CEEP™

CRUSTAL
EVOLUTION
EDUCATION
PROJECT

Plate Boundaries And Earthquake Prediction

TEACHER'S GUIDE

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For use with Student Investigation 34W1122
Class time: two 45-minute periods

Developed by
THE NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

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Plate Boundaries And Earthquake Prediction

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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Plate Boundaries And Earthquake Prediction

INTRODUCTION

Some people wouldn't think of going outside each day until they have heard the weather prediction. Don't you think it would be sensible for people to check for an earthquake prediction before they go to work or travel in an area? Scientists may be on the verge of predicting certain kinds of earthquakes. Some correct predictions have already taken place. To make correct earthquake predictions become a regular reality, scientists are making concentrated research efforts.

New theories of plate tectonics have contributed to research on earthquake prediction. Since most quakes on earth occur on or near plate boundaries, the researchers have to understand plate tectonics.

Two general kinds of data useful for prediction are the history of earthquakes and land movement in an area, and strange events, called **precursors,** that usually occur some time before an earthquake.

PREREQUISITE STUDENT BACKGROUND

It would be helpful for students to have some knowledge of earthquakes. Most of the data and relationships presented in this module are based on the assumption of an active major fault in which there is a constant build-up and periodic release of strain. Students should be familiar with the basic kinds of faults, especially strike-slip faults. Earthquake magnitude also should be explained before the activity. The important point is that magnitude on the Richter scale does not increase evenly from one number to the next. Rather it is logarithmic (each number designates a magnitude ten times greater up the scale), recognizing that higher magnitude earthquakes release a vastly greater energy than those with low numbers.

OBJECTIVES

When you have completed these activities, you should be able to:

1. Locate and relate plate boundaries and areas having frequent earthquakes.

2. Explain how to use historical seismic data to predict earthquakes in an area.

3. List three precursors and briefly explain how they are used in earthquake prediction.

4. Make an earthquake prediction based on simulated data.

MATERIALS

None

BACKGROUND INFORMATION

Earthquake prediction involves specifying the time, place and magnitude of an individual future event. All three of these parameters are poorly known and are complicated by functions of the relative motions of parts of the earth's crust and mantle, the rate of strain accumulation in rocks and the strength of those rocks. Even if the processes by which the energy is accumulated and released were completely understood, the imprecise knowledge of the initial conditions, boundary conditions and relevant material properties would make the prediction of a particular seismic event very difficult.

Nevertheless, earthquake prediction has been a research goal of some seismologists and other geophysicists for about a decade. One approach is to base predictions on studies that show gaps in the seismic activity at a particular location. If major earthquakes are periodic, then a long seismic gap may mean a recurrence is likely or overdue at that place. But the main thrust is the search for precursors, that is, phenomena that occur in a characteristic way prior to an earthquake. Most of the research to date has been empirical.

Recently, however, a physical model of processes preceding a seismic event has been successful in explaining and unifying a number of independent observations. Although this theory, known as "dilatancy," is still being tested, it offers hope that at least some earthquakes in some geological settings are predictable on the basis of easily observable phenomena.

The setting of an active fault, the San Andreas Fault, will be used as an example in this module. Plate boundary settings such as this are more useful for prediction than other locations because strain and movement are operating constantly. Accurate prediction is still a goal for the future.

SUGGESTED APPROACH

PART A requires some important teacher direction. In order to keep student reading at a minimum, the graphs, relationships and exercises in PART A are presented here with no explanation. Students are instructed to wait for your direction. The following section, PROCEDURE, explains the graphs. The graphs were simplified for student use so some of the original formulas could be presented. The students are expected to gain a basic understanding of the relationship so they can read and logically follow the graph.

If students seem to be understanding the various relationships, they may not need much help in synthesizing them to make their own predictions in PART B. If some students are having difficulty, go through the first example with them.

An important point that should be stressed from the beginning is that research and development in this field is young. The graphs have been simplified from research that is currently being argued and disputed. Some precursors under investigation today may prove invalid tomorrow. Likewise, scientists may have over-looked the key to prediction thus far. In any case, the intent is to expose students to a field of endeavor that will experience rapid growth and increasing importance in the next few years. When the breakthroughs occur, the students who learn from this module will have a fuller understanding.

PROCEDURE

PART A: Is it possible to predict earthquakes?

Students examine the relationships between earthquake magnitudes and recurrence intervals, diameter of uplifted areas and duration of precursors. Students will also examine the relationships between travel-time ratios for S- and P-waves and the occurrence of an earthquake.

