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AUTHOR Stoever, Edward, C., Jr.
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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 four 45-minute class periods required; (8) summary questions (with answers); (9) extension activities; and (10) list of references. Activities in this module include describing the relationship between north geographic and north magnetic poles and how this may vary in space and time, demonstrating the principle of a gyroscope and explaining how it relates to the earth, plotting positions and drawing a curve showing possible locations of the north geographic pole in the past, and telling how polar wandering might be used to explain continental movements. (Author/JN)

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 numbers that are 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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Drifting Continents And Wandering Poles

INTRODUCTION

When scientists locate the position of the north geographic pole during the geologic past, it seems to have been at different places at different times. The positions of the pole can be plotted on a map, to show its path through geologic time to the present time This path is called a **polar wandering curve.** It tells us some important things about the Earth's history

To find the position of the north pole in the past, you need to know something about the relationship between the **north geographic pole** and the **north magnetic pole.** Can the magnetic pole, which can be located more precisely, be used to locate the north geographic pole? Is the movement real or is it only apparent? What is the evidence for movement and how can this be explained? These are all difficult questions which will be studied in this module

PREREQUISITE STUDENT BACKGROUND

In order to do these activities the students should have a basic understanding of the Earth's movement in space and the difference between the north geographic pole and the north magnetic pole. They should be able to plot locations using latitude and longitude.

OBJECTIVES

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

1. Describe the relationship between the north geographic pole and the north magnetic pole and how this may vary in space and time,
2. Demonstrate the principle of a gyroscope and explain how it relates to the Earth.
3. Plot the positions and draw a curve showing the possible locations of the north geographic pole in the geologic past.
4. Tell how polar wandering curves might be used to explain the movements of continents.

MATERIALS

Gyroscope—one for each group of students

Colored pencils

World globe (or map)

Small piece of tracing paper, approximately 5 cm x 5 cm—one for each student

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BACKGROUND INFORMATION

The concept of polar wandering is not as simple as it might appear. For instance, since the thing we call the "pole" is a point on the Earth's surface, it might seem that "polar wandering" is a process where that point moves about freely. Thus, you might guess that 100 million years ago the pole was in Russia, now it is in its familiar spot atop the globe and 100 million years in the future it may be in the center of Los Angeles. Unfortunately, this simple picture of wandering won't do. Because the poles mark the ends of the spin-axis of the Earth, polar wandering then would imply some sort of motion, or apparent motion, of the imaginary line (axis) through the Earth about which the Earth rotates. Thus, much more is involved than simply moving a spot on the surface of the Earth.

A second problem involves the relationship between the geographic and geomagnetic poles. This arises because these two poles are not coincident now and never have been since man began to observe them. Polar wandering usually refers specifically to the geographic pole, yet the principal observations are of rock magnetism, which refers to the geomagnetic pole. From this comes two related questions. First, does the magnetic evidence establish wandering of the geographic pole? If the answer to this is "yes," then how can the apparent wandering of the spin-axis of a huge rotating ball take place? We will discuss each question in turn.

The techniques used in paleomagnetism enable geologists to measure the direction of permanent magnetism of rock bodies and then calculate where the magnetic pole must have been to give that direction. Such a pole, calculated from a measured direction of rock magnetism, is called a *Virtual Geomagnetic Pole* (VGP). For instance, the average direction of magnetism for a certain group of 50-million-year-old lava flows in Oregon is about due east and inclined some 50° below the horizontal. Such a direction yields a highly peculiar VGP (for rocks in Oregon) in the Atlantic Ocean. A study of similar rocks in Africa places the VGP in the central Pacific. All that is needed to calculate a VGP is the location of a rock body and its magnetic direction, thus, the VGP merely represents a fictitious location of the magnetic pole that would produce the observed magnetic direction at the point in question. It reveals nothing at all about the geographic pole. For a variety of reasons, peculiarities may occur. For example, rocks of a particular area, which may appear in normal position, may be rotated by faulting, resulting in a VGP which does not agree with other rocks of the same age.

If VGP's for hundreds of modern lava flows and sedimentary rocks were calculated from around the world, they would form a dense cluster of points centered on the present geomagnetic pole. That is, they would cluster at a small but distinct angle (about 10°) from the geographic pole. However, if many VGP's for slightly older rocks (say one million years or less) were calculated, the cluster would center about the geographic pole but would have more scatter than points determined from the modern rocks. Because modern rocks have faithfully recorded the location of the magnetic pole and the one-million-year example seems to indicate that the magnetic pole moves in some manner about the geographic pole, it is believed that over a million-year period (actually, perhaps as little as a few thousand years) the average position of the magnetic pole is centered on the geographic pole. An example of such motion is shown in Figure 1. Thus, when averages of VGP for rocks formed over periods of time in the order of one million years, such averages are called "paleomagnetic poles." In making such averages, rocks which give peculiar results usually are not used. Paleomagnetic poles, therefore, represent former locations of the geographic pole.

Two more lines of evidence support the idea that paleomagnetic poles are geographic poles. The first is theoretical and concerns the origin of the geomagnetic field. Because the magnetic field is believed to be caused by motion of molten iron in the Earth's core, we would expect it to have the same basic symmetry, or general shape, as the fluid motions that cause it. These should be symmetrical about the geographic pole because of the effect of the Earth's rotation (the trade winds have a similar origin). Thus, the geographic and geomagnetic poles should be identical.

The second line of evidence concerns the climates, which also are symmetrical about the geographic pole. We can identify warm and cold-weather rocks and fossils in the geological record by comparison with conditions today. For instance, reef corals and similar organisms indicate equatorial latitudes, while glacial deposits generally suggest polar latitudes. "Paleolatitude" can also be calculated from paleomagnetic poles. This makes reasonably good sense in terms of the climatic evidence. That is, rocks that seem to have originated in a warm climatic zone usually yield magnetic directions indicating that the pole was far away, while cold-climate rocks normally show a nearby pole. Thus, the magnetic, climatic, and theoretical evidence strongly suggest that the paleomagnetic method, properly applied, can give the locations of the geographic pole at various times in the past.

What does paleomagnetism reveal about the location of the pole long ago in the past? If rocks of successively greater age from any one continent are investigated, their magnetic directions measured, and paleomagnetic poles calculated, the poles are found to form clusters. These clusters are not centered on the present geographic pole. For example, rocks roughly 100 million years old from North America give a polar cluster in the extreme eastern tip of Siberia. Rocks roughly twice that old, again from North America, yield a polar cluster several thousand kilometers farther west. By the Paleozoic (300-600 million years ago) the polar clusters had swung south through China and then into the Pacific Ocean. A smooth curve joining these polar clusters gives the path along which the pole apparently has moved. For reasons that will be explained later, such a path is properly referred to as the path of "apparent polar wandering relative to North America."

Next the question of whether it is the pole, or North America, that has done the moving, needs to be examined. Obviously, any path of apparent polar wandering could be caused by North America remaining stationary and the pole moving, or the pole remaining stationary and North America moving, or by both moving at once. All you can see in the rock record is the relative motion between the two, Hence, because the pole may not move at all, this is referred to as the path of apparent polar wandering.

A simple test can be used to demonstrate that the continents do move, relative to each other, and that they also may move relative to the pole. The test consists of constructing separate paths of apparent pole wandering for each continent. If the continents had not moved relative to each other, then these wandering curves should be identical because obviously the pole can only be in one place at a time. In fact, none of the curves of apparent polar wandering for the various continents coincide. This makes it nearly certain that the continents themselves have moved relative to each other. (This is a very powerful argument in favor of continental drift.) An example of mismatch in paths of apparent polar wandering is shown in Figure 3. The path for North America in this illustration is displaced from the path for Europe by almost exactly the width of the Atlantic Ocean.

But is there true polar wandering as distinct from continental drift? The answer is that we don't really know, although the balance of current (1977) evidence is negative. What is meant by true polar wandering is motion of the entire Earth, or perhaps its complete outer shell, relative to a spin-axis that is fixed in space. We are reasonably certain that it would have to be the Earth, not the pole, that would move for two very good reasons. First, the spinning Earth is a huge gyroscope, and any force great enough to tilt such a gyroscope probably would tear it (the gyroscopic Earth) to pieces. Second, as shown in Table 1, the Earth and other planets tend to rotate about axes that are nearly perpendicular to the plane in which they rotate about the Sun. This looks very much like a condition that originated with the Solar System, and argues that the poles have not been tilted since. It seems that true polar wandering, if it exists, must consist of motion of the Earth or of its outer shell. This, of course, would go on simultaneously with continental drift and would add a similar component to all curves of apparent polar wandering. Such a common component has been sought and, to date, not detected. For this reason we say that *true* polar wandering, as distinct from the *apparent* polar wandering that points to continental drift, may not exist. In view of how rapidly ideas are changing the earth sciences, however, almost certainly this is not the final word on the subject.

SUGGESTED APPROACH

Except for PART B, these activities should be done by the students as independent inquiry, working at their own pace. Because the activities involve a series of ideas and conclusions which may become confusing if each is not clearly understood, it is recommended that a class discussion be conducted at the end of each part. You may have to summarize the conclusions.

PART B involves using gyroscopes and is loosely structured. The groups, depending upon the number of gyroscopes available, should be encouraged to try to make the gyroscopes do different things.

PROCEDURE

PART A. What are the relations between the Earth's movements in space, the north geographic pole and the north magnetic pole?

In this activity the students review the relationship between the axis of rotation, the north and south geographic poles, the climate and the magnetic poles. The similarities of the ecliptical planes and inclination of the axes of the planets of the Solar System are noted. The relationship of the north magnetic pole to the north geographic pole since A.D. 1 is studied and conclusions are reached about the relationships in the geologic past.

Key words: ecliptical plane, axis of rotation, north geographic pole, north magnetic pole, inclination of ecliptical plane, inclination of axis of rotation, paleomagnetism, polar wandering curve

Time required: one 45-minute period. However, questions 4 and 6 ask the students for some original thinking which might require more time for some students.

Materials: none

Students should be able to work by themselves. However, they might become "bogged down" with questions 4 and 6 and need help.

The Earth revolves around the Sun in 365¼ days. The path it takes forms what is called the **ecliptical plane.** At the same time, the Earth rotates on its imaginary axis every 24 hours. The **axis of rotation** is the imaginary axis about which the Earth rotates.

