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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 two 45-minute class periods; (8) summary questions (with answers); (9) extension activities; and (10) list of references. The activity in this module (requiring knowledge of Pythagorean theorem) is designed to answer such questions as: (1) Are crustal plates moving? (2) How fast and in what direction do they move? (3) Are motions constant? (4) Do plates stretch? (5) Does an entire plate move as a unit? (6) How is the earth's rotation linked to plate motions? (Author/JN)

CEEP™

CRUSTAL EVOLUTION EDUCATION PROJECT

Measuring Continental Drift: The Laser Ranging Experiment

TEACHER'S GUIDE

Catalog No. 34W1019

For use with Student Investigation 34W1119
Class time: two 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

Measuring Continental Drift: The Laser Ranging Experiment

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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Measuring Continental Drift: The Laser Ranging Experiment

INTRODUCTION

This activity deals with a very complex experiment. Imagine trying to measure a change in distance of 1 cm between two points several thousand kilometers apart. Consider for a moment some of the reasons for doing this experiment. Continental drift has never been directly measured. All such motions have been inferred from scientific evidence. So, a direct measurement would be a clinching point to settle the argument between "drifters" and "nondrifters".

The experiment is designed to answer such questions as: 1) Are the crustal plates moving?, 2) How fast are the plates moving?, 3) In what direction is motion taking place?, 4) Are the motions of the plates constant?, 5) Do the plates stretch?, 6) Does an entire plate move as a unit? and 7) How is the earth's rotation linked to plate motions?

Clearly, the answers to these questions will make major contributions to the new theories of global tectonics.

Scientists are interested in knowing how far they can see on the earth's curved surface The reason scientists want to see a long way is because they want to measure the distance between fixed points on two or more continents If they can measure this distance accurately, they will be able to answer questions like these

1. Are the crustal plates moving? How fast are they moving? In what direction are they moving?
2. Are the motions of the plates constant?
3. Do the plates stretch?
4. Does a whole plate move as one piece?

Scientists have not answered these questions yet, but they are trying. It is not easy to measure slow movements accurately—just centimeters per year—between continents

PREREQUISITE STUDENT BACKGROUND

Students should know how to use the Pythagorean Theorem. They should know how to measure with a meter stick and plot points on a graph.

OBJECTIVES

After you have completed this activity, you should be able to

1. Calculate how far on the earth you can see from a mountaintop.
2. Explain what is meant by the phrase "line-of-sight."
3. Explain how the curvature of the earth affects how far we can see along the earth's surface.
4. Discuss what happens to the distance between a point on the earth and a point on the moon, in terms of the earth's rotation
5. Graph data on a grid and draw a curve to fit the data.
6. Explain how scientists might accurately measure the distance between two points located on different crustal plates

MATERIALS

Masking tape

Meter stick—one for each group of students

String

Figure 2 in PART B can be constructed out of cardboard or heavy construction paper, but it is suggested that it be marked on the floor with masking tape. Use the dimensions shown in Figure 2. Take seven pieces of string and stretch them from point Y on the moon to points A, B, C, D, E, F and G on the circle. The strings will help the students to measure in a straight line. The strings should be between 2 and 3 m long.

BACKGROUND INFORMATION

Scientists are devising instruments that can be placed almost anywhere on earth and then establish the precise location of that spot on the earth. The instrument shoots a laser beam at the moon. The beam is reflected from a reflector placed on the moon by the astronauts.

Since the astronomers know precisely where the moon is located at all times, they can use the computer to solve from 30 to 40 simultaneous equations necessary to locate the laser instrument on the earth. These equations include the variables that astronomers use to determine the precise position of the instrument. Some of these instruments are mobile and can be placed at many different locations on the earth.

Astronomers will make many observations from these same points during the next ten or more years. Changes of distance between any two points will be measured, and the rate and direction of movements can be established.

This complex problem involves a rotating earth and a moving moon. However, the moon's position is known mathematically and is considered as being fixed at the moment the moon is on the earth's meridian passing through the observing site. Similarly, in the activity the moon is thought of as being fixed and the earth's turning is the only variable being observed.

SUGGESTED APPROACH

Students can work individually or in small groups. The mathematics in PART A should be checked periodically.

PROCEDURE

PART A How far on the earth can we see from a mountaintop?

Students use the Pythagorean Theorem to find distances.

Key words: right triangle, line-of-sight

Time required: one 45-minute period

Materials: none

The Greek mathematician Pythagoras (6th Century B.C.), worked out a formula for finding the length of the sides of all right triangles. (A right triangle is one that has one angle of 90°.) Every right triangle has two sides shorter than the third. Pythagoras said to take each short side, multiply it by itself, and add these two products together. The answer will equal the longest side multiplied by itself.

Let's apply Pythagoras' idea to our problem with the mountain. Look at Figure 1. Find right triangle AUT. Its sides are AT, AU and UT.

1. When you stand on the surface of the earth, you are 6400 km from the center of the earth. How far are you from the center of the earth if you stand on a mountaintop that is 2 km above the surface? 6402 km. This is side AT of the triangle AUT.

