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ABSTRACT

Crustal Evolution Education Project (CEEP) modules were designed to: (1) provide students with the methods and results of continuing investigations into the composition, history, and processes of the earth's crust and the application of this knowledge to man's activities and (2) to be used by teachers with little or no previous background in the modern theories of sea-floor spreading, continental drift, and plate tectonics. Each module consists of two booklets: a teacher's guide and student investigation. The teacher's guide contains all of the information present in the student investigation booklet as well as: (1) a general introduction; (2) prerequisite student background; (3) objectives; (4) list of required materials; (5) background information; (6) suggested approach; (7) procedure, recommending three 45-minute class periods; (8) summary questions (with answers); (9) extension activities; and (10) list of references. Assuming knowledge of magnetism, latitude, longitude, geographic poles, and mid-ocean ridges, activities give students experiences with magnetic polarity and polarity reversal, including using a compass to determine magnetic field direction, using data on magnetic field direction and age of rocks in sea floor to find direction and rates of sea-floor spreading, explaining how paleomagnetic data are used in studying earth history, and locating older/younger sea floor parts. (Author/JN)

CEEP™

CRUSTAL EVOLUTION EDUCATION PROJECT

Which Way Is North?

TEACHER'S GUIDE

Catalog No. 34W1032

For use with Student Investigation 34W1132
Class time: three 45-minute periods

Developed by
THE NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

Produced and Distributed by
Ward's Natural Science Establishment, Inc. Rochester, NY • Monterey, CA

NAGT Crustal Evolution Education Project

Edward C. Stoever, Jr., Project Director

Welcome to the exciting world of current research into the composition history and processes of the earth's crust and the application of this knowledge to man's activities The earth sciences are currently experiencing a dramatic revolution in our understanding of the way in which the earth works CEEP modules are designed to bring into the classroom the methods and results of these continuing investigations The Crustal Evolution Education Project began work in 1974 under the auspices of the National Association of Geology Teachers CEEP materials have been developed by teams of science educators classroom teachers and scientists Prior to publication the materials were field tested by more than 200 teachers and over 12 000 students

Current crustal evolution research is a breaking story that students are living through today

Teachers and students alike have a unique opportunity through CEEP modules to share in the unfolding of these educationally important and exciting advances CEEP modules are designed to provide students with appealing firsthand investigative experiences with concepts which are at or close to the frontiers of scientific inquiry into plate tectonics Furthermore the CEEP modules are designed to be used by teachers with little or no previous background in the modern theories of sea-floor spreading continental drift and plate tectonics

We know that you will enjoy using CEEP modules in your classroom Read on and be prepared to experience a renewed enthusiasm for teaching as you learn more about the living earth in this and other CEEP modules

About CEEP Modules...

Most CEEP modules consist of two booklets a Teacher's Guide and a Student Investigation The Teacher's Guide contains all the information and illustrations in the Student Investigation plus sections printed in color intended only for the teacher as well as answers to the questions that are included in the Student Investigation In some modules there are illustrations that appear only in the Teacher's Guide and these are designated by figure letters instead of the number sequence used in the Student Investigation

For some modules maps rulers and other common classroom materials are needed and in varying quantities according to the method of presentation Read over the module before scheduling its use in class and refer to the list of MATERIALS in the module

Each module is individual and self-contained in content but some are divided into two or more parts for convenience The recommended length of time for each module is indicated Some modules require prerequisite knowledge of some aspects of basic earth science this is noted in the Teacher's Guide

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Which Way Is North?

INTRODUCTION

This module will give the students first-hand experience with the concepts of magnetic polarity and polarity reversal. Students will learn the probable significance of linear patterns of normal and reversed polarity observed to be associated with mid-ocean ridges. Then the students will apply this inference to a calculation of sea-floor spreading rates, based on plotting of actual data, for an area of the Atlantic Ocean south of Iceland.

You would expect a magnetic compass needle to point toward the north and south magnetic poles. Since continents can drift or move around, can you depend on the two poles to stay in the same places?

Over long periods of time, the earth's magnetic field changes directions. We know that rocks record the earth's magnetic field at the time at which they are formed. This is called **paleomagnetism.** With this knowledge, measurements made at sea allow us to find out a great deal about the past movements of the earth's crust. In these activities, you will be doing the same thing that scientists have done in working out the history of crustal changes.

PREREQUISITE STUDENT BACKGROUND

This module assumes that the student is acquainted with the basics of magnetism and of latitide, longitude, and geographic poles. The physiography of the ocean bottom (i.e., the mid-ocean ridges) should have been covered in your class.

It will be helpful to have local maps (road maps or topographic maps will do) and a world globe or atlas in the room when working on this activity. In making some of the required calculations, it may be necessary to remind the students that there are 1000 meters in a kilometer, and 100 centimeters in a meter. Beyond that, the arithmetic is very simple.

OBJECTIVES

After you have completed these activities, you should be able to

1. Use a compass to determine the direction of a magnetic field
2. Use data on magnetic field direction and age of rocks in the sea floor to find direction and rates of sea-floor spreading
3. Explain how paleomagnetic data are used in studying the history of the earth.
4. Locate the older and younger parts of the sea floor with respect to mid-ocean ridges.

MATERIALS

Bar magnets—one for each group of students, plus 10 for each set of boxes used.

Compasses—one for each group of students.

10 boxes to a set—shoe boxes, or any similar boxes available.

Metric rulers—one for each group of students.

NOTE: Students may work individually or in groups of any size, depending upon amount of equipment available; groups of three to four are recommended. One set of boxes will suffice; two or three are desirable.

You will need bar magnets, the "north" end of which attracts the north-seeking end of the compass needle. This is in contrast to the rule that like poles repel one another. The easiest way to handle this is to relabel the north end of the magnets *south*, and label the south end of the magnets *north*. This is an artificial device to make the bar magnets act like the earth's magnetic field. Explain this fully to any students who see a contradiction in what happens with the magnets and compasses.

The relabeled bar magnets that the students use at the outset of this activity can also be used in the box activity (step 6 of PROCEDURE, PART A). You will need one bar magnet for each box that you use. Shoe boxes are ideal for this activity because of their size and shape. But you can use any boxes you have on hand to make a pile as long as you can find the orientation of each magnet with a compass. Place the bar magnets in the boxes, in the orientation as shown in Figure A, and tape them in place. Number the boxes as shown in Figure A, and put a label or mark at the bottom center of the end of each box to show the students where to hold their compasses to find the polarity.

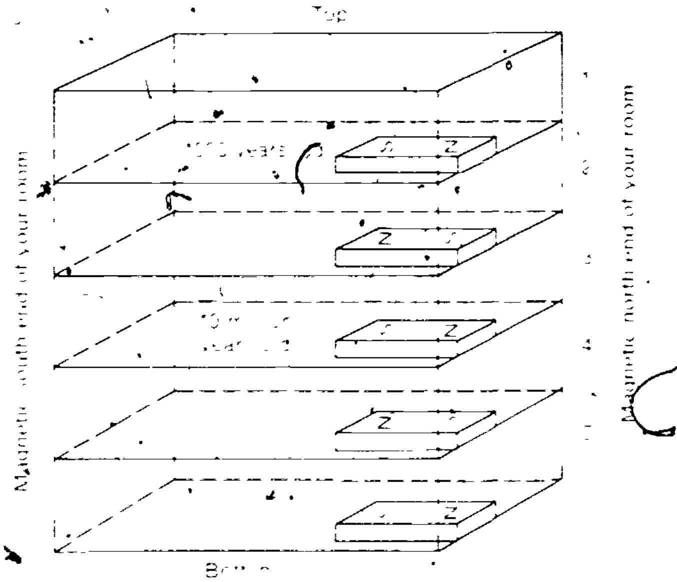


Figure A. The relabeled bar magnets are taped to the boxes which are then stacked.

BACKGROUND INFORMATION

Scientists know regrettably little about the processes that are responsible for the magnetism of the earth. Beyond the observation that the magnetic field originates inside the earth, probably in the fluid outer portion of its iron core, our ignorance is almost complete. We do know that most of the earth's magnetic field behaves very much as if it were caused by a short, powerful bar magnet, or dipole, at the center of the earth. No such dipole exists, of course; the interior of the earth is far too hot to permit simple permanent magnets to exist. Instead, the dipole field must originate as a consequence of huge electrical currents flowing in a pattern of loops or rings in the liquid metal of the outer core. The science of paleomagnetism, involving the study of the magnetism of rocks, shows that the earth's magnetic field has behaved in an essentially dipolar manner.

An interesting property of the magnetic field caused by electrical current flowing in a loop is that it reverses direction if the direction of the electrical current flow is also reversed. Set up as in Figure B, the compass needle will completely reverse its direction if the wire hookups to the terminals of the battery are interchanged, so that the current in the wire loop flows in the opposite direction.

The analogy of the reversing magnetic field caused by reversal of current flow in a wire loop has direct relevance to the earth because the magnetic record retained by many common rocks shows that the earth's magnetic field has undergone hundreds, perhaps thousands, of similar polarity reversals during the past several billion years. For instance, the thick piles of basaltic lava flows, of which Iceland is composed, retain a record of the magnetic field that existed at the time each flow cooled. Naturally, the oldest flows (first formed) are at the bottom of the pile and the youngest (last formed) at the top. These piles of lavas have been studied very carefully by investigators from England, Holland, and the United States. It was found that nearly half of the flows are magnetized approximately parallel to the earth's present magnetic field (called "normal"); an equal number are magnetized nearly opposite (called "reverse") to the present field. Only a tiny fraction are magnetized in any other direction (so-called "transitional" flows). Figure C shows a cliff face with a series of older normal flows at the bottom, a series of younger reverse flows at the top, and transitional flows in between.

