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ABSTRACT

Crustal Evolution Education Project (CEEP) modules were designed to: (1) provide students with the methods and results of continuing investigations into the composition, history, and processes of the earth's crust and the application of this knowledge to man's activities and (2) to be used by teachers with little or no previous background in the modern theories of sea-floor spreading, continental drift, and plate tectonics. Each module consists of two booklets: a teacher's guide and student investigation. The teacher's guide contains all of the information present in the student investigation booklet as well as: (1) a general introduction; (2) prerequisite student background; (3) objectives; (4) list of required materials; (5) background information; (6) suggested approach; (7) procedure, including number of 45-minute class periods required; (8) summary questions (with answers); (9) extension activities; and (10) list of references. In this 2-period module, students study earthquake depth and distribution patterns around the world and the relationship between earthquakes and various types of plate boundaries. The activities require observational, recording, plotting, and inference-making skills and serve as an introduction to plate tectonic theory or as a follow-up activity after a unit on earthquakes. (Author/JN)

NAGT Crustal Evolution Education Project

Edward C. Stoever, Jr., Project Director

Welcome to the exciting world of current research into the composition history and processes of the earth's crust and the application of this knowledge to man's activities. The earth sciences are currently experiencing a dramatic revolution in our understanding of the way in which the earth works. CEEP modules are designed to bring into the classroom the methods and results of these continuing investigations. The Crustal Evolution Education Project began work in 1974 under the auspices of the National Association of Geology Teachers. CEEP materials have been developed by teams of science educators, classroom teachers and scientists. Prior to publication the materials were field tested by more than 200 teachers and over 12 000 students.

Current crustal evolution research is a breaking story that students are living through today.

Teachers and students alike have a unique opportunity through CEEP modules to share in the unfolding of these educationally important and exciting advances. CEEP modules are designed to provide students with appealing firsthand investigative experiences with concepts which are at or close to the frontiers of scientific inquiry into plate tectonics. Furthermore the CEEP modules are designed to be used by teachers with little or no previous background in the modern theories of sea-floor spreading, continental drift and plate tectonics.

We know that you will enjoy using CEEP modules in your classroom. Read on and be prepared to experience a renewed enthusiasm for teaching as you learn more about the living earth in this and other CEEP modules.

About CEEP Modules...

Most CEEP modules consist of two booklets, a Teacher's Guide and a Student Investigation. The Teacher's Guide contains all the information and illustrations in the Student Investigation plus sections printed in color intended only for the teacher, as well as answers to the questions that are included in the Student Investigation. In some modules, there are illustrations that appear only in the Teacher's Guide, and these are designated by figure letters instead of the 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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Earthquakes And Plate Boundaries

INTRODUCTION

In this activity, the student studies earthquake depth and distribution patterns around the world and the relationship between earthquakes and various types of plate boundaries. It is an exercise involving observation, recording, plotting and inference-making based on observation. It should be useful as an introduction to plate tectonic theory, or as a follow-up activity after a unit on earthquakes.

Why do earthquakes occur where they do? What causes earthquakes? Are earthquakes related to any earth structures? The earth's outer shell of rock is believed to be made up of a number of rigid plates, called **lithospheric plates,** which are from 80 km to 160 km thick. The plates are made up of the two upper rock zones of the earth, the crust and the upper portion of the **mantle** (Figure 1). Some plates include only **oceanic crust.** Other plates include both oceanic and the lighter **continental crust.** These plates ride on a zone in the mantle where the rock is almost melted and therefore not rigid. An example to help you picture this would be a block of wood floating in a bowl of honey.

In this activity you will find out that different patterns of earthquakes and topography are related to different kinds of plate boundaries.

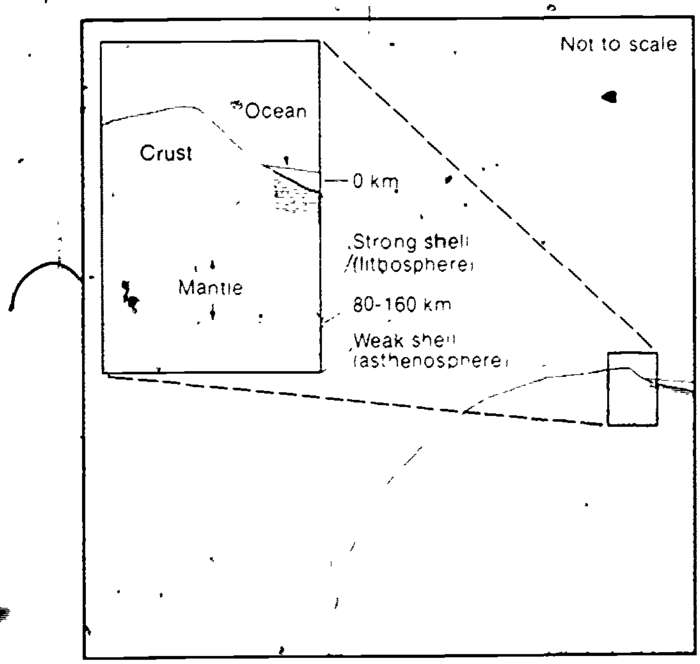

Figure 1 The rigid lithospheric plates and their relationship to the outer rock zones of the earth. (Thickness of zones not to scale.)

PREREQUISITE STUDENT BACKGROUND

Although this activity is intended to serve as an early introduction to the concept of lithospheric plates, you should provide some background knowledge of earthquakes and how epicenters are located. Activities similar to Investigation 16-4 in *Investigating the earth* (3rd ed., 1978) would provide helpful background material in understanding how time-travel curves are used in locating the epicenter of an earthquake.

