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ABSTRACT

The Ocean Drilling Project brings together scientists and governments from 20 countries to explore the earth's structure and history as it is revealed beneath the oceans' basins. Scientific expeditions examine rock and sediment cores obtained from the ocean floor to learn about the earth's basic processes. The series of activities in this curriculum plan is to simulate some of the activities that would be involved in a scientific expedition. Through cooperative learning groups, students plan and operate a 2-month internationally staffed expedition. Students analyze data that were actually collected during an expedition. The curriculum plan is an interdisciplinary approach to learning about plate tectonics and incorporates decision-making, along with mathematics, geography, and writing skills. As they participate in the simulation, students gain an understanding of how international cooperation is used to study the earth. An outline of the ocean drilling simulation describes activities that: (1) establish the planning committee; (2) develop a cultural awareness of participating countries; (3) develop mapping skills; (4) elaborate on the scientific investigations of the simulation; (5) discuss problems encountered; and (6) evaluate the simulation. (MDH)

OCEAN DRILLING SIMULATION ACTIVITY

CURRICULUM IMPLEMENTATION PLAN (CIP)

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Subjects: Mathematics and Earth Science

Grade Level: 8th

SUMMARY OF CIP

Our curriculum Implementation Plan will simulate the activities conducted at the Ocean Drilling Program (ODP). The ODP is a multinational effort that seeks to understand the structure and the history of the earth beneath the ocean basins through drilling core samples in various locations around the world. Through cooperative learning groups, students will represent the various member countries and staff personnel nedded to complete a leg on the drillship JOIDES Resolution.

The implementation plan will be an interdisciplinary appproach to learning about earth science that will incorporate various skills in geography, writing, and mathematics. Students will learn about plate tectonics through discovery learning activities that utilize actual ODP data. Scientific activities included in the plan are the interpretation of magnetic reversals and sea floor sediments. Students will also conduct an experiment that demonstrates the rate of sedimentation along a rift zone.

In addition to scientific investigations, the plan will incorporate decision making skills. The students will develop logistical plans that will determine various costs, allocations of time, and interpretation of scientific results. Students will also have an opportunity to formulate solutions to various operational problems that may arise during the leg.

As students participate in the simulation of an ODP expedition, they will develop an understanding of how international cooperations is used in the gathering of scientific date to determine how the processes in the oceans have shaped the earth.

PREFACE

This workbook was compiled by the authors during a summer intern program at the Ocean Drilling Program (ODP), arranged through the Texas Alliance for Math, Science, and Technology Education which is sponsored by Texas A&M University; the program is called Teacher-in-Industry.

The Ocean Drilling program receives many requests for educational materials. As part of our internship, we organized information that would be appropiate for jr. high school age childern concerning Earth Science. The gathering of this data was supervised by staff scientists in the ODP Science Operations Department.

We focused on the organization of ODP and provided real-life scientific data that support the Theory of Plate Tectonics. This workbook provides real-life scenarios and interdisciplinary problem solving activities that are either mathematical in nature or require thinking skills to solve, such as deciding various courses of actions, planning a cruise, and how to respond to injuries on board the ODP oceanographic research ship, JOIDES Resolution.

A Current educational trend is to have students work in cooperative groups. ODP is a world wide scientific, cooperative organization which is ideal to model in the classroom since scientists from various countries work together towards a common goal. We hope you find the material interesting and rewarding for you and your students.

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OUTLINE OF OCEAN DRILLING SIMULATION ACTIVITY

I. Planning Committee
   A. Composition of membership
      1. Representative from each member country
      2. Majority vote determines policy decisions
   B. Policy Decisions
      1. Time allocation per site
      2. Port of call (arrival/departure/emergencies)
      3. Strategies for achieving scientific objectives

II. Cultural Awareness of JOIDES member countries
   A. Background information
      1. unique customs
      2. geographic location
      3. unique geologic features
      4. flag of country
   B. Oral presentation
      1. prepare and share foods of the nation
      2. explain unique customs and folklore
      3. wear dress appropriate to the nation

III. Mapping Skills
   A. Geographic location
      1. Plot the drilling sites using latitude and longitude
      2. Locate participating member countries on a world map
   B. Ocean Map
      1. Compare topography of various drill sites
      2. Label major geologic features of the Atlantic Ocean

IV. Scientific Investigations
   A. Magnetic Anomalies
      1. Comparison of seismic chart to magnetic anomaly profiles
      2. Use magnetic record and seismic data to determine rate of spreading along the mid-ocean ridge
   B. Sea floor spreading activity
      1. Demonstrate how the record of marine sedimentation records ocean history and development
      2. Determine the approximate relative age of sediment along a rift zone
   C. Lithographic analysis
      1. Determine the correlation of the drilled sites by examining various stratigraphic columns
      2. Interpret the geologic history of the mid-ocean ridge by analyzing the fossil record
   D. Core analysis
      1. Calculate the presence of carbonate material in various sediment samples
      2. Determine the density of various sediments

E. How did the North Atlantic Form?
   1. groups create paper model of the Atlantic Ocean as it develops over geologic history
   2. determine how bedrock reveals the history of the Atlantic Ocean

V. Problems
   A. Math Calculations
      1. Drill pipe estimates
      2. Fuel consumption rates
      3. Cost estimates
   B. Operational Problems
      1. Encounter five real or imaginary problems that can be encountered during a leg
      2. As a team, formulate possible solutions to the problem

VI. Evaluation of ODP Simulation
   A. Reports
      1. Oral team presentations on scientific results
      2. Oral team presentations on member countries
   B. Written reports
      1. Math calculations
      2. Operational problems

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OCEAN DRILLING SIMULATION ACTIVITY

O''ERVIEW OF THE OCEAN DRILLING PROGRAM:

Let's bring up the past! Some people would like to keep the past hidden as if it were something to be avoided; but not JOIDES, Joint Oceanographic Institutions for Deep Earth Sampling. As in the study of History, these scientists are learning about the oast, Earth's past, and they bring up deep, dark secrets from the depths of the ocean.

However, JOIDES is within the structure of the Ocean Drilling Program. The Ocean Drilling Program (ODP) brings together scientists and governments from 20 countries to explore our planet's last frontier- Earth's structure and history as it is revealed beneath the oceans' basins.

Under the sponsorship of ODP, scientists from around the world participate in a continous series of scientific cruises called Legs, each approximately eight weeks long, aboard the drill ship JOIDES Resolution.

During these cruises, scientists retrieve cores of sediment and rock and obtain geophysical data from holes drilled into the seafloor. The cores are slender cylinders approximately 31 feet (9.5 meters) long; they contain clues to Earth's origin, evolution and present day structure. Scien tists examine the cores to learn about Earth's basic processes including: a) rearrangement of the continents (Plate Tectonics), b) evolution of life in the sea, c) cycles of glaciation, d) changes through time in global climate, ocean currents, worldwide sea levels and e) Earth's magnetic field.

What type of scientists are on board? There are representatives from many scientific disciplines who contribute to our basic understanding of Earth's history. For example, Paleontologists examine microfossils preserved in the oceans' sediments to better describe the timing, nature and causes of evolutionary changes. Geochemists and sedimentologists analyze the records of composition, ocean temperatures and currents revealed in the sediments and rocks to reconstruct ancient sources, climates and depositional environments. Geophysicists study measurements taken in the drilled hole to better understand the temperatures, structure, and composition of the earth beneath the seafloor, as well as study Earth's paleomagnetism. Let's not forget the Engineers who aide in designing equipment that must operate under extreme physical environments in the oceans and who design drilling operations.

Futhermore, the Ocean Drilling program is a continuation of the work of the Deep Sea Drilling Project (DSDP) which was establised in 1966 at the Scripps Institution of Oceanography. Between 1968 and 1983, Scripps used the drilling vessel Glomar Challenger to drill the ocean floor mainly to verify the Theory of Plate Tectonics, as well as to gather other data.

As mentioned, the Deep Sea Drilling Project was the forerunner to the Ocean Drilling Program. ODP is funded by the National Science Foundation (NSF). The National Science Foundation has chosed the Joint Oceanographic Institutions, Inc., (JOI) to act as manager of ODP. JOI is composed of ten institutions of higer education that are located across the United States. Texas A&M is currently the Science Operator for the Ocean Drilling Program responsible for staffing scientists, implementing at sea the recommendations of the JOIDES Planning Committe for drilling, coring, and logging, after the recommendations have been reviewed operationally and approved by ODP/TAMU management; they also oversee scientific reports that are generated during the cruise.

The purpose of the activities in this curriculum plan is to simulate some to the activities that would be involved in a scientific expedition. Through cooperative learning groups, students will be responsible for the planning and operations of a two month internationally staffed expedition. Students will also analyze the data that was actually collected during an expedition. The curriculum plan is an interdisciplinary approach to learning about plate tectonics and will incorporate decision-making, along with math, geography, and writing skills. Finally, as students participate in the simulation of a scientific expedition, they will gain an understanding of how international cooperation is used to unlock the secrets of the earth.

OVERVIEW OF SIMULATION ACTIVITIES

I. Planning

The planning phase of the expedition will be in two parts. The first part will be determining the logistics needed to complete a leg. Students should work in teams of four students to complete the problems listed on the "Problems of Logistics." Students should be ready to discuss their findings with the other groups.

The second part of the planning stage will be completed by the Planning Committee. Every group of four students should represent one of the twenty JOIDES member countries. Within each member country consortium, a group leader should be chosen. This leader will represent the other group members in the decisions needed for executing a successful scientific expedition. Each group leader will use the input from their original team in determining operational and planning decisions necessary for the execution of a successful leg.

Prior to making decisions on the logistic, planning, and operational problems, students should be familiar with the objectives and location of sites for this expedition.
Decisions will be made by majority voting. Each team leader can vote only once on an issue.

II.MEMBER NATION REPORTS

In an attempt for students to gain an appreciation for diverse cultures and improve their geography skills, students should research and prepare an oral report on one of the JOIDES member countries. The students should try to dress in native costumes and prepare dishes that are representative of the country that they researched. In addition, students should create a model of the flag for that nation. As the groups give their oral reports to the class, the other students should be able to label the member country on a world map. The specifics for the report are given on the worksheet title "Around the World."

III. MAPPING SKILLS

To appreciate the data collected, the students should have an understanding on where the drill sites were located. The students should plot the drill sites on a map using latitude and longitude. In addition, a bathymetric contour map activity will give the students an appreciation for the topographic contours of the ocean. This would also be a good time to review the various topographic features of the seafloor and label these features on a map.

IV. SCIENTIFIC INVESTIGATIONS

A variety of scientific activities have been included in this packet to try to clarify the idea of sea-floor spreading and plate tectonics. The activities try to emphasize that data from magnetic anomalies and evidence from fossils within a stratigraphic column tell scientists that the earth is constantly changing. This data should show the student that the earth is adding new crustal material along a rift zone.

V. SUPPLEMENTARY ACTIVITIES

A variety of lab activities could supplement the investigations included in this packet. Additional activities might compare the gravitational attraction and temperature variation along the mid-ocean ridge as in the lab experiment titled "Geophysical Investigations" by Thomas McGuire. Other activities of interest might be "How did the North Atlantic Form?" by Paul Johnston. This activity gives the students an overview of the changes the Atlantic Ocean has undergone over time. Students can determine the percent of calcium carbonate by completing the activity titled "Analyzing a Rock Containing Two Minerals" by Frank H. Roberts. These activities can be found in the lab manual titled Earth Science Investigations published in 1990 by the American Geological Institute.

VI. CONCLUSION

By the end of this simulation activity, the students should have an overall understanding of the changes the earth has undergone along a mid-ocean ridge. The students will be able to realize that the history of the earth is constantly changing. Scientists try to determine the history of the earth by analyzing sediment records and comparing the sediment to the paleomagnetic record.

To check for the student's understanding of these concepts, each group could be assigned to interpret the data collected on this scientific expedition. Reports on paleomagnetism, sea-floor spreading, stratigraphic correlation,and logistics could be summarized through brief group summaries presented to the class.

"IN SEARCH OF EARTH'S SECRETS" SUMMARY OF OCEAN DRILLING SIMULATION ACTIVITY

The simulation of the Ocean Drilling Program was devised for students to learn about plate tectonics while incorporating cooperative learning activities. The activities listed in this plan can be a month-long teaching unit on plate tectonics or the activities can be used individually to supplement the activities already used in the classroom. The activities were planned so that students were placed in cooperative learning groups consisting of four students. Each student should have a specific role to play in each activity. The roles utitilized in each activity can vary and the teacher should try to get students to play a different role for each assigned activity.

Cooperative learning roles could include titles such as writer, checker, materials coordinator, and encourager. The writer is responsible for making sure that the students in the group each write down the answers to the assigned activities. The checker makes sure the spelling, grammar, and math for the activity is correct. The materials coordinator would gather the lab materials or worksheets needed for the activity. This person is also responsible for cleaning up the lab materials. The encourager makes sure that each student participates in the activity. In addition, the encourager makes sure that each person in the group has input into a problem or question. The encourager will get everyone to agree to an answer before the writer places the information onto the worksheet. All activities and answers should be a cooperative effort.

During this simulation, students will participate in a modified version of a scientific expedition. The Ocean Drilling Program refers to these two month expeditions as legs. Each leg has specific scientific objectives. To achieve these objectives, holes are drilled into the sea floor so that scientists may analyze the sediments and rocks recovered in the cores. The areas of the sea floor designated by scientists as areas necessary to reach their objectives are called sites. Within each site, there can be one or more holes drilled since the first hole may not meet the intended objective of the site.

During this simulation activity, students will have an opportunity to experience a wide variety of problems and analyze site data on their mock expedition to the Mid-Atlantic Ridge.

AROUND THE WORLD
MEMBER NATION ORAL REPORTS

REQUIREMENTS FOR REPORT:

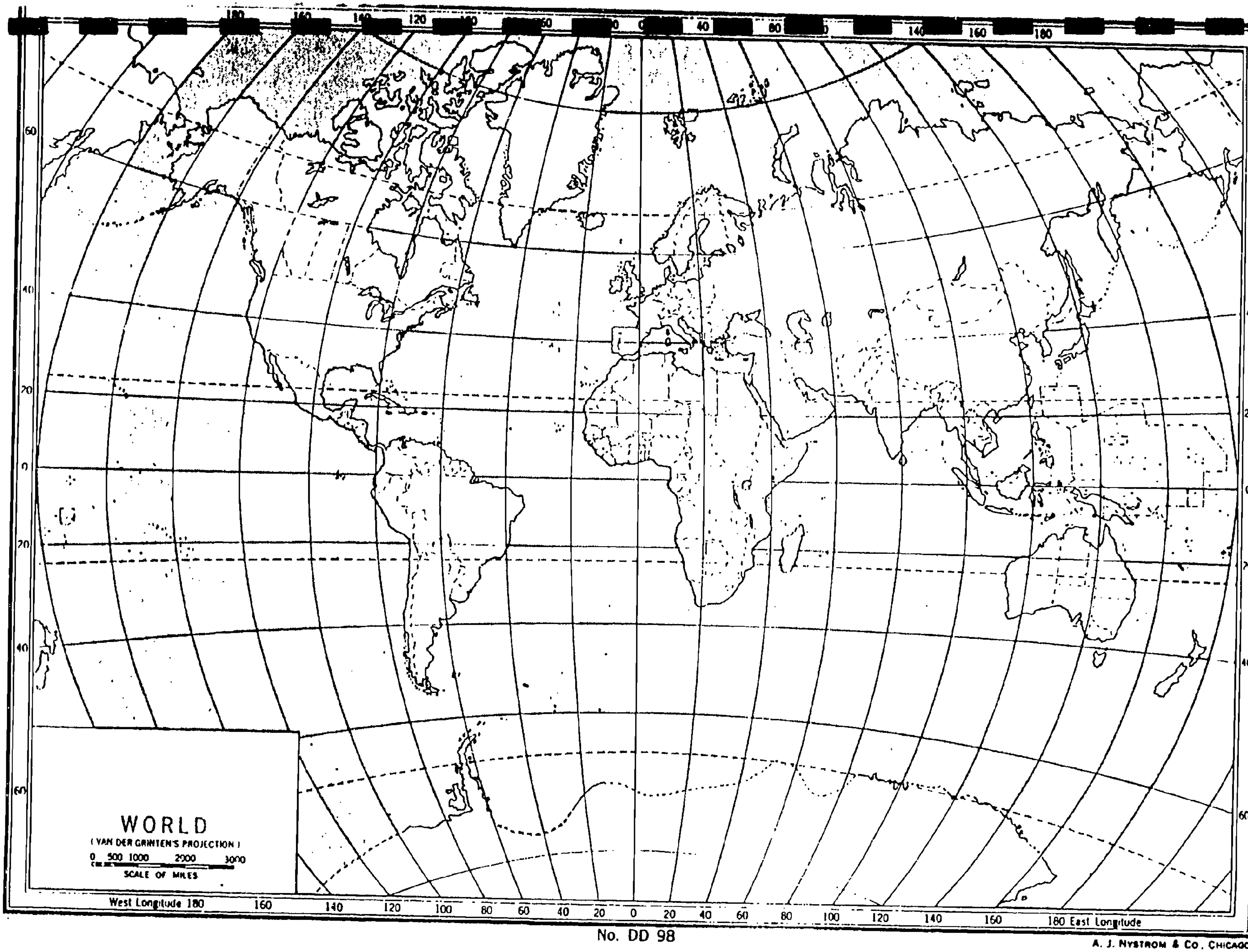
Your team will present a five minute report on one of the JOIDES member countries. Each person should research a specific topic and be prepared to present this information in form of an oral group presentation to the class. All presentations should include the following information for the chosen country:

1. System of government
2. Unique customs of the country
3. Major geologic features of the land
4. Major industries of the nation
5. Map of the country showing major cities, rivers, and geologic features
6. A paper model of the flag of the country along with an explaination of its symbolic meaning

The reports should be about one to two pages per topic. In addition, the students should dress in costumes native to the country that they are describing. Finally, the group should prepare various foods that are representative of that country to share with the class.

Your group should choose one of the following countries for your report:

A. Japan
B. United Kingdom
C. Canada
D. Russia
E. Federal Republic of Germany
F. Italy
G. Australia
H. Belgium
I. Denmark
J. France
K. Iceland
L. Sweden
M. Switzerland
N. Turkey
O. Norway
P. Spain
Q. Finland
R. Greece
S. Netherlands



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JOIDES' PLANNING COMMITTEE

How does an ODP cruise begin? Well, each ODP cruise has its origins in drilling proposals submitted to the JOIDES Office. The proposals allow individual scientists and groups to have the opportunities to respond to the major thematic priorities for ODP. The themes are agreed upon at a meeting of a group of worldwide scientists that discuss the philosophy and major goals of ODP.

