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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. Designed for independent work, this activity serves as an introduction to heat flow (movement from a point of higher to lower concentration), focusing on pattern of flow distribution in rocks of northeast Pacific Ocean and the relationship between heat flow and age of the ocean crust. Skills fostered include interpreting data from a map, plotting a graph, and making interpretations based on the graph. (JN)

CEEP™

CRUSTAL
EVOLUTION
EDUCATION
PROJECT

How Does Heat Flow Vary In The Ocean Floor?

How Does Heat Flow Vary In The Ocean Floor?

TEACHER'S GUIDE

Catalog No. 34W1012

For use with Student Investigation 34W1112
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

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How Does Heat Flow Vary In The Ocean Floor?

INTRODUCTION

In this activity the students study the pattern of heat flow distribution in the rocks of the northeast Pacific Ocean and the relation between heat flow and age of the ocean crust. This is an exercise in interpreting data from a map, plotting a graph, and making inferences based on the graph.

Did you ever think that heat is coming from the floor of the ocean? Scientists have found that the heat flowing from the floor of the ocean is not the same everywhere. Scientists have found areas of ocean floor that have much greater heat flow than other places. They have discovered interesting patterns of high and low heat flow on the ocean floor.

Heat always travels or "flows" from a point of higher to lower temperature. This phenomenon has been called **heat flow**. To understand this, think of water flowing down a slope, through a channel with a cross section of one square meter in area. The "water flow" is the amount of water going through the one square-meter channel each second. The amount of heat flowing through a square centimeter area each second is the heat flow. Heat is flowing out of the earth to the bottom of the ocean somewhat like water flows in a stream.

If there is a difference in temperature between any two points being measured, heat will flow from the point of higher temperature to the point of lower temperature. The greater the difference in temperature, the higher the rate of heat flow.

A **heat probe** is an instrument that is lowered from a ship to measure heat flow in the ocean crust. Heat flow values are written as microcalories per square centimeter per second ($\mu cal/cm^{2}/sec^{1}$). That is the amount of heat measured in calories passing through one square centimeter each second.

In this activity you will investigate heat flow patterns in the northeast Pacific Ocean.

PREREQUISITE STUDENT BACKGROUND

This activity is intended to serve as an introduction to heat flow. No background knowledge about heat flow is necessary and none is assumed.

Students are expected to complete a graph and should know techniques of graphing, including drawing a smooth curve as a "best fit" line.

OBJECTIVES

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

1. Estimate the rate at which heat is flowing out of any part of the ocean floor in the northeast Pacific Ocean
2. Estimate the rate at which heat flows out of any ocean floor of a particular age.
3. Estimate the age of ocean crust using heat flow measurements.
4. Make a hypothesis about the relationship between heat flow and age of the ocean crust.

MATERIALS

Pencils

Metric rulers—one for each student

BACKGROUND INFORMATION

Heat flow measurements require measurements at two depths, a known distance apart, and determination of the thermal conductivity (efficiency in conducting heat) of the material between those points. The rate of heat flow through the ocean floor is the product of temperature gradient and thermal conductivity.

The temperature gradient is measured by forcing a heat probe containing two temperature sensors (one near the bottom of the probe and the other near the top) into the sediments on the ocean floor. Temperature readings are transmitted to recording devices inside a water-tight, pressure-resistant chamber at the upper end of the heat probe. Thermal conductivity is measured on sediment core samples collected at the same time with a coring device.

Heat flow values through ocean floor rocks are nearly identical to those of the continents. This is an unexpected result. Continental rocks have three times more radioactive elements (which decay and produce heat) than oceanic rocks. Heat flow in continental rocks should be about three times greater than that of oceanic rocks.