OBJECTIVES

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

1. Explain the method used to find the location and depth of earthquakes on the *World Seismicity Map.*

2. Explain the relationship between earthquakes and plate boundaries.

3. Make a graph showing the distribution of earthquake depths near a coast, given the location and depth of earthquakes.

4. Describe the distribution of earthquake depths in an area where continental and oceanic plates collide.

5. Describe the relationship between earthquakes and major geographic features in South America.

6. Interpret data to identify the type of plate boundary in a given area.

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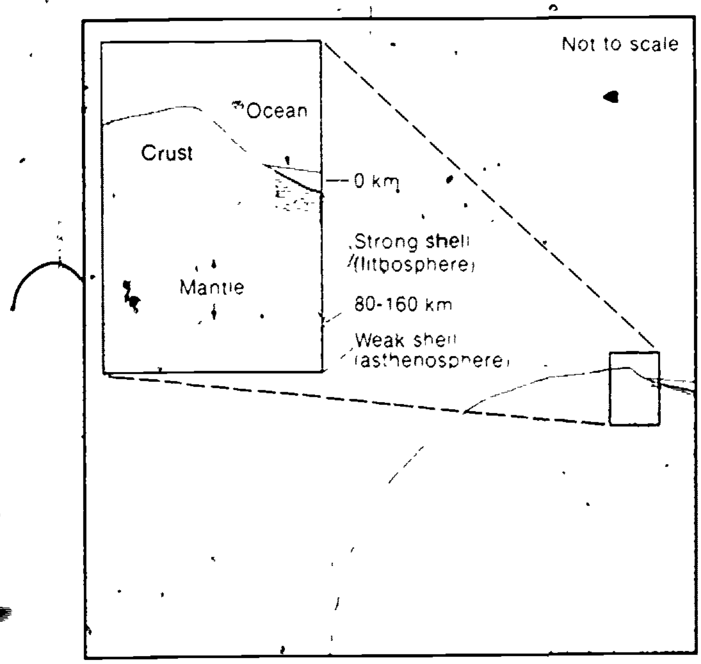

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MATERIALS

World Seismicity Map (compiled by Arthur Tarr), United States Geological Survey, 1200 S. Eads Street, Arlington, VA 22202—one for each group of four students, or several per classroom.

Map, *The Physical World*, National Geographic Society, Educational Services, Department 79, Washington, D.C. 20036—one for classroom

Colored pencils—for each student

BACKGROUND INFORMATION

The earth's surface is composed of seven major plates which are about 80 km to 160 km thick. These rigid plates are made up of the lighter rocks which form the earth's crust and denser rocks of the uppermost portion of the mantle. The crust and upper mantle are called the lithosphere. The plates of the lithosphere ride on a less rigid layer of rock, deeper in the mantle, called the asthenosphere. Rock in the asthenosphere is almost at its melting point and therefore has some plastic properties. The plates ride like giant rafts on the asthenosphere.

Along these major plate boundaries a great deal of geologic activity takes place. Great stresses build up in these zones as one plate edge presses against another. Eventually the stress becomes too great and the plates move against each other, causing an earthquake. See Figures 3, 4 and 5. Knowledge of where earthquakes occur can help identify the location and types of boundaries of the major plates of the earth.

Although it may now seem rather simple to draw a line through earthquake epicenters, the earthquake information required to define the nature of plate boundaries took many years of careful record-keeping.

Several major types of plate boundaries are hypothesized:

1. Spreading boundaries where the lithosphere is moving apart, as along the oceanic ridges (Figure 2).
2. Transform boundaries where plates are sliding past each other (Figure 3).
3. Boundaries of convergence where plates collide, causing buckling and upthrusting of the crustal plates (Figure 4).
4. Boundaries of subduction where plates having continental crust collide with plates having oceanic crust, causing the leading edge of the plate with oceanic crust to be thrust under the leading edge of the one with continental crust (Figure 5).

Study of these plate boundaries shows that spreading boundaries are under tension, transform boundaries show lateral or sliding motion and convergent and subduction boundaries are under compression.

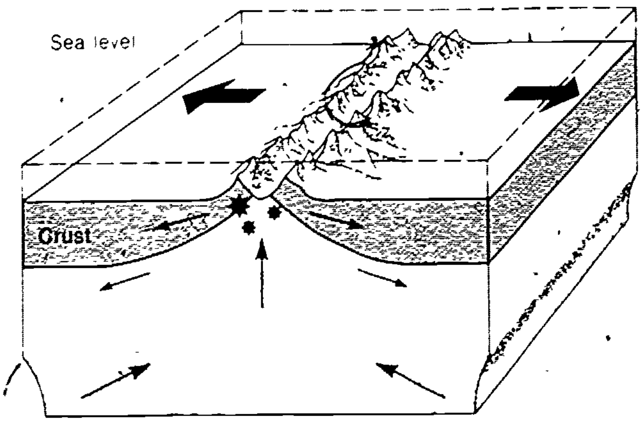


Figure 2 Plates may move apart from one another Magma rises upward into mid-ocean ridge

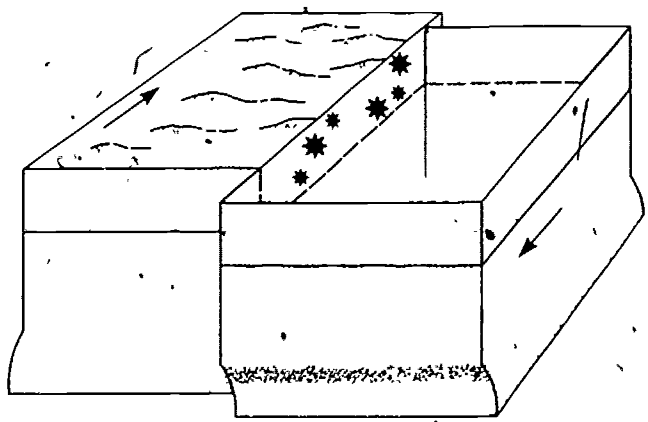


Figure 3 Plates may move past one another One block of crust is transparent to show location of earthquakes (foci)

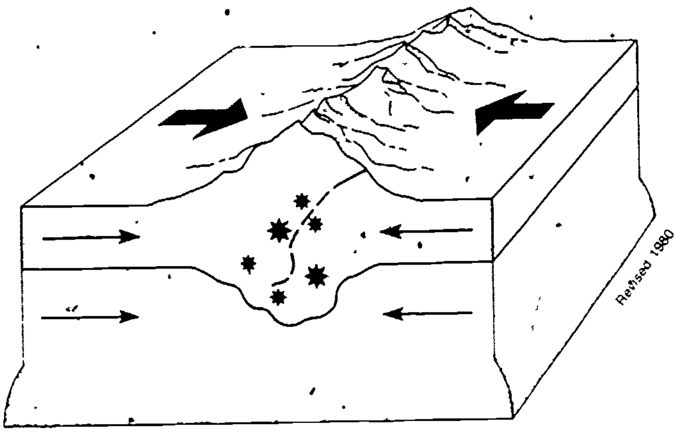


Figure 4 Plates with continental crust may collide with one another.