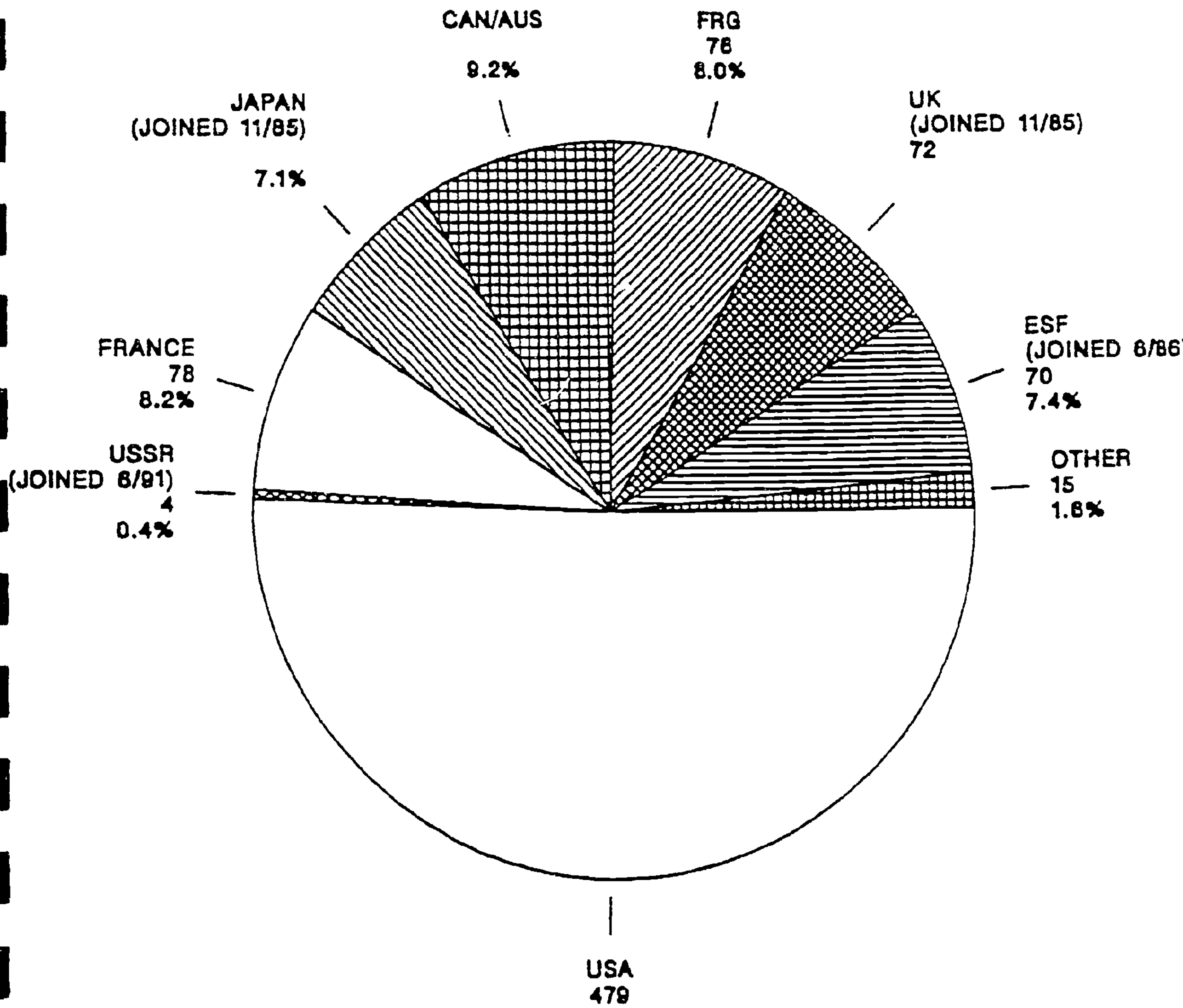
Proposals are submitted to a Thematic Panel which is a group of scientists that represents a scientific field, such as lithospheric scientists, who prioritize the proposals and advises the Planning Committee on their recommendations. The Thematic Panel is concerned with the processes of science, developing scientific drilling objectives and defining long term scientific goals of Ocean Drilling.

The Planning Committee monitors and directs the proposal review process, reviews the recommendations of the advisory panels, decides the fate of proposals, and ultimately intergrates the approved proposals into a detailed drilling plan and ship's track.

Since it may be impractical to fully model ODP's Planning Committee in the classroom, it is suggested that students form a mock Planning Committe whose task will be to solve the given planning problems. Further information concerning this is given in the section Overview of Simulation Activities.

SHIPBOARD PARTICIPANT TALLY
LEGS 101 - 139

(January 1985 - September 1991)



TOTAL 948 PARTICIPANTS

Use the pie chart to answer the following questions:

1. What is the total number of participants?

2. What is the percent of USA participants?

3. The United Kingdom had 72 participants. What is their percent participation?

4. How many participants were from Japan?

5. How many participants were from Canada-Australia?

6. If the United States provides 50% of the funding for the Ocean Drilling program, is the number of US participants adequate? Explain your answer.

7. Canada and Australia are partners in the program. Canada is allowed 2/3 of their allotment of participants. If the partnership is allowed 6 participants on a cruise to the Great Barrier Reefs, how many can Australia have?

Solutions to Shipboard Tally

1. 948
2. 50.5%
3. 7.6%
4. 67
5. 87
6. Yes, because the number of US participants is in line with the funding.
7. 2, 1/3 of 6

PLANNING PROBLEMS FOR A SCIENTIFIC EXPEDITION

PLANNING COMMITTEE:

The Planning Committee will consist of a team leader from each of the member countries. The committee will be responsible for making some planning decisions necessary for a successful scientific expedition. The team leaders will vote to determine the plan of action needed to solve the planning problems. In the case of a tie, the teacher's decision will determine the policy that will be enacted. Students should review the objectives and location of drill sites before discussing the problems below.

PLANNING PROBLEM NUMBER 1:

Based on the objectives of the leg, what type of scientists will be needed on this expedition? Briefly give a job description for each type of scientist chosen. (Use the information on the sheet titled "Responsiblities of Shipboard Scientists" to guide you.)

PLANNING PROBLEM NUMBER 2:

If an accident occurred while the ship was drilling for core samples along the mid-ocean ridge, where would the injured person be taken to receive medical attention? How would the person be transported to the medical facility?

PLANNING PROBLEM NUMBER 3:

A typical planning problem would involve the selection of shipboard scientists for a leg. The Co-Chief Scientists are selected by ODP/TAMU from a list of names submitted by the JOIDES Planning Committee. The Co-Chief reviews the applications of scientists wishing to participate on an expedition. A team of twenty four scientists is chosen for each leg. All non- U.S. partners in the consortium usually have two shipboard scientists on each leg. The rest of the scientists are from the United States.

The following countries should be represented in the selection of the scientists:

United States
USSR (Russia)
France
Canada/Australia
Germany
UK (England)
Japan
European Science Foundation: (Italy, Greece, Belgium, Denmark, Iceland, Sweden, Switzerland, Turkey, Norway, Spain, Finland, and the Netherlands)

In addition, each branch of science must be represented on the ship. Assume that the needs of the leg can be met by staffing:

- 4 Sedimentologists
- 4 Paleontologists
- 4 Paleomagnetists
- 2 Inorganic Chemists
- 4 Petrologists
- 4 Physical Property Specialists
- 2 Organic Chemists

Also assume that each applicant is an expert in his or her field of study. Thirty five scientists applied for twenty four positions. Your group is to determine which scientists will participate on the expedition. Remember, each member country should be represented along with the correct number of scientists for each discipline.The following scientists have applied to participate on the leg.

COUNTRY	NUMBER	TYPE OF SCIENTIST
U.S.A.	4	Paleomagnetists
	3	Physical Properties Specialists
	3	Petrologists
	2	Paleontologists
	1	Sedimentologist
Canada	2	Paleontologists
	1	Organic Geochemist
USSR	1	Petrologist
	2	Sedimentologists
Germany	1	Organic Geochemist
	1	Paleomagnetist
France	1	Physical Properties Specialist
	1	Sedimentologist
European Science Foundation	2	Organic Geochemists
	1	Petrologist
	1	Sedimentologist
Japan	1	Sedimentologist
	1	Paleomagnetist
	2	Inorganic Geochemists
U.K.	1	Paleontologist
	1	Organic Geochemist

PROBLEM 3A:

Make the staffing decisions needed to make this a successful internationally staffed expedition based on the criteria listed above.

PROBLEM 3B:

Occasionally on an expedition, a country may request more than their normal share of scientists. For example, when an expedition studied the Sea of Japan, the Japanese requested four scientists be staffed for this expedition. How would you deal with this situation?

Ocean Drilling Program Cruise Participant Application Form

Name (first, middle, last) ____________________

Institution (including address) ____________________

____

Telephone (work) __________ (home) __________ **Telex/Cable** __________ **Fax** __________

Permanent Institution Address (if different from above) ____________________

____

Bitnet Address ____________________

Present Position __________ **Country of Citizenship** __________

Place of Birth __________ **Date of Birth** __________ **Sex** ______

Passport No. __________ **Place Issued** __________ **Date Issued** __________ **Exp. Date** ______

Geographic Region(s), Scientific Problem(s) of Interest (Leg number(s) if known) ____________________

____

Date(s) Available ____________________

Reason(s) for Interest (if necessary, expand in letter) ____________________

____

Expertise (petrologist, sedimentologist, etc.) ____________________

Education (highest degree and date) ____________________

Experience (attach curriculum vitae) ____________________

____

____

Selected Publications You Have Written Relevant to Requested Cruise ____________________

____

____

Personal and/or Scientific References (name and address) ____________________

____

Previous DSDP/ODP Involvement and Nature of Involvement (i.e. cruise participant, shore-based participant, contributor, reviewer, etc.) ____________________

____

Staffing decisions are made in consultation with the co-chief scientists and take into account nominations from partner countries; final responsibility for staffing rests with ODP at TAMU. Please return this form to: **Manager of Science Operations**
Ocean Drilling Program
Texas A&M University Research Park

Responsibilities of Shipboard Scientists

Shipboard scientists collect, analyze and compile data conforming to ODP standards and format. They assist the co-chief scientists in producing shipboard scientific reports by recording data on standard ODP computerized and paper forms and writing a description of their disciplines' results for each site chapter of the *Initial Reports of the Proceedings of the Ocean Drilling Program.*

Scientists aid the curatorial technician by taking samples for themselves and others for later shore-based study. A team of highly trained marine technicians, some specializing in particular equipment areas, assist the shipboard scientists by maintaining the flow of core samples through the laboratories and helping with analyses.

At the end of the cruise, the shipboard scientists are requested to complete cruise evaluations. These evaluations guide ODP in upgrading laboratory equipment and procedures and in improving life on board ship.

Shipboard scientists are primarily on board to pursue their own scientific interests. After the cruise, they are responsible for analyzing their samples and reporting the results, which are included in the ODP database and published in the cruise volumes. Following is a brief description of the shipboard responsibilities of the scientific staff.

Sedimentologists provide accurate visual and written descriptions of the cored sediments and interpret the depositional and diagenetic history or other related sedimentological processes. They work as a team, designating a lead sedimentologist for each site and exchanging specific responsibilities from site to site. Sedimentologists' responsibilities include:

- written and graphic core descriptions on ODP data forms, including the sedimentologic portion of core description sheets (barrel sheets)
- smear-slide preparation and petrographic analysis of smear slides and thin sections
- selection of samples for shipboard analyses of XRD, XRF, carbonate percentage and thin sections

The **paleontologists'** chief responsibility is to assign an age to the core-catcher samples as soon as possible after cores are recovered. They may need to examine additional samples to provide as complete a biostratigraphic characterization of the cored section as possible within the time available, including recognition of boundaries and hiatuses.

A reference library with texts, journals and reprints is available to help shipboard paleontologists identify fossil groups that do not fall within their areas of expertise.

Petrologists classify thin sections and hand specimens and provide the written and graphic descriptions of all igneous and metamorphic rocks recovered on the cruise. Petrologists should be experienced in one or more of the following aspects of the petrology of oceanic rocks: chemical petrology, volcanology, mineralogy and petrography.

Paleomagnetists conduct or supervise all paleomagnetic measurements including the reduction of paleomagnetic data to intensities and direction of magnetization.

Paleomagnetists work with other shipboard scientists and the drilling crew to ensure that core material is not magnetically damaged by heating or exposure to strong magnetic fields and that core sections are not inverted.

Physical properties specialists select cores to determine velocities, shear strength, thermal conductivity and index properties (water content, porosity and bulk density). They also ensure that data are collected in a manner consistent with ODP format. The physical properties specialists and the sedimentologists select samples for carbonate analyses.

Organic geochemists monitor cores for gas and oil (hydrocarbon accumulations) and organic compounds. They advise when hydrocarbons in cores may constitute a safety or pollution hazard.

Inorganic geochemists are primarily responsible for conducting interstitial water, X-ray diffraction (XRD)and X-ray fluorescence (XRF) analyses. ODP chemists and marine technicians assist in these analyses.

Logging scientists advise the co-chief scientists on the logging program for the cruise. They work closely with the Schlumberger field engineer and the Lamont-Doherty Geological Observatory logging scientist in designing, implementing and interpreting the logging program.

SOLUTION KEY - PLANNING PROBLEMS FOR A SCIENTIFIC EXPEDITION

POSSIBLE SOLUTIONS

The students could formulate a variety of possible solutions to these problems. The Planning Committee should be able to support whatever decision they agree upon in a written explanation. Some possible solutions are listed below.

PLANNING PROBLEM NUMBER 1:

Since Leg 37 is going to the Atlantic Ocean to study the basaltic rocks formed from a rift zone, the majority of shipboard scientists should have a varied background in studying igneous rocks. The team of shipboard scientists should include:

A) Paleontologist - This person would try to determine the age of the sediments by correlating fossils.

B) Petrologist - This person helps classify all the igneous rocks collected in the core samples.

C) Paleomagnetist - This person would conduct various magnetic measurements on the rocks.

D) Sedimentologist - This person would create a written and visual record of the sediment collected on the cruise so that a geologic history of the area can be pieced together.

E) Organic Geochemist - This person would monitor the cores for gas and oil by testing for the presence of hydrocarbons.

Additional types of scientific specialists might include inorganic geochemists, logging scientists and physical properties specialists. Most expeditions will include at least a representative from each scientific discipline.

An organic geochemist does various X-ray analyses. A logging scientist may conduct various tests through the drilling hole. A physical properties specialist conduct tests on the cores. These tests will determine the velocity, shear strength, thermal conductivity, and index properties (water content, porosity, and bulk density) of the core sample.

SOLUTION TO PROBLEM 3B:

In this situation, ODP would try to fill the special request of that nation. The other nations would be informed of the request. In addition, the other JOIDES member countries should also be given an additional staffing opportunity on future expeditions.

LOGISTICS

CRUISE DURATION: 60 days.

FUEL: 500,000 gallons (marine gas oil) loaded at every port call.
Fuel Capacity: 1,000,000 Gallons.
322 gals. = 1 metric ton.
Average Cost = $190/metric ton.
During Persian Gulf war, average cost = $365/metric ton.

OIL (for main engines): 55,000 gallons loaded during every port call.
Cost = (assume) $5.00/gallon.

FOOD: 10 tons loaded during every port call.
Average Cost: $70,000.

WATER: 14,000 metric tons loaded during every port call.
Average Cost = (assume) $2.00/gallon.

DRILL PIPE: (2 strings on board).
Total Length = 30,000 feet (9,150m) for each string.
Average Cost = $650/30 feet of pipe.

SPARE PARTS: Average Cost = $150,000 worth used every cruise.

TRAVEL COSTS OF CREW: variable (Depends on where the crew members live in the world).

SCIENTIFIC AND TECHNICAL PARTY: 51

SHIP'S CREW: 68

SPEED AND CRUISING RANGE: 11 knots per hour and 120 days.
(speed may vary if fuel conservation is required)

PROBLEMS OF LOGISTICS

NOTE TO THE TEACHER: THE FOLLOWING ARE EXAMPLE PROBLEMS USING THE DATA FROM THE LOGISTIC PAGE. YOU MAY CREATE YOUR OWN SET. THIS PROVIDES AN OPPORTUNITY FOR THE STUDENTS TO USE REAL LIFE DATA IN SOLVING MATH PROBLEMS; MOST OF THE QUESTIONS DEAL WITH RATIOS AND PROPORTIONS. THE NATIONAL COUNCIL FOR THE TEACHERS OF MATHEMATICS IS RECOMMENDING USING MATHEMATICAL COMMUNICATION IN THE CLASSROOM TO ENHANCE THE LEARNING OF MATH; ENCOURAGE A MATH DIALOG BETWEEN THE STUDENTS WITHIN THE GROUPS AND OUTSIDE OF THE GROUPS.

1. The good ship JOIDES Resolution is sailing towards Majuro, Marshall Islands in the South Pacific; the islands depend on rainfall to supply its water needs. The wet season is June thru December; their reservoir capacity is 22 million gallons, a 45 day supply for the island. The JOIDES Resolution is due to make a port call there. However, the port can not guarantee that water would be loaded on board the ship. You must make port at Majuro. What would you do in case water can not be loaded on board the ship?

2. a) Determine the fuel capacity of the resolution in metric tons.

   b) How much would the fuel cost ODP when the ship pulls into port after 60 days? (500,000 gallons)

   c) What was the cost of the fuel for 500,000 gallons during the Persian Gulf War?

   d) The price of fuel increased from $190 per metric ton to $365 per metric ton. What is the percent increase in the cost of the fuel? How would this effect the operating budget for the ship?

3. How much water, on average, is allocated per person each day aboard the ship?
4. During an actual drilling operation, 6000 meters of drill pipe was lost; it fell to "Davy Jone's Locker", the ocean floor. How much pipe was left on board? (hint: there are two strings on board)

5. How would the loss of drill pipe affect the mission of the ship?

6. What is the cost of the drill pipe on board? Determine the cost of the lost pipe.

7. Determine the total cost of the logistics (fuel-1,000,000 gallons, oil, food, water, drill pipe,and spare parts).

8. Using the answer from question 7, determine the cost per day of a 60 day cruise.

Bonus: Within groups, discuss cities where you live or dream of living in the future, find out what the round trip air fare is from that city to a port call in Acapulco, Mexico. Give the total cost for your group.

SOLUTIONS TO PROBLEMS OF LOGISTICS

1. ODP handled the situation by stocking up on most supplies, including water, prior to departing Honolulu. It was recommended that Majuro be a shortened port call (3 days), due to the limited facilities.

2a. Method 1: $\dfrac{1 \text{ metric tons}}{322 \text{ gallons}} = \dfrac{N}{1{,}000{,}000 \text{ gallons}}$

$322N = 1{,}000{,}000$

$N = 3105.6$ metric tons

Method 2: $1{,}000{,}000 \text{ gal.} \times \dfrac{1 \text{ metric ton}}{322 \text{ gal.}} = \dfrac{1{,}000{,}000 \text{ metric tons}}{322}$

$= 3105.6$ metric tons

2b. Method 1: $\dfrac{3105.6 \text{ m.t.}}{N} = \dfrac{1 \text{ m.t.}}{\$190}$

$1N = \$190 \times 3105.6$

$N = \$\,590{,}062.11$

Method 2: $3105.6 \text{ m.t.} \times \dfrac{\$190}{1 \text{ m.t.}} = \$\,590{,}062.11$

2c. (using method 1)

Step 1: convert gallons to metris tons.

$\dfrac{500{,}000 \text{ gal.}}{N} = \dfrac{322 \text{ gal.}}{1 \text{ m.t.}}$

$322N = 500{,}000$

$N = 1{,}552.8$ m.t.