Heat flow along the axis of the mid-ocean ridge system was found to be significantly higher than elsewhere in the ocean. Most scientists have concluded that material must be rising through the mantle in the form of a convection current, carrying heat with it. (The sea-floor spreading hypothesis states that molten material from the mantle rises to the surface at the mid-ocean ridge system.) If the heat under the oceans is brought up by rising convection currents, there should be corresponding regions of low heat flow in places where the material is sinking, such as at trenches.

The convection current hypothesis is not as widely accepted as the sea-floor spreading hypothesis. Principal objections are geophysical and are based on scale. Some geophysicists think that convection currents of the size required by the model are not possible in the thin upper mantle region. Resolution of the "convection current problem" awaits results of current intensive research.

Figure A shows the relationship that heat flow decreases with increasing distance from spreading centers. Remember that age of the ocean floor increases with distance from the ridges.

Scientists have studied the variations of ocean-floor heat flow and found that it decreases systematically with increasing age of the ocean floor away from ridges. That notion forms the basis of this student investigation.

A good, historical treatment of heat flow investigations can be found in Sullivan (1974).

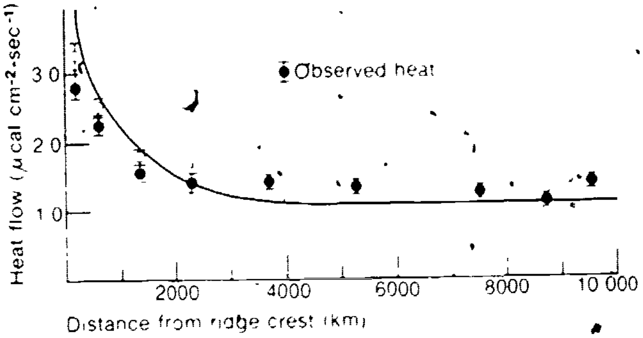

Figure A. Heat flow decreases with increasing distance from a spreading center. (After Sclater and Francheteau, Geophysical Journal of the Royal Astronomical Society, 1970, vol. 20, pp. 509-42, Figure 17, with permission from Blackwells Scientific Publications, Ltd.)

SUGGESTED APPROACH

This activity is designed to allow students to work independently. A group discussion of results would be beneficial, with particular attention to interpretation of the graph.

Make sure students understand how to complete a graph. Discuss how to make a smooth curve "best fit" line rather than "connecting the dots."

It is suggested that you evaluate the students' progress and answers to the questions during their work on the activity.

PROCEDURE

The students will interpret heat flow data shown on the map.

Key words: heat flow, heat probe, isochron, spreading center

Time required: two 45-minute periods

Materials: pencil and metric ruler

In this activity you are going to investigate the pattern of heat flow in part of the northeast Pacific Ocean.

Figure 1 is a map of part of the Pacific Ocean floor. The map shows individual heat flow measurements (numbers are next to points where heat flow measurements were taken) The map also shows **isochrons** (*iso* meaning **same**; *chron* meaning **age**). Isochrons are lines of equal age.

The ocean floor along an isochron is the same age. The number on each isochron is the age of the ocean crust in millions of years Notice that the isochrons are offset at certain places.

Notice the heavy line on the right side of the map. This line represents a **spreading center** (a region where new ocean crust material is being added to the present ocean crust).

