

SEA-FLOOR SPREADING MADE EASY

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TOPIC: Sea Floor Spreading Demonstration

GRADE LEVEL: 7-12

CONTENT STANDARD:

National Earth and Space Science Standard
Colorado Science Standard 4, Earth and Space Science

CONTENT OBJECTIVE:

To help understand the fundamental concept of captured magnetism directions on the sea floor of the Atlantic Ocean that provides key evidence for the plate tectonics theory.

TIME REQUIRED: 30 minutes if plate tectonics concepts have already been discussed

MATERIALS NEEDED:

2 magic markers of differing colors
2 pieces of legal paper (legal is fine but it is fun to use the continuous feeding computer paper if you have some!)
2 desks facing one another
Student pages

TEACHER BACKGROUND:

Teachers of higher-level students may wish to provide them with this information.

Before performing this activity, the teacher should make sure the students are familiar with:

- 1) types of boundaries between lithospheric plates;
- 2) features of the ocean floor;
- 3) the concept of sea-floor spreading; and
- 4) the nature of the Earth's magnetic field and the fact that it has reversed its polarity many times in the past.

The Earth's layers — The Earth is a layered planet consisting of crust, mantle and core (Fig. 1). The outer 100 km or so is a rigid layer called the **lithosphere** that is made up of the crust and uppermost mantle. The lithosphere is broken into a number of large and small plates that move over the **asthenosphere**, a plastic layer in the upper mantle. Earthquakes and volcanoes are concentrated at the boundaries between lithospheric plates. It is thought that plate movement is caused by convection currents in the mantle (Fig. 2), although the exact mechanism is not known. Lithosphere plates are moving at rates of a few cm per year, on average.

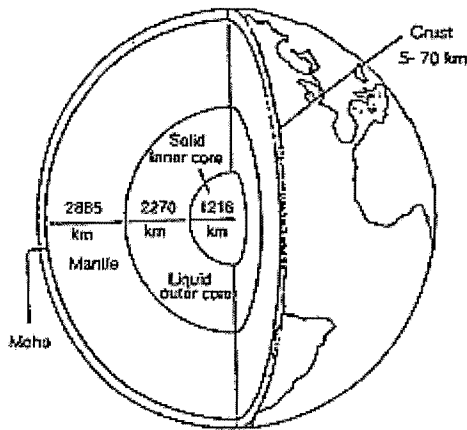


Figure 1. The Earth's layers. The Moho is the boundary between crust and mantle. Modified from NSTA/FEMA (1988).

Types of plate boundaries — There are three types of boundaries between lithospheric plates (Fig. 3):

- 1) **convergent boundary** — plates converge, or come together. If a plate of oceanic lithosphere collides with thicker and less dense continental lithosphere, the denser oceanic plate will dive beneath the continent in a subduction zone (Fig. 2).
- 2) **divergent boundary** — two plates diverge, or move apart and new crust or lithosphere is formed.
- 3) **transform boundary** — plates slide past one another with no creation or destruction of lithosphere.

The Ocean Floor — A map of the ocean floor shows a variety of topographic features: flat plains, long mountain chains, and deep trenches. **Mid-ocean ridges** are part of chain of mountains some 84,000 km long. The Mid-Atlantic Ridge is the longest mountain chain on Earth. These ridges are spreading centers or **divergent boundaries** where the upwelling of magma from the mantle creates new ocean floor. The **rift zone** is the valley between the two ridges where the plates are pulling apart and new material is rising.

Deep-sea trenches are long, narrow basins that extend 8-11 km below sea level. Trenches develop adjacent to subduction zones, where oceanic lithosphere slides back into the mantle (Fig. 2).