Key word: precursor

Time required: one 45-minute period

Materials: none

Look at Figure 1. This map has thousands of earthquake centers plotted as dots. These quakes, large and small, happened over a six-year period. Do you notice a pattern to these quakes? They seem to occur in dark bands or lines. It is no coincidence that these lines match the boundaries of major plates on the earth. The highest numbers of quakes occur in areas where plates are bumping into or sliding past one another.

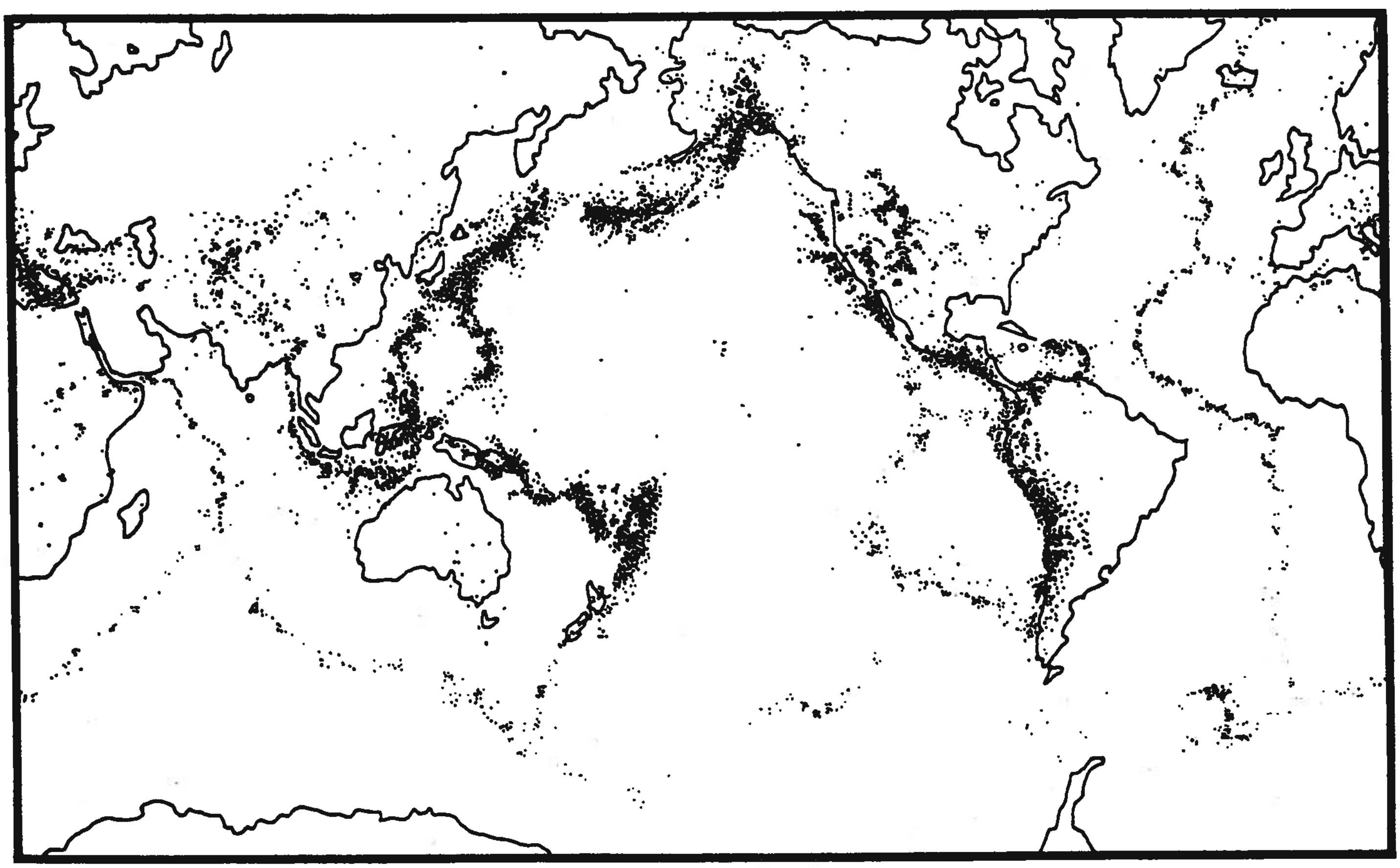

Figure 1. A view of the earth's surface showing earthquake epicenters from 1961–1967. (Modified from A.E. Brotman, 1978, The origin of metal deposits in the oceanic lithosphere. *Scientific American* and F. Press, 1975, Earthquake prediction. *Scientific American.)*