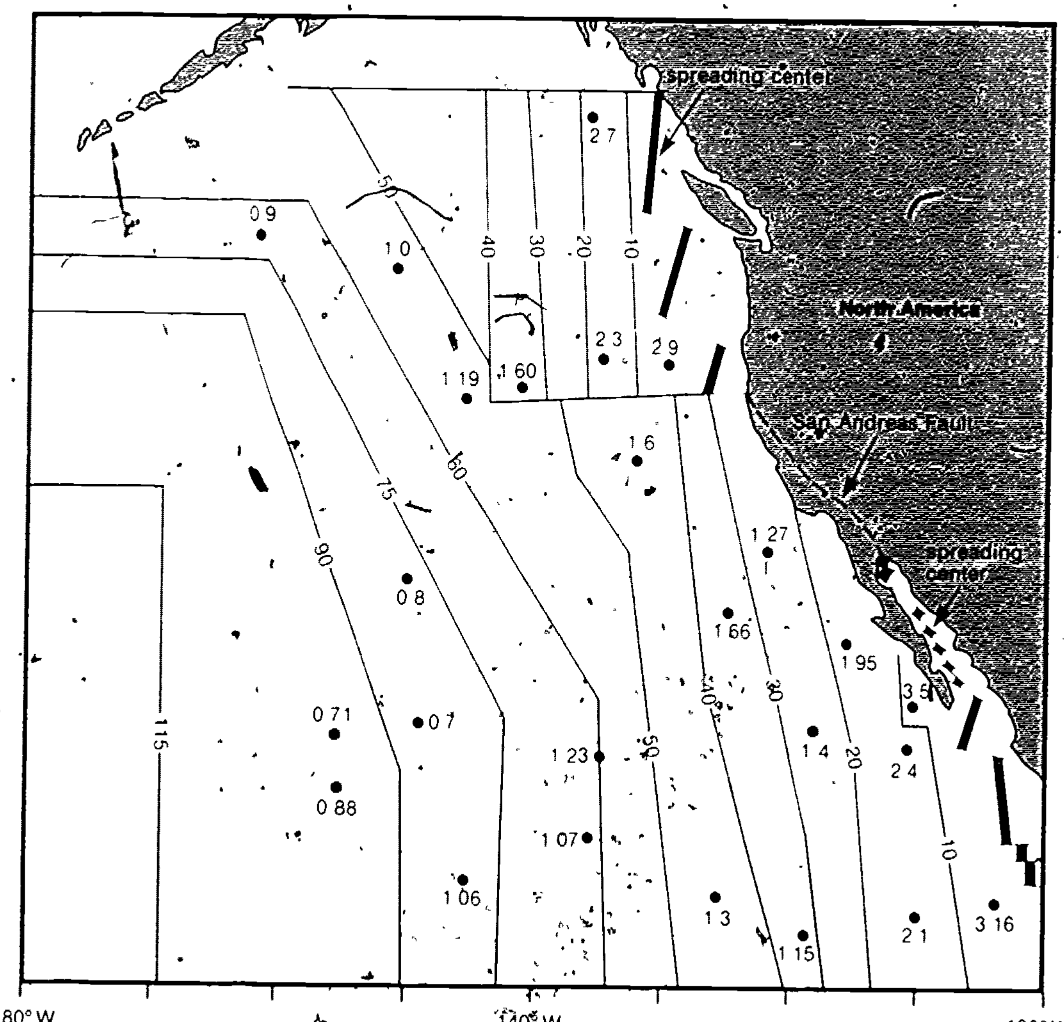

Figure 1 Map of heat flow values in the northeast Pacific Ocean.

4. Use the data in Table 1 to complete the graph of heat flow units and age of ocean crust on the Worksheet. Mark your graph where each heat flow value matches the age of the ocean floor. The first three points are already plotted for you.

5: Connect the points you have plotted on the Worksheet with a smooth curve. (Do not connect each point on the graph. Draw a line which is the "average" of all the points.) Compare your graph to the graph your teacher will show you. Is your graph different? How do you explain any differences you observe? Describe the relationship between heat flow and the age of ocean floor.

Prepare a transparency of the Answer Sheet and discuss with the class as a group.

Student graphs should show the general shape of the curve. Individual points may vary and probably result from variations in interpolating age of the ocean floor. In any case, the curve (best fit line) should illustrate the general pattern: heat flow decreases with increasing age of the ocean floor.

Table 1.
Heat flow values and estimated age of ocean crust.

