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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, including number of 45-minute class periods required; (8) summary questions (with answers); (9) extension activities; and (10) list of references. Two periods are recommended to examine the topography of the Pacific Ocean floor, relate this topography to plate tectonics, and determine how data on the age of the sea floor can be used to estimate the direction and velocity of apparent sea-floor movement. (Author/JN)

CEEP™

CRUSTAL EVOLUTION EDUCATION PROJECT

Movement Of The Pacific Ocean Floor

Movement Of The Pacific Ocean Floor

TEACHER'S GUIDE

Catalog No. 34W1021

For use with Student Investigation 34W1121
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

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

The material was prepared with the support of National Science Foundation Grant Nos SED 75-20151 SED 77-08539 and SED 78-25104 However any opinions findings conclusions or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of NSF

Movement Of The Pacific Ocean Floor

INTRODUCTION

In this module students will investigate the following questions:

1. What does the floor of the Pacific Ocean look like?

2. How is the Pacific sea-floor topography related to plate tectonics?

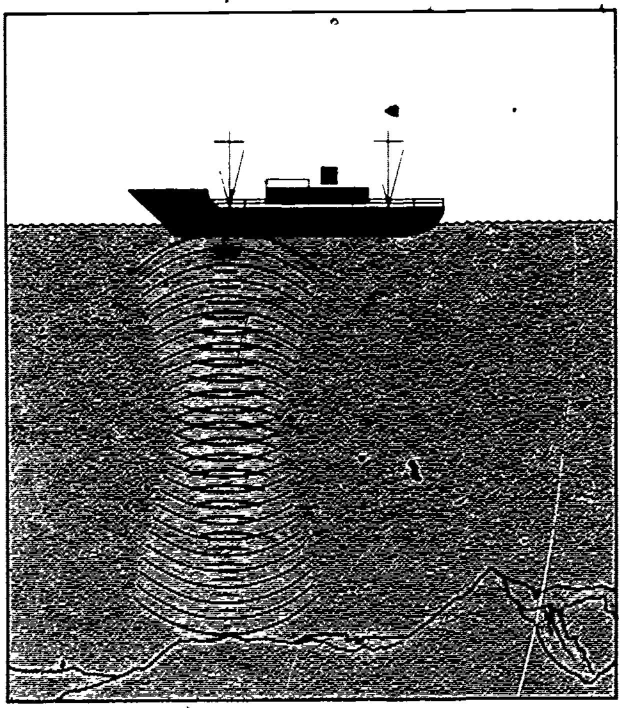
3. How can data on the age of the sea-floor at different locations be used to estimate the direction and velocity of apparent sea-floor movement?

What does the floor of the Pacific Ocean Basin look like? Why does it look that way? What else can we discover about it?

The map of the *Pacific Ocean Floor* which your teacher will give you shows how the Pacific Ocean might appear without the seawater. On the map an artist has drawn the ocean bottom landscape as determined by thousands of depth soundings of the sea floor.

The map shows that there are several different kinds of features on the ocean bottom. In the southeast Pacific (lower right of map) lies a ridge, called the East Pacific Rise, which is slowly spreading outward. This mid-ocean ridge is cut by many fractures called **transform faults.**

The Pacific Ocean is mostly bordered by deep trenches. The central area of the map shows numerous volcanic islands and underwater mountains. Many of these, such as the Hawaiian



Islands and the Emperor Seamount Chain, are strung out in long, nearly straight lines.

For more detailed geographical information, refer to the conventional map of the Pacific area on the back of the sea-floor chart.

PREREQUISITE STUDENT BACKGROUND

Prior to doing this module, a basic knowledge of crustal processes as developed in introductory CEEP investigations (e.g. Earthquakes And Plate Boundaries) is necessary. Students should be familiar with the distortion that accompanies Mercator projections. In addition, the notion of vertical exaggeration and a great circle meridian should be discussed. Plotting data on a graph and using a simple rate formula are mathematical skills required of the students.

OBJECTIVES

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

1. Locate on a map the principal island chains, mid-ocean ridges and oceanic trenches of the Pacific Ocean Basin
2. Plot the data and find the relationship between the age and location of the islands
3. Determine the direction of apparent sea-floor movement in the Central Pacific
4. Calculate the average rate of Pacific sea-floor movement in centimeters per year.
5. Determine the approximate direction of ocean plate movement on both sides of the East Pacific Rise
6. Explain what eventually happens to the moving Pacific sea floor

MATERIALS

Map, *Pacific Ocean Floor*, National Geographic Society, Educational Services, Department 79, Washington, D.C. 20036—one map for each group of students. (Note: This map has English units of measurement. In this module students will be using both metric and English units.)