Step 2: Find the cost of the 1,552.8 m.t.

$\dfrac{N}{1{,}552.8 \text{m.t.}} = \dfrac{\$365}{1 \text{ m.t.}}$ » $1N = 365 \times 1{,}552.8$ » $N = \$566{,}770.19$

2d. % increase = $\frac{\text{amount of change}}{\text{original amount}}$ X 100%

$= \frac{\$365 - \$190}{\$190}$ X 100%

$= \frac{175}{190}$ X 100% » 0.921 X 100% = 92.1% Increase

3. Step 1: Convert metric tons to gallons.(using method 1)

$\frac{14{,}000 \text{ m.t.}}{\text{N gal.}} = \frac{1 \text{ m.t.}}{322 \text{ gal.}}$ » 1N = 14,000 X 322 = 4,508,000 gallons

Step 2: Find the number of gallons per day that are available.

$\frac{4{,}508{,}000 \text{ gal.}}{60 \text{ days}} = 75{,}133.3 \frac{\text{gallons}}{\text{day}}$

Step 3: Divide the number of gallons/day by the total number of people.

75,133.3 ÷ 119 = 631 gallons per day for each person.
(note: this is not all for drinking, other purposes include bathing, cooking, cleaning, etc.)

4. Step 1: Find the total amount of pipe on board before the accident.
Recall: there are 2 strings of pipe each 9,150 meters for total length.

9,15 m X 2 = 18,300 m

Step 2: Subtract the lost section » 18,300m - 6,000m = 12,300m

5. An open response question, ODP modified the scietific goals and proceeded to other locations to obtain data that would require drilling at shallower depths. This occured on Leg 93.

6. $\frac{\$650}{30 \text{ ft.}} = \frac{N}{60{,}000 \text{ ft.}}$ » 30N = 650 X 60,000 ft. » N = $1,300,000

6. (cont.)

Step 1: Convert meters to feet.

$$6{,}000\text{m} \times \frac{3.3 \text{ feet}}{1 \text{ m}} = 19{,}800 \text{ ft.}$$

Step 2: Determine the cost for 19,800 ft. of pipe.

$$\frac{19{,}800 \text{ ft.}}{\$N} = \frac{30 \text{ ft.}}{\$650} \quad » \quad 30N = 19{,}800 \times 650$$

$$30N = 12{,}870{,}000$$

$$N = \$429{,}000$$

7. Sum the following:

FUEL(1,000,000 gal. before the war) = $590,062.11

OIL(lubrication) = $275,000

FOOD: $70,000

WATER: $28,000

DRILL PIPE: $1,300,000 (This is not purchased for each cruise).

SPARE PARTS: $150,000

TOTAL: $2,413,062.11

8. $2,413,062.11÷ 60 days = $40217.70/day (without salaries)

SCIENTIFIC OBJECTIVES OF LEG 37

The information in this teaching unit is based on the actual data collected by the Deep Sea Drilling Program (DSDP) on Leg 37. The information that was collected on this leg has been simplified for use in the classroom.

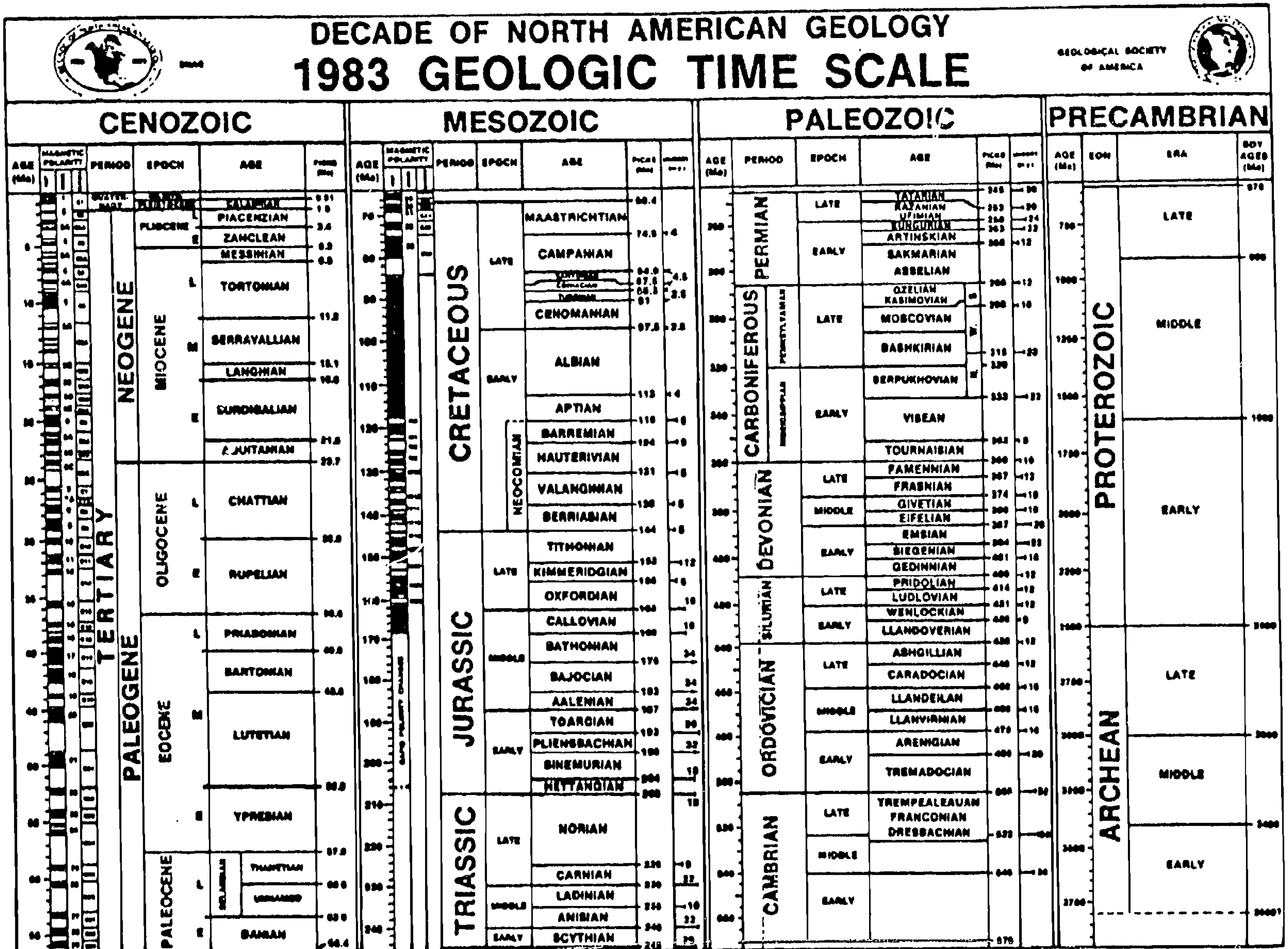
Leg 37 Drilled into the sea floor along the Mid-Atlantic Ridge within a 3-km-wide valley called Deep Drill Valley. This area had previously been surveyed during the FAMOUS (Franco-American Mid-Ocean Undersea Study Area) project. The FAMOUS project used submersibles and remote instruments to identify scarps and faults along the ridge. This area has been of interest to scientists since it is a geologically very young section of the American plate. Scientists were also interested in studying crustal layer 2 which is thickest on the ridge axis.

The main objective of Leg 37 was to penetrate and core into layer 2 of the ocean crust. Layer 2 is located beneath the ocean sediment layer and is usually composed of basaltic lavas. The basaltic material is underlain by intrusive dikes and gabbros. The gabbros are underlain by periodotites of the upper mantle. It is hypothesized that layer 2 is produced along a crustal spreading center. In addition, the layer is thought to hold evidence for the origin of the oceanic magnetic anomalies, along with evidence for the evolution of the mantle and the crust of the earth.

The main crust of the ocean is under layer 2 in a section called layer 3. This layer has an average thickness of about 4.7 km and it is thought to consist of gabbros. The boundary between layer 3 and the mantle is called Mohorovicic discontinuity.

Leg 37 successfully penetrated 583 m into the basement of the ocean floor at Site 332. Hole 332B was reentered on three different occassions for a total depth of 721.5 mbsf (meters below sea floor). The objectives of Leg 37 were based on the investigation of the material recovered from this deep hole. The objectives of Leg 37 were to:

1. determine where layer 2 is separated from layer 3.
2. determine the makeup of layer 2.
3. determine the nature and the thickness of the magnetized layer 2A.
4. determine the changes that occurred during the evolutionary history of layer 2.
5. investigate layer 2 to determine if it contains any economically important minerals.
6. determine the compositition of submarine basaltic lava.
7. calculate the heat flow and heat production in layer 2.



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THE RECORD OF TIME

To determine how the Earth has evolved through time, core samples have been retrieved from beneath the deep-sea floor. These core samples enable scientists to study the evolution of the ocean basins, the evolution of prehistoric life, the evolution of past ocean currents, and paleoclimates. In addition, the core samples enable scientists to determine the approximate age of a geologic area.

To determine the age of a core sample, scientists look for fossils. Fossils are records of past life. Specific marine microfossils are clues to the past because these fossils lived in great abundance usually in a wide geographic area. The distribution of any group of organisms through geologic time is called its stratigraphic range. If the age of the strata is known, the geologic age of the fossil can be determined. The age of a strata layer is often dated by radioactive dating and fossil correlation.

ACTIVITY:

1. On the core diagrams, use map colors to color the rock layers so that similar rock layers will have the same color.
2. By using the lithologic symbols as your guide, label the names of the various sediments for each hole. Place the name of the sediment or rock in the space provided in the core diagram.
3. Use the Fossil Correlation Chart to determine the approximate age to sub-epoch for each fossil shown on the core diagrams.
4. Answer the questions below in complete sentences.

QUESTIONS:

Use the core diagrams and the Fossil Correlation Chart to answer the questions.

1. What type of similar sediment and basement rock is found in all four holes? (Hole 332, Hole 333, Hole 334, and Hole 335)

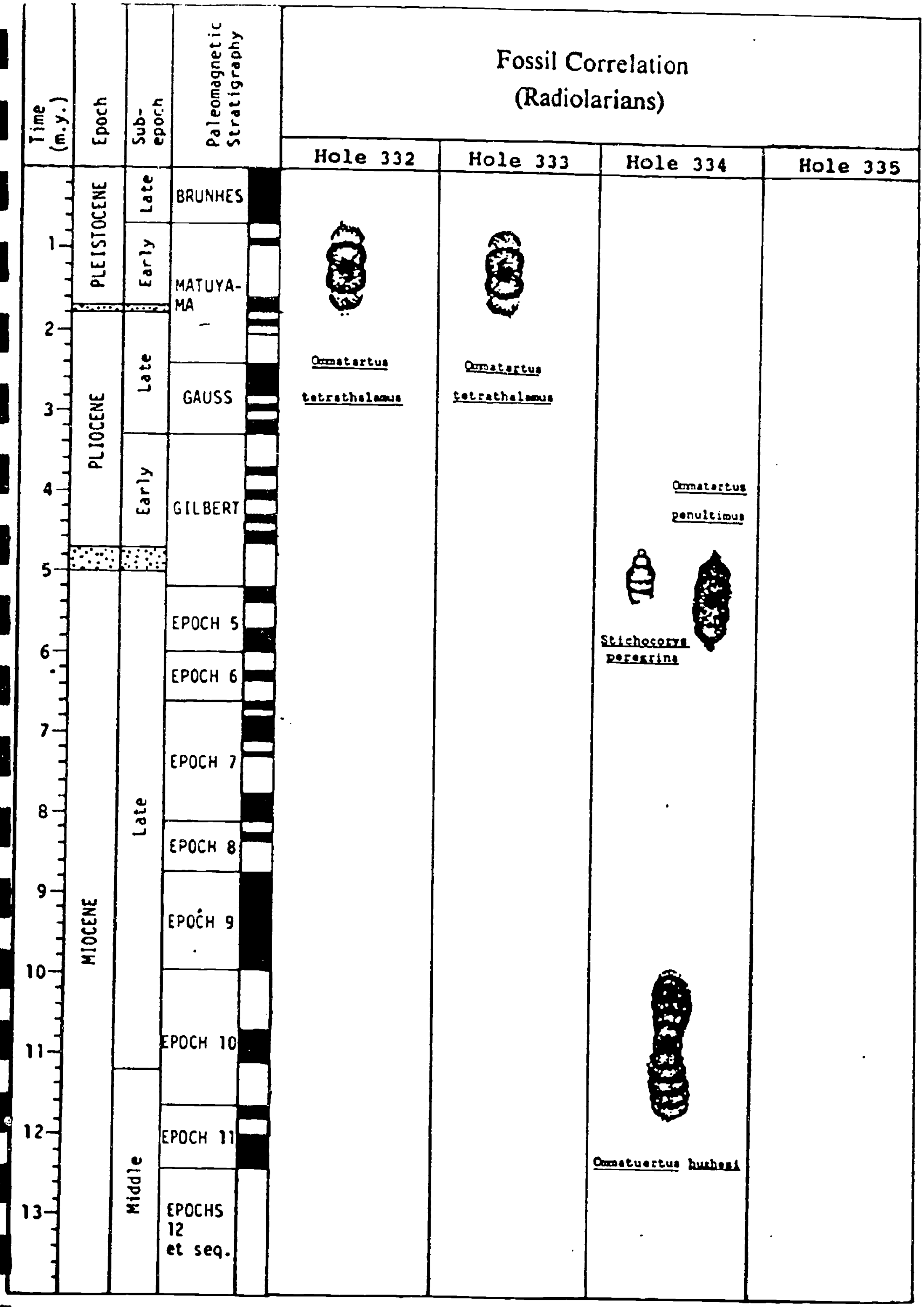
2. What hole has the most diversity in its basement rock?

3. Based on the fossil record, what hole(s) is the youngest?

4. Based on the fossil record, what hole is the oldest?

5. What age would you predict for hole 335? Why?

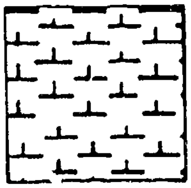
6. Write a paragraph describing the geologic history along the Mid-Atlantic Ridge. Use the information in the core diagrams and the fossil record for your historical data.


Fossil Correlation
(Radiolarians)
Time (m.y.)
Epoch
Sub-epoch
Paleomagnetic Stratigraphy
Hole 332
Hole 333
Hole 334
Hole 335
1
2
3
4
5
6
7
8
9
10
11
12
13
PLEISTOCENE
PLIOCENE
MIOCENE
Late
Early
Late
Early
Late
Middle
BRUNHES
MATUYA-MA
GAUSS
GILBERT
EPOCH 5
EPOCH 6
EPOCH 7
EPOCH 8
EPOCH 9
EPOCH 10
EPOCH 11
EPOCHS 12 et seq.
Ommatartus tetrathalamus
Ommatartus tetrathalamus
Ommatartus penultimus
Stichocorys peregrina
Ommatuertus hughesi

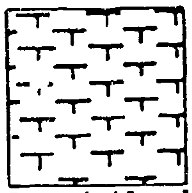
LITHOLOGIC SYMBOLS

Use these symbols to label the sediment and basement rocks on the worksheet titled "Core Diagrams from the Mid-Atlantic Ridge."

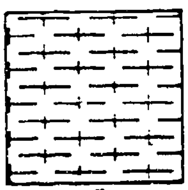
SEDIMENTS



Nanno Ooze

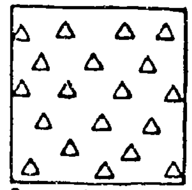


Foraminiferal Ooze

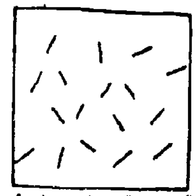


Nanno-Foram or Calcareous Ooze

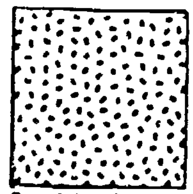
BASEMENT ROCKS



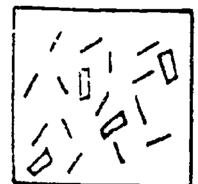
Breccia



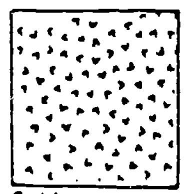
Aphyric Basalt



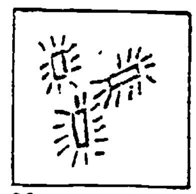
Peridotite



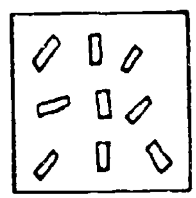
Sparsely-Phyric Basalt



Gabbro



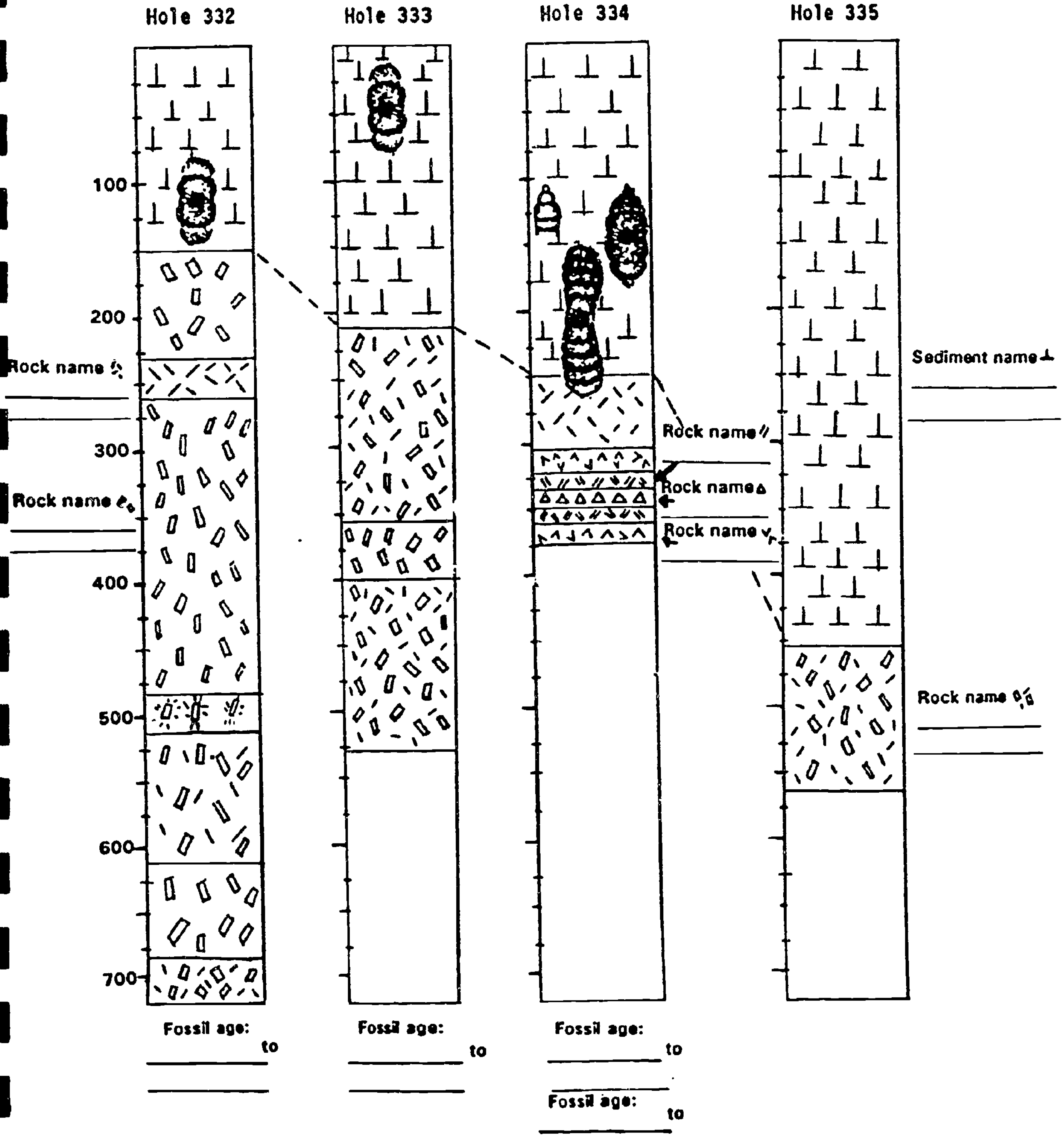
Glomerophyric Basalt



Porphyritic Basalt

CORE DIAGRAMS FROM THE MID-ATLANTIC RIDGE

The diagrams below are simplified stratigraphic columns based on the cores recovered from the scientific expedition. Not all units are represented in the columns.