2. The other sides of the triangle are AU and UT. AU is 6400 km long.

You now want to find out how long UT is. Here is how you do it:

3. First multiply the length of side AT by itself. Your answer is 40,985,604 sq km.

4. Second, multiply the length of side AU by itself. Your answer is 40,960,000 sq km.

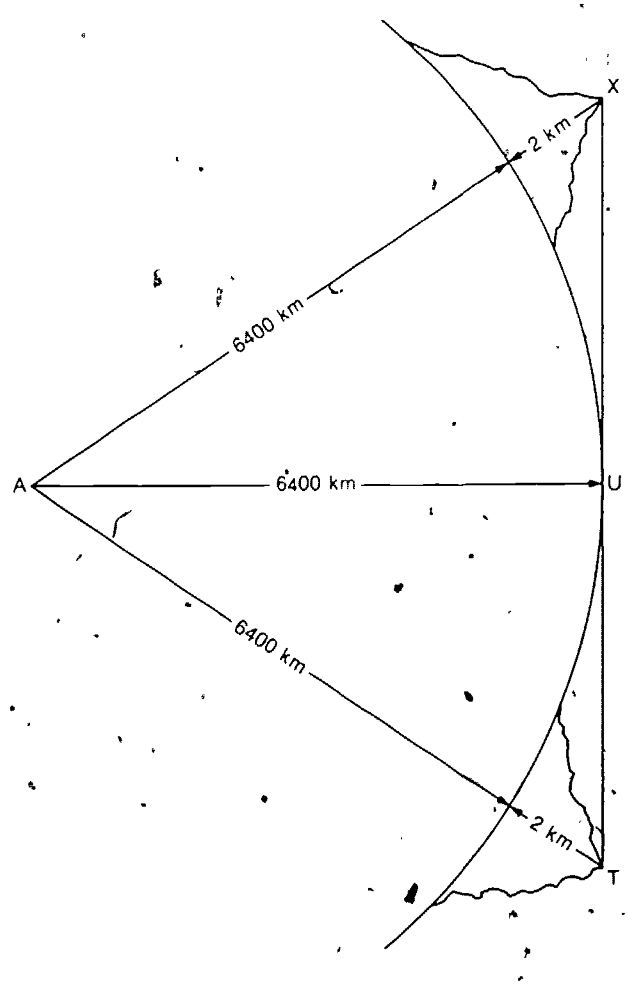


Figure 1.

5. Now subtract these two numbers. Your answer is 25,604 sq km

6. Side UT has a length equal to the square root of your answer to question 5. Side UT equals 160 km. (Round off this number to the nearest ones place.) This is the answer to the first question in PART A

7. XT is twice the length of side UT. Therefore, the length of XT is 320 km. This number is the distance between two mountains that are 2 km high, if you could stand on top of one and just barely see the other over the curvature of the earth. The line XT, along which you can see, is called your **line-of-sight.** Finding a high place from which to observe makes your line-of-sight longer. No mountains on earth are high enough to enable you to see a place which is several thousand kilometers away. Therefore, you cannot measure distances across continental plates, or plate movements, from a mountaintop. You must find some new way to make measurements over very long distances. This new way uses points on the earth and some other place.

8. List some places from which you might take measurements.

The moon, satellites, and other planets.

PROCEDURE

PART B. How can you tell when the moon and a point on the earth are closest together?

Students make measurements using meter sticks and plot the data on a graph.

Key words: none

Time required: one 45-minute period

Materials. meter sticks

Start by measuring something you can touch and see. In or near your classroom, your teacher has made a model that looks like Figure 2. Y represents the moon and the letters A, B, C, D, E, F and G are positions on the rotating earth. Notice the arrows on the arc. The arrows indicate the direction that the earth is turning.

1. Using the meter stick, measure the distance along each string from your point on the arc to point Y. Record your results below.

	A-Y	B-Y	C-Y	D-Y	E-Y	F-Y	G-Y
Distance (meters)							