Physical world globe (optional)—one per class.

BACKGROUND INFORMATION

Nowhere is the relative movement of an entire crustal plate more dramatically illustrated than on the Pacific Plate. As far back as 1838, an American geologist, James Dana, noted that the Hawaiian Islands become progressively older northwestward along the entire Hawaiian chain. Dana could only base his evidence on the relative amounts of erosion and weathering which were noticeable on the islands. Modern radiometric dating now supports the notion that movement of the Pacific Plate has accompanied the formation of a string of volcanoes that are progressively younger. Several other similar chains parallel the Hawaiian chain, i.e. Tuamotu Ridge and the Marshall Islands.

Although other evidence may be used to show the direction of Pacific Plate motion, such as the trend of the "Chalk Line," nothing appears to be a better indicator than the route indicated by the volcanic chains. (The "Chalk Line" is the deposit of carbonate shells of micro-organisms in equatorial waters. Throughout time this white, chalk-like material has been carried northwestward. Consequently, paleontological dating of these micro-organisms indicates a northwest-trending increase in age.)

In recent years the entire system of islands and seamounts has been considered a chain that shows the direction of plate motion. A bend in the volcanic island chain indicates a change in the direction of plate motion. Such a bend is obvious between the Midway Islands and the Milwaukee Seamount. Since the volcanic material in this area was deposited about 40 million years ago, it can be interpreted that this change of direction occurred at the same time. Other volcanic chains in the Pacific (i.e. the Tuamotu Chain) also bend sharply at an age of 40 million years.

SUGGESTED APPROACH

Although not absolutely essential, it would be helpful to have on hand a physical globe (e.g, National Geographic Society, 1971) which shows the same physiographic features of the Pacific sea floor without the distortion inherent in the Mercator projection.

As the maps generate much student interest, any orientation or background material that you deem necessary should be done prior to distributing the maps. The following skills and concepts should be reviewed before students begin the module:

1. The shortest distance between any two points on a sphere is along the arc of a great circle connecting the two points.
2. Review basic graphing skills. (Note that the graph has already been set up for the students.)
3. Review basic direction, rate, and time computations.

Once these skills and concepts have been established, the best way to approach the activity is to hand out the materials and have students get started. Questions that arise are best handled in small groups.

PROCEDURE

Students utilize the map, *Pacific Ocean Floor*, in identifying the location and directional trend of the Hawaiian, Milwaukee, and Emperor Seamount Chains. As the ages of the islands are plotted, it should become apparent that the islands grow progressively older away from the island of Hawaii.

By knowing the age of the different islands and the distance of these islands from Hawaii, the students can calculate an approximate rate of sea-floor movement. The fracture pattern on opposite sides of the East Pacific Rise is additional evidence for the directional trend of Pacific Plate motion.

Finally, students are asked to identify the ocean structure in which a seamount chain appears to end.

Key words: transform fault, seamount, plate, reef, ocean trench, ocean ridge

Time required: two 45-minute periods

Materials *Pacific Ocean Floor* map

1. Locate the Hawaiian Island chain, approximately in the center of the map In this island chain, the highest point above sea level is the top of the volcano Mauna Kea on the island of Hawaii From Hawaii the chain extends thousands of kilometers west-northwest to the vicinity of the Milwaukee Seamount group A seamount is an underwater mountain, commonly an extinct volcano From the vicinity of the Milwaukee group, the trend of the Emperor Seamount Chain changes to the northwest direction. Locate the northern end of the Emperor Seamount Chain At what ocean basin feature does the Emperor Seamount Chain end?

The Emperor Seamount Chain ends at the Aleutian trench.