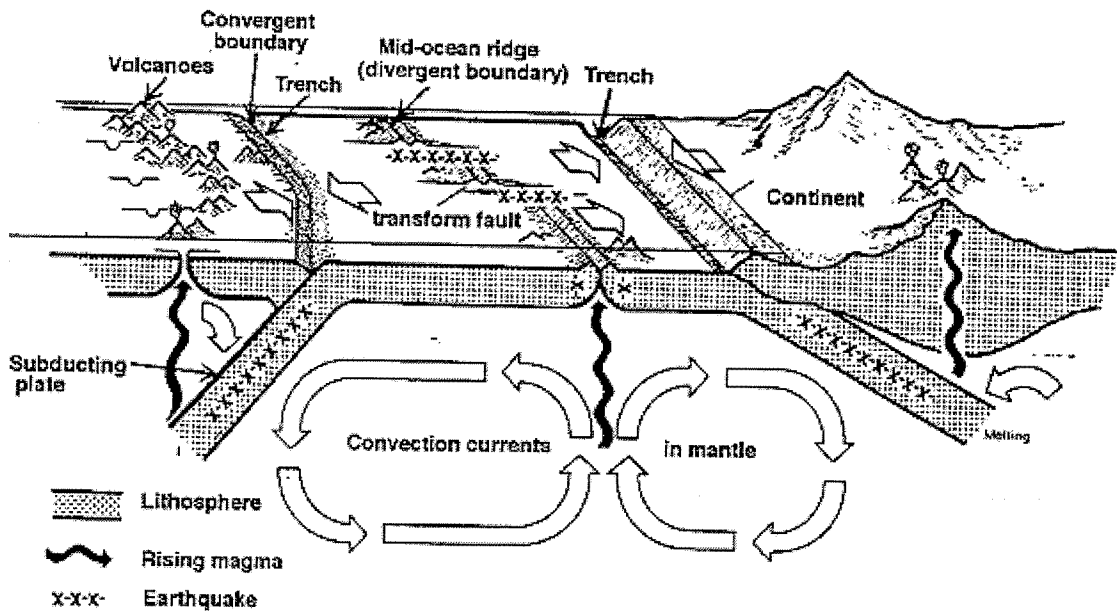


Figure 2. Sea-floor spreading. Modified from NSTA/FEMA (1988).

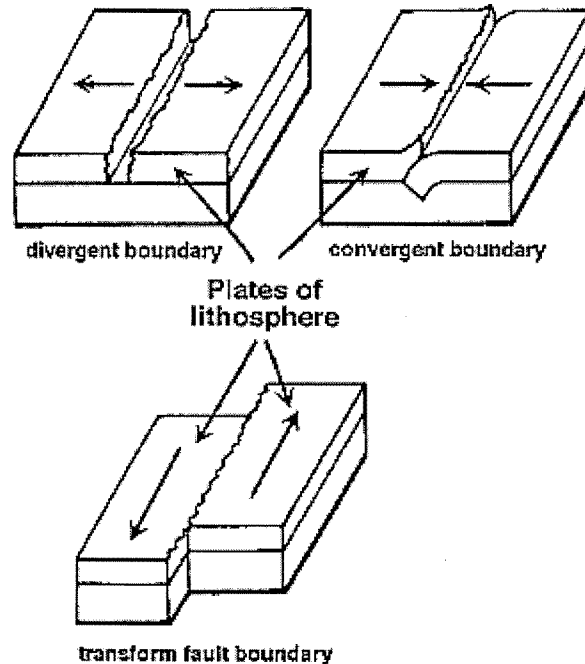


Figure 3. Types of plate boundaries. Modified from NSTA/FEMA(1988).

Continental Drift— The idea that continents move is an old one; Alfred Wegener, a German meteorologist, proposed the hypothesis of **continental drift** in the early 1900's. Wegener used several lines of evidence to support his idea that the continents were once joined together in a supercontinent called **Pangaea** and have since moved away from one another: (1) the similarity in shape of the continents, as if they once fit together like the pieces of a jigsaw puzzle; (2) the presence of fossils such as *Glossopteris*, a fossil fern whose spores could not cross wide oceans, on the now widely-separated continents of Africa, Australia, and India; (3) the presence of glacial deposits on continents now found near the equator; and (4) the similarity of rock sequences on different continents.