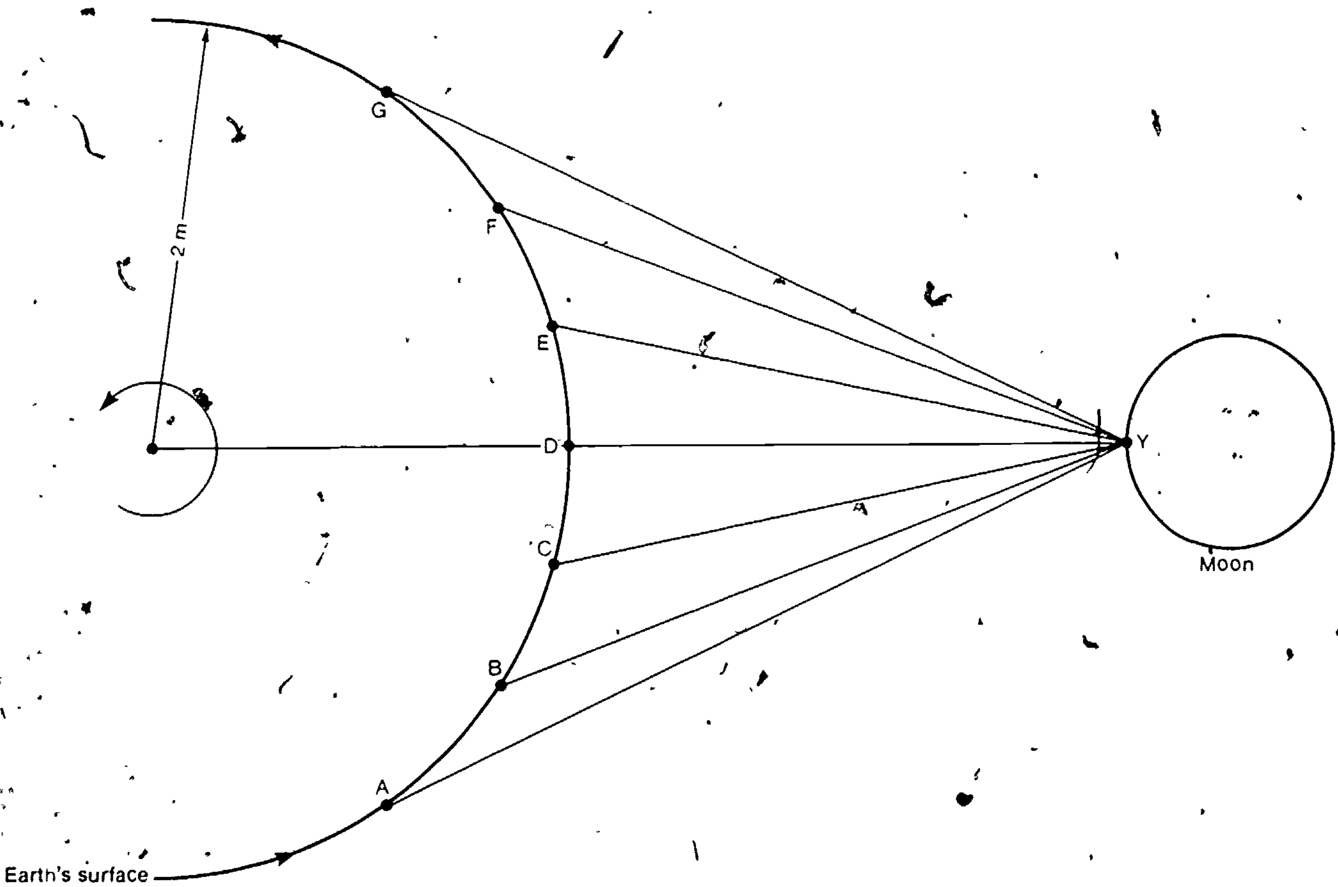
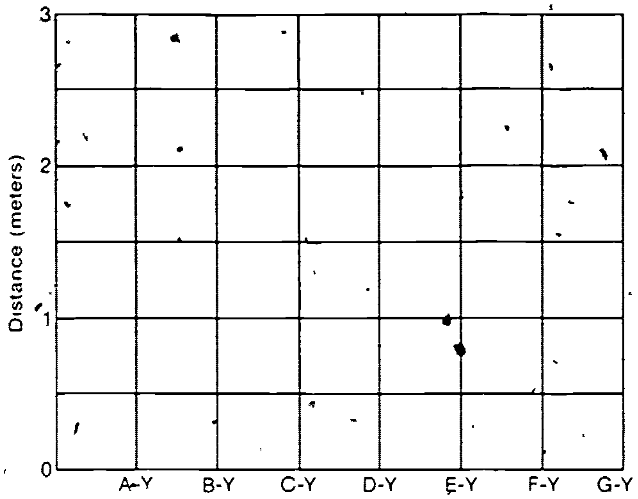


Figure 2. Earth-moon model.

2. Plot the data you collected in question 1 on the graph below.



3. When you moved from A to D, did you move toward or away from Y (the moon)? **Toward**
Going from D to G did you move toward or away from the moon? **Away**

4. Look at your graph. Estimate the distance to Y if you are located between B and C ______ m

The answer obtained by the students will depend on the size of the construction of Figure 2.

5. Now try to draw a reasonable line through the points on your graph. You can see that the line is curved. What best explains why the line is curved?

You were moving on a curve in going from A to G and point Y is fixed.

Think about the earth and the moon. The earth rotates, so a fixed point on the earth moves beneath the moon. [The moon does move slowly, but at this moment consider it fixed just as Y (the moon) was fixed.] One moment you are at A relative to the moon, the next moment at D and third moment at G. How can you tell when the moon and a point on the earth are closest together?

In Table 1 you have been given data to plot on a graph. Look over this table. This data is an example of the distances to the moon which would be measured by a laser ranging station located on the equator in South America. Notice that the earth-moon relationship in Figure 3 is similar to what you measured earlier.

TIME	*DISTANCE (km)*
6 a.m.	384,000
7 a.m.	382,344
8 a.m.	380,800
9 a.m.	379,475
10 a.m.	378,458
11 a.m.	377,818
12 a.m.	377,600
1 p.m.	377,818
2 p.m.	378,458
3 p.m.	379,475
4 p.m.	380,800
5 p.m	382,344
6 p.m.	384,000

Table 1 Distance from a point on the earth's surface to the moon measured by laser ranging equipment at a South American laser ranging station