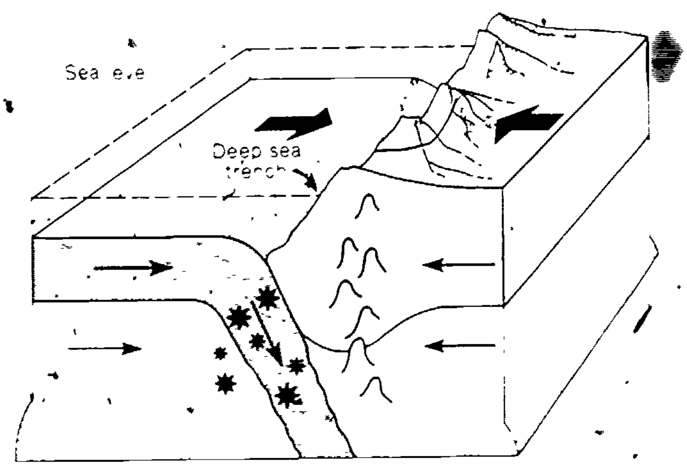


Figure 5 A plate with oceanic crust may collide with a plate with continental crust Magma rises upward into mountains

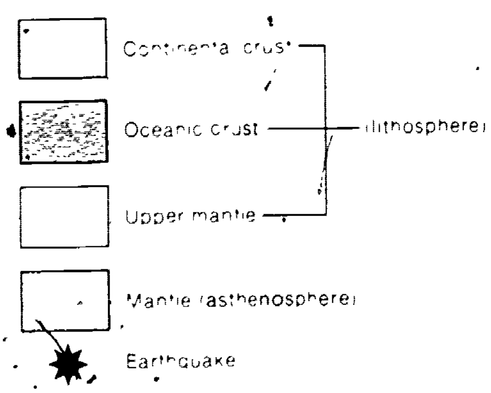


Illustration Key

Earthquake depths vary depending on the type of plate boundary:

1. Along spreading boundaries earthquakes are shallow.
2. Where plates slide past each other (as along the San Andreas Fault), earthquakes are shallow.
3. Where plates are colliding, most earthquakes are shallow, some are of intermediate depth and, occasionally, deep ones occur.

A very clear pattern of earthquakes, ranging from shallow to deep, is found where plates bearing oceanic crust collide with plates bearing continental crust. These earthquakes mark the subduction zone of the descending plate which contains the denser oceanic crust. The oceanic crust that is being pushed (subducted) down into the mantle descends at an angle of from 30° to nearly 90° (usually about 45°).

By plotting the depth of focus of earthquakes where continental crust and oceanic crust are colliding, students will be better able to understand the contact made by the crustal plate which is plunging down into the mantle.

The Peru-Chile trench is viewed by earth scientists as a classic ocean floor trench caused by a colliding of the Nazca and American plates. Similar trenches, which ring the Pacific Ocean basin, form the deepest surface features on earth and are frequently associated with earthquakes and volcanic activity.

SUGGESTED APPROACH

Students should work in groups of four, with each group having the *World Seismicity Map* and a map showing major features of the ocean basins, such as *The Physical World* map. Although less desirable, students could refer to maps posted around the room if enough maps are not available for each group. Up to a third of a class period will be required for studying the *World Seismicity Map* before the questions can be answered.

Discuss the *World Seismicity Map* with the students before they begin work, so they will be familiar with the symbols and will know what type of information is found on the map. Make sure students understand the four types of plate boundaries. Otherwise, little can be learned from the rest of the activity. Do not spend a great deal of time going over the details and interpretations of the seismicity map with the entire class. Answers to the questions are best handled in the small group settings.

You should plan on one to two 45-minute class periods for the completion of this activity, depending upon the ability and previous background of students. It is suggested that the students' progress and answers to the questions be evaluated while they are working in groups.

The profile that students develop does not hold for all ocean trenches. In some places, the deeper foci form a steeper slope than the shallower foci, suggesting that the crustal plate may become contorted after passing into the asthenosphere.

PROCEDURE

In the first part of this activity, each group of students will work with a copy of the *World Seismicity Map*. Interpretation of the map's notation and the pattern of earthquake distribution are primary objectives of this part of the activity.

Key words: oceanic crust, continental crust, mantle, lithospheric plates, epicenter, focus

Time required: two 45-minute periods

Materials colored pencils, *World Seismicity Map*, *The Physical World* map

A great deal of action takes place along adjacent plate boundaries Large forces build up as one plate moves with respect to another When the force becomes too great, the rocks move against each other, causing an earthquake Different types of movement of adjacent plates may occur Plate boundaries are the sites of much earthquake activity. Both the pattern of earthquake distribution and major topographic features are distinctive of the type of plate boundaries and motion (see Figures 2, 3, 4, and 5)

Look at a copy of the *World Seismicity Map* Note Please do not mark on this map Other students must use it Before proceeding, carefully read the box on the map entitled "EXPLANATION"

1. The dots on this map represent earthquakes that occurred over a period of time of **nine** years and **six** months

2. Large earthquakes are represented by **circles**, smaller earthquakes by **dots**

The **focus** of an earthquake is the point within the earth where an earthquake actually occurs The **epicenter** of an earthquake is the point on the earth's surface which lies directly above the focus. See Figure 6