During the past 50 million years, normal and reverse intervals have averaged approximately 100,000 years in length. There seems to have been at least 170 polarity transitions in the last 80 million years; the most recent was 700,000 years ago.

Two things which we would like very much to know about the earth's magnetic field are the causes of polarity transitions and the behavior of the magnetic field when a transition occurs. Unfortunately, at present we have very imperfect answers to both questions. During a transition the intensity of the earth's magnetic field seems to fall to very low levels and its direction appears to change somewhat erratically. Perhaps the dipole part of the field slowly disappears and then builds up again in the opposite direction, leaving only the non-dipole part of the field to govern the compass needle during transition. As to what causes transitions, we are almost completely "at sea". Transitions seem to be random processes, perhaps triggered by a number of different causal factors that occasionally, and accidentally, find themselves working together. The only difference between a normal and a reverse state of the earth's magnetic field is that in a reverse period, the south end of the compass needle would point in the general direction of the north geographic pole.

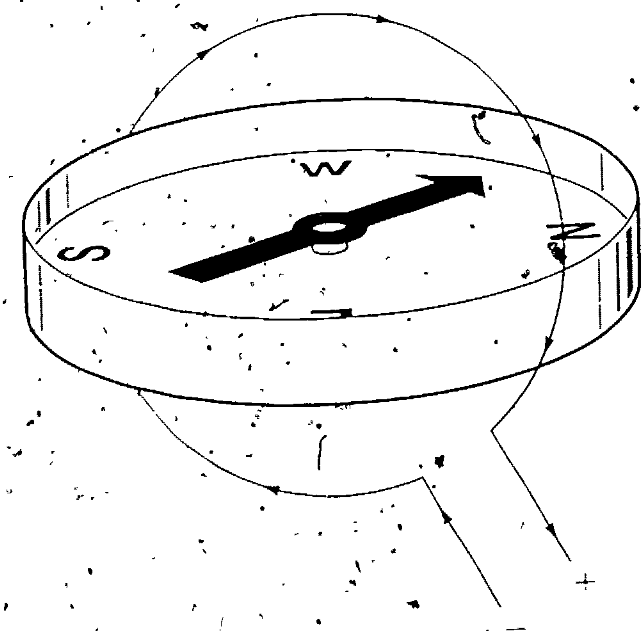


Figure B. Compass needle held at center of wire loop points 90° to plane of loop when direct current is flowing. Arrows show current flow. Reversing the current flow will cause the needle to point in the opposite direction.

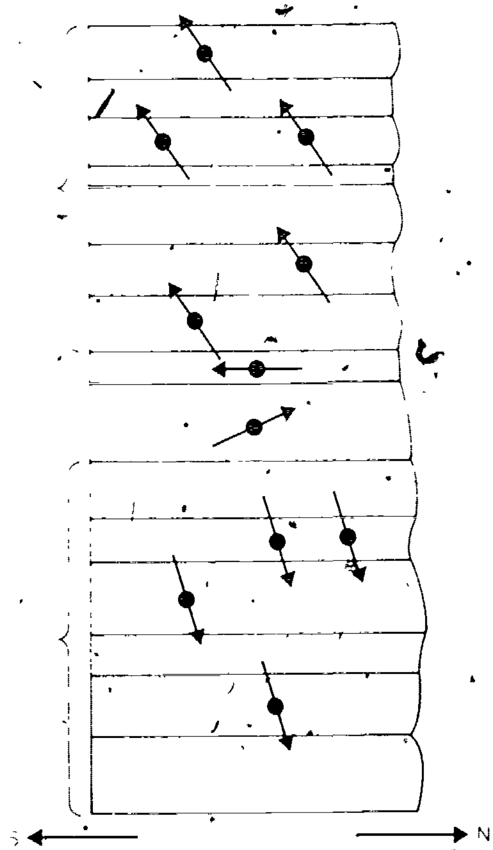


Figure C. Arrows show direction of magnetism of individual lava flows in Iceland. The earth's magnetic field is oriented steeply downward to the north in Iceland today. Iceland shows many such sequences of alternately magnetized lava flows.

Certainly the most exciting and scientifically fruitful outgrowth of the study of magnetic reversals has been the confirmation of the new theory of sea-floor spreading and the re-establishment and virtual proof of the closely related earlier theory of continental drift. These topics are discussed more fully in other modules. Here it is necessary only to describe processes acting at the mid-ocean ridge system (of which the Mid-Atlantic Ridge is a good example).

Just below the crest of the ridge, hot ductile rock that has moved up slowly from deep in the earth's mantle turns laterally outward and moves away from the ridge crest, carrying a layer of cooler, more brittle rock passively along with it, like egg crates on a conveyor belt. Moreover, as the hot mantle rock approaches the surface, the pressure exerted on it by the weight of the overlying rock decreases sufficiently to allow melting to begin. A small fraction of the upwelling mantle rock is thereby converted into magma, which seeps out at the surface and quickly freezes to form the basaltic lower part of the ocean floor. The basalt at the ridge crest is thus very young; for the most part a few tens of thousands of years old, or less. Naturally, as the underlying ductile rock moves laterally away from the ridge crest, the basaltic lava flows (and various other products of partial melting of the upwelling column) move along with it. Thus, the conveyor belt can be thought of as providing its own "egg crates". Figure D illustrates this process, which, of course, is known as "sea-floor spreading".

The basaltic lavas and similar rocks that form at the ridge crest become magnetized as they cool, and they pick up a magnetic direction that is related to the direction of the earth's magnetic field at that time. Thus, if a magnetometer (a device which is used to measure the strength of a magnetic field) is brought near the crest of the Mid-Atlantic Ridge, it records a greater intensity than expected because the magnetic field of the normally magnetized rocks enhances the present magnetic field of the earth. However, rocks formed roughly one million years ago were magnetized at a time when the geomagnetic field had reverse polarity. (The present—"normal"—magnetic epoch began about 700,000 years ago.) These rocks, which in the million years of their existence have been carried by sea-floor spreading roughly 10 kilometers to either side of the ridge crest, have a magnetism that is approximately opposite to the earth's present, or normal direction. Their magnetic effect subtracts from the geomagnetic field. A magnetometer towed back and forth over a segment of the mid-ocean ridge system thus maps long ribbons of alternating high and low magnetic field intensity (termed positive and negative anomalies). At most ridge crests the sea floor spreads equally to either side of the ridge, producing magnetic stripes that are symmetrical along both sides of the crest of the ridge (see Figure E). The magnetic anomaly pattern thus records the history of transitions of the geomagnetic field. An analogy can be drawn between the sea floor and a magnetic tape recorder.

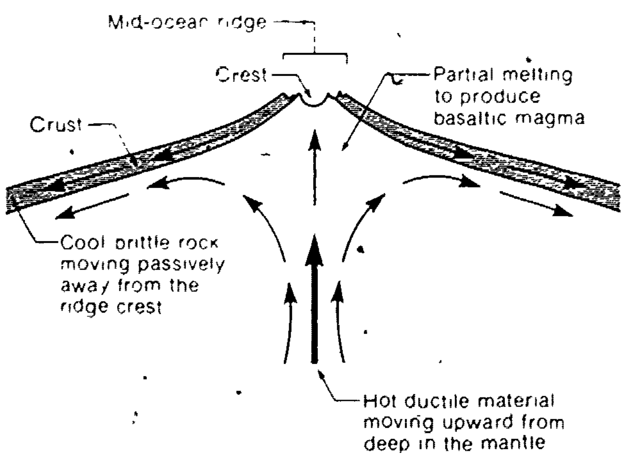


Figure D. Cross-section of ridge.

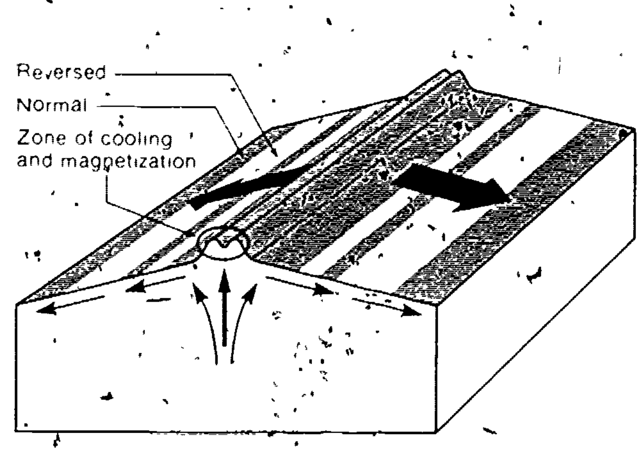


Figure E. Magnetic anomaly pattern.

This explanation for the pattern of magnetic stripes on the sea floor in terms of spreading and changes in the earth's magnetic polarity is quite important in the history of the earth sciences. In confirming the sea-floor spreading concept, it has opened up and made respectable a new chain of logic (termed "plate tectonics") that provides answers to many questions about the origin and nature of earthquakes, volcanoes, mountain ranges, and even the continents and oceans themselves.

SUGGESTED APPROACH

Basically, these activities should be carried out by the students as independent inquiry. Size of the groups should be dependent on available equipment and your strategy. The groups can work through the various steps of the activities as a class, or each group may proceed at its own pace. These matters are left here to your own preference and style. Open-ended activities (EXTENSIONS) are available for those students who proceed at a faster pace, or wish to go into greater depth.