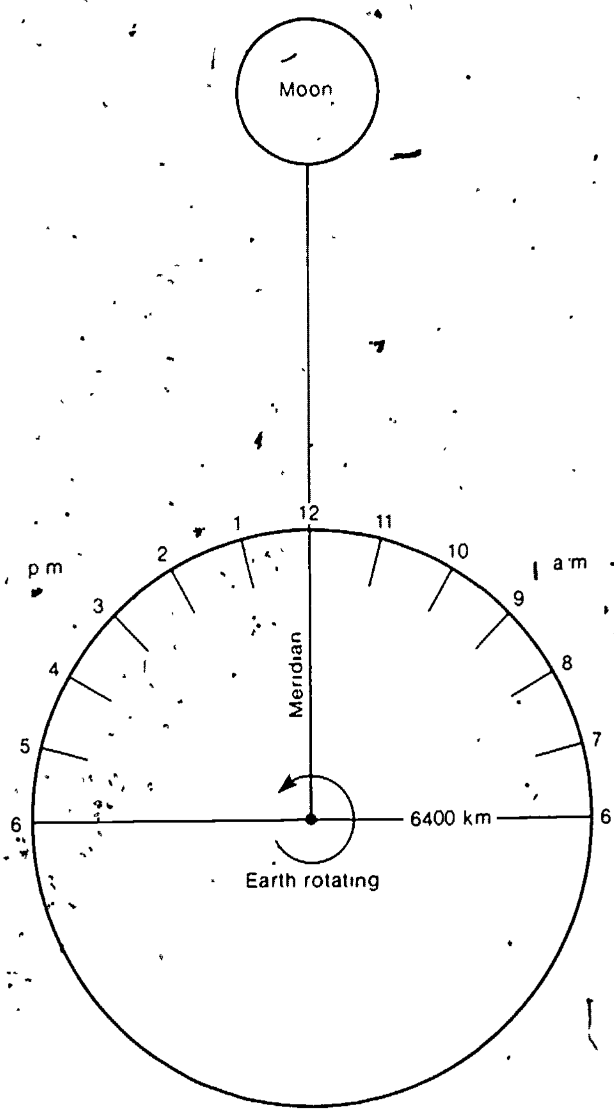
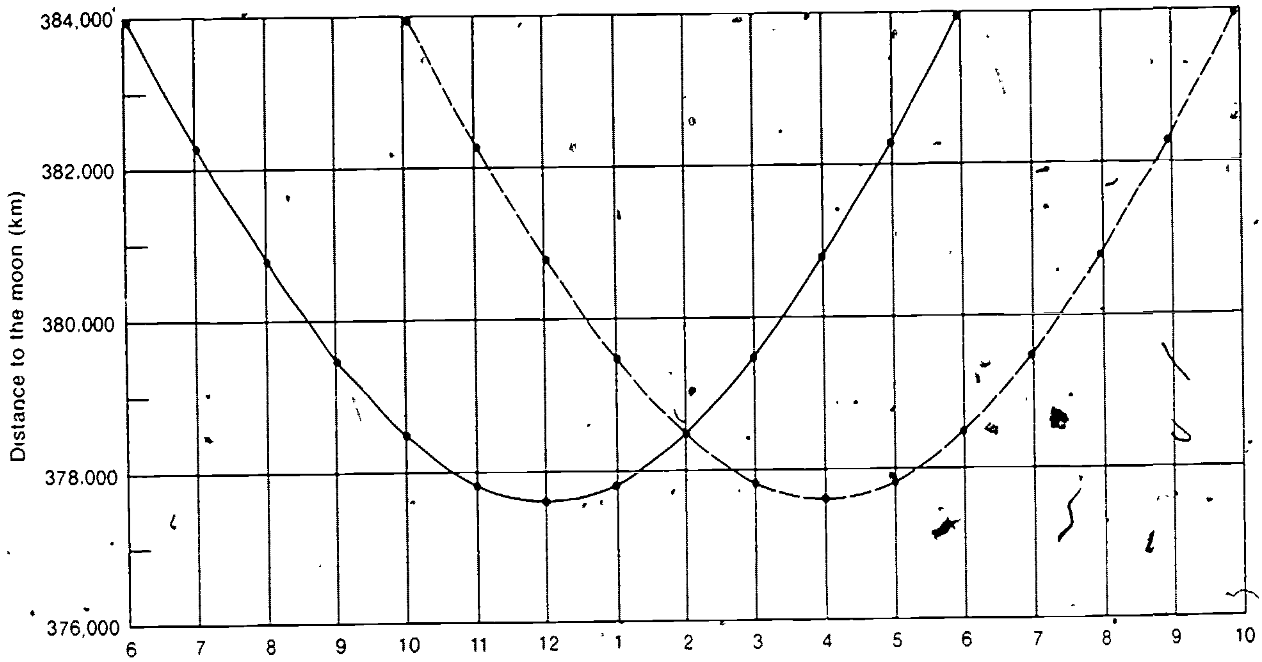


Figure 3. The sketch shows how the point rotates beneath the moon.



6. Plot the data from Table 1 on the graph above Note that a particular point on the earth's surface, the center of the earth, and the moon lie on a straight line only at one particular time during the day At that time, this point is closer to the moon than it is at any other time

7. On a Pacific island, on the equator, another class of students is doing the same activity. The moon passes their meridian exactly four hours later Plot the curve of their observations on your graph in question 6 (Plot the same curve, but everything should be moved to the right 4 hours.)

Look at Figure 3 Notice the points when the moon is on the meridian. In South America the time was 12 noon, on a Pacific island the time was 4 hours later. How far is the South American station from the Pacific island? To answer this question we need to know how far a point on the equator rotates in one hour Astronomers tell us this is about 1700 km. So the distance from the South American station to the Pacific island station is 1700 × 4 = 6800 km.

8. Suppose that astronomers continue to make this same measurement for ten years. Suppose that by ten years later the time difference between when the moon is on the meridian at the two locations has become .001 second longer than four hours The equipment is operating perfectly, what could account for that difference?

The two points have drifted apart.

9. How far does a point on the earth's surface move in 001 second?

Distance = rate × time

Rate = 1700 km/hr or about 500 m/sec

Distance = 500 m/sec × 001 sec =

.5 m or 50 cm in 10 years,

5 cm in one year

This is about as fast as your toenails grow. Do continents drift apart at that rate? Geologists suspect so but they don't know for sure. That's why they are trying the laser ranging experiment

SUMMARY QUESTIONS

1. Explain why geologists cannot measure the distance between continents by line-of-sight measurements.

Because the earth's surface curves and a point a great distance away is hidden behind the curve. We cannot see through the earth.