3. Which of these two points is represented by the location of the dots on the map showing earthquakes?

The epicenter locations

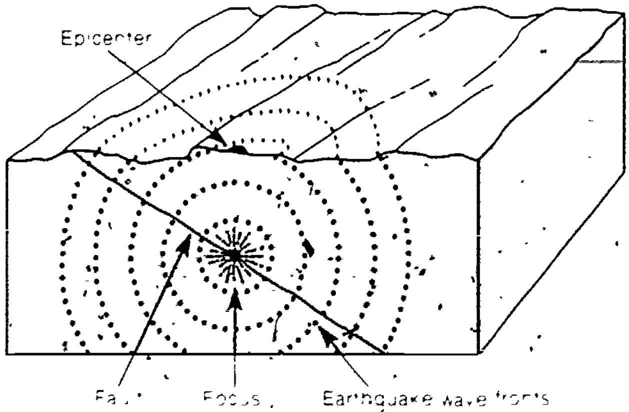


Figure 6 Focus and epicenter of earthquake

4. On the map, what color is used to indicate earthquakes of

a a shallow focus (0-70 km)? **red**

b an intermediate focus (71-300 km)? **green**

c a deep focus (301-700 km)? **blue**

Scientists believe that zones of frequent earthquake activity are the result of movements along plate boundaries Many of the earth's surface features are associated with plate boundaries See where the locations of epicenters are located on the *World Seismicity Map* Then find the locations of ocean ridges and trenches on *The Physical World* map

5. List at least two major kinds of ocean floor features which seem to coincide with the location of major zones of earthquake activity

Deep sea trenches and mid-ocean ridges

6. Where do most of the earthquakes occur in South America?

On the western coast in the countries of Peru and Chile.

List one kind of continental feature which seems to be related to frequent earthquakes

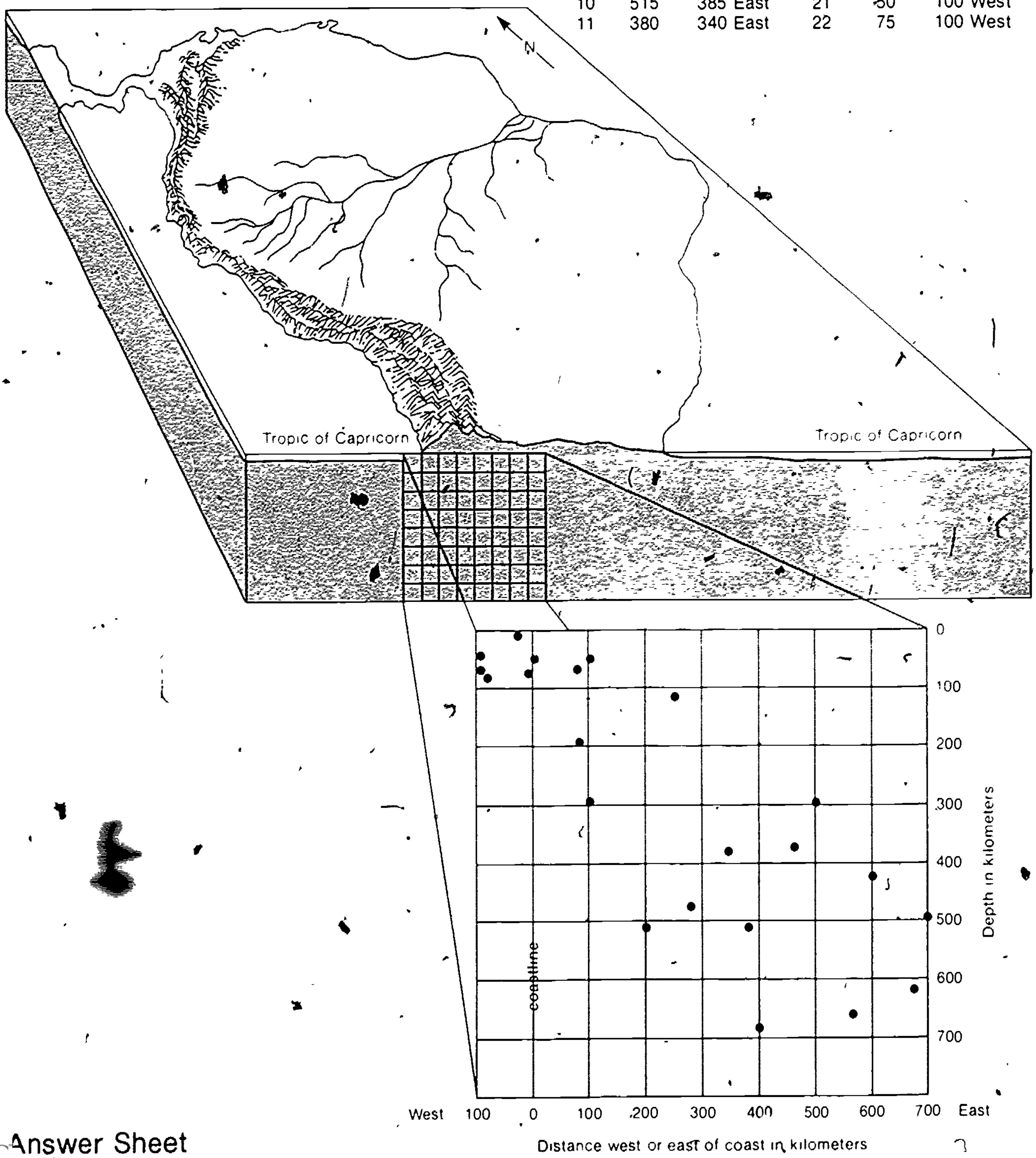
mountains

Data in Table 1 show the location and depth of earthquake activity along the west coast of South America near the Tropic of Capricorn.