Figure 2 shows the situation along the west coast of the United States. Circle this area on the map (Figure 1). Scientists from many fields are studying and recording all the earthquake activity in this area. One of the most active areas is the San Andreas Fault that runs up the length of California. (See Figure 2.) The land to the west of the fault is sliding northwestward in relation to the land to the east of the fault. This is one of the most active earthquake areas in the United States. The data presented in this activity comes from the study of earthquakes in this area. While looking at the graphs, keep in mind that there are arguments among scientists in this field. Some of them may even disagree as to the truth of some of the data presented.

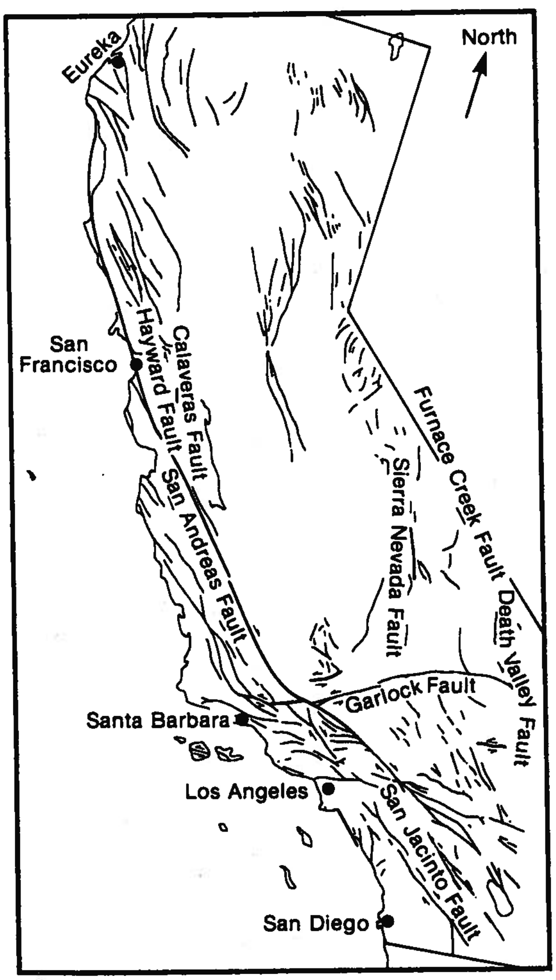

Figure 2. Index map of California showing location of some major faults.

The vertical scale of Figures 3, 4 and 6 does not increase at an even rate. It increases faster as you go up the scale.

Look at Figure 3 and then wait until your teacher explains this graph before you answer the questions.

PART A of this activity is intended to acquaint students with the basics of earthquake prediction (Figures 1 and 2). Check to see if students have circled the line of quakes in the western United States. If they have seen this plot in another activity, a quick reminder of the location of trenches and ridge zones may be helpful.

Make sure students realize that in Figure 3 the scale of years increases more rapidly as you read up it. This graph is a simplified diagram of a great deal of statistical data for a specific location. This relationship is only possible in an area that: (a) has historical earthquake data; (b) is constantly monitored by seismologists; (c) lies near an active fault; and (d) has a fairly constant rate of strain.

This is an idealized graph. It shows the full release of energy build-up in the given time period. It does not take into account other forms of energy release between quakes, such as creep and tremors. This graph is for a location that would experience movement of 2 cm/year along the fault if the ground moved freely.

The actual relationship is believed to follow the formula:

$$Rx = \frac{D}{s-c}$$

where Rx = recurrence interval at a point on the fault

D = displacement accompanying a quake of given magnitude

s = long term strain rate (here assuming average of 2 cm/year)

c = tectonic creep rate

1. If there had been no earthquake in this area for five years and then one occurred, what might be its magnitude?

About 5.1

2. A quake of magnitude 4.0 just happened. How many years has it been since the last quake?

1 year

3. People thought there would be no more quakes at the location here because there had been none for 100 years. But, they were surprised when one struck yesterday. What might be the magnitude of this killer quake?