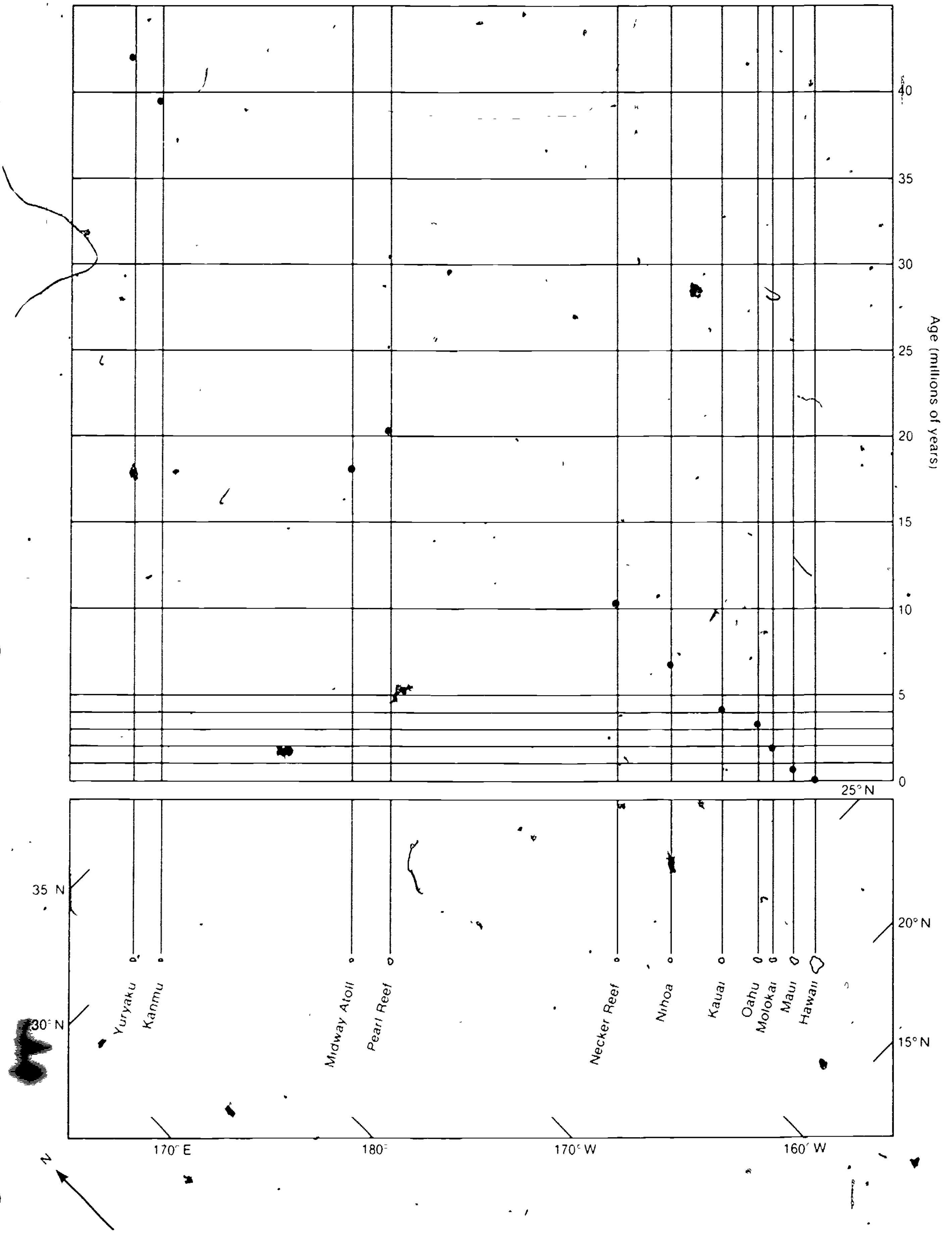
The ages of several islands in the Hawaiian chain are listed in Table 1. The locations of the islands are plotted on the Worksheet. (Note that the age listed for Midway atoll is questionable, due to difficulties in sampling)

2. Plot the ages of the islands on the graph on the Worksheet, above the map of their location. What happens to the age of the islands as their distance from the island of Hawaii increases?

The data suggest that there is a positive correlation between the age of any given island and its distance from the island of Hawaii. The farther away it is, the older it is.