2. When a point on the earth is closest to the moon, the moon is on the **meridian.**

3. If we know the time when the moon is on the meridian at two locations on the same parallel, what can we find?

We can find the distance between the stations.

4. The moon is on the meridian at an observatory in the Hawaiian Islands at 12:00 noon. It is on the meridian at an observatory in Hong Kong at 6:00 p.m Ten years later the time difference is .001 second shorter. What do you think is happening?

The two locations are moving toward each other.

REFERENCES

Science News, 1974, Tracking the restless crust: astronomical interferometric earth surveying. v. 106, no. 8 and 9 (Aug. 24 and 31), p. 136–137.

Sullivan, W., 1974, *Continents in motion*. New York, McGraw-Hill Publishing Company, 399 p.

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	2	34 W 1201
• Continents And Ocean Basins: Floaters And Sinkers	3	34 W 1202
• Crustal Movement: A Major Force In Evolution	2	34 W 1203
• Deep Sea Trenches And Radioactive Waste	1	34 W 1204
• Drifting Continents And Magnetic Fields	2	34 W 1205
• Drifting Continents And Wandering Poles	4	34 W 1206
• Earthquakes And Plate Boundaries	1	34 W 1207
• Fossils As Clues To Ancient Continents	2	34 W 1208
• Hot Spots In The Earth's Crust	3	34 W 1209
• How Do Continents Split Apart?	1	34 W 1210
• How Do Scientists Decide Which Is The Better Theory?	1	34 W 1211
• How Does Heat Flow Vary In The Ocean Floor?	1	34 W 1212
• How Fast Is The Ocean Floor Moving?	2	34 W 1213
• Iceland: The Case Of The Splitting Personality	3	34 W 1214
• Imaginary Continents: A Geological Puzzle	1	34 W 1215
• Introduction To Lithospheric Plate Boundaries	1	34 W 1216
• Lithospheric Plates And Ocean Basin Topography	1	34 W 1217
• Locating Active Plate Boundaries By Earthquake Data	1	34 W 1218
• Measuring Continental Drift: The Laser Ranging Experiment	2	34 W 1219
• Microfossils, Sediments And Sea-floor Spreading	3	34 W 1220
• Movement Of The Pacific Ocean Floor	1	34 W 1221
• Plate Boundaries And Earthquake Predictions	2	34 W 1222
• Plotting The Shape Of The Ocean Floor	1	34 W 1223
• Quake Estate (board game)	1-3	34 W 1224
• Spreading Sea Floors And Fractured Ridges	1	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?	1	34 W 1230
• When A Piece Of A Continent Breaks Off	1	34 W 1231
• Which Way Is North?	3	34 W 1232
• Why Does Sea Level Change?	2	34 W 1233

WARD'S

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MODULE NO. TX6 7-5
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CRUSTAL EVOLUTION EDUCATION PROJECT

NAME DATE

Student Investigation

Catalog No 34W1119

Measuring Continental Drift: The Laser Ranging Experiment

INTRODUCTION

Scientists are interested in knowing how far they can see on the earth's curved surface. The reason scientists want to see a long way is because they want to measure the distance between fixed points on two or more continents If they can measure this distance accurately, they will be able to answer questions like these.

1. Are the crustal plates moving? How fast are they moving? In what direction are they moving?
2. Are the motions of the plates constant?
3. Do the plates stretch?
4. Does a whole plate move as one piece?

Scientists have not answered these questions yet, but they are trying. It is not easy to measure slow movements accurately—just centimeters per year—between continents

OBJECTIVES

After you have completed this activity, you should be able to.

1. Calculate how far on the earth you can see from a mountaintop.
2. Explain what is meant by the phrase "line-of-sight."
3. Explain how the curvature of the earth affects how far we can see along the earth's surface.
4. Discuss what happens to the distance between a point on the earth and a point on the moon, in terms of the earth's rotation.
5. Graph data on a grid and draw a curve to fit the data.
6. Explain how scientists might accurately measure the distance between two points located on different crustal plates.

PROCEDURE

PART A: How far on the earth can we see from a mountaintop?

Materials: none

The Greek mathematician Pythagoras (6th Century B.C.), worked out a formula for finding the length of the sides of all right triangles. (A right triangle is one that has one angle of 90°.) Every right triangle has two sides shorter than the third. Pythagoras said to take each short side, multiply it by itself, and add these two products together. The answer will equal the longest side multiplied by itself.

Let's apply Pythagoras' idea to our problem with the mountain. Look at Figure 1. Find right triangle AUT. Its sides are AT, AU and UT.

1. When you stand on the surface of the earth, you are 6400 km from the center of the earth. How far are you from the center of the earth if you stand on a mountaintop that is 2 km above the surface? _____ km. This is side AT of the triangle AUT.

2. The other sides of the triangle are AU and UT. AU is ______ km long.

You now want to find out how long UT is. Here is how you do it:

3. First multiply the length of side AT by itself. Your answer is __________ sq km.

4. Second, multiply the length of side AU by itself. Your answer is __________ sq km.

5. Now subtract these two numbers. Your answer is ________ sq km.

6. Side UT has a length equal to the square root of your answer to question 5. Side UT equals ______ km. (Round off this number to the nearest ones place.) This is the answer to the first question in PART A

7. XT is twice the length of side UT. Therefore, the length of XT is _____ km. This number is the distance between two mountains that are 2 km high, if you could stand on top of one and just barely see the other over the curvature of the earth. The line XT, along which you can see, is called your **line-of-sight.** Finding a high place from which to observe makes your line-of-sight longer. No mountains on earth are high enough to enable you to see a place which is several thousand kilometers away. Therefore, you cannot measure distances across continental plates, or plate movements, from a mountaintop. You must find some new way to make measurements over very long distances. This new way uses points on the earth and some other place.