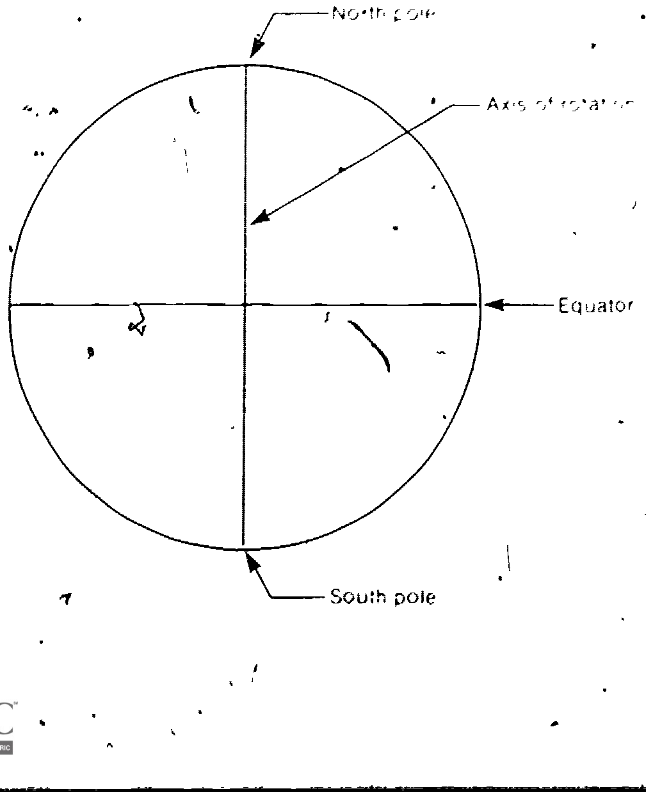
1. Using the information presented in Table 1 and the circle below which represents the Earth, draw and label the imaginary axis around which the Earth rotates. Label the equator, the north pole and the south pole.

The students should complete the drawings as shown below. As the Earth's orbit is usually thought of as a horizontal plane, the axis is usually visualized as being vertical or 23½° from vertical. Either drawing is correct, depending upon how the Earth is visualized in space. Because the question does not specify the orientation, other answers cannot be considered incorrect.

a. What is the relationship between the axis and the north and south poles?

The poles are the ends of the axis of rotation.

b. The angle between the Earth's axis and the plane of the equator is 90 degrees



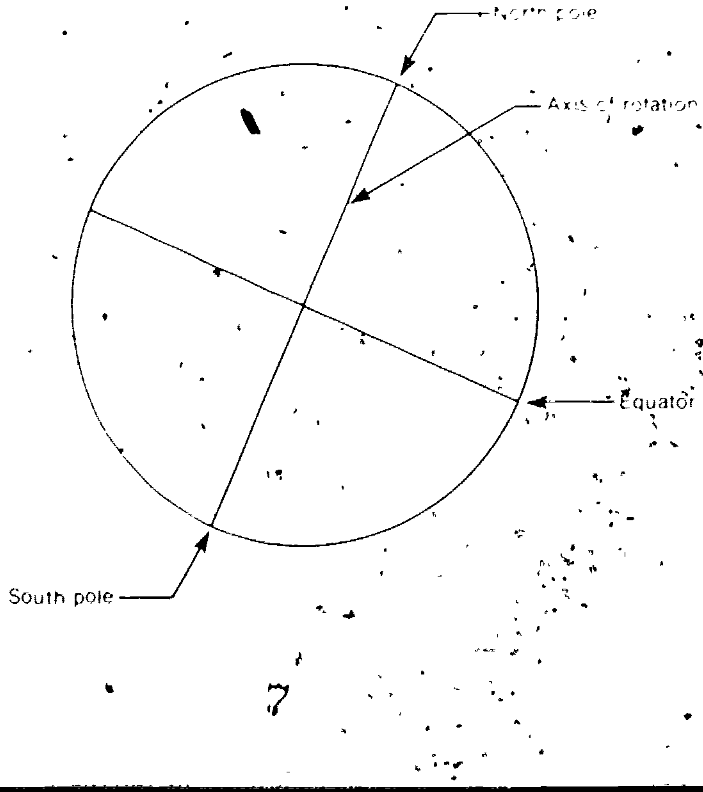


Table 1

Data on the planets of the Solar System, with a diagram of them revolving about the Sun
Diagram not drawn to scale

Name	*Approximate Distance from the Sun*	*Inclination of Ecliptical Plane, Compared to Earth*	*Inclination of the axes*
Mercury	58,000,000 km	7°	?
Venus	108,000,000 km	3° 24′	23°
Earth	150 000,000 km	0°	23½°
Mars	228,000,000 km	1° 51′	24°
Jupiter	779 000,000 km	1° 18′	3°
Saturn	1,432,000 000 km	2° 30′	27°
Uranus	2,870,000,000 km	0° 46′	*82°
Neptune	4,500,000 000 km	1° 47′	29°
Pluto	5 900 000 000 km	17° 17′	?

*sometimes listed at 98°

2. Study Table 1. Answer the following questions about the planets of our Solar System. The **inclination of the ecliptical plane**, compared to Earth, is the tilt of the planets' paths as compared to the Earth's path.

a. How similar are the inclinations of the ecliptical planes?

All are similar except Pluto, which is inclined 17°.

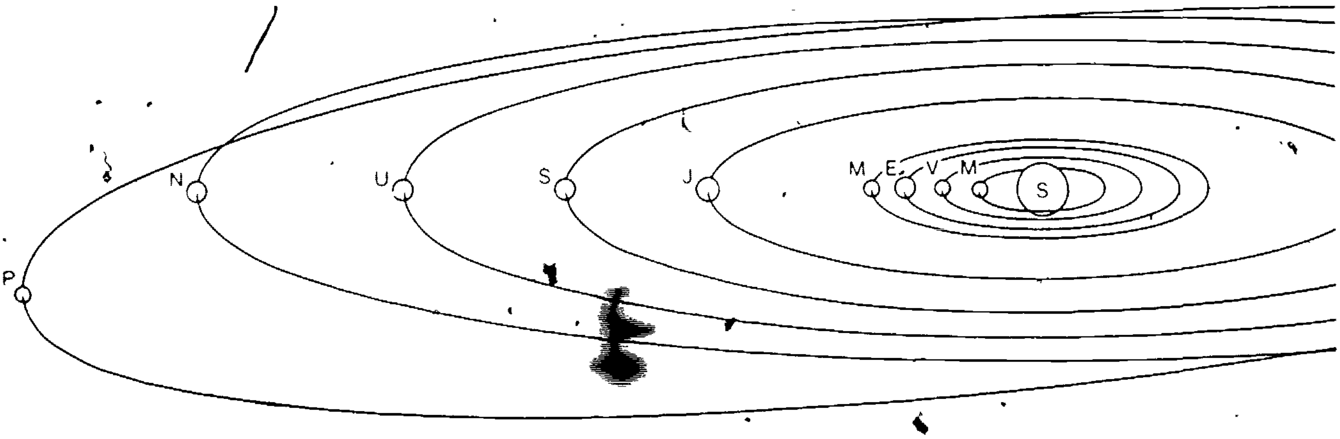
b. How similar are the **inclinations of the axes of rotation**? The inclinations of the axes of rotation are measured from a line vertical to the ecliptical plane.

All are fairly similar except Uranus, which has an inclination of 82°. No information is available for Mercury or Pluto.

c. If the planets (except for Mercury, Uranus and Pluto) had ice caps, or areas which are colder, how would these be related to the axes of rotation (or the geographic poles)?

As on Earth, the ice caps (or cooler areas) would be near or at the north and south geographic poles which are defined by the axes of rotation.

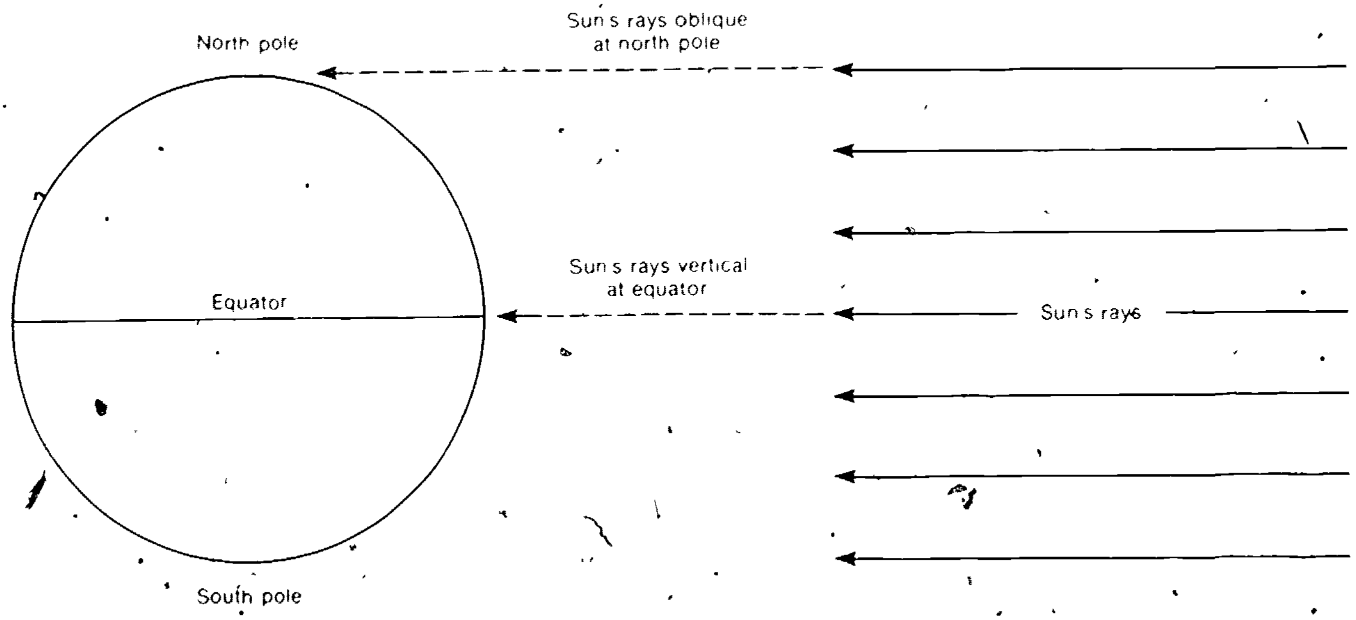
No information is available at this time for Mercury or Pluto. Because of the odd tilt of Uranus, the end of the axis towards the Sun would always be hottest, the equator would be intermediate and the end of the axis away from the Sun would always be coldest.



3. What is the explanation for the colder climates at the north and south poles and the hotter climate near the equator on Earth? Explain this by using the diagram below.

At the equator the Sun's rays are directly overhead so that a given area receives the maximum amount of heat (energy). At the poles, the rays are at an angle so the heat is distributed over a larger area. Because the area receives less energy, it is colder.

It is expected that this concept was developed in a previous science class at a lower grade level, so that the students will be able to answer the question from their own knowledge. If not, you may want to expand on this concept. One way to demonstrate this principle is to shine a flashlight with a strong narrow beam on a globe of the world. Hold the flashlight perpendicular to the equator so that the light (energy) is concentrated in a small area. Without changing the distance, raise the flashlight to show how the same amount of light is distributed over a much larger area at the north pole where the light is not perpendicular to the surface).



4. How might sedimentary rocks formed in warm, marine water or in the desert near the equator, be distinguished from those deposited in colder areas?