Table 1
Hawaiian Island ages

Island (or reef)	*Approximate age (millions of years)*
Hawaii (Kilauea)	0
Kanmu	39 0
Kauai	4 1
Maui (Haleakala)	0 6
Midway Atoll	18.0 (?)
Molokai	1.8
Necker Reef	10 1
Nihoa	7 0
Oahu	3 1
Pearl Reef	20 1
Yuryaku	42 3



Answer Sheet

The earth's crust consists of a number of separate rigid **plates,** some of whose boundaries are marked by chains of volcanoes For a long time, volcanic mountains near the center of crustal plates, like the Hawaiian chain, were a mystery to many earth scientists One possible explanation for their formation is that they are the result of hot spots in the earth material beneath the plates The hot spot is thought to be relatively fixed in position, compared to the crustal plate which is moving over it (See Figure 1)

As the plate moves over this hot spot, the crust above is partially melting Molten material reaches the surface, forming underwater volcanoes and eventually volcanic islands The volcanic islands that have been formed are then carried away in the direction the plate is moving.

Use the graph on the Worksheet to answer the following four questions

3. According to the explanation given, which island in the Hawaiian Island chain is presently above the hot spot?

Hawaii (Mauna Loa and Kilauea are active volcanoes on this island).

4. According to the explanation given, which island would have been above the hot spot 20 million years ago?

Pearl Reef

5. Assuming that the Pacific Plate has acted as one rigid plate during the past 30 or 40 million years, in what direction has the Pacific Plate been moving?

Northwest (or more accurately, west-northwest).

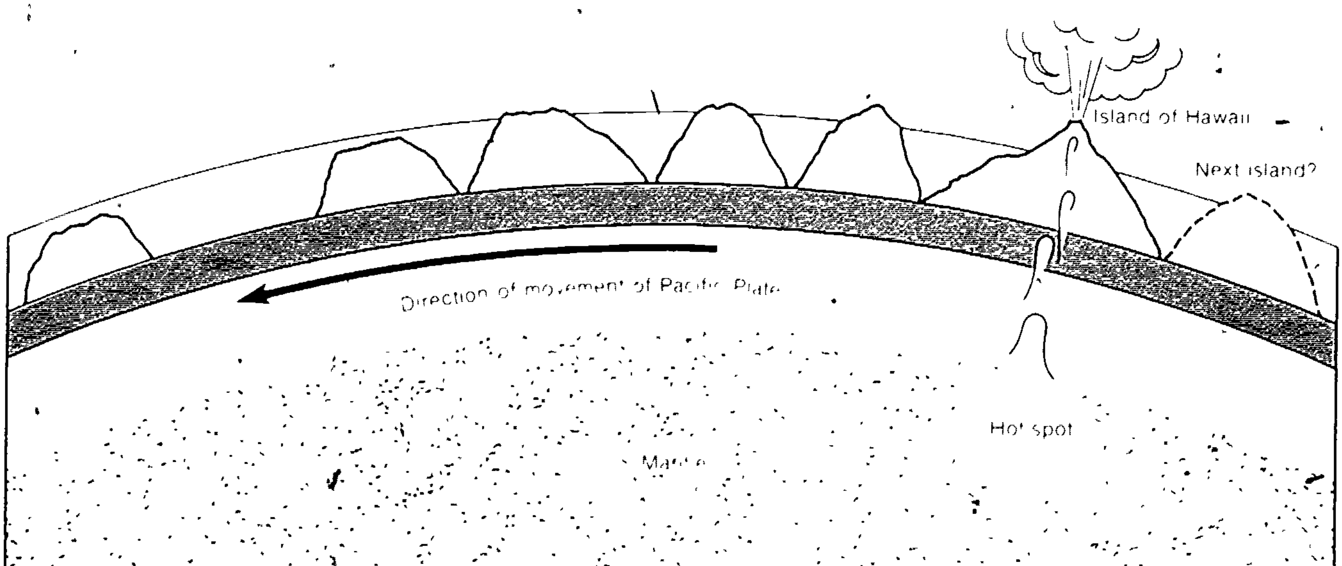


Figure 1 This diagram shows how volcanic islands may be formed by a hot spot which punches [th]ough the crust, forming volcanoes as the crustal plate slides by overhead

The distance from the island of Hawaii to Pearl Reef is about 2,000 km A **reef** is a ridge of rock, usually coral, which is at or near the surface of the water.

6. What has been the approximate rate or velocity of sea-floor movement, in centimeters per year, during the 20 million years since Pearl Reef was formed? (Note 1 km = 100,000 cm, so 2,000 km = 200,000,000 cm.)

$$\text{rate} = \frac{200{,}000{,}000 \text{ cm}}{20{,}000{,}000 \text{ yr}} = 10 \text{ cm/yr}$$

Note: This is an approximation. Students can utilize the map scale or a globe scale to determine a more precise distance between these two islands.