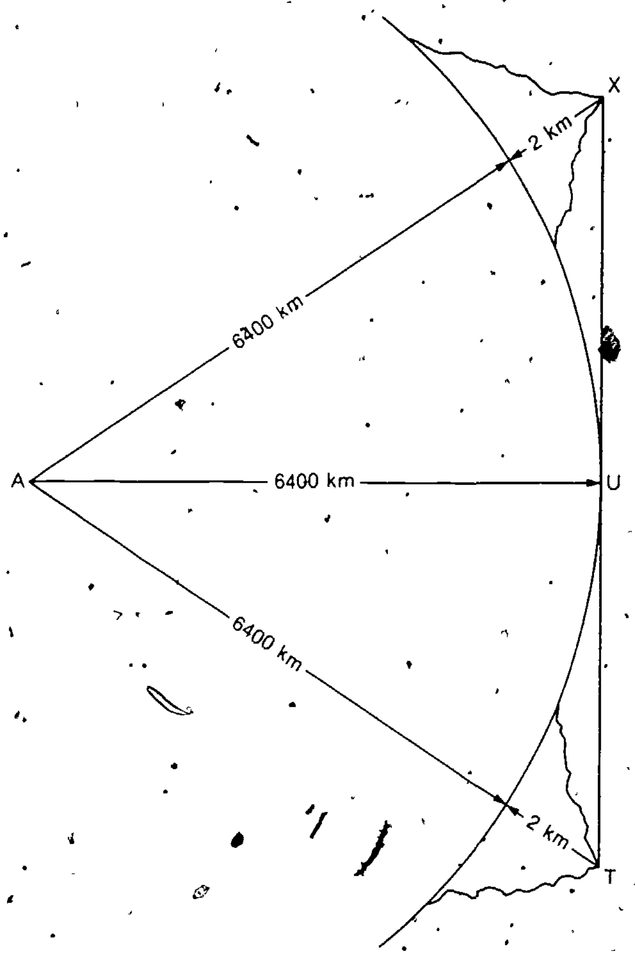


Figure 1.

8. List some places from which you might take measurements.

PROCEDURE

PART B: How can you tell when the moon and a point on the earth are closest together?

Materials: meter sticks

Start by measuring something you can touch and see. In or near your classroom, your teacher has made a model that looks like Figure 2. Y represents the moon and the letters A, B, C, D, E, F and G are positions on the rotating earth. Notice the arrows on the arc. The arrows indicate the direction that the earth is turning.

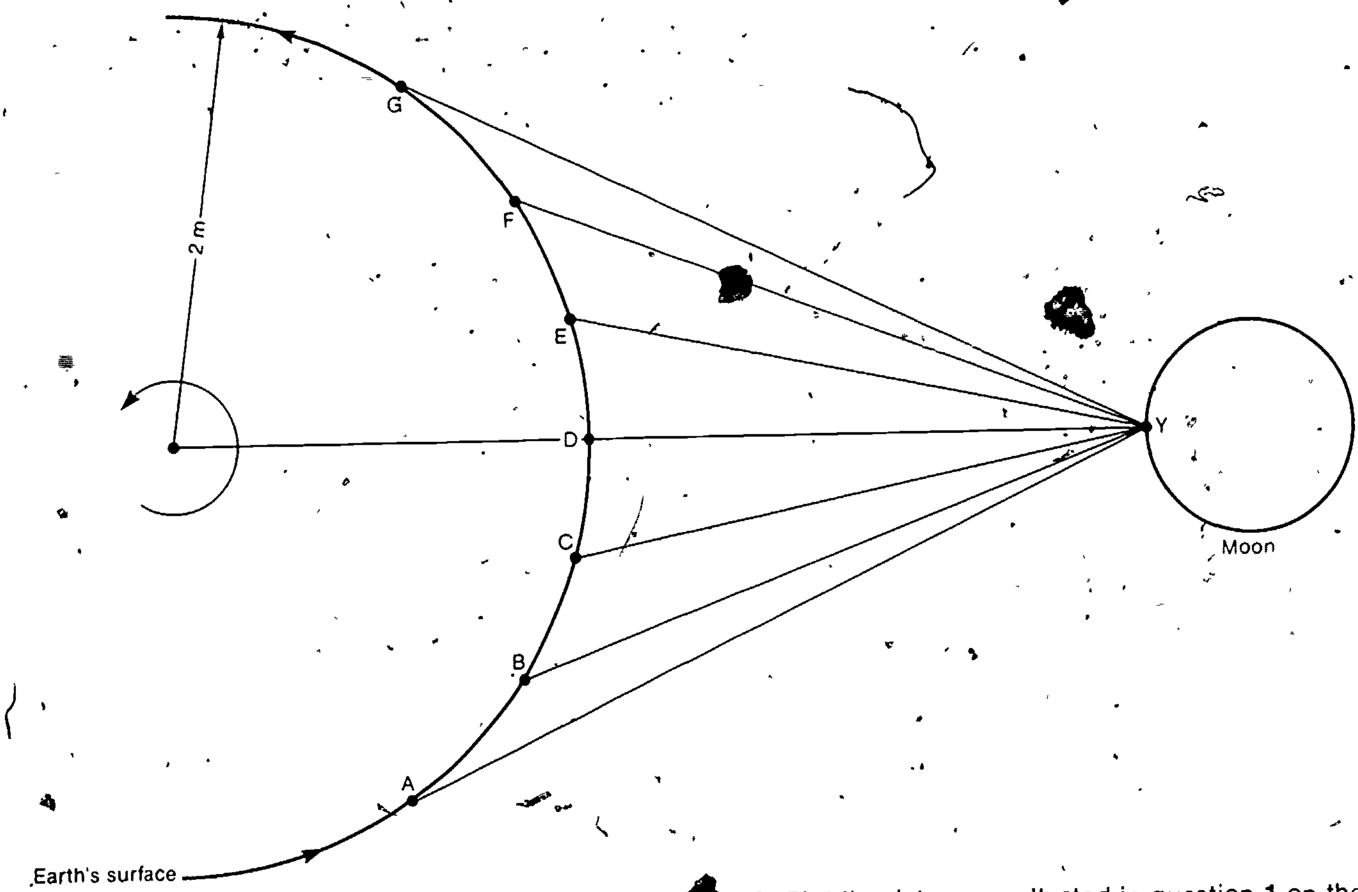
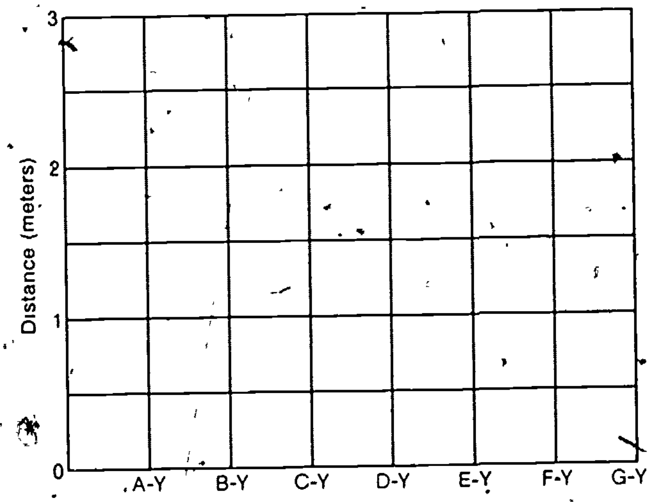