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TEACHER KEY -- RECORD OF TIME

BACKGROUND INFORMATION:

The geologic age of the sediments recovered from the ocean floor can be determined by comparing paleomagnetic data to the biostratigraphic data. Diatoms, planktonic foraminifera, calcareous nannofossils, and radiolarians make up the biostratigraphic data.

Few fossil groups leave as complete a record as the radiolarians. Radiolarians are usually single individual celled organisms with a skeleton made up of silica. These fossils are important since they can be used for long-range age determinations.

The age of the sediments recovered during Leg 37 match closely with the magnetic anomaly ages except for Site 335. At Site 335, a precise magnetic anomaly identification was not possible. The estimated ages for the sediments in Site 332 to Site 335 range from middle Miocene to Quaternary. The sediment ages are thought to be:

Site	Estimated Age (m.y. B.P.)
332	Pliocene to Pleistocene
333	Pliocene to Pleistocene
334	early to late Miocene
335	middle to late Miocene

Based on the magnetic anomaly data, it was determined that sea floor spreading took place about .69 to 11 million years ago at a rate of 1.17 cm/yr for Site 332. The age of the basement rocks (basalts) for Site 332 and Site 333 is approximately 3.5 m.y.B.P. (million years before the present). Site 335 is thought to have the oldest basement rocks sampled. These rocks are estimated to have a basement age of approximately 13 million years. Due to the age of the rocks, it is thought that the spreading along this site may have been greater than 1.17 cm/yr from 20 to 10 m.y.B.P.

KEY TO QUESTIONS:

1. All of the holes contain nanno ooze and sparsely-phyric basalt.

2. Hole 332 shows the greatest diversity of basaltic layers or basement rocks. It has aphyric basalt, porphyritic basalt, and glomerophyric basalt in its stratigraphic column. Hole 334 shows the greatest diversity in its type of rock. Hole 334 has layers not seen in the other holes since it consists of a plutonic complex made up of layers of gabbro, peridotite, and breccia.

3. Holes 332 and 333 have been estimated to be of Pliocene to Pleistocene age based on the radiolarian fossil record.

4. Based on the radiolarian fossil record, the sediment from Hole 334 is older than the sediment found in Holes 332 and 333. The Ommartus hughesi radiolarian dates Hole 334 as upper Miocene. Hole 335 is actually older than Hole 334 but since no complete fossil record was found for Hole 335, the data from the Fossil Correlation Chart indicates that Hole 334 is older than Holes 332 and 333.

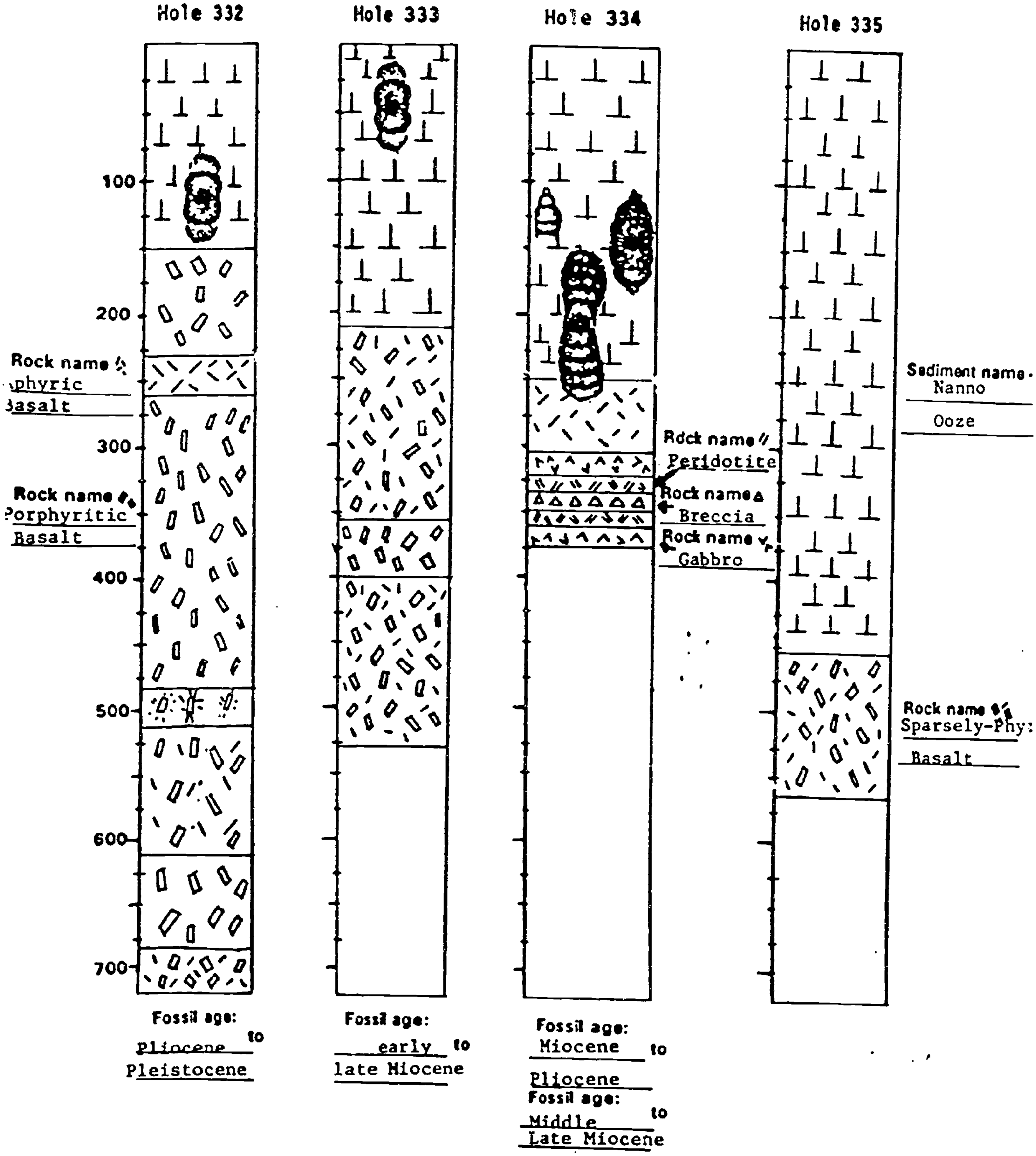
5. Hole 335 is located farthest from the rift zone of the Mid-Atlantic Ridge. According to the Theory of Sea-Floor Spreading, the closer to the rift, the younger the sediments. The core diagram of fossils can be correlated from Hole 334 to Hole 335. No complete radiolarian fossils were found in hole 335. Paleomagnetic data and other fossil data was used to place the age of the sediment in Hole 335 as late Miocene. Hole 335 is thought to be approximately 13 m.y. which is about 9.5 m.y. older than Hole 332 and Hole 333.

   From the Fossil Correlation Chart, Hole 334 can be estimated to be late Miocene with the oldest fossil dated at middle Miocene. Since Hole 335 is farther away from Hole 334, you must assume that the age of the rock for Hole 335 is at least the same age if not older than the estimated age of the fossils found in Hole 334. A good prediction based on this information would place the age of Hole 335 at middle to late Miocene.

6. The Mid-Atlantic Ridge is an undersea mountain chain. Along the ridge is a rift zone where magma undergoes a series of convection currents to reach the ocean floor. New crustal material is constantly being added to the ocean floor through the rift zone. The material extruded along this rift is composed of basaltic material. This basaltic material is the youngest closest to the rift and spreads out on either side of the ridge. The basalts may have different cooling rates and may mix with other sediments creating a diversity of basalts within a core. Nanno ooze was deposited on top of the volcanic sediment. Fossils were preserved in the ooze. Volcanism is though to either precipitate silia on the ocean floor or increase the production of siliceous organisms. Since radiolarians are composed of silica, these fossils help date the sediment in which they are found.

CORE DIAGRAMS FROM THE MID-ATLANTIC RIDGE

The diagrams below are simplified stratigraphic columns based on the cores recovered from the scientific expedition. Not all units are represented in the columns.



THE SEDIMENT RECORD ACTIVITY

BACKGROUND INFORMATION:

The sediments that have accumulated in the oceans may have come from a variety of sources. The sediment may be made up of the remains of marine organisms. Rivers also deposit sediments into the oceans. Over time, these sediments leave a record of geologic time. Through ocean drilling, cores of rock and sediment can be recovered from the ocean floor and analyzed by scientists. The cores allow scientists a greater understanding of the history and development of the Earth.

PURPOSE:

This activity will demonstrate how the record of marine sedimentation records the history of the ocean.

MATERIALS:

Each group of four students will need:

one small glass jar (baby food jar or a 50 ml beaker)
clear plastic straw
four different textures or colors of sand
water
egg timer or clock

PROCEDURE:

1. Fill the jar approximately 1/2 full of water.
2. One student in the group should be the designated time keeper.
3. The first sand samples should be slowly poured into the jar for approximately thirty seconds. The order in which the sands should be poured should be designated by the teacher. Each type of sand should represent a sediment deposit during a specific period of geologic time.
4. During the next thirty seconds, the second sample should be poured into the jar.

5. Carefully pour off any excessive water into the sink or another container. The water level should fill the container to approximately 3/4 full.
6. Continue slowly pouring the sand samples into the jar in thirty second intervals.
7. Push the straw through the sediment layers in the jar.
8. With your finger over the top of the straw, pull the straw out of the jar.

CONCLUSION:

1. Describe what your simulated core sample looks like.

2. Compare your core samples and jars with another group within the class. Are the sediment records similar? Why or why not?

3. Why would the sediment record vary from one location to another location in the same ocean?

4. The procedure you used to extract the sediment from the jar is similar to the piston coring procedure used in ocean drilling. How would rocks be cored in the oceans?

SCIENTIFIC INVESTIGATIONS

NOTE TO THE TEACHER:

All legs are based on specific scientific objectives. To achieve these objectives, the scientists are responsible for collecting and analyzing data collected from the sea floor. Shipboard scientists would be reponsible for analyzing the physical properties of the sediments and rocks recovered during an expedition. The following tests might be run on an igneous rock: seismic compressional velocity, shear wave velocity, bulk density, grain density, porosity, water content, and electrial resistivity. In addition to these tests, cores are analyzed to determine their magnetic and chemical makeup. The data generated from these scientific studies will lead to a better understanding of the processes of plate tectonics, of the earth's structure and composition, along with a fuller comprehension of the dynamics that have shaped the evolution of our planet.

Since the majority of the tests conducted on the ship are unable to be duplicated in the classroom, a simple density test has been included in this packet. The students will be able to simulate the role of a shipboard scientist by determining the densities of rock samples similar to those recovered in Hole 332B. Density is an important test used by scientists in an attempt to try to understand how various earth materials respond to the physical properties of nature.

Teachers can create their own scientific investigations by attaining the actual core samples collected by the Ocean Drilling Program. The samples that can be sent to a school for experimentation purposes are considered to be non-critical samples. These samples may be residues from other sampling programs or are samples that may have been disturbed during drilling. No scientific information as to its origin of location or its chemical composition is included with these samples. To request educational samples for the classroom, teachers should write to:

Supervisor of Curation and Repositories
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, TX 77845-9547

Phone: (409)-845-4819

SUPPLEMENTARY ACTIVITY:

You might want to try an additional activity to try to duplicate the sedimentation record along a rift zone.

PROCEDURE:

1. Gather five jars that were used in the activity above.
2. Line up the jars in a straight line.
3. The jars should be labeled:
   C B A B C

4. Insert the straw into jar A. Extract a sediment core and place the sediment into the jars labeled B.
5. Extract a core sample from the jars labeled B and place this in the jars labeled C.
6. Which jar represents the youngest sediment along the rift of the ridge?
7. Which jar represents the oldest sediment of the ridge?

DENSITY COMPARISON LAB

Density is the ratio of the mass of an object to its volume. The formula below is used to determine the density of an object.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The mass of an object is determined by placing the sample on a balance scale. The metric unit for mass is the gram.

Volume is the amount of space an object takes up in three dimensions. The three dimensions are length, width, and height. The volume of a solid is determined either by measuring and multiplying together its dimensions or by displacement. The metric unit for volume of a solid is either cm^3 or ml. One ml is equal to one cm^3 . The volume of a regularly shaped object can be determined by the following equation:

Volume = length x width x height

The volume of an irregularly shaped object is determined by displacement. The volume of the solid is determined by the amount of liquid it displaces in a container. The following equation can be used to determine the volume of an irregularly shaped object:

Volume = Displaced water level - Original water level

Once the mass and the volume of an object is determined, its density can be calculated by comparing its mass to its unit volume.

Purpose: to determine the mass of different rock samples

Materials: small samples of basalt, gabbro, breccia, and peridotite

Hypothesis: I think the ________________ will have the greatest density.

Procedure:

1. Place each sample on a triple balance scale to determine its mass.
2. Record the mass of each sample onto the data table.
3. Determine the volume of the sample.
   A. Regular shaped object:
   Volume = length x width x height
   Measure each dimension in centimeters and record this information in the data table. Multiply the dimensions together to determine the volume.

B. Irregularly shaped object:
Fill a 100 ml graduated cylinder with about 50 ml of water. Record this volume of water as the original water level in the data table. Carefully place the rock sample into the graduated cylinder. Record this displaced water level on the data table. Subtract the water volumes to determine the volume of the rock. Record the volume of the rock onto the data table.

4. Determine the density of the samples using the equation below:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

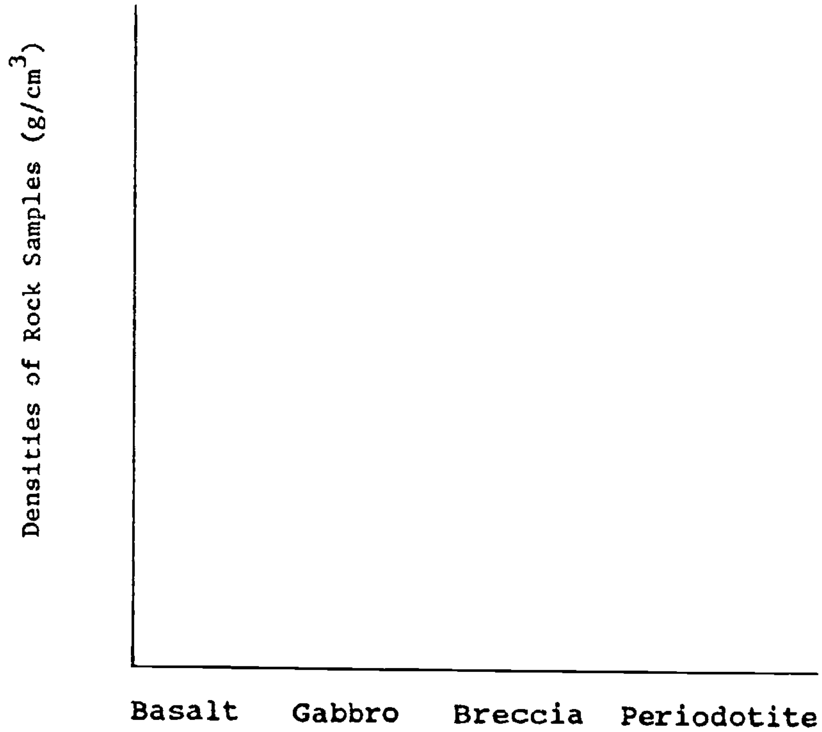
5. Record the densities of the rock samples on the data table.
6. Create a bar graph to show the densities of the samples.
7. Answer the conclusion questions in complete sentences.

DATA TABLE:

SAMPLE NAME	MASS (g)	VOLUME OF SAMPLE (cm or ml)					DENSITY (g/ml or g/cm)
		LENGTH	WIDTH	HEIGHT	ORIGINAL Level	DISPLACED Level	

GRAPH:

Make a bar graph of the densities of the rock samples. Round the densities to whole numbers before graphing your results.



QUESTIONS:

1. What rock sample had the greatest density? Why?

2. What rock sample had the least density? Why?

3. What is density?

4. What geologic process formed these rocks? How do you know?

Paleomagnetism

The early seafarers were the first humans to use the earth's magnetic field. The compass was invented to show the early navigators the direction of the ship in relation to magnetic north. Today, the earth's magnetic field is used to determine its geologic history. The discovery of the property of magnetic anomalies was an accident; during World War II, the U.S. Navy used magnetic detectors to seek the enemy's submarines in the Atlantic Ocean. Later, scientists looked at the patterns that were made by the recorders. The scientists thought that these patterns were a result of the magnetism of the ocean crust.

Let's talk about the formation of the magnetism recorded in the ocean crust. The earth's magnetic field results from the circulation of core materials. Rising magma from the mantle boils out through cracks onto the ocean floor; this material contains the element iron. Those rocks containing iron minerals retain a record of the earth's magnetic field in their internal structure, at the time of their formation. Scientists or geophysicists studying magnetization of rocks have noted the earth's field has not remained constant; in fact, it has reversed itself many times throughout geologic time. The term *Normal* magnetic orientation is in relation to a compass needle now pointing north, while the term *Reversed* magnetization refers to today's north seeking pole pointing south.

Magnetic surveys, like the survey conducted by the Glomar Challenger, produces a recorded pattern as seen in figure 1c. This figure shows a profile, measured in gammas, across the Juan da Fuca Ridge in northeast Pacific; we will see magnetic surveys across the mid-Atlantic ridge from the Glomar Challenger. Figure 1a provides a ridge model, showing upwelling of basalt spreading out to the left and right of the source. The alternating black and white striping indicates normal and reverse magnetization respectively.

How are the ages of the rocks determined? Well, the scientists have several methods. One, they drill into the basement rock and take samples which are then examined in the laboratory; there they may use radiometric dating. Also, the striping patterns of continental lavas, whose ages are known, are compared to lavas of the ocean floor, suggesting that 50% of the deep ocean bottom has formed during the past 70 million years (Gross, 1972).