The students will need to rely on their own knowledge to answer this question. By "brain storming" some of the class may come up with some good ideas. Two kinds of answers are possible: evidence from fossils in the rock and evidence from the nature of the rock itself. For example, at the present time, reef corals live only in warm water and occur only in a belt around the equator, extending to latitudes of about 30° north and south of the equator. From this, it is presumed that fossil reef corals may be used as evidence that the rock originated in warm water. Finding evidence of a cold climate is somewhat more difficult. One example is when the rock itself is an indurated glacial deposit. Some answers which the students might give are listed below:

Evidence of hot or warm climates:

- Fossil reef corals
- Other fossil animals or plants that live only in warm water (tropical fish, certain kinds of marine life with unusual shells)
- Certain fossil plants (ferns, palms)
- Coal deposits (indicating heavily vegetated swamp areas)
- Salt deposits (usually formed in hot, dry areas)
- Red-beds (usually formed in hot, dry areas; color indicates the oxidation of iron)
- "Fossil" sand dunes (cross-bedding in some sandstones)

Evidence of cold climates:

- Fossils of organisms that lived in cold climates (woolly mammoth)
- Rocks which formed from glacial deposits
- Fossil pollen from cold-climate fir trees

When geologists study the sedimentary rocks of a given age, something can be learned about the climate when the rocks were formed. In some cases, the hot-climate rocks occur as a band which can be traced around part of the Earth in a strange direction. From this, it can be shown that the equator which existed at the time the rock formed was at a different place than it is now. Usually the equator or the poles can be located only approximately. However, evidence indicates that something strange has happened in geologic time. either the equator and poles have wandered or the rocks moved after they were formed.

Because these studies give only approximate locations in terms of latitude, more accurate information is needed Such information can be obtained through the study of **paleomagnetism.** Paleomagnetism involves studying rocks of a given geologic age to determine the location of the north and south magnetic poles which existed when the rocks were formed

First, you need to know something about the relation between the geographic pole and the magnetic pole Can one be used to locate the other? Let's begin by looking at the relations since A.D. 1, which are shown in Figure 1.

5. On the basis of the locations from A.D. 1 to the present, how would the average position of the magnetic pole relate to the north geographic pole?

The average position of the magnetic pole is close to the north geographic pole.

Even if you decide that the magnetic and geographic poles have been near each other since A.D 1, how do you know if they have always been this way? Maybe the magnetic pole was located near the equator sometime in the geologic past This possibility is shown in Figure 2.

6. Using paleomagnetism, can you think of a way to prove that the magnetic pole could not have been located near the equator for any length of time, as shown in Figure 2b? (The coral reef deposits, representing hot-climate rocks around the equator, are shown in the diagrams as a clue.)

If the north magnetic pole were near the equator as postulated in 2b, the paleomagnetism of some rocks containing reef corals (indicating that the rock originated near the equator) would show that the rocks were formed near a magnetic pole. The answer is given in the paragraph which follows the question, so the student only needs to read further to find the answer.

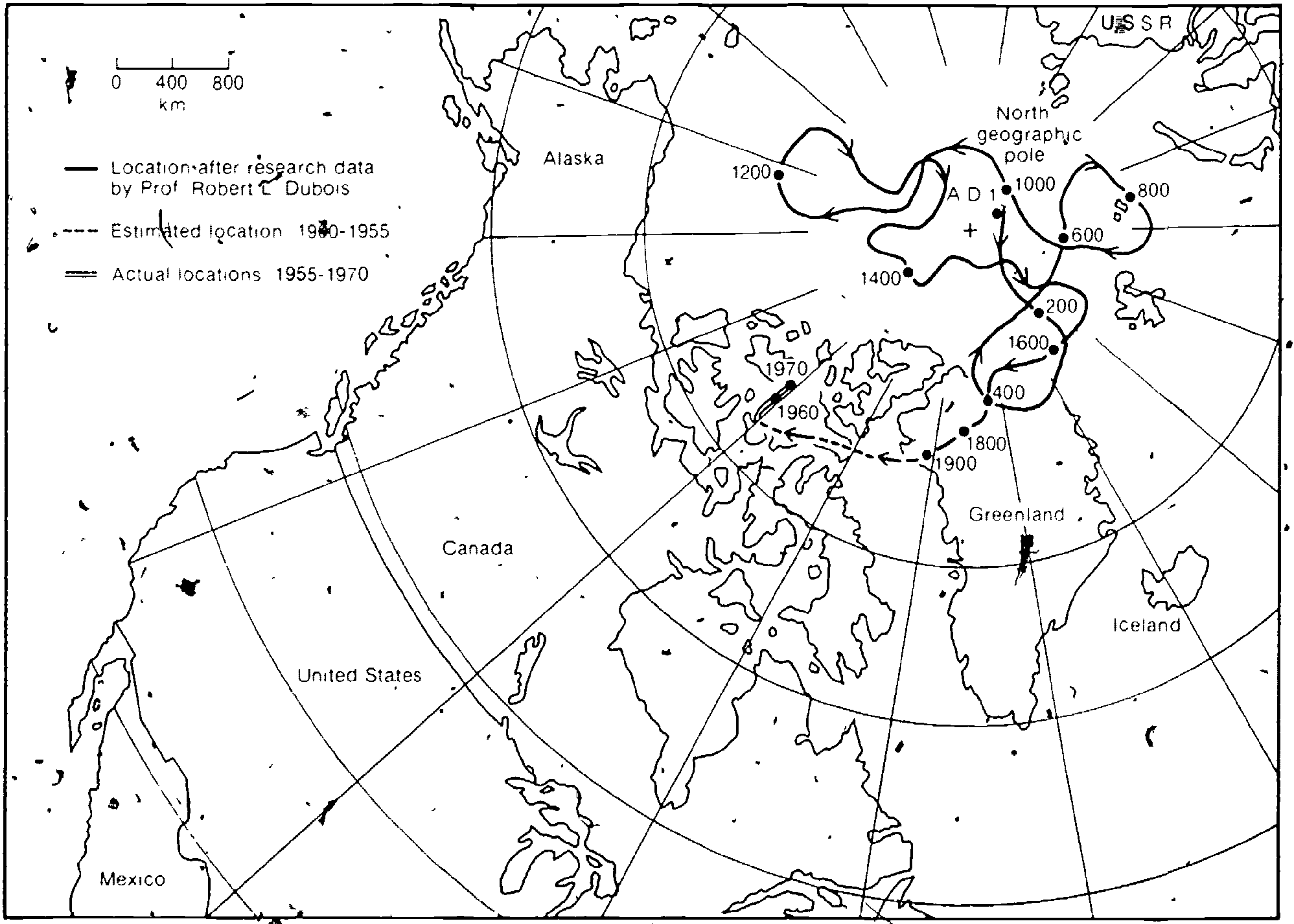
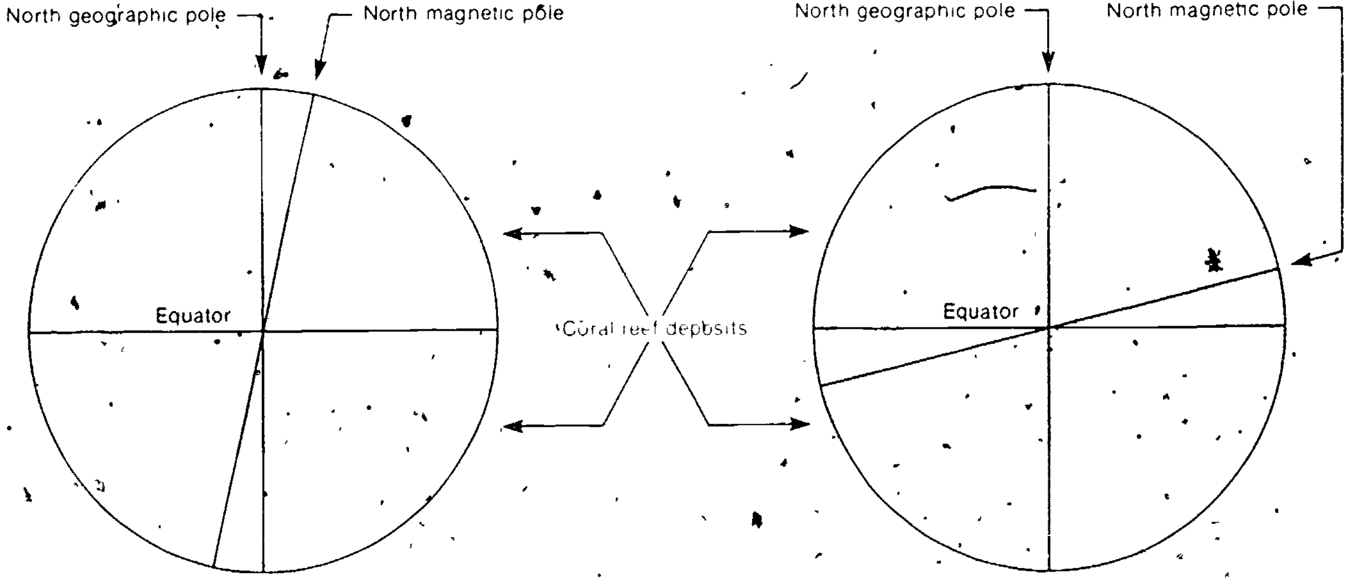


Figure 1 The constant position of the north geographic pole is marked with a "+". The different positions or path of the magnetic north pole since A.D. 1 are shown with the line and arrows.

(Permission granted from Bisque, L., Pratt, H., and Thompson, J., 1975, *Earth science. patterns in our environment*. Englewood Cliffs, N.J., Prentice-Hall, Inc., p. 90.)

When the paleomagnetism of hot-climate rocks is studied, the magnetic poles have always been found to be great distances (90° or so) away from the rocks, as shown in Figure 2a. No places have been found where the paleomagnetism indicates that the magnetic poles were near the hot-climate rock deposits, as would be the case if Figure 2b were true.

From this kind of negative evidence, it has been assumed that the average location of the magnetic poles may be used also as the location of the geographic poles throughout geologic time.



a. Present relation, with magnetic pole close to the north geographic pole.

b Possible relation in the past, with magnetic pole located near the equator.

Figure 2. Relation of geographic and magnetic poles of the Earth

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PROCEDURE

PART B. How do the principles of a gyroscope relate to the Earth?

With your guidance, the students investigate how a gyroscope works. The purpose of this activity is to show that it is difficult to change the direction of the axis of a rotating body. Because the Earth is similar to a gyroscope, it is believed that the axis of rotation has always been at 23½° and that the geographic poles have not changed in terms of the axis and the ecliptical plane.

Key word: gyroscope

Time required: one 45-minute period

Materials: gyroscope

As the students are to work in groups, the number and size of the groups will determine how many gyroscopes are needed. If the groups are small, more students will be actively involved in this activity.

In preparation for this activity, you should practice putting a gyroscope in motion. From this experience you should be able to give the students advice on how much string to use, how tight to wind the string, how to hold the gyroscope and how hard to pull the string. These instructions will vary with the size of the gyroscope and the nature of the string, so a practice session is strongly advised.