Figure 2. Earth-moon model.

1. Using the meter stick, measure the distance along each string from your point on the arc to point Y. Record your results below.

	A-Y	B-Y	C-Y	D-Y	E-Y	F-Y	G-Y
Distance (meters)							

2. Plot the data you collected in question 1 on the graph below.



3. When you moved from A to D, did you move toward or away from Y (the moon)? ________
Going from D to G did you move toward or away from the moon? ________

4. Look at your graph. Estimate the distance to Y if you are located between B and C. ______ m

5. Now try to draw a reasonable line through the points on your graph. You can see that the line is curved. What best explains why the line is curved?

Think about the earth and the moon. The earth rotates, so a fixed point on the earth moves beneath the moon. [The moon does move slowly, but at this moment consider it fixed just as Y (the moon) was fixed.] One moment you are at A relative to the moon, the next moment at D and third moment at G. How can you tell when the moon and a point on the earth are closest together?

In Table 1 you have been given data to plot on a graph. Look over this table. This data is an example of the distances to the moon which would be measured by a laser ranging station located on the equator in South America. Notice that the earth-moon relationship in Figure 3 is similar to what you measured earlier.

TIME	DISTANCE (km)
6 a.m.	384,000
7 a.m.	382,344
8 a.m.	380,800
9 a.m.	379,475
10 a.m.	378,458
11 a.m.	377,818
12 a.m.	377,600
1 p.m.	377,818
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4 p.m.	380,800
5 p.m.	382,344
6 p.m.	384,000

Table 1 Distance from a point on the earth's surface to the moon measured by laser ranging equipment at a South American laser ranging station