Use the map, *Pacific Ocean Floor*, to answer the next four questions Locate the East Pacific Rise in the southeast part of the Pacific basin This is thought to be a **mid-ocean ridge** (or spreading center) from which new ocean crust material is spreading outward The many fractures that cut across the ridge are believed to point in the approximate direction of sea-floor spreading

7. Locate the area **west** of the East Pacific Rise between the Challenger Fracture Zone and the Eltanin Fracture Zone Looking at the fracture pattern in this area, tell the direction in which the Pacific Plate appears to be moving

West-northwest

8. Locate the area between the same two fracture zones on the **east** side of the East Pacific Rise. What is the approximate direction of sea-floor spreading?

East-southeast

Notice the deep **ocean trenches** that border the Pacific Ocean basin. Ocean trenches are long, narrow depressions found near the edges of continents. Record the maximum depth of these features

Peru-Chile Trench	**-26,454**	feet
Aleutian Trench	**-25,194**	feet
Japan Trench	**-27,600**	feet
Marianas Trench	**-36,198**	feet

9. Which of the trenches listed in question 8 is the deepest?

Marianas Trench

How does this maximum depth compare with the height of the highest point on earth above sea level (Mt Everest. 29,028 ft.)?

The Marianas Trench is more than 7,000 feet deeper than the elevation of Mt. Everest.

10. Trace the Emperor Seamount Chain northward from the Hawaiian Ridge At what ocean structure does the Emperor Seamount Chain end?

The Aleutian Trench

What may this indicate about what is happening to the Pacific Ocean floor?

It indicates that the Pacific Ocean floor may be plunging downward into the deep bordering oceanic trenches.

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SUMMARY QUESTIONS

1. In what direction does the Pacific Ocean floor as a whole appear to be moving?

West-northwest

Evidence from what types of ocean features can be used to suggest this direction?

Island chains; fracture patterns on both sides of oceanic ridges.

2. How can the fractures that cut across an oceanic ridge help in determining the direction of sea-floor spreading?

The fractures are oriented in the approximate direction of sea-floor spreading.

3. Into what kind of ocean feature does the Pacific ocean floor appear to be moving?

The Pacific Ocean floor appears to be plunging downward into deep oceanic trenches.

REFERENCES

Burke, K C, and Wilson, J.Tuzo, 1976, Hot spots on the earth's surface *Scientific American*, v 235, no 2 (Feb), p 46-57

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Jarrard, R D, and Clague, D A, 1977, Implications of Pacific island and seamount ages for the origin of volcanic chains *Reviews of Geophysics and Space Physics*, A G U, v 15, no 1 (Feb), p 57-76

Matthews, S W, 1973, This changing earth. *National Geographic*, v 143, no. 1 (Jan), p 1-37

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. MD9 8-5
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CRUSTAL EVOLUTION EDUCATION PROJECT

NAME DATE

Student Investigation

Catalog No 34W1121

Movement Of The Pacific Ocean Floor

INTRODUCTION

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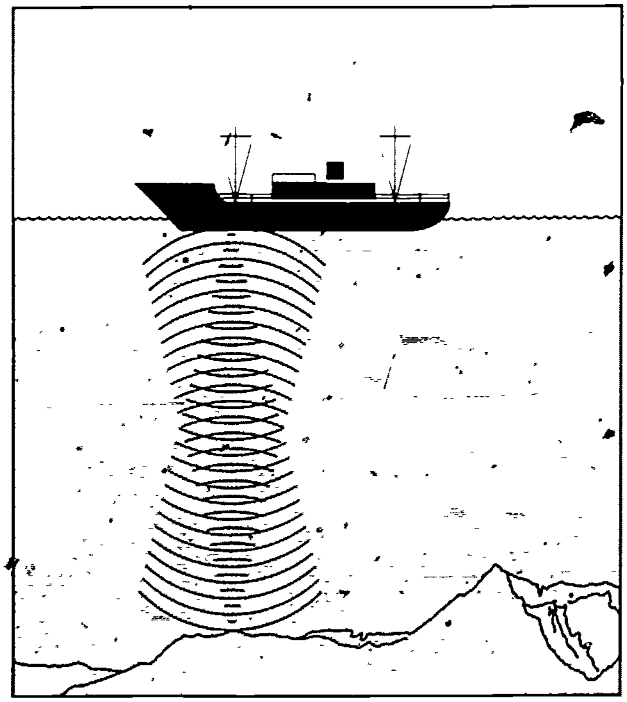
The map of the *Pacific Ocean Floor* which your teacher will give you shows how the Pacific Ocean might appear without the seawater On the map an artist has drawn the ocean bottom landscape as determined by thousands of depth soundings of the sea floor