Furthermore, there are other uses for the study of paleomagnetism; for example, the position of the earth's magnetic pole in relation to the rock's position, when it formed, can be determined (Gross, 1972). the information may be used to plot the path of continental blocks, assuming the blocks changed position and not the magnetic poles (Gross, 1972).

The purpose of this activity is to instill the students with a concept that plate tectonics is supported by the theory of sea-floor spreading which is supported by evidence from paleomagnetization, and that the earth's magnetic field has changed through time from normal polarity to reverse polarity.

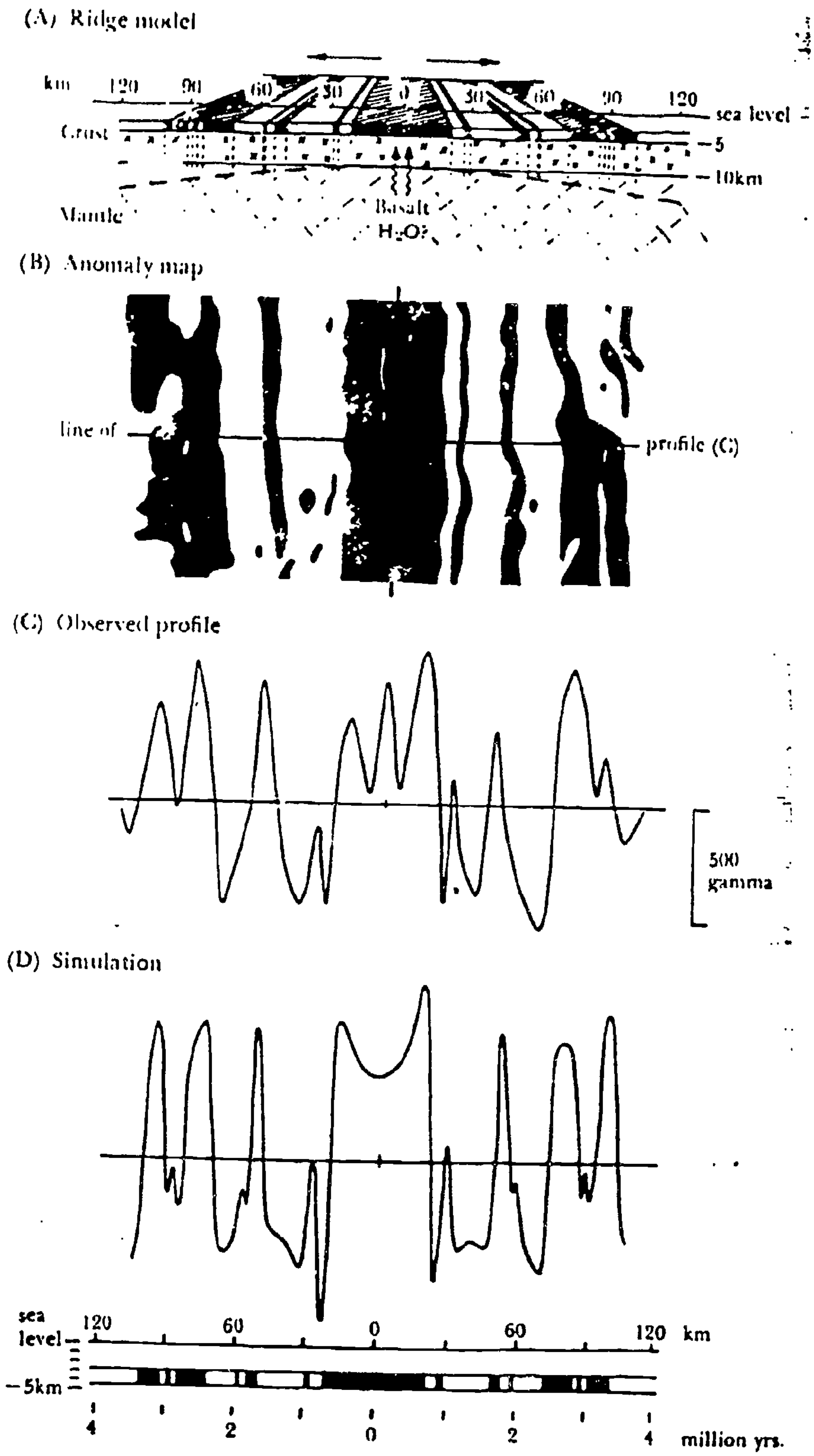


Figure 1. *A.* The generation of magnetic anomalies by a spreading ridge. Shaded material is normally magnetized, unshaded is reversely magnetized. *B.* Part of a map of magnetic anomalies over the Juan da Fuca Ridge in the northeast Pacific. The black regions are positive anomalies, the white are negative. *C.* Magnetic anomaly profile along line shown in *B.* *D.* A profile computed from the reversal time scale.

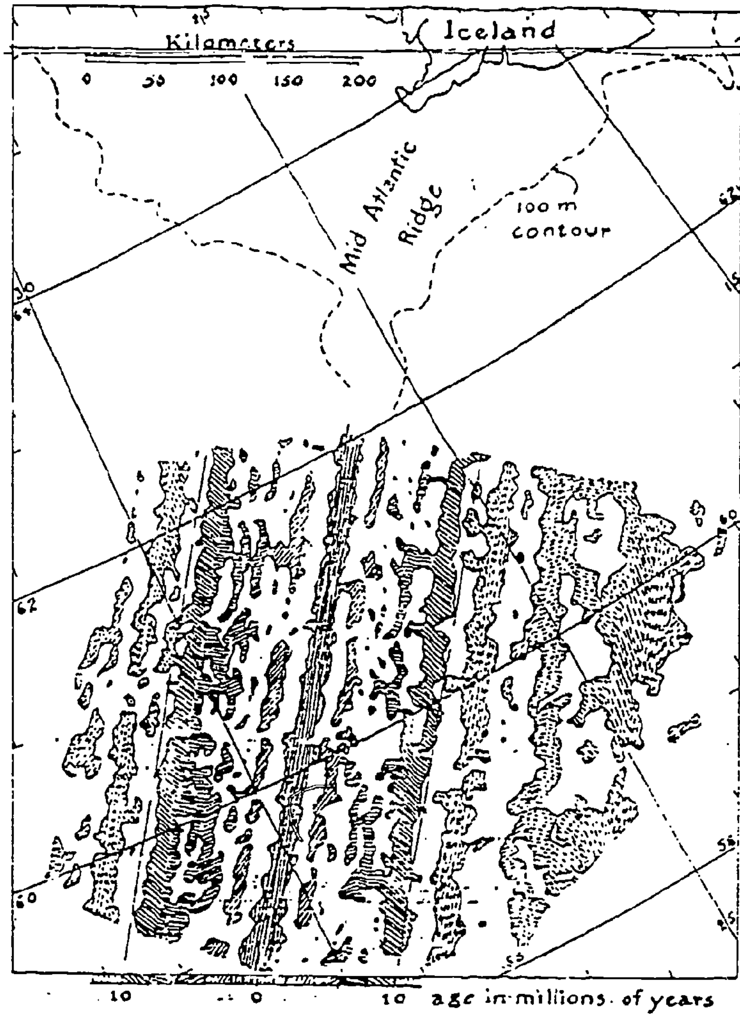


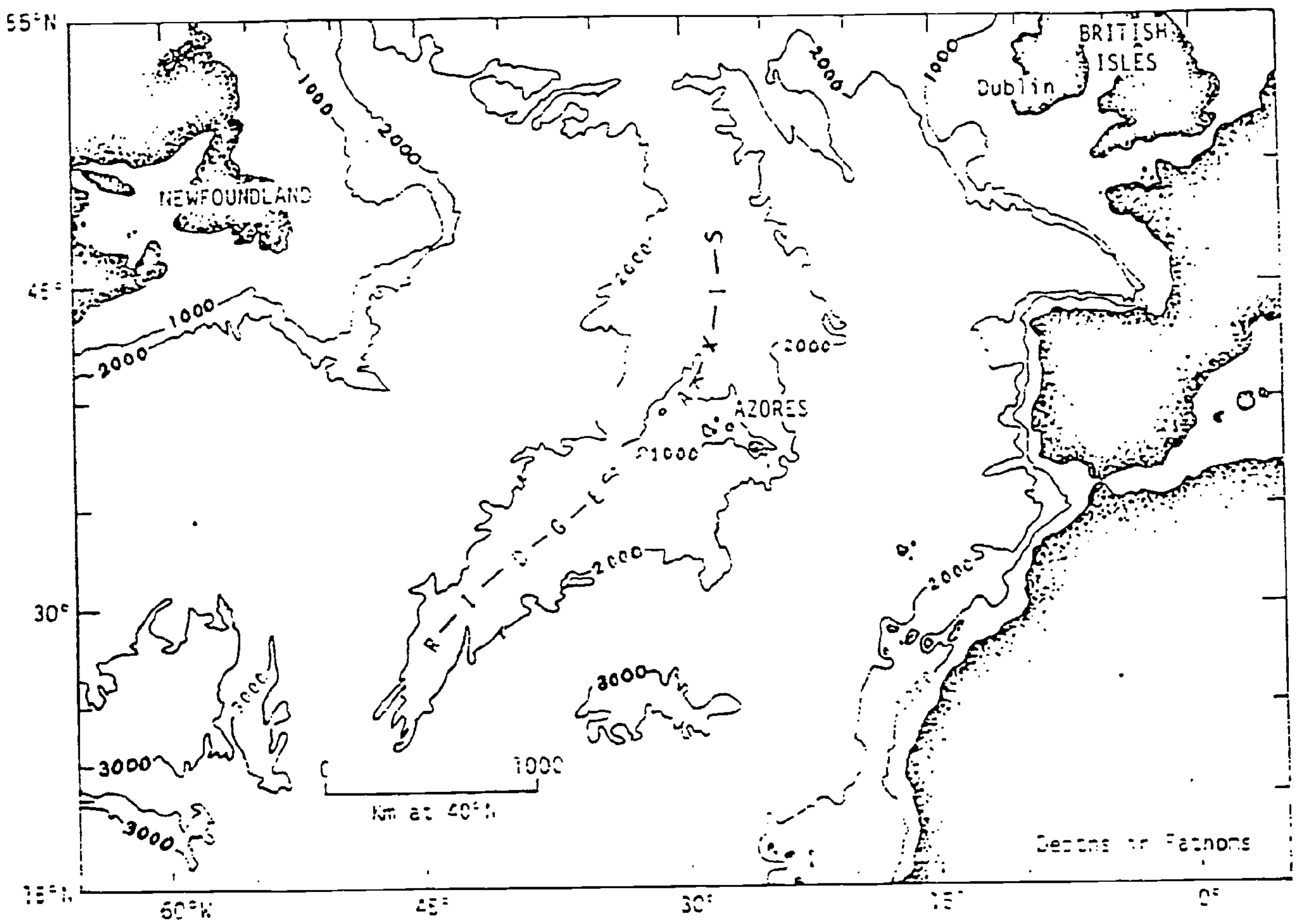
FIG. 2

Diagramatic representation of the magnetic field at an oceanic rise showing the different magnetic orientations of the crust, resulting from crustal formation when the earth's magnetic field is normal and reversed. A constant rate of spreading is assumed in estimated crustal ages given at the bottom of the figure.

MAPPING THE DRILL SITE LOCATIONS

Use the latitude and longitude data to plot the location of the sites below:

Site	Latitude	Longitude
332	36°52.72'N	33°38.46'W
333	36°50.45'N	33°40.05'W
334	37°02.13'N	34°24.87'W
335	37°17.74'N	35°11.92'W



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QUESTIONS:

1. The drilling sites are located along what major ocean feature?

2. What hole is located closest to the rift zone?

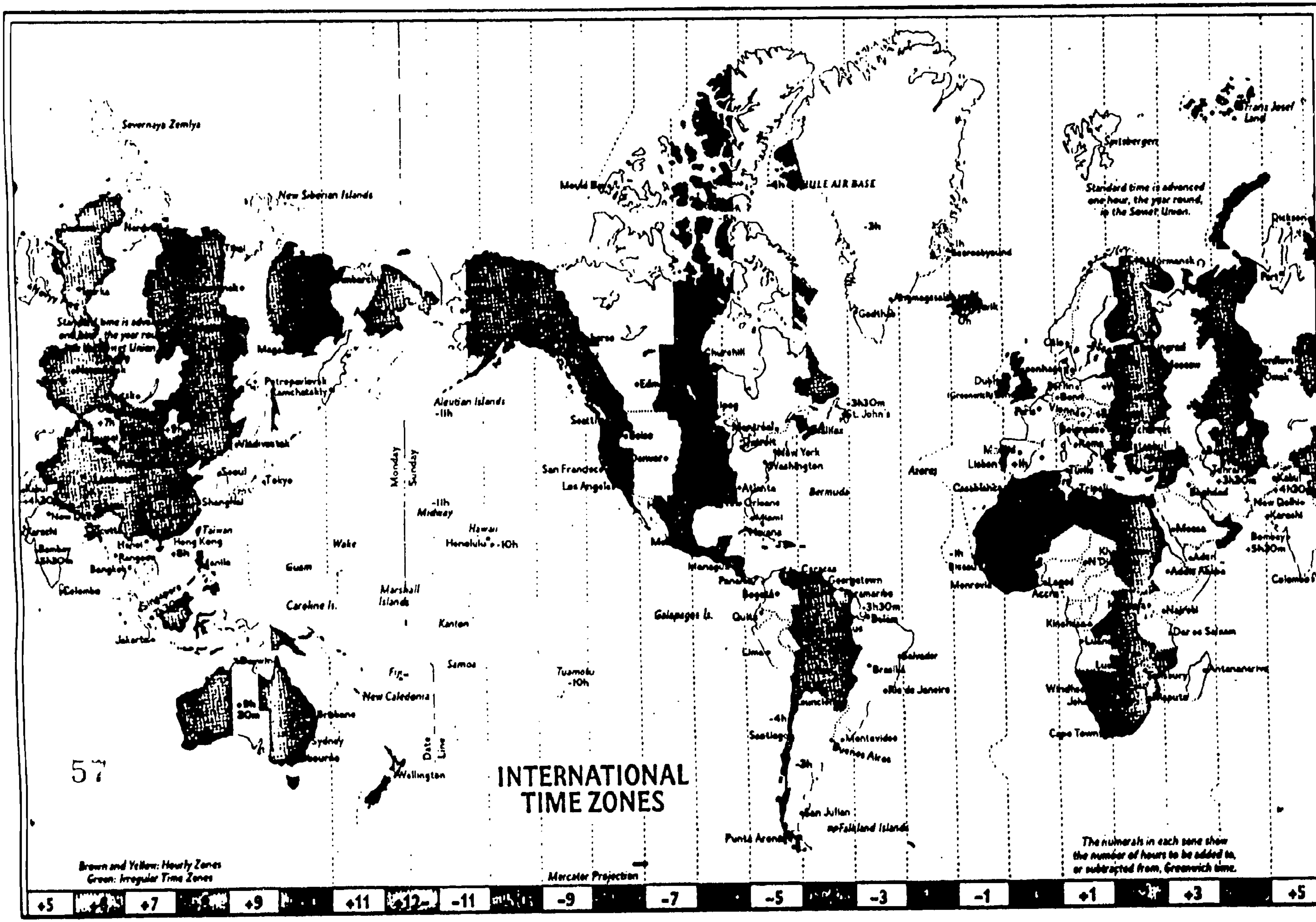
3. In what major body of water are these sites located?

4. What significance does the location of the drilling sites have in relationship to the age of the sediments along the ridge?

5. Label the Prime Meridian (0 longitude) on the map. This location is the standard of time called Greenwich Mean Time (GMT). For every 15 of longitude, time changes one hour. As a person travels east, time gets one hour later for each 15 of longitude. As a person travels west, time gets earlier. If a country or island would be split into different time zones, the time zone boundaries of that country are often skewed. If it was 3:00 p.m. at the Prime Meridian, what time would it be at Site 332 on the ridge?

6. If it is 3:00 p.m. at the Prime Meridian, what time is it at your school?

TIME AROUND THE WORLD



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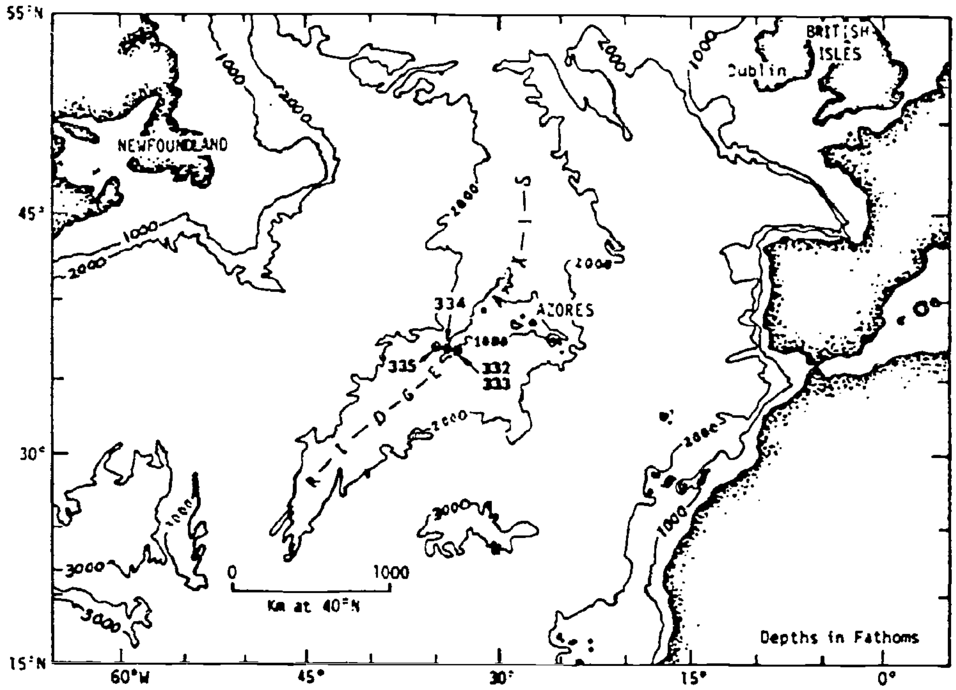
TEACHER KEY - MAPPING THE DRILL SITE LOCATIONS

The drill sites for this leg are located on the map below.



QUESTIONS:

1. All of the sites are located across the mid-ocean ridge in the Atlantic Ocean.

2. Site 332 is located in Deep Drill Valley about 30 km west of the crest of the Mid-Atlantic Ridge. Site 333 is located about 1.8 km southwest of site 332.