7.1

4. Finish this statement: In an area along an active fault, the longer the time between quakes, **the stronger the earthquake and the greater the magnitude.**

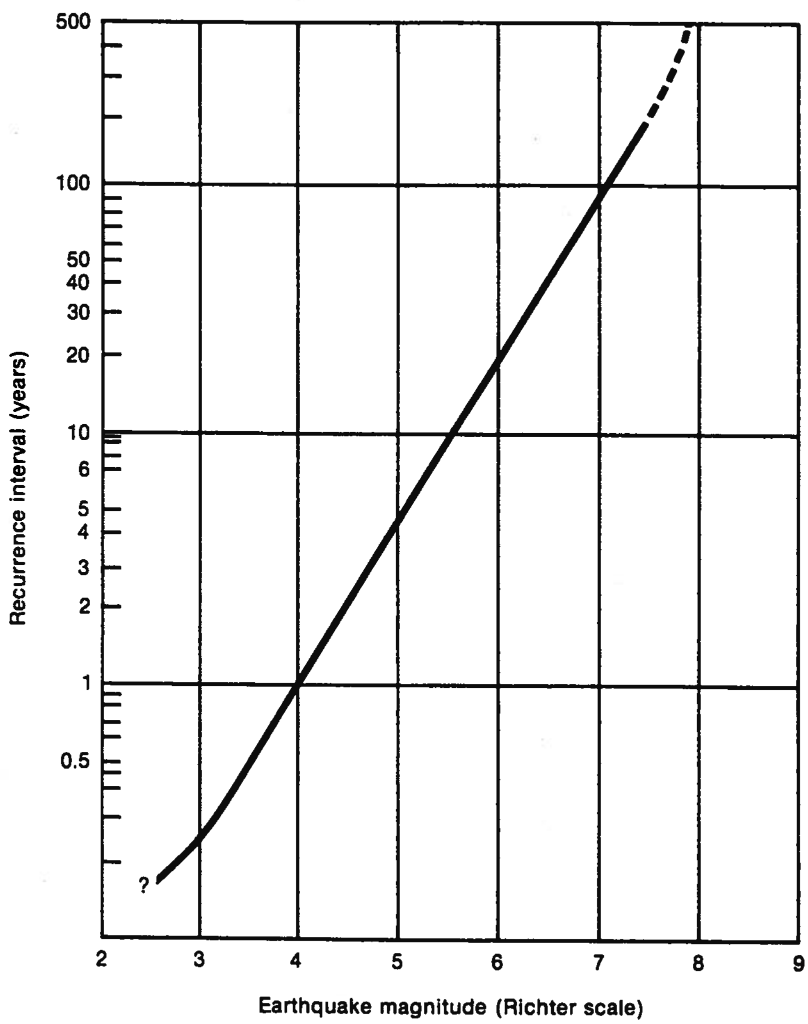

Figure 3. The graph shows the full release of energy build-up in the given time period.

Look at Figure 4 and wait for an explanation from your teacher.

The model or theory known as dilatency is based on the idea that rock undergoes an inelastic volume increase prior to failure. For example, changes in tilt, or bulging in the rock, is a precursor phenomenon. This is revealed by changing elevation of benchmarks or using sensitive tilt meters. The size of the region of uplift has been correlated with the magnitude of the future earthquake. Japanese scientists have suggested the relation from which Figure 4 was derived.

M = 1.96 log r + 4.45
M = magnitude; r = radius of uplifted area

5. An earthquake with a magnitude of 4.5 occurred. If land was uplifted some time before the quake, what might be the diameter of the uplift?

2 km

6. Scientists in a certain area measured the diameter of the area bulging up a few years ago. The bulge measured 80 km across. What is the likely magnitude of the next quake?