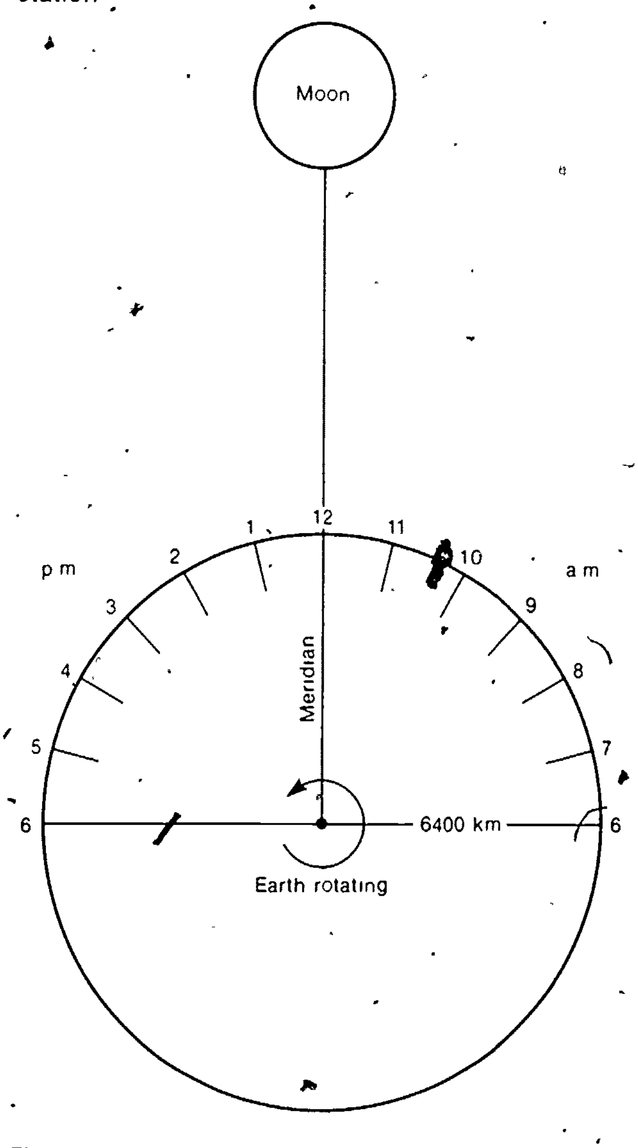
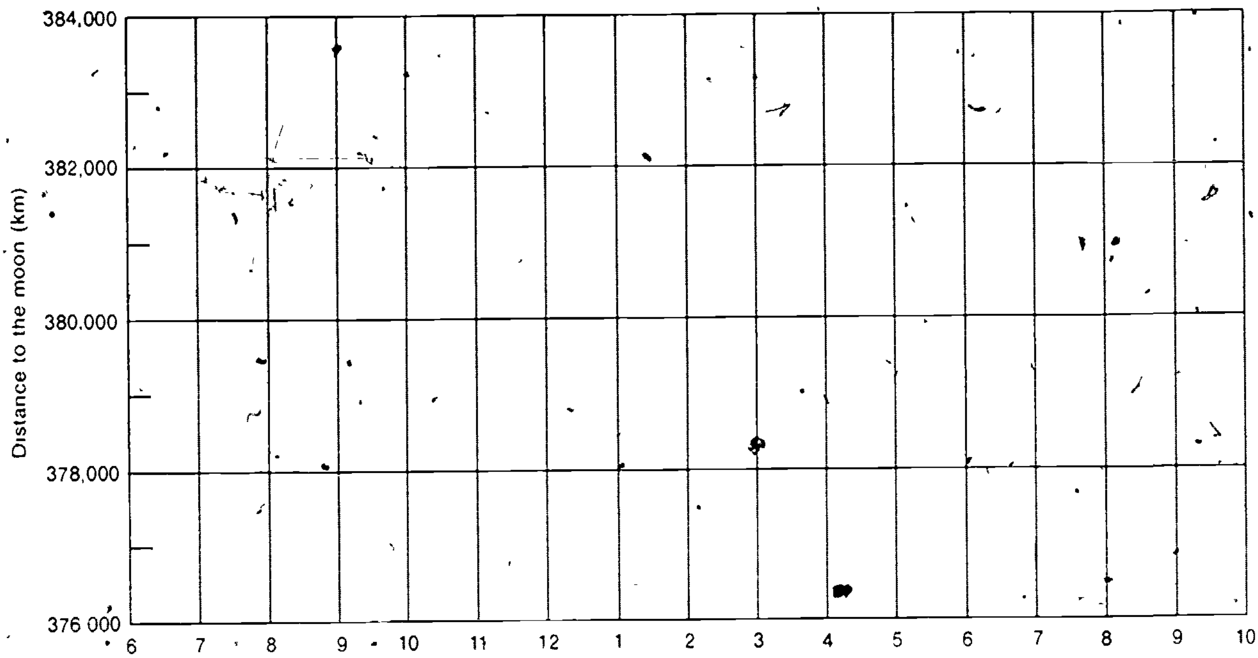


Figure 3. The sketch shows how the point rotates beneath the moon.



6. Plot the data from Table 1 on the graph above. Note that a particular point on the earth's surface, the center of the earth, and the moon lie on a straight line only at one particular time during the day At that time, this point is closer to the moon than it is at any other time.

7. On a Pacific island, on the equator, another class of students is doing the same activity. The moon passes their meridian exactly four hours later Plot the curve of their observations on your graph in question 6. (Plot the same curve, but everything should be moved to the right 4 hours.)

Look at Figure 3. Notice the points when the moon is on the meridian. In South America the time was 12 noon, on a Pacific island the time was 4 hours later How far is the South American station from the Pacific island? To answer this question we need to know how far a point on the equator rotates in one hour. Astronomers tell us this is about 1700 km. So the distance from the South American station to the Pacific island station is 1700 × 4 = 6800 km.

8. Suppose that astronomers continue to make this same measurement for ten years. Suppose that by ten years later the time difference between when the moon is on the meridian at the two locations has become .001 second longer than four hours. The equipment is operating perfectly; what could account for that difference?

9. How far does a point on the earth's surface move in 001 second?
Distance = rate × time
Rate = 1700 km/hr or about 500 m/sec
Distance = 500 m/sec × 001 sec =
_____ m or _____ cm in 10 years,
_____ cm in one year.
This is about as fast as your toenails grow
Do continents drift apart at that rate?
Geologists suspect so but they don't know for sure
That's why they are trying the laser ranging experiment

SUMMARY QUESTIONS

1. Explain why geologists cannot measure the distance between continents by line-of-sight measurements.

2. When a point on the earth is closest to the moon, the moon is on the ________ .

3. If we know the time when the moon is on the meridian at two locations on the same parallel, what can we find?

4. The moon is on the meridian at an observatory in the Hawaiian Islands at 12.00 noon It is on the meridian at an observatory in Hong Kong at 6:00 p.m. Ten years later the time difference is .001 second shorter. What do you think is happening?

REFERENCES

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