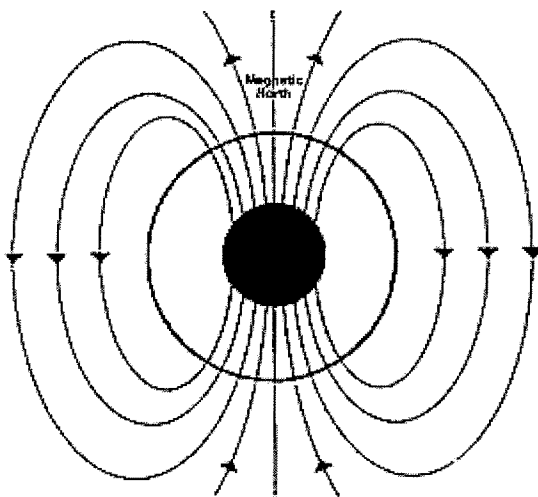
Wegener's hypothesis of continental drift was not widely accepted because he had no mechanism to explain how the continents move. Physicists at that time knew the continents could not withstand the pressure of being pushed or pulled *through* oceanic crust. The idea was not revived until new technology made exploration of the ocean floor possible.

Sea-floor spreading — In the early 1960s, Princeton geologist Harry Hess proposed the hypothesis of sea-floor spreading, in which basaltic magma from the mantle rises to create new ocean floor at mid-ocean ridges. On each side of the ridge, sea floor moves from the ridge towards the deep-sea trenches, where it is subducted and recycled back into the mantle (Fig. 2). Without hard evidence for the hypothesis, he called his idea “geo-poetry”. A test of the hypothesis of sea-floor spreading was provided by studies of the Earth's magnetism.

The Earth's Magnetic Field — The Earth's magnetic field is thought to arise from the movement of liquid iron in the outer core as the planet rotates. The field behaves as if a permanent magnet were located near the center of the Earth, inclined about 11 degrees from the geographic axis of rotation (Fig. 4). Note that magnetic north (as measured by a compass) differs from geographic north that corresponds to the planet's axis of rotation.

Placing a bar magnet beneath a piece of paper with iron filings on it will create a pattern as the filings align themselves with the magnetic field generated by the magnet. The Earth's magnetic field is similar to that generated by a simple bar magnet. At present, the lines of force of the Earth's magnetic field are arranged as shown in Figure 4; the present orientation of the Earth's magnetic field is referred to as **normal polarity**. In the early 1960s, geophysicists discovered that the Earth's magnetic field periodically reverses; i.e. the north magnetic pole becomes the south pole and vice versa. Hence, the Earth has experienced periods of **reversed polarity** alternating with times (like now) of normal polarity. Although the magnetic field reverses at these times, the physical Earth does not move or change its direction of rotation.

Basaltic lavas contain iron-bearing minerals such as magnetite, which act like compasses. That



is, as these iron-rich minerals cool below their **Curie point**, they become magnetized in the direction of the surrounding magnetic field. Studies of ancient magnetism (**paleomagnetism**) recorded in rocks of different ages provide a record of when the Earth's magnetic field reversed its polarity.

During World War II, sensitive instruments called magnetometers were developed to help detect steel-hulled submarines. When research scientists used magnetometers to study the ocean floor, they discovered a surprising pattern. Measurements of magnetic variations showed that, in many areas, alternating bands of rocks recording normal and reversed polarity were arranged symmetrically about mid-ocean ridges (Fig. 5).

Figure 4. The Earth's magnetic field. Source: NASA.