7.6

7. Finish this statement: The smaller the area of land uplifted, **the smaller the magnitude of the next quake.**

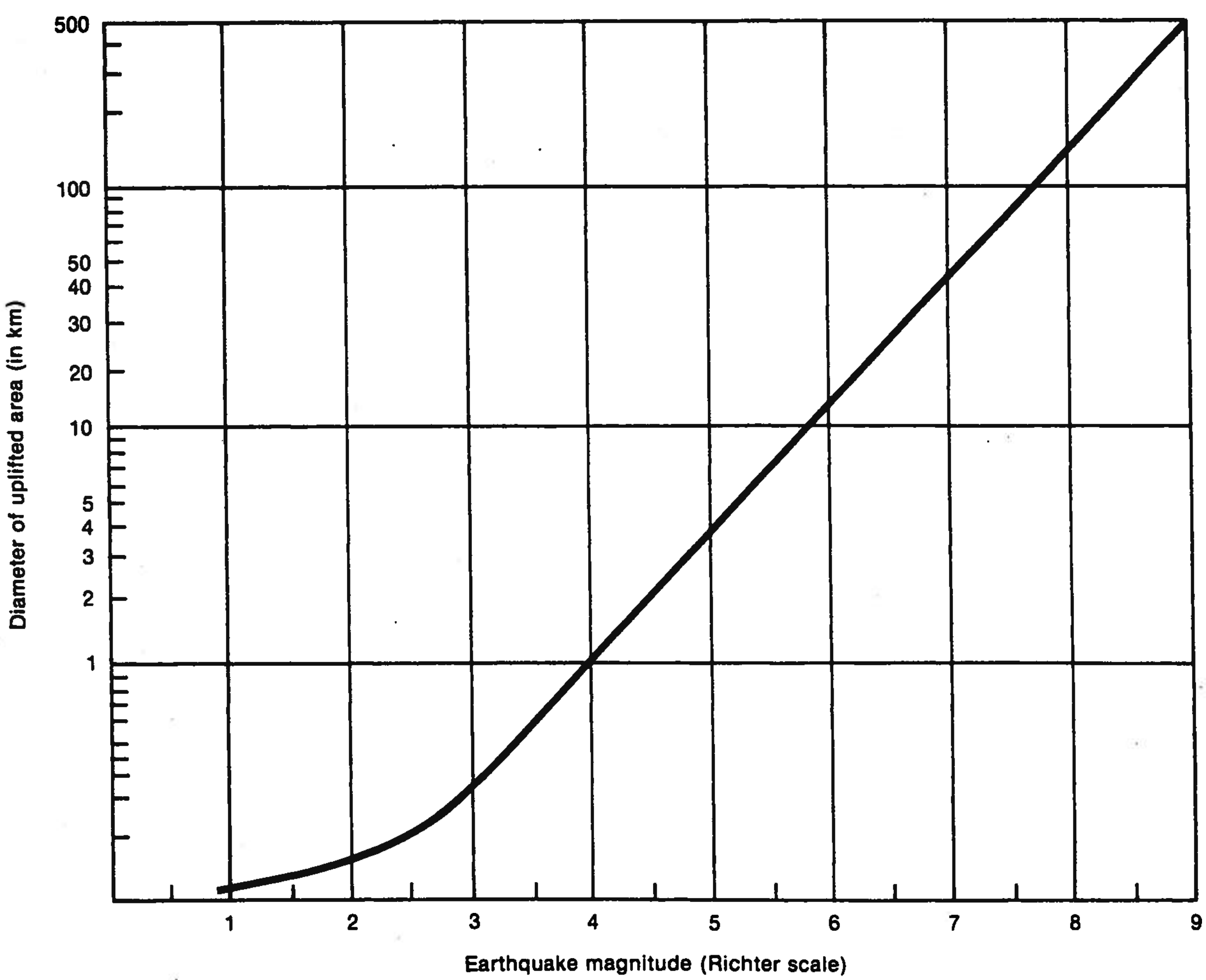

Figure 4. The graph shows the correlation between size of the region of uplift and the magnitude of a future earthquake.

Look at Figures 5 and 6 and wait for an explanation from your teacher.

The graph in Figure 6 was derived from apparent correlation between duration (not size) of an anomaly and the magnitude of the future event. In stating the relation, Kisslinger did not limit this relation to any particular precursor. The derived graph in Figure 6 is fairly simple for students to use. (If magnitude is first determined from Figure 6 or Figure 4, the student can go back to Figure 3 to find a likely recurrence interval.) Figure 5 shows raw data from an area in New York. Some scientists have determined that the ratio of the velocity of S-waves to the velocity of P-waves decreases prior to earthquakes. (Once again, this method could only work in an area where constant monitoring takes place.) Each mark on the graph was the result of a shock wave, either small explosions or foreshocks, being sent through the rock in question. This lower velocity is explained by the dilatency model. When the land increases in volume, extra spaces open up which would tend to slow waves traveling through the rock. Water fills in the spaces prior to the quake, which would bring the wave velocity back to normal. Make sure students draw a smooth "best fit" line, to show the trend of other points, instead of trying to connect them.