These activities are grouped into approximations of three 45-minute class periods. Your schedule may require extending some parts or regrouping others.

PROCEDURE

PART A Which way is north?

In this activity the students learn to use a compass and to determine the orientation of bar magnets concealed in boxes.

Key words: paleomagnetism, paleomagnetic field, polarity reversal, normal (polarity), reversed (polarity)

Time required: one 45-minute period

Materials: bar magnets, compasses, and boxes

1. Can you figure out which way is north? What part of your classroom is on the north side?

By looking out of the windows, doorway to hall, etc. have the students orient themselves and find out which way is north and what part of the room is the most northerly. A local road map or topographic map may be helpful here.

2. Examine your compass. What colors are at each end of the compass needle?

Here, the student should recognize that each end of the compass needle is a different color.

3. Which end of the needle points to the north? ______________ (color).

In this step, the compass needle will point to the north part of the room, thus establishing north on the compass. The reason for this action, though, is to find out which end of each compass needle points north. On inexpensive compasses, with pointers usually one-half blue and one-half silver, some blues and some silvers will point north. They are not all magnetized uniformly, so the color of north has to be determined for each compass and recorded by the students. Once this is established, have each student use the same compass throughout the activity. As it becomes necessary to stop and start at another time in the course of this activity, the students can easily find out again which end of the needle points to the north by checking which end points to the north part of the classroom.

Note that in the next paragraph of step 3 there is a comment addressed to the student, concerning the fact that the bar magnet has been set up to work like the earth's magnetic field. If a student asks why like poles (the N on the compass and the N on the bar magnet) attract, explain that this was done only for the sake of the demonstration value of these activities. The purpose of this will become clearer when the student works with the boxes.

The bar magnets have been labeled so that the north-seeking end of the compass will point to the north end of the magnet. In that way, the bar magnets are like the earth's magnetic field.

Put your magnet on this page as shown with north at the top and south at the bottom.

4. Which end of the compass points to the north end of the magnet? ____________ (color)

Here the students merely establish that the same end (or color) of their compass needle that points to the north part of the room points to the north pole of the bar magnet.

5. Which end of the compass points to the south end of the magnet? ____________ (color)

The same applies to the south end. If you wish, you may have the students take turns with their team members in hiding the magnet under a piece of paper and finding which end is which; or find the north and south ends of a bar magnet that you hold with a hand over each end.

6. Look at the pile of five boxes that has been put out for you to work with. Imagine that each box is a layer of igneous rock, like an old lava flow. This rock cooled and hardened on the surface of the earth a long time ago. The age of some of the layers is known and is given to you in the diagram here. The magnetic field of each layer has stayed the same as the earth's at the time the rock cooled. The magnetic field in this rock is called the **paleomagnetic field.** You can locate the direction of the north magnetic pole at the time the rock formed by testing these layers of rock with your compass.

Using the compass, find the north and south magnetic pole directions in each layer. Label the diagram here to show these directions.

Place a set of five boxes (as described in the MATERIALS section) on a table for each group of students. The students will find that in the pile of boxes, representing a sequence of layered rocks, the north and south magnetic pole orientations in the rocks have changed places (i.e., reversed) in the past.

Discuss with the others in your group what you discovered about the north and south magnetic directions in these boxes. What you have found is what geologists have found in layered rocks at many places around the world. Now answer these questions.

7. These boxes represent old lava flows that piled up on the surface of the earth and cooled to form layers of hard rock.

Which is the oldest layer? **bottom: no. 5**

Which is the youngest layer? **top: no. 1**

Obviously, as a sequence of layered rocks accumulates on the surface of the earth, the layer at the bottom is the oldest and the layer at the top is the youngest. This is known as the principle of superposition.

8. What did you find out about the north and south magnetic pole direction in each layer?

Layer 1 **N is toward the magnetic north end of your room.**

Layer 2 **S is toward the magnetic north end of your room.**

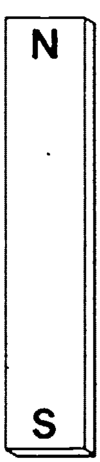
Layer 3 **N is toward the magnetic north end of your room.**

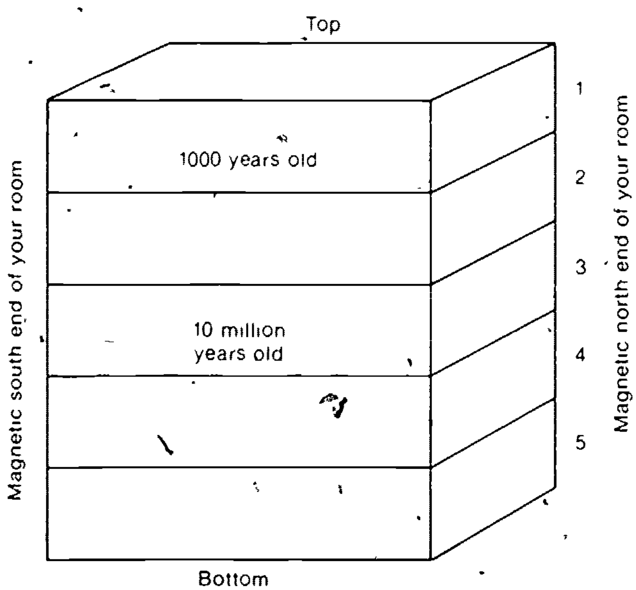
Layer 4 **S is toward the magnetic north end of your room.**

Layer 5 **N is toward the magnetic north end of your room.**

The students will find that you have placed the bar magnets in alternating orientations.

You have just found that the magnetic field in some layers is reversed. This is called **polarity reversal.**





9. What do you think caused these reversals?

There are three ways of explaining such a series of magnetic reversals. While these layers of rock were accumulating and preserving the magnetic field record of their time: (1) the north and south magnetic poles changed places (reversed) with each other each time a layer of rock was deposited; (2) the landmass or continent these rocks were on turned completely around (rotated 180 degrees) in between the deposition of each layer of rocks; (3) the magnetic field in the rock could have reversed by itself. All of these hypotheses could be used to explain the observations, but the reversals of the poles seems to be the one most accepted by scientists.

When the north magnetic pole is located near the north geographic pole and the south magnetic pole is located near the south geographic pole, we call the earth's magnetic field **normal.** When the two magnetic poles exchange places, the earth's magnetic field is **reversed.**

Have the students find the terms polarity reversal, normal and reverse polarity, in the textbook or reference your class is using.

PROCEDURE

PART B. How does paleomagnetism help explain how the sea floor is formed?

In this activity the students observe and map a pattern of alternate polarity reversals.

Key word: sea-floor spreading

Time required: one 45-minute period

Materials compasses and boxes

Start this activity by distributing compasses and having the students find which end of the needle points to the north end of the room. Now, place two stacks of boxes (stacked exactly as you had them in the first activity) side by side. It would be ideal to start with these on the floor, between the ends of two tables or desks that face each other across an aisle or narrow space. Then each time you bring up a pair of boxes, the students get the visual effect of the mantle rising up at a ridge to form more of the earth's crust. If this cannot be done, just set the two sets of boxes aside and use the top of a table and proceed as follows.

You have found that north and south magnetic pole directions are preserved when rock is formed. What would the patterns of polarity reversals look like preserved in the rocks forming along a mid-ocean ridge?

Most scientists believe that mid-ocean ridges are places where **sea-floor spreading** is taking place In this process, molten rock rises along the ridge as the two sides of the ridge move apart (Figure 1) Then, new ocean floor is created by the cooling and hardening of this molten rock material

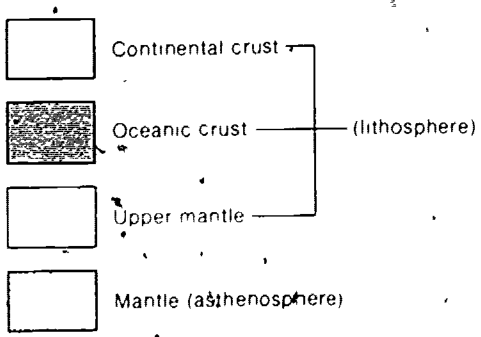


Illustration Key

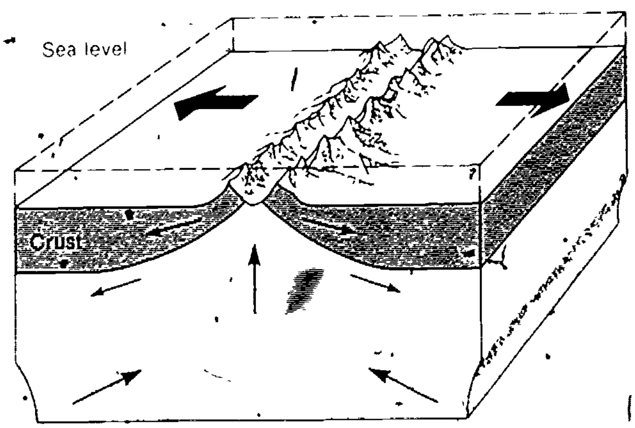
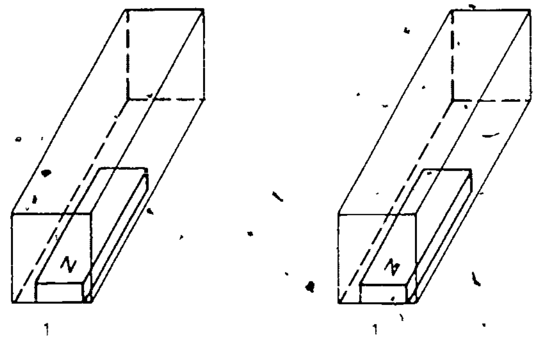


Figure 1. Sea-floor spreading New ocean floor is created as the two sides of the ridge move apart.