Isochron Numbers	*Heat Flow Value*	*Estimated Age of Ocean Crust*
0–10	2.9	**6** million years
	3 5	**9** m.y.
	3 16	**6** m y.
10–20	2.7	**18** m.y.
	2.3	**17** m y.
	1 95	**18** m.y.
	2 4	**13** m.y
	2 1	**15** m.y.
20–30	1.27	**27** m.y.
	1 4	**26** m.y.
30–40	1.60	**34** m.y.
	1 66	**35** m.y.
	1 15	**33** m y.
40–50	1 6	**44** m.y
	1 3	**45** m.y
50–60	1 0	**54** m.y
	1 19	**55** m.y
	1 23	**60** m.y
60–75	0.9	**69** m.y.
	1 07	**62** m.y
75–90	0 8	**79** m y.
	0 7	**87** m y
	1 06	**81** m y
90–115	0 71	**96** m.y
	0 88	**97** m y

4. Use the data in Table 1 to complete the graph of heat flow units and age of ocean crust on the Worksheet. Mark your graph where each heat flow value matches the age of the ocean floor. The first three points are already plotted for you.

5: Connect the points you have plotted on the Worksheet with a smooth curve. (Do not connect each point on the graph. Draw a line which is the "average" of all the points.) Compare your graph to the graph your teacher will show you. Is your graph different? How do you explain any differences you observe? Describe the relationship between heat flow and the age of ocean floor.

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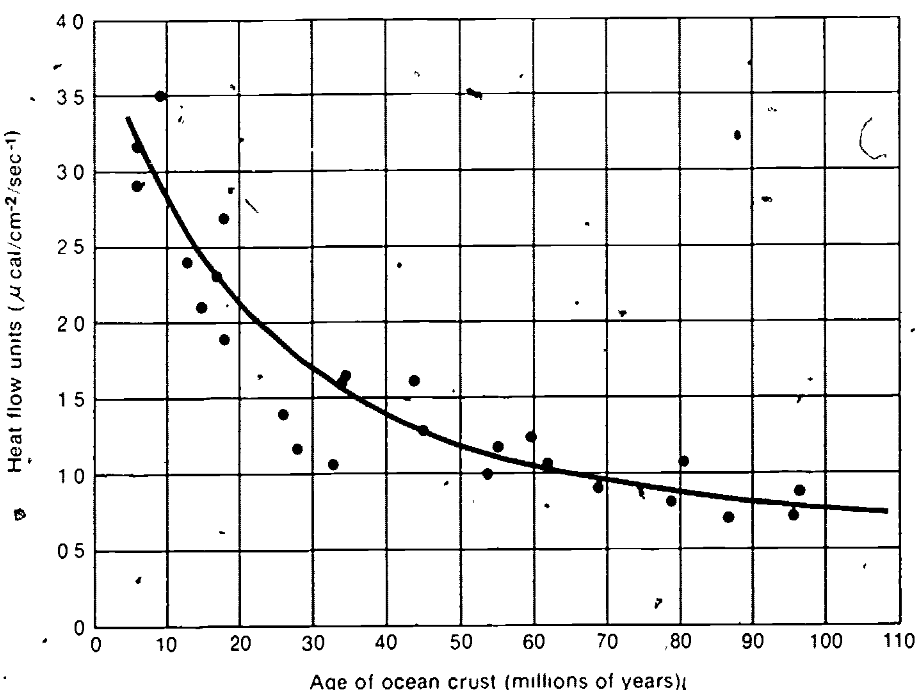
	2 7	**18** m.y.
10–20	2.3	**17** m.y
	1 95	**18** m y
	2.4	**13** m.y.
	2.1	**15** m.y.
20–30	1.27	**27** m y
	1 4	**26** m y.
	1 60	**34** m.y.
30–40	1 66	**35** m y.
	1 15	**33** m.y.
40–50	1 6	**44** m.y
	1 3	**45** m.y
	1 0	**54** m y
50–60	1.19	**55** m y
	1 23	**60** m y
60–75	0 9	**69** m.y.
	1 07	**62** m y
	0 8	**79** m y.
75–90	0 7	**87** m y
	1 06	**81** m y
90–115	0 71	**96** m y
	0 88	**97** m.y



4 0
3 5
3 0
2 5
2 0
1 5
1 0
0 5
0
Heat flow units (μ cal/cm^{-2}/sec^{-1})
0
10
20
30
40
50
60
70
80
90
100
110
Age of ocean crust (millions of years)

SUMMARY QUESTIONS

1. Describe the general pattern of heat flow values with increasing age of the ocean floor.

Heat flow decreases as age of the ocean floor increases.