7. Plot the data on the graph on Worksheet, using colored pencils for each range of depth, as shown on the *World Seismicity Map*. Then answer the questions which follow.

Table 1
Location and depth of earthquake foci for plotting on Worksheet

Datum Point No	*Depth (km)*	*Distance (km) and direction from coast*	*Datum Point No.*	*Depth (km)*	*Distance (km) and direction from coast*
1	50	0	12	50	100 East
2	300	100 East	13	300	500 East
3	385	450 East	14	485	280 East
4	60	80 East	15	660	550 East
5	125	250 East	16	90	90 West
6	200	70 East	17	520	200 East
7	690	400 East	18	90	25 West
8	25	40 West	19	440	600 East
9	500	700 East	20	640	660 East
10	515	385 East	21	50	100 West
11	380	340 East	22	75	100 West



Answer Sheet

8. Describe the relationship between the location of the epicenters (east or west) and the depth of focus of earthquakes along the coast of South America, as shown by your graph

The earthquakes are shallow near the coastline (focus less than 70 km). Going eastward toward the center of the continent, the earthquake foci become deeper.

9. Describe the type of plate boundary which you think is present along the west coast of South America

The type of boundary along the west coast of South America is thought to be a subduction boundary, i.e., where a plate having oceanic crust is colliding with a plate having continental crust. Note. The student graph is representative of the boundary, and students should be cautioned that it is probably better thought of as a zone than as a line.

Follow the zone of earthquake activity, from South America northward past Central America, as shown on the *World Seismicity Map.*

SUMMARY QUESTIONS

1. From what you have learned in this activity, draw a cross section of what you think the profile of the continent and ocean plate boundary might look like along the west coast of South America (Hint look at Figures 2, 3, 4, and 5) On this sketch, show and label the location of the deep Chile-Peru trench and the volcanic mountains (the Andes)

Based upon their investigation in this activity, students should be able to sketch something similar to this diagram.

2. In what way is the plate boundary along the coast of California different from the plate boundary along the west coast of South America?

The distribution of earthquake foci along the coast of California suggests a vertical plate boundary similar to that shown either in Figure 2 or in Figure 3. Since the California earthquake zone is bounded on one side by continental crust, this boundary is best represented as the type shown in Figure 3.

On the other hand, the plate boundary along the west coast of South America is a collision-type boundary similar to that shown in Figure 5. This is evident from the existence of an oceanic trench and a zone of earthquake foci inclined downward under the edge of the continental crust.

10. Where does the plate boundary appear to change?

By looking at the earthquake activity northward along the western coastline of South and Central America, it is noticeable that the depths of foci become shallower. Northward from southern Mexico virtually all the earthquake activity has a shallow focus. It is interpreted that the shallow focus earthquakes are a result of a change in the type of the plate boundary.

11. Offer a possible explanation for this change.

In the vicinity of southern Mexico, the plate boundary along the west coast of South America and Central America appears to terminate against another plate boundary, which can be traced continuously along the East Pacific Rise and western margin of North America. This can be inferred from the distribution of clusters of earthquake foci.

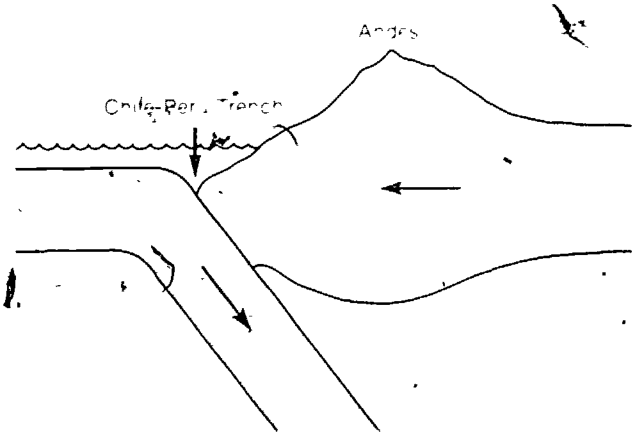


Figure A. Sample student diagram of a cross section of the west coast of South America.

EXTENSIONS

1. What type of plate boundary do you think would best account for the type of earthquake activity found in California?

Sliding motion, as would be found along a transform boundary, could account for the earthquake activity in California. (Refer students to Figure 3.)

2. Locate three other areas on the earth's surface which would most likely have plate boundaries similar to the one in South America. Explain the reason for your choices.

Most of the Pacific Ocean Plate is bordered by plate boundaries similar to the South American boundary. Notable examples are along the Aleutian Islands, the islands of Japan, the Mariana Islands, and the Samoa-Tonga-Kermadec Islands northeast of New Zealand. However, note that in the New Hebrides Islands, west of the Samoa Islands, the usual pattern is reversed, and earthquake foci become deeper toward the Pacific Ocean basin, rather than away from it. In this region, the Australian Plate, interpreted to be moving rapidly northward, is being overridden by the Pacific Plate, thereby reversing the shallow-to-deep earthquake focus sequence.

3. Locate three areas on the earth's surface which appear to have boundaries similar to the kind shown in Figure 2.

Areas along mid-oceanic ridges would have earthquakes similar to the kind shown in Figure 2.

4. Locate one area on the earth's surface which appears to have boundaries similar to the kind shown in Figure 4.

The Himalayan mountain range is an example of an area which has a boundary similar to the kind shown in Figure 4. This is an area where two plates of continental crust are colliding along a boundary of convergence.

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NAGT Crustal Evolution Education Project Modules

CEEP Modules are listed here in alphabetical order. Each Module is designed for use in the number of class periods indicated. For suggested sequences of CEEP Modules to cover specific topics and for correlation of CEEP Modules to standard earth science textbooks, consult Ward's descriptive literature on CEEP. The Catalog Numbers shown here refer to the CLASS PACK of each Module consisting of a Teacher's Guide and 30 copies of the Student Investigation. See Ward's descriptive literature for alternate order quantities.