In this activity, the boxes in the starting position represent rocks forming in the middle of a mid-ocean ridge. As the rocks move outward (sideways), new rock is added to the ocean floor along the ridge.

1. Find which end of your compass needle points to the north end of your room. Using the compass, find the north and south magnetic pole direction in each box and label the diagram to show these directions.

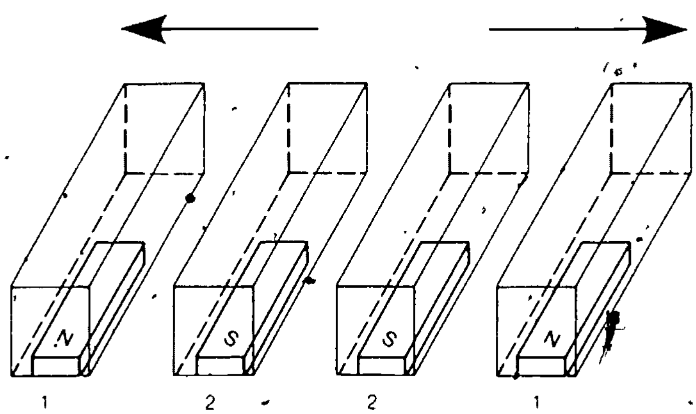
Put out the two top boxes (labeled #1) from the stack, as shown below, with their numbered ends toward the north part of the room. The students will find that the north magnetic pole within the box is towards the north end of the room; thus it is normal.



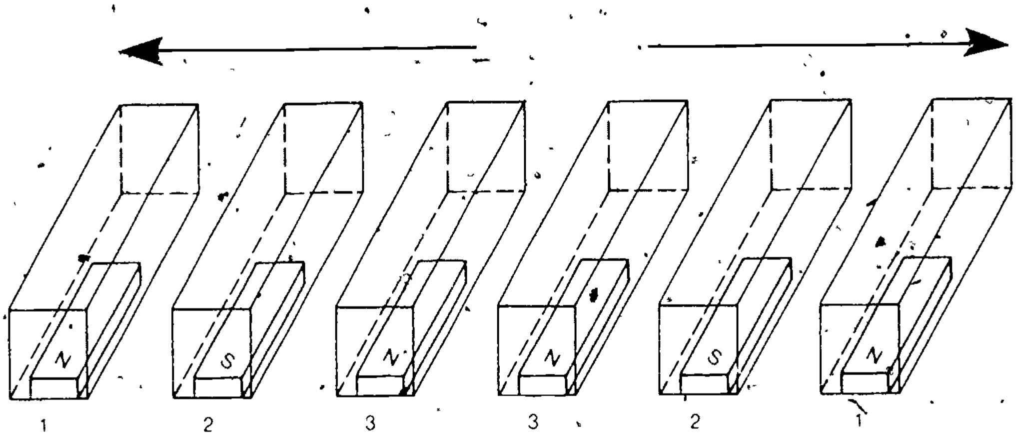
2. Do the same thing each time your teacher adds another set of boxes

The arrows show which way the boxes are being moved.

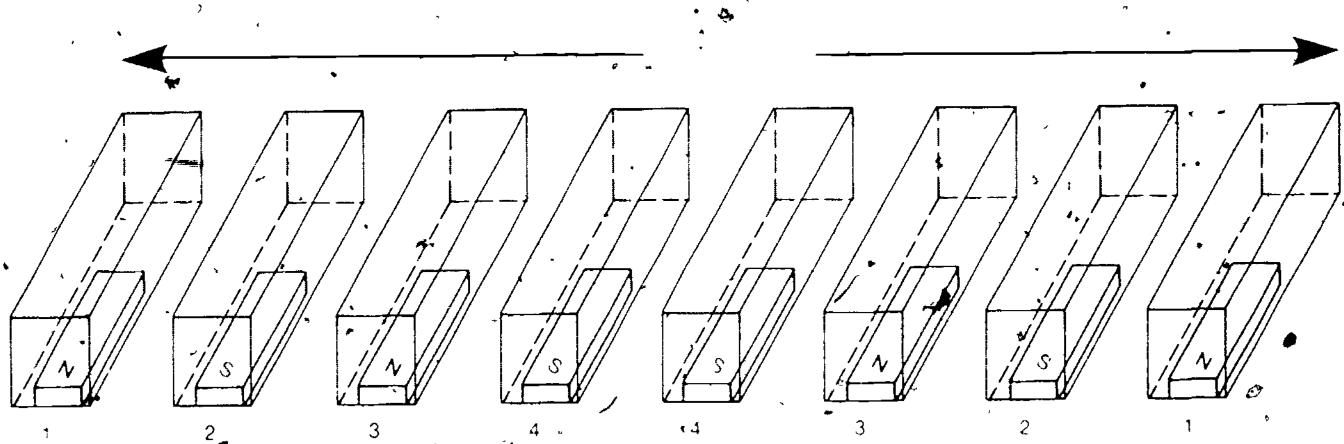
A. Move the two #1 boxes apart, and insert the pair of #2 boxes in the middle position as shown. These, of course, will have reversed polarity.



B. Continue as before; moving the boxes out and putting the next pair in the middle.



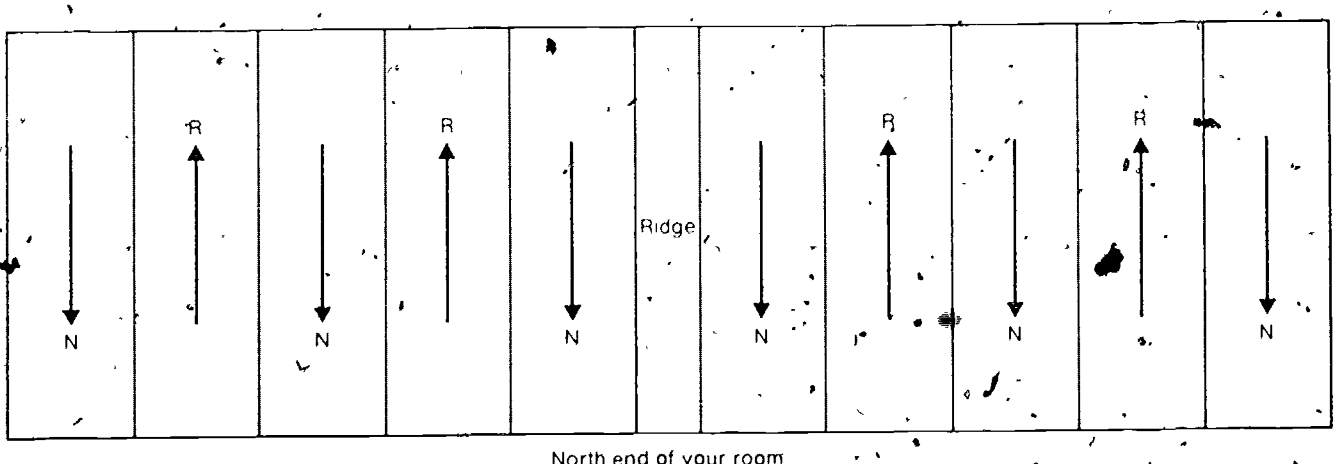
C.



You can, if you wish, ask the students to predict what they will find if you put the #5 boxes into the sequence; then do it and let them check their predictions.

3. Using your observations of polarity direction shown in these boxes, draw a map of the polarity directions preserved in the ocean floor on both sides of a mid-ocean ridge. A map is what you would see if you were looking down at the earth.

The map should look something like this:



4. Explain what would happen if the ocean floor spread constantly from a ridge while the earth's magnetic field kept reversing

If this happened, we would eventually observe a series of alternating reversals on each side of the ridge and the pattern or sequence on one side would match that on the other side. (Be sure to stress this last point.) The text which you are using possibly has an illustration showing this.

PROCEDURE

PART C. What can be learned from observations of polarity directions in the sea floor?

Here the students plot real paleomagnetic data and find the direction and rate of ocean-floor spreading.

Key words: magnetometer, normal, reverse

Time required: one 45-minute period

Materials. ruler

In this activity, you are going to act as marine geologists on a cruise You will collect magnetic data as you sail in a zig-zag pattern across the Mid-Atlantic Ridge just southwest of Iceland Table 1 shows the data which were collected The data used here were collected during a magnetic study of that area The scientists used an instrument called a **magnetometer,** carried aboard a U S. Navy plane. The magnetometer does not have a compass needle that really reverses. It measures the strength of the magnetic field. When the magnetometer is above reversely magnetized rock, it will show the field to be weaker than when it is over normally magnetized rock

1. On the Worksheet, mark an X or an O at the location of each station on Table 1. Note that the X indicates reversed magnetism and O indicates normal magnetism. Where each age is given, write next to the symbol either the number 10 (for 10 million years) or the letter P (for Present). Note the example of station 2 already plotted on the map.

Each student should do his or her own plotting on the map.

2. After you have marked all of the normal and reversed symbols and the ages that are given for some locations, draw one straight line with your ruler that will connect all the stations where the rocks are of Present age (P). This will separate the groups of 10 million-year-old rocks. Draw one straight line through each group of 10 million-year-old rocks (10).

a. Where do you think the Mid-Atlantic Ridge is located on your map? What is your reason?