In 1963, F. Vine and D.H. Matthews reasoned that, as basaltic magma rises to form new ocean floor at a mid-ocean spreading center, it records the polarity of the magnetic field existing at the time magma crystallized. As spreading pulls the new oceanic crust apart, stripes of approximately the same size should be carried away from the ridge on each side (Fig. 5). Basaltic magma forming at mid-ocean ridges serves as a kind of "tape recorder", recording the Earth's magnetic field as it reverses through time. If this idea is correct, alternating stripes of normal and reversed polarity should be arranged symmetrically about mid-ocean spreading centers. The discovery of such magnetic stripes provided powerful evidence that sea-floor spreading occurs.

The age of the sea-floor also supports sea-floor spreading. If sea-floor spreading operates, the youngest oceanic crust should be found at the ridges and progressively older crust should be found in moving away from the ridges towards the continents. This is the case. The oldest known ocean floor is dated at about 200 million years, indicating that older ocean floor has been

destroyed through subduction at deep-sea floor. The Atlantic Ocean has not been destroyed by subduction but instead did not even exist before that time, but instead was created as the continents on either side of it broke and moved apart.

It took exploration of the ocean floor to discover sea-floor spreading, the mechanism for the movement of continents that Alfred Wegener lacked. The hypothesis of continental drift gained renewed interest and, when combined with sea-floor spreading, led to the theory of **plate tectonics**. The history of thought about the movement of continents provides a wonderful example of how hypotheses such as continental drift and sea-floor spreading are thoroughly tested before a new theory emerges. For an overview of the history of plate tectonics, see Tarbuck and Lutgens (1994).

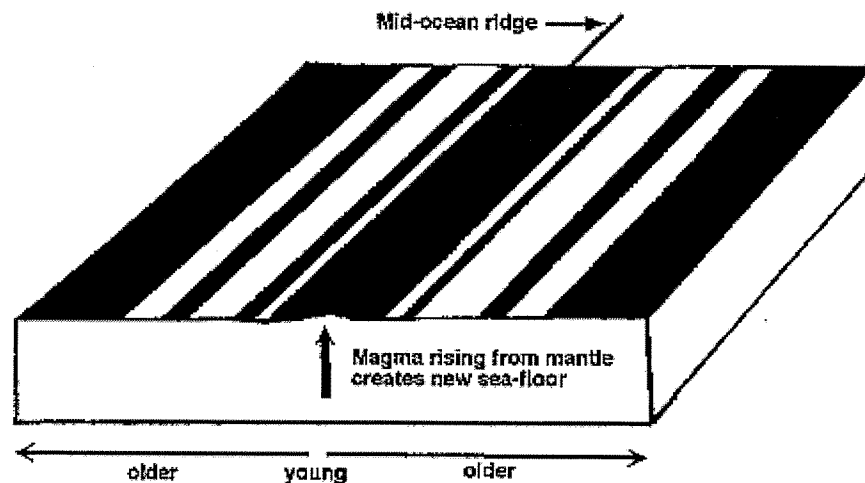
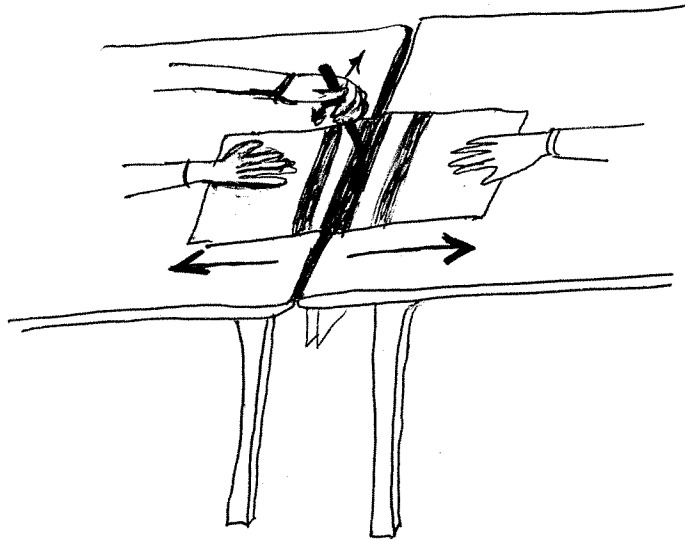


Figure 5. Schematic diagram of magnetic anomalies on the sea-floor. Black represents normal polarity; white is reversed polarity.