CEEP Module	Class Periods	CLASS PACK Catalog No.
• A Sea-floor Mystery: Mapping Polarity Reversals	3	34 W 1201
• Continents And Ocean Basins: Floaters And Sinkers	3-5	34 W 1202
• Crustal Movement: A Major Force In Evolution	2-3	34 W 1203
• Deep Sea Trenches And Radioactive Waste	1	34 W 1204
• Drifting Continents And Magnetic Fields	3	34 W 1205
• Drifting Continents And Wandering Poles	4	34 W 1206
• Earthquakes And Plate Boundaries	2	34 W 1207
• Fossils As Clues To Ancient Continents	2-3	34 W 1208
• Hot Spots In The Earth's Crust	3	34 W 1209
• How Do Continents Split Apart?	2	34 W 1210
• How Do Scientists Decide Which Is The Better Theory?	2	34 W 1211
• How Does Heat Flow Vary In The Ocean Floor?	2	34 W 1212
• How Fast Is The Ocean Floor Moving?	2-3	34 W 1213
• Iceland: The Case Of The Splitting Personality	3	34 W 1214
• Imaginary Continents: A Geological Puzzle	2	34 W 1215
• Introduction To Lithospheric Plate Boundaries	1-2	34 W 1216
• Lithospheric Plates And Ocean Basin Topography	2	34 W 1217
• Locating Active Plate Boundaries By Earthquake Data	2-3	34 W 1218
• Measuring Continental Drift: The Laser Ranging Experiment	2	34 W 1219
• Microfossils, Sediments And Sea-floor Spreading	4	34 W 1220
• Movement Of The Pacific Ocean Floor	2	34 W 1221
• Plate Boundaries And Earthquake Predictions	2	34 W 1222
• Plotting The Shape Of The Ocean Floor	2-3	34 W 1223
• Quake Estate (board game)	3	34 W 1224
• Spreading Sea Floors And Fractured Ridges	2	34 W 1225
• The Rise And Fall Of The Bering Land Bridge	2	34 W 1227
• Tropics In Antarctica?	2	34 W 1228
• Volcanoes: Where And Why?	2	34 W 1229
• What Happens When Continents Collide?	2	34 W 1230
• When A Piece Of A Continent Breaks Off	2	34 W 1231
• Which Way Is North?	3	34 W 1232
• Why Does Sea Level Change?	2-3	34 W 1233

WARD'S

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MODULE NO. MD1 4-2

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CRUSTAL EVOLUTION EDUCATION PROJECT

NAME DATE

Student Investigation
Catalog No 34W1107

Earthquakes And Plate Boundaries

INTRODUCTION

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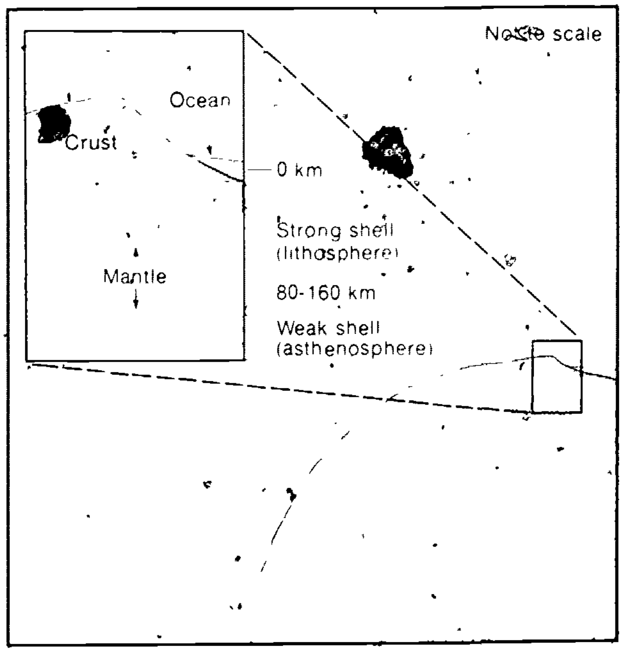

Figure 1 The rigid lithospheric plates and their relationship to the outer rock zones of the earth. (Thickness of zones not to scale.)

OBJECTIVES

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1. Explain the method used to find the location and depth of earthquakes on the *World Seismicity Map.*

2. Explain the relationship between earthquakes and plate boundaries

3. Make a graph showing the distribution of earthquake depths near a coast, given the location and depth of earthquakes.

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5. Describe the relationship between earthquakes and major geographic features in South America

6. Interpret data to identify the type of plate boundary in a given area.

PROCEDURE

Materials: colored pencils, *World Seismicity Map*, *The Physical World* map

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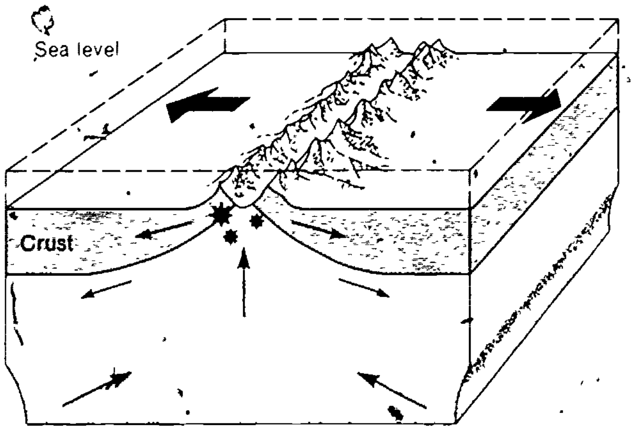


Figure 2. Plates may move apart from one another. Magma rises upward into mid-ocean ridge

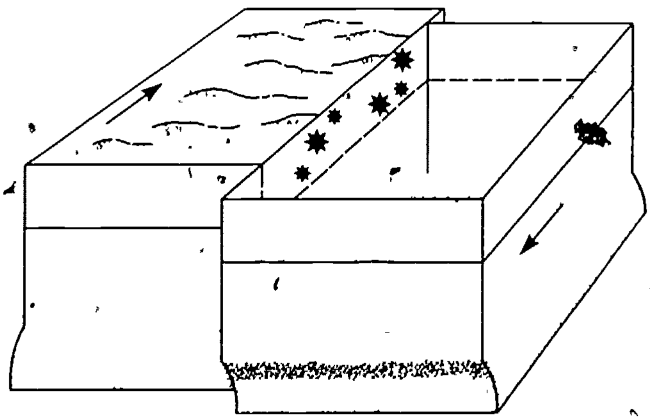


Figure 3. Plates may move past one another. One block of crust is transparent to show location of earthquakes (foci).