The most reasonable assumption is that the mid-ocean ridge is where the strip of Present normal magnetic orientation is located because that is where new rock, squeezed up to form the ridge, is now being magnetized in today's magnetic field.

b. What pattern do you see on your map?

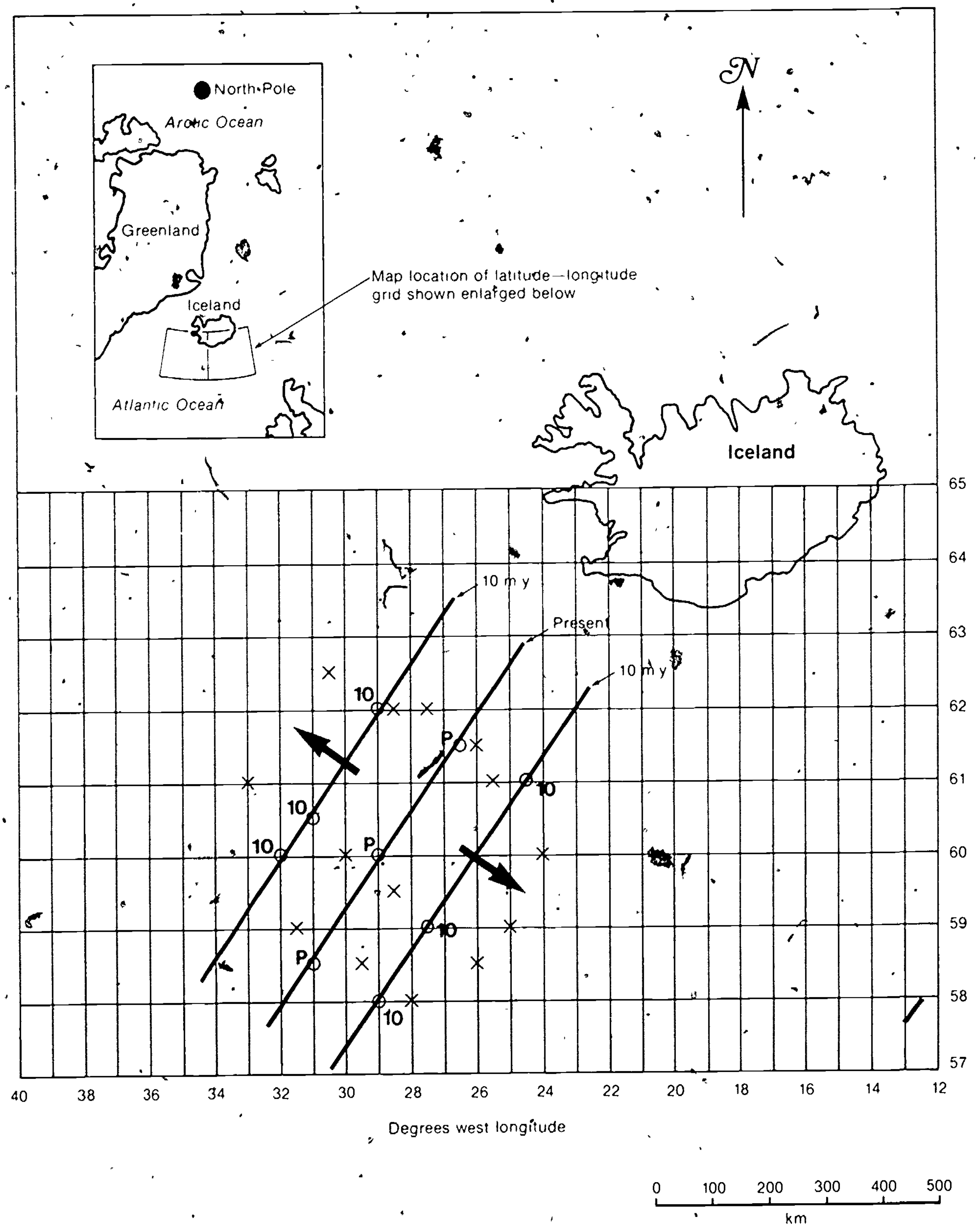
There is a pattern of stripes.

c How can you explain this pattern?

The striped pattern is the result of new rock being formed as the magnetic field reverses periodically. Thus, you will find alternate zones of normal and reversed polarity with the same pattern on each side of the ridge.

Table 1.
Magnetic study data.

Station	North Latitude	West Longitude	Magnetic Field Orientation	Symbol	Age (million years)
1	58 0°	28 0°	Reversed	X	
2	58 0°	29 0°	Normal	O	10 m y
3	58 5°	29 5°	Reversed.	X	
4	58 5°	31 0°	Normal	O	Present
5	59 0°	31 5°	Reversed	X	
6	60 0°	32 0°	Normal	O	10 m y
7	61 0°	33.0°	Reversed	X	
8	60 5°	31 0°	Normal	O	10 m y
9	60 0°	30 0°	Reversed	X	
10	60 0°	29 0°	Normal	O	Present
11	59 5°	28 5°	Reversed	X	
12	59 0°	27 5°	Normal	O	10 m y
13	58 5°	26 0°	Reversed	X	
14	59 0°	25.0°	Reversed	X	
15	60 0°	24 0°	Reversed	X	
16	61.0°	24 5°	Normal	O	10 m y
17	61 0°	25 5°	Reversed	X	
18	61 5°	26 0°	Reversed	X	
19	61 5°	26 5°	Normal	O	Present
20	62 0°	27 5°	Reversed	X	
21	62 0°	28.5°	Reversed	X	
22	62 0°	29 0°	Normal	O	10 m y
23	62 5°	30 5°	Reversed	X	



Answer Sheet (PART C)

3. Draw arrows on your map to show in what direction the ocean floor on each side of the ridge is moving. How do you know this?

The left-hand side of the sea floor is moving to the northwest because the ocean floor is youngest near the ridge and gets older as you go out on each side of the ridge. The right-hand side is moving southeast.

4. If a car travels 100 kilometers in two hours, how fast is it going (kilometers) per hour? How can you find out how fast the ocean floor is moving on each side of the ridge?

The way to approach this problem is similar to finding the speed (rate) at which a car travels. If a car travels 100 km in two hours, we divide the distance by the time (100/2), and find that it was going 50 km per hour. By measuring the distance which the ocean floor moved away from the ridge in a known period of time, we can calculate the rate of movement in a similar fashion.

5. Find the rate (in centimeters per year) at which the ocean floor is moving in the area of Iceland. (Remember that 1 km equals 1000 m, and 1 m equals 100 cm. Therefore, to convert kilometers to centimeters, you must add 5 zeros to the number of kilometers.)

From the diagram which they have made, the students can see that it took 10 million years for each of the two outer normal stripes or zones to get where they are from the ridge. Using the scale at the bottom of the page (they can cut out the scale and use it like a ruler), they should measure the distance from the line of the present zone to the line of the 10-million-year zone. Have them do this first on one side of the ridge and then on the other side. If they get a different distance on each side due to the vagaries of how they drew their diagram, encourage them to average the two distances and use that figure. Actually, there will probably be a variety of distances found by the students, ranging from about 125 km to about 150 km. This is tolerable and depends entirely on the accuracy of their plotting of the data and the drawing of their lines. This might be a good time to hold a class discussion on reasonable limits of accuracy.

In working out this calculation we will use 150 km as the distance, but we will provide rough approximations for the other possible distances that the students may have used. There are 1000 m in a kilometer, so 150 km is equal to 150,000 m. Similarly, there are 100 cm in a meter, so 150,000 m equals 15 million cm. It's just a matter of adding the zeros. If you divide 15,000,000 (the distance in centimeters) by 10,000,000 (the time in years), you get 1.5 (simply move the decimal point an equal number of times). Therefore, the rate of movement is 1.5 cm per year. For the other possible distances the rates are:

125 km—1.25 cm per year

130 km—1.3 cm per year

140 km—1.4 cm per year

Within the limits of accuracy of this activity, these are all acceptable rates, for they are close to the correct magnitude for this area as determined by oceanographers.

Point out that 1.5 cm is about the width of their thumbs (they can check this with a ruler), or the amount their fingernails grow in one year.

6. If the sea floor spreads at a constant rate, what is the age of the sea floor at station 14?

The age is about 20 m.y. Point 14 is about twice as far as the 10 m.y. line.

7. Now that you know the rate at which the ocean floor is moving, use this figure to find out how fast the ocean floor is spreading apart on the two sides of the ridge.

If the sea floor on each side of the ridge has been moving away from the ridge at a rate of 1.5 cm per year (rate of motion); then the spreading rate, or rate at which the two sides have been moving apart from one another, will be exactly twice that rate of motion, or 3.0 cm per year. Spreading rates for other motion rates which the students may have come up with are:

Motion Rate	*Spreading Rate*
1.25 cm/yr	**2.5 cm/yr**
1.3 cm/yr	**2.6 cm/yr**
1.4 cm/yr	**2.8 cm/yr**

If the students each put their thumbs together, side by side, they can see how much the sea floor spreads apart in one year.

SUMMARY QUESTIONS

The first two questions are relatively easy; the third is considered more difficult.

1. You have looked at just a small portion of the approximately 64,000 km of mid-ocean ridges. Do you think that what you found southwest of Iceland might be found alongside the rest of the ridges?