3. All of the drill sites are located in the Atlantic Ocean.

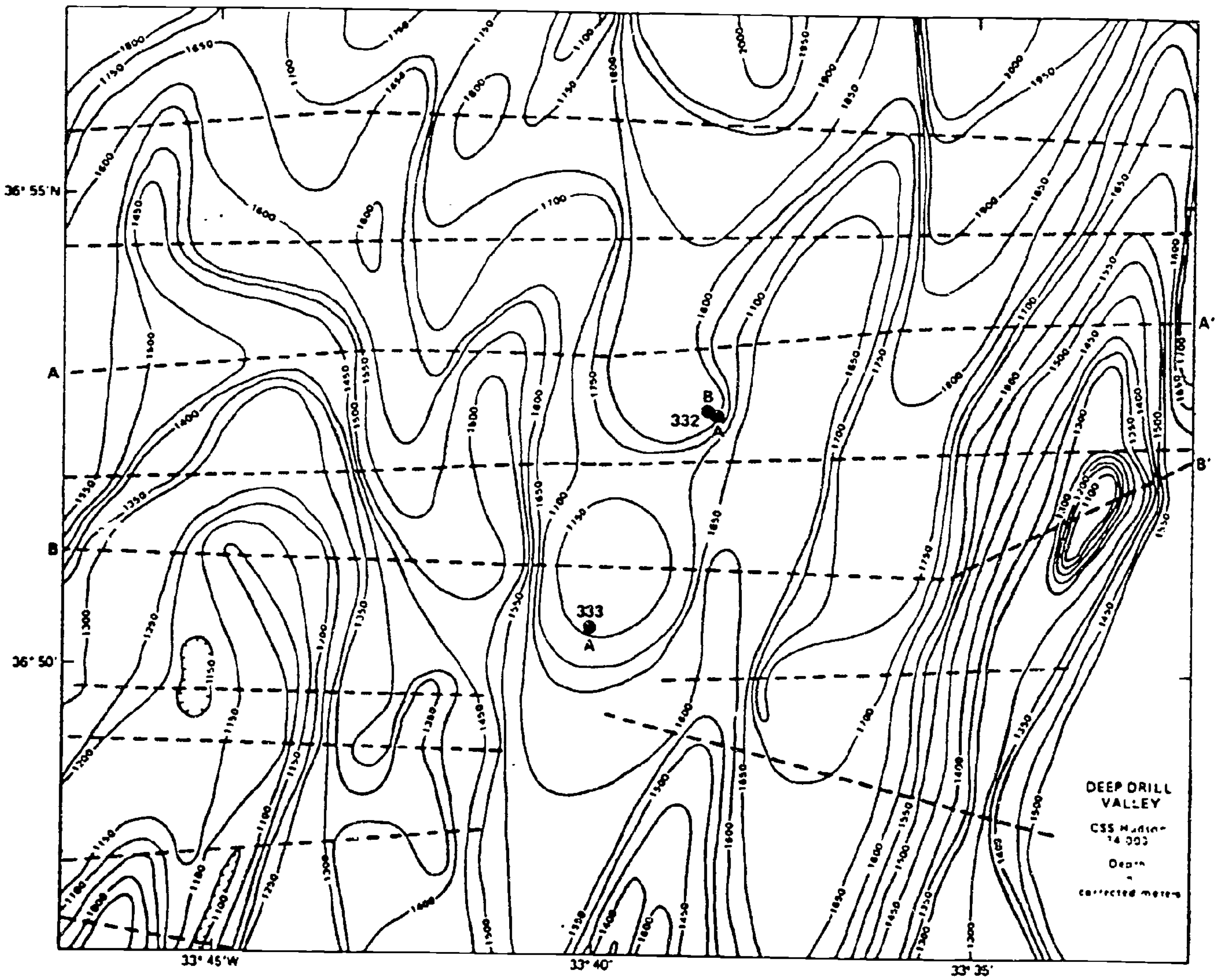
4. Along the Mid-Atlantic Ridge, convection currents bring magma to the rift zone area of the ridge creating new crustal material. The youngest crustal material is located along the rift and spreads out on either side of the ridge. Deep Drill Valley is a geologically very young part of the American plate. Sites 335 and 334 should be geologically older than sites 332 and 333 due to their location to the ridge.

5. It would be 2:00 p.m. at the ridge since the Azores Islands have a skewed time zone boundary.

6. Answers will vary depending on locality.

BATHYMETRIC CONTOUR CHART OF DEEP DRILL VALLEY

Use the chart to answer the questions.



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QUESTIONS

1. What is the contour interval for this map?

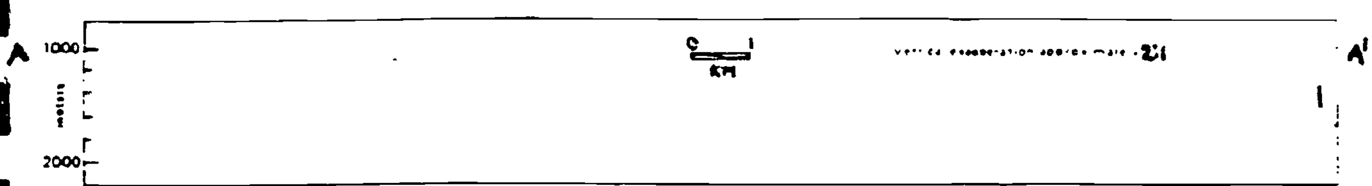
2. Find seismic track B-B' on the map. What do the close contour lines near location B' indicate about the topography of this location of the ocean floor?

3. What is the ocean depth of hole 332A?

4. Which hole has a deeper ocean depth, hole 332A or 332B? Why?

Supplementary Activity:

Create a profile of the ocean floor along tracks A-A'.



ANSWER KEY - BATHYMETRIC CONTOUR CHART OF DEEP DRILL VALLEY

Answers:

1. The contour interval for the map is 50 meters.

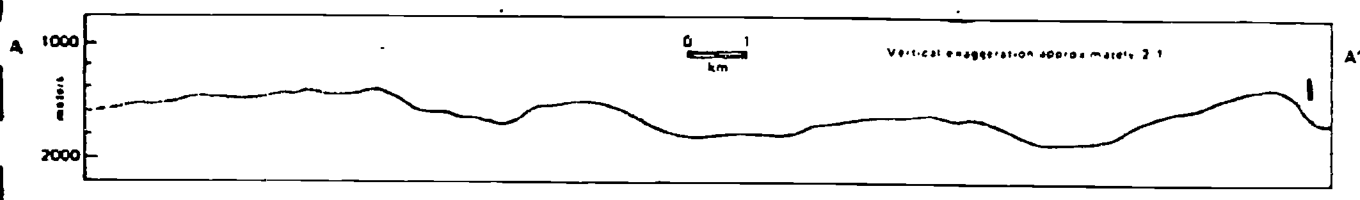
2. The close contour lines indicate a rapid change in elevation. The area near B' that has enclosed circles is an area of the sea floor where the elevation is decreasing. This area is called a basin.

3. Hole 332A has an ocean depth of 1800 m.

4. Hole 332B has a deeper ocean depth than Hole 332A. Although these holes are located close to each other, Hole 332B is closer to the 1850 m contour line while Hole 332A is located on the 1800 m contour line.

SUPPLEMENTARY ACTIVITY:

Students should plot the ocean depths along track A-A'.



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INQUIRY ACTIVITY-EARTH'S MAGNETIC PERSONALITY

TEACHER'S INFORMATION:

The activity provides background concepts concerning the earth's magnetic field and magnetic reversals. It allows the students to actively establish a mental schema, mental coat hooks, to hang their knowledge of the earth's magnetic properties, the magnetic field and magnetic reversals through time. Please refer to the section-Paleomagnetism for background information. Also, feel free to make any adaptations that you think are neccessary.

PURPOSE:

To demonstrate magnetic reversals and to illustrate a magnetic field.

MATERIALS:

For each group: compass
large iron nail(16d or 16 penny)
6 volt battery
#18 gage wire
iron filings
small shoe box
ruler

PROCEDURE:

A. First, we will illustrate a magnetic field.

1. Punch a hole through the top of the box and one of its sides.
2. Wrap the wire around the nail, leave some of its ends unwrapped.
3. Attach one end of the wire to the positive terminal, and the other end, thread through the hole in the side of the box, connect to the negative terminal.
4. Sprinkle iron fillings on top of the box, around the nail. You may need to tap the box to evenly spread the filings.
5. Draw the shape of the field you have observed.
6. Remove the filings and the nail.

PROCEDURE(cont.)

7. Lay the nail under the box's lid or a sheet of paper, and sprinkle the iron filings on the lid. What do you observe? Draw what you see. Is the shape of the field the same, why?

B. Second, we will demonstrate a magnetic reversal.

1. Remove the iron filings and the cover.
2. Pick up your compass; observe the direction of the compass needle. Which direction is it pointing? Why?
3. Align the nail so that its point is pointing north.
4. With the current passing through the nail, hold the compass over the nail. Observe the direction of the needle and record it.
5. Reverse the wire connections. Again, overlay the compass above the nail. Record the direction it is pointing. Is it the same direction as in step 4?

C. Have you determined that the nail represents the iron in rocks? Also, the battery represents the earth's "battery," core, creating a magnetic field in a certain direction. Now, choose one of your partners to act like the earth's core. The job will be to alternate the connections for certain time periods. Choose another person who will be the time keeper and someone else to record the data and observe the compass needle. Note: the "earth's core" should make the reversals last a reasonable amount of time. Record your data in a chart and draw a magnetic striping pattern, black for normal and white for reversals.

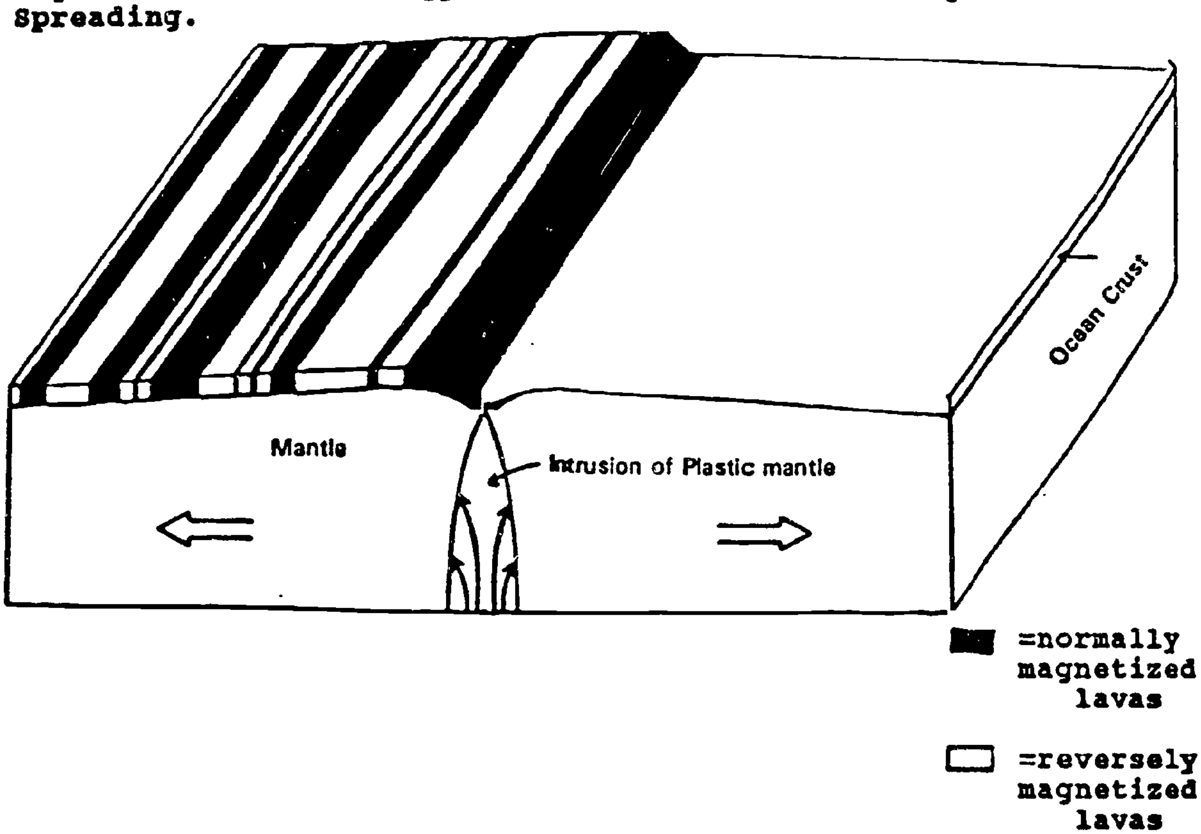
FOR EXAMPLE:

TIME:	POLARITY
0-10 sec.	N
10-30 sec.	R
30-70 sec.	N
70-90 sec.	R

10 sec. = 1cm
1 sec. = 1,000 years

MODEL OF A MID-OCEAN RIDGE

Material within the Earth's mantle rises to the surface at ocean ridges forming new crustal material. This new crustal material moves slowly at a rate of a few centimeters a year away from the ridge. As the material cools, it becomes magnetized in the existing magnetic field of the earth, whether that field is normal or reversed. Over time, the rocks leave a record of the earth's magnetic field. This hypothesis is called the Theory of Sea-Floor Spreading.



ACTIVITY:

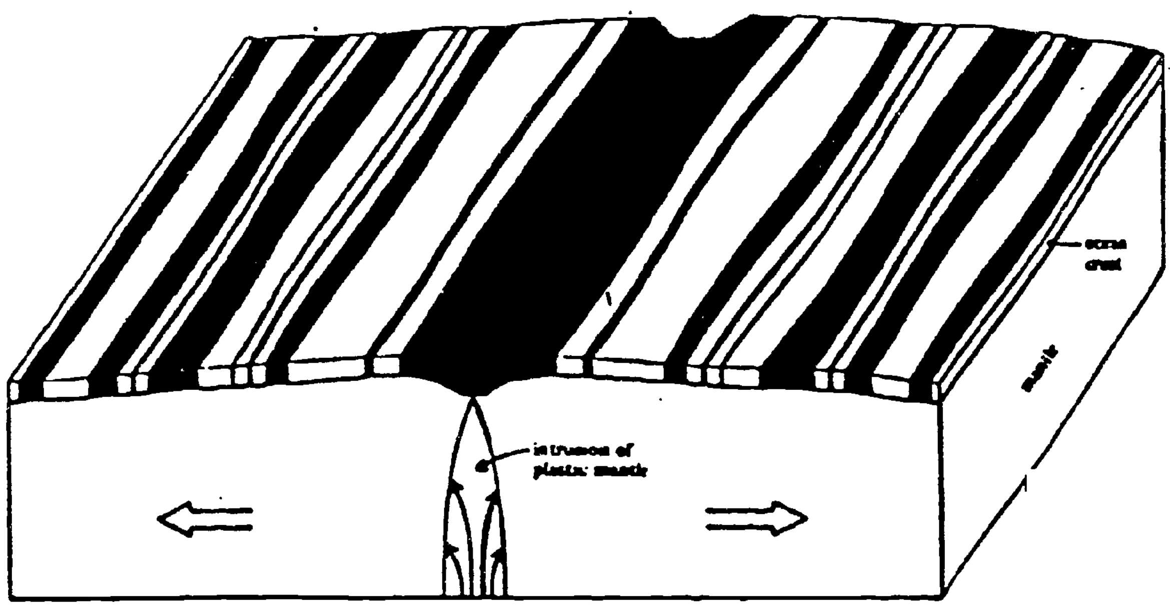
1. Complete the magnetic striping pattern on the right side of the ridge.
2. What do you think is the reason behind the striping being wider in one place than other?

3. How many magnetic reversals have occurred across the ridge?

TEACHER KEY - MODEL OF A MID-OCEAN RIDGE

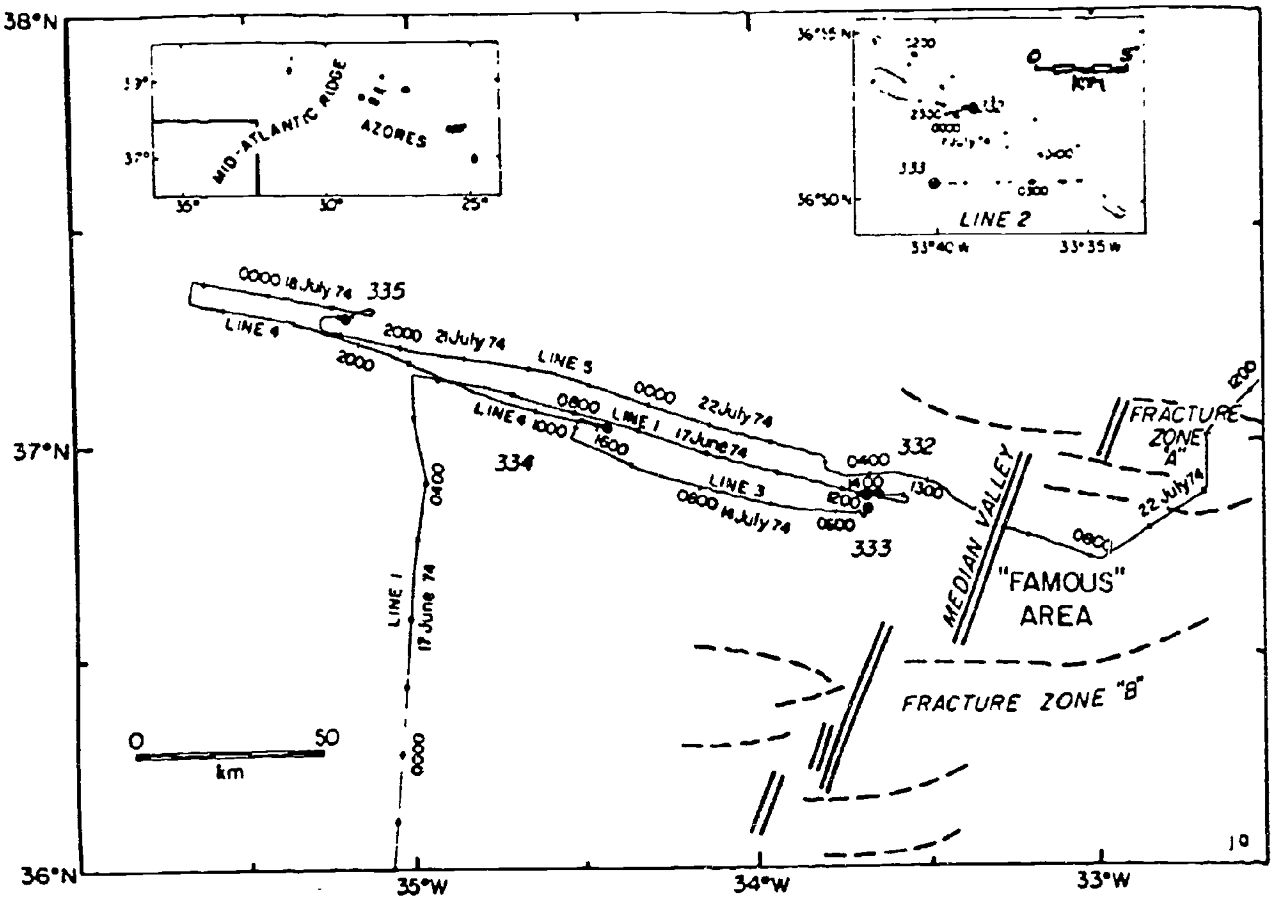
ANSWERS TO THE ACTIVITY QUESTIONS:

1. The magnetic striping pattern on the right should be a mirror image of the striping pattern on the left of the diagram.. To be accurate, the students should measure the width of the magnetic stripe on the left of the diagram so that the corresponding stripe on the right is the same width.



