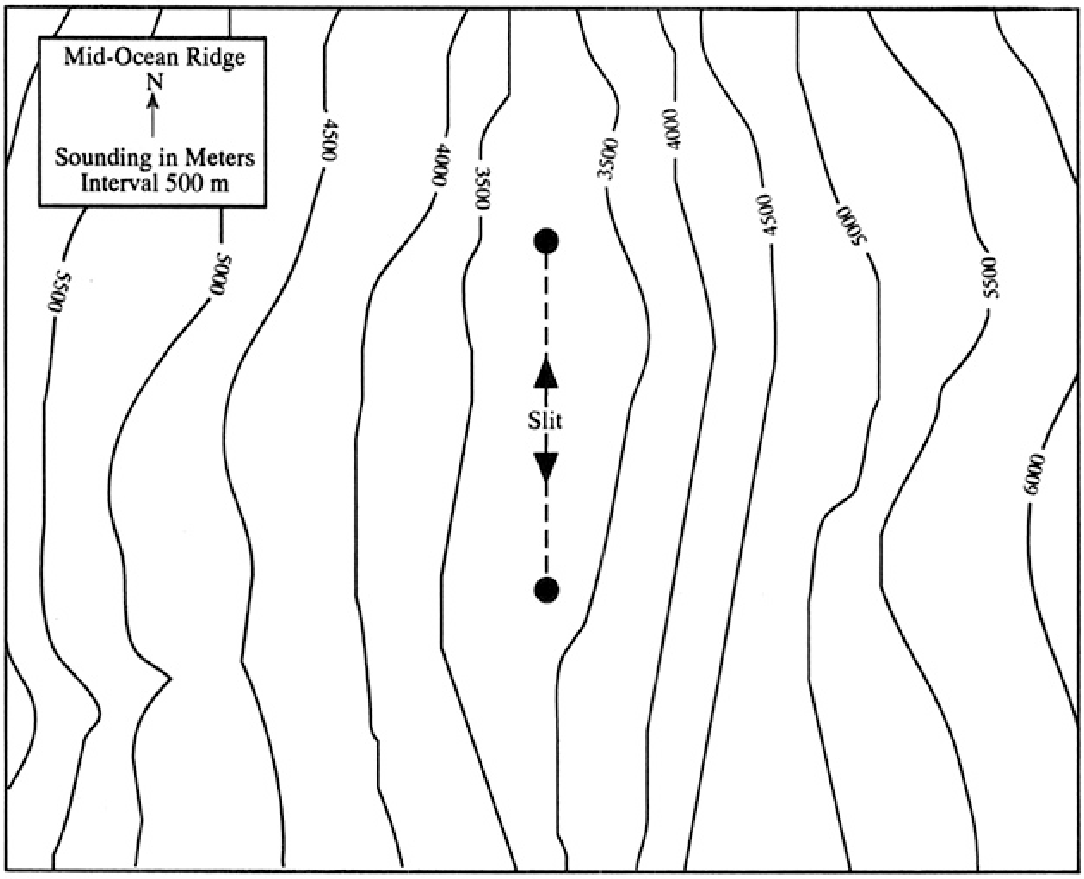
A Natural Cycle

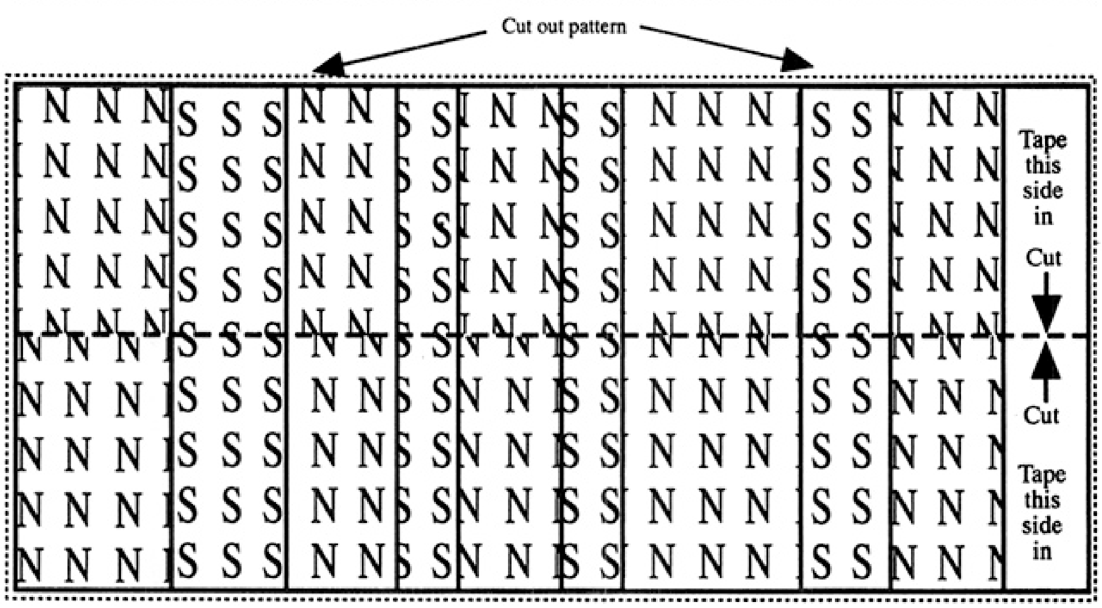
One result of all this slow, steady motion is the gradual opening and closing of ocean basins. As tectonic processes rearrange the surface of the planet, shifting lands and seas over millions of years, they also cause earthquakes. Now, and for the foreseeable future, human beings have no way to affect these mighty tectonic processes. By understanding them, however, we can learn to conduct our own lives in ways that minimize our risk from any disturbances they may cause.