By inference, what was found on both sides of the mid-ocean ridge south of Iceland should be found alongside all the ridges because all the ridges and ocean floor are forming in the same way.

2. How far out from the ridge area that you studied would you expect to find the magnetic reversal patterns?

Since the ocean floor forms at the ridges and spreads out on both sides, the reversal pattern should be found all the way out to the continents on both sides of the oceans (actually, to the bottom of the continental slopes).

3. As you go away from a mid-ocean ridge, how do you think the age of the bottom sediment on the ocean floor changes?

If the ocean floor is formed at the ridge and spreads out, then the sediment that accumulates (from the water) near the ridge would be carried outward as the ocean floor spreads. Therefore, sediment deposited later on the newer ocean floor bottom, near the ridge, would be younger. In fact, it has been found that the bottom sediment on the ocean floor is progressively older in a direction away from the ridges.

EVALUATION

In addition to a written *(formal)* evaluation you can observe the students' participation and performance as a means of *informal* evaluation. Alternatively, you may wish to give each student a map of an ocean with the mid-ocean ridge shown, and ask them to draw in the magnetic reversal pattern, show which way the ocean floor is moving, and label the older and younger parts of the ocean floor.

EXTENSIONS

1. You found a spreading rate for the ocean floor just southwest of Iceland. Now measure the distance in kilometers from Labrador to Great Britain on a map. Can you figure out how long ago North America and Europe separated? Compare the number of years that you get with a geologic time scale to see in what geologic period your answer would fall

This is just a matter of working the spreading rate problem in reverse. Your students probably arrived at a spreading rate of 2.5 to 3.0 cm per year in the last part of question number 6 in PART C. Let them use whatever figure (in that range) that they got then in this activity. From globes or atlases in your classroom, your students will find that it is approximately 3,060 km from Labrador to Great Britain (multiply miles by 1.61 to get kilometers). They may get any number from this up to 3,260 or so. Within the realm of accuracy for this activity, these values are acceptable.

The problem now resolves into dividing the distance in centimeters by the rate of movement. Using 3,060 km and 3.0 cm per year, we get:

$$\frac{306{,}000{,}000 \text{ cm}}{3.0 \text{ cm/yr}} = 102{,}000{,}000 \text{ yrs}$$

A rough approximation of the answers your class will get is as follows:

cm/yr	*3,060 km*	*3,260 km*
2.5	122 m.y.	130 m.y.
2.6	118 m.y.	125 m.y.
2.8	109 m.y.	116 m.y.
3.0	102 m.y.	109 m.y.

When you compare the range of years found here with a geologic time table, you will discover that the time falls within the Cretaceous Period, which was 65 to 135 million years ago. It was actually during the Cretaceous that the landmasses now known as North America and Europe began to break apart. If your students end up with an approximation of a Middle Cretaceous date (102–130 m.y.), they have done very well.

2. Sea-floor spreading occurs throughout all of the ocean basins of the world. What does this suggest has been happening to the size of the earth as time has gone on? Does your conclusion seem reasonable to you?

Since sea-floor spreading apparently has taken place, can you invent any possible explanations which would result in the earth staying the same size even though sea-floor spreading is taking place? Make a list of these other possibilities. See if you and your classmates can agree on what is most likely the correct (or most reasonable) solution to this problem.

Your students may suggest that the earth is expanding. As the earth expands, it may push new crust out of the mid-ocean ridge.

One explanation is that while new material is being added to the earth's surface, other material is being destroyed somehow. Another explanation for the size of the earth may be that the entire earth expands and then contracts. Both of these have been suggested by scientists and are valid theories. You may want to discuss this further with your students when using other modules.

REFERENCES

Alexander, T., 1975, A revolution called plate tectonics has given us a whole new earth. *Smithsonian*, v. 5, no. 10 (Jan.), p. 30–40 (first of 2-part article).

Alexander, T., 1975, Plate tectonics has a lot to tell us about the present and future earth. *Smithsonian*, v. 5, no. 11 (Feb.), p. 38–47 (conclusion of 2-part article).

Calder, N., 1972, *The restless earth*. New York, Viking Press, 152 p.

Dewey, J.F., 1976, *Readings from Scientific American: Continents adrift and continents aground*. San Francisco, W H. Freeman and Co., p. 34–45.

Matthews, W.H. III, and others, 1978, *Investigating the earth*. Boston, Houghton Mifflin, 557 p.

Ramsey, W.L., and others, 1973, *Modern earth science*. New York, Holt, Rinehart & Winston, 580 p.

Sullivan, W., 1974, *Continents in motion: the new earth debate*. Highstown, N.J., McGraw-Hill, 399 p.

Tarling, D., and Tarling, M., 1975, *Continental drift*. Garden City, N Y., Doubleday, 140 p.

Wilson, J. Tuzo, ed., 1972, *Continents adrift*. San Francisco, W.H. Freeman and Co., 172 p

Wyllie, P J , 1976, *The way the earth works*. New York, John Wiley and Sons, Inc., 296 p.

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NAGT Crustal Evolution Education Project Modules

CEEP Modules are listed here in alphabetical order Each Module is designed for use in the number of class periods indicated. For suggested sequences of CEEP Modules to cover specific topics and for correlation of CEEP Modules to standard earth science textbooks, consult Ward's descriptive literature on CEEP The Catalog Numbers shown here refer to the CLASS PACK of each Module consisting of a Teacher's Guide and 30 copies of the Student Investigation See Ward's descriptive literature for alternate order quantities

CEEP Module	Class Periods	CLASS PACK Catalog No.
• A Sea-floor Mystery: Mapping Polarity Reversals	3	34 W 1201
• Continents And Ocean Basins: Floaters And Sinkers	3-5	34 W 1202
• Crustal Movement: A Major Force In Evolution	2-3	34 W 1203
• Deep Sea Trenches And Radioactive Waste	1	34 W 1204
• Drifting Continents And Magnetic Fields	3	34 W 1205
• Drifting Continents And Wandering Poles	4	34 W 1206
• Earthquakes And Plate Boundaries	2	34 W 1207
• Fossils As Clues To Ancient Continents	2-3	34 W 1208
• Hot Spots In The Earth's Crust	3	34 W 1209
• How Do Continents Split Apart?	2	34 W 1210
• How Do Scientists Decide Which Is The Better Theory?	2	34 W 1211
• How Does Heat Flow Vary In The Ocean Floor?	2	34 W 1212
• How Fast Is The Ocean Floor Moving?	2-3	34 W 1213
• Iceland: The Case Of The Splitting Personality	3	34 W 1214
• Imaginary Continents: A Geological Puzzle	2	34 W 1215
• Introduction To Lithospheric Plate Boundaries	1-2	34 W 1216
• Lithospheric Plates And Ocean Basin Topography	2	34 W 1217
• Locating Active Plate Boundaries By Earthquake Data	2-3	34 W 1218
• Measuring Continental Drift: The Laser Ranging Experiment	2	34 W 1219
• Microfossils, Sediments And Sea-floor Spreading	4	34 W 1220
• Movement Of The Pacific Ocean Floor	2	34 W 1221
• Plate Boundaries And Earthquake Predictions	2	34 W 1222
• Plotting The Shape Of The Ocean Floor	2-3	34 W 1223
• Quake Estate (board game)	3	34 W 1224
• Spreading Sea Floors And Fractured Ridges	2	34 W 1225
• The Rise And Fall Of The Bering Land Bridge	2	34 W 1227
• Tropics In Antarctica?	2	34 W 1228
• Volcanoes: Where And Why?	2	34 W 1229
• What Happens When Continents Collide?	2	34 W 1230
• When A Piece Of A Continent Breaks Off	2	34 W 1231
• Which Way Is North?	3	34 W 1232
• Why Does Sea Level Change?	2-3	34 W 1233

WARD'S

Ward's Natural Science Establishment, Inc.
P.O. Box 1712, Rochester, New York 14603 • P.O. Box 1749, Monterey, California 93940

MODULE NO. WA3 4-4
)-00072-062-7

Printed in U.S.A.

CEEP

CRUSTAL EVOLUTION EDUCATION PROJECT

NAME DATE

Student Investigation

Catalog No 34W1132

Which Way Is North?

INTRODUCTION

You would expect a magnetic compass needle to point toward the north and south magnetic poles Since continents can drift or move around, can you depend on the two poles to stay in the same places?

Over long periods of time, the earth's magnetic field changes directions We know that rocks record the earth's magnetic field at the time at which they are formed This is called **paleomagnetism.** With this knowledge, measurements made at sea allow us to find out a great deal about the past movements of the earth's crust In these activities, you will be doing the same thing that scientists have done in working out the history of crustal changes

OBJECTIVES

After you have completed these activities, you should be able to:

1. Use a compass to determine the direction of a magnetic field.
2. Use data on magnetic field direction and age of rocks in the sea floor to find direction and rates of sea-floor spreading.
3. Explain how paleomagnetic data are used in studying the history of the earth.
4. Locate the older and younger parts of the sea floor with respect to mid-ocean ridges.

SE 038134

PROCEDURE

PART A Which way is north?