2. There are two possible explanations as to the variation in width of the magnetic stripes. The amount of rock material extruded has an effect on the width of the magnetic stripe. The more material extruded through the rift, the larger the magnetic band. The length of time the earth was magnetized in a certain direction will also determine the width of the magnetic stripe.

3. Based on the diagram above, there have been seventeen reversals across the ridge which excludes the present normal polarity. Remember that the extruded material moves out from the rift on either side of the ridge. Each time the band changes from black to white is a reversal. The patterns of magnetic reversals can be used to estimate the rate of sea-floor spreading.



Track chart of Glomar Challenger in the vicinity of the drill sites. Notice the four figure numbers. They are times in GMT and the dates are shown. Inset, upper left, locates this area regionally. Inset, upper right, is annotated every 10 minutes, and gives the detail of the track between Sites 332 and 333.

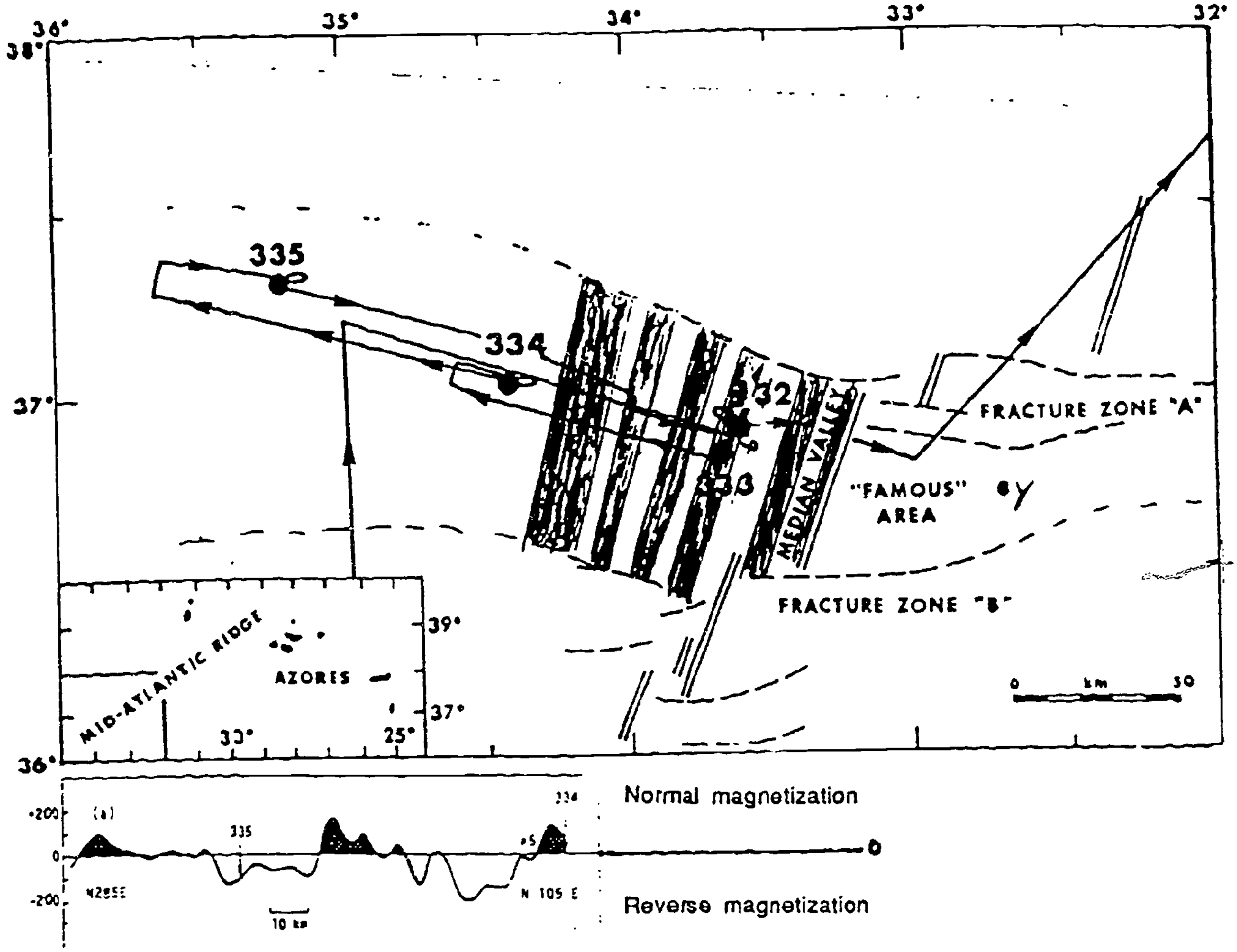
USE THE CHART TO ANSWER THE FOLLOWING QUESTIONS:

1. What Islands are near the Sites 332-335?

2. Give the arrival time at Site 335 GMT (Greenwich Mean Time) and your local time, and the ship's local time.

3. Determine the scale of the main chart.

4. Determine the distances from Site 332 to Site 334 and from Site 334 to Site 335.



Magnetic anomaly profile

MAGNETIC ANOMALIES MAPPING:

1. Use the scale of 0.7cm = 10km. Complete the map of the basement crust, similiar to figure 1b. Using the anomaly profile, measure the length of the reversals on the anomaly profile and use that distance to determine the width of the stripe on the map of the drill sites. Start at Site 334 and follow the ship's track to Site 335. When interpeting the chart, remember that a bump above 0 is normal magnetization and a dip below 0 is generally a reversal.

2. Starting from Median Valley, complete your map across the spreading center, draw what you think the striping pattern would look like to point y.

3. Give an explanation for drawing the map your way.

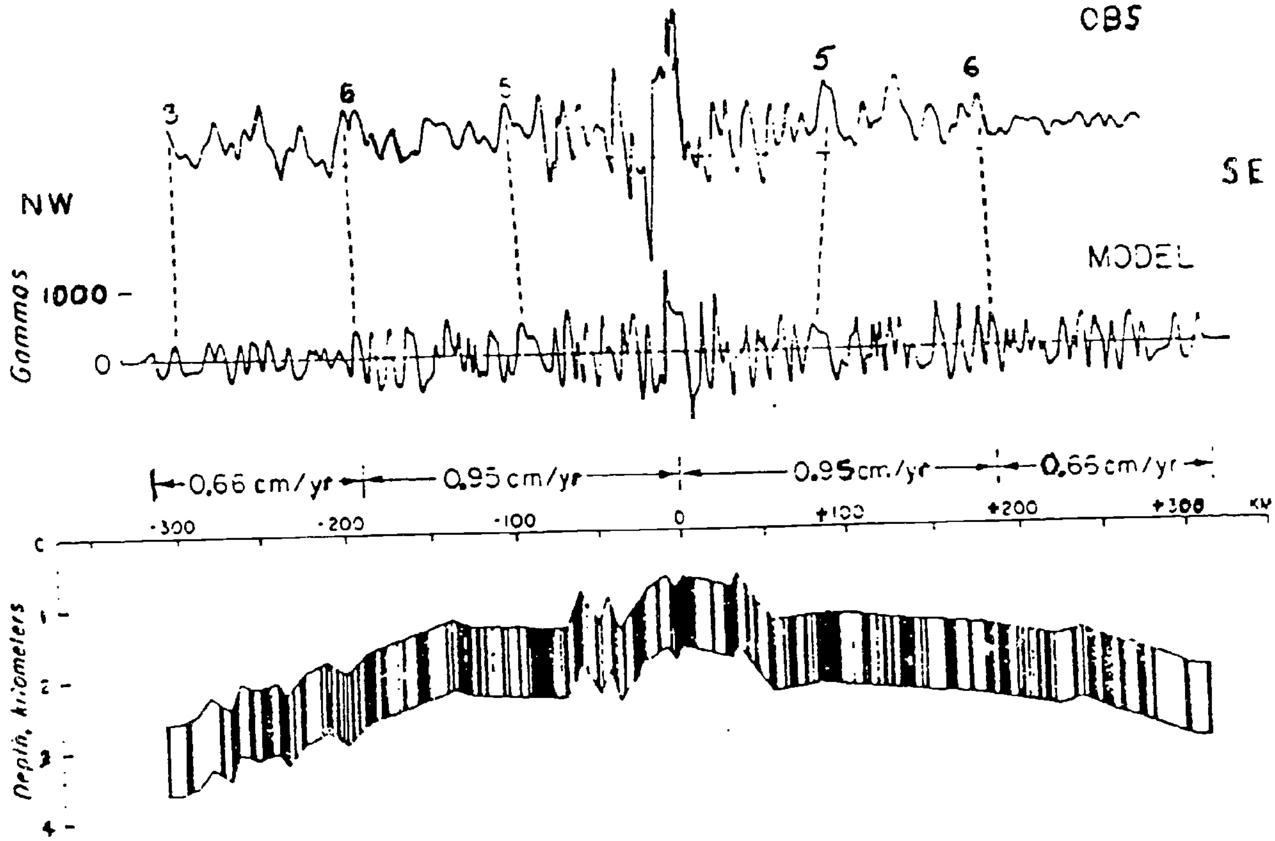
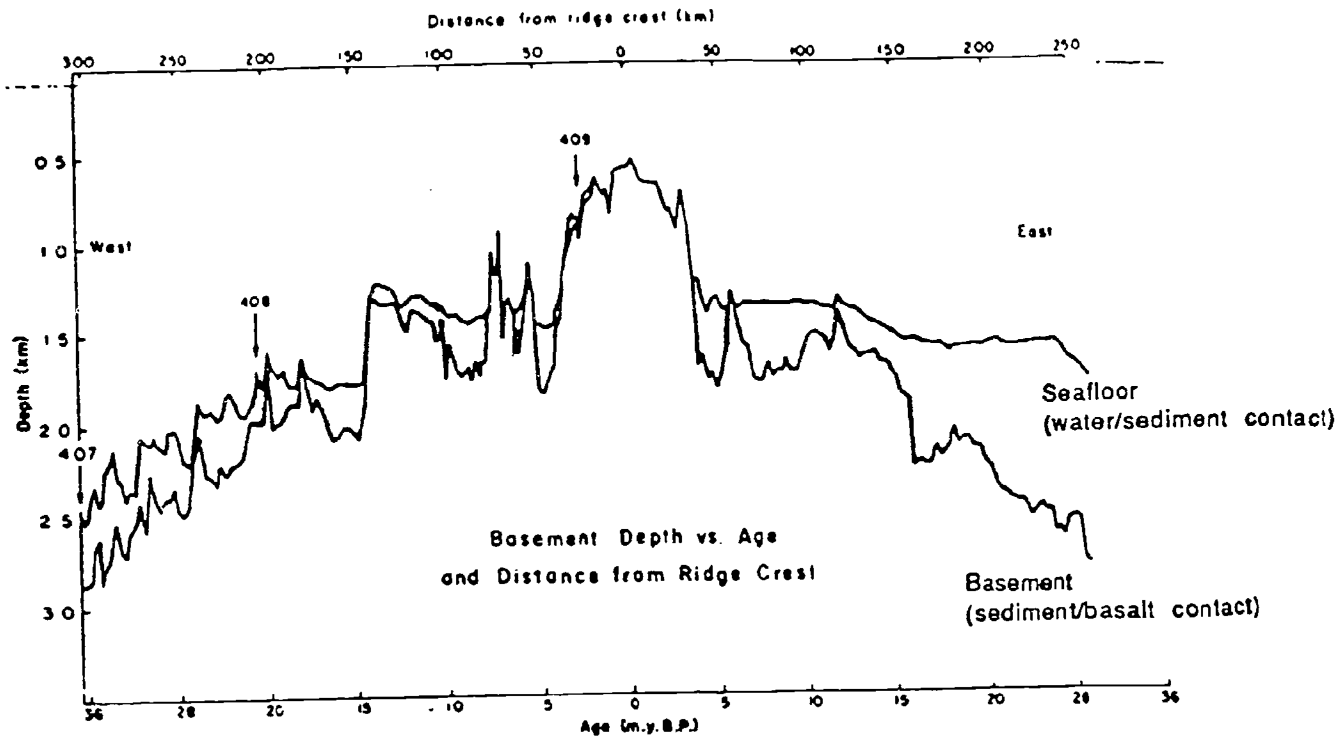


Figure 3. Sea-floor spreading model, using the time scale of La Brecque et. al., (1977), across the Reykjanes Ridge by the Glomar Challenger on Leg 49.

USE THE ABOVE MAGNETIC ANOMALY-SEISMIC CHART TO ANSWER THE FOLLOWING QUESTIONS:

1. Has the spreading rate remained constant? How do you know?
2. How does the data from the model compare with the observed (OBS) data?
3. Where is the shallowest section of the crust located? What is the depth?
4. Give the depth of the deepest section along the ridge.
5. Is the polarity at the center of the ridge normal or reversed?



A line drawing interpretation of a seismic profile across the Reykjanes Ridge.

MORE ABOUT SEA-FLOOR SPREADING:

1. The diagram provides distances from the ridge crest and ages of the rock. Use that information and determine the spreading rate(cm/yr) from 0 km to 190 km and 190 km to 250 km.

2. Did the spreading rate stay the same all the way across the ridge? If not, when did the fastest rate of spreading occurr?

3. How would you describe sea-floor spreading to a friend?

4. Did you know, the rate of spreading is the same as how fast your fingernails grow? Calculate how much the rift has spread during your life time.(use an average rate if necessary)

5. Recent data has shown that the spreading rate for the North Atlantic is 1.17cm per year. Use 1.17cm/yr. and a distance of 2315km from a ridge to the continental shelves. When did the Atlantic begin to open?

6. Does spreading at rift zones increase the size of the Earth? Justify your answer. (hint: there are deep sea trenches at other zones.)

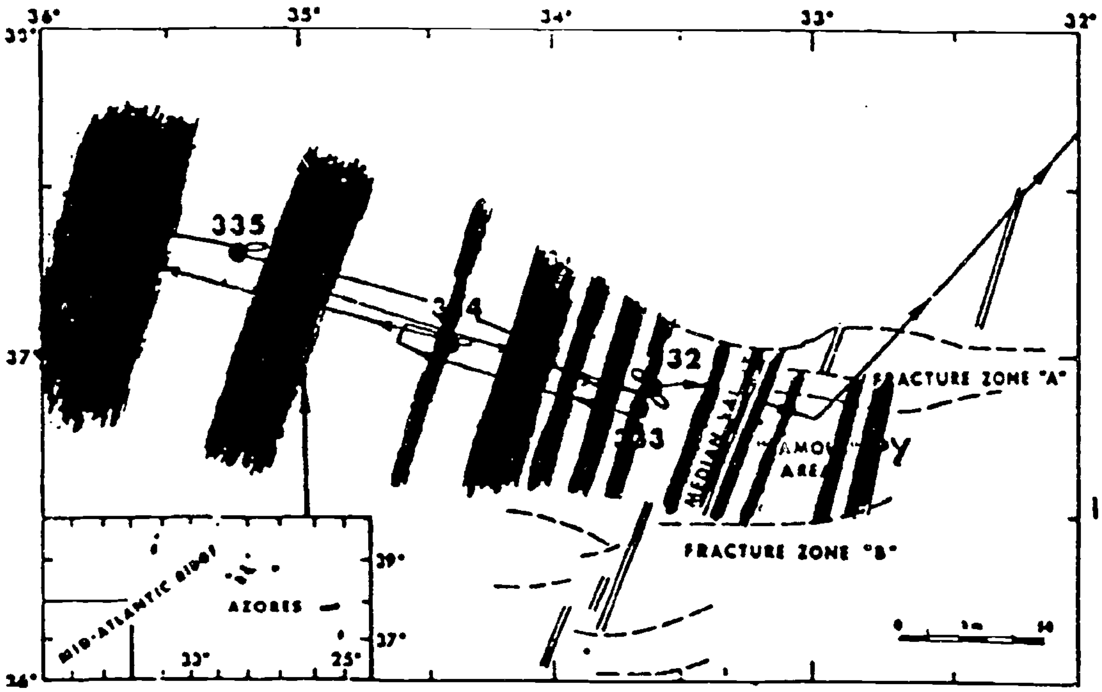
ANSWERS TO PALEOMAGNETIC ACTIVITIES

I. NAVIGATION CHART:

1. The Azore Islands.
2. 0000 GMT, midnight, local time-answers will vary, ship's 2300.
3. 1cm = 20km
4. The distance is about 80km for each distance.

II. ANOMALY MAP:

1. Allow for variations.



3. The striping pattern should be near the same on each side of the spreading center.

III. ANOMALY-SEISMIC CHART

1. No, the chart, at the top, indicates different rates across the ridge.
2. The patterns are very similiar.
3. The center of the ridge is the shallowest. Its depth is about 1km.
4. Near 2.5 to 3.0km.
5. Normal polarity("zero-age crust, formed in today's mag. field.)

IV. BASEMENT DEPTH vs. AGE AND DISTANCE FROM RIDGE CREST CHART

1. $$\frac{190km}{20,000,000yrs.} \times \frac{1,000m}{1km} \times \frac{100cm}{1m} = 0.95cm/yr$$

   250/300 = 0.83 cm/yr

2. No, from 0 to 20 m.y.b.p.

3. Magma, or molten rock, flows onto the sea-floor from cracks called rifts. It then spreads out and is carried by plate motion away from the center of the ridge. The spreading is recorded by magnetic reversals due to the iron minerals aligning to the direction of the Earth's magnetic field at the time of their formation. The variable speeds along the ridge causes transform faults to develop.

4. Answers will vary according to the ages. You may use 0.95cm/yr or the average rate across the ridge, 0.89cm/yr.

5. The total distance from each continental shelf is 4630km; we divide that by 2 to get 2315km.

   $$2315km \times \frac{1000km}{1km} \times \frac{100cm}{1m} \times \frac{1yr.}{1.17cm} = 197,863,248 \text{ yrs.}$$

   You may wish to begin a discussion as to why is the rate for the Reykjanes Ridge different from the overall rate. Also, the age of the oldest Atlantic oceanic crust shows that the central Atlantic ocean began to form in Triassic time about 200 Ma., which is in agreement with the above calculated figure.

6. No, because the earth's oceanic crust is subducted beneath continental crust at subduction zones.

The Theory of Plate Tectonics

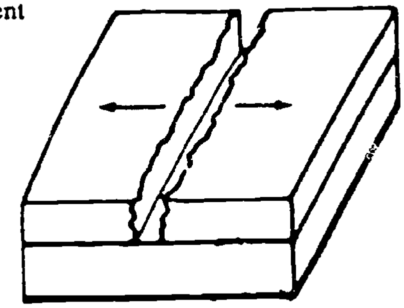
Movement of the Earth's lithosphere which includes the crust and the uppermost layer of the mantle was unthinkable until the 1960's. During this time, the Theory of Plate Tectonics was conceived. Many geologists believe that the theory explains many geologic activities, such as earthquakes and volcanism. If you have ever tried to piece together the peelings of an orange, you have an idea of the plates. The lithosphere consits of pieces called plates, twelve of them and many smaller plates, as if someone was trying to piece together an orange.

However, the plates do not sit on top of solid rock. As a result from the extremely high temperatures from deep within the earth, the plates move or float on top of the asthenosphere like icebergs. The high temperatures are thought to cause convection currents, and the plates ride the currents like the icebergs on top of the warm ocean.