Earth Cross Section

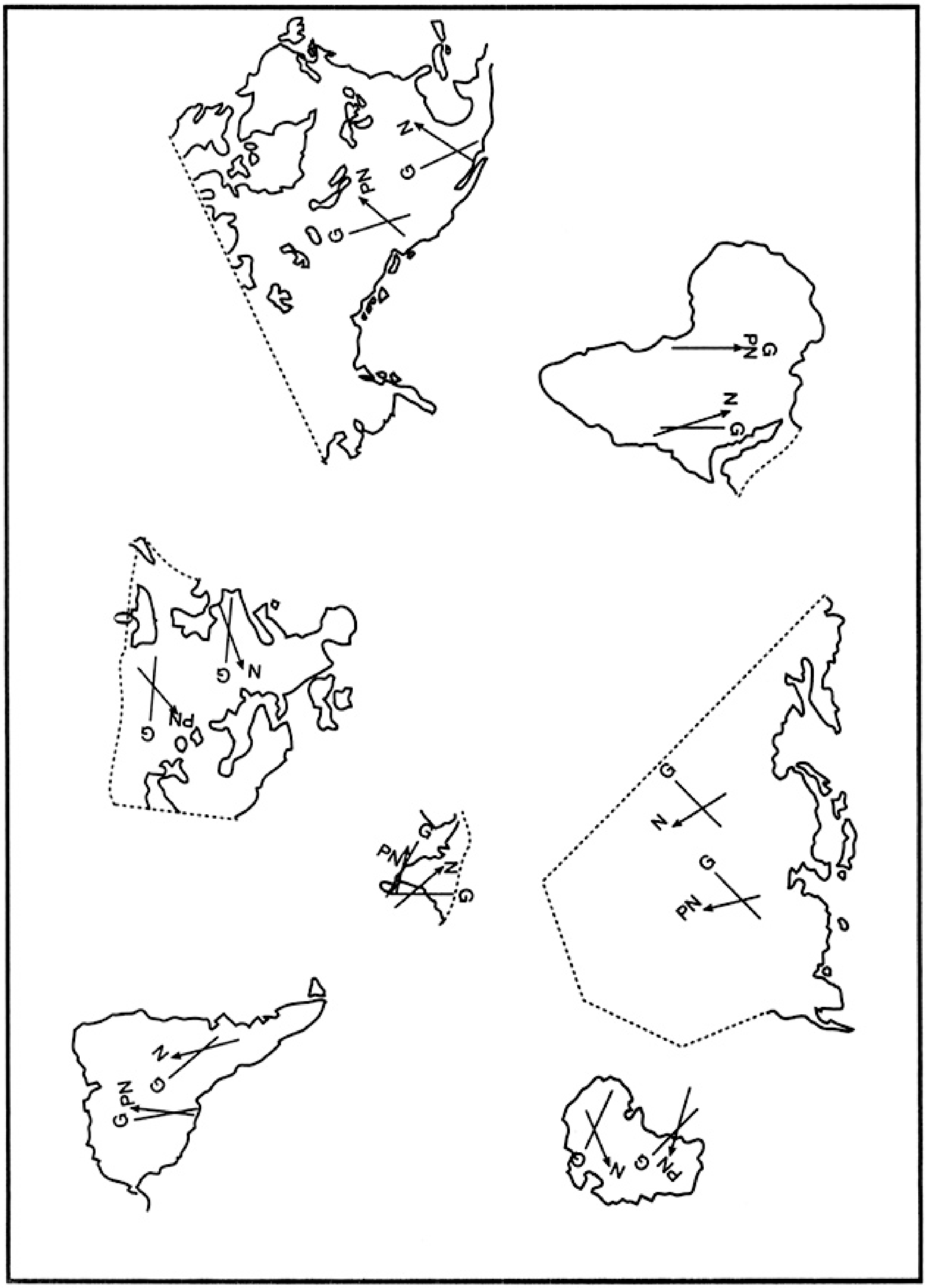


Reading the Patterns

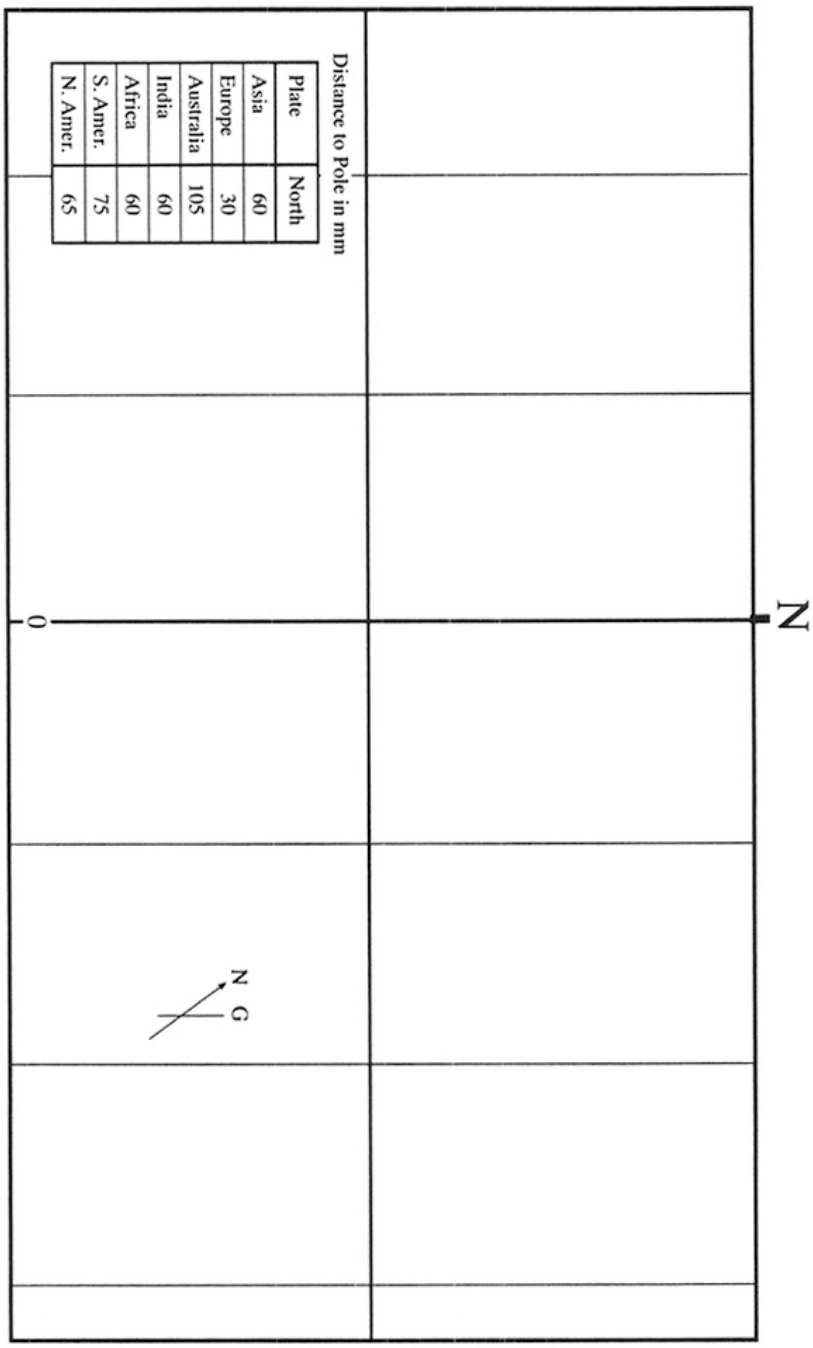