Materials. bar magnets, compasses, and boxes

1. Can you figure out which way is north? What part of your classroom is on the north side?

2. Examine your compass What colors are at each end of the compass needle?

3. Which end of the needle points to the north? ______________ (color)

The bar magnets have been labeled so that the north-seeking end of the compass will point to the north end of the magnet In that way, the bar magnets are like the earth's magnetic field

Put your magnet on this page as shown with north at the top and south at the bottom

4. Which end of the compass points to the north end of the magnet? ______________ (color)

5. Which end of the compass points to the south end of the magnet? ______________ (color)

6. Look at the pile of five boxes that has been put out for you to work with Imagine that each box is a layer of igneous rock, like an old lava flow. This rock cooled and hardened on the surface of the earth a long time ago. The age of some of the layers is known and is given to you in the diagram here. The magnetic field of each layer has stayed the same as the earth's at the time the rock cooled. The magnetic field in this rock is called the **paleomagnetic field.** You can locate the direction of the north magnetic pole at the time the rock formed by testing these layers of rock with your compass

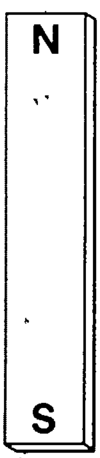
Using the compass, find the north and south magnetic pole directions in each layer Label the diagram here to show these directions

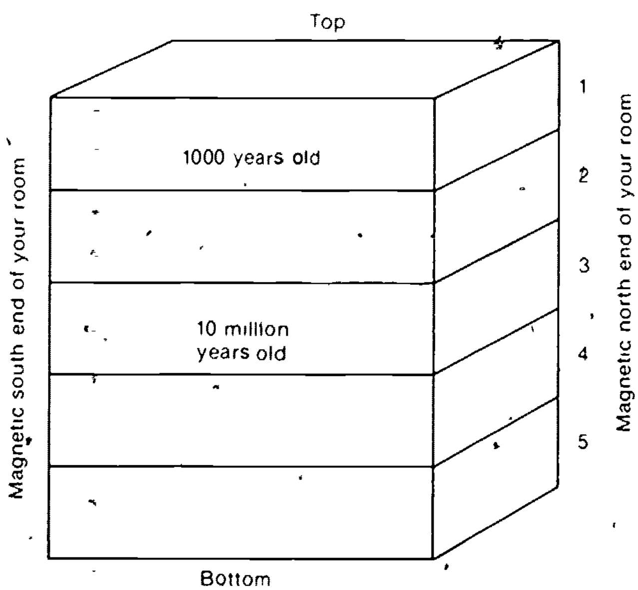
Discuss with the others in your group what you discovered about the north and south magnetic directions in these boxes What you have found is what geologists have found in layered rocks at many places around the world Now answer these questions

7. These boxes represent old lava flows that piled up on the surface of the earth and cooled to form layers of hard rock

Which is the oldest layer? ______________

Which is the youngest layer? ______________





8. What did you find out about the north and south magnetic pole direction in each layer?

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

You have just found that the magnetic field in some layers is reversed. This is called **polarity reversal.**

9. What do you think caused these reversals?

When the north magnetic pole is located near the north geographic pole and the south magnetic pole is located near the south geographic pole, we call the earth's magnetic field **normal.** When the two magnetic poles exchange places, the earth's magnetic field is **reversed.**

PROCEDURE

PART B How does paleomagnetism help explain how the sea floor is formed?

Materials: compasses and boxes

You have found that magnetic north and south pole directions are preserved when rock is formed. What would the patterns of polarity reversals look like preserved in the rocks forming along a mid-ocean ridge?

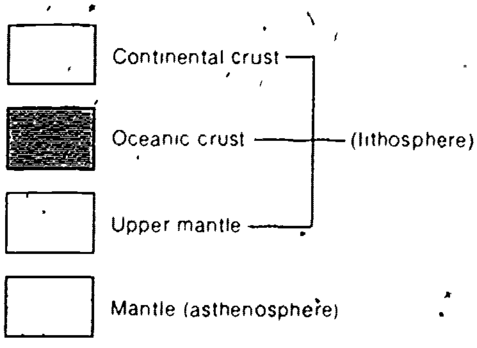


Illustration Key

Most scientists believe that mid-ocean ridges are places where **sea-floor spreading** is taking place. In this process, molten rock rises along the ridge as the two sides of the ridge move apart (Figure 1). Then, new ocean floor is created by the cooling and hardening of this molten rock material.

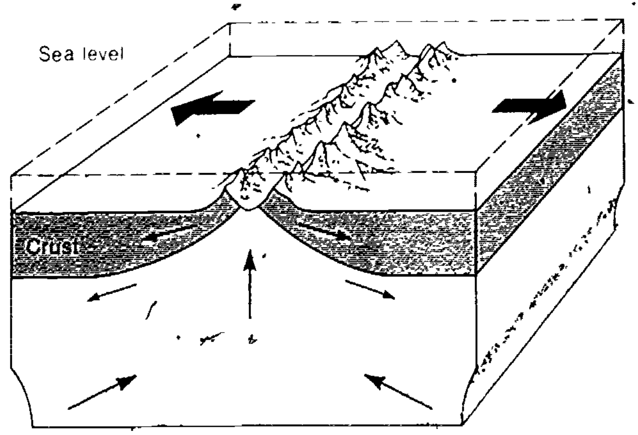
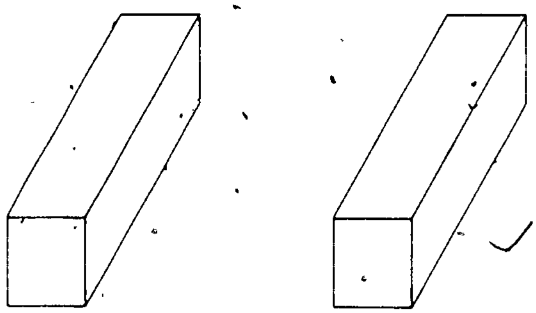


Figure 1 Sea-floor spreading. New ocean floor is created as the two sides of the ridge move apart.

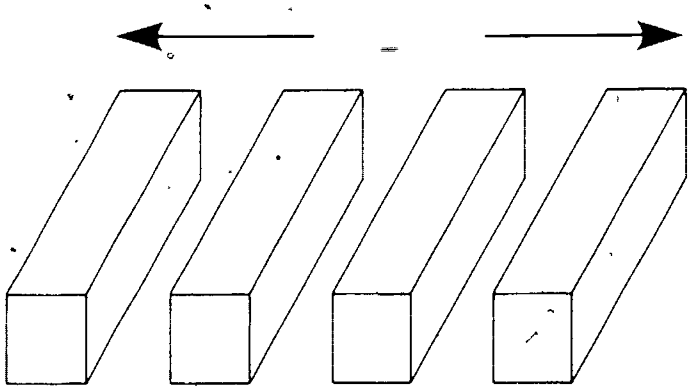
In this activity, the boxes in the starting position represent rocks forming in the middle of a mid-ocean ridge As the rocks move outward (sideways), new rock is added to the ocean floor along the ridge

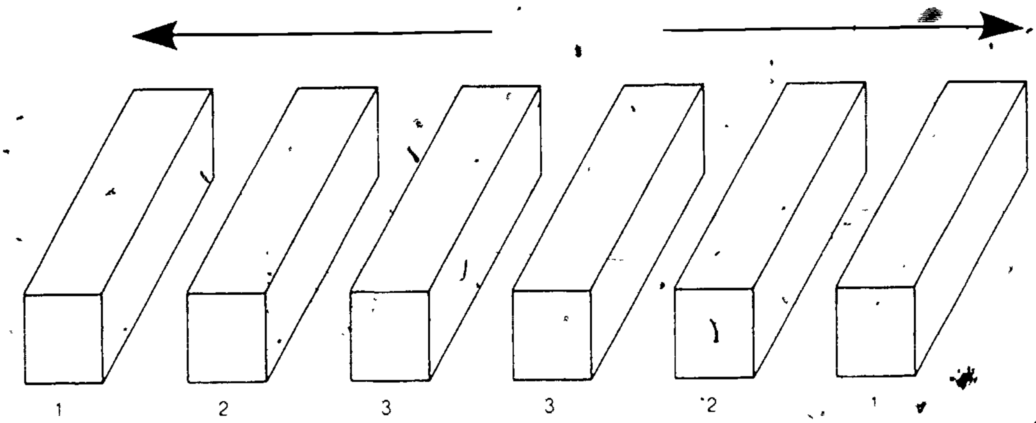
1. Find which end of your compass needle points to the north end of your room. Using the compass, find the north and south magnetic pole direction in each box and label the diagram to show these directions.

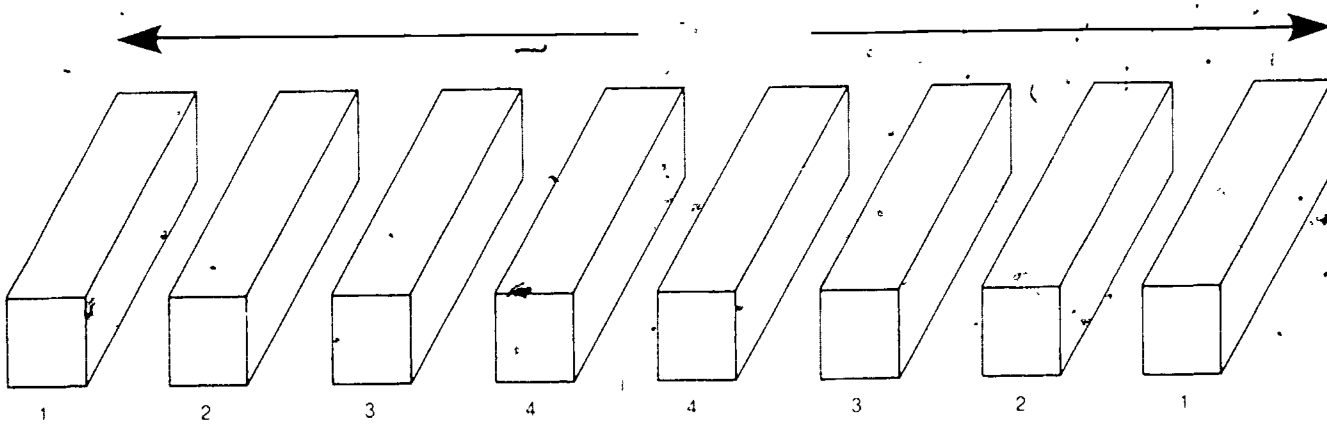


2. Do the same thing each time your teacher adds another set of boxes.

The arrows show which way the boxes are being moved







3. Using your observations of polarity direction shown in these boxes, draw a map of the polarity directions preserved in the ocean floor on both sides of a mid-ocean ridge. A map is what you would see if you were looking down at the earth.