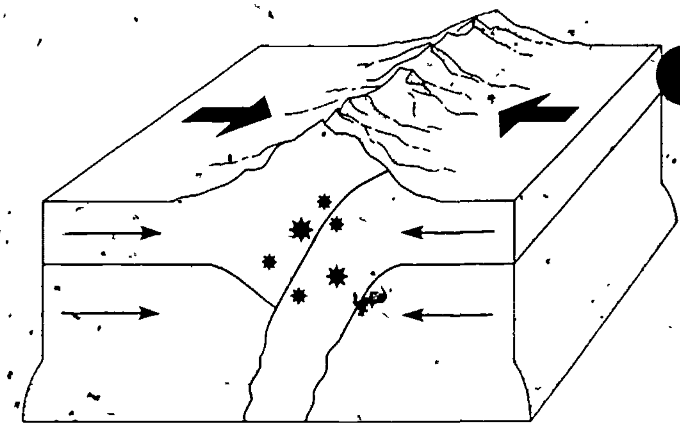


Figure 4. Plates with continental crust may collide with one another

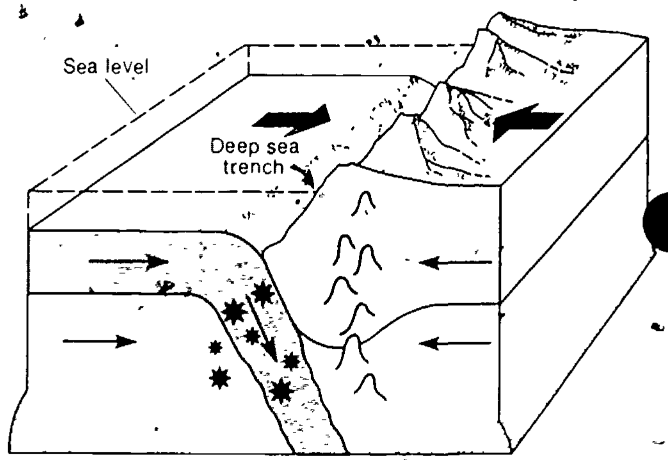


Figure 5. A plate with oceanic crust may collide with a plate with continental crust. Magma rises upward into mountains

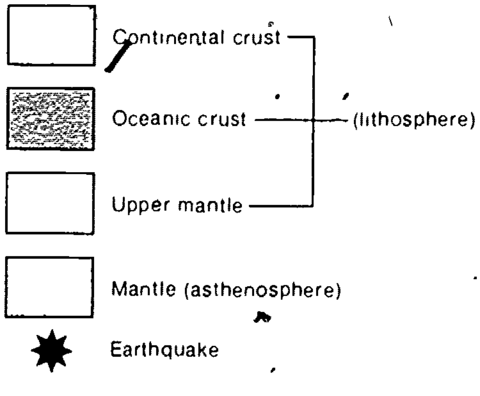


Illustration Key

Look at a copy of the *World Seismicity Map*. Note: Please do not mark on this map. Other students must use it. Before proceeding, carefully read the box on the map entitled "EXPLANATION."

1. The dots on this map represent earthquakes that occurred over a period of time of ______ years and ______ months.

2. Large earthquakes are represented by ______, smaller earthquakes by ______

The **focus** of an earthquake is the point within the earth where an earthquake actually occurs. The **epicenter** of an earthquake is the point on the earth's surface which lies directly above the focus. See Figure 6.

3. Which of these two points is represented by the location of the dots on the map showing earthquakes?

4. On the map, what color is used to indicate earthquakes of

a. a shallow focus (0-70 km)? ______
b. an intermediate focus (71-300 km)? ______
c. a deep focus (301-700 km)? ______

Scientists believe that zones of frequent earthquake activity are the result of movements along plate boundaries. Many of the earth's surface features are associated with plate boundaries. See where the locations of epicenters are located on the *World Seismicity Map*. Then find the locations of ocean ridges and trenches on *The Physical World* map.

5. List at least two major kinds of ocean floor features which seem to coincide with the location of major zones of earthquake activity.

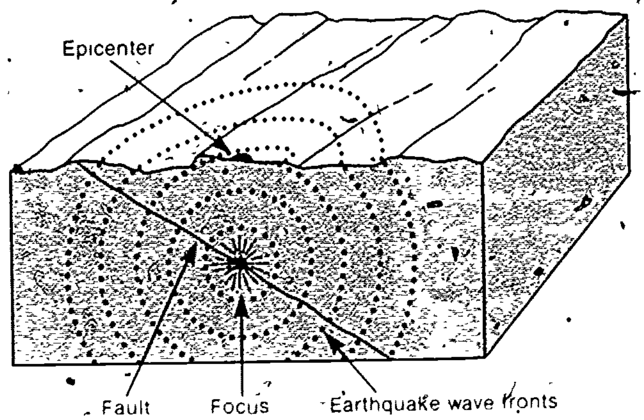


Figure 6 Focus and epicenter of earthquake.