Continental Pieces



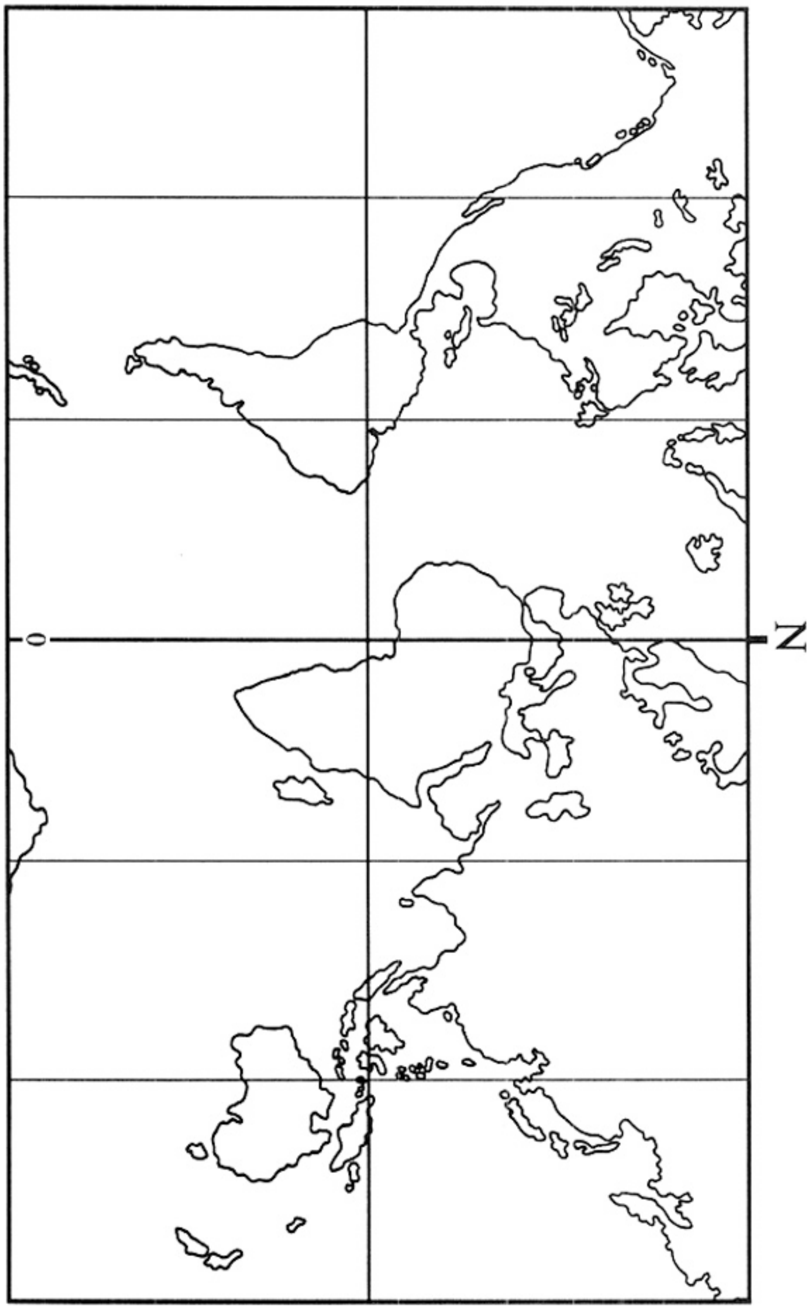
World Map Grid



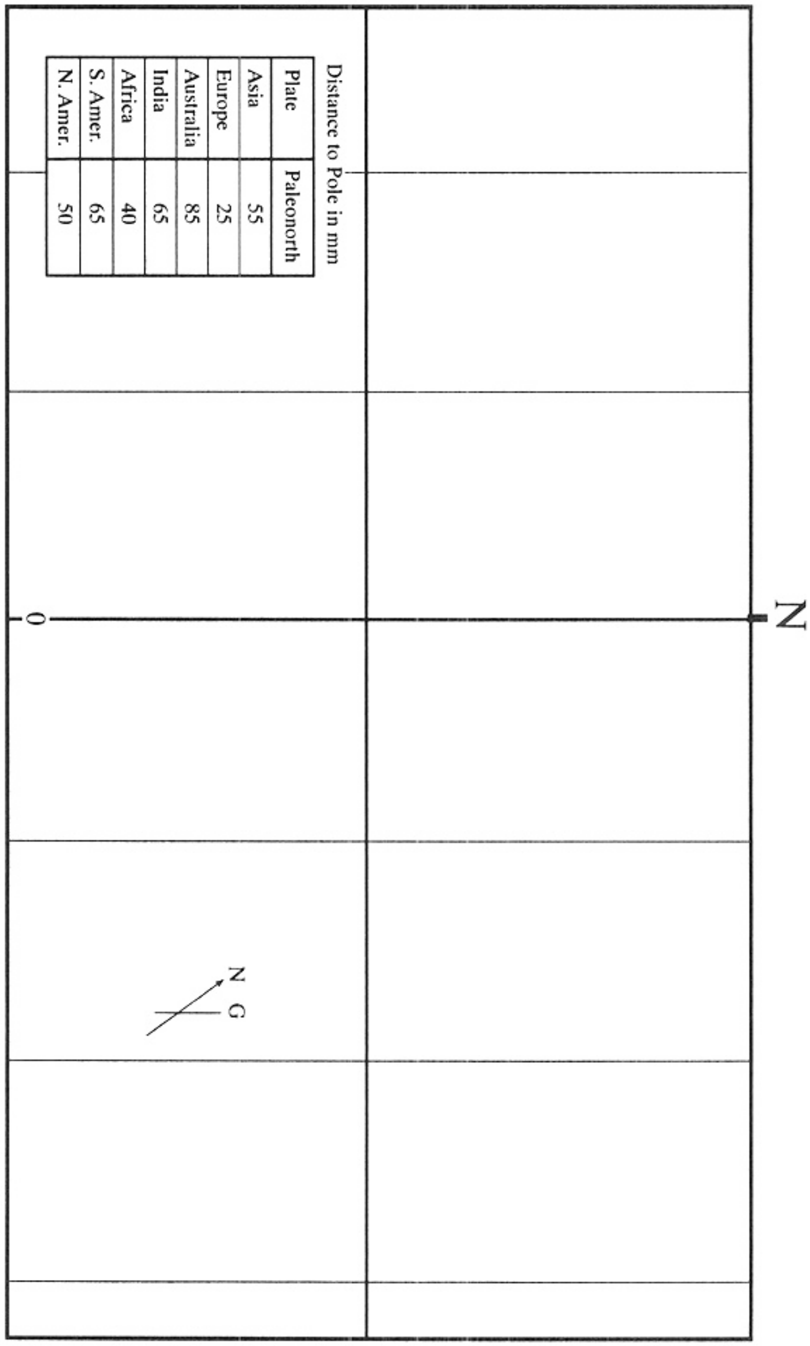
Distance to Pole in mm

Plate	North
Asia	60
Europe	30
Australia	105
India	60
Africa	60
S. Amer.	75
N. Amer.	65

World Map Grid (key)



World Map Grid, 120 MYA



Distance to Pole in mm

Plate	Paleonorth
Asia	55
Europe	25
Australia	85
India	65
Africa	40
S. Amer.	65
N. Amer.	50

World Map Grid, 120 MYA (key)