2. Why do ocean ridges have greater heat flow values than other areas of the ocean floor?

Spreading centers, such as the Mid-Atlantic Ridge and the East Pacific Rise, are places where material from the earth's upper mantle reaches the surface. Measurements of the earth's thermal gradient indicate the temperature of the rock material in the mantle is hotter than at the surface, thus contributing to higher heat flow values.

3. Remember that the 0 million-year isochron is a spreading center. Can you suggest a reason why heat flow decreases as the sea floor gets older?

The heat flow values decrease as time increases. The older rocks have existed a longer time, giving up their heat. Consequently, older ocean crust tends to have lower heat flow values.

The behavior of heat flow with age has been described mathematically (see Figure A) and vindicated experimentally.

REFERENCE

Sullivan, W., 1974, *Continents in motion*. New York, McGraw-Hill Book Company, p. 61–68.

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

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CRUSTAL EVOLUTION EDUCATION PROJECT

NAME DATE

Student Investigation

Catalog No 34W1112

How Does Heat Flow Vary In The Ocean Floor?

INTRODUCTION

Did you ever think that heat is coming from the floor of the ocean? Scientists have found that the heat flowing from the floor of the ocean is not the same everywhere Scientists have found areas of ocean floor that have much greater heat flow than other places They have discovered interesting patterns of high and low heat flow on the ocean floor

Heat always travels or "flows" from a point of higher to lower temperature This phenomenon has been called **heat flow.** To understand this, think of water flowing down a slope, through a channel with a cross section of one square meter in area The "water flow" is the amount of water going through the one square-meter channel each second The amount of heat flowing through a square centimeter area each second is the heat flow Heat is flowing out of the earth to the bottom of the ocean somewhat like water flows in a stream.

If there is a difference in temperature between any two points being measured, heat will flow from the point of higher temperature to the point of lower temperature The greater the difference in temperature, the higher the rate of heat flow

A **heat probe** is an instrument that is lowered from a ship to measure heat flow in the ocean crust Heat flow values are written as microcalories per square centimeter per second ($\mu cal/cm^{-2}/sec^{-1}$) That is the amount of heat measured in calories passing through one square centimeter each second

In this activity you will investigate heat flow patterns in the northeast Pacific Ocean

OBJECTIVES

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

1. Estimate the rate at which heat is flowing out of any part of the ocean floor in the northeast Pacific Ocean

2. Estimate the rate at which heat flows out of any ocean floor of a particular age

3. Estimate the age of ocean crust using heat flow measurements.

4. Make a hypothesis about the relationship between heat flow and age of the ocean crust.

PROCEDURE

Materials pencil and metric ruler

In this activity you are going to investigate the pattern of heat flow in part of the northeast Pacific Ocean

Figure 1 is a map of part of the Pacific Ocean floor The map shows individual heat flow measurements (numbers are next to points where heat flow measurements were taken). The map also shows **isochrons** (*iso* meaning **same;** *chron* meaning **age**) Isochrons are lines of equal age The ocean floor along an isochron is the same age. The number on each isochron is the age of the ocean crust in millions of years Notice that the isochrons are offset at certain places.

Notice the heavy line on the right side of the map This line represents a **spreading center** (a region where new ocean crust material is being added to the present ocean crust)

1. What is the age of the ocean floor along the line where spreading occurs?

There are two to five heat flow measurements between each pair of isochrons. Notice that the heat flow values are usually not exactly on an isochron You will have to estimate the age of the ocean floor where each heat flow value was measured

2. If a heat flow value is located exactly between isochron 10 (10 million years old) and isochron 20 (20 million years old), how old is the floor of the ocean at that point?