6. Where do most of the earthquakes occur in South America?

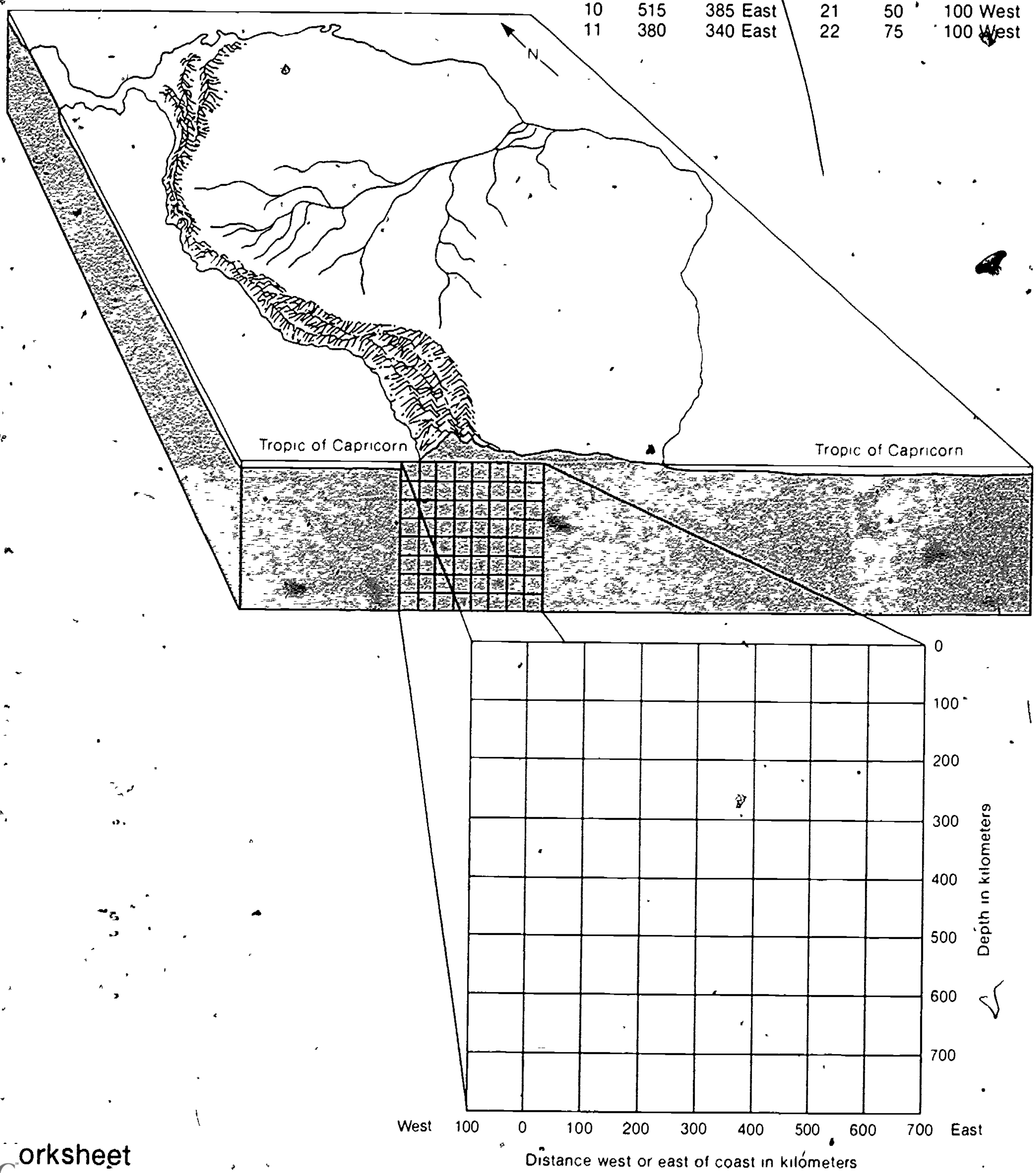
List one kind of continental feature which seems to be related to frequent earthquakes.

Data in Table 1 show the location and depth of earthquake activity along the west coast of South America near the Tropic of Capricorn.

7. Plot the data on the graph on Worksheet, using colored pencils for each range of depth, as shown on the *World Seismicity Map*. Then answer the questions which follow.

Table 1.
Location and depth of earthquake foci for plotting on Worksheet

Datum Point No	*Depth (km)*	*Distance (km) and direction from coast*	*Datum Point No*	*Depth (km)*	*Distance (km) and direction from coast*
1	50	0	12	50	100 East
2	300	100 East	13	300	500 East
3	385	450 East	14	485	280 East
4	60	80 East	15	660	550 East
5	125	250 East	16	90	90 West
6	200	70 East	17	520	200 East
7	690	400 East	18	90	25 West
8	25	40 West	19	440	600 East
9	500	700 East	20	640	660 East
10	515	385 East	21	50	100 West
11	380	340 East	22	75	100 West



Worksheet

8. Describe the relationship between the location of the epicenters (east or west) and the depth of focus of earthquakes along the coast of South America, as shown by your graph.

9. Describe the type of plate boundary which you think is present along the west coast of South America

Follow the zone of earthquake activity, from South America northward past Central America, as shown on the *World Seismicity Map.*

10. Where does the plate boundary appear to change?

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11. Offer a possible explanation for this change.

SUMMARY QUESTIONS

1. From what you have learned in this activity, draw a cross section of what you think the profile of the continent and ocean plate boundary might look like along the west coast of South America (Hint look at Figures 2, 3, 4, and 5) On this sketch, show and label the location of the deep Chile-Peru trench and the volcanic mountains (the Andes)

2. In what way is the plate boundary along the coast of California different from the plate boundary along the west coast of South America?

EXTENSIONS

1. What type of plate boundary do you think would best account for the type of earthquake activity found in California?

2. Locate three other areas on the earth's surface which would most likely have plate boundaries similar to the one in South America Explain the reason for your choices

3. Locate three areas on the earth's surface which appear to have boundaries similar to the kind shown in Figure 2

4. Locate one area on the earth's surface which appears to have boundaries similar to the kind shown in Figure 4

REFERENCES

Canby, T.Y., 1973, California's San Andreas Fault. *National Geographic,* v. 143, no. 1 (Jan.), p. 38-53.

Science Year: The World Book Science Annual, 1973 ed., s.v. Earth's heat engines: the force that moves continents, by Deffeyes, K.S., p. 163-187.

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