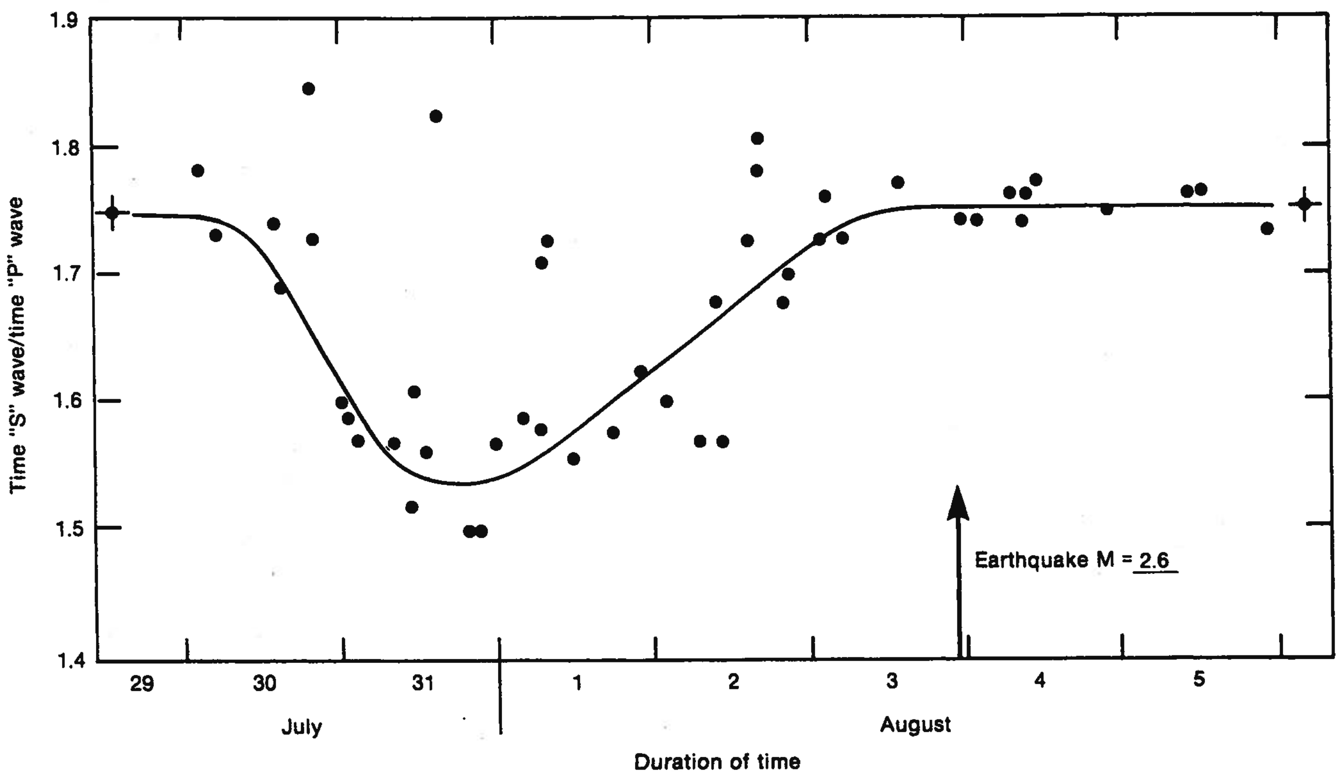

Figure 5. Travel-time ratios (tS/tP) for the August 3, 1973, Blue Mountain Lake earthquake, predicted by Aggarwal and others.

Look at Figure 6 as you answer the following:

8. A certain precursor or unusual event lasted for about three months and then started to go back to normal. After the precursor returned to normal, a quake struck. What might be its magnitude?

4.7

The normal velocity of waves through a rock had been unusual for a long while. Last week a devastating quake occurred that had a magnitude of 7.6. Your teacher explained that the points plotted in Figure 5 are from a place in New York. The normal value from the time of the S-wave divided by the time for the P-wave is about 1.75. Place your pencil on that value on July 29. The values remain the same for a little while and then decrease. With a smooth line, draw the approximate pattern for the decrease and then return to normal some time later. Then notice when the quake occurs.

9. For how many days was the value unusual?

3.5–4 days

Now use Figure 6 to determine the magnitude of the quake. Write your answer both here and on Figure 5 where it says M = **2.6**

10. State the relationship between the duration of a precursor and the magnitude.

The longer a precursor lasts, the greater the magnitude of the subsequent earthquake.