The map shows that there are several different kinds of features on the ocean bottom In the southeast Pacific (lower right of map) lies a ridge, called the East Pacific Rise, which is slowly spreading outward This mid-ocean ridge is cut by many fractures called **transform faults.**

The Pacific Ocean is mostly bordered by deep trenches The central area of the map shows numerous volcanic islands and underwater mountains Many of these, such as the Hawaiian Islands and the Emperor Seamount Chain, are strung out in long, nearly straight lines

OBJECTIVES

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

1. Locate on a map the principal island chains, mid-ocean ridges and oceanic trenches of the Pacific Ocean Basin
2. Plot the data and find the relationship between the age and location of the islands
3. Determine the direction of apparent sea-floor movement in the Central Pacific
4. Calculate the average rate of Pacific sea-floor movement in centimeters per year
5. Determine the approximate direction of ocean plate movement on both sides of the East Pacific Rise
6. Explain what eventually happens to the moving Pacific sea floor

PROCEDURE

Materials *Pacific Ocean Floor* map

1. Locate the Hawaiian Island chain, approximately in the center of the map In this island chain, the highest point above sea level is the top of the volcano Mauna Kea on the island of Hawaii. From Hawaii the chain extends thousands of kilometers ____________ to the vicinity of the Milwaukee Seamount group A **seamount** is an underwater mountain, commonly an extinct volcano From the vicinity of the Milwaukee group, the trend of the Emperor Seamount Chain changes to the ____________ direction. Locate the northern end of the Emperor Seamount Chain At what ocean basin feature does the Emperor Seamount Chain end?

The ages of several islands in the Hawaiian chain are listed in Table 1 The locations of the islands are plotted on the Worksheet (Note that the age listed for Midway atoll is questionable, due to difficulties in sampling)

2. Plot the ages of the islands on the graph on the Worksheet, above the map of their location What happens to the age of the islands as their distance from the island of Hawaii increases?