3. Determine the age of the ocean floor for each heat flow point shown in Figure 1. You may want to use a ruler to get the best estimate. Enter the estimated age in Table 1 next to the matching heat flow value

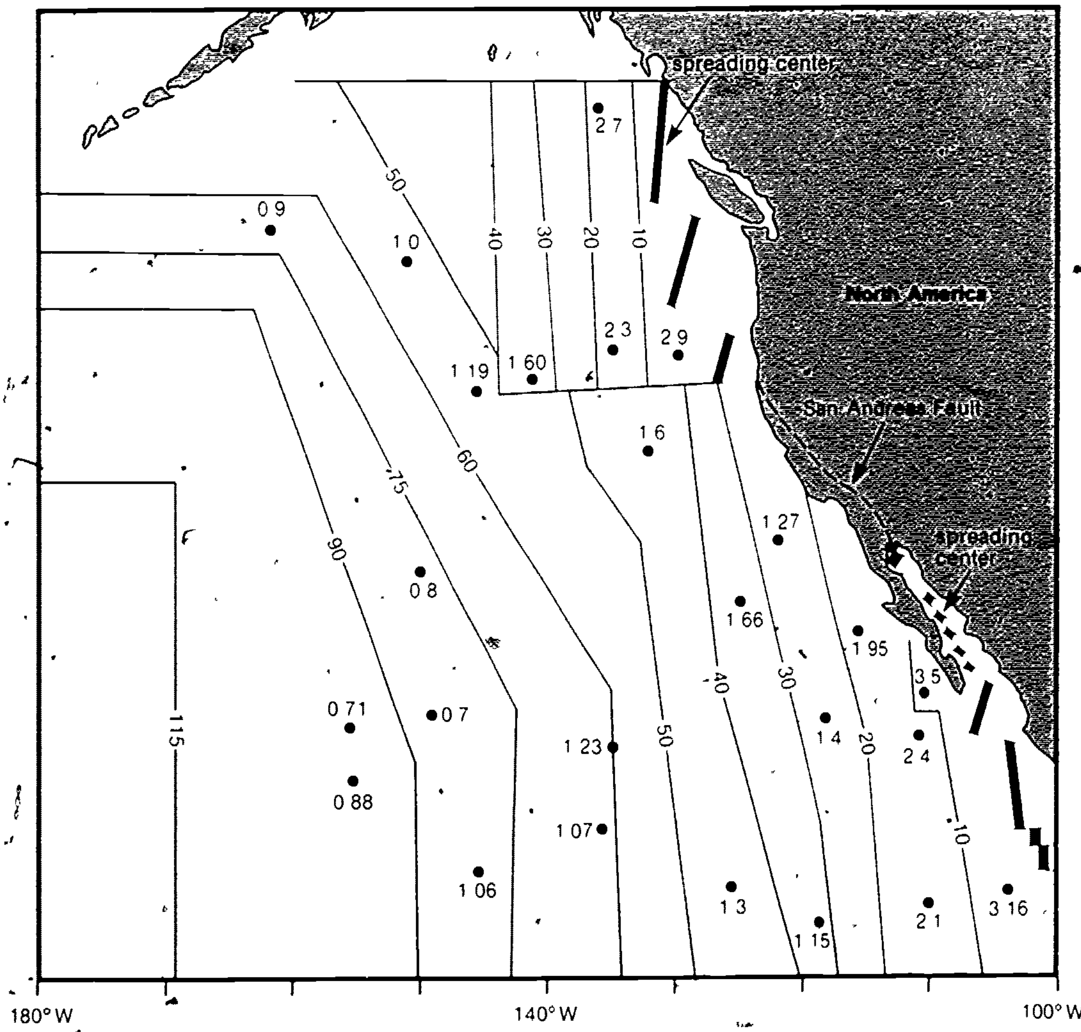

Figure 1. Map of heat flow values in the northeast Pacific Ocean

4. Use the data in Table 1 to complete the graph of heat flow units and age of ocean crust on the Worksheet Mark your graph where each heat flow value matches the age of the ocean floor The first three points are already plotted for you