The extension of demonstrating with a bicycle wheel is fun and should be done, if possible. (See details after step 5.)

The question you need to think about ne[illegible]s whether the axis of the Earth has always been inclined about 23½°. Could it, like Uranus which is inclined at 82°, have had a greater inclination in the geologic past? To help answer this question, you can learn about the actions of a spinning body by studying a **gyroscope.** For this study, the teacher will divide you into groups, depending upon the number of gyroscopes

1. Before you set your gyroscope into motion, imagine that it represents the planet Earth. On the diagram below label what would represent the north pole, south pole, equator and axis of rotation.

2. Your teacher will show you how to set your gyroscope in motion. After it is spinning, try tilting it and changing its position Answer the following questions.

a. Is it easy to tilt your gyroscope when it is spinning?

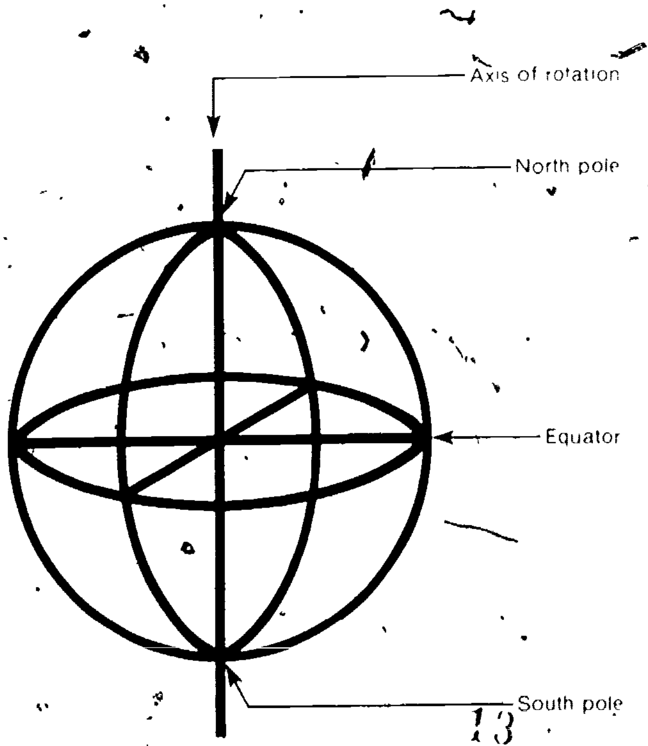
No

b. What happens when you try to tilt it?

The whole thing moves in the direction you push it. The axis of rotation remains pointed in the same direction.

3. The Earth is spinning in space like a gyroscope What can you conclude about the Earth changing its axis of rotation?

The axis of rotation has probably always remained the same.



4. Based on this, do you think it is likely that the north and south geographic poles moved around during geologic time?

It is unlikely that the geographic poles have changed in terms of their direction in space relative to the ecliptical plane.

5. You have determined that the north and south geographic poles (the axis of rotation) have not moved in the geologic past and were never far apart. How is it possible, then, that many rock samples contain a paleomagnetic record which suggests a quite different location for the magnetic poles? Think carefully.

The rocks have changed position. Parts (or all) of the crust of the Earth may have moved. Rocks which formed at the equator at one time in the geologic past are no longer located at the equator.

Upon the conclusion and discussion of this activity, a demonstration with a large bicycle wheel, which is used as a gyroscope, is excellent to reinforce the basic concept of this activity. It should be done if at all possible.

You can probably borrow this piece of equipment from someone in your school district. It might be used in a physical science or physics class.

Holding the large gyroscope (bicycle wheel), by the axle with the axis horizontal, have a student spin it very rapidly. If a motor is used, a much faster spin may be obtained which will achieve better results. After the wheel is spinning, note that it takes a tremendous amount of energy to tilt the axis of rotation. While it is still spinning fast, give it to a student to hold. Let the student try to tilt it. Depending upon the speed, the student probably will not be able to tilt it. If it can be tilted, it will be obvious that a great amount of energy is required.

PROCEDURE

PART C: What is the apparent path that the north pole has taken through geologic time?

In this activity the students plot 15 paleomagnetic poles by their latitude and longitude onto a map which is a polar projection. Visually, they average together poles of a similar age to locate the apparent paleomagnetic pole of that age. These points are connected to form the apparent path of polar wandering. The activity concludes with some questions based on plotting and the implications of the data.

Key words: none

Time required: 1½ to 2 45-minute periods, depending upon how many questions are asked by the students.

Materials. Worksheet, colored pencils (optional) When the data are plotted on the maps, the information is easier to read if a different color is used for each of the six geologic periods.

Plotting the data and drawing the curve are straightforward so the students should be able to work on their own. Question 4 requires some independent thinking.

However, if the students are not familiar with a polar projection (map on Worksheet), you may wish to talk about the following features of the map:

a. The outside circle represents the equator at 0° latitude.

b. The larger dashed circle represents the Tropic of Cancer at 23½° N.

c. The smaller dashed circle represents the Arctic Circle at 66½° N.

d. The smallest circle near the north pole represents 85° N. latitude. (This might be mistaken for the 80° N. line if one is not careful.)

Because the Answer Sheet is printed in brown and black, the relationship of the poles of different geologic ages is not as obvious as it should be on the student maps (if colored pencils are used).

On this Answer Sheet the geomagnetic poles have been connected by straight lines, so these can hardly be called a "curve." To draw a curve would require more data and more interpretation. If your students wish to connect the points to form a curved line, this should be encouraged, as long as they understand that they are making an interpretation in deciding how to draw the curves.

Table 2 gives the locations of the magnetic poles for six periods of geologic time. These were found by studying the paleomagnetism of the rocks at the places listed. For example, when a study was made on the Columbia River basalts of Washington and Oregon, the north magnetic pole was found to be at 86° N. 26° E This represents an average of values obtained from 911 rock samples from 433 different places. These basalts were formed and cooled about 20 million years ago Thus, the latitude and longitude give the position of the magnetic pole when the rocks formed 20 million years ago.

When igneous rocks of similar age from other places were studied, these gave a somewhat different location (73° N. 142° E. and 72° N. 146°W) for the north magnetic pole. Not as many rock samples were studied at these localities, but each pole location represents an average of many samples. The three locations for the north magnetic pole 20 million years ago, plus others not given on the data sheet (Table 2), were plotted on a map The location of the north geographic pole 20 million years ago is presumed to be located at the midpoint position

Plot on the Worksheet the positions of all the magnetic poles given on Table 2 for each of the six time periods. If you have colored pencils, use a different color for each age. Estimate the average position for each age from the different locations. Mark this with an "X" on the map as the north geographic pole for that age. Label the age of the pole with the letter symbol which represents the time period

T = Tertiary (20 million years ago)
K = Cretaceous (100 million years ago)
Tr = Triassic (200 million years ago)
C = Carboniferous (300 million years ago)
O = Ordovician (450 million years ago)
Ꞓ = Cambrian (525 million years ago)

After you have located and labeled these six north geographic poles, connect them from oldest to youngest to show the apparent path of polar wandering

1. Of the six ages, when was the hypothetical location of the north geographic pole closest to its present location?

During the Upper Tertiary.

2. Of the six ages, when was the hypothetical location of the north geographic pole farthest from its present location?

During the Cambrian.

3. Of the six ages, which hypothetical location of a north geographic pole is most apt to be incorrect? Why?

The Ordovician geomagnetic pole. It may be incorrect because its location is based on only one point, and it seems out of place in comparison to the Carboniferous and Cambrian poles.

Table 2.
Location of the magnetic poles based on paleomagnetic studies of rocks from North America. (Data selected from McElhinny, M.W., 1973, *Paleomagnetism and plate tectonics* Cambridge, Cambridge University Press.)

20 million years ago (Upper Tertiary)		
Columbia River basalts, Washington and Oregon	86°N	26°E
Nevada rocks	73°N.	142°E.
Montana volcanics	72°N	149°W.
100 million years ago (Cretaceous)		
Bucks Batholith, California	58°N	165°W.
Magnet Cove, Arkansas	65°N	173°W
Diabase, Parry Islands	69°N	180°W
200 million years ago (Triassic)		
Igneous rock, Connecticut Valley	65°N	87°E.
Sedimentary rock (Marron Fm.), Colorado	56°N	100°E.
Basalt, North Mtn , Nova Scotia	66°N.	113°E.
300 million years ago (Carboniferous)		
Hopewell Group, New Brunswick	34°N.	118°E.
Barnett Fm., Texas	41°N.	135°E.
Cumberland Group, New Brunswick	36°N.	125°E.
450 million years ago (Ordovician)		
Newfoundland	28°N.	168°W.
525 million years ago (Cambrian)		
Ratcliff Brook Fm , Maine	10°N.	124°E.
Wichita Granite, Oklahoma	2°N	147°E.

4. In terms of what has moved, how would you explain the location of the north geographic pole during Cambrian time? Can you think of two or three ways for this to happen?

The Cambrian rocks which are now near the equator were near the north pole when they were formed.

If the Earth's axis is fixed in space, it becomes a question of visualizing how much of the Earth's rock is moving.