4. Explain what would happen if the ocean floor spread constantly from a ridge while the earth's magnetic field kept reversing.

PROCEDURE

PART C: What can be learned from observations of polarity directions in the sea floor?

Materials: ruler

In this activity, you are going to act as marine geologists on a cruise. You will collect magnetic data as you sail in a zig-zag pattern across the Mid-Atlantic Ridge just southwest of Iceland. Table 1 shows the data which were collected. The data used here were collected during a magnetic study of that area. The scientists used an instrument called a **magnetometer**, carried aboard a U.S. Navy plane. The magnetometer does not have a compass needle that really reverses. It measures the strength of the magnetic field. When the magnetometer is above reversely magnetized rock, it will show the field to be weaker than when it is over normally magnetized rock.

1. On the Worksheet, mark an X or an O at the location of each station on Table 1. Note that the X indicates reversed magnetism and O indicates normal magnetism. Where each age is given, write next to the symbol either the number 10 (for 10 million years) or the letter P (for Present). Note the example of station 2 **already plotted** on the map.

2. After you have marked all of the normal and reversed symbols and the ages that are given for some locations, draw one straight line with your ruler that will connect all the stations where the rocks are of Present age (P). This will separate the groups of 10 million-year-old rocks. Draw one straight line through each group of 10 million-year-old rocks (10).

a. Where do you think the Mid-Atlantic Ridge is located on your map? What is your reason?

Table 1.
Magnetic study data.

Station	North Latitude	West Longitude	Magnetic Field Orientation	Symbol	Age (million years)
1	58 0°	28 0°	Reversed	X	
2	58 0°	29 0°	Normal	O	10 m y
3	58 5°	29 5°	Reversed	X	
4	58 5°	31 0°	Normal	O	Present
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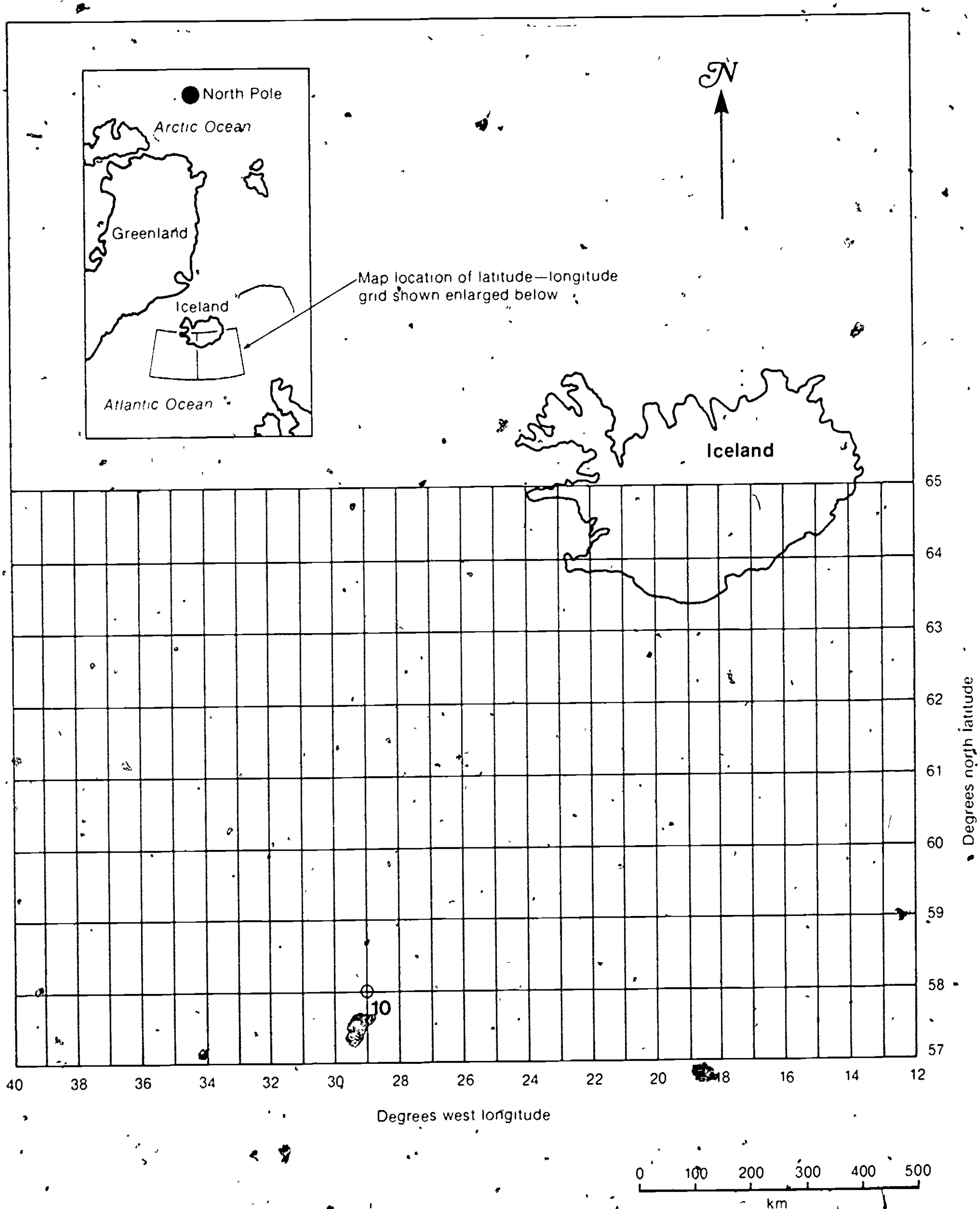
14	59 0°	25 0°	Reversed	X	
15	60 0°	24 0°	Reversed	X	
16	61 0°	24 5°	Normal	O	10 m y
17	61 0°	25 5°	Reversed	X	
18	61 5°	26 0°	Reversed	X	
19	61 5°	26 5°	Normal	O	Present
20	62 0°	27 5°	Reversed	X	
21	62 0°	28 5°	Reversed	X	
22	62 0°	29 0°	Normal	O	10 m.y
23	62 5°	30 5°	Reversed	X	

b. What pattern do you see on your map?

c. How can you explain this pattern?



Worksheet (PART C)

3. Draw arrows on your map to show in what direction the ocean floor on each side of the ridge is moving. How do you know this?

4. If a car travels 100 kilometers in two hours, how fast is it going (kilometers) per hour? How can you find out how fast the ocean floor is moving on each side of the ridge?

5. Find the rate (in centimeters per year) at which the ocean floor is moving in the area of Iceland. (Remember that 1 km equals 1000 m, and 1 m equals 100 cm. Therefore, to convert kilometers to centimeters, you must add 5 zeros to the number of kilometers.)

6. If the sea floor spreads at a constant rate, what is the age of the sea floor at station 14?

7. Now that you know the rate at which the ocean floor is moving, use this figure to find out how fast the ocean floor is spreading apart on the two sides of the ridge.

SUMMARY QUESTIONS

1. You have looked at just a small portion of the approximately 64,000 km of mid-ocean ridges. Do you think that what you found southwest of Iceland might be found alongside the rest of the ridges?

2. How far out from the ridge area that you studied would you expect to find the magnetic reversal patterns?

3. As you go away from a mid-ocean ridge, how do you think the age of the bottom sediment on the ocean floor changes?

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EXTENSIONS

1. You found a spreading rate for the ocean floor just southwest of Iceland. Now measure the distance in kilometers from Labrador to Great Britain on a map. Can you figure out how long ago North America and Europe separated? Compare the number of years that you get with a geologic time scale to see in what geologic period your answer would fall.

2. Sea-floor spreading occurs throughout all of the ocean basins of the world. What does this suggest has been happening to the size of the earth as time has gone on? Does your conclusion seem reasonable to you?

Since sea-floor spreading apparently has taken place, can you invent any possible explanations which would result in the earth staying the same size even though sea-floor spreading is taking place? Make a list of these other possibilities. See if you and your classmates can agree on what is most likely the correct (or most reasonable) solution to this problem.

REFERENCES

Alexander, T., 1975, A revolution called plate tectonics has given us a whole new earth. *Smithsonian*, v. 5, no. 10 (Jan.), p. 30-40 (first of 2-part article).

Alexander, T., 1975, Plate tectonics has a lot to tell us about the present and future earth. *Smithsonian*, v. 5, no. 11 (Feb.), p. 38-47 (conclusion of 2-part article).

Matthews, W.H. III, and others, 1978, *Investigating the earth*. Boston, Houghton Mifflin, 657 p.

Ramsey, W.L., and others, 1973, *Modern earth science*. New York, Holt, Rinehart & Winston, 580 p.

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