5. Connect the points you have plotted on the Worksheet with a smooth curve. (Do not connect each point on the graph. Draw a line which is the "average" of all the points) Compare your graph to the graph your teacher will show you. Is your graph different? How do you explain any differences you observe? Describe the relationship between heat flow and the age of ocean floor.

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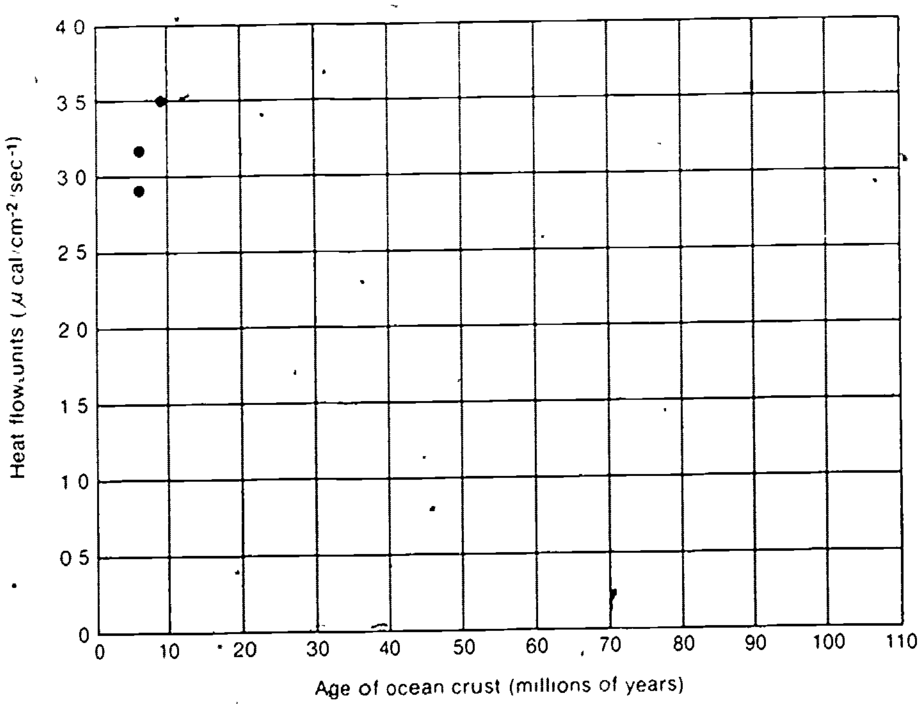
	3 16	6 m.y
10-20	2 7	m y
	2 3	m y.
	1 95	m y.
	2 4	m y
	2 1	m y.
20-30	1 27	m.y
	1 4	m y
30-40	1 60	m y.
	1 66	m y
	1 15	m y
40-50	1 6	m.y.
	1 3	m y
50-60	1 0	m y
	1 19	m.y
	1 23	m y
60-75	0 9	m y
	1 07	m y
75-90	0 8	m y
	0 7	m.y
	1 06	m y
90-115	0 71	m.y
	0 88	m y



Heat flow units (μ cal/cm⁻² sec⁻¹)
Age of ocean crust (millions of years)

Worksheet

SUMMARY QUESTIONS

1. Describe the general pattern of heat flow values with increasing age of the ocean floor.

2. Why do ocean ridges have greater heat-flow values than other areas of the ocean floor?

3. Remember that the 0 million-year isochron is a spreading center. Can you suggest a reason why heat flow decreases as the sea floor gets older?

REFERENCE

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