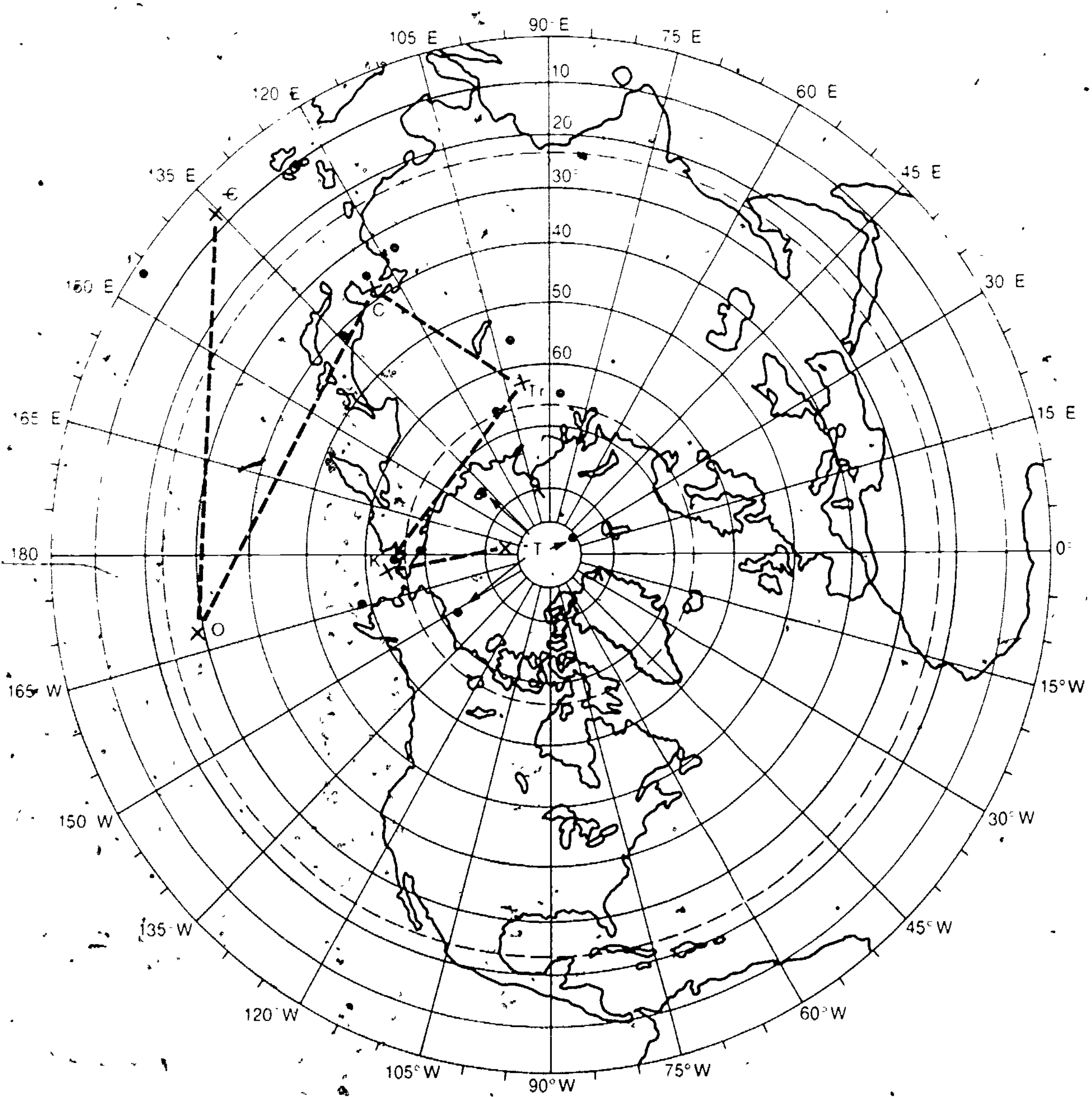
a. Only the outermost parts or pieces (of the crust) could move. The continents could split apart and move in different directions over the surface. (This could be like a wet postage stamp on an orange. Besides slipping around on the surface it could break into pieces.)

b. The entire outer crust could move as a unit. This could be like the peel of the orange which became separated from the interior so that the peel could shift around while the interior and axis remained in the same place.

c. The entire Earth, the crust and interior, could shift with only the axis remaining fixed in space.

d. Combinations of the three above kinds of movement might be taking place at the same time.

The answer to this question is not known. Theories a, b, and c, above, are listed in the general order of probability.



PROCEDURE

PART D: How do you explain the differences between the polar wandering curves?

In this activity the students examine a map (Figure 3) showing the polar wandering curves for North America and western Europe. Although the curves pass through different places, students discover that the curves have similar shapes by tracing one and comparing it with the other. The amount of rotation needed to bring the curves together is about equal to the width of the Atlantic Ocean. From this the students should recognize that the curves strongly support the idea of continental drift.

Key words: none

Time required: one 45-minute period (or less)

Materials: small piece of tracing paper (approximately 5 cm x 5 cm) for each student and a globe or world map.

One strange fact about polar wandering curves is that they are not the same for rocks from different continents. You would think, for example, that studies made on any Cambrian rocks would locate the north geographic pole at approximately the same place. Everyone knows that the north geographic pole could only be at one place at any given time. However, Cambrian rocks from North America give a pole location which is 50° away from the one for Cambrian rocks of Europe. The values are too far apart to be explained by known variations or by errors in the method. Figure 3 shows the two polar wandering curves based on rocks from North America and Europe.

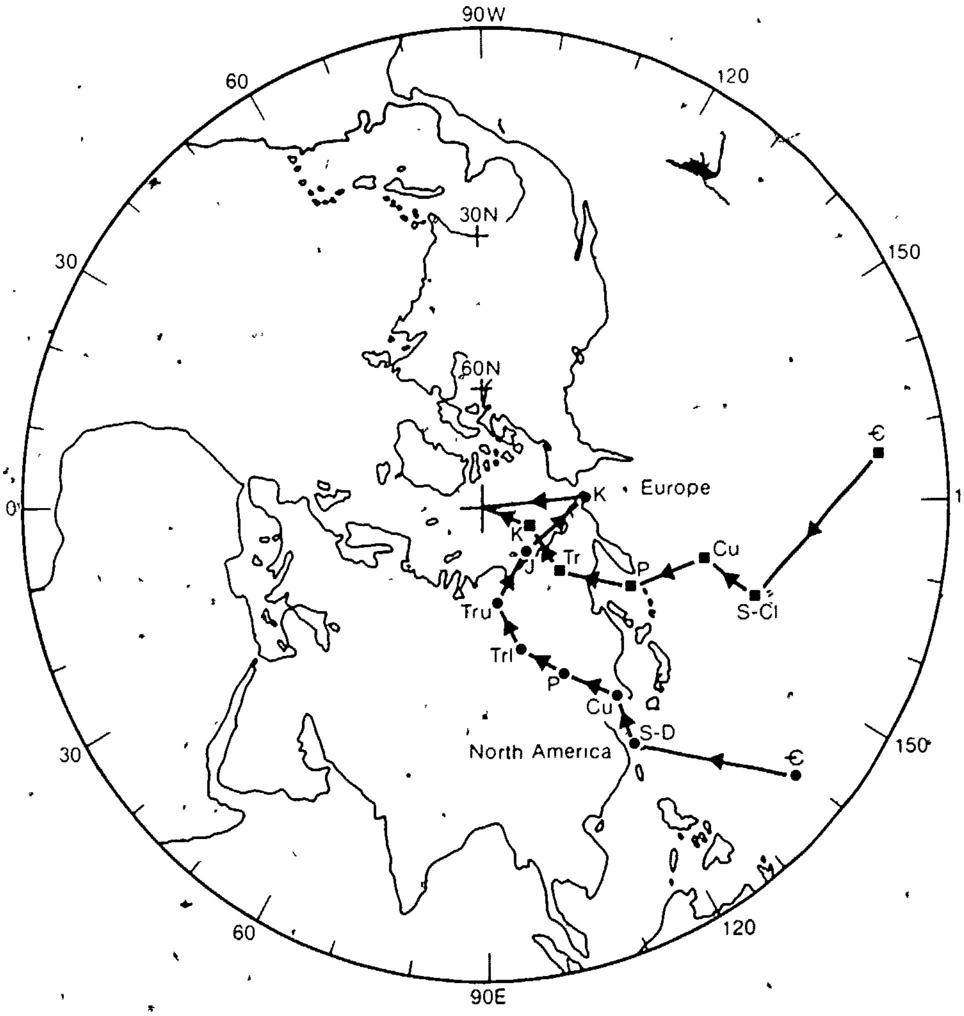


Figure 3. North American polar wandering curve for north pole (shown with dark circles) and Europe polar wandering ourve (shown with dark squares) from McElhinny, M.W., 1973, *Paleomagnetism and plate tectonics*, Cambridge, Cambridge University Press. The symbols for the geologic periods (youngest to oldest) are K = Cretaceous, J = Jurassic, Tr = Triassic (Tru = Upper Triassic, Tri = Lower Triassic), P = Permian, Cu = arboniferous (Upper), S-Cl = Silurian-Lower Carboniferous, S-D = Silurian-Devonian, and Є = Cambrian

1. How does the curve which you drew differ from the published curve for North America shown in Figure 3?

The curve made by the class is based on fewer points. The published curve is based on more points and omits the Ordovician one (which may be incorrect).

2. Although the curves for North America and Europe shown on Figure 3 are different, in what ways are they similar?

They have similar shapes and end at the same point.

3. Take a piece of tracing paper and trace off either the curve for North America or the one for Europe. Put your tracing over the other curve to see if they have the same shapes What can you conclude about the shapes?

They are quite similar.

4. Can you think of a way to explain why the north geographic poles recorded in the Cambrian rocks of North America and western Europe are about 50° apart?

During Cambrian time the rocks that were forming were 50° closer together. Since that time, they have moved apart by 50°.

5. Look at a globe or map and count how many degrees of longitude are between the east coast of North America and the west coast of Europe. What is the approximate number of degrees?

50°

6. What major idea does the evidence of these polar wandering curves support?

The evidence supports the idea of continental drift. It shows that North America and Europe were once next to each other, as during Cambrian time, but they have split and drifted apart by 50° (the width of the Atlantic Ocean). Because the curves start coming together after the Permian, this suggests that the continental drift between North America and Europe began at that time.

SUMMARY QUESTIONS

1. What are the reasons for believing that the magnetic poles have always been close to the geographic poles?

The magnetic and geographic poles have been close to each other since A.D. 1. The midpoint of these magnetic pole positions is close to the geographic pole. When older rocks are studied, those which show evidence of having been formed near the equator (reef corals, for example) have geomagnetic poles which are some 90° away.

Thus, the climatic evidence of the location of the equator and polar areas agrees with the geomagnetic evidence. (This is significant because it is believed, based on the gyroscope principle, that the direction of the axis of rotation has remained fixed in space. Thus, the relations of the hotter and cooler areas, as determined by the rocks, may be used to determine the location of the geographic poles.)

2. How are the locations of the magnetic poles determined from the rocks for a given geologic period, such as the Cambrian?

The geomagnetic poles for a given geologic period, such as the Cambrian, are determined by studying the remnant magnetism of those rocks formed during that time. When many such determinations are plotted, they form a cluster of possible pole positions. The average of the cluster is taken as the apparent paleomagnetic pole for that period.

3. If you believe that the axis of rotation of the Earth is fixed and you find evidence that the north geographic pole appears to wander, what is probably moving?

If the rotation of the Earth is fixed and the evidence shows that the poles appear to wander, this means that the rocks must have moved. This could be the rocks of the continental masses, or all the crust, or all the Earth.

4. When it is obvious that the locations of the north geographic pole can form only one curve, why are the polar wandering curves of North America and Europe located at different places?

Because the polar wandering curves of North America and Europe are different, but can be rotated to have a similar path, this is taken as evidence that the two continents have drifted apart.

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EXTENSION

Using the data below, plot the poles from western Europe onto your map.

Period	*North Pole*	
Upper Tertiary	80° N.	157° E.
Lower Tertiary	75° N.	151° E.
Cretaceous	86° N.	0°
Jurassic	36° N.	50° E.
Triassic	45° N	143° E.
Permian	45° N.	160° E.
Upper Carboniferous	38° N	161° E
Silurian-Devonian to Lower Carboniferous	17° N	161° E.
Upper Silurian to Lower Carboniferous	0°	136° E.
Ordovician	10° N	176° E.
Ordovician (Ireland)	2° N.	212° E.
Cambrian	22° N	167° E

(From McElhinny, M.W., 1973, *Paleomagnetism and plate tectonics* Cambridge, Cambridge University Press)

The data for the geomagnetic poles for western Europe should give a curve similar to the one predicted for Europe on Figure 3.