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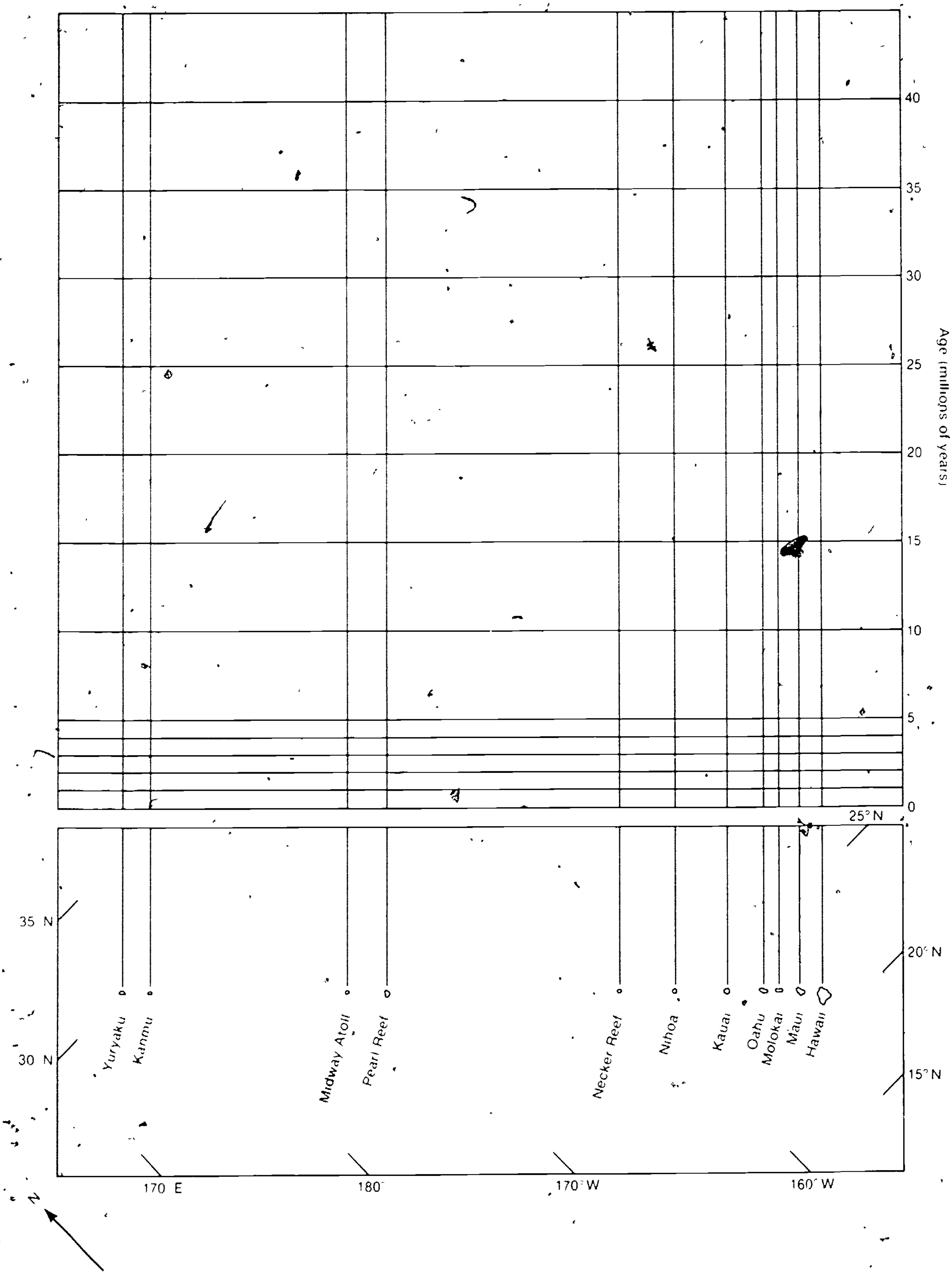
Midway Atoll	18 0 (?)
Molokai	1 8
Necker Reef	10 1
Nihoa	7 0
Oahu	3 1
Pearl Reef	20 1
Yuryaku	42 3


Age (millions of years)
40
35
30
25
20
15
10
5
0
25° N
35 N
20° N
30 N
15° N
Yuryaku
Kanmu
Midway Atoll
Pearl Reef
Necker Reef
Nihoa
Kauai
Oahu
Molokai
Maui
Hawaii
170 E
180°
170° W
160° W
N

Worksheet

The earth's crust consists of a number of separate rigid **plates,** some of whose boundaries are marked by chains of volcanoes For a long time, volcanic mountains near the center of crustal plates, like the Hawaiian chain, were a mystery to many earth scientists One possible explanation for their formation is that they are the result of hot spots in the earth material beneath the plates The hot spot is thought to be relatively fixed in position, compared to the crustal plate which is moving over it (See Figure 1)

As the plate moves over this hot spot, the crust above is partially melting Molten material reaches the surface, forming underwater volcanoes and eventually volcanic islands The volcanic islands that have been formed are then carried away in the direction the plate is moving