DEMONSTRATION DIRECTIONS:

This activity may be done as a demonstration by the teacher with one other student's help, or with the whole class performing the activity in pairs, with their desks facing one another. The directions will proceed as if the latter scenario is occurring. I have, however, used this as a demo only, with all the students watching, and without a real evaluation, as an effective way to provide a visual aid in understanding sea-floor spreading.

Have two students turn their desks so that they are facing each other and almost touching. Have each student take a piece of paper and place them together vertically into the slight gap between the desks as far down as they can go while still having a grip on the paper. Have students practice pulling both papers out of the desk at the same time and same rate of movement (this is the spreading ridge). Each student should pull her or his own paper toward her or him, so that the effect is like the new crust forming and then spreading out from the ridge. This works especially well with desks that are slanted toward the student, giving the sloping effect similar to the shape of the ocean floor.



Once everyone has this motion down, have each student open a different colored marker. Start with a little bit of paper showing. As each student very slowly pulls the paper out at the same rate, have one student color both pieces of paper along the ridge with one marker, so that there is a strip of color parallel to the ridge that grows wider as more paper is pulled out. Announce that this color represent rocks that are formed with their magnetic minerals facing toward a magnetic pole that is in the north (normal polarity). After a few seconds, announce that the magnetic pole has faded and then shifted to the south (reversed polarity), at which time the first student stops using his/her marker and the second student should take the second colored marker and make the same type of strip of color. Let this student color a little longer than the last one, and then announce that the pole has shifted again. Continue to change directions, altering the timing between each switch so that the pair of students has two papers that are a mirror image of each other with strips of color that vary in width. It should look something like the figure shown above (figure 5) but more colorful of course.

EVALUATION:

1. When they are finished, have the students spread their pages out and tape the papers together down the center (where the last colors are, representing the spreading ridge) and label the following:
 - (1) the rift zone
 - (2) which strips of color represent N (normal) and which are S (reversed) polarity
 - (3) where the oldest rocks are
 - (4) where the youngest rocks are
2. Have them put their names on the back of the paper and describe in detail what the activity is showing and what it represents. Make sure to point out the mirror image effect.
3. Lastly, have them answer the following questions (see student page at the end of this lesson):
 - 1). Imagine that your hands as you pulled the paper out from the desk represent two continents that were once together but must move away from each other as the sea floor

grows. You have heard about the continental drift theory and why it was not accepted. Why does this model provide very strong evidence for the plate tectonics model?

2). The Earth is about 4.6 billion years old. Based on observations of your sea-floor spreading model, why do you think that the oldest ocean floor is only about 200 million years old?

3) You will notice that the alternating stripes of normal and reversed polarity are not all of equal width. What does this tell you about the lengths of time of normal and reversed polarity throughout geologic history?

After they have performed this activity, showing a video that explains how this evidence was discovered and the shows actual magnetometer printouts helps clarify the activity to the students. One excellent video is from the Planet Earth Series, "The Living Planet" (see below). You will also find that they understand what the video is stating much more easily than if they hadn't done this activity first.

Answers for Evaluation:

1. The rift zone should be on the strip where the tape is holding the pages together. The oldest rocks are on the outer edges of the pages; the youngest rocks are along the rift zone.

2. The students should describe in detail that the paper being pulled out represents new crust being formed at the sea-floor rift zone, and that the colors are the cooling igneous rocks with magnetic minerals that point toward the magnetic poles. The mirror image pattern of the stripes is very important since it shows that the layers on either side of the ridge that are the same distance away from the ridge were formed at the same time.

3. (1) This activity, a model for sea-floor spreading, shows that the continents did not drift or plow through the ocean floor, as was supposed with continental drift. It shows that new ocean floor comes up between the continents and therefore they are pushed (or pulled, scientists aren't sure which) apart. The continents remain in one piece, riding on the mantle.