Another precursor is unusual animal behavior. Eyewitness accounts of unusual animal behavior preceding an earthquake have been reported for centuries from all over the world. Studies of animal behavior are difficult to carry out. All animals would have to be observed constantly for long periods of time in order to decide what behavior is unusual.

The Chinese government has issued a list of behaviors of animals before and during earthquakes.

Some of the behaviors are that cattle or horses refuse to get into their corrals, rats run from their hiding places, chickens fly into trees, pigs break out of their pens, ducks refuse to go to water, dogs bark for no obvious reason, snakes come out of their winter hibernation, pigeons are frightened and will not return to their nests, rabbits jump or crash into things, and fish jump out of water as if frightened.

Animal behavior is the oldest recorded precursor of earthquakes. The use of unusual animal behavior scientifically depends on careful observation of normal behavior for that animal. Much interesting research is being done in this area using such diverse animals as chimpanzees and cockroaches. Students should be told that unusual animal behavior has been observed for no more than 24–36 hours prior to a quake and at a distance of no more than 50 km from the epicenter.

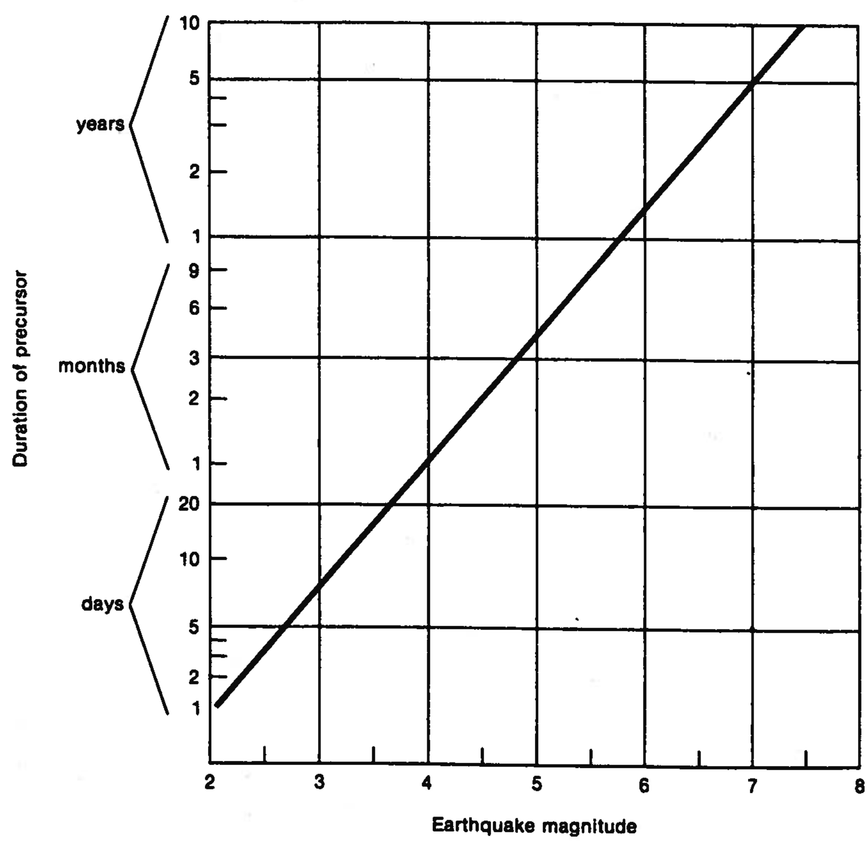

Figure 6. The graph shows apparent correlation between duration of a precursor and the magnitude of a future earthquake.

PROCEDURE

PART B: Can you predict an earthquake?

Students try to make their own predictions based on source-idealized data. Students should be aware of the hypothetical nature of the data and the predictions they will come up with.
They should be encouraged to set out their data carefully and use more space than provided if necessary.

Key words: none

Time required: one 45-minute period

Materials: none

You are the director of an imaginary governmen agency called the Bureau of Earthquake Prediction. It is your job to analyze data and make decisions. Your decision may affect the lives of millions of people. Your prediction may cause people to leave the area. They will be angry if no earthquakes occur. You may predict a small quake, or one happening some time in the future. If you are wrong, many people may die. Good luck!

For each of the three simulations do the following:

1. Read the data given in the description.
2. Use the graphs or other information from PART A to come up with various guesses.
3. Roughly average the values and using your own judgment, predict the magnitude of the earthquake and the approximate range of time in the future you think it will happen.