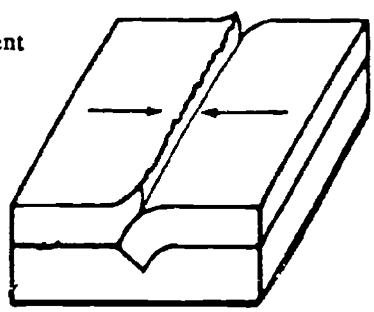
What happens when the plates move? Well, the plates have three basic motions, rifting(oozing crust), collision-subduction, and lateral-strike-slip. Rifting occurs on the sea floor, often called sea-floor spreading. Magma, hot molten rock, oozes up through cracks or faults onto the seafloor and moves away from the crack. Rifting occurs at the Mid-Atlantic Ridge and other locations. When plates carry continents and move toward each other, BANG, a collision occurs resulting in mountain building. The Himalayas were formed by this process. Subduction occurs when two plates are moving toward each other, without colliding, one plate made of oceanic crusts sinks beneath the plate made up of continental crust. The feature created is called a deep-sea trench. Heat is created from friction as the plates are subducting. When the lower plate is pushed under, it heats up in the hotter mantle and begins to melt. The melted rock becomes lighter and rises, often creating volcanoes. Mt. St. Helens was a result of subduction. Finally, the fourth motion is lateral motion or slipping by sideways. An example of this motion is the San Andreas Fault; here the Pacific and North American Plates are passing each other sideways, neither plate is destroyed. All of these motions produce stress in the rocks, at times, resulting in earthquakes. Many earthquakes and volcanoes occur at the boundries or margins of the plates. There is one other type of activity earth scientists call hot spots. These form when a narrow plume of hot material rises through the mantle underneath the plate. Plates may slowly move over the hot spots and create islands like the Hawaiian Islands.

THREE TYPES OF PLATE MOVEMENTS

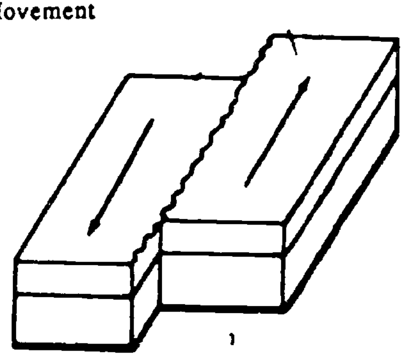
Divergent (spreading)
Plate Movement



Convergent (colliding-
subducting)
Plate Movement



Lateral (sliding)
Plate Movement



THE DYNAMIC EARTH

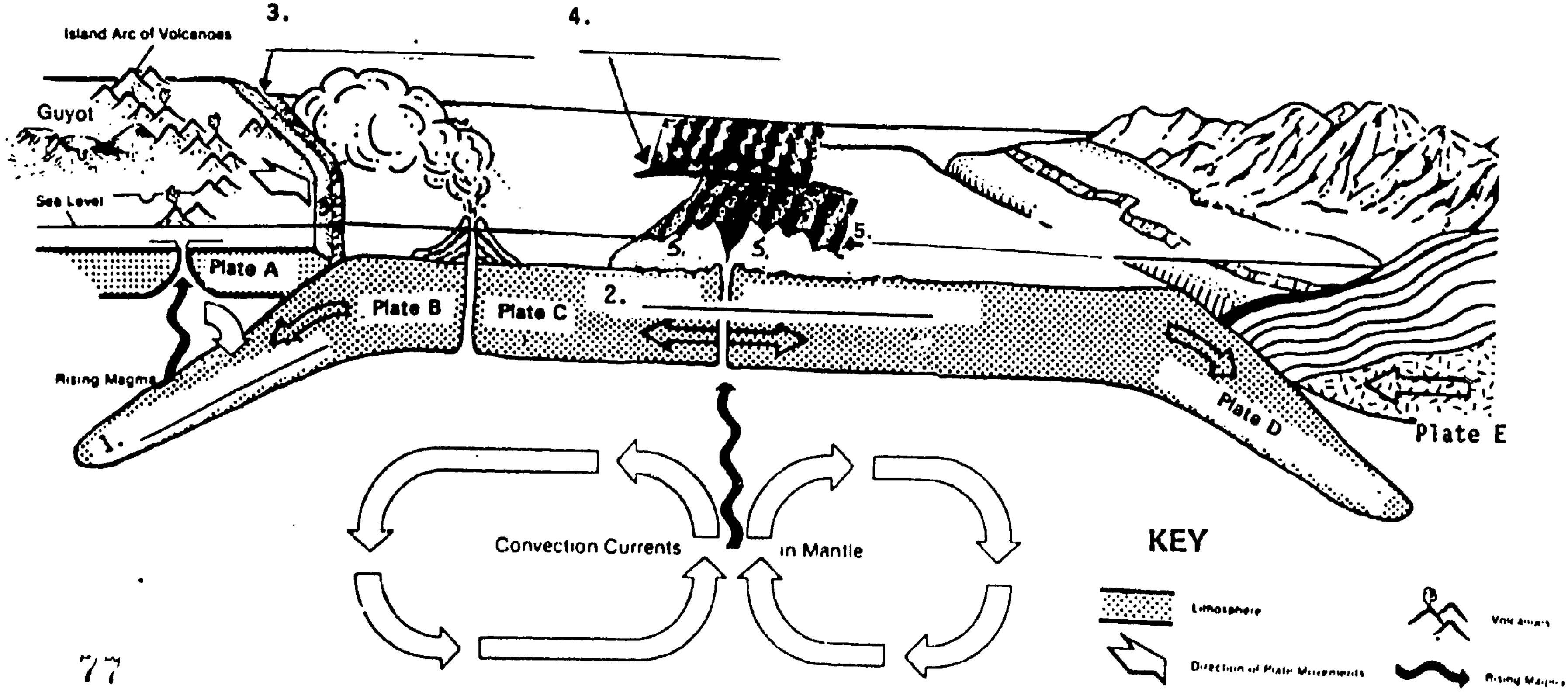
ACTIVITY:

1. Use the information on the sheet titled "Theory of Plate Tectonics" to help you label the features of the ocean listed below.

   divergent boundary   convergent boundary
   mid-ocean ridge   lateral fault   trench

2. The collision of Plate A with Plate B is called a __________ boundary that results in a one plate subducting under the other plate. The feature formed by this process is called a ____________________.

3. The pulling apart of Plate C from Plate D is called a ________________ boundary. New crustal material is being added along the ______________________________.



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THE DYNAMIC EARTH

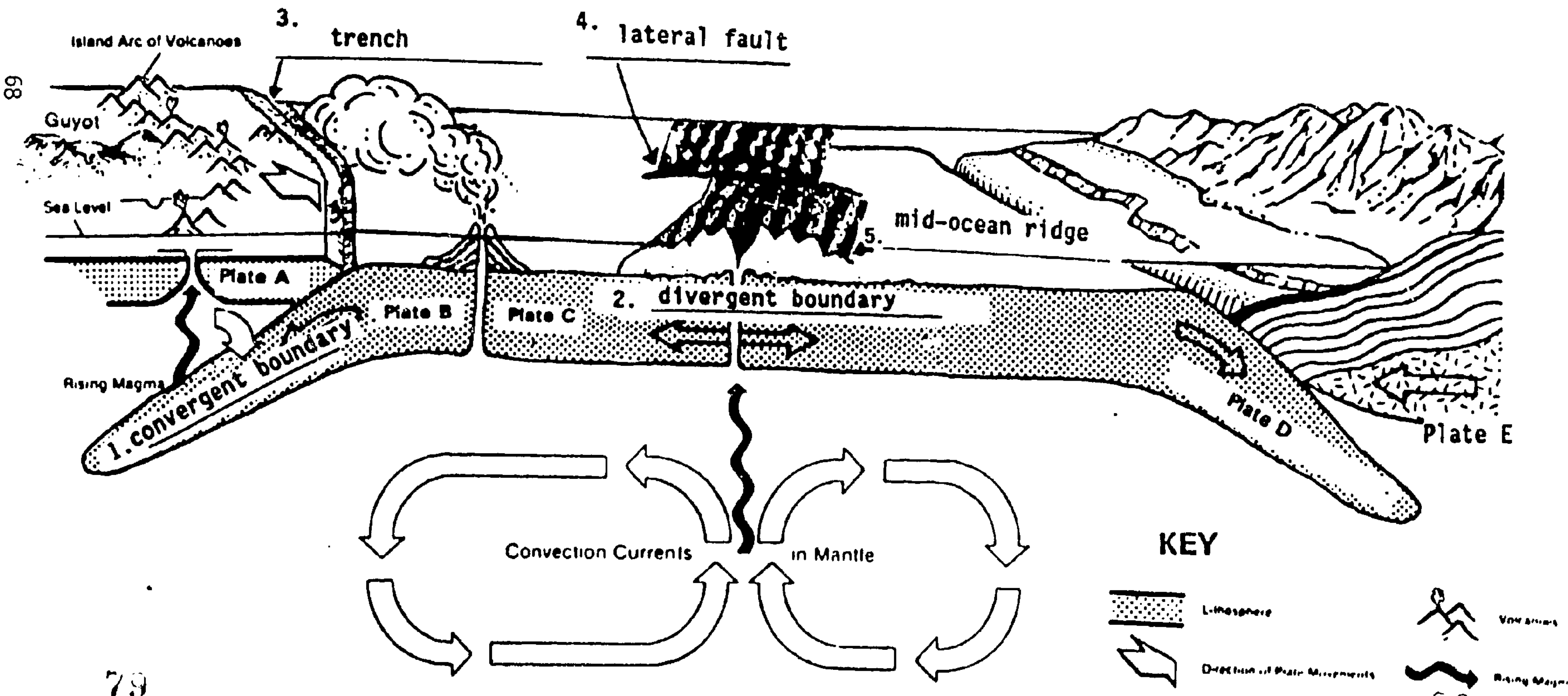
ACTIVITY:

1. Use the information on the sheet titled "Theory of Plate Tectonics" to help you label the features of the ocean listed below.

   divergent boundary   convergent boundary
   mid-ocean ridge   lateral fault   trench

2. The collision of Plate A with Plate B is called a convergent boundary that results in one plate subducting under the other plate. The feature formed by this process is called a trench.

3. The pulling apart of Plate C from Plate D is called a divergent boundary. New crustal material is being added along the mid-ocean ridge.



THE SEA-FLOOR AND PLATE TECTONICS

USE THE MAP CALLED SEA-FLOOR AND PLATE BOUNDRIES TO ANSWER THE FOLLOWING QUESTIONS CONCERNING PLATE TECTONICS.

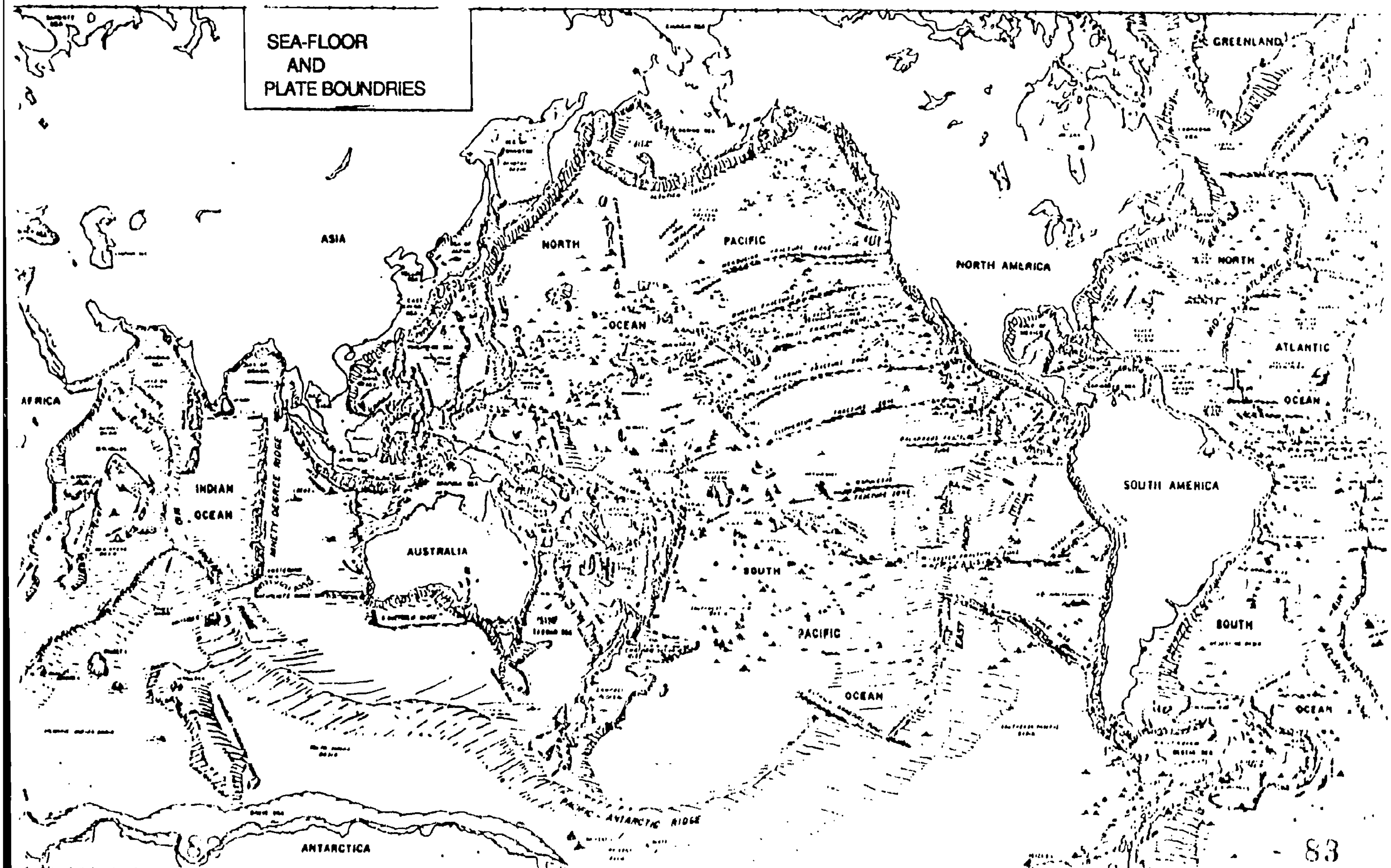
1. Draw the boundries of as many plates as you can. There are twelve major plates. Look for rifts, and trenchs. These are clues to the boundries of plates.

   The names of the plates are: North American Plate
   Caribbean Plate
   Cocos Plate
   Nazca Plate
   South American Plate
   Antarctic Plate
   Eurasian Plate
   Pacific Plate
   African Plate
   Austrilian-Indian Plate
   Arabian Plate
   Philipine Plate

2. List two sets of plates that are rifting (diverging), subducting(converging).

3. Which two plates have lateral motion? (hint: San Francisco)

SEA-FLOOR AND PLATE BOUNDRIES



Answers to The Sea-Floor and Plate Tectonics

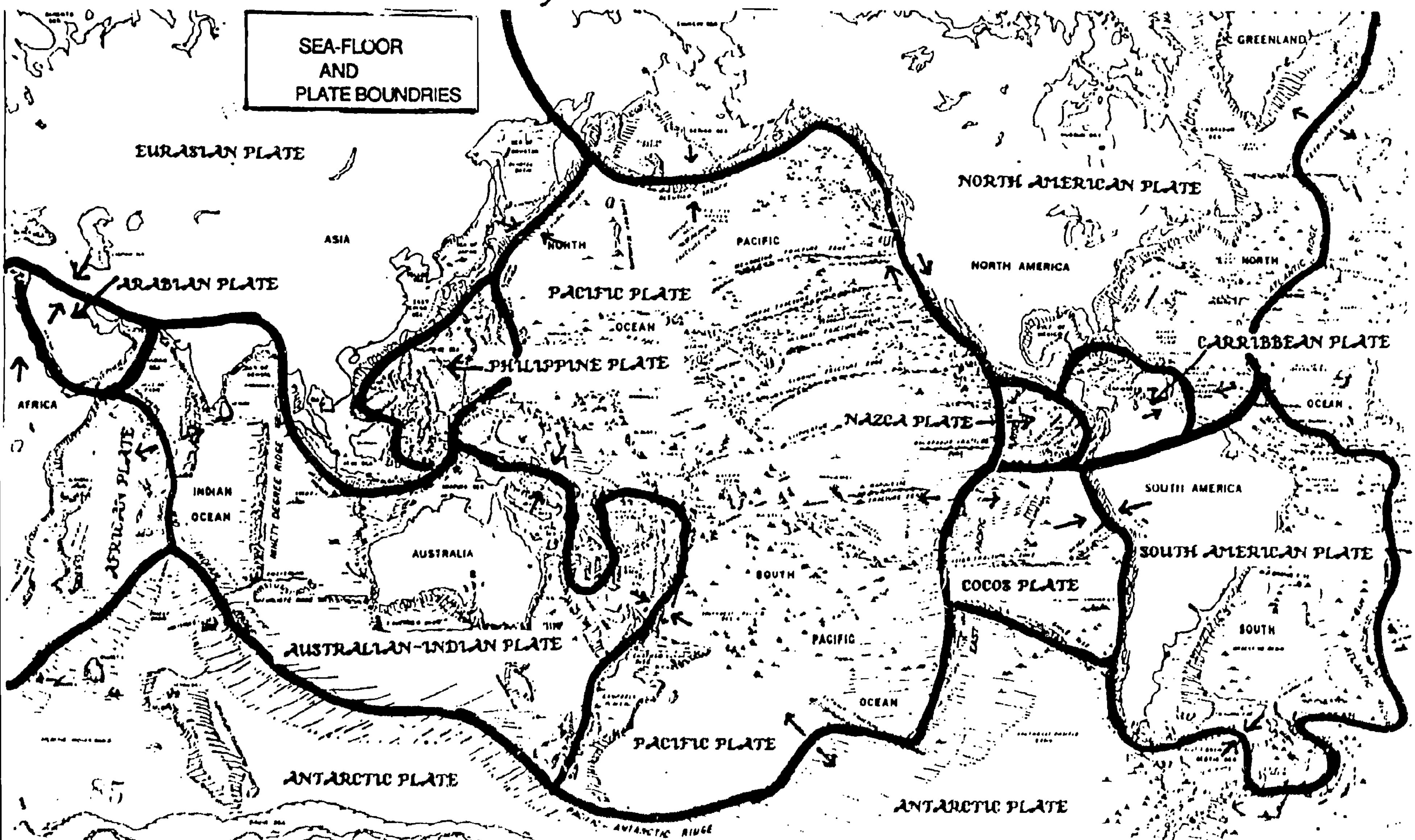
1. See map "The Major Plates of The Earth"

2. Rifting Plates: North American and Eurasian
South American and African
Pacific and Antarctic
African and Australian-Indian
Pacific and Cocos
Antarctic and Austrilian-Indian

Subducting Plates: Carrribbean and North American
Cocos and South American
South American and Antarctic
Eurasian and Arabian
Eurasian and Pacific
Pacific and North American
Pacific and Australian-Indian
Eurasian and Philipine

3. Lateral Motion Plates: Pacific and North American

THE MAJOR PLATES OF THE EARTH



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