(2) The model shows new ocean crust being formed, but the Earth is not getting bigger, so somewhere else crust is being destroyed. We now know that crust is destroyed as it is carried down a subduction zone into the mantle. Because of the constant size of the earth, there is only so much new crust that can be formed without the old crust being destroyed. This restricts the age of the ocean floor. In the case of the Atlantic Ocean (which doesn't have subduction zones along its border yet), another acceptable answer is that it did not start forming until less than 200 million years ago, and therefore did not exist before that time.

(3) This tells us that the time the Earth's magnetic field stays in one position is not constant. The periods of reverse and normal polarity vary throughout geologic history.

REFERENCES AND RESOURCES:

NSTA/FEMA, 1988, Tremor Troop Earthquakes: National Science Teachers' Association, Washington, D.C.

Tarback, E. J. and Lutgens, F. K., 1994, *Earth Science* (7th ed.), Macmillan Publishing Company, p. 207-242.

General information:

Yulsman, T., 1993, *Charting Earth's Final Frontier: Earth*, vol. 2, no. 4 (July 1993), p. 36-41. Discusses mapping of volcanoes, faults, canyons, and lava flows on the ocean floor using a side-scan sonar device called GLORIA (Geologic Long-Range Inclined Asdic).

The General Interest Publication "Marine Geology: Research Beneath the Sea" from the United States Geological Survey provides an overview of the methods and equipment that marine geologists employ to study the ocean floor. The pamphlet describes studies of ocean floor topography, sediments and mineral resources. Order up to 50 free copies (use school letterhead) from the United States Geological Survey, Box 25286, Denver Federal Center, Bldg. 810, Denver CO 80225; phone (303) 236-7476.

For Younger Children:

Cole, J., 1992, *The Magic School Bus on the Ocean Floor*: Scholastic, Inc., New York. The kids in Mrs. Frizzle's class take a field trip to the deep ocean floor to study animal and plant life, a hot-water vent, and a coral reef (for elementary school children).

Videos:

"The Living Planet," from the series *Planet Earth*, narrated by Richard Kiley (403 minutes). This entire series of videos sets out to explore our world in a different way. Examine such diverse topics as the effect of termites on global warming and the search for Nemesis, the hypothesized mystery planetoid that may be responsible for the demise of the dinosaurs. Includes seven parts narrated by Richard Kiley: "The Living Machine," "The Blue Planet," "The Climate Puzzle," "Tales From Other Worlds," "The Solar Sea," "Gifts From the Earth," and "The Fate of the Earth." Available from most science video catalogs, or order from www.cduniverse.com for only \$13.29 at press time (for the CD; \$78.49 for the VHS box set).

"Treasures of Neptune: Klondike on the Ocean Floor" (\$149.00; 26 min). Looks at the relationship between plate tectonics and marine mineral deposits; shows how the ocean floor is being mapped and looks at recovery systems for marine resources including underwater scoops and shovels and giant "vacuum cleaners". Order from Films for the Humanities & Sciences, P.O. Box 2053; Princeton, N. J. 08543-2053; phone 1-800-257-5126.

"The Last Frontier on Earth" (\$79.00; 26 min.). Shows how scientists are exploring the sea floor using Side Scan Sonar mapping and deep sea drilling. Order from: Britannica Learning Materials, Customer Service, 310 South Michigan Avenue, Chicago, IL 60604-9839; phone 1-800-554- 9862.

GLOSSARY

asthenosphere — a portion of the mantle that underlies the lithosphere. This zone consists of easily deformed rock and in some regions reaches a depth of 700 km.

continental drift — The first hypothesis proposing large horizontal motions of continents. This idea has been replaced by the theory of plate tectonics.

convergent plate boundary — a boundary between two lithospheric plates that move towards each other. Such boundaries are marked by subduction, earthquakes, volcanoes, and mountain-building.