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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

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MODULE NO. WA2 2-3
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CRUSTAL
EVOLUTION
EDUCATION
PROJECT

NAME DATE

Student Investigation
Catalog No 34W1106

Drifting Continents And Wandering Poles

INTRODUCTION

When scientists locate the position of the north geographic pole during the geologic past, it seems to have been at different places at different times The positions of the pole can be plotted on a map to show its path through geologic time to the present time This path is called a **polar wandering curve.** It tells us some important things about the Earth's history

To find the position of the north pole in the past, you need to know something about the relationship between the **north geographic pole** and the **north magnetic pole.** Can the magnetic pole, which can be located more precisely, be used to locate the north geographic pole? Is the movement real or is it only apparent? What is the evidence for movement and how can this be explained? These are all difficult questions which will be studied in this module

OBJECTIVES

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

1. Describe the relationship between the north geographic pole and the north magnetic pole and how this may vary in space and time.
2. Demonstrate the principle of a gyroscope and explain how it relates to the Earth.
3. Plot the positions and draw a curve showing the possible locations of the north geographic pole in the geologic past.
4. Tell how polar wandering curves might be used to explain the movements of continents

PROCEDURE

PART A: What are the relations between the Earth's movements in space, the north geographic pole and the north magnetic pole?

Materials. none

The Earth revolves around the Sun in 365¼ days The path it takes forms what is called the **ecliptical plane.** At the same time, the Earth rotates on its imaginary axis every 24 hours. The **axis of rotation** is the imaginary axis about which the Earth rotates.

1. Using the information presented in Table 1 and the circle below which represents the Earth, draw and label the imaginary axis around which the Earth rotates. Label the equator, the north pole and the south pole.

a What is the relationship between the axis and the north and south poles?

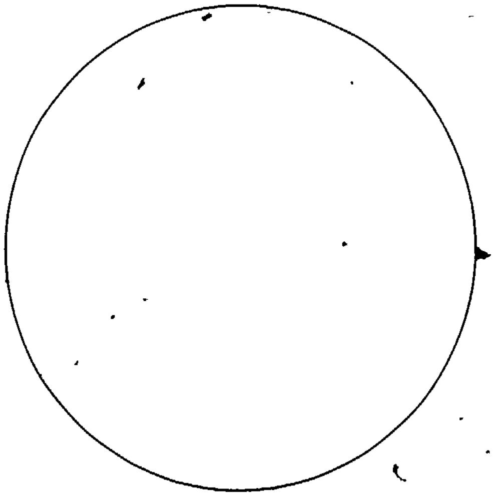
b The angle between the Earth's axis and the plane of the equator is ____ degrees.

Table 1.

Data on the planets of the Solar System with a diagram of them revolving about the Sun. Diagram not drawn to scale.

Name	*Approximate Distance from the Sun*	*Inclination of Ecliptical Plane, Compared to Earth*	*Inclination of the axes*
Mercury	58,000,000 km	7°	?
Venus	108,000,000 km	3° 24′	23°
Earth	150,000,000 km	0°	23½°
Mars	228,000,000 km	1° 51′	24°
Jupiter	779,000,000 km	1° 18′	3°
Saturn	1,432,000,000 km	2° 30′	27°
Uranus	2,870,000,000 km	0° 46′	*82°
Neptune	4,500,000,000 km	1° 47′	29°
Pluto	5,900,000,000 km	17° 17′	?

*sometimes listed at 98°

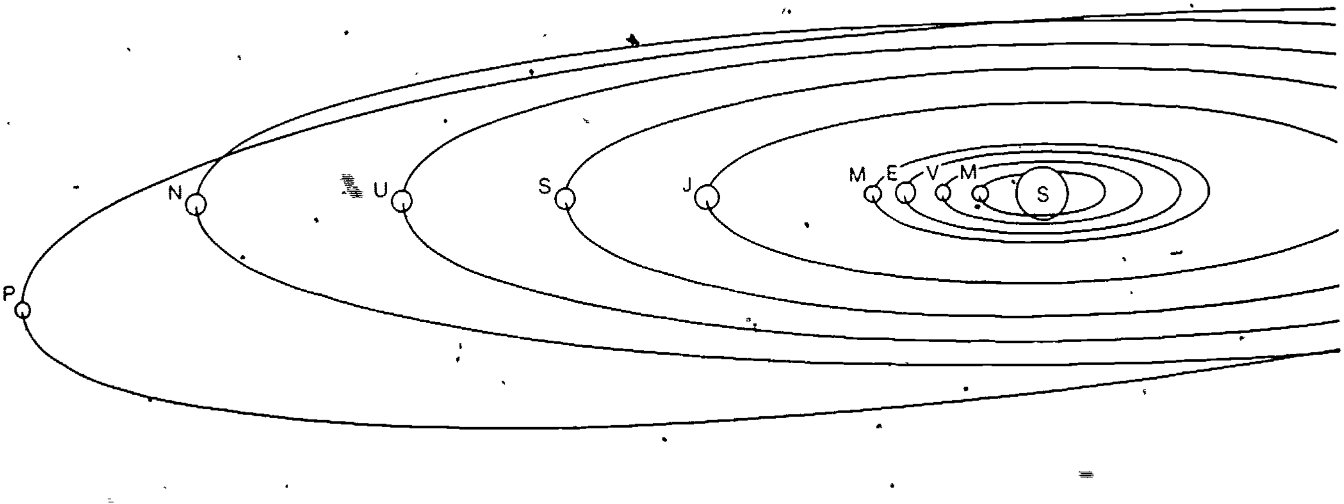


2. Study Table 1. Answer the following questions about the planets of our Solar System. The **inclination of the ecliptical plane,** compared to Earth, is the tilt of the planets' paths as compared to the Earth's path.

a How similar are the inclinations of the ecliptical planes?

b. How similar are the **inclinations of the axes of rotation?** The inclinations of the axes of rotation are measured from a line vertical to the ecliptical plane

c. If the planets (except for Mercury, Uranus and Pluto) had ice caps, or areas which are colder, how would these be related to the axes of rotation (or the geographic poles)?

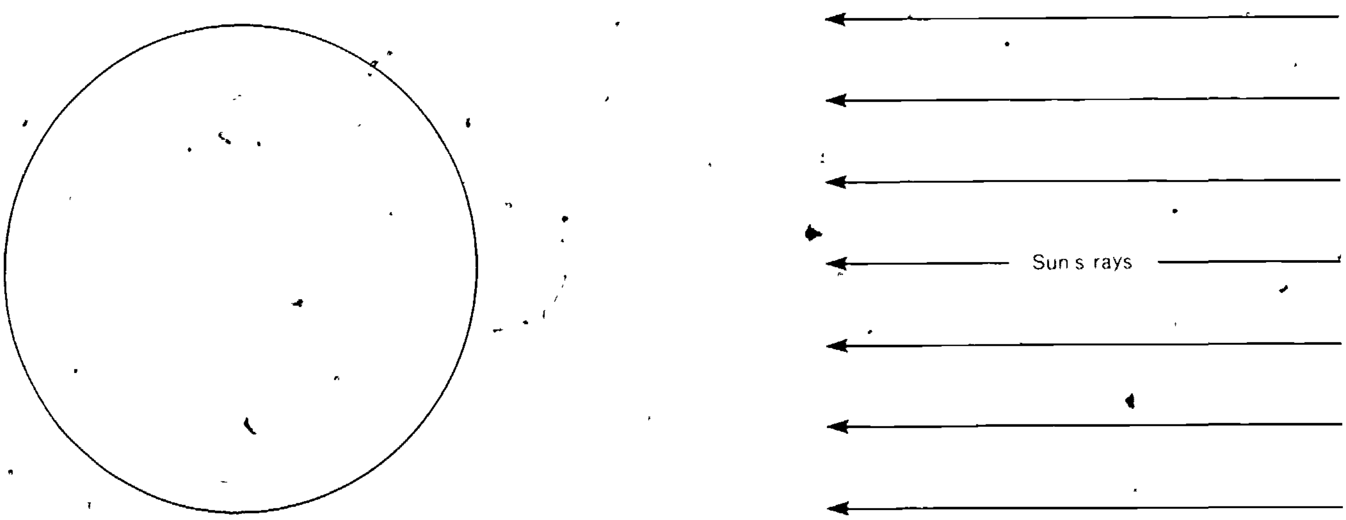


3. What is the explanation for the colder climates at the north and south poles and the hotter climate near the equator on Earth? Explain this by using the diagram below.

4. How might sedimentary rocks formed in warm, marine water or in the desert near the equator, be distinguished from those deposited in colder areas?

When geologists study the sedimentary rocks of a given age, something can be learned about the climate when the rocks were formed. In some cases, the hot-climate rocks occur as a band which can be traced around part of the Earth in a strange direction. From this, it can be shown that the equator which existed at the time the rock formed was at a different place than it is now. Usually the equator or the poles can be located only approximately. However, evidence indicates that something strange has happened in geologic time: either the equator and poles have wandered or the rocks moved after they were formed.

Because these studies give only approximate locations in terms of latitude, more accurate information is needed. Such information can be obtained through the study of **paleomagnetism.** Paleomagnetism involves studying rocks of a given geologic age to determine the location of the north and south magnetic poles which existed when the rocks were formed.



First, you need to know something about the relation between the geographic pole and the magnetic pole Can one be used to locate the other? Let's begin by looking at the relations since A D 1, which are shown in Figure 1.

5. On the basis of the locations from A.D 1 to the present, how would the average position of the magnetic pole relate to the north geographic pole?