Use the graph on the Worksheet to answer the following four questions

3. According to the explanation given, which island in the Hawaiian Island chain is presently above the hot spot?

4. According to the explanation given, which island would have been above the hot spot 20 million years ago?

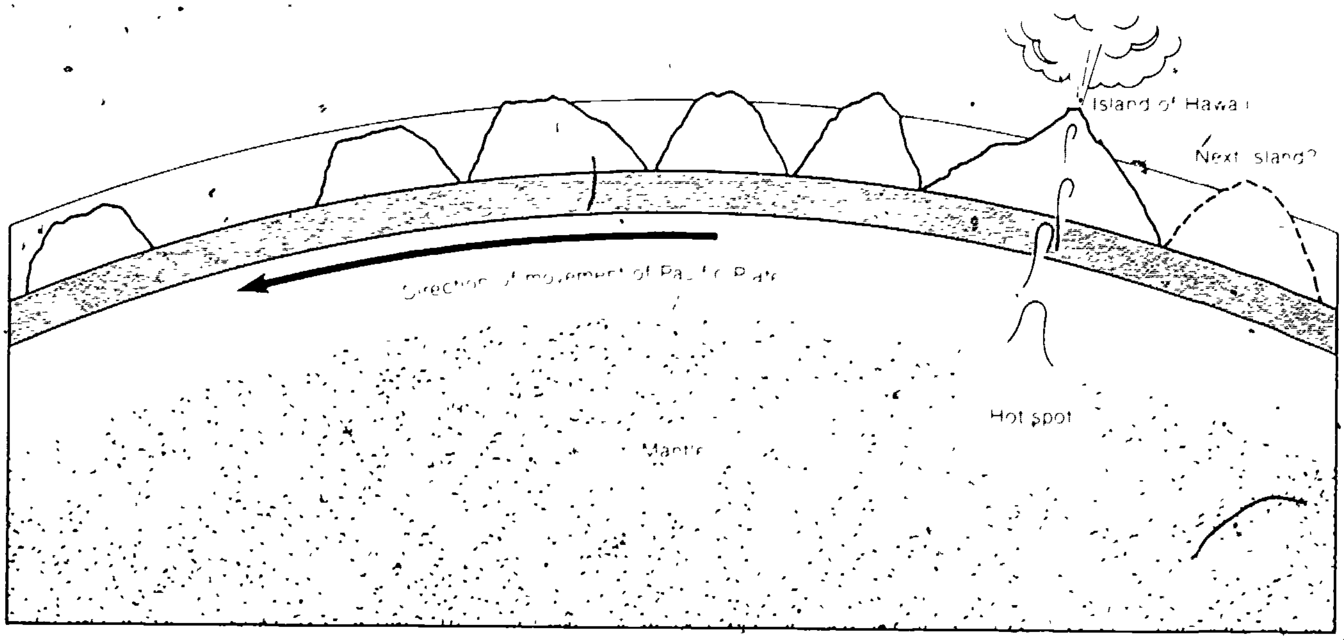


Figure 1 This diagram shows how volcanic islands may be formed by a hot spot which punches through the crust, forming volcanoes as the crustal plate slides by overhead.

5. Assuming that the Pacific Plate has acted as one rigid plate during the past 30 or 40 million years, in what direction has the Pacific Plate been moving?

The distance from the island of Hawaii to Pearl Reef is about 2,000 km. A **reef** is a ridge of rock, usually coral, which is at or near the surface of the water.

6. What has been the approximate rate or velocity of sea-floor movement, in centimeters per year, during the 20 million years since Pearl Reef was formed? (Note: 1 km = 100,000 cm, so 2,000 km = 200,000,000 cm.)

Use the map, *Pacific Ocean Floor*, to answer the next four questions. Locate the East Pacific Rise in the southeast part of the Pacific basin. This is thought to be a **mid-ocean ridge** (or spreading center) from which new ocean crust material is spreading outward. The many fractures that cut across the ridge are believed to point in the approximate direction of sea-floor spreading.

7. Locate the area **west** of the East Pacific Rise between the Challenger Fracture Zone and the Eltanin Fracture Zone. Looking at the fracture pattern in this area, tell the direction in which the Pacific Plate appears to be moving.

8. Locate the area between the same two fracture zones on the **east** side of the East Pacific Rise. What is the approximate direction of sea-floor spreading?

Notice the deep **ocean trenches** that border the Pacific Ocean basin. Ocean trenches are long, narrow depressions found near the edges of continents. Record the maximum depth of these features.

Peru-Chile Trench	______	feet
Aleutian Trench	______	feet
Japan Trench	______	feet
Marianas Trench	______	feet

9. Which of the trenches listed in question 8 is the deepest?

How does this maximum depth compare with the height of the highest point on earth above sea level (Mt. Everest, 29,028 ft.)?

10. Trace the Emperor Seamount Chain northward from the Hawaiian Ridge. At what ocean structure does the Emperor Seamount Chain end?

What may this indicate about what is happening to the Pacific Ocean floor?

13

SUMMARY QUESTIONS

1. In what direction does the Pacific Ocean floor as a whole appear to be moving?

Evidence from what types of ocean features can be used to suggest this direction?

2. How can the fractures that cut across an oceanic ridge help in determining the direction of sea-floor spreading?

3. Into what kind of ocean feature does the Pacific ocean floor appear to be moving?

REFERENCES

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Matthews, S W , 1973, This changing earth *National Geographic*, v 143, no 1 (Jan.), p. 1-37