Curie point — the temperature (about 580 degrees C) above which a rock loses its magnetism.

deep-sea trenches — long, narrow, and very deep (up to 11 km) basins oriented parallel to continents and associated with subduction of oceanic lithosphere.

divergent plate boundary — a boundary between two plates that move away from one another; new lithosphere is created between the spreading plates.

lithosphere — the rigid, outermost layer of the Earth; includes crust and uppermost mantle and is about 100 km thick.

mid-ocean ridge — a continuous mountain chain on the floor of all major ocean basins that marks the site where new ocean floor is created as two lithospheric plates move away from one another.

normal polarity — a magnetic field that has the same direction as the Earth's present one.

paleomagnetism — the permanent magnetization recorded in rocks that allows reconstruction of the Earth's ancient magnetic field.

Pangaea or Pangea — the proposed "supercontinent" that began to break apart 200 million years ago to form the present continents.

plate tectonics — the theory that proposes that the Earth's lithosphere is broken into plates that move over a plastic layer in the mantle. Plate interactions produce earthquakes, volcanoes, and mountains.

reversed polarity — a magnetic field with direction opposite to that of the Earth's present field.

transform plate boundary — a boundary between lithosphere plates that slide past one another.

sea-floor spreading — a hypothesis, proposed in the early 1960s, that new ocean floor is created where two plates move away from one another at mid-ocean ridges.

subduction zone — a long, narrow zone where one lithospheric plate descends beneath another.

Please contact Christine McLelland at subaruteacher@geosociety.org with any comments, suggestions or corrections.

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Names _____

Sea-Floor Spreading Made Easy!

Student worksheet

Content Objective:

To help understand the fundamental concept of captured magnetism directions on the sea floor of the Atlantic Ocean that provides key evidence for the plate tectonics theory.

Materials Needed:

- 2 magic markers
- 2 pieces of papers (11" x 17" is nice, but 8.5" x 11" is just fine)
- 2 desks facing one another
- Student page

Directions:

Turn your two desks so that they are facing each other and almost touching. Each student should take a piece of paper and place them together in the slight gap between the desks as far down as they can go while still having a grip on the paper. Practice pulling both papers out of the desk at the same time and at the same rate of movement (this is the spreading ridge). You should each pull your own paper toward you, so that the effect is like the new crust forming and then spreading out from the ridge.

Once that is accomplished, each of you should take a different colored marker. Start with a little bit of paper showing. Following your teacher's directions, and as you both very slowly pull the paper out at the same rate, have one student color both pieces of paper along the ridge with one marker, so that there is a strip of color parallel to the ridge. This color represents rocks that are formed with their magnetic minerals facing toward a magnetic pole that is in the north (normal polarity). Listen to your teacher for instructions. When the magnetic pole has faded and then shifts to the south (reversed polarity), the second student should take the second colored marker and make the same type of strip of color. Continue to change directions at your teacher's instruction.

Evaluation:

1. Tape the papers together down the center (what would be the middle of your ocean ridge) and label the following:
 - (1) the rift zone
 - (2) the strips of color that represent N (normal) polarity and those that represent S (reversed) polarity
 - (3) where the oldest rocks are
 - (4) where the youngest rocks are
2. Put your names on the paper model.
3. Describe in detail what the activity is showing and what it represents. Make sure to emphasize the mirror image effect:

4. Answer the following questions:

1). Imagine that your hands as you pulled the paper out from the desk represent two continents that were once together but must move away from each other as the sea floor grows. You have heard about the Continental Drift theory and why it was not accepted. Why does this model provide very strong evidence for the Plate Tectonics Model?

2). The Earth is about 4.6 billion years old. Based on observations of your sea-floor spreading model, why do you think that the oldest ocean floor is only about 200 million years old?

3) You will notice that the alternating stripes of normal and reversed polarity are not all of equal width. What does this tell you about the lengths of time of normal and reversed polarity throughout geologic history?