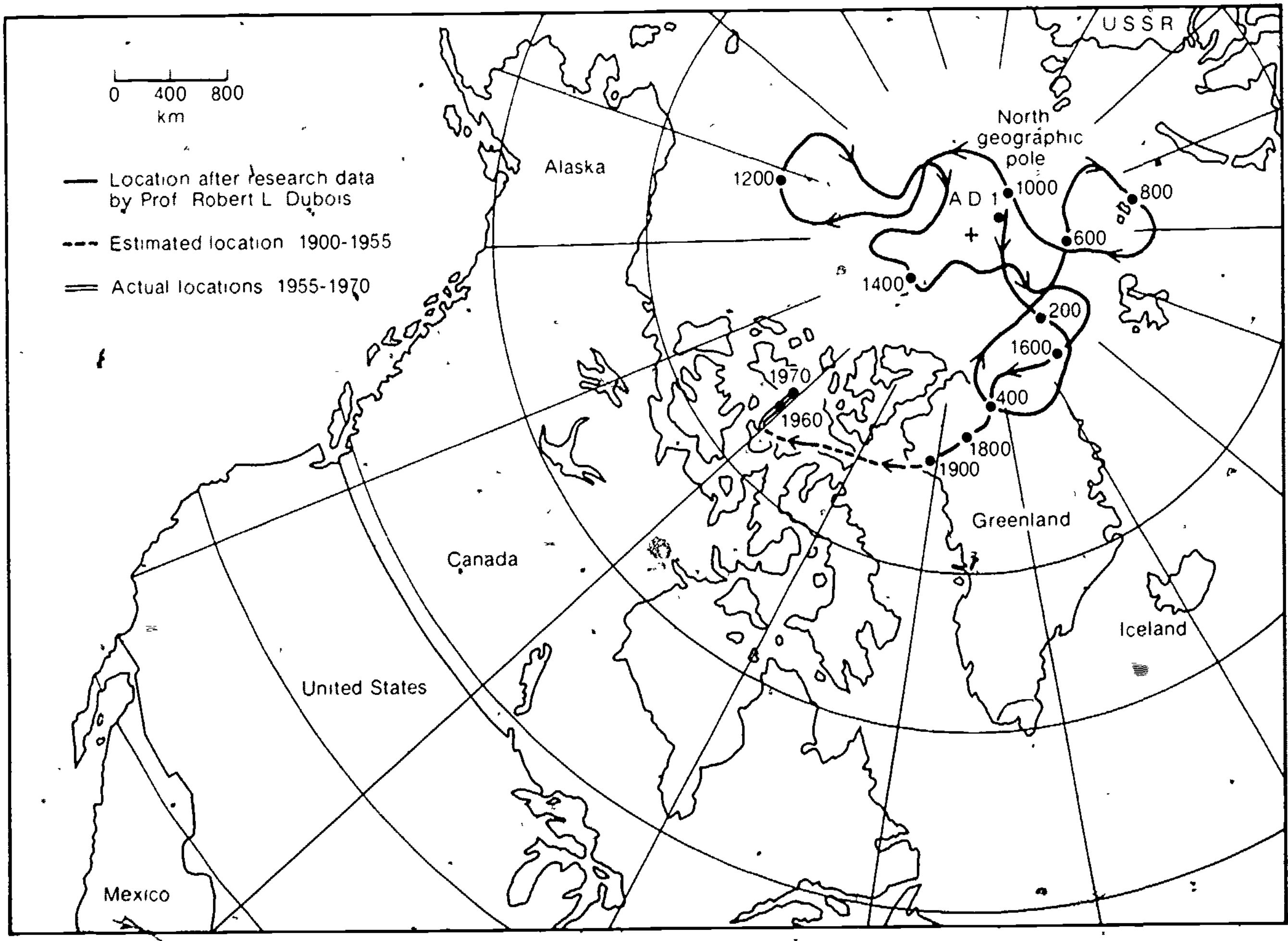


Figure 1. The constant position of the north geographic pole is marked with a "+". The different positions or path of the magnetic north pole since A.D. 1 are shown with the line and arrows.

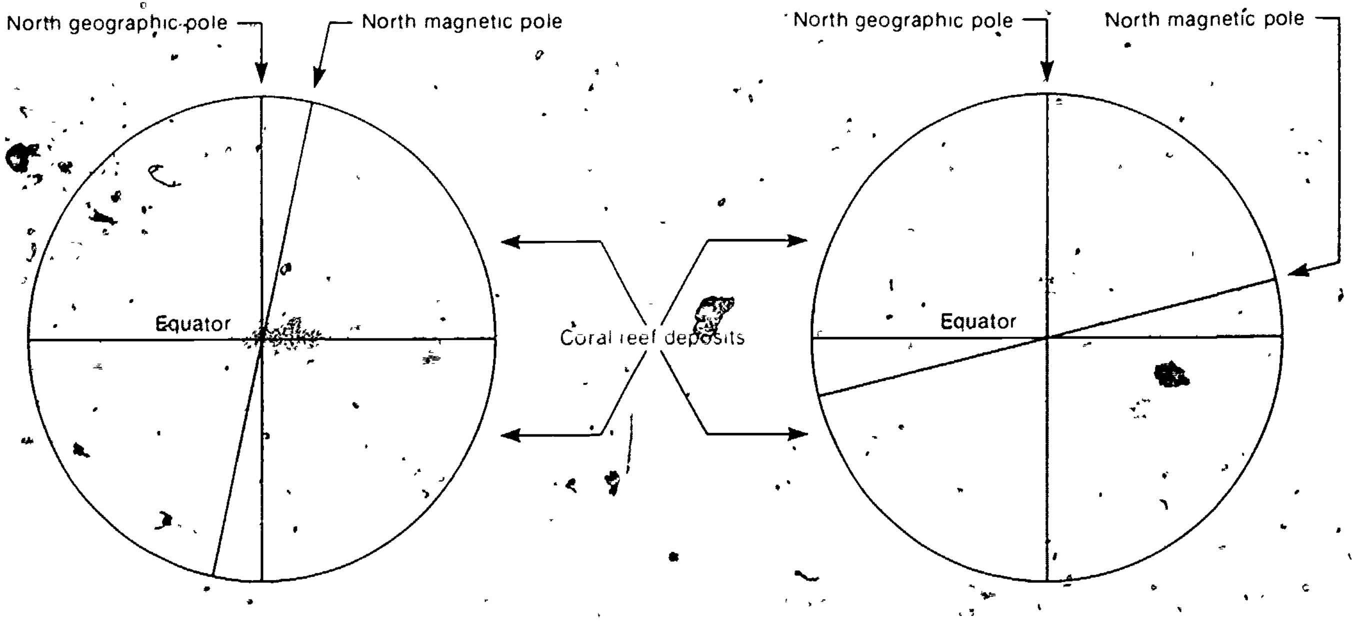
(Permission granted from Bisque, L., Pratt, H., and Thompson, J., 1975, *Earth science: patterns in our environment*: Englewood Cliffs, N J., Prentice-Hall, Inc., p. 90.)

Even if you decide that the magnetic and geographic poles have been near each other since A.D 1, how do you know if they have always been this way? Maybe the magnetic pole was located near the equator sometime in the geologic past. This possibility is shown in Figure 2.

6. Using paleomagnetism, can you think of a way to prove that the magnetic pole could not have been located near the equator for any length of time, as shown in Figure 2b? (The coral reef deposits, representing hot-climate rocks around the equator, are shown in the diagrams as a clue)

When the paleomagnetism of hot-climate rocks is studied, the magnetic poles have always been found to be great distances (90° or so) away from the rocks, as shown in Figure 2a No places have been found where the paleomagnetism indicates that the magnetic poles were near the hot-climate rock deposits, as would be the case if Figure 2b were true.

From this kind of negative evidence, it has been assumed that the average location of the magnetic poles may be used also as the location of the geographic poles throughout geologic time.



a. Present relation, with magnetic pole close to the north geographic pole.

b Possible relation in the past, with magnetic pole located near the equator.

Figure 2. Relation of geographic and magnetic poles of the Earth.

PROCEDURE

PART B: How do the principles of a gyroscope relate to the Earth?

Materials: gyroscope

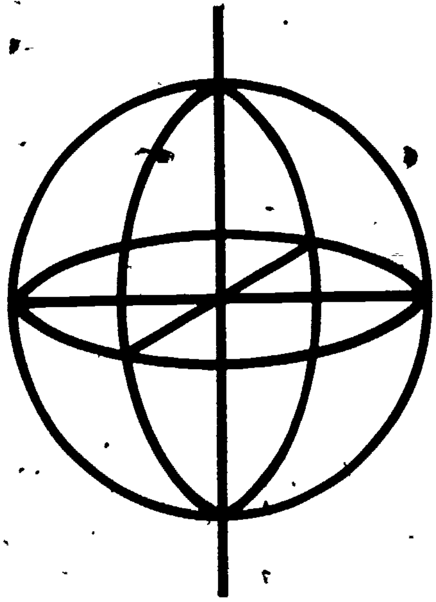
The question you need to think about next is whether the axis of the Earth has always been inclined about 23½°. Could it, like Uranus which is inclined at 82°, have had a greater inclination in the geologic past? To help answer this question, you can learn about the actions of a spinning body by studying a **gyroscope.** For this study, the teacher will divide you into groups, depending upon the number of gyroscopes.

1. Before you set your gyroscope into motion, imagine that it represents the planet Earth. On the diagram below label what would represent the north pole, south pole, equator and axis of rotation

2. Your teacher will show you how to set your gyroscope in motion. After it is spinning, try tilting it and changing its position Answer the following questions:

a Is it easy to tilt your gyroscope when it is spinning?

b. What happens when you try to tilt it?



3. The Earth is spinning in space like a gyroscope. What can you conclude about the Earth changing its axis of rotation?

4. Based on this, do you think it is likely that the north and south geographic poles moved around during geologic time?

5. You have determined that the north and south geographic poles (the axis of rotation) have not moved in the geologic past and were never far apart How is it possible, then, that many rock samples contain a paleomagnetic record which suggests a quite different location for the magnetic poles? Think carefully.

PROCEDURE

PART C. What is the apparent path that the north pole has taken through geologic time?

Materials. Worksheet, colored pencils (optional). When the data are plotted on the maps, the information is easier to read if a different color is used for each of the six geologic periods.

Table 2 gives the locations of the magnetic poles for six periods of geologic time. These were found by studying the paleomagnetism of the rocks at the places listed. For example, when a study was made on the Columbia River basalts of Washington and Oregon, the north magnetic pole was found to be at 86° N. 26° E. This represents an average of values obtained from 911 rock samples from 433 different places These basalts were formed and cooled about 20 million years ago Thus, the latitude and longitude give the position of the magnetic pole when the rocks formed 20 million years ago.

When igneous rocks of similar age from other places were studied, these gave a somewhat different location (73° N 142° E. and 72° N. 146°W.) for the north magnetic pole. Not as many rock samples were studied at these localities, but each pole location represents an average of many samples The three locations for the north magnetic pole 20 million years ago, plus others not given on the data sheet (Table 2), were plotted on a map The location of the north geographic pole 20 million years ago is presumed to be located at the midpoint position.

Plot on the Worksheet the positions of all the magnetic poles given on Table 2 for each of the six time periods. If you have colored pencils, use a different color for each age. Estimate the average position for each age from the different locations. Mark this with an "X" on the map as the north geographic pole for that age. Label the age of the pole with the letter symbol which represents the time period.

T = Tertiary (20 million years ago)
K = Cretaceous (100 million years ago)
Tr = Triassic (200 million years ago)
C = Carboniferous (300 million years ago)
O = Ordovician (450 million years ago)
Ꞓ = Cambrian (525 million years ago)

After you have located and labeled these six north geographic poles, connect them from oldest to youngest to show the apparent path of polar wandering.

Table 2.
Location of the magnetic poles based on paleomagnetic studies of rocks from North America. (Data selected from McElhinny, M.W., 1973, *Paleomagnetism and plate tectonics*. Cambridge, Cambridge University Press.)