Follow through the first example and fill in the data. The second and third examples may be done using the same method, or another, if you prefer.

Shakeytown, California

Residents of Shakeytown are used to quakes by now. They have rebuilt the town a number of times in the past. The last quake occurred about a year ago. Since then there has been one instance of mild tremor. People were awakened last night by rabbits bumping into buildings. That activity has decreased today. Tilt meters have indicated an uplifted area of about .5 km diameter. What is your prediction?

Data Layout

Category	*Observation*	*Implication*
last quake	1 year	M = 4
any activity	minor tremor	will decrease M
animal behavior	**rabbits bumped into buildings**	earthquake in 24–36 hours
uplifted area	.5 km diameter	3.2

Now carefully consider all factors together and write your predictions.

Next quake may occur in 1–2 (days, minutes, years).

Its magnitude will be 3.4

Justification of prediction: **The animal behavior means a quake will occur soon. Tremors will decrease the strain build-up so the lower values of magnitude will probably be the case.**

What action should you take? The following are some of your alternatives:

a. Notify local officials to evacuate the people.
b. Notify local officials to secure homes.
c. Notify government agency for future action.
d. Suggest that existing structures be strengthened.
e. Change building code for next few years.
f. Other (you specify)

Action: **Notify local officials to secure homes since there is little time. The quake will likely be mild.**

Help students go through this first example if they are having trouble. They may want to use a separate sheet of paper for data. If they can justify their prediction, it is not necessarily wrong. You should decide ahead of time whether you will announce the actual outcome of the quake. It may be in the form: "Two days after the rabbits stopped bumping into buildings, an earthquake of magnitude 3.2 struck." Have students discuss the results of taking the wrong action.

Crackintheground, Oregon

A few kilometers away from this town a large crack opened up during a quake 10 years ago. Since this time there has been no seismic activity. Animals seem to be happy. For the last three years there has been a slight bulging of the ground in an area measuring 20 km across. The town is growing rapidly and large offices and apartments are being built. What is your prediction? (Hint: Don't use Figure 3 until you decide on a magnitude.)

Data Layout

Category	*Observation*	*Implication*
animal behavior	**not unusual**	**quake not imminent**
uplift	**20 km diameter**	**M = 6.5**
duration of uplift	**3 years**	**M = 6.8**
using Figure 3 for M = 6.6	**35 years– 10 years**	**quake in 25 years**

Next quake may occur in 25 (days, minutes, years).

Its magnitude will be **6.4**

Justification of prediction: **Although there are no precursor indications of an imminent earthquake, a large future quake seems to be indicated by present bulging.**

Action: **Notify government to change building codes and start a program of strengthening buildings.**

Muddywaters, California

Last year you made a prediction for the people of this city based on your observations. At the time you noted that the velocity of seismic waves had been low for 2 years. The last quake was 20 years ago, and you did not have time to measure uplift because you predicted a 6.5 magnitude quake to occur within a few weeks. There was great confusion and many people left. A quake did strike a few weeks later but it was only M = 2.5. The people were angry. Now you have measured uplift again and find the land is still deformed over a diameter of 1 km. What is your new prediction?

(Hint: lay out your data for both predictions and consider them together.)

Data Layout

Category	*Observation*	*Implication*
seismic velocity low	**2 years**	**M = 6.5**
last quake	**20 years ago**	**M = 6**
seismic activity	**small quake M = 2.5**	**will decrease next quake**
land uplift	**1 km diameter**	**M = 3.8**

Next quake may occur in 1 (days, minutes, years).

Its magnitude will be 4.0

Justification of prediction: **Since it was apparent that a large amount of strain was building, the release of energy during the 2.5 quake was not enough. New data indicates that the rest of the strain will be released within a year.**

Action: **Strengthen structures, etc.**

You may want to fabricate the actual outcomes to these three situations; possibly deviate from the implications of the data to show that earthquake prediction is not infallible.

SUMMARY QUESTIONS

1. Where do most earthquakes occur on the surface of the earth?

Along plate boundaries, especially where plates are colliding.

2. In an area of an active fault, if earthquakes occur regularly, what can you say about the magnitude?

It will be small because of the constant release of strain.

3. Explain a precursor and tell how to use it.

The students may choose to explain any precursor and explain how to use it.

EXTENSION

You and your classmates may want to make up your own situations (not haphazardly, but using the graphs) and try to come up with an accurate prediction.

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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