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Diabase, Parry Islands	69° N	180° W.
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Sedimentary rock (Marron Fm), Colorado	56° N	100° E.
Basalt, North Mtn , Nova Scotia	66° N	113° E
300 million years ago (Carboniferous)		
Hopewell Group, New Brunswick	34° N	118° E.
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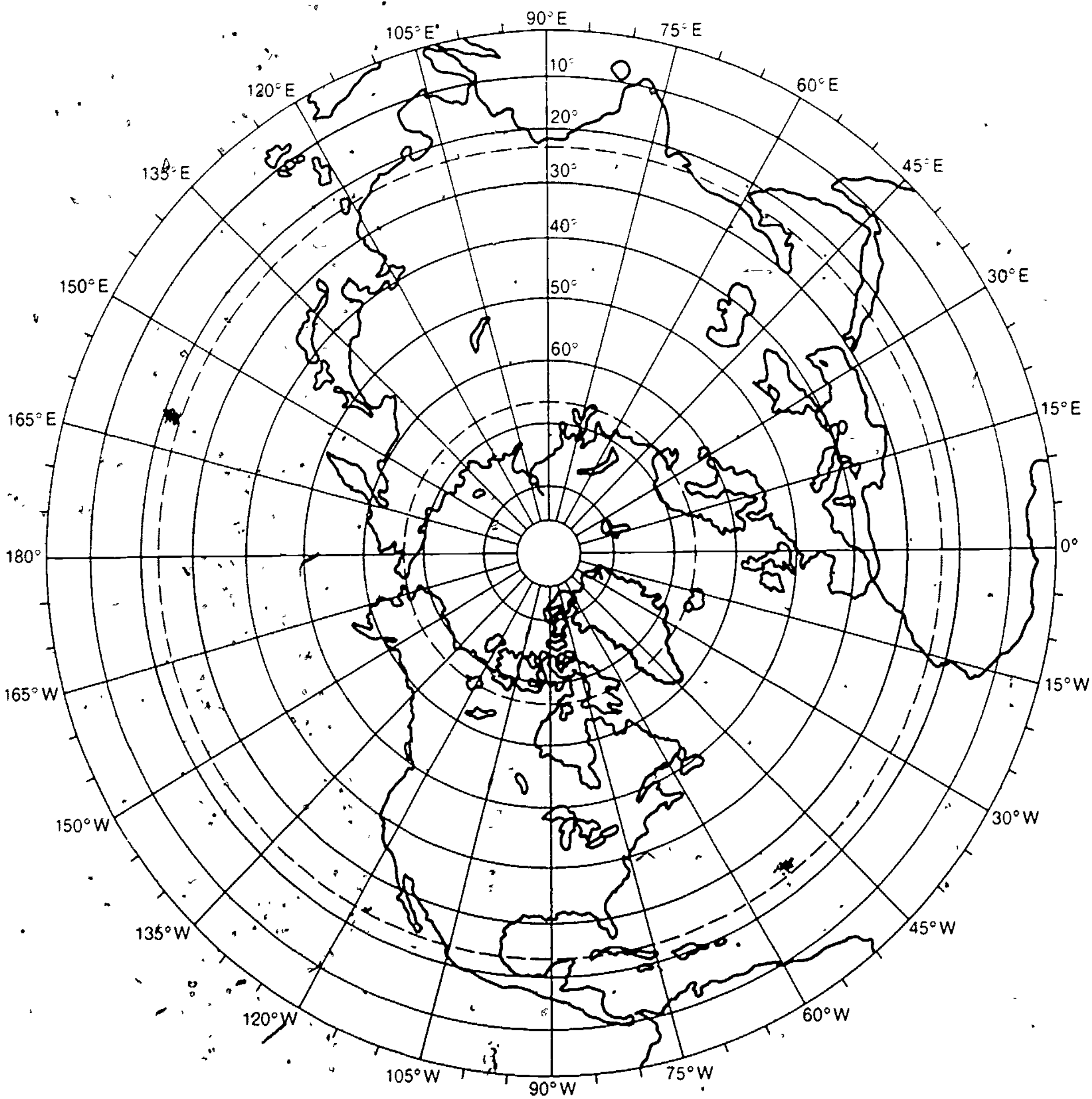
525 million years ago (Cambrian)		
Ratcliff Brook Fm., Maine	10° N	124° E
Wichita Granite, Oklahoma	2° N.	147° E.

1. Of the six ages, when was the hypothetical location of the north geographic pole closest to its present location?

2. Of the six ages, when was the hypothetical location of the north geographic pole farthest from its present location?

3. Of the six ages, which hypothetical location of a north geographic pole is most apt to be incorrect? Why?

4. In terms of what has moved, how would you explain the location of the north geographic pole during Cambrian time? Can you think of two or three ways for this to happen?



● Plotted pole positions

X Average pole positions

Vorksheet (PART C)

PROCEDURE

PART D. How do you explain the differences between the polar wandering curves?

Materials: small piece of tracing paper (approximately 5 cm x 5 cm) for each student and a globe or world map

One strange fact about polar wandering curves is that they are not the same for rocks from different continents. You would think, for example, that studies made on any Cambrian rocks would locate the north geographic pole at approximately the same place. Everyone knows that the north geographic pole could only be at one place at any given time. However, Cambrian rocks from North America give a pole location which is 50° away from the one for Cambrian rocks of Europe. The values are too far apart to be explained by known variations or by errors in the method. Figure 3 shows the two polar wandering curves based on rocks from North America and Europe.

1. How does the curve which you drew differ from the published curve for North America shown in Figure 3?

2. Although the curves for North America and Europe shown on Figure 3 are different, in what ways are they similar?

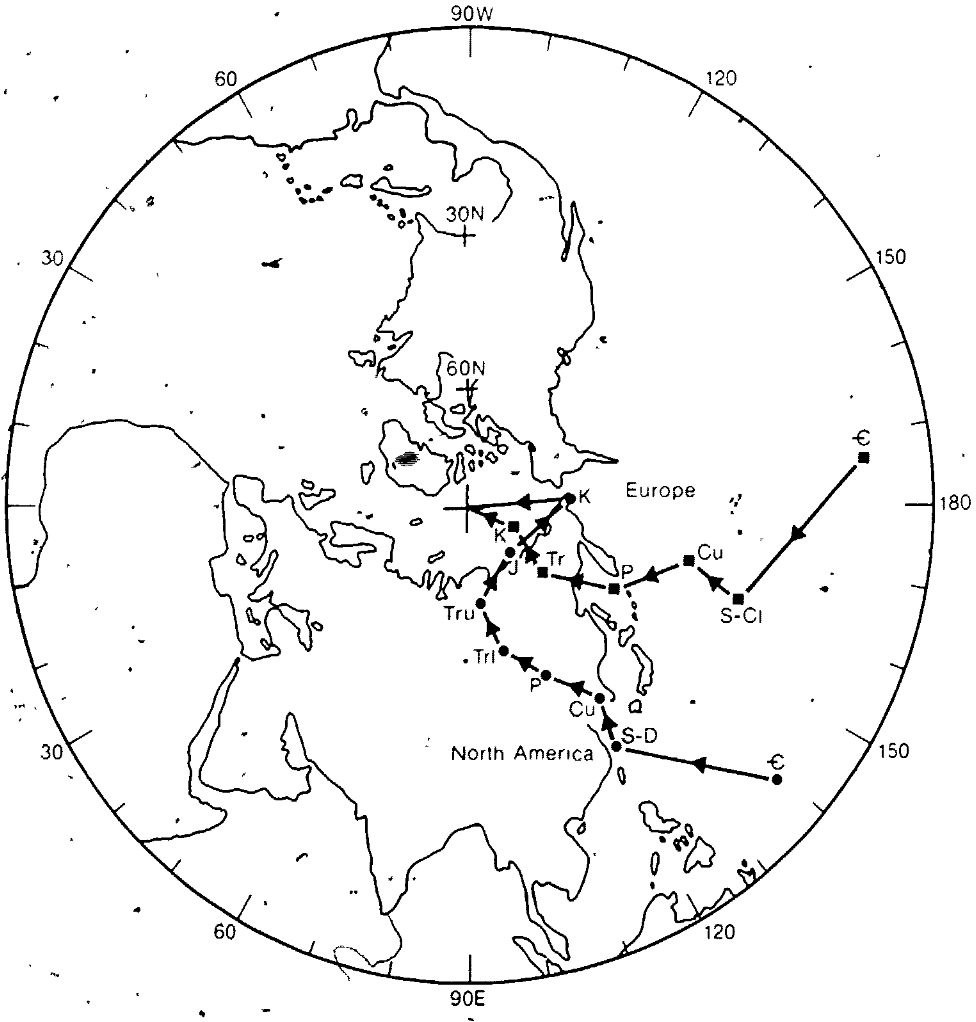


Figure 3. North American polar wandering curve for north pole (shown with dark circles) and Europe polar wandering curve (shown with dark squares) from McElhinny, M.W., 1973, *Paleomagnetism and plate tectonics*, Cambridge, Cambridge University Press. The symbols for the geologic periods (youngest to oldest) are K = Cretaceous, J = Jurassic, Tr = Triassic (Tru = Upper Triassic, Tri = Lower Triassic), P = Permian, Cu = boniferous (Upper), S-Cl = Silurian-Lower Carboniferous, S-D = Silurian-Devonian, and € = Cambrian.

3. Take a piece of tracing paper and trace off either the curve for North America or the one for Europe. Put your tracing over the other curve to see if they have the same shapes. What can you conclude about the shapes?

4. Can you think of a way to explain why the north geographic poles recorded in the Cambrian rocks of North America and western Europe are about 50° apart?

5. Look at a globe or map and count how many degrees of longitude are between the east coast of North America and the west coast of Europe. What is the approximate number of degrees?

6. What major idea does the evidence of these polar wandering curves support?

SUMMARY QUESTIONS

1. What are the reasons for believing that the magnetic poles have always been close to the geographic poles?

2. How are the locations of the magnetic poles determined from the rocks for a given geologic period, such as the Cambrian?

3. If you believe that the axis of rotation of the Earth is fixed and you find evidence that the north geographic pole appears to wander, what is probably moving?

4. When it is obvious that the locations of the north geographic pole can form only one curve, why are the polar wandering curves of North America and Europe located at different places?

EXTENSION

Using the data below, plot the poles from western Europe onto your map.

Period	North Pole	
Upper Tertiary	80°N.	157°E.
Lower Tertiary	75°N.	151°E.
Cretaceous	86°N.	0°
Jurassic	36°N	50°E
Triassic	45°N.	143°E.
Permian	45°N	160°E.
Upper Carboniferous	38°N	161°E.
Silurian-Devonian to Lower Carboniferous	17°N	161°E.
Upper Silurian to Lower Carboniferous	0°	136°E
Ordovician	10°N	176°E.
Ordovician (Ireland)	2°N	212°E
Cambrian	22°N	167°E

(From McElhinny, M.W., 1973, *Paleomagnetism and plate tectonics.* Cambridge, Cambridge University Press.)

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